FINAL REPORT

Performance Assessment of Past Bioremediation Approaches for Chlorinated Solvent Source Zones

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The primary objective of this project was to assess the long-term effectiveness of past biological treatment approaches for remediating source areas of chlorinated solvent-contaminated aquifers. In support of this objective the project team (1) developed a large database and statistically evaluated the effectiveness of source area bioremediation to identify factors that resulted in or prevented successful application of different in situe bioremediation strategies; and (2) utilized traditional and new tools at select sites to evaluate long-term treatment effectiveness and to assess whether degradation is ongoing.

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ACRONYMS AND ABBREVIATIONS

‰	per mil; part per thousand
%	percent
AFB	Air Force base
ANOVA	analysis of variance
AOC	area of concern
APTIM	Aptim Federal Services, LLC
ATL	APTIM's Analytical and Treatability Laboratory
Bgs	below ground surface
C	carbon
°C	degrees Celsius
CAFB	Charleston Air Force Base
CB&I	Chicago Bridge & Iron Company Federal Services, LLC
CE	chlorinated ethenes
CFR	Code of Federal Regulations
Cl	chlorine
COC	chain of custody
CSIA	compound-specific isotope analysis
DCE or *cis*-DCE	*cis*-1,2-dichloroethene
1,1-DCE	1,1-dichloroethene
1,2-DCA	1,2-dichloroethane
$\delta^{13}C$	delta carbon 13, a measure of the ratio of carbon 13 to carbon 12
DHC	*Dehalococcoides mccartyi*
DNA	deoxyribonucleic acid
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DOC	dissolved organic carbon
DPT	direct push technology
DoD	Department of Defense
dPCR	digital polymerase chain reaction
EAB	enhanced anaerobic bioremediation
EDD	electronic data deliverables
EMD	Environmental Molecular Diagnostics
EPA	Environmental Protection Agency
ERIS	Environmental Restoration Information System
ERPIMS	Environmental Resources Program Information Management System
ESTCP	Environmental Security Technology Certification Program
EVO	emulsified vegetable oil
Fe	iron

GC	gas chromatography
H_2	hydrogen
H_3PO_4	phosphoric acid
HCl	hydrochloric acid
HNO_3	nitric acid
HPLC	high-performance liquid chromatography
IPR	in progress review
ITRC	Interstate Technology & Regulatory Council
IW	injection well
KB-1	*Dehalococcoides* containing bioaugmentation culture
KW	Kruskal-Wallace test
L	liter
µg/L	micrograms per liter
M	mass
MCL	Maximum Contaminant Level
MBT	molecular biological tool
MEE	methane, ethane, ethene
Mg	milligrams
Mg/L	milligrams per liter
mL	milliliter
mL/min	milliliters per minute
Mn	manganese
NAPL	non-aqueous phase liquid
NB	naval base
NIRIS	Navy Installation Restoration Information Solution
nL	nanoliter(s)
nM	nanomoles
NO_3^-	nitrate
NRC	National Research Council
NS	Naval Station
NWS	Naval Weapons Station
O_2	oxygen
O&M	Operation & Maintenance
ORP	oxidation-reduction potential
PCE	tetrachloroethene
PFM	passive flux meter
pH	hydrogen potential
PI	principal investigator
PM	project manager

QA	quality assurance
QC	quality control
qPCR	quantitative polymerase chain reaction
recirc	recirculation of groundwater
RD-qChip	real-time polymerase chain reaction chip
RPM	Remedial Project Manager
rRNA	ribosomal ribonucleic acid
SDC-9	*Dehalococcoides* containing bioaugmentation culture
SERDP	Strategic Environmental Research and Development Program
SO_4^{2-}	sulfate
SOP	standard operating procedure
SQL	Structured Query Language
SRO	Spearman Rank Order
T	temperature
1,1,1-TCA	1,1,1-trichloroethane
1,1,2-TCE	1,1,2-trichloroethane
TCE	trichloroethene
tDCE	trans-1,2-dichloroethene
TDS	total dissolved solids
TOC	total organic carbon
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
UST	underground storage tank
VC	vinyl chloride
VOC	chlorinated volatile organic compounds
VFA	volatile fatty acid
VOA	volatile organic analysis
VOC	volatile organic compound
WRS	Wilcoxon Rank Sum test

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The project team includes Paul B. Hatzinger, Mark Tucker and Jonathan Myers (Aptim Federal Services, LLC.), who were responsible for project coordination, field sampling, database development, data interpretation, statistical analysis, and reporting); Mike Annable and Alexander Haluska (University of Florida), who were responsible for conducting studies with passive flux meters and interpreting the data; and Frank Löffler and Cindy Swift (University of Tennessee) who conducted the molecular analyses of dehalogenating organisms and gene markers. We wish to specifically acknowledge Mark Tucker, who did a masterful job of coordinating all of the sampling events, developing parameters for the database, and sorting through hundreds of reports to obtain necessary data. Our research team gratefully acknowledges the financial and technical support provided for this project by the Environmental Security Technology Certification Program (ESTCP). We thank Dr. Andrea Leeson, the Environmental Restoration Program Manager from ESTCP, for her guidance and the support staff at Noblis for their administrative assistance. We wish to acknowledge the many different DoD personnel and contractors at the following military facilities who spent their time to facilitate site access and provide reports and data for the statistical analysis: Alameda Naval Air Station, former Charleston Air Force Base, Dover Air Force Base, Moody Air Force Base, Myrtle Beach Air Force Base, North Island Naval Air Station, Orlando National Training Center, Point Mugu Ventura County Naval Base, Former Raritan Arsenal , Seal Beach Naval Weapons Station, St. Juliens Creek Annex, Treasure Island Naval Station, and Vandenberg Air Force Base. This project would not have been possible without their efforts. We also wish to thank Hunter Anderson (USAF) for thoughtful discussions on statistical analysis of project data and for conducting independent statistical analyses. Finally, we wish to acknowledge Pace Analytical for conducting the relevant compound specific isotope analysis measurements of chlorinated volatile organic compounds. Views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of Defense position or decision unless designated by other official documentation. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

EXECUTIVE SUMMARY

INTRODUCTION

Source areas of chlorinated volatile organic compounds (VOCs) in groundwater create and perpetuate dilute groundwater plumes that subsequently pose risks to downgradient receptors for decades or centuries. Although bioremediation has been applied to treat many contaminant source areas over the past two decades, the overall success of this treatment and factors that differentiate successful from unsuccessful treatment applications have not been thoroughly assessed. We used two separate approaches to evaluate the success or failure of different bioremediation applications and to evaluate factors that may have contributed to those outcomes.

Initially, we selected fifteen (15) VOC sites with chlorinated ethenes as the primary contaminant that have been treated using common bioremediation techniques and with data that allow statistical evaluation of remedial performance over time. Sites with extensive pre- and post-treatment data were given priority, and overburden aquifers were selected over bedrock aquifers. A large database was developed from these sites that includes 1) site location; 2) VOC concentrations over time; 3) hydrogeology; 4) geochemistry; 5) water chemistry; 6) abundances of relevant microbial biomarkers where available; 7) treatment approach; and 8) other relevant site data. A large database was developed and statistical analyses were then performed to identify factors that may promote or prevent successful application of different bioremediation strategies.

From the 15 selected sites for historical data compilation and statistical analysis, 5 sites were chosen for sampling of select wells and application of current assessment tools in order to quantify (1) contaminant mass flux, (2) presence of key dehalogenating organisms and genes, and (3) whether biodegradation is still occurring using parent and daughter product VOC concentrations and compound-specific isotope analysis (CSIA). Pre-treatment data and post-treatment data were compared with information on site conditions (geologic, hydrogeologic, and geochemical) and treatment methods. The historical and current data were used to draw conclusions about the long-term effectiveness of VOC bioremediation at the 5 sites.

OBJECTIVE

The primary project objective was to assess the long-term effectiveness of past biological treatment approaches for remediating source areas of chlorinated ethene-contaminated aquifers. In support of this objective the project team:

- Developed a large database and statistically evaluated the effectiveness of source area bioremediation to identify factors that resulted in, or prevented, successful application of different bioremediation strategies;
- Conducted sampling at select sites to obtain a current snapshot of the effectiveness of past treatment approaches using traditional measures (e.g., contaminant concentrations) and new tools, including analysis of key dehalogenating organisms/genes; passive flux meters to assess current contaminant flux; and CSIA to quantify whether degradation is ongoing

TECHNOLOGY DESCRIPTION

Database and Statistical Analyses

The multi-site evaluation included gathering of historical analytical data and information on site conditions and the treatments applied. Electronic data were obtained for each of the evaluation sites whenever possible. Data was also gathered from hard copy sources when electronic data were not available. Key sources of electronic data included the following databases:

- The Environmental Restoration Information System (ERIS) is the Army's web-based database system for the storage of Army environmental restoration field data. It serves as a central repository for the Army installation chemical, geological, and geographical data.
- The Environmental Resources Program Information Management System (ERPIMS) is the Air Force system for management of data from environmental projects at Air Force installations. This data contains analytical chemistry samples, tests, and results, as well as hydrogeological information, site/location descriptions, and monitoring well characteristics.
- The Navy Installation Restoration Information Solution (NIRIS) provides analytical data along with data management and visualization tools. NIRIS also includes a collection of site documents.

Documents generated as part of site remediation activities were obtained from web-based document-sharing sites, where available, and through direct requests to installation Remedial Project Managers (RPMs). Site reports were reviewed to obtain details on hydrogeologic conditions and the treatments applied at each site. Typical documents with site information included, for example, Remedial Designs, Remedial Action Workplans, Remedial Action Completion Reports and Monitoring and Progress Reports.

Because of the large amount of existing information and data collected and analyzed during this project, a database was created to organize and evaluate the data. Data were housed in a SQL Server database. The SQL server provided a back-end data repository for analytical data and was managed by a front-end Microsoft Access database. Data added to the Microsoft Access database included: 1) site location; 2) VOC concentrations; 3) hydrogeology (e.g., groundwater velocity, groundwater gradient, porosity, etc.); 4) geochemistry; 5) water chemistry (pH, Eh, anions, cations, metals, VFAs, co-contaminants, DOC, TOC, methane, ethene, ethane, acetylene, etc.); 6) abundances of relevant microbial biomarkers (e.g., *Dehalococcoides* numbers, reductive dehalogenase genes); 7) treatment approach (bioaugmentation, biostimulation, active, passive); and 8) other relevant site information.

The data analysis included a statistical evaluation comparing measures of remedial effectiveness to a number of possible factors. The evaluation was conducted on a well-by-well basis for each of the treatment zones and treatment phases at the 15 evaluation sites. Measures of effectiveness were developed to provide quantitative metrics for the statistical evaluation. The measures were as follows: *Mass Reduction, Dechlorination* (mols of chlorine removed from initial chlorinated ethenes)*, Risk Reduction* (MCLs of initial and residual VOCs)*, Rebound, DCE Accumulation, and VC Accumulation.* These measures were compared to a number of potential factors for success including *Hydrogeologic factors* (percent fines, heterogeneity, hydraulic conductivity, hydraulic

gradient and seepage velocity); *Treatment Approach factors* (substrate used, substrate loading, substrate dosing, nutrient amendments, treatment approach and spacing of injection points); *Geochemical factors (*DO, ORP, pH, alkalinity, iron , manganese, sulfate, sulfide, TOC, temperature); and *Biological factors (*abundance of *Dehalococcoides*, abundance of reductase genetic markers).

Correlations between selected pairs of numerical parameters were evaluated using the Spearman Rank Order (SRO) procedure, which is a nonparametric method to evaluate statistical dependence between two variables. It assesses how well the relationship between two variables can be described using a monotonic function. The coefficient *R* ranges from –1.0 to +1.0. The SRO procedure also returns a *p*-value, which allows the results to be interpreted in terms of the statistical confidence in any apparent correlation. The nonparametric SRO approach was selected here because there is no expectation that any of the parameters considered in this evaluation will be linearly related to each other, but at least some monotonic relationships were expected.

Some of the parameters in the database are categorical (non-numeric) so their effects on performance cannot be evaluated with the SRO method. The relationships between these parameters (e.g., presence of DNAPL: Y/N) versus performance parameters were evaluated using box plots for visual comparisons of the distributions within each individual category versus a performance parameter, and the quantitative Wilcoxon Rank Sum (WRS) test or the Kruskal-Wallis (KW) test. Both nonparametric procedures test the null hypothesis that the sub-groups of results being compared are drawn from the same population. Both tests also return a *p*-value that indicates the probability of the null hypothesis (no difference between sub-groups) being true.

The software package *Statistica* (version 12) was used to evaluate the correlations between selected parameters in the database using SRO correlations, KW tests, and WRS tests; and was also used to generate the box plots.

Bioremediation Performance Evaluation at Five Sites

Five field sites were selected for additional field investigations to assess current post-treatment conditions. The investigations included groundwater sampling from existing monitoring wells and analysis of a variety of parameters. The five field sites were as follows:

- Former Raritan Arsenal, AOC 2
- Dover Air Force Base, Area 6
- Charleston Air Force Base, Zone 4
- Seal Beach Naval Weapons Station, Site 70
- Treasure Island Naval Station, Site 24

The objective of the groundwater sampling was to assess the long-term impacts of the previously performed biostimulation and/or bioaugmentation treatments on contaminant concentrations, groundwater quality, and biogeochemistry. Field activities at each site included the collection of groundwater samples and installation of passive flux meters (PFMs) in existing monitoring wells at each of the five field sites.

Groundwater samples were collected at monitoring wells variously located within treatment zones and at downgradient locations. Wells were selected based on treatment effectiveness and include sites with apparent successful and unsuccessful bioremediation applications at different times in the past. The analysis included the following parameters:

VOCs

VOCs analysis by EPA Method 8260 at APTIM's Analytical and Treatability Lab (ATL) was used to assess the extent of treatment and/or rebound, and the extent to which reductive dechlorination has occurred/continued to occur since treatment implementation.

Reduced Gases

Reduced gases, including methane, ethane, and ethene (MEE) measured using EPA Method 3810, RSK-175 were used to assess the extent to which complete reductive dechlorination is still occurring within the treatment area. Methane data also provide insight into the redox conditions.

Anions

Anions, including chloride, nitrate, and sulfate, measured by EPA Method 300.0, provide insight into the current redox conditions and the dominant electron acceptors. Total sulfate plays a significant role in rates/extents of reductive dechlorination at specific sites or locations at a given site. Chloride levels provide a measure of salinity at each site.

Dissolved Iron and Manganese

Dissolved iron and manganese levels were measured using EPA Method 601.0. These data provide insight into the current redox conditions and dominant electron acceptors and may also provide useful information about potential abiotic reactions.

Volatile Fatty Acids

Volatile fatty acids (VFAs), measured by EPA Method 300m, are commonly present during active bioremediation treatment. Groundwater samples were analyzed to determine if residual levels persist, possibly serving as electron donors.

Dissolved Hydrogen

Dissolved hydrogen levels, measured using EPA Method 3810, are used to assess whether hydrogen is present at detectable levels at any site months to several years after biological treatment, as an indication of ongoing fermentation.

Total Organic Carbon

Total Organic Carbon (TOC) levels, measured using EPA Method 415.1, indicate available organic carbon that could support reductive dechlorination.

Field Parameters

Dissolved oxygen (DO), pH, turbidity, and ORP were measured as indicators of geochemical conditions using a standard multi-parameter field meter. Values were recorded during low-flow sampling after each well had stabilized.

Microbial Community Analysis by qPCR

A targeted microbial community analysis was conducted by qPCR to determine the presence and abundance of organohalide-respiring bacteria including *Dehalococcoides*, *Dehalobacter*, and *Dehalogenimonas*. Key functional genes involved in reductive dechlorination of chlorinated solvents were also quantified. The presence of dehalogenating organisms and genes was evaluated as a measure of current day biodegradation potential. Analyses were conducted by Dr. Frank Löffler at the University of Tennessee.

CSIA

CSIA analysis was performed for carbon in TCE, cis-DCE, and VC as a means to assess whether VOC degradation is occurring or has occurred in the recent past based on current values of $\delta^{13}C$. The measured $\delta^{13}C$ value for TCE were evaluated as a function of (1) historical values of $\delta^{13}C$ in manufactured TCE (generally -30 ± 5 ‰); (2) previous CSIA analyses conducted at the site when available and/or (3) distance from the source area. The analysis conducted was dependent on the current and historical data available. The analysis was done by Pace Analytical, Inc. (Pittsburgh, PA).

Mass Flux

Contaminant mass flux was estimated at the different sites using passive flux meters (PFMs). PFMs are self-contained, permeable units that are inserted into a well or subsurface boring such that they intercept, but do not retain, groundwater flow. PFMs allow measurements of both groundwater flow and contaminant mass flux. The mass of contaminant accumulated on a permeable sorbent (typically granular activated carbon) is used to calculate a time-averaged contaminant mass flux, while residual resident tracer mass loss is used to calculate cumulative water flux. VOC concentrations also can be estimated by this procedure. Mass flux measurements were collected and analyzed by Drs Mike Annable and Alexander Haluska at the University of Florida.

PERFORMANCE ASSESSMENT

Statistical Analysis of Database

The parameter *Concentration Reduction*, equal to the greatest reduction in total chlorinated ethene concentration for each well during the treatment period prior to any rebound, was selected as a key performance parameter for the majority of the statistical evaluations. Rebound parameters (*Rebound* and *cis-DCE Accumulation*) were also evaluated.

Numerical site characteristics that showed statistically significant (α= 0.05) positive (+) or negative (-) correlations with *Concentration Reduction* include *Min Sulfate* (-), *Sulfate Depletion* (+), *Initial ORP* (-), *Max Iron* (+), *Fines* (-), *Initial Sulfate* (-), *Initial CE* (+), *Min ORP* (-), and *DNAPL 1/0* (+) in decreasing order. The strongest correlations were with *Min Sulfate* (-) and *Sulfate Depletion* (+), suggesting that creating strongly reducing redox conditions that reduce sulfate concentrations as low as possible will contribute to a more successful remediation. The third and fourth most significant correlations were with *Initial ORP* (-) and *Max Iron* (+) demonstrating that either initial or minimum redox potentials are strong predictors of successful concentration reductions. These first four strongest correlations provide independent evidence that creating redox conditions corresponding to sulfate-reducing (or lower) redox potentials is beneficial for reducing chlorinated ethene concentrations.

Initial Sulfate had a significant negative correlation with *Concentration Reduction*, indicating that high initial sulfate is a predictor of poor performance. High initial sulfate may be present at coastal sites or at arid sites where gypsum layers are present in the treatment zone. *Fines* also had a significant negative correlation with *Concentration Reduction.* This observation suggests that it may be more difficult to lower chlorinated ethene concentrations in treatment zones that have a high proportion of finer-grained sediments. Diffusion of chlorinated ethenes into the fine-grained units over time within the treatment zone may extend the time required for treatment and may also increase the likelihood of rebound as the compounds slowly diffuse back out of the fine-grained units after treatment has stopped. The presence of fine-grained layers can also prevent adequate distribution of amendments in the subsurface.

Cases where DNAPL was present show significantly greater concentration reduction than cases where DNAPL was not present. This is likely caused by higher initial chlorinated ethene concentrations were DNAPL was present. The significant correlations between *Concentration Reduction* versus *Initial CE* (+) and *DNAPL 1/0* (+) likely reflect the fact that chlorinated ethene concentrations can only show strong decreases if they are initially high.

Numerical parameters that contribute to *Rebound* include *Min Sulfate* (+) and *Initial ORP* (+), suggesting that high initial ORP is a predictor of rebound. In addition, failure to adequately reduce sulfate to low concentrations in the groundwater during treatment may also lead to rebound. A positive correlation with the categorical *Fines Rank* parameter indicates that a high proportion of fines in the treatment zone is a predictor of rebound, as well as poor reduction in chlorinated ethene concentrations, as noted above. In addition, sites that have undergone previous remediation show significantly less rebound than sites that have not had previous remediation.

Numerical site characteristics that have significant correlations with *cis-DCE Accumulation* are *Minimum Sulfate* (+), *Initial Iron* (-), *Initial Sulfate* (+), *Heterogeneity* (-), and *Initial ORP* (+) in decreasing order. These results suggest that high initial redox conditions, as indicated by high initial ORP and low initial iron, are predictors of cis-DCE accumulation. The use of recirculation loops was observed to correlate negatively with accumulation of cis-DCE, most likely by allowing more effective mixing of amendments in the subsurface. Initial pH below 5.0 is a predictor of cis-DCE accumulation presumably by causing inhibition of complete dehalogenation.

In summary, the key parameters that control chlorinated ethene reduction are similar to the parameters that control rebound. These parameters are as follows:

Redox conditions – The strongest predictors of chlorinated ethene concentration reduction and rebound are *Initial Sulfate*, *Min Sulfate*, and *Sulfate Depletion*. These results demonstrate that it is essential to establish sulfate-reducing (or lower) redox potentials for successful remediation. Correlations of these performance measures with other redox-related parameters such as *Initial ORP*, *Min ORP*, and *Initial Iron* provide independent evidence for these predictors. High initial sulfate or lack of sufficient sulfate depletion may prevent successful remediation if there is an ongoing source of sulfate during the treatment period that prevents redox conditions from falling below sulfate-reducing potentials. Sources of sulfate may include seawater intrusion, arid climate (where sulfate groundwater concentrations are typically high), or the presence of gypsum in the treatment zone.

Fines – The presence of fines in the treatment zone is correlated with poor concentration reduction, as well as rebound and cis-DCE accumulation. These results provide independent evidence that the presence of fine-grained layers in the treatment zone interfere with performance, likely by allowing diffusion of chlorinated ethenes into the fine layers over time. During remediation when the chlorinated ethenes concentrations decrease in groundwater along interconnected flow paths, the local concentration gradients reverse, and chlorinated ethenes that had diffused into the fine layers slowly diffuses back out, thus contributing to rebound. In addition, the presence of fine-grained layers can interfere with the distribution of amendments in the subsurface.

Initial pH – Initial pH below 5.0 is a predictor of poor chlorinated ethenes concentration reduction and is also a predictor of cis-DCE accumulation. These effects are likely caused by inhibition of microbial activity.

Previous remediation – Cases that have undergone previous remediation have significantly higher CE reduction and significantly less rebound and cis-DCE accumulation. These results highlight the need for multiple rounds of remediation at some locations.

Presence of DNAPL – One surprising result was that cases where DNAPL was present had significantly greater reductions in chlorinated ethenes concentrations than cases where DNAPL was absent. This result is likely due to the fact that sites with DNAPL usually have higher initial CE concentrations relative to sites without DNAPL, so the sites with DNAPL tend to show a greater decrease during remediation. (The presence of DNAPL as the parameter *DNAPL 1/0* is positively correlated with *Initial CE*, *Min CE*, *Max CE* and *Final CE*.) These results also suggest that the presence of DNAPL at a site does not interfere with reductions in CE concentrations during remediation. The degree of rebound and cis-DCE accumulation were insensitive to the presence or absence of DNAPL.

Current Assessment

Summary results from the five different sites are provided below:

Former Raritan Arsenal, AOC 2

Site AOC 2 at the former Raritan Arsenal previously had a TCE plume that extended approximately 3,000 ft downgradient. Excavation of contaminated soil occurred in 1998 and 2002. Bioremediation was implemented in the source area in 2009 to reduce contaminant concentrations. The system included recirculation with sodium lactate and nutrients along with the SDC-9 bioaugmentation culture in a deep aquifer zone. Sodium and potassium hydroxide were used to raise the pH. The recirculation system operated for a 10-month period. Near the end of the recirculation period, an emulsified oil substrate was introduced to provide a longer-term, slow release of electron donor to promote continuing biodegradation. A shallower contaminated zone was treated with emulsified oil and bioaugmentation culture SDC-9 using direct push. The site was sampled ~ 5.5 years after treatment ended.

Groundwater monitoring, CSIA and PFM data collected during this project suggest that the size of the plume at Raritan has decreased and biodegradation continues 5.5 years after active treatment ended. Source zone groundwater and PFM data show that cis-DCE and VC dominate the source area but dramatic declines in the concentration and flux of both VOCs are apparent downgradient.

CSIA data provides further evidence of dechlorination of TCE to cis-DCE and then cis-DCE to VC. Based on the simple calculations using $\delta^{13}C$ values for TCE and cis-DCE along the groundwater flow path, half-lives for the two compounds were estimated at ~ 80 days for TCE and 30 days for cis-DCE. The microbial community analysis indicated the presence of several different dehalogenation- associated organisms/genes in water samples from the Raritan Site 5.5 years after cessation of active treatment. *Dehalococcoides* was detected in all of the aforementioned wells, albeit at rather low concentrations ($\leq 1 \times 10^2$ cells/mL). The vcrA gene and the bvcA gene (both of which encode enzymes that dehalogenate cis-DCE) also were detected as was the cobS gene, which encodes a vitamin B12 pathway in *Dehalococcoides.* The data suggest that dehalogenating organisms/genes are present in the deep aquifer zone more than 5.5 years after the last treatment, which included bioaugmentation with SDC-9. This zone also contains the highest concentration of residual VOCs at the site. Overall, site data suggest that removal of organic contaminants was highly effective and is still occurring where some residual persists in the deep zone (shallow zone is clean) and that the potential for anaerobic reductive dechlorination persists, although electron donor is likely limiting at his time. Target treatments with an electron donor, buffer (to ensure optimal pH) and nutrients may be sufficient to promote conditions necessary for complete reductive dechlorination in the deep zone at the site.

Dover Air Force Base, Area 6

Area 6 at Dover Air Force Base was previously characterized by a large plume of chlorinated ethenes and ethanes, approximately 2,500 ft wide and 6,500 ft long. Several source areas were identified. Maximum TCE concentrations historically exceeded 20,000 µg/L. PCE, cis-DCE, and VC were present at lesser concentrations. A recirculation system for bioremediation was actively operated at Building 719 between 2002 and 2006. Sodium lactate and diammonium phosphate (DAP) were added as biostimulation amendments. The system was converted to a passive mode in 2007 with recirculation temporarily restarted to introduce additional amendments. The system was operated for this purpose on three occasions: September 2008, June 2011 and February 2013.

The data collected from the site by our project team indicate highly effective bioremediation of chlorinated ethenes across the site. Low concentrations of chlorinated ethenes persist in a few of the wells, possibly as a result of diffusion from low permeability materials, but concentrations are orders of magnitude lower than pre-treatment. In wells MW605S, MW605D, and MW608S, *Dehalococcoides* was detected at concentrations ranging from 3×10^3 to 8×10^4 cells/mL, methane concentrations were relatively high (ranging from 19.1 to 22.5 mg/L) and the presence of ethene and low ORP suggest that conditions are conducive to ongoing reductive dehalogenation. CSIA data supported this conclusion in MW608S (with VOC concentrations too low to measure in the other two wells). Conversely, in wells MW102S and MW102D, *Dehalococcoides* were not detected, ORP values were positive, methane concentrations were low, and no ethane or ethene were detected, suggesting the conditions were not conducive to reductive dechlorination at these well. However, MW102S had no residual VOCs. MW102D had very low concentrations of PCE, TCE, and cis-DCE. Overall, the data from this site suggest that treatment has been highly effective and that reductive dechlorination at the site continues in many areas 5 years after cessation of active treatment.

Charleston Air Force Base, Zone 4

Zone 4 at Charleston Air Force Base (CAFB) is an industrial area near the CAFB flight line. Trichloroethene (TCE) was formerly used for aircraft parts cleaning. Two distinct plumes of TCE

contamination, designated Plume 1 and Plume 2, are present at Zone 4. TCE was historically present in Plume 1 at concentrations exceeding 100,000 µg/L, and the plume extended 600 ft. Historical TCE concentrations at Plume 2 exceeded 10,000 µg/L. Plume 2 is also approximately 600 ft in length.

Multiple phases of bioremediation have been implemented at Zone 4. The first phase of treatment began in 2003 with the introduction of molasses and bicarbonate buffer using injection wells at Plume 1. Follow-up treatments were initiated in 2004 using molasses, whey, and bicarbonate. This phase of treatment was expanded to include both Plume 1 and Plume 2 and used direct-push technology (DPT) in addition to injection wells. A third phase was implemented in 2008 with the injection of emulsified vegetable oil (EVO) in Plume 1, and a fourth phase was implemented in 2010 with additional EVO injections at both Plume 1 and Plume 2. The EVO injections included both grids and transects of injection wells.

Data from Charleston collected during this project indicate that biogeochemical conditions remain generally favorable for reductive dechlorination of chlorinated ethenes. The presence of daughter products as well as ethane and/or ethene in most wells based on both sampling and PFM data indicates ongoing dehalogenation, although significant mass was still likely present in the Plume 1 source area. The microbial community analysis showed the presence of numerous different dehalogenation-associated organisms/genes in water samples from across the site with *Dehalococcoides* concentrations ranging from 9×10^1 cells/mL to 3.3×10^6 cells/mL. The overall CSIA data did not support degradation in the Plume 1 source area well (MW 89-7), but this may reflect the presence of DNAPL, and the continued resupply of unenriched TCE as biodegradation occurs. All other measures indicated ongoing degradation in this area. Moreover, CSIA clearly indicated ongoing biodegradation downgradient of this source. The same scenario was found in Plume 2: ambiguous data in the most upgradient well (MW29-30), with clear isotopic enrichment in daughter products (TCE is largely gone), downgradient of this well, indicative of ongoing biodegradation. Groundwater and PFM data showed that free-phase DNAPL was still present at the site in and or around well MW 89-7 (Plume 1 source area). Overall, the results suggest that biological degradation processes have persisted ~ 4 years after cessation of active bioremediation.

Seal Beach Naval Weapons Station, Site 70

Seal Beach Site 70 is also known as the Research, Testing, and Evaluation Area. TCE was used during various research and development activities that occurred at the site between 1962 and 1985. Groundwater contamination is present in the source area where dense non-aqueous phase liquid (DNAPL) is suspected to occur based on the groundwater concentrations; however, DNAPL has not been observed in the various subsurface investigations. A dissolved-phase plume currently extends at least 4,000 ft downgradient to a depth of approximately 160 ft below ground surface (bgs). TCE was the primary contaminant in the plume before bioremediation. High sulfate concentrations (>1,000 mg/L) are present throughout much of the site.

An ESTCP demonstration was implemented in the source area from 2008 to 2010 (ESTCP Project ER-200513). The primary objective of the demonstration was to compare the ability to distribute *Dehalococcoides* via passive versus active approaches. Two test cells were established in the source area, designated the Passive Cell and the Active Cell. Sodium lactate and the SDC-9 bioaugmentation culture were introduced into both cells. The amendments were allowed to migrate with the natural groundwater gradient in the Passive Cell. In the Active Cell, the amendments were distributed by recirculation established between two injection wells and two extraction wells.

The treatment time for the ESTCP demonstration extended over a 10-month period, and significant dechlorination occurred in both test cells as a result.

A full-scale bioremediation program was implemented shortly after the ESTCP demonstration, with a combination of a grid of injection wells in the source area and a series of biobarriers perpendicular to the dissolved-phase plume further downgradient. EVO and the KB-1 bioaugmentation culture were the amendments used in the full-scale design. The full-scale system was implemented in areas of the plume with TCE exceeding 250 μg/L. The initial injections in the biobarriers occurred in 2009 and in the source area grid in 2010. The second round of injections occurred in 2013 in the source area and all but one of the biobarriers.

Based on our project data, the long-term results from the Seal Beach site varied by treatment approach and, in some instances, by well in a given treatment area. VOC concentrations in an upgradient well declined since the conclusion of the ESTCP test project completed at the site (evaluating passive vs active approaches for adding electron donors) and daughter products were present, but CSIA data provided no indication of ongoing degradation, and relevant dehalogenating cultures and genes were absent. In the former ESTCP active treatment plot, one well had high concentrations of TCE and daughter products, and the second well had non-detect concentrations. CSIA data showed no clear indication of ongoing degradation of TCE or daughter products. In the former ESTCP passive treatment area, 2/3 wells appeared to have ongoing degradation based on CSIA data. Microbial community analysis indicated the presence of dehalogenation-associated organisms/genes in several but not all locations at the Seal Beach Site. Wells sampled in the passive treatment plots contained *Dehalococcoides* at ~ 9 x 10^2 to 4 x 10^3 cells/mL, whereas *Dehalococcoides* was not detected in the active treatment cell. Groundwater data in both the active and passive cell suggest that TCE rebound had occurred in some areas, but below the historically high concentration. In the full-scale treatment area (most recently treated via bioaugmentation), all indications suggest ongoing VOC biodegradation. Taken in sum, the data suggest that biodegradation has persisted in the former ESTCP passive treatment plot ~3 years after injection of cultures and electron donor, whereas dechlorination has largely ceased in the former ESTCP cell that underwent active treatment. The full-scale area that received EVO and bioaugmentation culture also appears to have ongoing VOC biodegradation based on all relevant measures.

Treasure Island Naval Station, Site 24

Site 24 at Naval Station Treasure Island is contaminated with PCE, and a plume of contamination extends over 1,100 ft to the San Francisco Bay. The main source area, Building 99, contained dry cleaning facilities that operated between 1942 and 1977. Total VOC concentrations above 1 mg/L occurred throughout much of the plume before remediation. A freshwater aquifer is present in the upper part of the fill material, but the groundwater becomes saline at depths of greater than 30 ft. The aquifer is generally anaerobic, has a neutral pH, and has relatively high sulfate concentrations.

An initial pilot study was conducted at the Building 99 source area from 2003 to 2004. The pilot study system included recirculation with three injection wells and three extraction wells arranged to provide three test loops. Sodium lactate, hydrogen gas, and SDC-9 were applied to various degrees in each of the loops. The pilot study results data showed a substantial decrease in contamination due to the treatment.

Following the successful pilot study, the full-scale treatment was implemented in three phases. Phase 1, conducted from November 2004 to May 2007, consisted of injecting and recirculating a lactic acid solution, hydrogen gas, and SDC-9 across the plume downgradient of the pilot study area. Phase 2, conducted from June 2008 to October 2010, consisted of a combination of recirculating a sodium lactate solution in some areas and injections of emulsified vegetable oil substrate in other areas. The biotreatment was successful throughout much of the plume, but several pockets of contamination remained. Phase 3 was conducted from 2011 to 2012 to address the remaining hot spots of contamination and included additional source area recirculation with lactic acid and SDC-9, along with direct-push applications of Lactoil™ in other parts of the plume. Three areas there were targeted for additional treatment included the South Source Area Treatment Area, the EW12 Treatment Area, and the EW30 Treatment Area.

Results from this study showed that biogeochemical conditions remain generally favorable for reductive dechlorination of chlorinated ethenes. Residual PCE was detected in 24-TW-11, in the South Source Treatment Area at 1,190 µg/L. This well also had 779 µg/L of TCE, 7,840 µg/L of cis-DCE and 937 µg/L of VC, respectively. This well showed rebound of PCE after various treatment phases with levels as high as 16,000 µg/L in 2011, but minimal rebound was observed after treatment in 2012 until this sampling event approximately 5 years later. The other well in this same treatment area, 24-EW04 had much lower levels of VOCs than 24-TW-11, with PCE at 1.7 µg/L, TCE at 9.0 µg/L, and VC at 204 µg/L. This well had concentrations as high as 36,000 µg/L in 2005. The other 4 wells that were sampled at Site 24 had residual PCE < 7 µg/L, cis-DCE < 16 µg/L, and VC < 3 µg/L. Thus, overall treatment effectiveness in the EW-12 and EW-30 areas showed little to no rebound after treatment. These wells were primarily contaminated with *cis*-DCE and VC during previous years.

Both groundwater sampling and the limited amount of PFM data detected the presence of ethene and ethane at the site, suggesting that complete biological reductive chlorination was still occurring ~5 years after the cessation of active treatment. The microbial community analysis indicated the presence of quantifiable dehalogenation-associated organisms/genes only in well 24-TW-11, which is the well with highest residual VOCs. It is likely that dehalogenators are not present in the vicinity of other wells due to the exceedingly low residual VOC concentrations. Overall, the CSIA data from this site suggest a rather complex scenario. Wells in the EW30 area, where concentrations of VOCs are very low, each show isotopic evidence of ongoing *cis*-DCE degradation. One of the two wells in the South Source Zone Treatment Area (24-EW04) showed clear evidence of both cis-DCE and VC degradation, but no measurable numbers of relevant dehalogenating organisms/genes. The other well in this region (24-TW-11) showed some evidence of ongoing cis-DCE biodegradation, and very light VC ($ö^{13}C$ = -38.9‰) indicating that VC was being formed from cis-DCE (i.e., very light daughter product is expected initially as a parent VOC degrades), but probably not biodegrading further. This well had detectable dehalogenating organisms/genes and the highest residual VOC concentrations.

COST ASSESSMENT

The nature of this project does not allow for a traditional ESTCP cost assessment, where one remediation or other technology is evaluated against traditional alternatives. However, a reasonable cost estimate for the different assessment technologies utilized during this demonstration is provided. The cost includes labor and per diem for field sampling and PFM

installation, materials for sample collection, CSIA, molecular analysis, PFM analysis, basic geochemistry and VOC analysis. The assessment does not include monies spent on the development of the site database and statistical analysis of the database results.

For the cost assessment, we assume that a total of 8 groundwater wells would be sampled by a single field technician using low-flow sampling, and that the technician could sample 4 wells per day. For each well, basic field parameters (dissolved oxygen, oxidation-reduction potential, pH, conductivity) would be determined using a field meter, and samples would subsequently be collected for (1) VOC concentrations (EPA Method 8260); (2) anions (EPA Method 300); (3) C stable isotope analysis of TCE, cis-DCE and VC and (4) molecular analysis of important dehalogenating organisms and genes. For the PFM analysis, it was assumed that pricing included installation, removal and data analysis on a per PFM basis. Based on all assumptions provided above, the estimated cost of sampling and analysis of 8 wells in support of a complete biodegradation evaluation of PCE/TCE and daughter products was $37,883. A complete breakdown is provided in the report.

IMPLEMENTATION ISSUES

The primary end-users of these technologies (MBT, PFM, CSIA) are expected to be DoD site managers and their contractors, consultants and engineers. The general concerns of these end users are likely to include the following: (1) technology availability and cost; (2) appropriate application of the technology at DoD sites; and (3) interpretation of CSIA, MBT and PFM data. These implementation issues are addressed in the following sections. The database developed during this project will also be made available via the ESTCP website.

Availability: The C and Cl stable isotope analyses of VOCs described herein as well as the general qPCR analysis of important organisms and genes responsible for VOC biodegradation are commercially available and conducted in multiple university laboratories. Commercial laboratories include Microbial Insights (Knoxville, TN) and Pace Analytical (Pittsburgh, PA). PFM installation, sampling and analysis is also commercially available from EnviroFlux (Gainsville, Fl). Thus, the key technologies used in this ESTCP project are commercially available. The database developed during this project will also be made available via the ESTCP website.

Technology Application: Appropriate application of the technologies used in this project will vary by site depending on specific conditions and the questions to be answered. During this project, our primary question was the long-term effectiveness of bioremediation and the different tools were combined toward this end and to assess whether biodegradation was still occurring at select sites a few to several years after active treatment.

Data Interpretation: CSIA. CSIA data gathered on environmental pollutants has been utilized to (1) document biological and abiotic contaminant degradation, (2) estimate or constrain rates of contaminant degradation; (3) identify dominant degradation mechanisms; and (4) forensically determine dominant sources of a specific contaminant in the environment, as well as various other specific applications for individual contaminants. The application and interpretation of CSIA data for the above purposes have been thoroughly reviewed in a US Environmental Protection Agency (EPA) document entitled “A Guide for Assessing Biodegradation and Source Identification of Organic Groundwater Contaminants Using Compound Specific Isotope Analysis (CSIA).”

This document is available online through the EPA NEPIS Site. The readers of this ESTCP report are referred to Chapter 4 in this document entitled "Interpretation of Stable Isotope Data from Field Sites" which clearly describes and provides examples of how CSIA data can be utilized to document and quantify the biodegradation of organic contaminants in groundwater aquifers. The Interstate Technology and Regulatory Council (ITRC) Environmental Molecular Diagnostics (EMD) team has also developed online guidance and instruction on CSIA. The C isotope data for TCE, cis-DCE and VC gathered during this project provide information on ongoing degradation of these contaminants at 5 different sites and, for the Raritan Site where samples were collected along a flowpath, an ability to estimate field rates.

Data interpretation: MBT. The molecular analysis conducted during this project (qPCR of key dehalogenating organisms/genes) is now conducted routinely at VOC sites. Guidance concerning the application of this technique and interpretation of results is available at the ITRC EMD website and via Microbial Insights, who provide information on the relative abundance of different gene markers at groundwater sites.

Data interpretation: PFMs. PFM installation, sampling, and analysis is a specialty service that can be provided commercially by EnviroFlux (Enviroflux.com), Dr. Mike Annable at the University of Florida can also provide data analysis and interpretation.

1.0 INTRODUCTION

1.1 BACKGROUND

Aptim Federal Services, LLC (APTIM), along with its project team members at the University of Florida and the University of Tennessee, have prepared this Final Report to describe the methods and results for ESTCP Project ER-201427. We also wish to acknowledge Pace Analytical for conducting the relevant compound specific isotope analysis (CSIA) measurements of chlorinated volatile organic compounds (VOCs).

Source areas of chlorinated VOCs in groundwater create and perpetuate dilute groundwater plumes that subsequently pose risks to downgradient receptors for decades or centuries. Although bioremediation has been applied to treat many source areas with chlorinated ethenes over the past two decades, the overall success of this treatment and factors that differentiate successful from unsuccessful treatment applications have not been thoroughly assessed. We used two separate approaches to evaluate the success or failure of different bioremediation applications and to evaluate factors that may have contributed to those outcomes.

Initially, we selected fifteen (15) VOC sites contaminated primarily with chlorinated ethenes that have been treated using common bioremediation techniques and with data that allow statistical evaluation of remedial performance over time. Sites with extensive pre- and post-treatment data were given priority, and overburden aquifers were selected over bedrock aquifers. A large database was developed from these sites that includes 1) site location; 2) VOC concentrations over time; 3) hydrogeology (e.g., groundwater velocity, depth, groundwater gradient, porosity, percent fines etc.); 4) geochemistry (mineralogy, etc.); 5) water chemistry (pH, Eh, anions, cations, metals, volatile fatty acids (VFAs), co-contaminants, dissolved organic carbon (DOC), total organic carbon (TOC), dissolved gases (methane, ethene, ethane, etc.)); 6) abundances of relevant microbial biomarkers where available (e.g., *Dehalococcoides* (DHC) and relevant reductive dehalogenase genes where available); 7) treatment approach (bioaugmentation, biostimulation, active, passive); and 8) other relevant site data. Statistical analyses were then performed to identify factors that resulted in, or prevented, successful application of the different bioremediation strategies.

From the 15 selected sites for historical data compilation and statistical analysis, 5 sites were chosen to conduct current-day sampling of select wells and used current tools to assess (1) contaminant mass flux, (2) presence of key dehalogenating organisms and genes, and (3) extent of biodegradation that has occurred via CSIA. Pre-treatment data and post-treatment data were compared along with information on site conditions (geologic, hydrogeologic, and geochemical) and treatment methods.

A more thorough understanding of the effectiveness of historical bioremediation applications for treating contaminant source areas will provide the Department of Defense (DoD) with an improved ability to optimize future remediation efforts and to understand the extent of remaining liability at sites where biological treatment has been performed to remediate source areas.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overall objective of ESTCP Project ER-201427 was to assess the long-term effectiveness of past biological treatment approaches for remediating source areas of chlorinated solvent-contaminated aquifers. In support of this objective, the project team:

- evaluated the effectiveness of source area bioremediation as it has been applied over the past decade;
- determined the distribution and persistence of dechlorinating organisms and genes following bioremediation treatment at select sites;
- determined impacts of biotreatment on contaminant flux from source areas;
- identified important factors that resulted in successful, or failed, bioremediation of chlorinated solvent source areas; and
- identified approaches and characterization/monitoring tools that were most effective.

This multi-site effort identified field-scale aquifer effects of *in situ* bioremediation technologies and provided data for identifying factors affecting the success of bioremediation for source area treatment. Several sites where bioremediation treatment had been implemented were evaluated by using a variety of methods, including:

- historical data review of VOC and geochemical parameters;
- a statistical evaluation of factors contributing to treatment effectiveness;
- field measurements to estimate contaminant flux using Passive Flux Meters (PFMs);
- compound-specific stable isotope analysis (CSIA) to determine the extent and mechanisms of degradation; and
- real-time quantitative polymerase chain reaction (qPCR) to monitor the relevant microbes and indicator genes.

The evaluation contained two major components: (1) a multi-site review and statistical evaluation of historical data for fifteen sites; and (2) additional PFM, CSIA, and molecular biology (qPCR) site characterization at five field sites.

1.3 REGULATORY DRIVERS

The most common chlorinated solvents formerly used at DoD facilities include tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane (1,1,1-TCA). Degradation of these parent compounds results in several chlorinated daughter products. Many of the above compounds are regulated by both the U.S. Environmental Protection Agency (USEPA) and various states. The federal Maximum Contaminant Levels (MCLs) are commonly used as remediation standards, however many states have established more stringent standards. The MCLs for the commonly occurring parent chlorinated compounds and their daughter products are listed in **Table 1-1**.

Table 1-1. Federal Maximum Contaminant Levels.

Constituents	USEPA MCL (µg/L)
Tetrachloroethene (PCE)	5
Trichloroethene (TCE)	5
cis-1,2-Dichlorethene (cis-DCE)	70
trans-1,2-Dichloroethene (tDCE)	100
Vinyl Chloride (VC)	2
1,1,1-Trichloroethane (1,1,1-TCA)	200
1,1,2-Trichloroethane (1,1,2-TCA)	5
1,1-Dichloroethene (1,1-DCE)	7
1,2-Dichloroethane (1,2-DCA)	5

Code of Federal Regulations 40 CFR Part 141

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION AND DEVELOPMENT

2.1.1 Background – Long-term Performance of Enhanced Anaerobic Bioremediation

Chlorinated solvents, such as PCE and TCE, were widely used as degreasing agents at both military installations and in industrial processes. Poor disposal processes resulted in widespread contamination of groundwater sources in the United States. Dense non-aqueous phase liquid (DNAPL) dissolution can serve as a long-term source of contamination, creating plumes that can stretch for miles. In the past three decades, several remediation technologies have been developed for in situ treatment of source zone groundwater, which includes chemical oxidation or reduction, thermal treatment, enhanced DNAPL dissolution and enhanced anaerobic bioremediation (EAB) (Alvarez and Illman, 2006). Among these technologies, EAB has emerged as a promising and cost-effective treatment for the removal of high dissolved concentrations of chloroethenes (Aulenta et al., 2007; Cope and Hughes, 2001; Da Silva et al., 2006; Harkness et al., 1999; Hood et al., 2008; Lendvay et al., 2003; Rodriguez et al., 2004; Major et al., 2002; Pérez-de-Mora et al., 2014; Schaefer et al., 2009; Schaefer et al., 2010; Song et al., 2002; Yu and Semprini, 2009).

For chlorinated ethenes, EAB typically involves the subsurface injection of organic substrates and sometimes *Dehalococcoides* sp. (DHC) that are capable of completely dechlorinating PCE and TCE. Hydrogen (H_2) is produced as a result of microbial degradation of a organic substrates via fermentation (e.g., lactate, acetate, emulsified vegetable oils, etc.) and is the only electron donor *Dehalococcoides* can use to reduce TCE to ethene (Grady et al., 2011; Schink, 1997). VFAs, a by-product of fermentation, can be further fermented to hydrogen (Grady et al., 2011; Schink, 1997). Thus, a steady supply of organic carbon can support dechlorination over the long-term (Rectanus et al., 2007; Thomas et al., 2013).

During DNAPL source zone EAB, microorganisms drive down the dissolved phase contamination concentration and increase the mass transfer of contaminants from DNAPL to the aqueous phase (Chen et al., 2013). Enhanced solubilization of DNAPL sources creates the potential for subsequent complete dechlorination downgradient of the source zone. Despite the promise of this technology, questions about the long-term sustainability remain.

High aqueous phase concentrations near saturation have been shown to be toxic to dechlorinating microbes, leading to inhibition of reductive dechlorination of chloroethenes (Adamson et al., 2003, 2004; Amos et al., 2008; Yang and McCarty, 2000). Adamson et al. (2003) noted the accumulation of TCE and cis-DCE until PCE concentrations decreased to approximately 10 µM (~ 1.7 mg/L). Amos et al. (2008) demonstrated that dissolved phase PCE concentrations above 0.54 mM (~ 90 mg/L) inhibited dechlorinating microorganisms but also noted that some PCE dechlorinators produced cis-DCE in the presence of PCE DNAPL. In such cases, PCE-to-DCE dechlorination rates exceeded the rates of PCE dissolution, resulting in non-inhibitory aqueous phase PCE concentrations. Bioremediation has been shown to enhance the rate of PCE DNAPL dissolution in sand columns and flow cells by factors ranging from 1.1 to 21 (Amos et al., 2008; Amos et al., 2009; Christ and Abriola, 2007; Glover et al., 2007; Haest et al., 2012). Bioremediation has resulted in enhanced dissolution in DNAPL source zone field studies, despite the fact that (in some cases) only partial dechlorination to cis-DCE occurs or contaminant rebound occurs (Bondehagen 2010; ITRC, 2007).

Short-term data sets suggest that EAB is an effective treatment strategy for source zones, but the long-term sustainability of this technology is unproven (Hood et al., 2008; Lookman et al. 2007; Puigserver et al., 2016; Scheurtz et al. 2008; Semkiw and Barcelona, 2011; Suthersan et al., 2011). Schaefer et al. (2018) and Haluska et al. (2019) completed a field study showing reductive dechlorination was still occurring ~3.7 years after active treatment in an aquifer containing two hydrological units with different permeabilities. DNAPL entrapped in the lower permeability zone was likely inaccessible to microorganisms, but dechlorinating microorganisms still persisted as mass flux emanating from the source zone decreased and ethene production was sustained long after active treatment (Haluska et al., 2019; Schaefer et al., 2018). McGuire et al. (2016) conducted a multi-site evaluation of post-source zone monitoring data showing a median concentration reduction of 90% at 34 sites, but rebound occurred at 35% of these sites, suggesting remediation is sustainable in the long-term but the rate may not be sufficient to prevent rebound. Tilloston and Borden (2017) also conducted a multisite performance assessment of 37 EAB sites and found that PCE and TCE were removed at ~90% of the sites, but cis-DCE and VC often persisted after active treatment. However, the demonstration of sustained biological activity after treatment requires documented loss of contaminants at field scale, biogeochemical indicator trends, and confirmation of microbial species/genes and degradative activity. Mass flux measurements have also become valuable tools in the assessment of sustained biological activity. We used traditional approaches (biogeochemical measures, contaminant concentration trends, daughter products, etc) and modern tools including compound specific isotope analysis (CSIA) to document ongoing dehalogenation of chlorinated ethenes, quantitative polymerase chain reaction (qPCR) to quantify key dehalogenating organisms and genes, and passive flux meters (PFMs) to quantify contaminant mass flux at several sites in order to assess past performance and post-treatment acitvity of EAB.

2.1.2 Modern Tools for Monitoring In Situ Bioremediation Processes

Several modern tools are now available for evaluating the performance of bioremediation approaches for remediating VOC source zones. Examples of these tools include CSIA, which allows practitioners to evaluate the extent of contaminant degradation at a given location in a plume over time, and to calculate or constrain degradation rates by evaluating the extent of isotopic enrichment at multiple points along a contaminant plume. Likewise, contaminant flux measurements using PFMs allow measurements of the contaminant mass leaving a source area, as well as a highly discrete evaluation of contaminant flow paths in a vertical cross-section of the plume. Together, these tools allow for a more precise evaluation of contaminant mass flux following treatment. Molecular biological tools (MBTs) also are available to evaluate the presence and abundance of degradative microorganisms and to assist in estimating the rate of ongoing biodegradation at a site. Combined with reactive transport modeling and statistical analyses, these tools allow more detailed assessments of treatment effectiveness, factors affecting successful treatment, predictions of on-going treatment, a site's future trajectory, and overall risk reduction. Many of these modern tools have been developed and verified with funding from SERDP and ESTCP. Their application is described in more detail below.

CSIA, especially for PCE and TCE and their degradation daughter products, has become a well-established and useful tool for evaluating the extent of transformation of these compounds in plumes, and for estimating their rates of transformation *in situ* (e.g., USEPA, 2008a; Braeckevelt et al., 2012; Hatzinger et al., 2013). The CSIA technique relies on the observation that biological degradation of these compounds results in a change in the ratio of $^{13}C/^{12}C$ in the remaining parent compound.

This ratio is commonly measured as "delta 13 C" ($\delta^{13}C$) (Meckenstock et al., 2004; Sherwood Lollar et al., 2001; Song et al., 2002) (**Figure 2-1**). Thus, by measuring the ratio of $^{13}C/^{12}C$ in the chlorinated solvent parent compound and its daughter products at a given sample location and comparing those ratios to the same ratios of contaminants in the source area, the extent of biodegradation can be estimated. By comparing the extent of degradation along a contaminant plume at different distances from the source, and by using a groundwater reactive transport model to estimate travel times between the sampling points, the rate of contaminant transformation also can be calculated (USEPA, 2008a; Meckenstock et al., 2004; Braeckevelt et al., 2012; Thullner et al., 2012; Song et al., 2002). When combined with flux measurements and discrete groundwater flow estimates, the method can be applied to evaluate the effectiveness of a source area treatment approach over extended time periods (i.e., years following technology implementation). CSIA analysis for this demonstration was conducted by our subcontracted team member Pace Analytical (Pittsburg, PA).

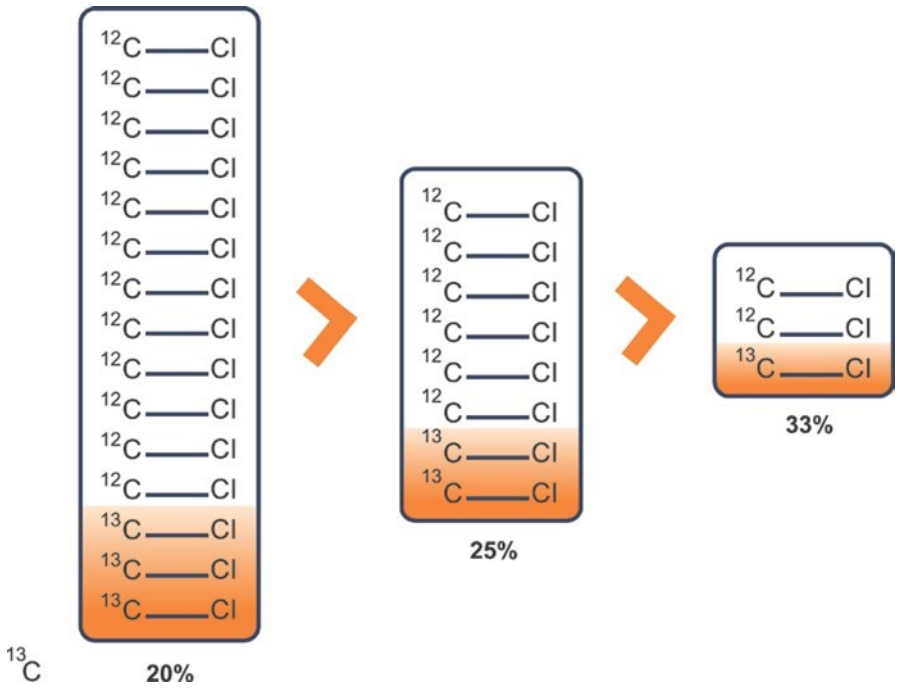


Figure 2-1. Illustration of 13C Enrichment During Degradation of a Contaminant with a C-Cl Bond.

(Source: Microseeps, Inc., used with permission.)

A key measure of the success of remedial actions is a reduction of risk to downgradient receptors. This can be reflected in a reduction of the quantity of contaminant mass, leaving a source area following treatment over a period of time or a flux reduction. This contaminant flux can be estimated by using PFMs. The PFMs are self-contained, permeable units that are inserted into a well or subsurface boring such that it intercepts, but does not retain, groundwater flow (University of Florida, 2006; Annable et al., 2006). PFMs allow measurements of both groundwater flow and contaminant mass flux (University of Florida, 2006). The mass of contaminant accumulated on a permeable sorbent (typically granular activated carbon) is used to calculate a time-averaged contaminant mass flux, while residual resident tracer mass loss is used to calculate cumulative water flux.

An advantage of the PFM technology is that the medium in the PFM can be sectioned vertically to obtain fine detail profiles (i.e., discrete sampling) of groundwater flow and contaminant mass flux through the subsurface porous media (**Figure 2-2**). Thus, this important information can be ascertained without the high cost of additional drilling and the use of mechanical devices and extensive sample collection to measure discrete groundwater flow and, ultimately, contaminant flux.

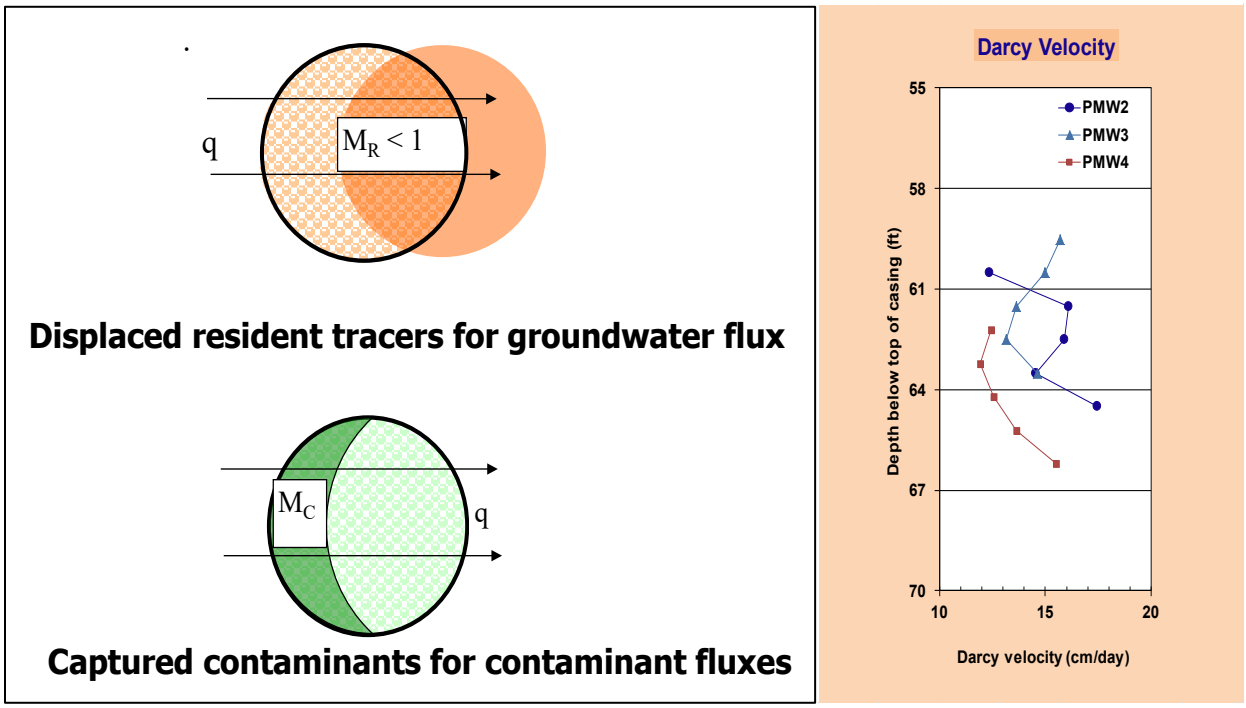


Figure 2-2. Graphic Showing the Dual Use of Mass Flux Meters for Both Groundwater and Contaminant Mass Flux (Left Panel) and an Example of Data Generated Using Passive Flux Meters to Quantify Fluid Flux in a Groundwater Aquifer in Rancho Cordova, CA (Right Panel).

In the right panel, the three lines show groundwater velocity in different wells with each symbol representing a data point from a different depth in the aquifer (data from ESTCP ER-200828, final report).

The qPCR technique has emerged as the method of choice for monitoring organisms- and process-specific genes in environmental samples, including groundwater (Bustin et al., 2009; Ritalahti et al., 2006, Capiro et al. 2014). A wide number reductive dechlorination and VOC degradation biomarker genes have been identified and validated qPCR assays are available. Until recently, the number of potentially relevant target genes that could be analyzed was limited, primarily because each gene required a separate assay, and the cost associated with the analysis of many biomarkers has been problematic. The more recent advances in chip technology allows the simultaneous analysis of numerous biomarker genes in a single instrument run. The reductive dechlorination quantitative real-time PCR chip (RD-qChip), for example, uses a nanoliter fluidics platform (QuantStudio 12K Flex Real-Time PCR System, Life Technologies, Grand Island, NY) that offers

flexibility, scalability, and high-throughput sample processing to analyze over 12,000 individual qPCR assays in a single instrument run. The flexibility in array construction allows appropriate scaling to achieve stepwise progression to the current limit of 224 biomarker targets on a single array plate (with up to four plates per run). Each array plate can accommodate from 56 assays with 48 samples or up to 224 assays with 12 different samples in parallel. In contrast to manual plate setup in conventional qPCR, the QuantStudio platform uses simple, automated workflows with integrated data analysis software and built-in quality controls, thus effectively mitigating inherent human bias, and generating data that are comparable between samples (i.e., sites) and analytical laboratories. The majority of variation would arise from the sample collection and nucleic acid extraction procedures, but those errors can be accounted for by adding appropriate internal standards (Hatt, et al., 2013). This technology has been adapted for monitoring organisms- and process-specific biomarker genes for chlorinated solvent degradation by our collaborator Dr. Frank Löffler as part of SERDP project ER-2312 (Kara-Murdoch et al., 2020; in preparation). The qPCR chip technology was tested at some locations during this project along with a conventional 384-well plate approach and shown to be very comparable. Data from the conventional approach are reported herein for consistency.

With the data collected on contaminant mass flux, degradation (e.g., through CSIA analysis and traditional measures) and microbial biomarkers, an analysis of ongoing biodegradation was performed at the study sites as a "snapshot in time". Several analytical tools are available to compare VOC degradation activities at different sites, and in some cases, factors influencing remedial performance can be understood. For example, bivariate and multivariate statistical methods can be used to identify correlations between these measures of effectiveness versus site characteristics, such as contaminant type(s), pre-remediation VOC concentrations and DHC abundance, presence or absence of DNAPL, the extent of source control, background pH and redox conditions, dynamics of microbial populations present, water quality parameters, etc. Measures of effectiveness (e.g., mass reduction, dechlorination, risk reduction) versus remediation parameters such as remediation methodology (e.g., electron donor used, bioaugmentation versus biostimulation, injection versus recirculation, etc.) were evaluated in conjunction with the analysis of post-remediation redox conditions, post-remediation microbial populations, etc. to recognize patterns and establish correlations.

In terms of technology maturity, CSIA analysis, especially for chlorinated solvents, has become well established as a useful tool for evaluating the extent of transformation of these compounds in plumes and for estimating their rates of transformation *in situ* (USEPA, 2008b; Morrill et al., 2006; Mundle et al., 2012). In addition, contaminant mass flux characterization is an accepted method for evaluating the success of remedial processes, especially in relation to source areas (Brooks at al., 2008), and MBTs, especially for monitoring chlorinated solvent-degrading bacteria, are becoming widely used for monitoring the performance of biological treatment approaches. The ITRC Environmental Molecular Diagnostics (EMD) Team, of which two of the performers on this project were contributing members, published an extensive online Guidance Document concerning the use of CSIA and new molecular tools for documenting *in situ* bioremediation of VOCs and other contaminants (online: http://www.itrcweb.org/emd-2/). Statistical evaluations are an essential component of many fields of research, and the statistical techniques used in this document are well established.

Table 2-1. qPCR Gene Assays Chosen to Characterize the Microbial Community Associated with VOC Transformation.

Dechlorination step	RDase gene	Organism	Organism-specific assay		Functional gene assay
			Genus[a]	Species	
PCE/TCE → cis-DCE	*pceA*	*Dehalococcoides mccartyi*	+	+	-[b]
TCE → VC	*tceA*	*Dehalococcoides mccartyi*	+	+	+
cis-DCE → ethene	*vcrA*	*Dehalococcoides mccartyi*	+	+	+
cis-DCE → ethene	*bvcA*	*Dehalococcoides mccartyi*	+	+	+
tDCE → VC	-	*Dehalogenimonas* sp.	+		-
1,1,1-TCA → 1,1-DCA	*cfrA*	*Dehalobacter* sp.	+		+
1,1-DCA → CA	*dcrA*	*Dehalobacter* sp.	+		+
1,2-DCA → ethene	*bvcA*	*Dehalococcoides mccartyi*	+	+	+
1,2-DCA → ethene	-	*Dehalogenimonas* spp.	+		-
1,1,2-TCA → VC	-	*Dehalogenimonas* spp.	+		-

PCE, tetrachloroethene; TCE, trichloroethene; cis-DCE, *cis*-1,2-dichloroethene; tDCE, *trans*-1,2-dichloroethene; VC, vinyl chloride;1,1-TCA, 1,1,1-trichlororethane; 1,1-DCA, 1,1-dichloroethane; 1,2-DCA, 1,2-dichloroethane;

[a] Genus-specific MBTs are available; however, not all members of the genus are capable of catalyzing the respective dechlorination step.

[b] A specific assay has not been designed but is possible with the available information.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The technologies used in this Demonstration included the CSIA, PFMs, MBTs described in **Section 2.1** along with a multi-site statistical evaluation. The advantages and limitations of these technologies are summarized below.

CSIA

Advantages

Advantages of CSIA technology include:

- CSIA does not rely on concentration trends or the observation of daughter products.
- Because it isolates the contaminant (i.e., is compound-specific), CSIA is relevant only to the compound of interest.
- CSIA can detect minute changes in the isotopic ratio with a high level of precision, which allows for careful assessment across a site to reveal subtle but essential differences in contaminant behavior.
- CSIA is a versatile monitoring tool and can be used for many contaminants in a wide range of applications.

Limitations

Limitations of the CSIA technology include:

- A limited number of laboratories provide CSIA services.
- There is the potential for interference when many contaminants are present. However, modifications to CSIA methods can be used to overcome interferences, such as dual gas chromatograph (GC) column separation methods.
- Isotopic fractionation may be so minimal that little or no isotopic enrichment is detected.
- The initial fractionation factors for non-degraded chlorinated solvents area variable and introduce uncertainties into the evaluation.
- Isotopic shifts in daughter products can be challenging to interpret.
- Enrichment factors for some degradation processes may not be available.

PFM

Advantages

Advantages of PFM technology include:

- The PFM technique improves the ability to identify high-concentration source areas.
- The PFM technique provides a direct measurement of contaminant loading to receptors.
- The technique enables the cumulative measurement of the flow system and averages the variability obtained in grab sampling.

Limitations

Limitations of the PFM technology include:

- Subsurface heterogeneities introduce uncertainty into the results.
- Long time periods may be needed for fluxes to reach equilibrium following remediation.

MBT

Advantages

Advantages of the MBT technologies include:

- qPCR has emerged as a robust technology for obtaining a quantitative understanding of the abundance of microorganisms of interest in environmental samples. Refined protocols for sample collection and handling, DNA extraction, PCR analysis, and data interpretation are available. In addition, extensive know-how of dealing with potential issues such as the presence of PCR inhibitors (e.g., heavy metals, humic acids) has been generated, and appropriate solutions are available.
- The key microbes and functional genes leading to the detoxification of chlorinated ethenes have been identified, and a comprehensive suite of qPCR assays is available.

Limitations

Limitations of the MBT technologies include:

- qPCR will only provide information about known biomarker genes, and no information was obtained about unknown genes that have not been characterized. Many relevant microorganisms and functional biomarker genes (e.g., genes encoding for dehalogenases) have been identified; however, the sequence variability and diversity of existing biomarker genes is not fully understood. Thus, false-negative results are possible, or, more likely, the analysis does not capture the full diversity of target genes, and the results represent a conservative estimate of the true target gene abundance.
- qPCR analysis is generally performed using biomass collected from groundwater samples. Since aquifer microbes, including the dechlorinators, also attach to aquifer solids, qPCR analysis performed on groundwater samples misses the attached fraction. Consequently, the groundwater analysis represents a conservative estimate of the true target gene abundance.
- The presence of a gene of interest does not necessarily correlate to enzymatic activity.

Multi-Site Statistical Evaluation

Advantages

Advantages of the statistical evaluation technologies include:

- The multi-site approach allows for a comparison of factors that span a wide range of hydrogeologic and geochemical conditions.
- A consistent evaluation approach is used, thereby eliminating site-by-site bias.

Limitations

Limitations of the statistical evaluation technologies include:

- Historical data are not available for PFM, CSIA, and MBT at most sites because these methods are relatively new and not widely used historically.
- Historical data used for the evaluation was obtained from external databases with generally unknown data quality. The data were assumed to be useable from a data quality perspective; independent data validation was not performed.
- Historical data was not consistently available for many analytes of interest. For example, VOC concentrations are used extensively for performance monitoring at bioremediation sites; but other analytes such as anions and metals were analyzed on an inconsistent basis or not at all.
- A general principle of statistical evaluations is the caveat that correlations do not prove causation. Any observed correlation must be carefully evaluated to determine if a valid conclusion can be drawn from the observation.

3.0 PERFORMANCE OBJECTIVES

The performance objectives for the study, along with data requirements and success criteria, are described below and summarized in **Table 3-1**. The following subsections provide a brief description of each objective, along with data requirements and success criteria.

3.1 EVALUATE THE EFFECTIVENESS OF SOURCE AREA BIOREMEDIATION – HISTORICAL DATA

One of the primary objectives of this demonstration is to assess the long-term effectiveness of applying bioremediation at chlorinated solvent source areas. Understanding the extent to which source area concentrations have been reduced, and the subsequent impact on groundwater quality downgradient is critical in this evaluation

Data Requirements

Several factors were considered as part of the statistical evaluation of historical data, including information on remedial design and substrate loading along with historical site data on pre-and post-treatment conditions. The following site data was gathered for the evaluation:

1. Chlorinated VOC concentrations before, during, and after treatment are the primary means to determine changes due to treatment.
2. Hydrogeologic factors include hydraulic conductivity, hydraulic gradient, porosity, and seepage velocity. Geologic characteristics include aquifer heterogeneity and the grain-size distribution of soils.
3. Geochemical indicator parameters include pH and oxidation-reduction potential (ORP). Commonly occurring native electron acceptors include dissolved oxygen (DO), nitrate, sulfate, iron, and manganese.
4. Treatment approaches include a variety of factors, including:
    - the method of injection such as recirculation wells, direct-push injections, standard injection wells, and temporary injection points installed by direct-push methods;
    - the substrate used, for example, sodium lactate or emulsified vegetable oil;
    - the dosing of the substrate expressed as the concentration of the substrate as a percentage;
    - the substrate loading (total pounds injected per treatment);
    - the spacing of the injection points;
    - whether bioaugmentation was employed, and if so, the specific microbial culture; and
    - whether or not nutrients were added.
5. The presence, nature, and distribution of microbial populations were evaluated in comparison to treatment effectiveness.

Table 3-1. Performance Objectives.

Performance Objective	Data Requirements	Success Criteria	Criteria Met
Quantitative Performance Objectives			
Identify important factors that result in successful, or failed, bioremediation (15 sites total) Develop a database to correlate, remedial approach, remedial success, and relevant site factors	• Treatment approach • Historical contaminant data (VOC; µg/L) • Historical geochemical data (ORP, anions, metals, pH) • Current and/or past microbial community – key organisms and genes • Site geology	Statistical correlations between treatment approach, remedial success, and site factors	Yes
Evaluate the long-term effectiveness of source area bioremediation (5 sites)	• Groundwater samples from multiple wells per site – multiple remediation approaches in some cases. • Current VOC data (µg/L), • Mass flux data ($M/L^2/T$), • CSIA data (CSIA, $\delta^{13}C$) • Microbial community analysis (arrays; cells/genes/mL)	Source reduction based on parent VOC concentrations at or below historical levels Estimation of current occurrence/rate of bioremediation *CSIA* *VOC flux measurement* *Daughter products* *Microbial communities*	Yes
Qualitative Performance Objectives			
Develop a useful database and tools for evaluating long-term bioremediation/quantifying key factors	Project results and data output	Expandable database Useful correlations observed	Yes

Success Criteria

Measures of effectiveness are related to various aspects of VOC concentration reduction and the extent of dechlorination. Metrics were developed for each of the following measures of success and failure:

- Mass Reduction
- Dechlorination
- Risk Reduction (based on MCLs)
- Rebound

- DCE Accumulation
- VC Accumulation

The development of the metrics for the above measures is described in **Section 5**.

3.2 EVALUATE LONG-TERM EFFECTIVENESS OF SOURCE AREA BIOREMEDIATION

The primary objective of this task is to evaluate the past effectiveness of source area bioremediation at five different sites where different remedial approaches were implemented. VOC analysis, mass flux analysis, CSIA analysis, and microbial community analysis were conducted on groundwater from several different source areas and downgradient locations. The data requirements and success criteria for each of these technologies are described in the following subsections.

3.2.1 Microbial Community/Gene Analysis

Dechlorination activity following the active phase of bioremediation treatment (i.e., electron donor additions) can occur due to both biotic and abiotic processes. Both processes can provide a remedial benefit and attenuate contaminants in post-remediation aquifers. Improved understanding of these long-term processes leads to improved treatment design and site management.

Data Requirements

The data requirements for the microbial/gene analysis include the results of the qPCR analysis of key target organisms/genes from the University of Tennessee.

Success Criteria

A key success criterion of the microbial analysis is the ability to quantify important dehalogenating organisms/genes in the site groundwater samples at current conditions. Ideally, these values can then be correlated with other site measures (VOC concentrations and/or mass flux at the same locations, daughter products, CSIA data) to provide an assessment of the important organisms/genes and/or their critical densities for long-term degradative activity at a site.

3.2.2 Contaminant Mass Flux from Source Areas

Decreases in groundwater VOC concentrations were the primary metric used to assess potential downgradient impacts. However, migration of DHC and changes in biogeochemical conditions also are useful. Decreases in mass flux emanating from the source area also were used as a metric.

Data Requirements

Data requirements include flux measurements using PFMs combined with flux modeling based on pre- and post-treatment data.

Success Criteria

Quantification of site-specific flux measurements was conducted at various sites. The mass flux measurements were evaluated along with CSIA and qPCR analyses to evaluate long-term degradative activity at a site.

3.2.3 CSIA Analysis

CSIA analysis was conducted for TCE and daughter products (cis-DCE and/or VC) to provide evidence of ongoing biodegradation of these VOCs at the field sites.

Data Requirements

Measurement of $\delta^{13}C$ of TCE, cis-DCE and/or VC (based on site conditions and concentrations) was conducted using groundwater samples from source area and downgradient wells and/or areas where different approaches were used. The data were used to obtain evidence of ongoing biodegradation of these VOCs based on (1) historical $\delta^{13}C$ values of TCE and/or (2) increasing $\delta^{13}C$ values along a contaminant flow path where wells/samples were available for such analysis.

Success Criteria

The success criterion is the ability to document ongoing contaminant biodegradation based on isotopic enrichment compared to relevant source $\delta^{13}C$ of TCE. If a flow path and groundwater velocity can be estimated, then rates of degradation can be estimated based on known fractionation factors and enrichment in ^{13}C in TCE, (cis-DCE or VC) as a function of travel time in the aquifer.

3.3 IDENTIFY IMPORTANT FACTORS THAT RESULT IN SUCCESSFUL OR FAILED BIOREMEDIATION

The identification of important factors results from the statistical evaluation of effectiveness.

Data requirements

As previously described, important data requirements include (1) historical site data showing pre- and post-treatment contaminant concentrations, geochemical indicators and microbial composition (2) geochemical and hydrogeologic site characteristics, and (3) treatment approach information including amendments used and delivery methods.

Success Criteria

Success is evaluated using statistical methods to compare conditions to measures of effectiveness.

3.4 IDENTIFY APPROACHES, CHARACTERIZATION AND MONITORING TOOLS THAT WERE MOST EFFECTIVE

The identification of approaches and tools that were most effective were obtained from examining the most successful sites.

Data requirements

Data requirements are site information gathered from site reports along with historical analytical data.

Success criteria

The results of the multivariate statistical analysis are used to identify approaches and tools that were most effective.

4.0 SITE DESCRIPTIONS

A Site Selection Memorandum was previously prepared that described the site selection process. The goal of the site selection effort was to have a group of sites that were representative of widely used bioremediation techniques and that allow statistical evaluation of remedial performance. Sites with extensive pre- and post-treatment data available and accessible for collecting additional samples were given priority, and overburden aquifers were selected rather than bedrock aquifers. Some sites were also selected that have applied bioaugmentation using various commercially available dehalogenating cultures.

The site selection process was initiated by first identifying DoD sites where bioremediation has been applied. A list of approximately 200 sites was identified by searching readily available public information. Sources of information included ESTCP case studies, other publications, administrative records, and general internet searches.

Sites were selected for this study based on: 1) the remedial approach used (e.g., bioaugmentation vs. biostimulation; active vs. passive); 2) electron donor used (e.g., vegetable oil, lactate, poly-lactate, molasses, lactate oil); 3) hydrogeology; 4) geographical location; 5) contaminant type and concentration(s); 6) background redox and pH conditions; and 7) time since remedial activities commenced.

Many of the selected sites have had multiple phases of implementation over time with differing amendments and approaches for delivery, thereby allowing the evaluation of different treatments at the same sites. Likewise, many of the sites also have multiple depth horizons with differing geologic characteristics, thereby allowing an evaluation of the same treatment approaches under varying geologic conditions at the same site.

Fifteen sites were selected for the statistical evaluation based on the criteria described above and preliminary interviews with installation Remedial Project Managers (RPMs). These sites, which are also summarized in **Table 4-1**, were the following:

- Alameda Naval Air Station, Site 4
- Former Charleston Air Force Base, Zone 4
- Dover Air Force Base, Area 6
- Moody Air Force Base, FT-07
- Former Myrtle Beach Air Force Base, FT-11
- North Island Naval Air Station, OU 24
- Orlando National Training Center, SA 17
- Point Mugu Ventura County Naval Base, Site 24
- Former Raritan Arsenal AOC 2
- Seal Beach Naval Weapons Station, Site 70
- St Juliens Creek Annex, Site 21
- Treasure Island Naval Station, Site 24
- Vandenberg Air Force Base, Site 15A,15B
- Vandenberg Air Force Base, Site 32C/35
- Vandenberg Air Force Base, Site 19

Table 4-1. Sites Selected for Evaluation.

Sites	Area	Contaminant	Added Carbon	Bioaugmentation	Implemented	Geology	Delivery
Alameda NAS	Site 4	TCE	Lactate	SDC-9	2012	Sand	Recirc
Former Charleston AFB	Zone 4	TCE	EVO, Molasses	None	2003, 2004, 2008, 2010	Interbedded fine sand, silt, clay	IW, DPT
Dover AFB	Area 6	TCE	Lactate, DAP	None	2002, 2007, 2008, 2011	Medium sand	Recirc, DPT
Moody AFB	FT-07	TCE	HRC, EOS	SDC-9	2002, 2005 2008	alluvial clay, silt, sand	IW
Former Myrtle Beach AFB	FT-11	TCE	Lactate, Lactoil™,	SDC-9	2005, 2006, 2007, 2008	interbedded sand, silty sand	Recirc
North Island NAS	OU 24	TCE	Lactate	KB-1	2007, 2012	silty sand, silt, clay	Recirc
Orlando National Training Center	SA 17	TCE	EOS	None	2006, 2008, 2012	interbedded sand, silty sand	Recirc, DPT
Point Mugu Ventura County NB	Site 24	TCE	ESO, Lactic acid	BAC-9	2002, 2006, 2013	mixed fill, sand and clay	DPT
Former Raritan Arsenal	AOC 2	TCE	Lactate, Lactoil™,	SDC-9	2009	interbedded, sand, silty sand	Recirc
Seal Beach NWS	Site 70	TCE	EVO, Lactate	KB-1, SDC-9	2008, 2009, 2010, 2011	layered silt and sand	IW
St Juliens Creek Annex	Site 21	TCE	EVO	None	2008, 2010	silty sand	DPT, IW
Treasure Island NS	Site 24	PCE	Lactate, Lactic acid	SDC-9	2004, 2008, 2009, 2012	sand and silt	Recirc, IW
Vandenberg AFB	Site 15A	TCE	Lactate, Hydrogen	SDC-9	2010, 2011	sand and clayed sand	Recirc, DPT
Vandenberg AFB	Site 15B	TCE	Vegetable Oil	SDC-9	2010, 2011	sand and clayed sand	Recirc, DPT
Vandenberg AFB	Site 32C/35	TCE	Molasses, Lactoil™, Lactate	SDC-9	2000, 2009	Unknown	IW
Vandenberg AFB	Site 19	PCE	HRC, Lactoil™	BDI, SDC-9	2006, 2008, 2010, 2011	interbedded, sand, clay	DPT

*NAS = Naval Air Station; *AFB = Air Force Base; *NB = Naval Base; *NS = Naval Station; *NWS = Naval Weapons Station; *EVO = Emulsified vegetable oil

A subset of five of the above sites was selected for additional field investigations. The field investigation included standard laboratory analysis, including VOCs, anions, reduced gases, and alternate electron acceptors, along with PFM contaminant flux analysis, CSIA analysis, and MBT analysis. The suite of analytes is described further in **Section 5.2**. The five field sites are as follows:

- Former Charleston Air Force Base, Zone 4
- Dover Air Force Base, Area 6
- Former Raritan Arsenal, AOC 2
- Seal Beach Naval Weapons Station, Site 70
- Treasure Island Naval Station, Site 24

Brief descriptions of each of the five field sites are provided below. Brief descriptions of the remaining ten sites used in the statistical analysis are provided in **Table 4-1** and **Appendix B.**

4.1 FORMER CHARLESTON AIR FORCE BASE ZONE 4

Zone 4 at Charleston Air Force Base (CAFB) is an industrial area near the CAFB flight line. Trichloroethene (TCE) was formerly used for aircraft parts cleaning. Two distinct plumes of TCE contamination, designated Plume 1 and Plume 2, are present at Zone 4. Plume 1 is associated with an oil/water separator at Building 543. TCE was historically present in Plume 1 at concentrations exceeding 100,000 µg/L, and the plume extended to a distance of 600 ft. The origin of Plume 2 is a solvent spill that occurred in 1978 at Building 532. Historical TCE concentrations at Plume 2 exceeded 10,000 µg/L. Plume 2 is also approximately 600 ft in length. Additional details are provided in **Section 5.3.1.**

4.2 DOVER AIR FORCE BASE AREA 6

Area 6 at Dover Air Force Base contains a large plume of chlorinated ethenes and ethanes that is approximately 2,500 ft wide and 6,500 ft long. Several source areas have been identified with the most important source area being Site OT14, also known as Building 719. Building 719 is a jet engine maintenance facility, and TCE was used to degrease engine parts in the 1960s. Dip tanks and associated drain lines are the suspected sources of TCE contamination at this site (ORNL 2004-10). Significant contamination is present beneath the engine cleaning rooms. Two underground storage tanks (USTs) were formerly present at Building 719 that may have been contributing sources. This site contains a mixed solvent plume with PCE, TCE, and 1,1,1-TCA contributing to the source. Maximum TCE concentrations historically exceeded 20,000 µg/L. PCE, cis-DCE, and VC are present at lower concentrations. Baseline concentrations of 1,1,1-TCA and its breakdown product 1.1-dichloroethane (1,1-DCA) ranged between 500 and 1,000 µg/L. The breakdown product 1,1-DCE was present at lower concentrations. Additional details are provided in **Section 5.3.2.**

4.3 FORMER RARITAN ARSENAL AOC 2

AOC 2 at the former Raritan Arsenal contains a TCE plume that extends approximately 3,000 ft. Multiple sources contribute to the plume; however, the source at Building 256 is apparently the most significant contributor to contamination. Concentrations of VOCs exceeded 1 mg/L before treatment with cis-DCE having the highest concentration. The primary source of the plume is

located at Area 18C, the Building 256 Ramp Area. Building 256 was formerly used for vehicle maintenance. The specific operations that produced the contamination are uncertain, but TCE likely was discharged to the ground surface at the Ramp Area. Additional details are provided in **Section 5.3.3.**

4.4 SEAL BEACH NAVAL WEAPONS STATION SITE 70

Seal Beach Naval Weapons Station is located south of Los Angeles. Seal Beach Site 70 is also known as the Research, Testing, and Evaluation Area. TCE was used during various research and development activities that occurred at the site between 1962 and 1985. From 1962 to 1973, the area was used for the design and manufacture of Saturn II launch vehicles for the Apollo space program. Additional research and development activities were subsequently conducted at the site (Geosyntec 2008). Additional details are provided in **Section 5.3.4.**

4.5 TREASURE ISLAND NAVAL STATION SITE 24

Site 24 at Naval Station Treasure Island is contaminated with PCE, and a plume of contamination extends over 1,100 ft to the San Francisco Bay. The main source area, Building 99, contained dry cleaning facilities that operated between 1942 and 1977. Total VOC concentrations above 1 mg/L occurred throughout much of the plume before remediation. Additional details are provided in **Section 5.3.5.**

5.0 TEST DESIGN

The following subsections describe the system design and testing conducted to address the performance objectives described in **Section 3.0**. The primary phase of the project included database development, field investigations at the 5 select sites, data analysis, and statistical evaluations as described in the following subsections.

5.1 DATABASE DEVELOPMENT

The multi-site evaluation included the gathering of historical analytical data and information on site conditions and the treatments applied. Electronic data were obtained for each of the evaluation sites whenever possible. Data was also gathered from hard copy sources when electronic data were not available. Critical sources of electronic data include the following databases maintained by the government:

- The Environmental Restoration Information System (ERIS) is the Army's web-based database system for the storage of Army environmental restoration field data. It serves as a central repository for the Army installation chemical, geological, and geographical data.
- The Environmental Resources Program Information Management System (ERPIMS) is the Air Force system for the management of data from environmental projects at Air Force installations. This data contains analytical chemistry samples, tests, and results, as well as hydrogeological information, site/location descriptions, and monitoring well characteristics.
- The Navy Installation Restoration Information Solution (NIRIS) provides analytical data along with data management and visualization tools. NIRIS also includes a collection of site documents.

Documents generated as part of site remediation activities were obtained from web-based document-sharing sites, where available, and through direct requests to installation Remedial Project Managers (RPMs). Site reports were reviewed to obtain details on hydrogeologic conditions and the treatments applied at each site. Typical documents with site information included, for example, Remedial Designs, Remedial Action Workplans, Remedial Action Completion Reports and Monitoring, and Progress Reports.

Because of the large amount of existing information and data collected and analyzed during this project, a database was created to organize and evaluate the data. Data were housed in a SQL Server database. The SQL server provided a back-end data repository for analytical data and was managed by a front-end Microsoft Access database. Data added to the Microsoft Access database included: 1) site location; 2) VOC concentrations; 3) hydrogeology (e.g., groundwater velocity, groundwater gradient, porosity, etc.); 4) geochemistry; 5) water chemistry (pH, Eh, anions, cations, metals, VFAs, co-contaminants, DOC, TOC, methane, ethene, ethane, acetylene, etc.); 6) abundances of relevant microbial biomarkers (e.g., DHC, reductive dehalogenase genes); 7) treatment approach (bioaugmentation, biostimulation, active, passive); and 8) other relevant site information. A chart showing the flow of data is provided in **Figure 5-1.**

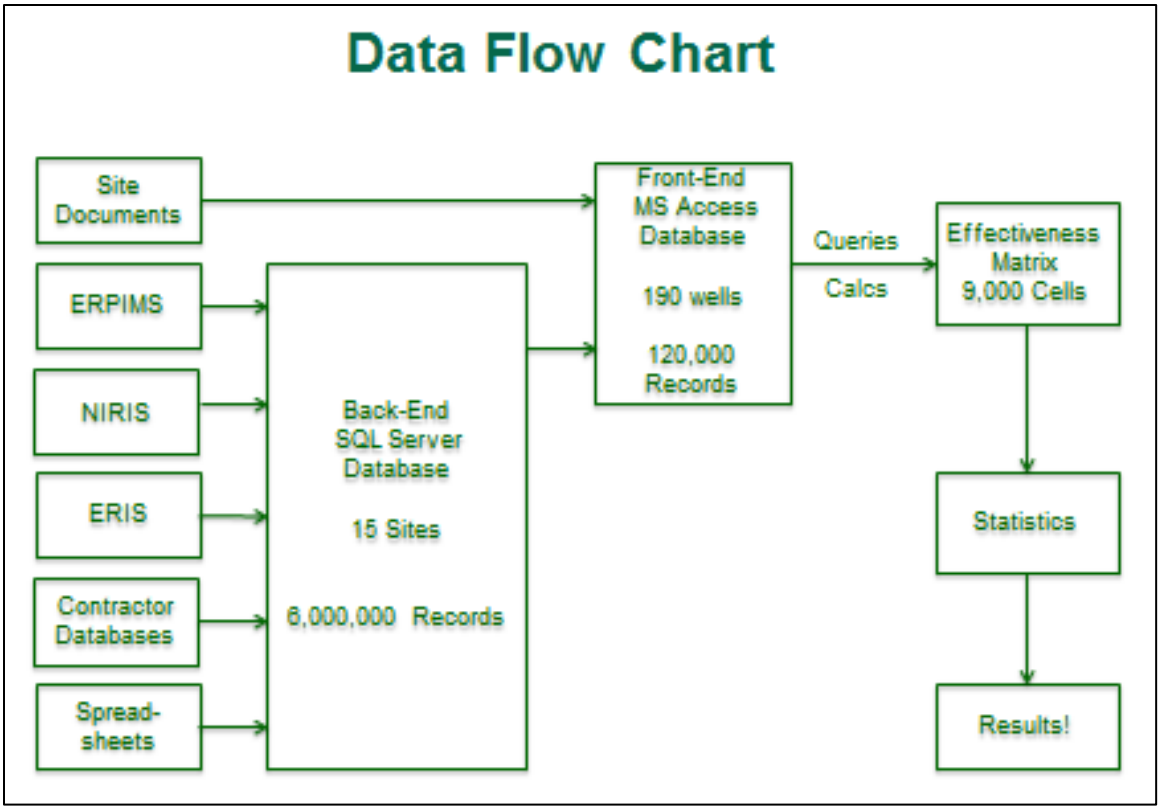


Figure 5-1. Data Flow Chart.

Database Data Quality Assessment

The analytical data obtained from the various sources (e.g., government databases, contractor databases, and data summary spreadsheet) was assumed to be accurate. An independent data validation of the original laboratory reports was not conducted as part of this evaluation. A limited data quality assessment was conducted, as described below.

Analytical results outside the normal range for some analytes were eliminated as outliers and not included in the evaluation. Criteria for elimination as outliers included results outside the following limits:

- pH < 0;
- pH > 14;
- DO < 0 mg/L;
- DO > 10 mg/L;
- ORP < - 600mV; and
- ORP > + 1,000 mV

The above analytes were all from measurements with field instruments. The results outside the ranges noted above likely resulted from instrument error, operator error, or transcription error. Regardless of the cause, the results outside the limits noted above were rejected as unusable.

Duplicate results included field duplicates, laboratory replicates, and data entry duplicates. Field duplicates were not used in the evaluation in preference to the non-field-duplicate result. Laboratory replicates occur as a result of multiple runs on the same sample. These results often differ by a factor of 15% or less. Often the laboratory designates a single result with a "Reportable Result" flag. However, this designation was not available in many cases. In the case of laboratory replicates without a Reportable Result flag, the maximum result of the laboratory replicates was selected as a conservative measure.

5.2 FIELD INVESTIGATIONS

5.2.1 Sampling Rationale

Five field sites were selected for additional field investigations to assess current post-treatment conditions. The investigations included groundwater sampling from existing monitoring wells and analysis of a variety of parameters. As previously noted, the five field sites were as follows:

- Former Raritan Arsenal, AOC 2
- Dover Air Force Base, Area 6
- Charleston Air Force Base, Zone 4
- Seal Beach Naval Weapons Station, Site 70
- Treasure Island Naval Station, Site 24

The objective of the groundwater sampling was to assess the long-term impacts of the previously performed biostimulation and/or bioaugmentation treatments on contaminant concentrations, groundwater quality, and biogeochemistry. Field activities at each site included the collection of groundwater samples and installation of passive flux meters (PFMs) in existing monitoring wells at each of the five field sites.

Groundwater samples were collected at monitoring wells variously located within treatment zones and at downgradient locations. Wells were selected based on treatment effectiveness and include sites with apparent successful and unsuccessful bioremediation applications at different times in the past. A description of each of the field sites, sampling rationale for each site, the monitoring wells selected for sampling, and the number of groundwater samples at each site is described in subsequent subsections.

The analysis included the following parameters:

<u>VOCs</u>

VOCs analysis by EPA Method 8260 at APTIM's Analytical and Treatability Lab (ATL) was used to assess the extent of treatment and/or rebound, and the extent to which reductive dechlorination has occurred/continued to occur since treatment implementation.

Reduced Gases

Reduced gases, including methane, ethane, and ethene (MEE) measured using EPA Method 3810, RSK-175 were used to assess the extent to which complete reductive dechlorination is still occurring within the treatment area. Methane data also provide insight into the redox conditions.

Anions

Anions, including chloride, nitrate, and sulfate, measured by EPA Method 300.0, provide insight into the current redox conditions and the dominant electron acceptors. Total sulfate plays a significant role in rates/extents of reductive dechlorination at specific sites or locations at a given site. Chloride levels provide a measure of salinity at each site.

Dissolved Iron and Manganese

Dissolved iron and manganese levels were measured using EPA Method 601.0. These data provide insight into the current redox conditions and dominant electron acceptors and may also provide useful information about potential abiotic reactions.

Volatile Fatty Acids

Volatile fatty acids (VFAs), measured by EPA Method 300m, are commonly present during active bioremediation treatment. Groundwater samples were analyzed to determine if residual levels persist, possibly serving as electron donors.

Dissolved Hydrogen

Dissolved hydrogen levels, measured using EPA Method 3810, are used to assess whether hydrogen is present at detectable levels at any site months to several years after biological treatment, as an indication of ongoing fermentation.

Total Organic Carbon

Total Organic Carbon (TOC) levels, measured using EPA Method 415.1, indicate available organic carbon that could support reductive dechlorination.

Field Parameters

Dissolved oxygen (DO), pH, turbidity, and ORP were measured as indicators of geochemical conditions using a standard multi-parameter field meter. Values were recorded during low-flow sampling after each well had stabilized.

Microbial Community

Dr. Frank Löffler at the University of Tennessee performed a targeted microbial community analysis (qPCR) to determine the presence and abundance of organohalide-respiring bacteria including DHC, *Dehalobacter*, and *Dehalogenimonas*. In addition, the University of Tennessee quantified functional genes involved in reductive dechlorination of chlorinated solvents.

CSIA

CSIA analysis was performed for carbon in TCE, cis-DCE, and VC as a means to assess whether VOC degradation is occurring or has occurred in the recent past based on current values of $\delta^{13}C$.

The measured $\delta^{13}C$ value for TCE are evaluated as a function of (1) historical values of $\delta^{13}C$ in manufactured TCE (generally -30 ± 5 ‰); (2) previous CSIA analyses conducted at the site when available and/or (3) distance from the source area. The analysis conducted will depend on the current and historical data that are available. The analysis was done by Pace Analytical, Inc. (Pittsburgh, PA).

Mass Flux

The mass flux of VOCs was evaluated by Dr. Mike Annable at the University of Florida using the PFM procedures summarized in **Appendix D.**

5.2.2 Groundwater Sampling Procedures

Groundwater wells were sampled in accordance with the procedures described in this section. The sampling method used was dependent on well construction, with standard parameter measurements taken in conventional large-diameter monitoring, extraction, and injection wells. Modified sampling procedures were applied to multi-level and small-diameter wells. The wells were purged, by micro-purge technique, prior to sampling using a pump and dedicated tubing.

Groundwater samples were collected from the monitoring wells using a portable bladder or peristaltic pump and low flow techniques. Dedicated polyethylene tubing was maintained for each monitoring well. Specific considerations for individual well types are as follows:

- Large Well (2-inch or greater diameter) – Sampling was conducted using a standard 1.5-inch (nominal) diameter down-hole bladder pump. Field chemistry parameters were measured during the purge process, and sampling was initiated once parameters had stabilized, as discussed below.
- Narrow Diameter Well (less than 2-inch diameter) - Sampling was conducted using a surface-based peristaltic pump. Field chemistry parameters were measured during the purge process, and sampling was initiated once parameters had stabilized as discussed below.
- Sampling of multilevel wells (if present) was conducted using a surface-based peristaltic pump. Sampling was initiated after purging a minimum of 1 liter of groundwater. No field chemistry parameters were measured during the purge process.

When purging required the measurement of field parameters, the field sampler monitored purged water for turbidity, pH, temperature, DO, ORP, and specific conductivity using a hand-held instrument (Horiba U-10 or equivalent) and a flow-through cell. After the monitoring wells had been purged, and the field parameters had stabilized, groundwater samples were collected directly from the end of the pump tubing.

The following standard procedures were followed when sampling.

1. Confirm the well identification at each well.
2. Calibrate field instruments following the manufacturer's directions. Record all calibration documentation in the field logbook.

3. Measure the depth to water at each well using an electronic water level indicator probe. Record the water level measurement to the nearest 0.01 inch in the field logbook. Decontaminate the water level indicator before each measurement.
4. Carefully lower the pump into the well. Use dedicated tubing for sampling. Place the intake of the pump to the middle of the screen interval. Ideally, the pump speed was set, so the water column in the well did not drop more than 1 ft below the initial water level reading, although sampling multi-level wells precludes simultaneous water level measurement. Using a micro-purge technique, the flow rates generally ranged between 300 and 500 milliliters per minute (mL/min).
5. Where required, water quality parameters (i.e., DO, conductivity, pH, ORP, turbidity, and temperature) were measured every 3 to 5 minutes during purging. In-line monitoring equipment was used to minimize exposure to the atmosphere to increase the reading stability for accurate measurements of DO and ORP. Water quality parameters were recorded on the groundwater sampling log forms. When the water quality parameters were stable for three consecutive readings, samples were collected for chemical analysis. Stabilization is achieved if successive readings are within +/- 0.1 pH units, +/- 1 degree Celsius for temperature, 3 percent for conductivity, and 10 percent for DO. Turbidity and ORP readings were not used as stabilization criteria. In situations where the water quality parameters could not be stabilized in a reasonable timeframe, purging was continued until at least three calculated well volumes were purged prior to sampling.
6. For sample collection, the pump flow was reduced to a rate of less than 300 mL/min. Flow rates during the collection of VOC samples were set not to exceed 100 mL/min. The pump was not stopped after stabilization and prior to sample collection unless the water level was approaching the base of the well.
7. Samples were collected from the discharge of the pump into the appropriate sample containers. Field quality control samples (e.g., field duplicates) were collected as required.
8. For microbial community analysis, 1L of groundwater was passed through Sterivex filters in the field, and the filters were subsequently be used for microbial/gene analysis. **Section 5.2.3** and **Appendix C** provides a detailed description of the procedure.
9. The samples were labeled, packaged, and prepared for shipment to the laboratory. All samples were placed in cold storage immediately after collection and until shipping/ transport in coolers on ice.

After sampling was complete at one well, the portable pump was decontaminated before being inserted into each monitoring well. Sampling and measuring equipment reused in multiple wells was decontaminated before use. This includes bladder pumps, water level indicators, and any other instrumentation or material potentially exposed to contaminants. Decontamination of sampling and measurement equipment included the following:

- Initial wash using Alconox or other approved detergent;
- Rinse with potable water; and
- Air dry or drying using a clean towel.

The use of dedicated down-hole tubing and the replacement of sampling bladders between wells precluded the need to decontaminate all but the reusable metallic components of bladder pumps. Peristaltic pumps using dedicated or disposable tubing require no decontamination. Purge water was disposed of following the established practices at each site.

5.2.3 qPCR Procedures

Groundwater samples were collected and shipped to the University of Tennessee either as groundwater in 1-L bottles, or the biomass that was collected on Sterivex-GP cartridges *on site* (Millipore, Billerica, MA, Cat.#: SVGPL10RC) (Ritalahti et al., 2010; Ritalahti et al. 2010a,b). Further details on sample collection procedures are provided in **Appendix C.**

DNA was isolated from the Sterivex-GP cartridges using the MoBio PowerLyzer PowerSoil Kit (MoBio, Carlsbad, CA) according to the manufacturer's recommendations. DNA concentrations were quantified using the Qubit dsDNA BR Assay (Life Technologies, Grand Island, NY) according to the manufacturer's manual. DNA solutions were stored at -80°C until analysis.

For qPCR analysis, each sample was diluted to three different dilutions using nuclease-free water (i.e. 1:10, 1:100 and 1:1,000) to determine if any contaminants were present that would interfere with the qPCR analysis. A non-linear response would indicate the presence of inhibitors and the dilute sample(s) that gave the best fit within the template DNA standard curve was included in the analysis (typically the 1:10 dilutions).

Standard curves were prepared using plasmid DNA (pDNA) synthesized and incorporated into *E.* coli by Life Technologies (Grand Island, NY). Alternatively, target gene fragments were amplified with PCR following isolation of gDNA using the MoBio PowerLyzer PowerSoil Kit per kit protocol (MoBio, Carlsbad, CA) and cloned into the pCR™2.1 vector and incorporated into *E.* coli using the Invitrogen TA Cloning™ kit per kit protocol (Life Technologies, Grand Island, NY). The *E. coli* transformants were grown in Lysogeny Broth (LB) with ampicilin (100 µg/L) or kanamycin (50 µg/L) at 37°C overnight. pDNA was isolated using the Zymo Research Zyppy™ Plasmid Miniprep Kit (Zymo Research Corp., Irvine, CA) and quanitified using a NanoDrop and the Qubit 2.0 Fluorometer. All standard curves had a total of eight calibration points.

5.2.4 Passive Flux Meter Procedures

The PFM design for organic contaminants is a self-contained permeable activated-carbon cartridge that is inserted into a well screen or boring such that groundwater flows horizontally through the cartridge under ambient hydraulic gradients. The PFM is constructed in units 1.5 meters long and can be stacked in wells to cover long vertical screen intervals. The activated carbon serves to intercept and retain dissolved organic contaminants present in groundwater flowing through the well screen. The activated carbon is also impregnated with known amounts of soluble 'resident tracers', typically alcohols. These tracers are leached from the sorbent at rates proportional to the water flux.

After a specified period of exposure to groundwater flow, the PFM is removed from the well. Next, the sorbent is carefully extracted to quantify the mass of all organic contaminants intercepted by the PFM and the residual masses of all resident tracers. The contaminant masses are used to calculate time-averaged or cumulative contaminant mass fluxes, while residual resident tracer

masses are used to calculate time-averaged or cumulative water flux. Depth variations of fluxes can be measured by vertically segmenting the exposed sorbent at specified depth intervals.

PFMs were installed in monitoring wells following the groundwater sampling event. PFMs remained in the wells for approximately two to four weeks, and then were collected and analyzed by the University of Florida. A description of the PFM protocol is provided in **Appendix D.**

5.2.5 Analytical Methods, Sample Preservation, and Containers

The groundwater samples were transported to laboratories for analysis of several parameters. The University of Tennessee received Sterivex cartridges with biomass collected from the monitoring wells. The PFM data were analyzed at the University of Florida. Pace Analytical Laboratory conducted CSIA analysis.

The analytical methods and sample preservation methods used are summarized in **Table 5-1.** Additional details were included in Sampling Plans prepared for each site.

Table 5-1. Analytical Methods, Preservation, and Containers.

Analyte	Method/ Laboratory	Preservative	Containers
VOCs	EPA 8260 APTIM	4°C with HCl	40 mL VOA vial (x3)
Anions	EPA 300.0 APTIM	4°C	120 mL polyethylene screw-cap (x1)
Reduced Gases	EPA 3810, RSK 175 APTIM	4°C with HCl	40 mL VOA vial (x2)
Dissolved Hydrogen	EPA 3810, RSK 175 APTIM	4°C with HCl	125 mL glass serum bottle with Teflon-lined cap and crimp seal
TOC	EPA 415.1 APTIM	4°C with H_3PO_4	120 mL polyethylene screw-cap (x1)
Volatile Fatty Acids	EPA 300m APTIM	4°C	40 mL VOA vial (x2)
Microbial Community	RD-qChip / University of Tennessee	4°C	1 L glass bottle filtered through a Sterivex cartridge
CSIA (carbon)	Carbon Isotopes in dominant VOCs ($\delta^{13}C$) Pace Analytical	4°C with HCl	40 mL VOA vial (x9)
Metals - dissolved (Fe, Mn)	EPA 6010 Pace Analytical	4°C with HNO_3	120 mL polyethylene screw-cap (x2)
DO, ORP, pH, Turbidity	Feld Meter	--	--

5.3 SAMPLING RESULTS

5.3.1 Former Raritan Arsenal AOC 2

5.3.1.1 Site Description, Former Raritan Arsenal AOC 2

Site AOC 2 at the former Raritan Arsenal previously had a TCE plume that extended approximately 3,000 ft downgradient. The primary source of the plume was Area 18C, the Building 256 Ramp Area (**Figure 5-2**). Building 256 was formerly used for vehicle maintenance. The specific manner of disposal is unclear, but presumably was the surface disposal of solvents at the Ramp Area.

Two sand units are present beneath the site. The Upper Sand contains sand and silty sand and is approximately 20 ft thick (**Figure 5-3a**). A 5-ft thick silty unit separates the Upper Sand from the Lower Sand. The Lower Sand is approximately 10 ft thick (**Figure 5-3b**). The depth to water is approximately 10 ft below ground surface (bgs). Aquifer pumping tests indicate the Upper Sand has a relatively low hydraulic conductivity of 2.3 ft per day, whereas the Lower Sand has a higher hydraulic conductivity of 50 ft per day. Baseline groundwater sampling indicates the aquifer is generally aerobic and acidic, with pH values ranging from 3.3 to 7.4.

Excavation of contaminated soil occurred in 1998 and 2002, and groundwater TCE concentrations subsequently decreased from approximately 3,000 µg/L to 100 µg/L from 1998 to 2007. Bioremediation was implemented in the source area in 2009 to reduce contaminant concentrations further. The system included recirculation via nine injection wells and nine extraction wells in the Lower Sand. Sodium lactate and nutrients were introduced as amendments along with the SDC-9 bioaugmentation culture. Sodium and potassium hydroxide were used to raise the pH to near neutral levels, to facilitate bioremediation. The recirculation system operated for a 10-month period. Near the end of the recirculation period, an emulsified oil substrate was introduced into the Upper Sand to provide a longer-term, slow release of electron donor to promote biodegradation where recirculation was not applied.

The bioremediation at the site substantially decreased the concentrations of contaminants. Long-term monitoring is currently occurring at the site with natural attenuation selected as the remedy for the remainder of the plume. No further active remediation is planned.

The field investigations at this site assessed rebound in contaminant concentrations since the remediation activities in 2009, and the persistence of the dechlorinating microbial community in a low pH aerobic aquifer environment.

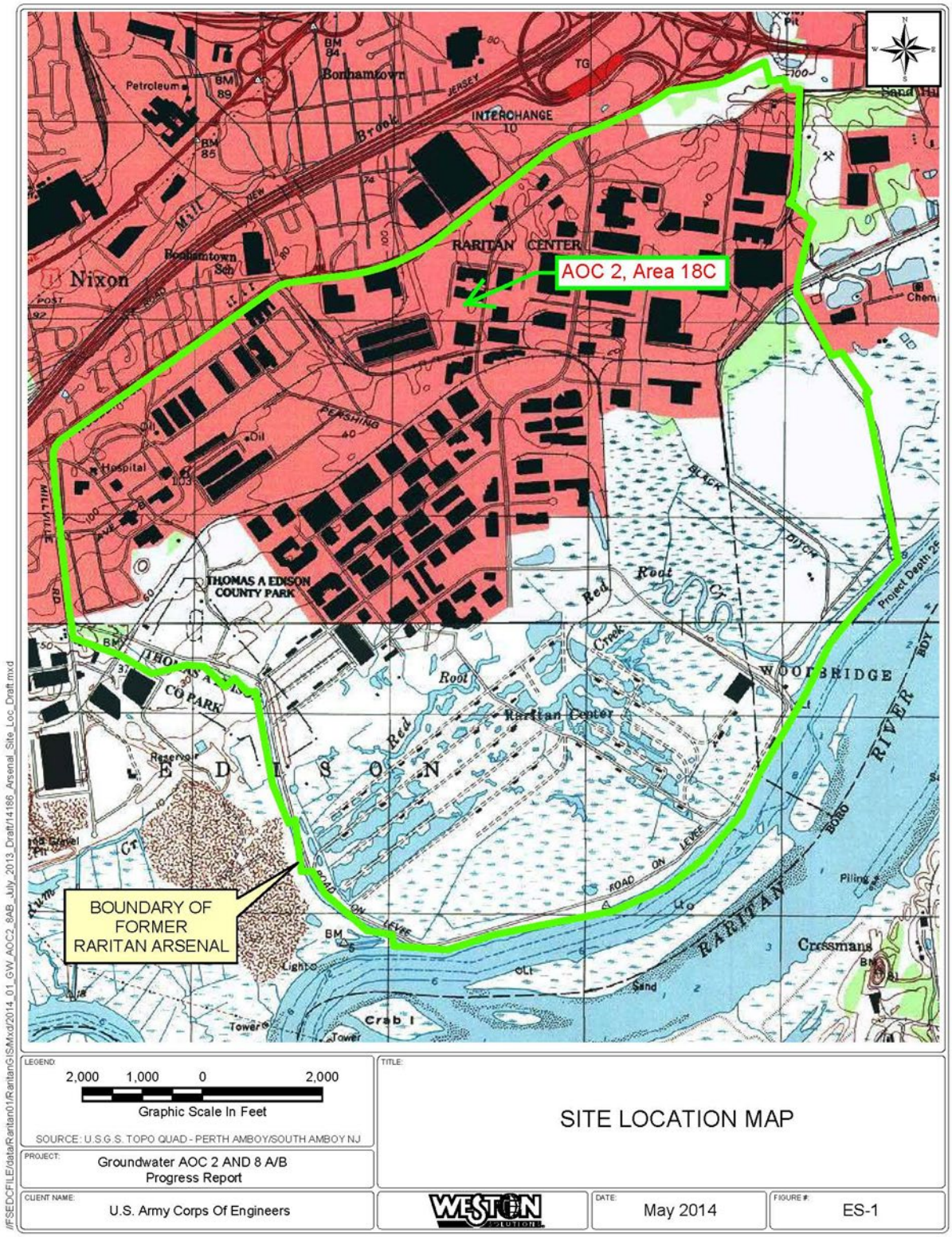


Figure 5-2. Site Location Map, Former Raritan Arsenal AOC 2.

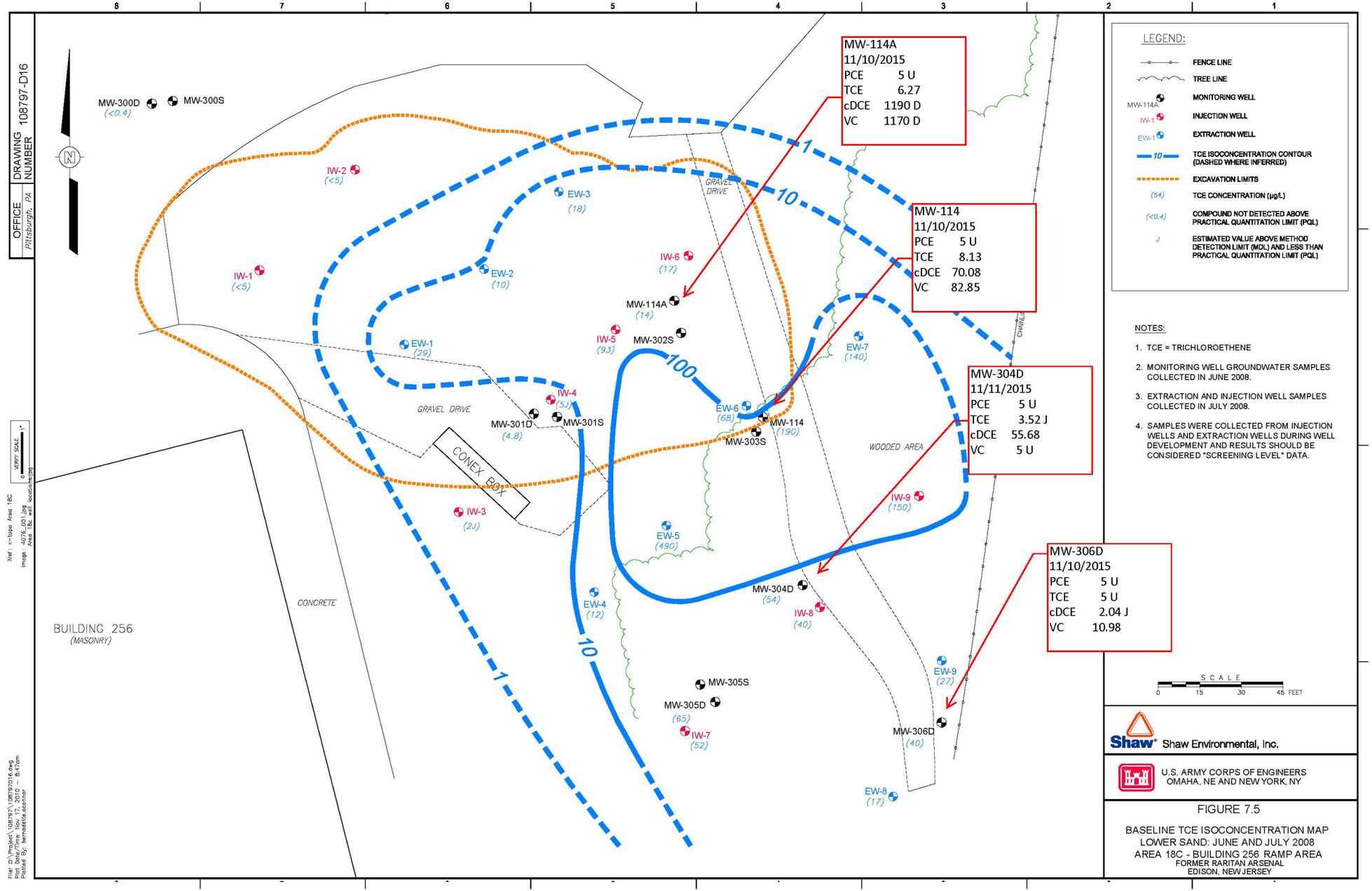


Figure 5-3a. Site Plan, Upper Aquifer, Former Raritan Arsenal AOC 2.

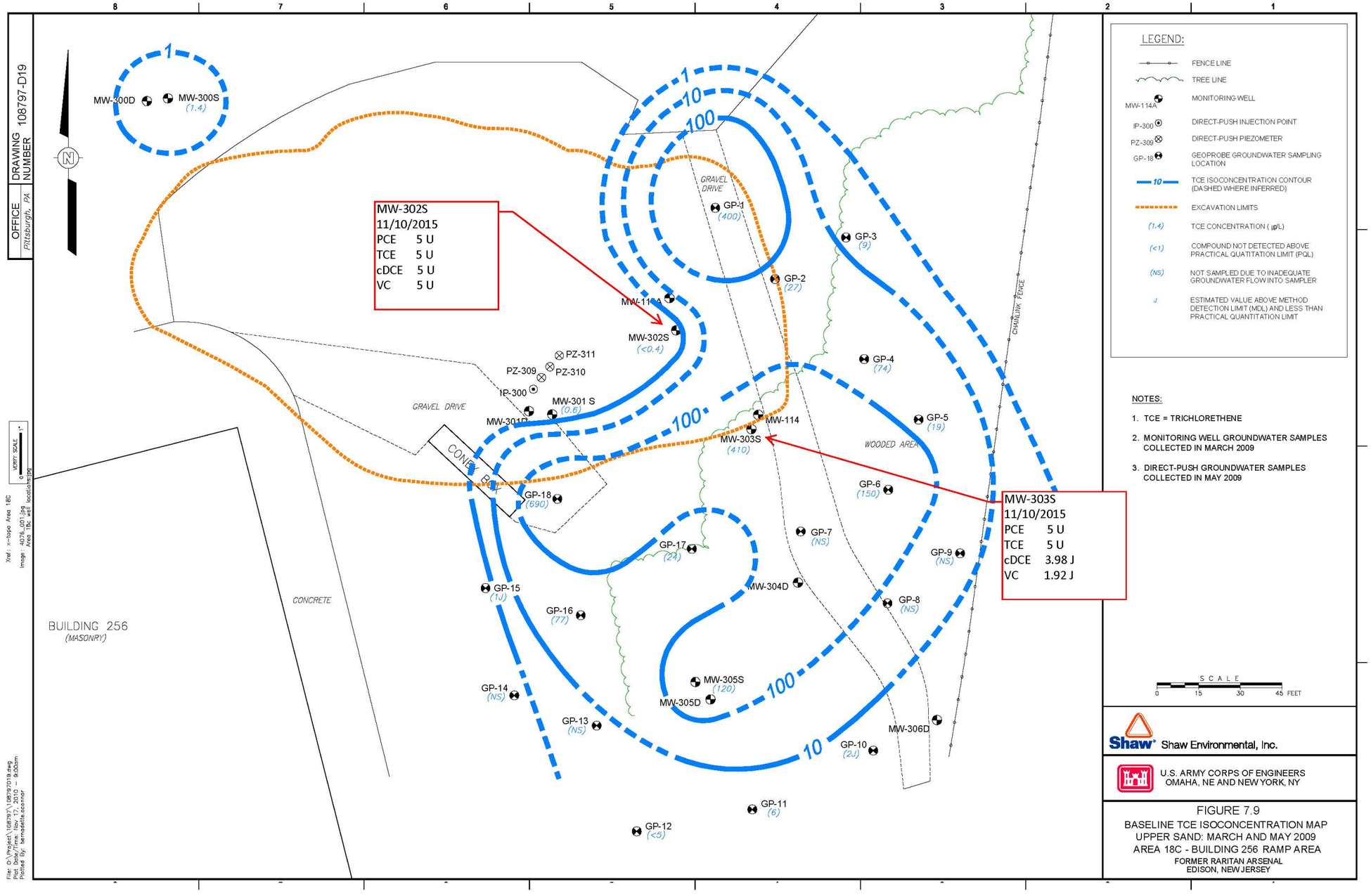


Figure 5-Error! Bookmark not defined.**b. Site Plan, Lower Aquifer, Former Raritan Arsenal AOC 2.**

5.3.1.2 Sampling Rationale, Former Raritan Arsenal AOC 2

The objective of the groundwater sampling was to assess the long-term impacts of the previously performed bioaugmentation treatment on groundwater quality and biogeochemistry. Monitoring locations within and downgradient of the Source Area were evaluated as described below. Monitoring wells sampled are shown in **Figure 5-3a,b**. **Table 5-2** summarizes the monitoring locations and rationale for the sampling program.

Table 5-2. Groundwater Sampling Locations and Rationale, Raritan Arsenal AOC 2, Area 18C.

Raritan AOC 2, Area 18C Monitoring Well	Sampling Rationale
MW-302S	Within the source area treatment zone and in the Upper Sand. This well represented the long-term effects of the treatment in the Upper Sand.
MW-114A	Within the source area treatment zone and in the Lower Sand. This well represented the long-term effects of the treatment in the Lower Sand.
MW-303S	Located at the downgradient edge of the source area and in the Upper Sand depth horizon. This well monitored contamination and flux exiting the source area in the Upper Sand.
MW-114	Located at the downgradient edge of the source area and in the Lower Sand depth horizon. This well monitored contamination and flux exiting the source area in the Lower Sand.
MW-304D	Downgradient of the treatment zone. This well was evaluated for downgradient effects.
MW-306D	Downgradient of the treatment zone. This well also was evaluated for downgradient effects.

Monitoring wells MW-302S and MW-114A are located within the central part of the original source area treatment zone. MW-303S is screened in the Upper Sand, and MW-114A is screened in the Lower Sand (**Table 5-3**). Monitoring wells MW-303S and MW-114 are located at the downgradient edge of the source area and treatment zone.

The above wells were used to evaluate contaminant concentrations and mass flux exiting the source area. Substantial degradation was observed in these wells during the active treatment period that extended from 2008 to 2010; total VOC concentrations were reduced between 74% and 100% in the various wells. Sampling was conducted approximately 5.5 years after the active treatment, and data from these wells was used to evaluate the long-term effectiveness of the treatment.

Monitoring wells MW-304D and MW-306D are screened in the Lower Sand and located downgradient of the Source Area at distances of approximately 60 and 130 ft, respectively. These wells were used to evaluate conditions downgradient. No degradation was observed in monitoring well MW-304D during the active treatment period, whereas a 90% reduction in total VOCs was observed in monitoring well MW-306D. Data from these wells was used to evaluate changes in downgradient conditions that may have occurred 5.5 years after active treatment.

Table 5-3. Monitoring Well Construction Details, Raritan Arsenal AOC 2.

Monitoring Well	Total depth (bgs)	Top of Screen (bgs)	Bottom of Screen (bgs)	Diameter (inches)
MW-302S	23	13	23	2
MW-114A	36	26	36	2
MW-303S	20	10	20	2
MW-114	34	24	34	2
MW-304D	31	21	31	2
MW-306D	27	17	27	2

bgs = ft below ground surface

5.3.1.3 Sampling Results, Former Raritan Arsenal AOC 2

Table 5-4 provides a summary of sampling results and **Figures 5-4** through **5-9** provide historical and project data for VOCs for each well.

5.3.1.3.1. VOCs

TCE and cis-DCE were both below detection (PQL 5 µg/L) the shallow site monitoring wells (MW-302S and MW-303S) more than 5.5 years after treatment with emulsified vegetable oil and bioaugmentation (**Figure 5-4, 5-5**). For MW-303S, concentrations of TCE and cis-DCE were as high as 400 and 1,000 µg/L, respectively, prior to/during treatment. A trace of vinyl chloride (1.9 µg/L as a J value) was detected in MW-303S but not in well MW-302S. Among the deep wells, > 1,000 µg/L of both cis-DCE and VC were detected in MW-114A, which is a source area well that is furthest upgradient among the deep wells **(Figure 5-6)**. Moving downgradient to wells MW-114, MW-304D, and MW-306D, those concentrations declined appreciably, with cis-DCE being below detection (< 5 µg/L) and VC being 11 µg/L at MW-304D, which is the furthest downgradient well (**Table 5-4; Figures 5-7, 5-8, 5-9**). The concentration data suggest continued attenuation of these chlorinated ethenes along the groundwater flow path. CSIA data from the site confirms this hypothesis (see **Section 5.3.1.3.7**). The presence of ethane and ethene in a subset of wells is also indicative of continuing reductive dehalogenation (**Table 5-4**).

5.3.1.3.2. Field Parameters

The ORP of all wells at the site were between +2.5 and -100 mV during sampling, indicative of moderately reducing conditions. The groundwater pH was between 5.8 and 6.7 at all wells except MW304D, where the pH was 4.9, which is below that typically considered optimal for reductive dehalogenation (≥ pH 5.5; Vainberg et al., 2009). The DO in the wells was measured between 0.09 mg/L at MW-306D and 3.13 mg/L at MW-303S. As is often the case when measuring field parameters, the DO and ORP at the site do not necessarily correspond, as the well with the highest measured DO, also had the second lowest ORP value at -79.5 mV.

5.3.1.3.3. Anions

Nitrate and nitrite were both below detection in site groundwater. Sulfate ranged from ~ 17 to 48 mg/L in the deep zone wells and from 5 to 13 mg/L in the shallow wells. Chloride was also somewhat higher in the deep compared to the shallow zone (**Table 5-4**).

5.3.1.3.4. Dissolved Iron and Manganese

Dissolved iron was detected in all wells at concentrations ranging from ~ 0.7 mg/L to 13 mg/L. Dissolved manganese was also present in each groundwater well, albeit at lower concentrations than for iron (62 - 389 µg/L). The presence of dissolved forms of these two metals is consistent with the measured ORPs, indicating continued reducing conditions at the site.

5.3.1.3.5. Dissolved Gases

Methane, ranging from ~ 0.4 mg/L to 6.6 mg/L, was detected in wells across the site, indicating reducing conditions. Ethane and ethene were detected in wells MW-114 and MW-114A at concentrations ranging from 4.4 to 13.4 µg/L. Well MW-302S had ethane detected at 104 µg/L. Both of these gases often represent the final product of reductive dehalogenation and are indicative of the occurrence of this process. Dissolved hydrogen, which is the ultimate electron donor for *Dehalococcoides*, was not detected in any of the groundwater samples above the PQL of 0.0084 µg/L.

5.3.1.3.6. Total Organic Carbon and Volatile Fatty Acids

Total organic carbon (TOC) in the different wells ranged from a high of 19.8 mg/L in MW-302S to a low of 2.9 mg/L in MW-304D. None of the common fatty acids associated with fermentation of emulsified oils (e.g., formic, lactic, acetic, propionic) were detected above 1 mg/L (PQL). Thus, the measured TOC presumably represents compounds other than these acids.

Table 5-4. Sampling Results Summary, Former Raritan Arsenal AOC 2.

Class	LOCATION_CODE		MW-114		MW-114A		MW-302S		MW-303S		MW-304D		MW-306D	
	SAMPLE_DATE		11/10/15		11/10/15		11/10/15		11/10/15		11/11/15		11/110/15	
	Parameter	Units	Result		Result		Result		Result		Result		Result	
Anion	Chloride	mg/L	**223**	D	**169**	D	**20.5**		**7.23**		**255**	D	**89.4**	D
	Sulfate as SO4	mg/L	**26.5**		**17.4**		**5.54**		**12.7**		**34.8**		**47.8**	
CSIA	del13C cDCE	ppt	**-8.62**		**-8.2**		NA		**-8.52**		**-18.7**		**22.17**	
	del13C TCE	ppt	**-18.6**		**-20.1**		NA		NA		**-13.4**		**-18.8**	J
Field	DO	mg/L	**1.33**		**1.68**		**2.19**		**3.13**		**0.37**		**0.09**	
	ORP	mV	**-69.9**		**-100**		**-70.8**		**-79.5**		**2.5**		**-45**	
	pH	su	**5.99**		**6.1**		**6.65**		**6.11**		**4.94**		**5.84**	
Gases	Ethane	µg/L	**4.49**		**8.59**		**104**		4	U	4	U	4	U
	Ethene	µg/L	**4.94**	J	**13.4**		5	U	5	U	5	U	5	U
	Methane	µg/L	**539**		**1280**		**6600**	D	**403**		**718**		**546**	
Metals	Dissolved Iron	µg/L	**5190**		**699**		**735**		**2050**		**3070**		**13000**	
	Dissolved Manganese	µg/L	**204**		**308**		**389**		**93.6**		**98.1**		**62.0**	
TOC	Total Organic Carbon	mg/L	**5.43**		**9.25**		**19.8**		**9.20**		**2.90**		**6.29**	
VOC	1,1-dichloroethylene	µg/L	5	U	**0.7**	J	5	U	5	U	5	U	5	U
	1,2-dichloroethane	µg/L	5	U	5	U	**4.4**	J	5	U	5	U	5	U
	1,3-dichlorobenzene	µg/L	5	U	5	U	**0.9**	J	5	U	5	U	5	U
	bromobenzene	µg/L	5	U	5	U	**1.0**	J	5	U	5	U	5	U
	Cis 1,2- Dichloroethylene	µg/L	**70.1**		**1190**	D	5	U	4	J	**55.7**		2	J
	Methyl tertiary butyl ether	µg/L	5	U	5	U	5	U	5	U	**2.4**	J	5	U
	o-xylene	µg/L	5	U	**0.5**	J	**1.1**	J	5	U	5	U	5	U
	sec-butylbenzene	µg/L	5	U	5	U	**7.9**		5	U	5	U	5	U
	tert-butylbenzene	µg/L	5	U	5	U	**1.7**	J	5	U	5	U	5	U
	trans-1,2-dichloroethylene	µg/L	5	U	**2.0**	J	5	U	5	U	5	U	5	U
	trichloroethylene	µg/L	**8.1**		**6.3**		5	U	5	U	**3.5**	J	5	U
	vinyl chloride	µg/L	**82.9**		**1170**	D	5	U	**1.9**	J	5	U	**11.0**	
	xylenes (m/p)	µg/L	10	U	10	U	**1.2**	J	10	U	10	U	10	U

Notes:

NA - Not Analyzed

U - Compound not detected above method practical quantitation limit.

D - Sample was diluted prior to analysis

J - Estimated value above MDL and less than PQL

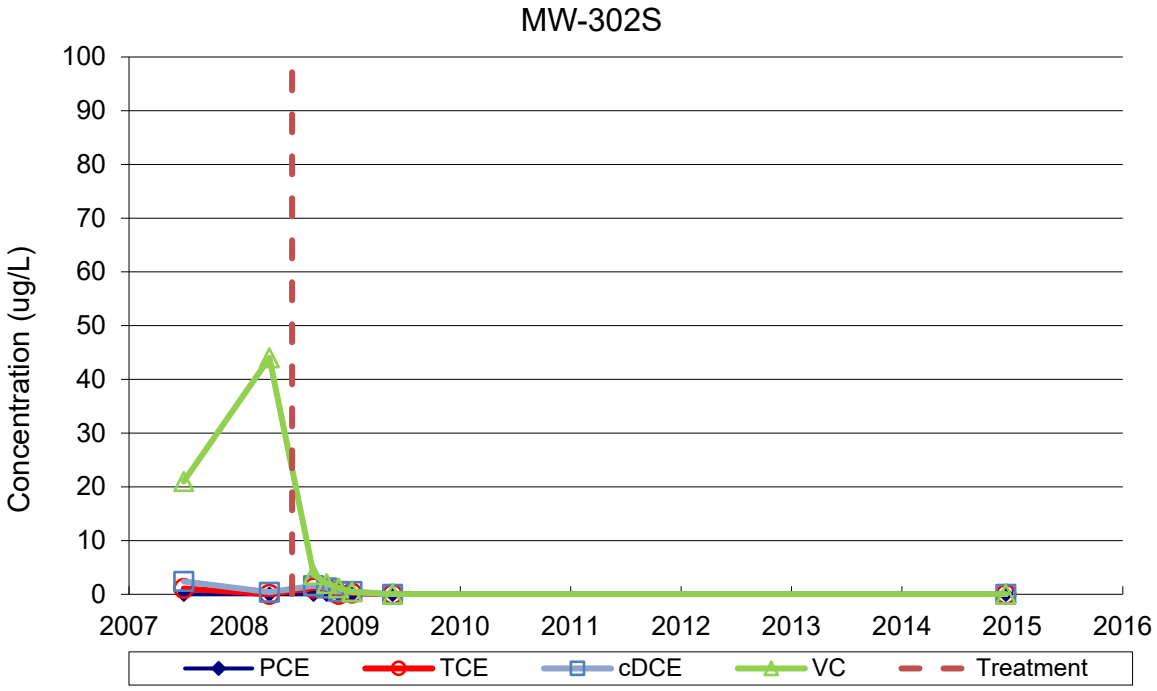


Figure 5-4. VOC Trends for MW-302S, Former Raritan Arsenal AOC 2.

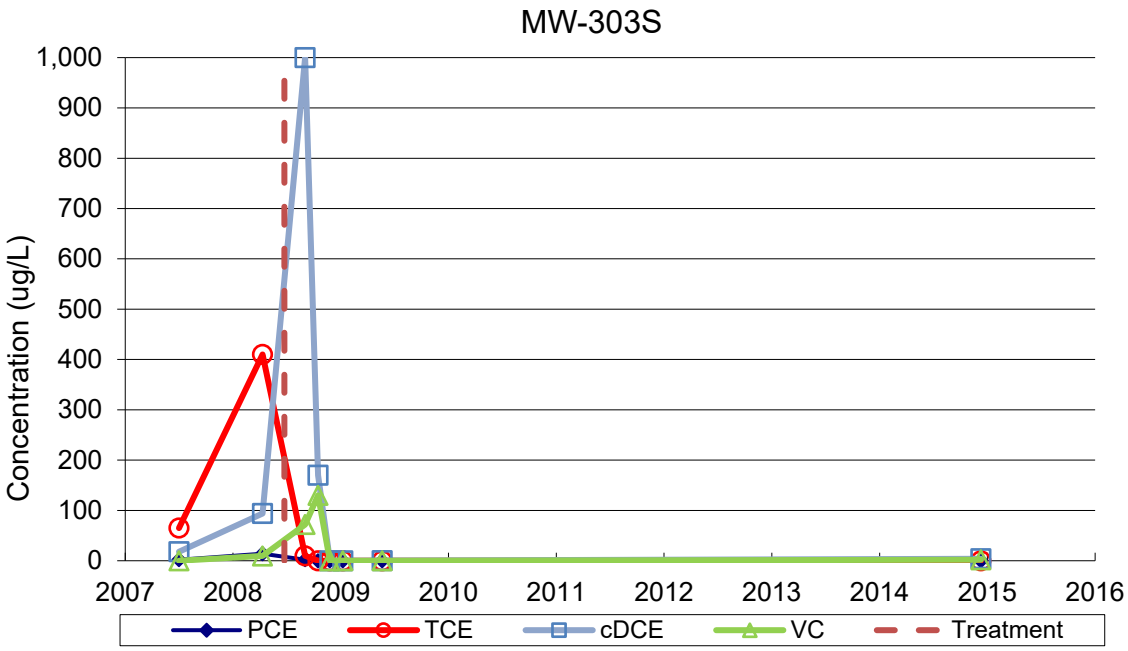


Figure 5-5. VOC Trends for MW-303S, Former Raritan Arsenal AOC 2.

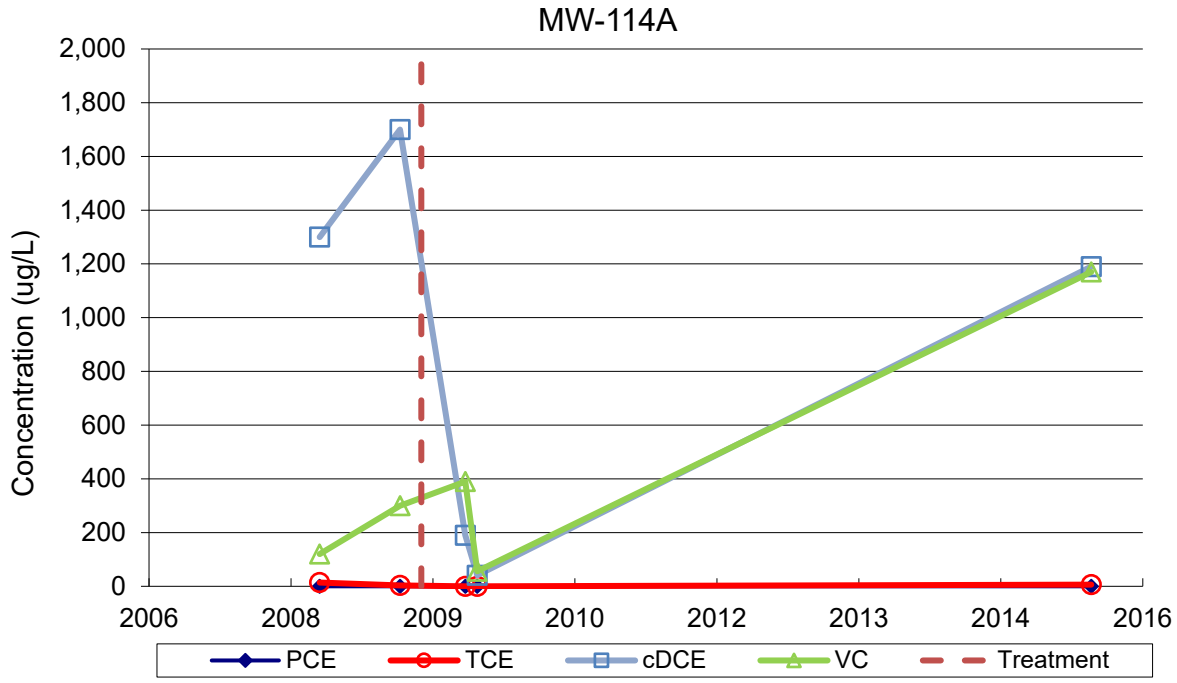


Figure 5-6. VOC Trends for MW-114A, Former Raritan Arsenal AOC 2.

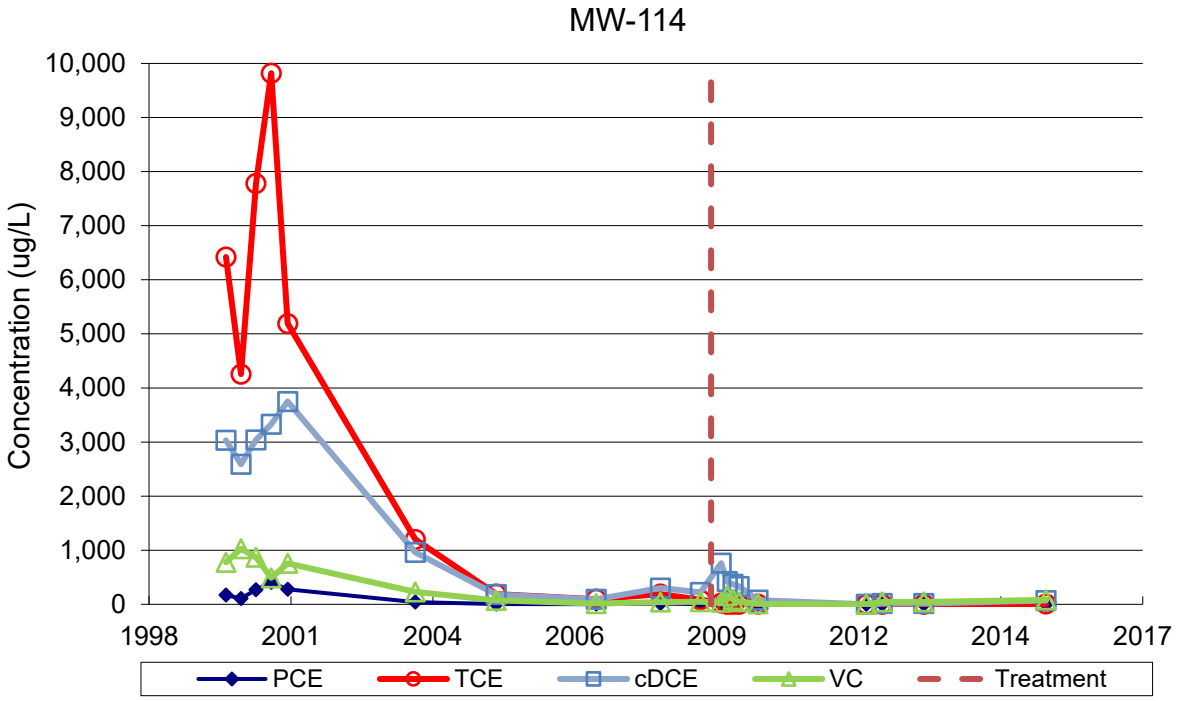


Figure 5-7. VOC Trends for MW-114, Former Raritan Arsenal AOC 2.

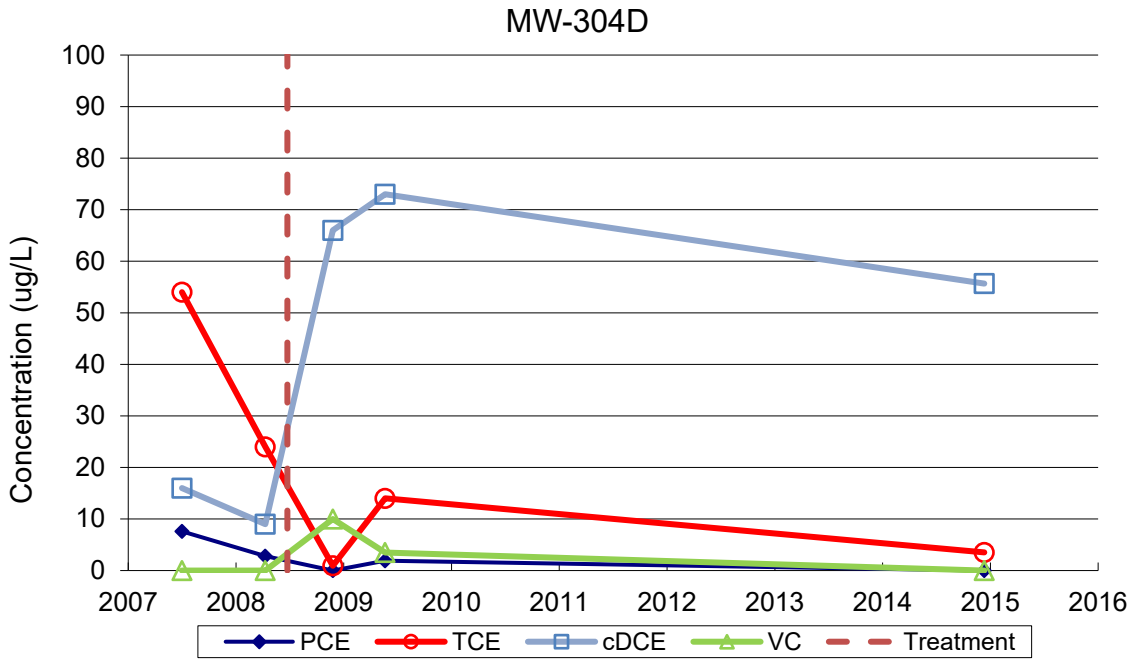


Figure 5-8. VOC Trends for MW-304D, Former Raritan Arsenal AOC 2.

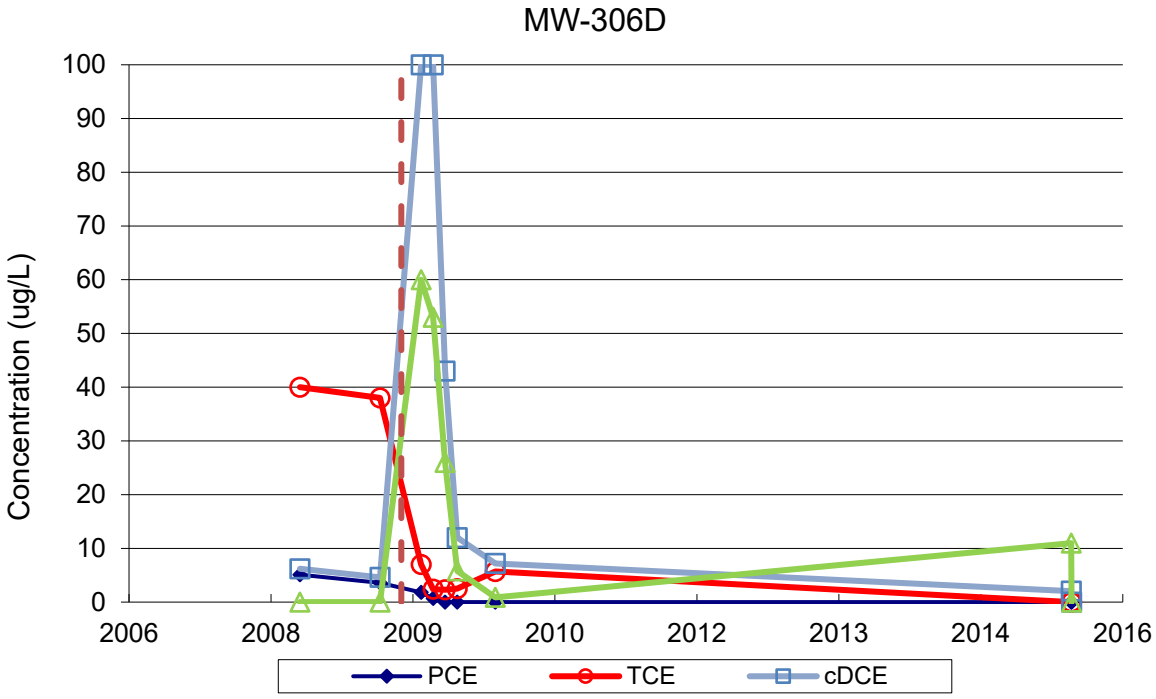


Figure 5-9. VOC Trends for MW-306D, Former Raritan Arsenal AOC 2.

5.3.1.3.7. Microbial Community

The microbial community analysis indicated the presence of several different dehalogenation-associated organisms/genes in water samples from the Raritan Site. The greatest diversity of organisms/genes was detected in the deep wells MW-114, MW-114A, and MW-306D (dup) (**Figure 5-10**). Data were not available from samples MW-304D and MW-306D (original not duplicate) due to difficulties with isolating DNA from those samples. *Dehalococcoides* was detected in all of the aforementioned wells, albeit at rather low concentrations ($\leq 1 \times 10^2$ cells/mL). The vcrA gene and the bvcA gene (both of which encode enzymes that dehalogenate *cis*-DCE) also were detected as was the cobS gene, which encodes a vitamin B12 pathway in *Dehalococcoides.* Interestingly, *Dehaligenomonas* spp, which are known for their ability to dehalogenate chlorinated ethanes, were also detected in each of these wells at concentrations exceeding those of *Dehalococcoides (*10^2 - 10^3 cells/mL). Overall, the data suggest that dehalogenating organisms/genes are present in the deep aquifer zone more than 5.5 years after the last treatment, which included bioaugmentation with SDC-9. This zone also contains the highest concentration of residual VOCs at the site.

Dehalogenimonas was also detected in both of shallow wells (MW-302S and MW-303S), and *Dehalococcoides* was detected in one well (MW-302S) but only at ~ 10 cells/mL. No other genes or dehalogenating bacteria were detected. The shallow aquifer showed the lowest residual levels of VOCs. Likely, the much lower levels and/or absence of specific dehalogenating organisms/genes reflects the absence of VOCs required by these organisms for growth. The presence of *Dehalogenimonas*, however, is unusual in that this species is largely associated with chlorinated ethanes, which were never detected at this site to our knowledge.

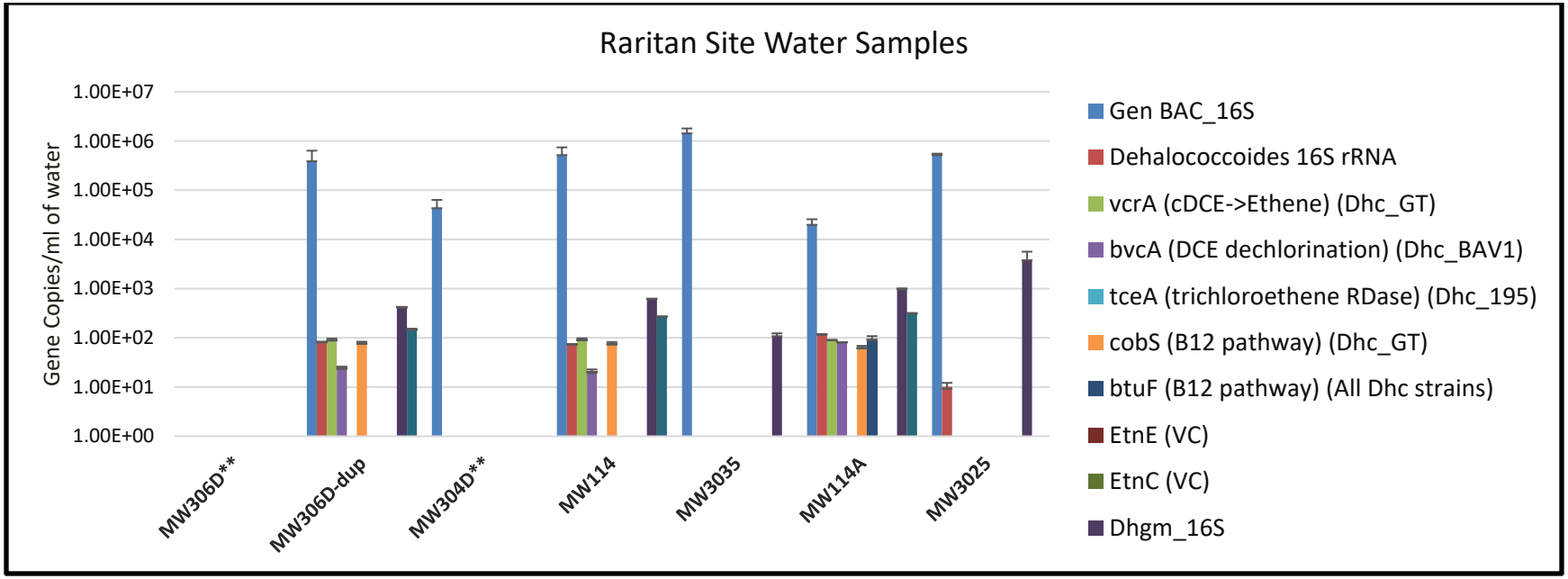


Figure 5-10. Organisms and/or Genes Associated with Reductive Dechlorination Detected in Wells at Former Raritan Arsenal AOC 2.

5.3.1.3.8. CSIA

Values of $\delta^{13}C$ were obtained for TCE and cis-DCE in monitoring wells where concentrations were sufficient for analysis (**Table 5-5; Figure 5-11**). A typical unfractionated $\delta^{13}C$ value for manufactured TCE ranges from ~ -34‰ to - 23‰, with a mean of -29‰ (USEPA, 2008). Similarly, for cis-DCE, values range from ~ -30‰ to - 22‰, with a mean of -26‰ (USEPA, 2008). The $\delta^{13}C$ values for TCE at the Raritan site ranged from -20.1‰ to – 13.4‰, indicating degradation from the parent (i.e., the $\delta^{13}C$ value is lower/heavier than the range of unfractionated parent values, indicating isotopic enrichment). Similarly, $\delta^{13}C$ values for cis-DCE at the Raritan site ranged from -18.6‰ to + 22.7‰, indicating significant degradation. In this case, all of the values are significantly heavier than the potential manufactured $\delta^{13}C$ values for TCE (cis-DCE is a degradation product of TCE), also indicating significant and likely ongoing biodegradation of cis-DCE.

In **Figure 5-11**, the $\delta^{13}C$ data for each compound in each deep well, and the corresponding concentrations are provided. The $\delta^{13}C$ data are subsequently plotted as a function of distance downgradient of the most upgradient well MW-114A in **Figure 5-12,** and the data are fitted using a linear regression. The slope of each of these lines is subsequently used to estimate the half-lives of the two contaminants, as a simple example of the potential application of CSIA data for such purposes at a site. There are several assumptions made with this simple example as is provided below:

Assuming 1st order degradation rates (k), and constant seepage velocity (V_x) and enrichment factor (ε), then

$$\delta^{13}C = \delta^{13}C_0 - \frac{k * \varepsilon}{V_x} * \mathrm{x}$$

TCE: Assuming $V_x \approx 2$ ft/day and $\varepsilon \approx$ -15 ‰ → $k \approx 8 \times 10^{-3}$ d^{-1} and $t_{1/2} \approx 80$ d for TCE of slope = 0.0583

DCE: Assuming $V_x \approx 2$ ft/day and $\varepsilon \approx$ -15 ‰ → $k \approx 2 \times 10^{-2}$ d^{-1} and $t_{1/2} \approx 30$ d for DCE of slope = 0.139

Based on the simple calculations and assumptions shown above, half-lives for the two compounds are estimated at ~ 80 days for TCE and 30 days for cis-DCE. The accuracy of this approach depends on many factors, including the curve fits (which were very good for TCE and less so for cis-DCE), number of overall data points, groundwater velocity estimate, and selection of fractionation factor ($\varepsilon \approx$ -15 ‰ was used) among other variables. However, this exercise shows how half-life data can be determined for compounds via CSIA without using concentration data.

Table 5-5. CSIA Data, Former Raritan Arsenal AOC 2.

Monitoring Well	$\delta^{13}C$ TCE (‰)	TCE (µg/L)	$\delta^{13}C$ DCE (‰)	DCE (µg/L)
MW-114	-20.1	8.1	-8.6	70
MW-114A	-18.6	6.3	-8.2	1190
MW-303D	-13.4	3.5	-18.6	56
MW-306D	NA	< 0.5	+ 22.7	4
MW-302S	NA	< 0.5	NA	< 0.5
MW-303S	NA	< 0.5	-8.5	4

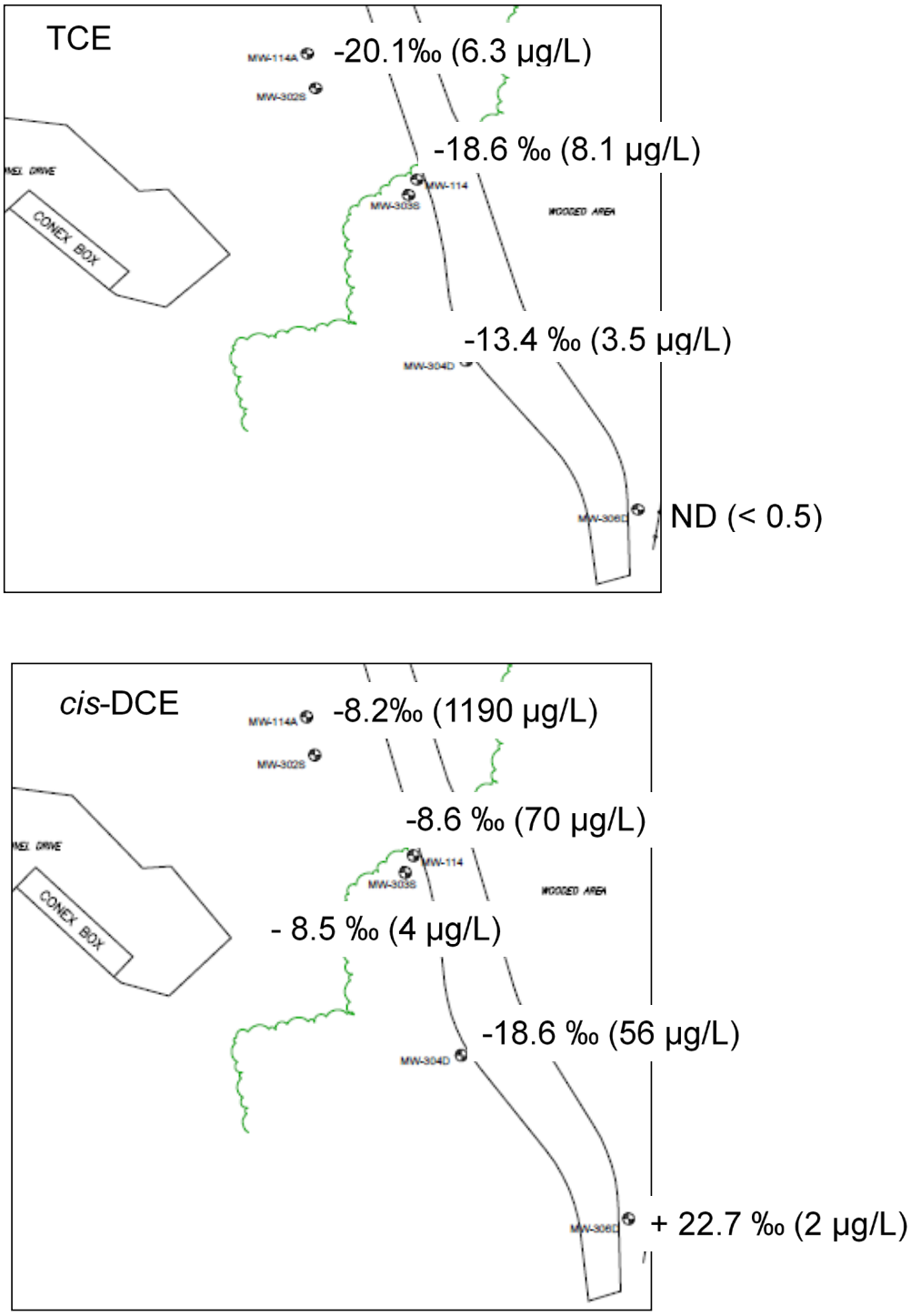
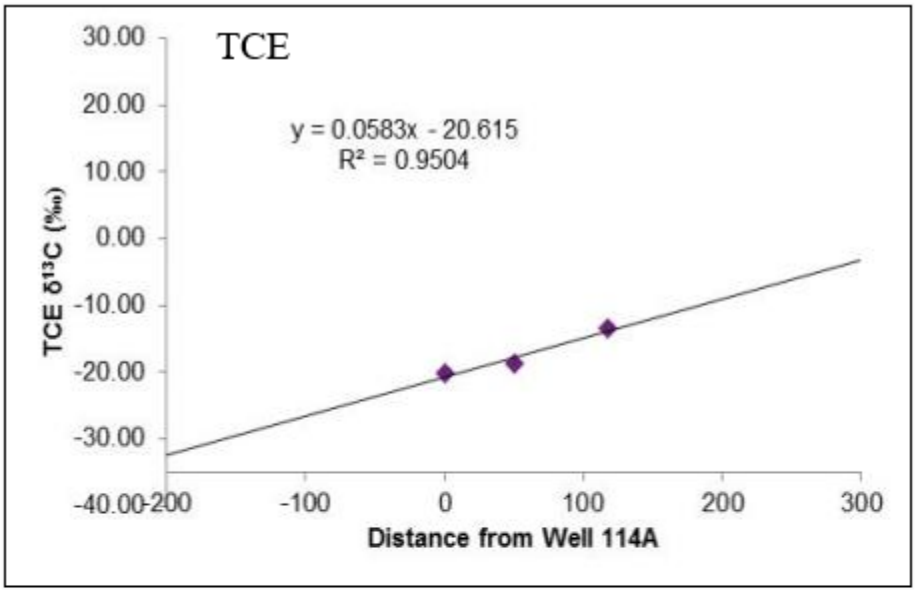


Figure 5-11. Overhead View of the Well Locations, VOC Concentrations (Top Panel; TCE, Bottom Panel; cis-DCE), and δ13C Values for the Relevant VOCs.

ND = Non-detect.



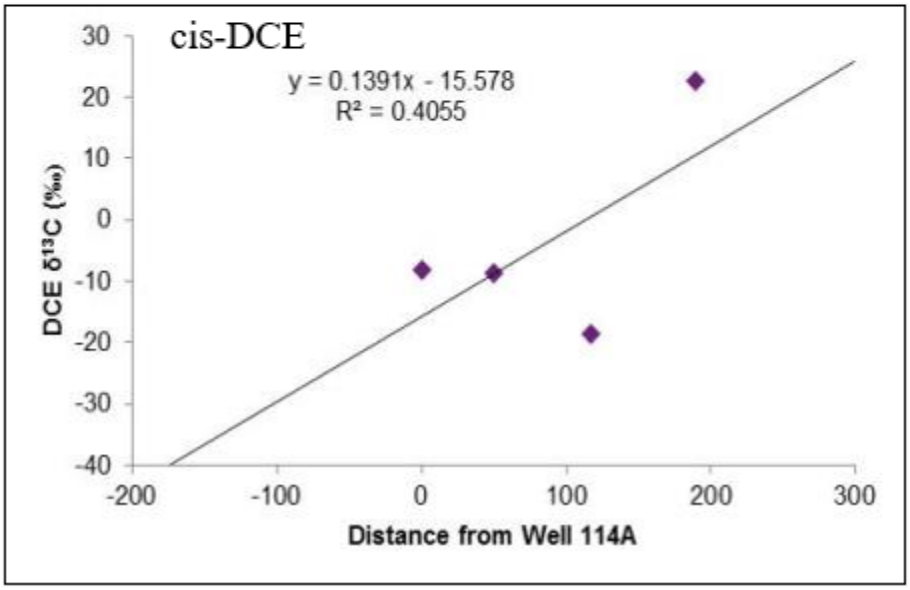


Figure 5-12. Plot of $\delta^{13}C$ Values for TCE (Top Panel) and *cis*-DCE (Bottom Panel) as a Function of Distance from Upgradient Well 114A.

5.3.1.3.9. Mass Flux

Passive flux meters (PFMs) were deployed in a centerline approach from the source zone down the length of the plume. No chlorinated ethenes or ethene were detected in MW-302S, MW-303S, and MW-306D. VC and cis-DCE, but no ethene, were detected in MW-114A, MW-114, MW-304D. MW-114A, located in the suspected source zone, had the highest fluxes of VC and cis-DCE, which were reported to be about ~67 mg/m^2/day and 78 mg/m^2/day. VC and cis-DCE fluxes in MW-114 and MW-304D, located in the plume, ranged from 0.7 to 1.6 mg/m^2/day (**Table 5-6**).

The PFM flux data can also be used to estimate the flux-averaged contaminant concentration, C_f (ml^{-3}), over the well screen interval/PFM sorbent section using (Basu et al., 2006):

$$C_f = \frac{\int J_{ddz}}{\int q_{ddz}}$$

C_f is independent of groundwater fluxes, meaning it is not subject to effects of flow convergence towards or divergence around the PFM. C_f represents a time-averaged contaminant concentration estimate over the deployment period, whereas traditional groundwater sampling techniques yield an instantaneous contaminant concentration that is estimated only at the time the groundwater samples were collected (Basu et al., 2006; Basu et al., 2009).

C_f values were compared against traditional groundwater concentration data to assess overall remediation performance at sites. In addition to individual contaminant species being repoerted, "Equivalent TCE" was also reported as a measure of overall contaminant mass present at the point sample, to make one to one comparisons of groundwater quality data. "Equivalent TCE" in this study includes degradation products TCE, cis-1,2-dichloroethene (cis-DCE), and vinyl chloride (VC) (Haluska et al., 2019).

The flux-averaged equivalent TCE concentration (TCE+cis-DCE+VC), estimate from the PFM results compared well with existing groundwater monitoring data taken from MW-114A (**Table 5-7**). Downgradient wells MW-114 and MW-304D suggest low concentrations of chlorinated ethenes persist downgradient. The groundwater time concentration profile (**Figure 5-6**) suggests that some rebound occurred in the original source area since the cessation of active treatment, but the increase in VC concentration over time indicates ongoing dechlorination. PFM flux averaged concentration profiles (**Figure 5-13**) corroborate the theory that incomplete dechlorination has occurred as both cis-DCE and VC have accumulated within the source zone. MW-114A and MW-304D groundwater profiles (**Figure 5-6 & 5-8**) and PFM profiles **(Figure 5-13a** & **5-13e**) only detected cis-DCE and VC downgradient of the source zone at significantly lower concentrations, consistent with well data. Although no ethene was detected, geochemical analysis suggests aerobic conditions may have persisted, and oxidation of both cis-DCE and VC may be occurring at the site (Fullerton et al., 2013; Gossett, 2010). No chlorinated ethenes or ethene were detected in MW-302S, MW-303S, and MW-306D, suggesting that biological processes have persisted in treating chlorinated solvent after the cessation of active bioremediation in 2009.

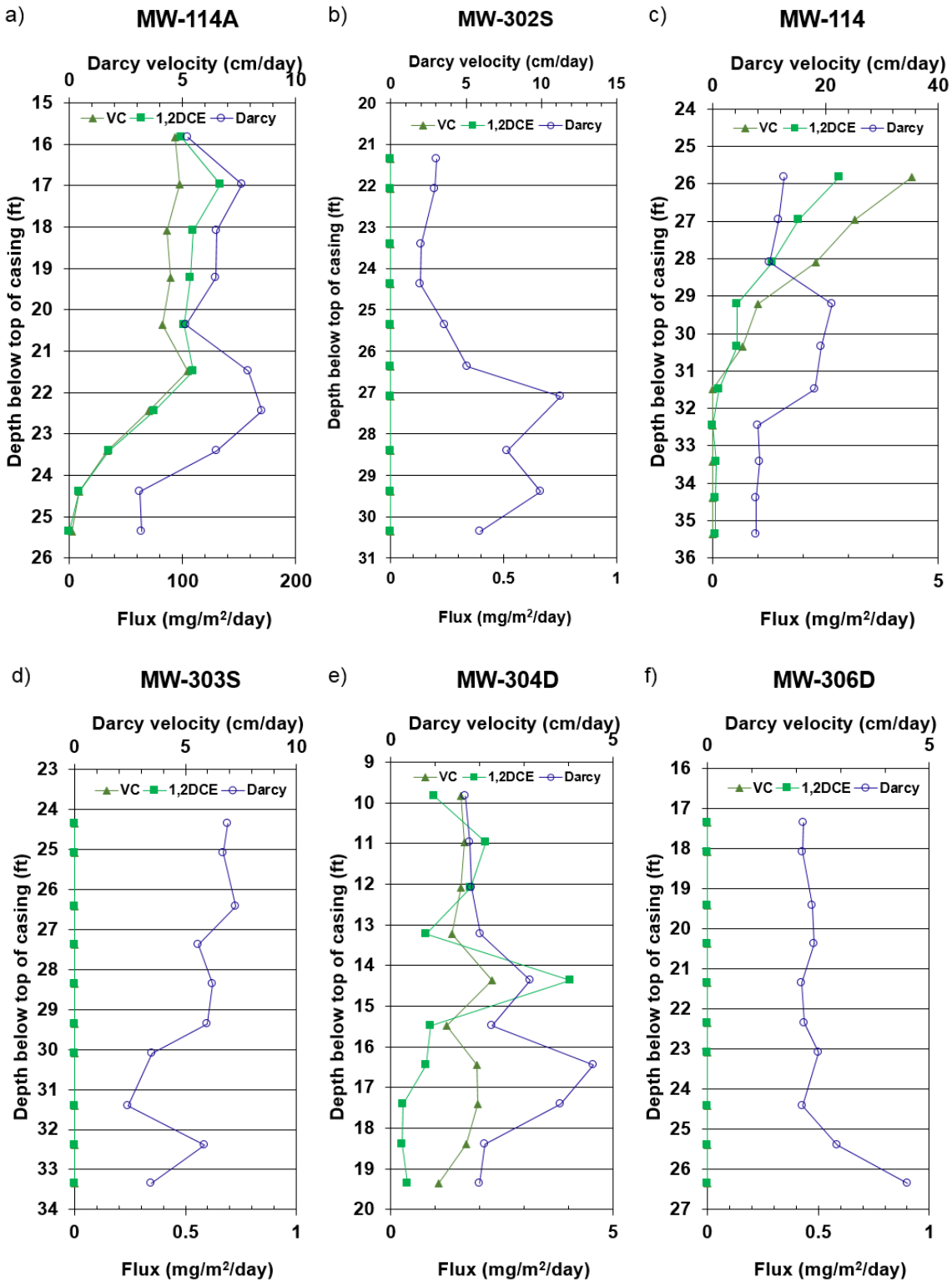


Figure 5-13. Mass Flux Profiles Measured in Select Wells Using the PFMs.

The solid dark green triangles represent VC, the solid light green squares represent DCE, and the open purple circles represent the Darcy Velocity. Panels a-f show flux values sampled on 12/03/2015. Note the changes in scale on both axes to accommodate the data.

Table 5-6. Average Mass Flux for Each Well.

Well_ID	Darcy Velocity (cm/day)	VC flux ($mg/m^2/day$)	DCE flux ($mg/m^2/day$)
MW114A	6.0	66.7	77.9
MW114	12.5	1.2	0.7
MW304D	2.5	1.6	1.2
MW303S	5.4	0.0	0.0
MW302S	5.3	0.0	0.0
MW306D	2.5	0.0	0.0

Table 5-7. Equivalent TCE Groundwater vs PFM Flux-Averaged Concentration.

Well_ID	Equiv. TCE groundwater concentrations (µg/L)	Equiv. TCE PFM flux-averaged concentrations (µg/L)	% Difference
MW114A	4078	3812	6.7
MW114	275	27.6	164
MW304D	79	219.9	94
MW303S	26	<dl	NA
MW302S	<dl	<dl	NA
MW306D	9	<dl	NA

[a]NA, not analyzed. <dl, less than detection limit.

5.3.1.3.10. Site Summary

Groundwater monitoring, CSIA and PFM data suggest that the size of the plume at Raritan has decreased and biodegradation continues 5.5 years after active treatment ended. Source zone groundwater and PFM data show that cis-DCE and VC dominate the source area but dramatic declines in the concentration and flux of both VOCs are apparent downgradient. CSIA data provides further evidence of dechlorination of TCE to cis-DCE and then cis-DCE to VC. Based on the simple calculations using $\delta^{13}C$ values for TCE and cis-DCE along the groundwater flow path, half-lives for the two compounds were estimated at ~ 80 days for TCE and 30 days for cis-DCE. The microbial community analysis indicated the presence of several different dehalogenation- associated organisms/genes in water samples from the Raritan Site 5.5 years after cessation of active treatment. *Dehalococcoides* was detected in all of the aforementioned wells, albeit at rather low concentrations ($\leq 1 \times 10^2$ cells/mL). The vcrA gene and the bvcA gene (both of which encode enzymes that dehalogenate *cis*-DCE) also were detected as was the cobS gene, which encodes a vitamin B12 pathway in *Dehalococcoides.* The data suggest that dehalogenating organisms/genes are present in the deep aquifer zone more than 5.5 years after the last treatment, which included bioaugmentation with SDC-9. This zone also contains the highest concentration of residual VOCs at the site. Overall, site data suggest that removal of organic contaminants is still occurring in the deep zone (shallow zone is clean) and that the potential for anaerobic reductive dechlorination persists, although electron donor is likely limiting at his time. Target treatments with an electron donor, buffer (to ensure optimal pH) and nutrients may be sufficient to promote conditions necessary for complete reductive dechlorination in the deep zone at the site.

5.3.2 Dover Air Force Base Area 6

5.3.2.1 Site Description, Dover Air Force Base Area 6

Area 6 at Dover Air Force Base was previously characterized by a large plume of chlorinated ethenes and ethanes, approximately 2,500 ft wide and 6,500 ft long. Several source areas were identified, with the most important source area being Site OT14, also known as Building 719. Building 719 was a former jet engine maintenance facility, and trichloroethene (TCE) was used to degrease engine parts in the 1960s. Significant contamination was detected beneath the engine cleaning rooms. Two underground storage tanks (USTs) were formerly present at Building 719 that may have been contributing sources. Maximum TCE concentrations historically exceeded 20,000 micrograms per liter (μg/L). PCE, cis-DCE, and VC were present at lesser concentrations.

The site is underlain by fluvial deposits of the Columbia Formation that extend to a depth of approximately 50 ft bgs. The Columbia Formation contains fine-to-coarse sand with silt and clay lenses and less common lenses of gravel. Monitoring wells are screened in what has been designated the Shallow and Deep Zones of the Columbia Formation. A hydraulic conductivity of 60 ft per day was obtained in an aquifer pumping test, indicating a relatively high permeability. Groundwater is generally oxidizing with a pH of about 5.5 to 6.

A recirculation system for bioremediation was actively operated at Building 719 between 2002 and 2006. The system included twelve injection wells and six extraction wells. Sodium lactate and diammonium phosphate (DAP) were added as biostimulation amendments. The system was converted to a passive mode in 2007 with recirculation temporarily restarted to introduce additional amendments. The system was operated for this purpose on three occasions: September 2008, June 2011 and February 2013.

The bioremediation at Building 719 was generally determined to be successful with a substantial reduction of contamination. The field investigation for this site provided results to evaluate the long-term persistence of source area contamination and associated degradation mechanisms in an aerobic aquifer.

5.3.2.2 Sampling Rationale, Dover Air Force Base, Area 6

The objective of the groundwater sampling was to assess the long-term impacts of the previously performed biostimulation-recirculation treatment on groundwater quality and biogeochemistry. Monitoring locations within and downgradient of the source area were evaluated as described below. **Table 5-8** summarizes the monitoring locations and rationale for the sampling program. Monitoring wells sampled are shown on **Figures 5-14** and **5-15.**

Table 5-8. Groundwater Sampling Locations and Rationale, Dover Air Force Base, Building 719.

Dover Air Force Base Monitoring Well	Sampling Rationale
MW605S	Within the source area treatment zone and in the Shallow Zone. Treatment was highly effective.
MW605D	Within the source area treatment zone and in the Deep Zone. Treatment was highly effective.
MW608S	Within the source area treatment zone and in the Shallow Zone. Lingering contamination remains.
MW102S	Downgradient of the source area in the Shallow Zone. Treatment was highly effective.
MW102D	Downgradient of the source area in the Deep Zone. Lingering contamination remains.

Monitoring well MW605S is located within the central part of the source area treatment zone and screened in the Shallow Zone. Monitoring well MW605D is also located within the source area treatment zone but screened in the Deep Zone. The treatment has been highly effective at these well locations, with a sustained decrease of VOC concentrations greater than 95%. In contrast, monitoring well MW608S is located in the source area treatment zone, but treatment has not been as effective, and lingering contamination remains.

Similarly, monitoring wells MW102S and MW102D are located downgradient of the source area treatment zone at a distance of approximately 250 ft. Treatment was highly effective at monitoring well MW102S but not at monitoring well MW102D. Monitoring wells MW102S and MW102D area screened in the Shallow and Deep Zones, respectively.

The above wells were selected to evaluate what conditions are associated with highly effective versus less effective treatment. **Table 5-9** presents monitoring well construction details.

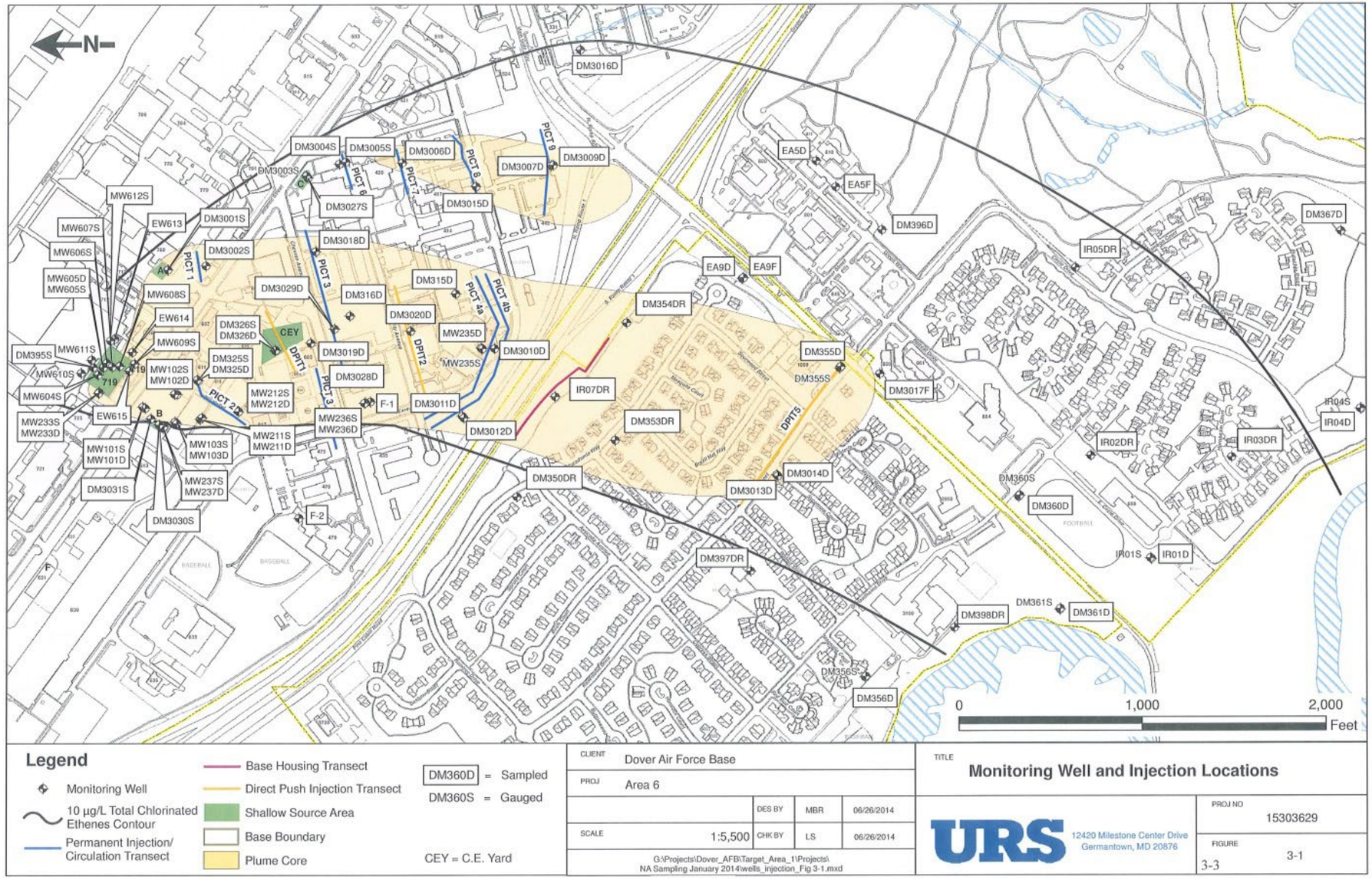


Figure 5-14. Site Location Map Showing the Original VOC Plume, Dover Air Force Base Area 6.

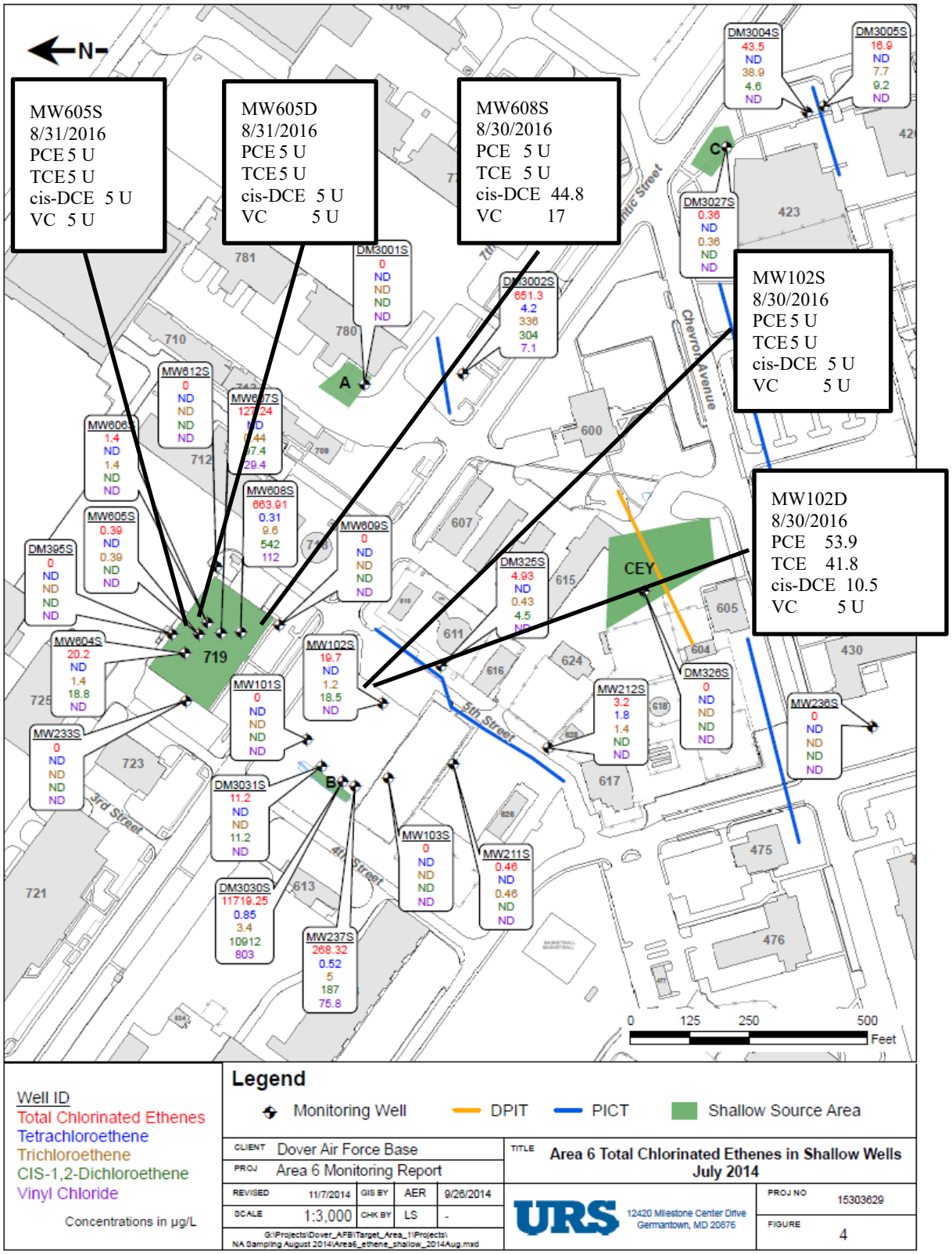


Figure 5-15. Site Plan. Dover Air Force Base Area 6.

Table 5-9. Monitoring Well Construction Details, Dover Air Force Base Area 6.

Monitoring Well	Total Depth (ft bgs)	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Diameter (inches)
MW605S	20	10	20	2
MW605D	30	20	30	2
MW608S	20	10	20	2
MW102S	27	17	27	2
MW102D	40	30	40	4

bgs = below ground surface

5.3.2.3 Sampling Results, Dover Air Force Base Area 6

5.3.2.3.1. VOCs

Table 5-10 provides a summary of the sampling results. Among the wells that were sampled, low levels of PCE, TCE, and cis-DCE (10 - 54 µg/L) were detected in MW102D, and cis-DCE, VC and 1,1- DCA were detected in MW608S (12 - 45 µg/L). These were the same wells that had lingering contamination after the final sampling event in February 2015, with the previous active recirculation treatment with amendment addition ending in 2013. However, it should be noted that MW102D had TCE and PCE exceeding 800 µg/L pre-treatment (**Figure 5-16**) and MW608S had concentrations of TCE as high as 7,000 µg/L and cis-DCE as high as 100,000 µg/L during the first treatment in the early 2000s (**Figure 5-17**). Low concentrations of some chlorinated benzenes were also detected, particularly in MW608S. The other three wells MW102S, MW605D, and MW605S had chlorinated ethenes below detection (< 5 µg/L); thus, no rebound was evident, even in wells in the previous source area (MW605D and MW605S). Overall, the biological treatment remedy appears to have been highly effective in this area.

5.3.2.3.2. Field Parameters

The ORP of wells at the site had a wide range, from +249 to -153 mV during sampling. The well with the highest ORP, MW102D, was also the only well with residual PCE and TCE, albeit at low concentrations. The groundwater pH was between 6.2 and 7.2 at all wells except MW102D, where the pH was 5.0, which is below that typically considered optimal for reductive dehalogenation (≥ pH 5.5). Thus, two separate factors appear to contribute to residual VOCs in this well. The DO in the wells was measured between 0.5 mg/L and 1.5 mg/L. In this case, the two wells with the highest ORP values (MW102D and MW102S) also had the highest oxygen concentrations. All of the wells with a negative ORP (-90 to -153 mV) also had measurable oxygen concentrations (0.5-1 mg/L), which is not necessarily consistent with a very negative ORP, as previously noted, but is typical for field data.

5.3.2.3.3. Anions

Nitrate was only detected in MW102D (4.12 mg/L and nitrate N), consistent with the high ORP and DO exceeding 1.4 mg/L. All other wells had nitrate < 0.2 mg/L as N. Sulfate ranged from a low of 0.2 mg/L in MW605S to a high of 34.9 mg/L in MW102S. Chloride was also somewhat variable, ranging from 7.28 to 24.7 mg/L in the various wells.

5.3.2.3.4. Dissolved Iron and Manganese

Dissolved iron and manganese were detected in some wells, but concentrations were consistently low across the site (< 600 µg/L for Fe and < 115 µg/L for Mn).

5.3.2.3.5. Dissolved Gases

Methane was detected in the different wells, with concentrations ranging from ~ 2 µg/L to 22,500 µg/L. The highest concentrations were observed in MW605S, MW605D, and MW608S, each having more than 15,000 µg/L. The high methane is consistent with the low ORP in these wells (-90 to -115 mV). Each of these wells also had detectable ethane, ranging from 5 to 32 µg/L, and one well (MW608S) also had ethene at 8.1 µg/L. These gases (ethene and ethene) are often observed as final degradation products of chlorinated ethenes and are indicative of ongoing biodegradation. Hydrogen gas, the ultimate electron donor for reductive dehalogenation, was near or below the MDL (0.0084 µg/L) in all wells except MW605D, where 0.021 µg/L was detected.

5.3.2.3.6. Total Organic Carbon and Volatile Fatty Acids

Total organic carbon (TOC) in the different wells ranged from non-detect (< 2 mg/L) to a high of 9.0 mg/L in MW102S. None of the common fatty acids were detected above 1 mg/L (PQL). Thus, the measured TOC presumably represents compounds other than these acids.

5.3.2.3.7. Microbial Community

The microbial community analysis indicated the presence of several different dehalogenation-associated organisms/genes in water samples from the Dover Site. *Dehalococcoides* was detected in wells MW605S, MW605D, and MW608S at concentrations ranging from 3×10^3 to 8×10^4 cells/mL. These were the wells with high methane, low ORP, and detectable ethane (and ethene in one case). Thus, the data suggest that conditions are conducive to ongoing reductive dehalogenation. The vcrA gene and the bvcA gene, (both of which encode enzymes that dehalogenate cis-DCE) also were detected in two of the three wells (MW605S and MW608S) as were *Dehalobacter* spp., which are known to dehalogenate chlorinated ethanes. Some chlorinated ethanes remain at this site in MW608S.

Conversely, *Dehalococcoides* were not detected in either MW102S or MW102D, nor were any associated genes associated with reductive dehalogenation of chlorinated ethenes. These two wells, only one of which had detectable VOCs (MW102D), also had positive ORPs, low methane, and no detectable ethane or ethene. Thus, geochemical conditions are not conducive to reductive dehalogenation in these wells.

Table 5-10. Sampling Results Summary, Dover Air Force Base, Area 6.

Class	LOCATION_CODE		MW102D		MW102S		MW605D		MW605S		MW608S	
	SAMPLE_DATE		08/30/16		08/30/16		08/31/16		08/31/16		08/30/16	
	Parameter	Units	Result		Result		Result		Result		Result	
Anions	Chloride	mg/L	**24.7**		**4.42**		**7.28**		**23.2**		**22.0**	
	Nitrate as N	mg/L	**4.12**		0.2	U	0.2	U	0.2	U	0.2	U
	Phosphate as P, ortho	mg/L	0.2	U	0.2	U	0.2	U	0.2	U	**0.21**	
	Sulfate as SO4	mg/L	**16.6**		**34.9**	D	**15.9**		**0.19**	J	**18.0**	
CSIA	del13C cDCE	ppt	**-21.4**		NA		NA		NA		**-11.3**	
	del13C PCE	ppt	**-28.4**		NA		NA		NA		NA	
	del13C TCE	ppt	**-22.4**		NA		NA		NA		NA	
	del13C VC	ppt	NA		NA		NA		NA		**-18**	
Field	DO	mg/L	**1.46**		**1.11**		**0.47**		**0.68**		**1.00**	
	ORP	mV	**249**		**57.6**		**-153**		**-90.1**		**-115**	
	pH	su	**5.02**		**6.16**		**7.26**		**6.65**		**7.05**	
Gases	Ethane	µg/L	4	U	4	U	**5.08**		**5.47**		**32.4**	
	Ethene	µg/L	5	U	5	U	5	U	5	U	**8.14**	
	Hydrogen	µg/L	**0.006**	J	**0.009**		**0.021**		0.0084	U	0.0084	U
	Methane	µg/L	**1.93**	J	2	U	**22,500**	D	**19,100**	D	**15,900**	D
Metals	Dissolved Iron	µg/L	70	U	**531**		70	U	**79.4**		70	U
	Dissolved Manganese	µg/L	**25.4**		**7.6**		5	U	**114**		5	U
TOC	Total Organic Carbon	mg/L	2	U	**9.04**		**2.47**		2	U	**3.06**	
VFA	Lactic Acid	mg/L	1	U	1	U	1	U	**2.98**		1	U
VOC	1,1-dichloroethane	µg/L	5	U	5	U	5	U	5	U	**12.1**	
	1,2,4-trimethylbenzene	µg/L	5	U	5	U	5	U	**3.20**	J	5	U
	1,2-dichlorobenzene	µg/L	5	U	5	U	5	U	5	U	**8.34**	
	1,2-dichloroethane	µg/L	5	U	5	U	5	U	5	U	**2.87**	J
	1,3-dichlorobenzene	µg/L	5	U	5	U	5	U	**2.37**	J	**1.21**	J
	1,4-dichlorobenzene	µg/L	5	U	5	U	5	U	**11.5**		**4.62**	J
	chlorobenzene	µg/L	5	U	5	U	**1.62**	J	**53.2**		**5.70**	
	chloroethane	µg/L	5	U	5	U	5	U	5	U	**16.7**	
	Cis 1,2- Dichloroethylene	µg/L	**10.5**		5	U	5	U	5	U	**44.8**	
	naphthalene	µg/L	5	U	5	U	5	U	**31.7**		5	U
	tetrachloroethylene	µg/L	**53.9**		5	U	5	U	5	U	5	U
	trichloroethylene	µg/L	**41.8**		5	U	5	U	5	U	5	U
	vinyl chloride	µg/L	5	U	5	U	5	U	5	U	**17.0**	

Notes:

NA - Not Analyzed

U - Compound not detected above method practical quantitation limit.

D - Sample was diluted prior to analysis

J - Estimated value above MDL and less than PQL

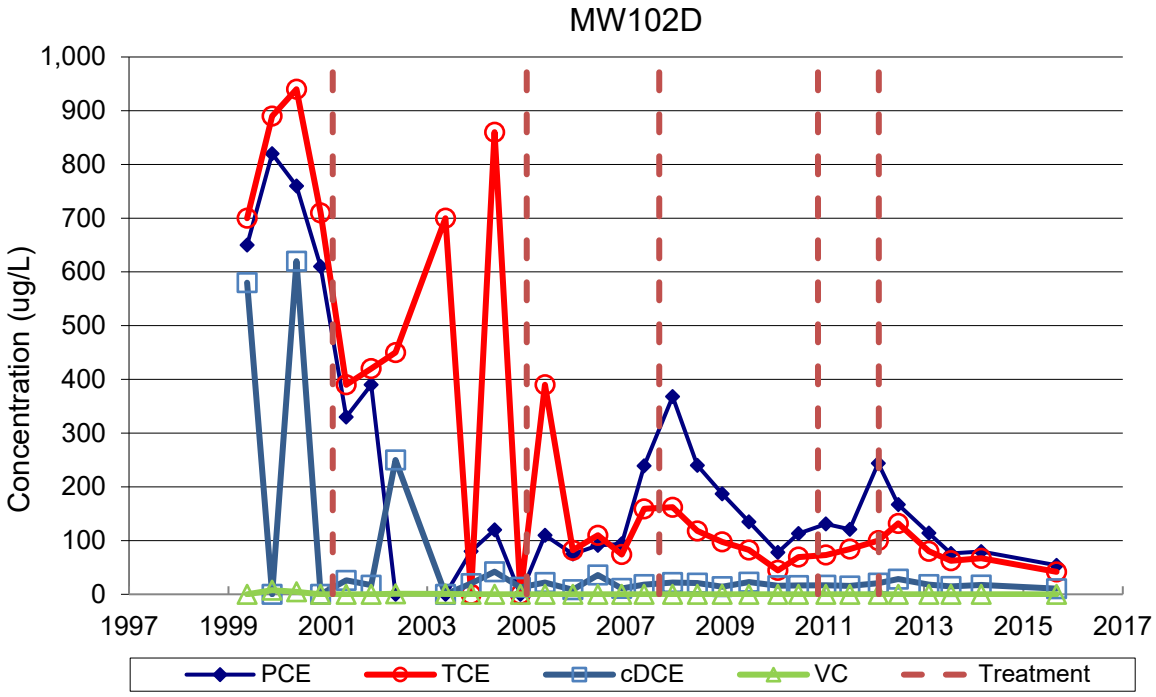


Figure 5-16. VOC Trends for MW102D, Dover Air Force Base Area 6.

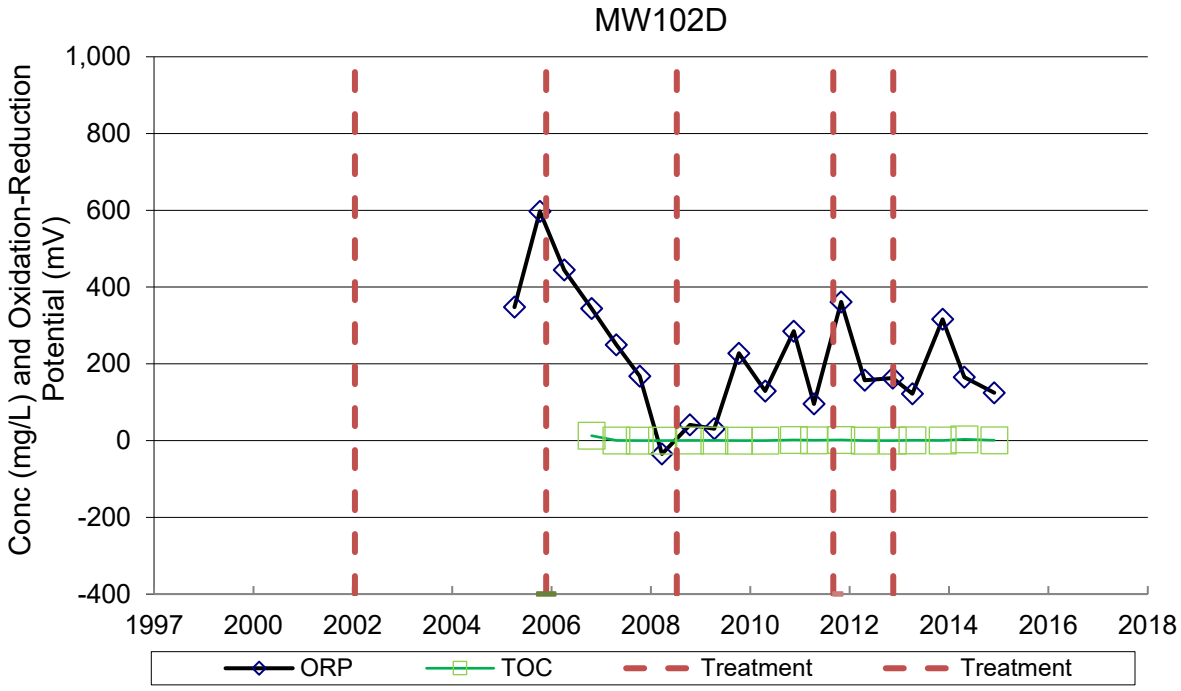


Figure 5-17. ORP and TOC Trends for MW102D, Dover Air Force Base Area 6.

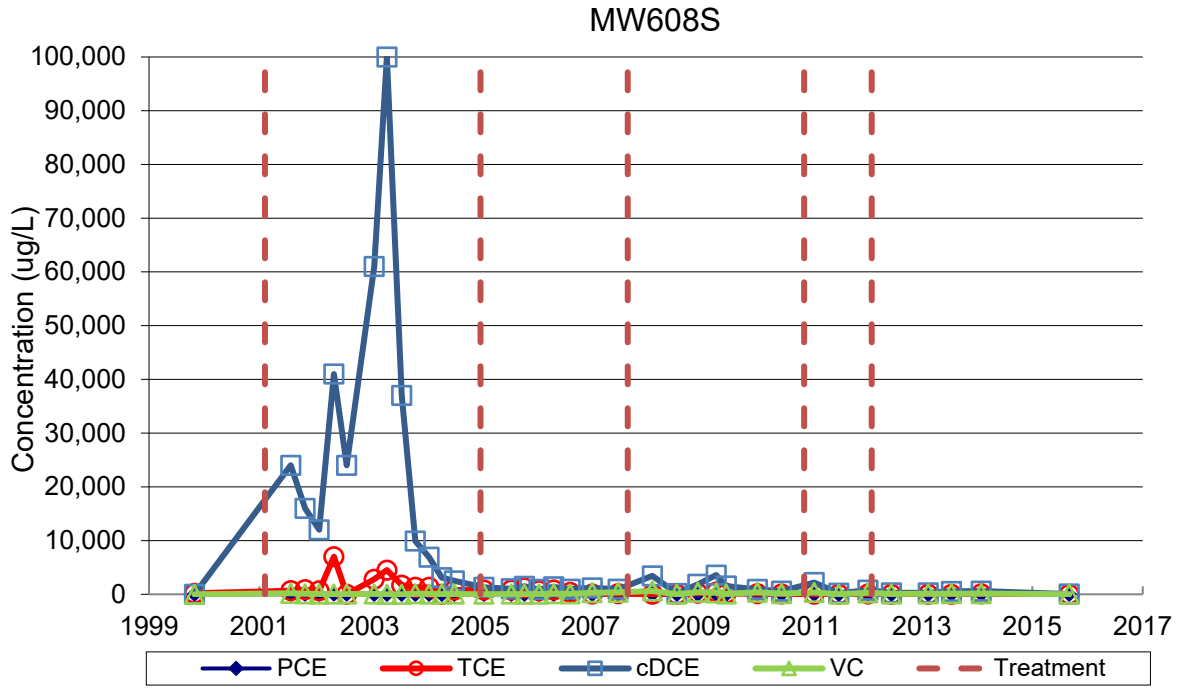


Figure 5-18. VOC Trends for MW608S, Dover Air Force Base Area 6.

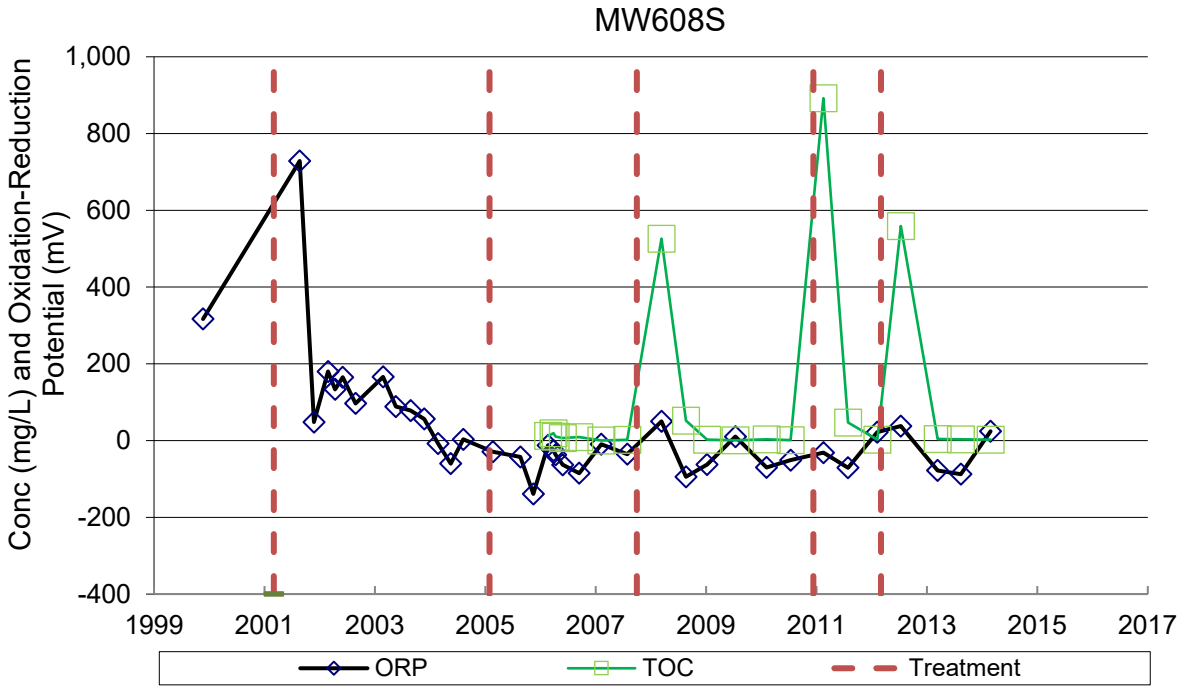


Figure 5-19. ORP and TOC Trends for MW608S, Dover Air Force Base Area 6.

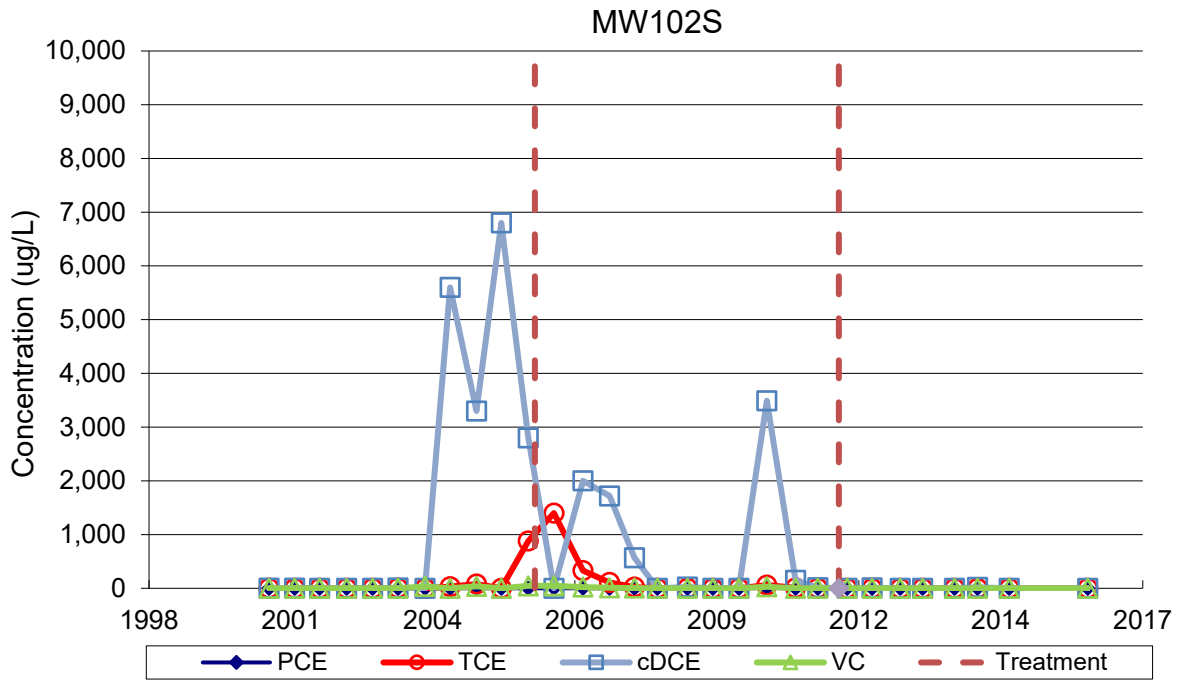


Figure 5-20. VOC Trends for MW102S, Dover Air Force Base Area 6.

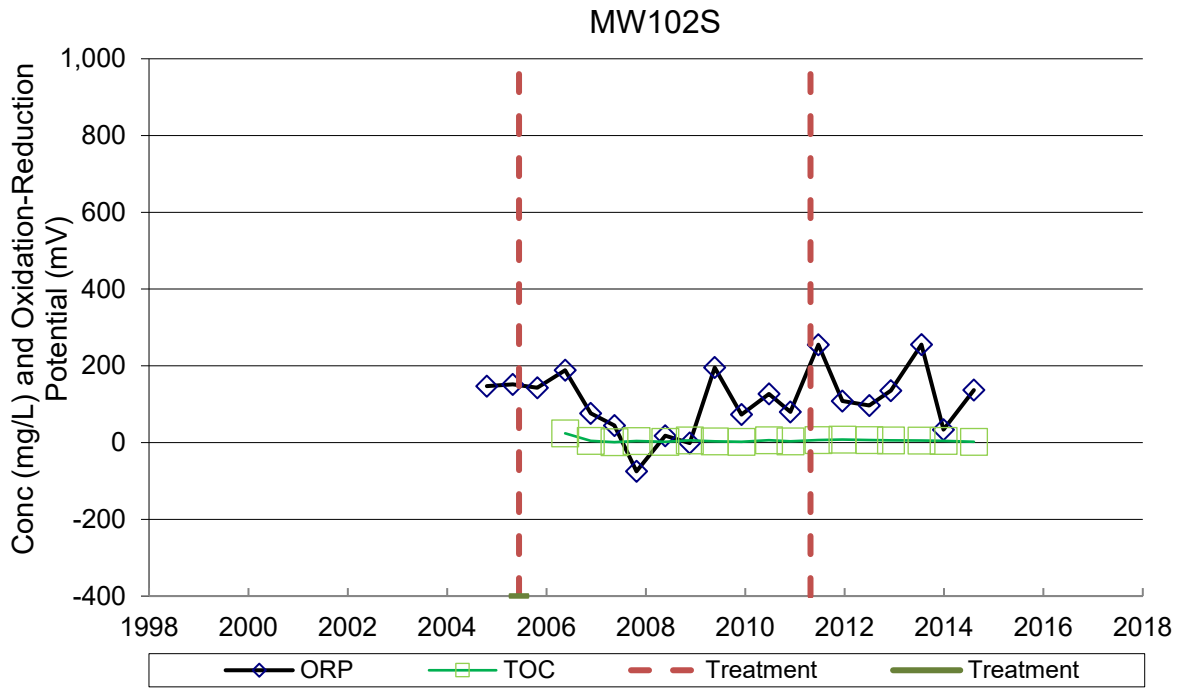


Figure 5-21. ORP and TOC Trends for MW102S, Dover Air Force Base Area 6.

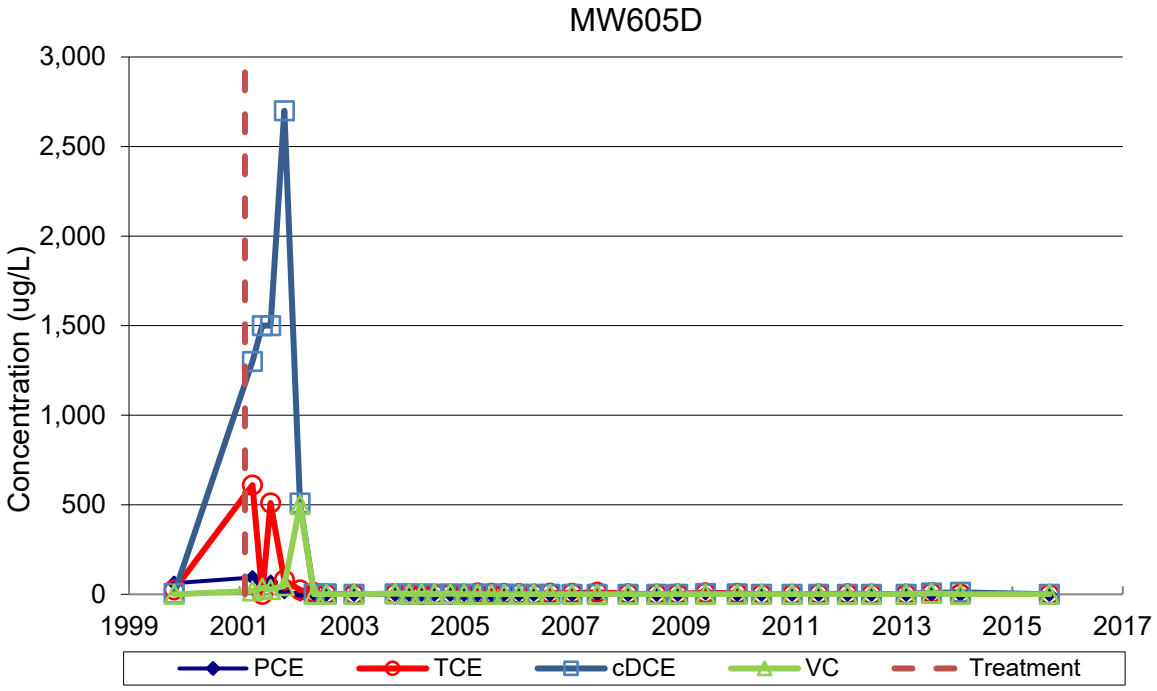


Figure 5-22. VOC Trends for MW605D, Dover Air Force Base Area 6.

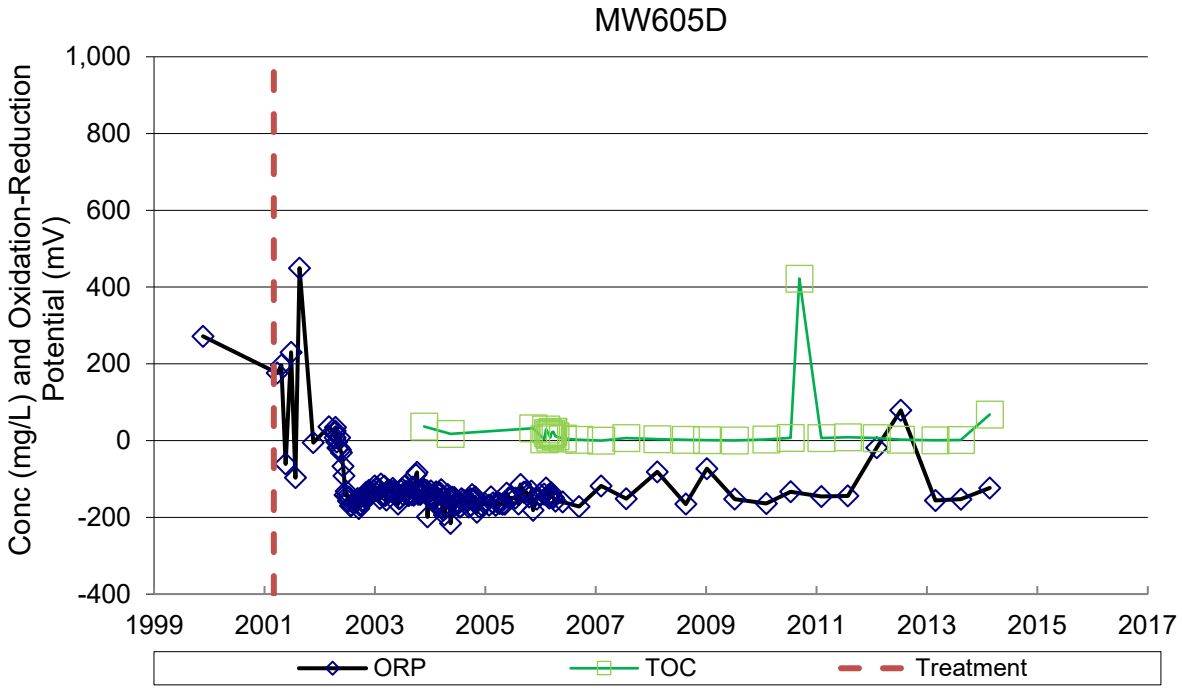


Figure 5-23. ORP and TOC Trends for MW605D, Dover Air Force Base Area 6.

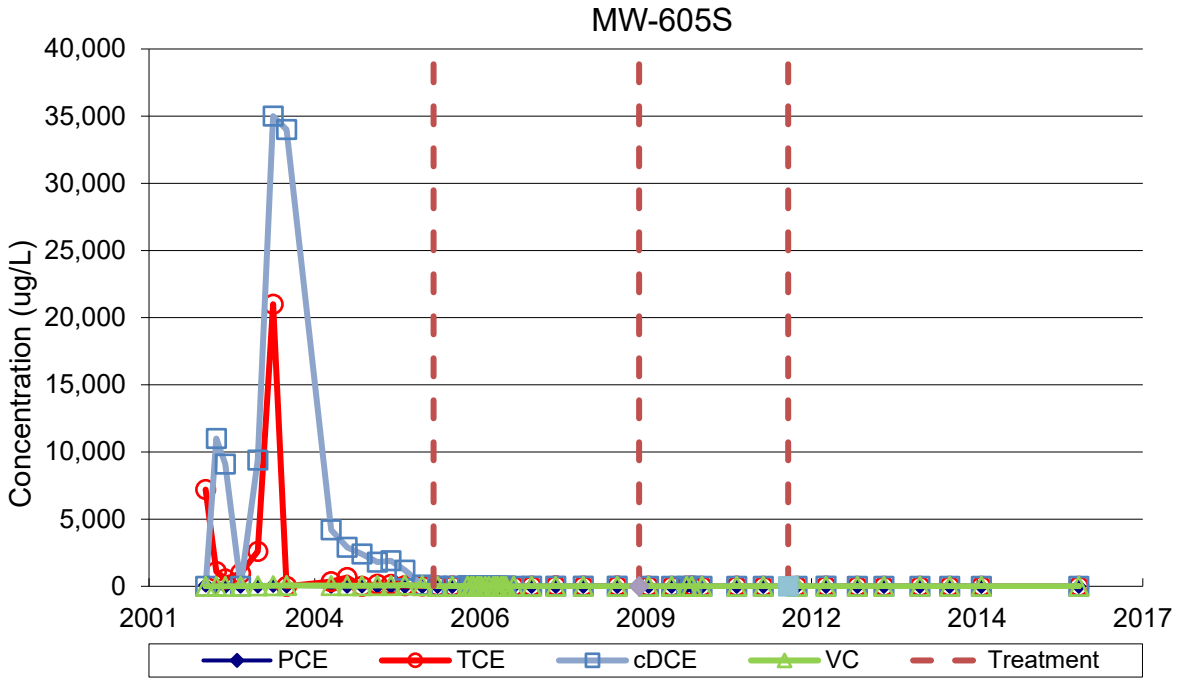


Figure 5-24. VOC Trends for MW605S, Dover Air Force Base Area 6.

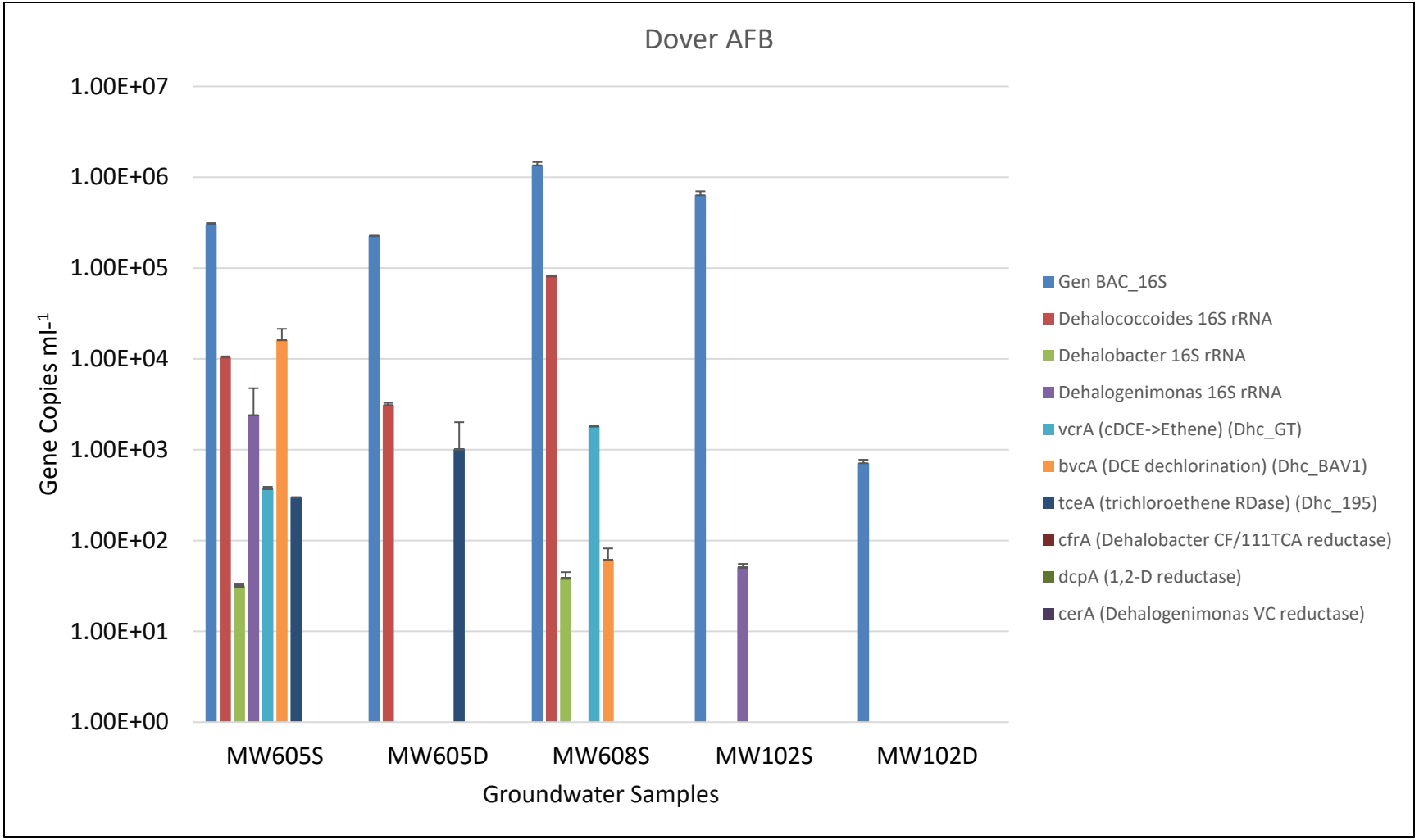


Figure 5-25. Organisms and/or Genes Associated with Reductive Dechlorination Detected in Wells at Dover Air Force Base Area 6.

5.3.2.3.8. CSIA

Values of $\delta^{13}C$ were obtained for PCE, TCE, and *cis*-DCE in MW102D and for cis-DCE in MW608S. Typical unfractionated $\delta^{13}C$ value for manufactured PCE ranges from~ -37‰ to - 24‰ with a mean of -30‰; TCE ranges from ~ -34‰ to - 23‰, with a mean of -29‰; and cis-DCE, values range from ~ -30‰ to - 22‰, with a mean of -26‰ (USEPA, 2008). The $\delta^{13}C$ values for PCE, TCE, and cis-DCE in well MW102D were -28.4‰, -22.4 ‰, and -21.4‰, respectively. The $\delta^{13}C$ value for cis-DCE in well MW608S was -11.3‰. The $\delta^{13}C$ value for cis-DCE in MW608S provides clear evidence that the compound is degrading because the delta value is significantly higher (i.e., compound is isotopically heavier or enriched) than the typical range for parent TCE. As shown in **Figure 5-26**, as a parent VOC (e.g., TCE) biodegrades via reductive dehalogenation, the initial daughter product (*cis*-DCE in the case of TCE) will initially be much lighter than the parent but will become heavier as the parent biodegrades and also gets heavier. However, if the daughter is not itself biodegrading, it will never become heavier than the original parent TCE (**Figure 5-26**, left panel). However, if the cis-DCE is biodegrading, it will eventually become heavier than the parent TCE (**Figure 5-26**, right panel). If one assumes the parent TCE to have a $\delta^{13}C$ in the range of -34‰ to - 23‰, a value of -11.3‰, as detected in MW608S, is significantly heavier than even the heaviest potential parent value, clearly indicating degradation.

The $\delta^{13}C$ values of TCE and cis-DCE in well MW102D are heavier than PCE, which may or may not have been the parent of the observed TCE (i.e., TCE may be an initial degradation product of PCE or a parent compound if both were used as solvents). In any event, presuming that TCE is the parent/predecessor of cis-DCE, the $\delta^{13}C$ value TCE (-22.4 ‰) is just marginally heavier than what would be expected for parent TCE, and cis-DCE is in the same range at -21.4‰. Overall, these data do not support the hypothesis that TCE or cis-DCE is undergoing continued degradation in the vicinity of this well. This conclusion is also consistent with the current geochemistry and microbial data in the groundwater in this region.

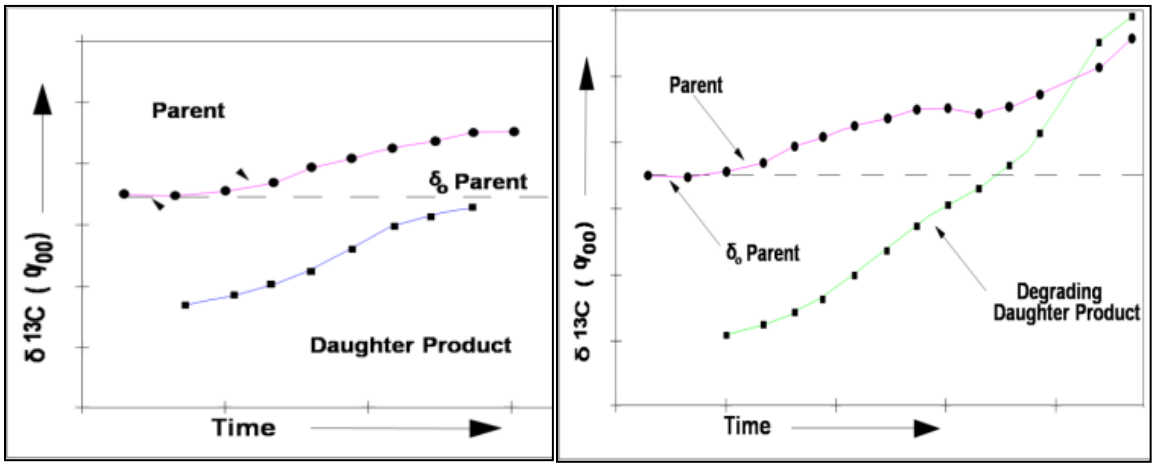


Figure 5-26. Graphs Showing the Expected $\delta^{13}C$ Trajectory in a Case Where the Parent Compound is Biodegrading, and the Daughter Product is Not Biodegrading

(Left Panel). Figure courtesy of Pace Analytical.

5.3.2.3.9. Mass Flux

The contaminant flux profiles, as measured by the PFM deployment, are shown in **Figure 5-27** for the five wells examined. PFMs were deployed in source zone (MW605D, MW605S, MW102D, MW10D) and at the toe of the source zone in the region of the plume (MW608S). No chlorinated ethenes or ethene were detected in wells MW-605D, MW-608S, or MW-102S. No cis-DCE, VC or ethene was detected in MW-102D, but TCE was present, albeit at an average mass flux of 0.02 mg/m^2/day, and a maximum flux of 0.04 mg/m^2/day was detected (**Table 5-11**). This maximum mass flux value at well MW-102D is equivalent to a maximum flux averaged TCE concentration of 2.7 µg/L. No PCE or TCE was detected in MW-605S, but the average mass fluxes of 1.19 mg/m^2/day for cis-DCE, 0.14 mg/m^2/day for VC and 0.17 mg/m^2/day ethene (**Table 5-11**). Maximum mass flux concentrations detected in MW-605S included 5 mg/m^2/day of cis-DCE, 0.72 mg/m^2/day for VC, and 0.86 mg/m^2/day for ethene, which translated to maximum flux-averaged aqueous phase concentrations of 280 µg/L cis-DCE, 47 µg/L VC and 56 µg/L ethene (**Table 5-12**).

The flux-averaged equivalent TCE concentration, estimates from the PFM results did not compare well with equivalent TCE groundwater concentration determined using grab samples (**Table 5-13**). Concentrations of contaminants in groundwater withdrawn from wells can be controlled partly by the mass transfer to flowing water during sampling: (1) mass sorbed to aquifer solids; and/or (2) mass trapped in immobile water. Mass transfercan result in extracted groundwater concentrations being underestimated. Flux data averaged across the well screen suggests minimal chloroethene contamination, but target concentrations measured at discrete intervals suggest that dechlorination above MCLs does persist. Taken together, these data suggest that the source of the low concentrations are chlorinated ethenes diffusing from low permeability zone within the aquifer. This suggests that the source zone is likely free of DNAPL and the plume persistence is due to low permeability zone mass release. Finally, as contaminant migrates downgradient dispersion and degradation lower contaminant levels below MCLs.

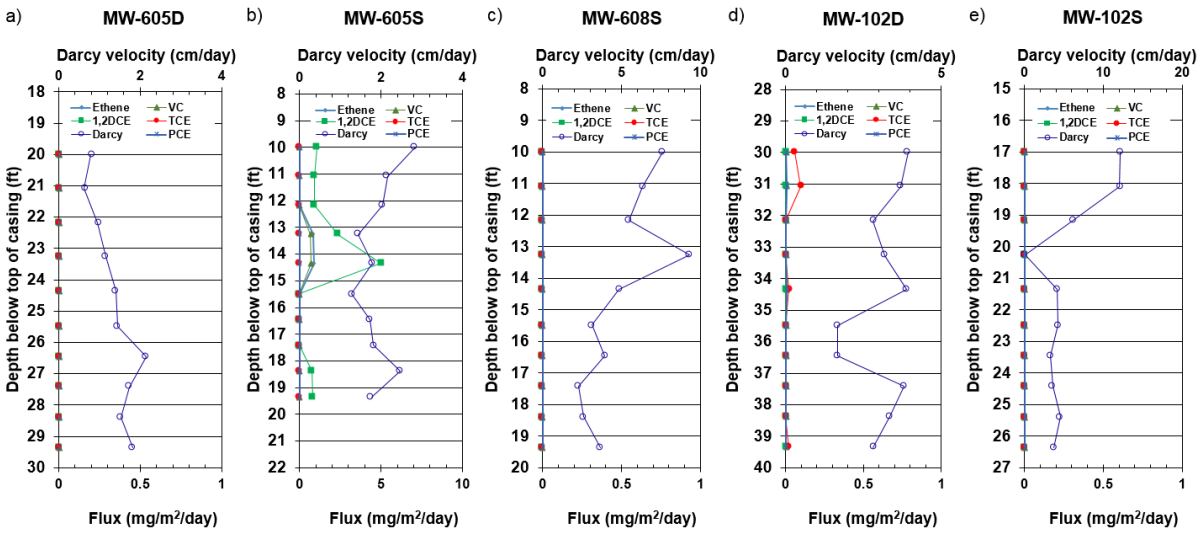


Figure 5-27. Mass Flux Profiles Measured in Select Wells Using the PFMs.

The solid blue diamonds represent ethene, the solid dark green triangles represent VC, the solid light green squares represent DCE, the solid red circles represent TCE, the open purple circles represent the Darcy Velocity, and the blue x's represent PCE. Panels a-e show flux values sampled on 09/22/2016. Note the changes in scale on both axes to accommodate the data.

Table 5-11. Average Mass Discharge for Each Well.

Well_ID	Average Darcy Velocity (cm/day)	Average Ethene flux ($mg/m^2/day$)	Average VC flux ($mg/m^2/day$)	Average 1,2DCE flux ($mg/m^2/day$)	Average TCE flux ($mg/m^2/day$)
MW-605S	1.93	0.17	0.14	1.19	0.00
MW-605D	1.36	0.00	0.00	0.00	0.00
MW-608S	4.91	0.00	0.00	0.00	0.00
MW-102S	5.41	0.00	0.00	0.00	0.00
MW-102D	3.08	0.00	0.00	0.00	0.02

Table 5-12. Maximum Detected TCE, DCE, and VC Flux Averaged Contaminant Concentrations for Each Well based on PFMs.

Well_ID	Average Darcy Velocity (cm/day)	Ethene (µg/L)	VC flux (µg/L)	1,2DCE (µg/L)	TCE (µg/L)
MW-605S	1.93	56	47	280	0.00
MW-605D	1.36	0.00	0.00	0.00	0.00
MW-608S	4.91	0.00	0.00	0.00	0.00
MW-102S	5.41	0.00	0.00	0.00	0.00
MW-102D	3.08	0.00	0.00	0.00	2.7

Table 5-13. Equivalent TCE Groundwater vs. PFM Flux-Averaged Concentration.

Well_ID	Equiv. TCE groundwater concentrations (µg/L)	Equiv. TCE PFM flux-averaged concentrations (µg/L)	% Difference
MW-605S	<dl	478	NA
MW-605D	<dl	<dl	NA
MW-608S	96	<dl	NA
MW-102S	<dl	<dl	NA
MW-102D	101	2.7	190

[a]NA, not analyzed. <dl, less than detection limit.

5.3.2.3.10. Site Summary

The data collected from the site indicate highly effective bioremediation of chlorinated ethenes across the site. Low concentrations of chlorinated solvents persist in a few of the wells, possibly as a result of diffusion from low permeability materials, but concentrations are orders of magnitude lower than pre-treatment. In wells MW605S, MW605D, and MW608S, *Dehalococcoides* was detected at concentrations ranging from 3×10^3 to 8×10^4 cells/mL, methane concentrations were relatively high (ranging from 19.1 to 22.5 mg/L) and the presence of ethene and low ORP suggest that conditions are conducive to ongoing reductive dehalogenation. CSIA data supported this conclusion in MW608S (with VOC concentrations too low to measure in the other two wells).

Conversely, in wells MW102S and MW102D, *Dehalococcoides* were not detected, ORP values were positive, methane concentrations were low, and no ethane or ethene were detected, suggesting the conditions were not conducive to reductive dechlorination at these well. However, MW102S had no residual VOCs. MW102D had low concentrations of PCE, TCE, and cis-DCE that, perhaps due to the elevated ORP and low pH, appear to be undergoing further degradation based on CSIA data. Overall, the data from this site suggest that treatment has been highly effective and that reductive dechlorination at the site continues in many areas 5 years after cessation of active treatment.

5.3.3 Former Charleston Air Force Base, Zone 4

5.3.3.1 Site Description Former Charleston Air Force Base, Zone 4

Zone 4 at Charleston Air Force Base (CAFB) is an industrial area near the CAFB flight line. Trichloroethene (TCE) was formerly used for aircraft parts cleaning (**Figure 5-28**).

Two distinct plumes of TCE contamination, designated Plume 1 and Plume 2, are present at Zone 4. Plume 1 is associated with an oil/water separator at Building 543 (**Figure 5-29**). TCE was historically present in Plume 1 at concentrations exceeding 100,000 µg/L, and the plume extended 600 ft. The origin of Plume 2 is a solvent spill that occurred in 1978 at Building 532 (**Figure 5-30**). Historical TCE concentrations at Plume 2 exceeded 10,000 µg/L. Plume 2 is also approximately 600 ft in length.

Monitoring wells are installed at three depth horizons within the Ladson Formation aquifer consisting of interbedded fine sand, silt, and clay. Groundwater at the site is generally anaerobic and moderately acidic.

Multiple phases of bioremediation have been implemented at Zone 4. The first phase of treatment began in 2003 with the introduction of molasses and bicarbonate buffer using injection wells at Plume 1. Follow-up treatments were initiated in 2004 using molasses, whey, and bicarbonate. This phase of treatment was expanded to include both Plume 1 and Plume 2 and used direct-push technology (DPT) in addition to injection wells. A third phase was implemented in 2008 with the injection of emulsified vegetable oil (EVO) in Plume 1, and a fourth phase was implemented in 2010 with additional EVO injections at both Plume 1 and Plume 2. The EVO injections included both grids and transects of injection wells.

Performance monitoring is currently being conducted. The results to date are somewhat mixed with significant contamination reduction in some areas and minimal reduction in others. Additional injections and/or source remediation are likely in the future. The objective of the field investigation at this site will be to evaluate differences in successful remediation areas versus less successful areas with similar site conditions.

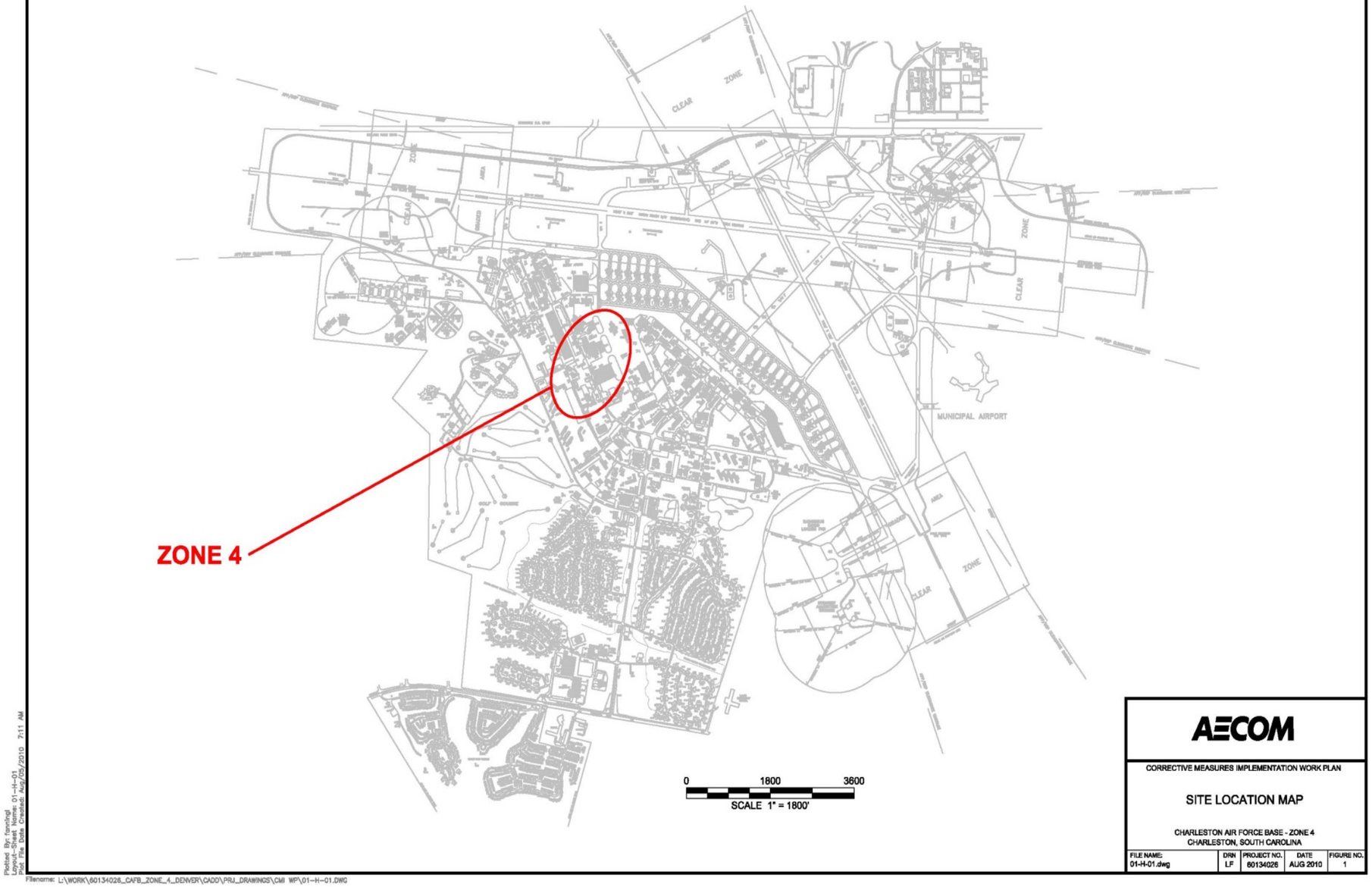


Figure 5-28. Site Location Map, Former Charleston Air Force Base Zone 4.

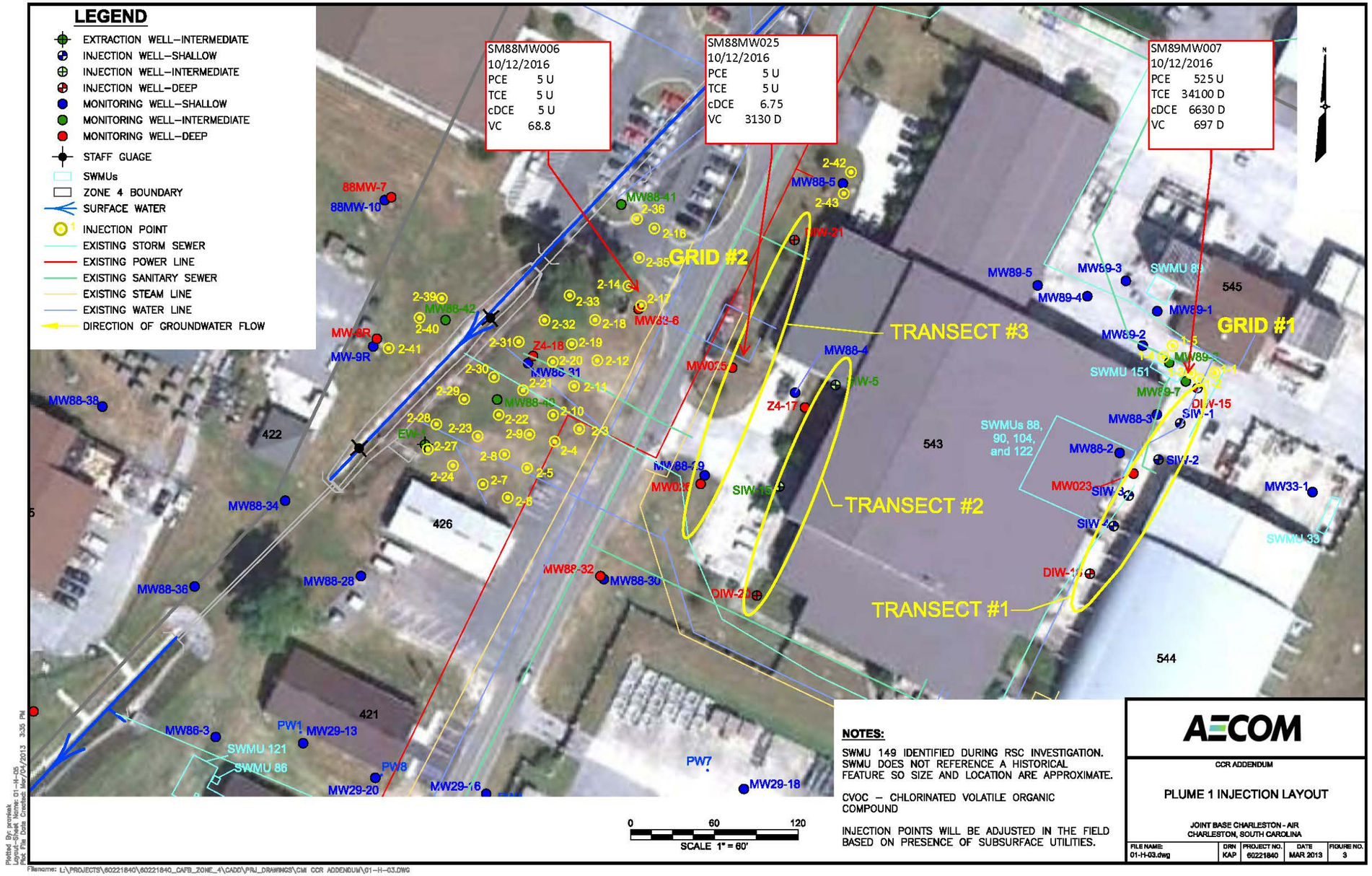


Figure 5-29. Plume 1 Injection Layout, Former Charleston Air Force Base Zone 4.

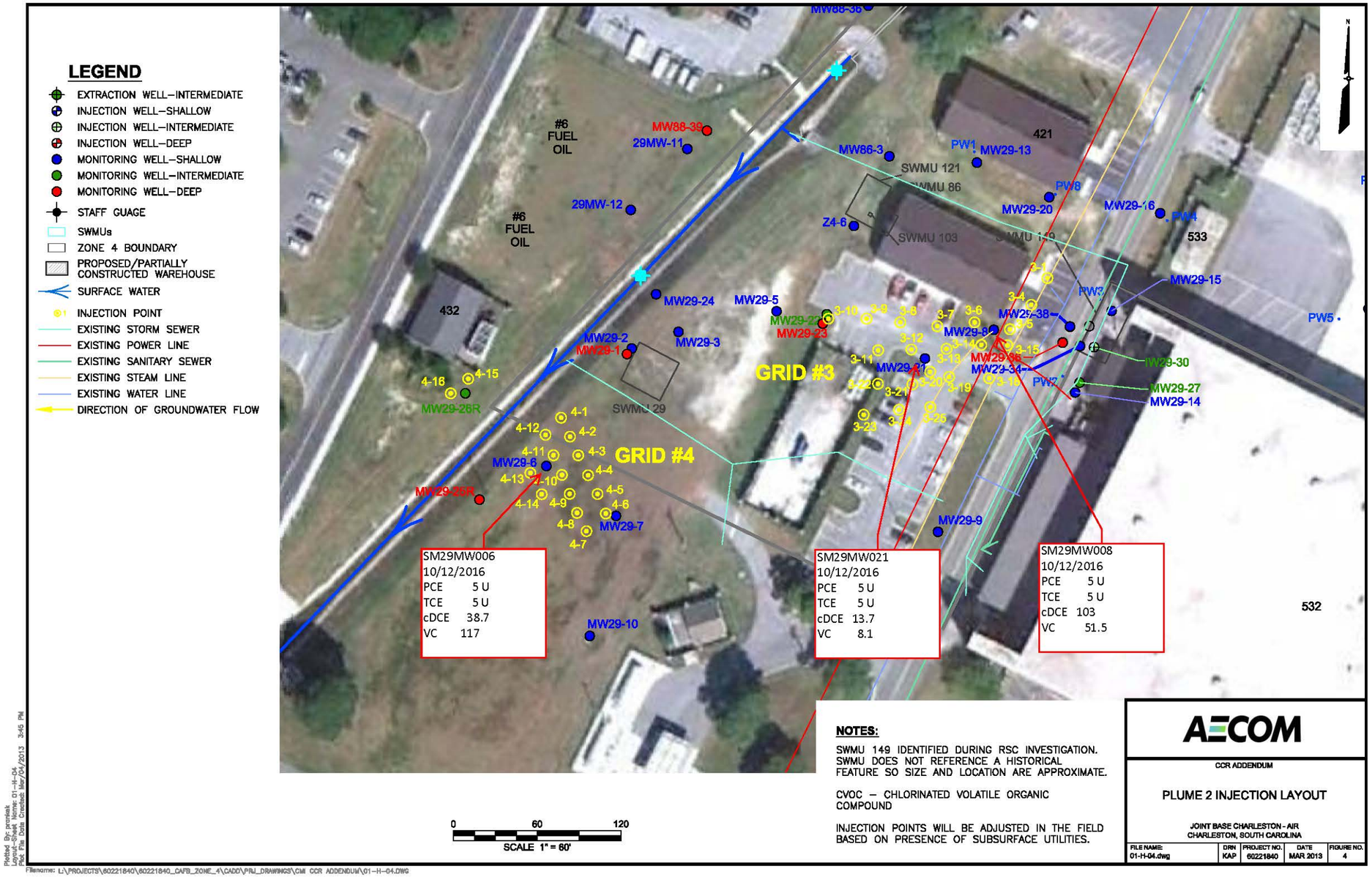


Figure 5-30. Plume 2 Injection Layout, Former Charleston Air Force Base Zone 4.

5.3.3.2 Sampling Rationale Former Charleston Air Force Base Zone 4

The objective of the groundwater sampling was to assess the long-term impacts of the previously performed biostimulation treatments on groundwater quality and biogeochemistry. Amendments were added during various treatment phases between 2004 and 2010, and contaminant reduction in the individual wells was variable. The sampling included wells with varying degrees of contaminant reduction to investigate factors that may contribute to treatment effectiveness. Also, monitoring wells were selected from the various depth horizons and treatment areas at the site. **Table 5-14** summarizes the monitoring locations and rationale for the sampling program and contains general comments on contaminant reduction. **Table 5-15** provides a summary of well construction details. The monitoring wells that were sampled are shown in **Figures 5-29** and **5-30**.

Table 5-14. Groundwater Sampling Locations and Rationale, Former Charleston Air Force Base Zone 4.

Monitoring Well	Contaminant Reduction	Depth Zone	Treatment Area
MW025	Negligible	Deep	Plume 1, Transect 3
MW29-8	Substantial	Shallow	Plume 2, Grid 3
MW29-21	Moderate	Shallow	Plume 2, Grid 3
IW29-30	Negligible	Intermediate	Plume 2, Grid 3
MW29-6	Moderate	Shallow	Plume 2, Grid 4
MW88-06	Substantial	Deep	Plume 1, Grid 2
MW89-07	Negligible	Shallow	Plume 1, Grid 1

Table 5-15. Monitoring Well Construction Details, Former Charleston Air Force Base Zone 4.

Monitoring Well	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Diameter (inches)
MW025	25	35	2
MW29-8	10	20	2
MW29-21	22	27	2
IW29-30	21	26	2
MW29-6	10	20	2
MW88-06	30	35	2
MW89-07	22	27	1
Z4-17*	26.5	31.5	2

bgs = below ground surface

*PFMs only deployed in this well. VOCs, CSIA, and geochemical analysis were not performed on wells due to scheduling conflicts.

5.3.3.3 Sampling Results, Former Charleston Air Force Base Zone 4

5.3.3.3.1. VOCs

Table 5-16 provides a summary of sampling results, and **Figures 5-31** to **5-46** provide historical and current VOC data and corresponding ORP and TOC data for each well. The primary parent contaminant at this site was TCE. Concentrations were below detection (< 5 µg/L) in 5 of the 7 wells sampled. The remaining wells, IW29-30 and MW29-07 had 62.6 µg/L and 34,100 µg/L of TCE, respectively (**Figure 5-31** and **5-32**). The latter well is a shallow source zone well where treatment has been relatively ineffective, most likely due to the continued presence of DNAPL based upon the dissolved TCE concentrations. Among the wells, *cis*-DCE was also detected at the highest concentrations in IW29-30 (1,160 µg/L) and MW29-07 (6,630 µg/L). Among the other 5 wells, *cis*-DCE ranged from below detection (< 5 µg/L: MW88-6) to 103 µg/L in MW29-8. VC was detected at the highest concentration in MW-025 (3,130 µg/L), a well without TCE and with only 6.75 µg/L or *cis*-DCE, indicating substantial reductive dechlorination, but perhaps with a much slower rate of VC reduction. All the other wells also VC, ranging from a low of 8.1 µg /L in MW29-21 to 697 µg /L in MW89-7. The prevalence of daughter products indicates ongoing reductive dechlorination.

5.3.3.3.2. Field Parameters

The ORP of wells across the site ranged from +40.7 to -137 mV, and DO was consistently low (0.1 to 0.42 mg/L). Thus, the conditions across the site were anoxic and mildly reducing. The historical ORP at this site, as shown in the accompanying figures for each well (see **Figures 5-31** to **5-46**) have also been in this general range since 2007, with some expected decreases after the addition of organic substrate. The groundwater pH was between 5.9 and 6.8 SU, which is in a range suitable for reductive dehalogenation to occur.

5.3.3.3.3. Anions

Nitrate, nitrite, and phosphate were all below detection (< 0.2 mg/L) across the site, and sulfate ranged from 0.14 to 2.42 mg/L. Previous data collected in 2003 showed sulfate ranging from a high of 34 mg/L to a low of ~1.5 mg/L across the site, indicating that sulfate is not naturally elevated in site groundwater.

5.3.3.3.4. Dissolved Iron and Manganese

Dissolved iron was high across the site, ranging from 3,510 µg/L in MW89-7 to 59,100 µg/L in IW29-30. Similarly, dissolved manganese was detected in every well ranging from 148 µg/L in MW89-6 to 794 µg/L in IW29-30. These data are indicative of iron and manganese reduction occurring in site groundwater.

5.3.3.3.5. Dissolved Gases

Methane was detected in groundwater across the site ranging from ~ 2,480 µg/L to 9,510 µg/L. The highest concentrations were observed in MW-025 and MW-89-7, each having more than 9,000 µg/L. Each of these wells also had detectable ethane, ranging from 4.1 µg/L in MW29-21 to 2,180 µg/L in MW-025. Moreover, all wells except MW29-21 had ethene ranging from 17 µg/L in MW29-6 to 5,840 µg/L in MW-025. These gases (ethene and ethene) are typically detected as final degradation products of chlorinated ethenes and are indicative of ongoing reductive dehalogenation.

Hydrogen gas, the ultimate electron donor for reductive dehalogenation, was near or below the MDL (0.0084 µg/L) in all wells except MW-025 (0.0785 µg/L) and MW88-6 (0.028 µg/L).

5.3.3.3.6. Total Organic Carbon and Volatile Fatty Acids

Total organic carbon (TOC) in the different wells ranged from 1.48 mg/L in MW29-8 to 204 mg/L in IW29-30. None of the common fatty acids were detected above 1 mg/L (PQL) except acetate, which was measured at 10.2 mg/L in MW29-21 and 46.2 mg/L in IW29-30. Thus, with the exception of these two wells, the measured TOC largely represents compounds other than fatty acids. Historical TOC data are provided in accompanying figures (**Figures 5-31** to **5-46**).

5.3.3.3.7. Microbial Community

The microbial community analysis indicated the presence of numerous different dehalogenation-associated organisms/genes in water samples from across the Charleston Site. *Dehalococcoides* was detected in water from wells MW29-21, MW29-8, MW-025, MW88-6, MW29-6, and IW29-30 at an abundance of between 9 x 10^1 cells/mL (MW29-21) to 3.3 x 10^6 cells/mL in IW-29-30 (**Figure 5-47**). The qPCR analysis indicated that *vcrA* gene (enzyme degrades cis-DCE to ethene) was present in MW29-8, MW-025, MW88-6, MW29-6, and MW29-30 at 1.4 x 10^2 cells/mL (MW88-6) to 4.2 x 10^5 cells/mL in IW-29-30.The *bvcA* gene, whose coded enzyme performs the same function as *vcrA* was only detected in three well*s,* but concentrations in IW29-30 were very high (3.1 x 10^5 cells/mL) as observed for *vcrA*. The *tceA* gene (enzyme degrades TCE to VC) was detected in MW29-8, MW-025, MW29-6, and IW29-30 at 4.5 x 10^1 cells/mL (MW29-8) to 3.0 x 10^4 cells/mL (IW29-30). *Dehalobacter* spp*.,* known for degrading chlorinated ethanes, were detected in samples from MW88-6, MW29-6, and MW29-30 in amounts ranging from 6.0 x 10^1 cells/mL to 1.0 x 10^6 cells/mL, and *Dehalogenimonas* (also chlorinated ethane degraders) were observed in MW29-8, MW-025, MW88-6, MW29-6, and MW29-30 in amounts from 6.4 x 10^1 cells/mL to 1.7 x 10^4 cells/mL.

Overall, qPCR results showed a wide array of dehalogenating organisms and genes in the samples. The numbers and diversity were generally greatest in IW29-30 followed by MW-025, MW29-6, and MW29-8. MW29-21 and MW89-7 had the lowest overall numbers and cell/gene diversity.

Table 5-16. Sampling Results Summary, Former Charleston Air Force Base Zone 4.

Class	LOCATION_CODE		MW-025		MW29-21		MW29-30		MW29-6		MW29-8		MW88-6		MW89-7	
	SAMPLE_DATE		10/12/16		10/12/16		10/12/16		10/12/16		10/12/16		10/12/16		10/12/16	
	Parameter	Units	Result		Result		Result		Result		Result		Result		Result	
Anion	Chloride	mg/L	**92.3**	D	**11.9**		**332**	D	**14.3**		**13.9**		**190**	D	**15.1**	
	Nitrate as N	mg/L	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U
	Nitrite as N	mg/L	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U
	Phosphate as P, ortho	mg/L	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U	0.2	U
	Sulfate as SO4	mg/L	**2.42**		**0.14**	J	**0.56**		**1.47**		**0.52**		**0.19**	J	**0.57**	
CSIA	del13C cDCE	ppt	NA		**-13.2**		**-22**		**-3.78**		**-7.84**		NA		**-25.7**	
	del13C TCE	ppt	NA		NA		**-21**		NA		NA		NA		**-25.1**	
	del13C VC	ppt	NA		**-9.29**		**-25.6**		**-13.3**		**-11.9**		**1.20**		NA	
Field	DO	mg/L	**0.34**		**0.33**		**0.1**		**0.38**		**0.42**		**0.23**		**0.24**	
	ORP	mV	**36.3**		**-15.5**		**-137**		**37.7**		**-8.6**		**-42.3**		**40.7**	
	pH	su	**6.29**		**5.99**		**6.81**		**5.95**		**5.99**		**6.52**		**5.92**	
Gases	Acetylene	µg/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U
	Ethane	µg/L	**2,180**	D	**4.09**		**23.1**		**4.34**		**23**		**332**		**131**	
	Ethene	µg/L	**5,840**	D	5	U	**55.2**		**17**		**6.52**		**82.9**		**210**	
	Hydrogen	µg/L	**0.0785**	D	0.0084	U	0.0084	U	0.0084	U	0.0084	U	**0.028**		0.0084	U
	Methane	µg/L	**9,510**	D	**4,080**	D	**2,480**	D	**6,990**	D	**5,200**	D	**6,380**	D	**9,490**	D
	Propane	µg/L	6	U	6	U	6	U	6	U	6	U	6	U	6	U
Metals	Dissolved Iron	µg/L	**12500**		**7800**		**59100**		**12400**		**8540**		**19800**		**3510**	
	Dissolved Manganese	µg/L	**299**		**134**		**794**		**148**		**130**		**278**		**163**	
TOC	Total Organic Carbon	mg/L	**14.4**		**26.5**		**204**	D	**25.7**		**1.48**	J	**160**	D	**9.02**	
VFA	Acetic Acid	mg/L	1	U	**10.2**		**46.2**		1	U	1	U	1	U	1	U
	Butyric Acid	mg/L	1	U	1	U	1	U	1	U	1	U	1	U	1	U
	Formic Acid	mg/L	1	U	1	U	1	U	1	U	1	U	1	U	1	U
	Lactic Acid	mg/L	1	U	1	U	1	U	1	U	1	U	1	U	1	U
	Propionic Acid	mg/L	1	U	1	U	1	U	1	U	1	U	1	U	1	U
	Pyruvic Acid	mg/L	1	U	1	U	1	U	1	U	1	U	1	U	1	U
	Valeric Acid	mg/L	1	U	1	U	1	U	1	U	1	U	1	U	1	U
VOC	1,1-dichloroethylene	µg/L	5	U	5	U	**2.30**	J	5	U	5	U	5	U	525	U
	1,2,4-trimethylbenzene	µg/L	**4.91**	J	5	U	**8.33**		5	U	5	U	**5.50**		525	U
	1,2-dichlorobenzene	µg/L	**2.84**	J	5	U	5	U	5	U	5	U	**1.00**	J	525	U
	1,3,5-trimethylbenzene	µg/L	**4.26**	J	5	U	**4.44**	J	5	U	5	U	**3.32**	J	525	U
	1,3-dichlorobenzene	µg/L	**75.9**		5	U	5	U	5	U	5	U	**45.9**		525	U
	1,4-dichlorobenzene	µg/L	**51.8**		5	U	5	U	5	U	5	U	**20.2**		525	U
	benzene	µg/L	**3.3**	J	5	U	5	U	5	U	5	U	**6.15**		525	U
	carbon disulfide	µg/L	**5.45**		5	U	5	U	5	U	5	U	**3.86**	J	525	U
	chlorobenzene	µg/L	**783**	D	5	U	5	U	**0.97**	J	5	U	**885**	D	525	U
	Cis 1,2- Dichloroethylene	µg/L	**6.75**		**13.7**		**1150**	D	**38.7**		**103**		5	U	**6630**	D
	ethylbenzene	µg/L	**6.91**		5	U	**1.00**	J	5	U	5	U	**7.21**		525	U
	methylene chloride	µg/L	5	U	5	U	5	U	5	U	5	U	5	U	**79.8**	JD
	o-xylene	µg/L	**7.92**		5	U	**4.28**	J	5	U	5	U	**5.80**		525	U
	tert-butylbenzene	µg/L	5	U	5	U	**0.71**	J	5	U	5	U	5	U	525	U
	Tetrahydrofuran (THF)	µg/L	10	U	10	U	**93.1**		10	U	**87.0**		10	U	1050	U
	toluene	µg/L	**127**		5	U	**7.41**		5	U	**0.45**	J	**4.64**	J	525	U
	trans-1,2-dichloroethylene	µg/L	5	U	**1.64**	J	**0.50**	J	5	U	**7.59**		5	U	525	U
	trichloroethylene	µg/L	5	U	5	U	**62.6**		5	U	5	U	5	U	**34100**	D
	vinyl chloride	µg/L	**3130**	D	**8.10**		**179**	JD	**117**		**51.5**		**68.8**		**697**	D
	xylenes (m/p)	µg/L	**25.8**		10	U	**11.6**		10	U	10	U	**27.9**		1050	U

Notes:

NA - Not Analyzed

U - Compound not detected above method practical quantitation limit.

D - Sample was diluted prior to analysis

J - Estimated value above MDL and less than PQL

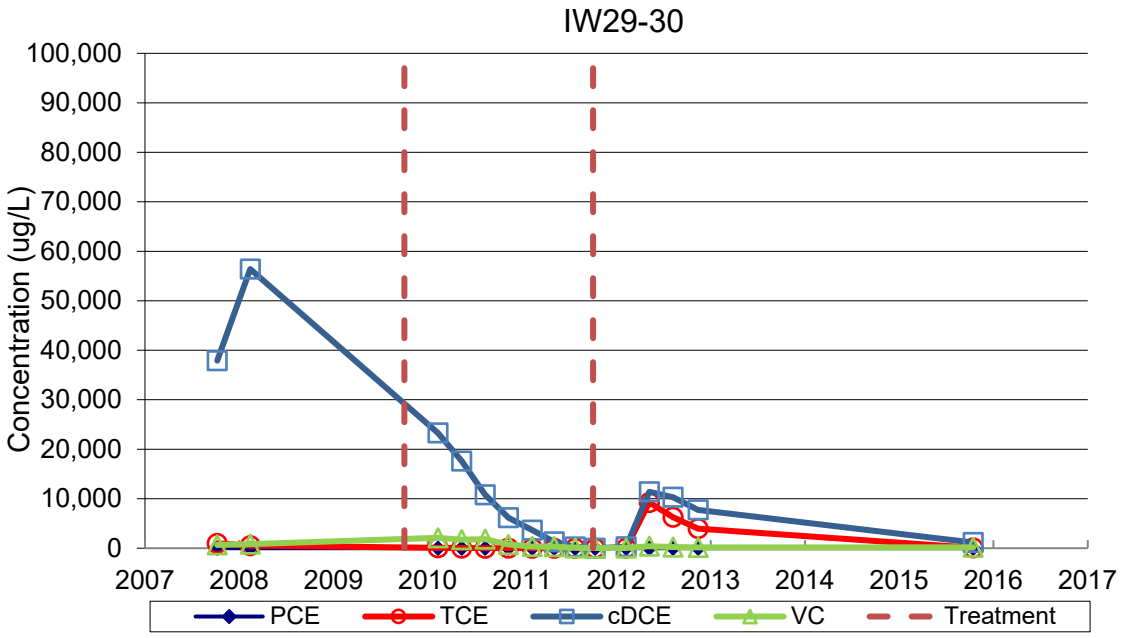


Figure 5-31. VOC Trends for IW29-30, Former Charleston Air Force Base Zone 4.

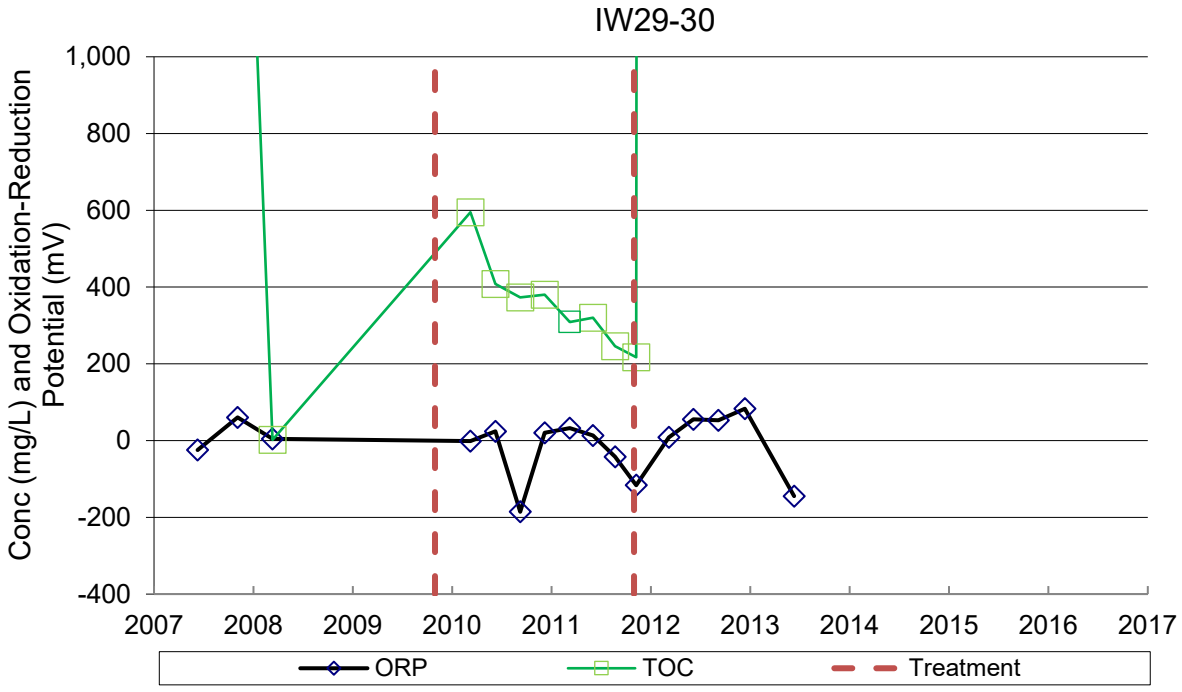


Figure 5-32. ORP and TOC for IW29-30, Former Charleston Air Force Base Zone 4.

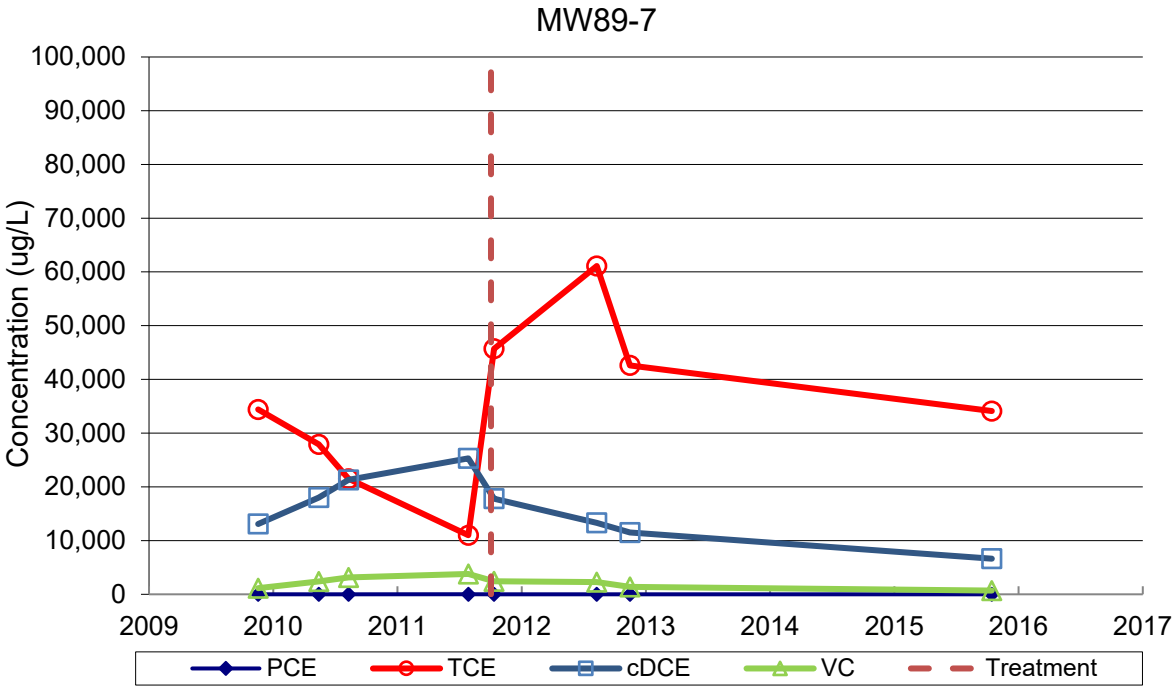


Figure 5-33. VOC Trends for MW89-7, Former Charleston Air Force Base Zone 4.

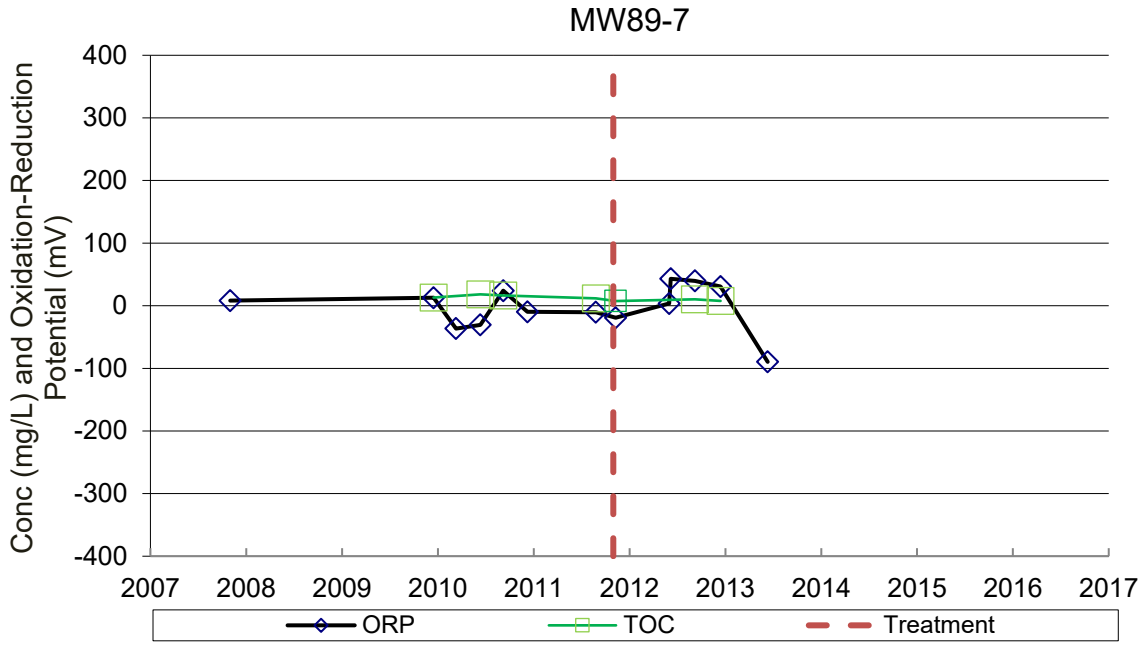


Figure 5-34. ORP and TOC for MW89-7, Former Charleston Air Force Base Zone 4.

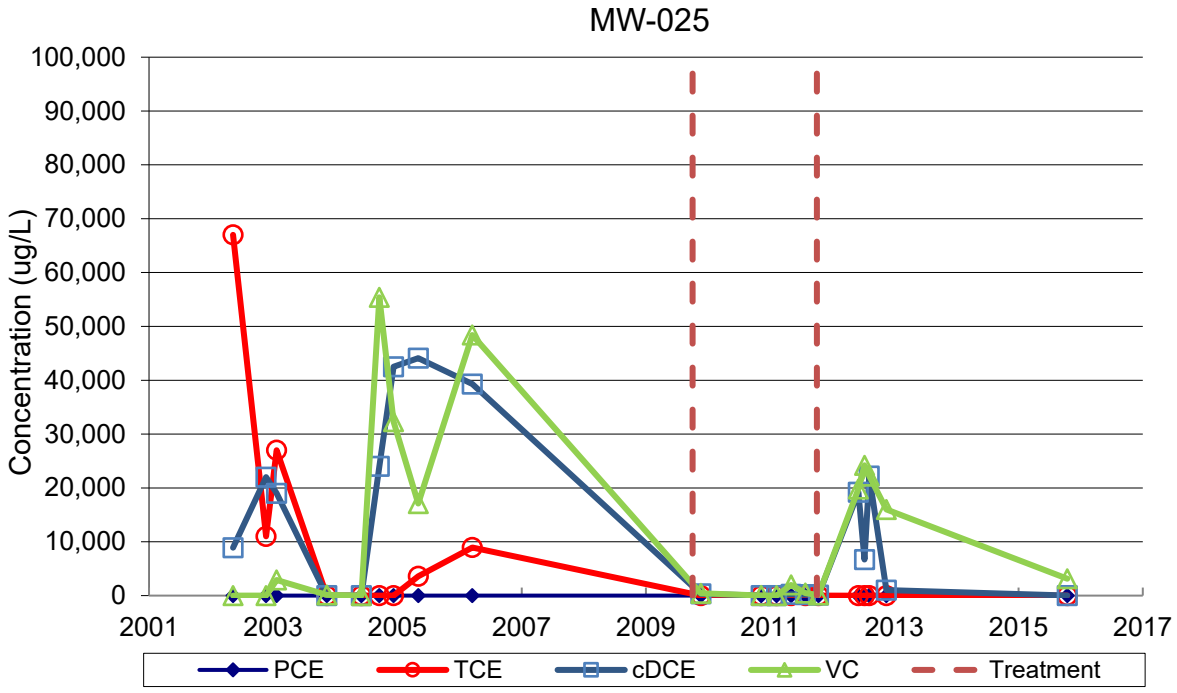


Figure 5-35. VOC Trends for MW-025, Former Charleston Air Force Base Zone 4.

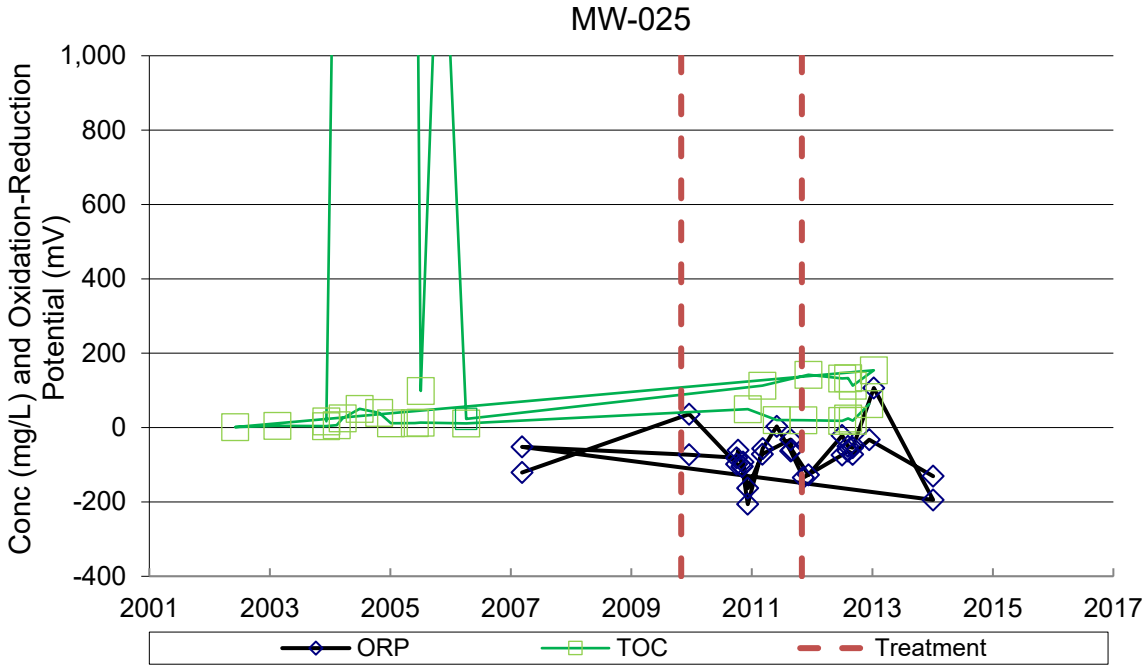


Figure 5-36. ORP and TOC for MW-025, Former Charleston Air Force Base Zone 4.

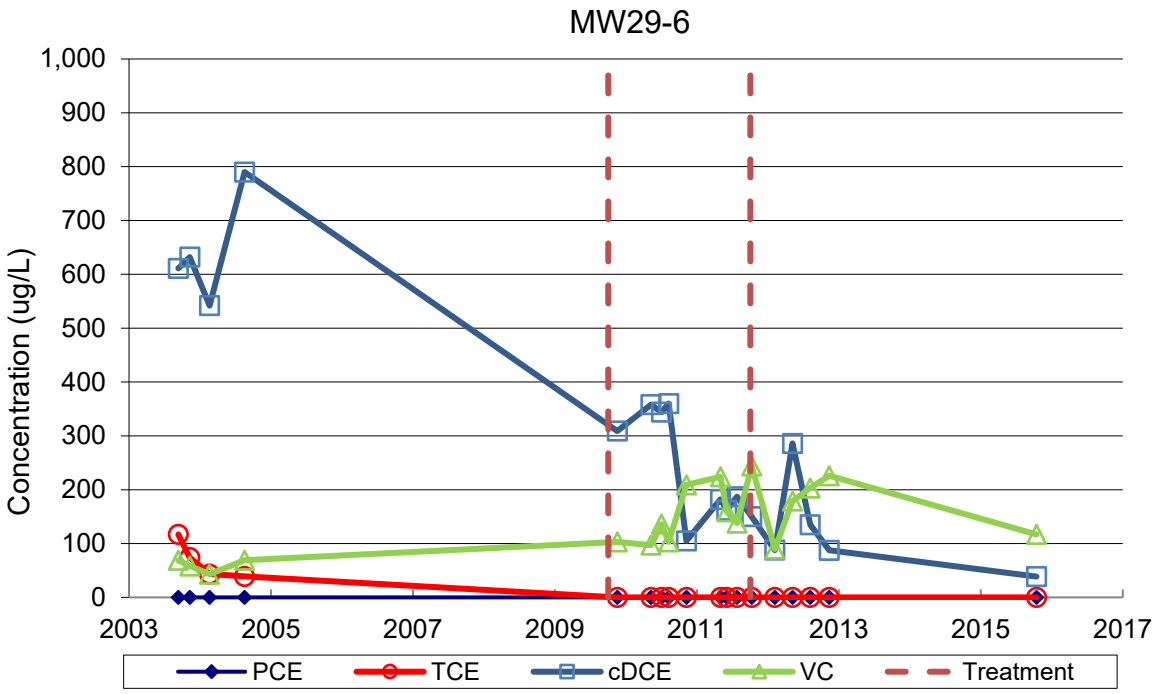


Figure 5-37. VOC Trends for MW29-6, Former Charleston Air Force Base Zone 4.

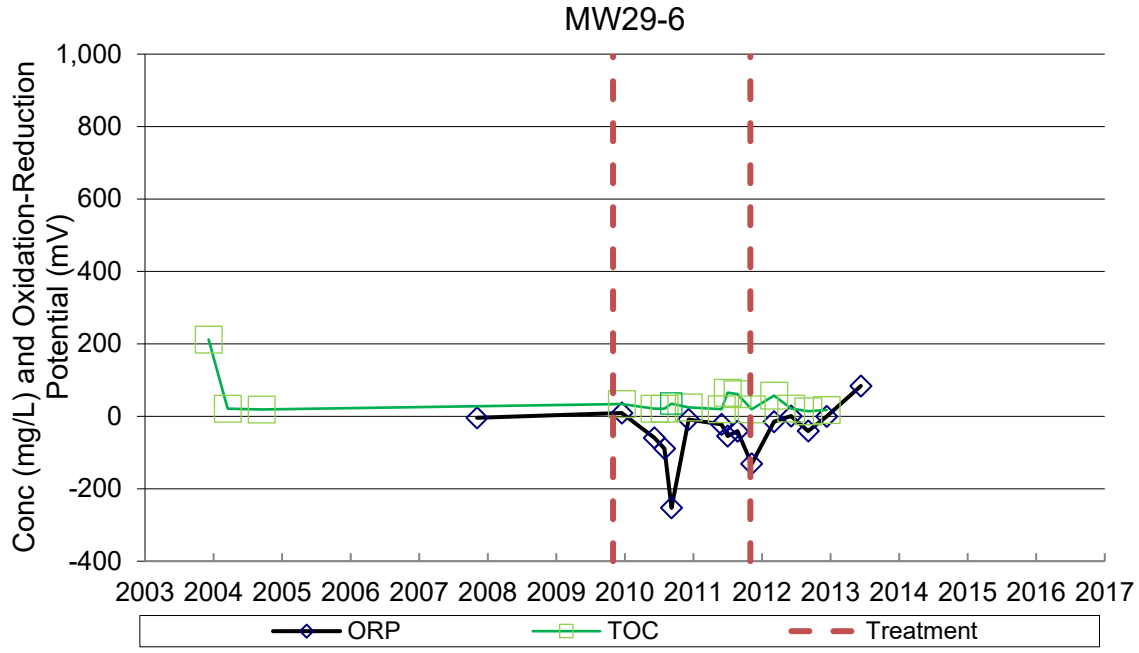


Figure 5-38. ORP and TOC for MW29-6, Former Charleston Air Force Base Zone 4.

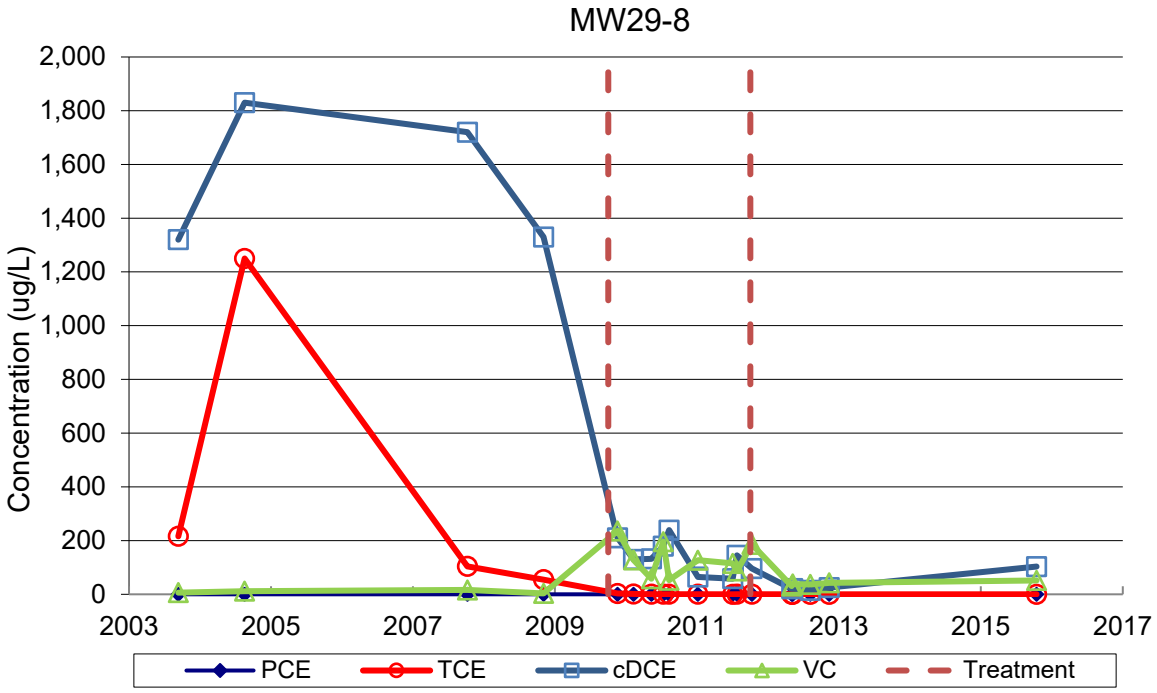


Figure 5-39. VOC Trends for MW29-8, Former Charleston Air Force Base Zone 4.

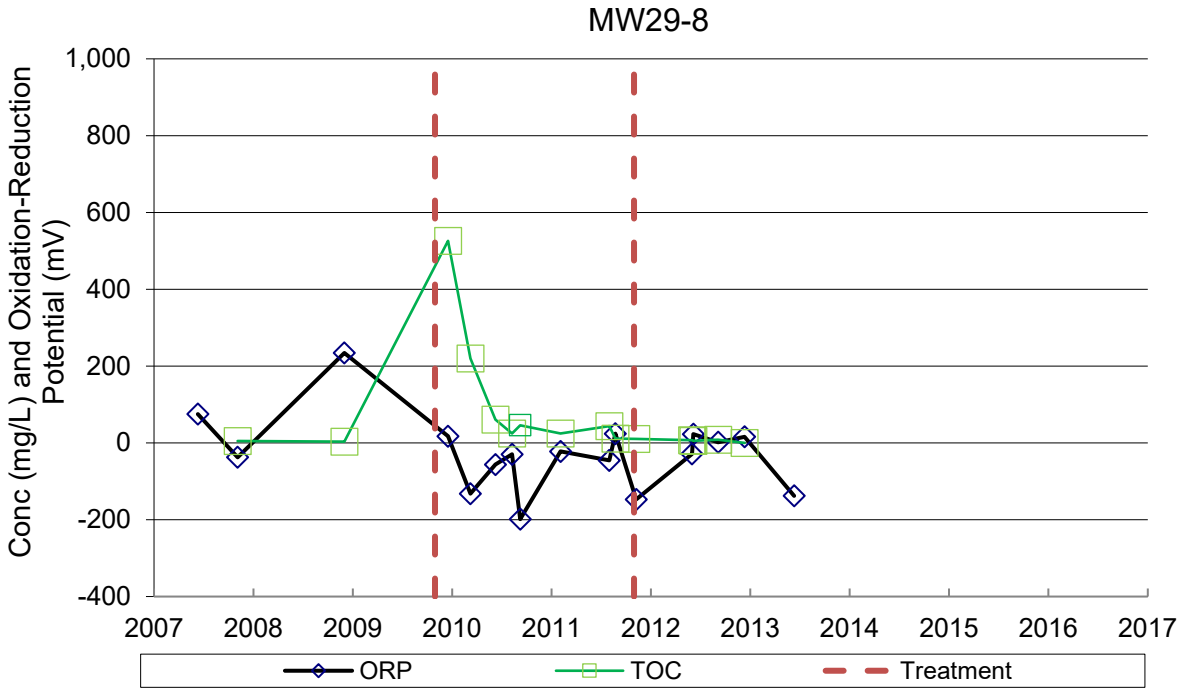


Figure 5-40. ORP and TOC for MW29-8, Former Charleston Air Force Base Zone 4.

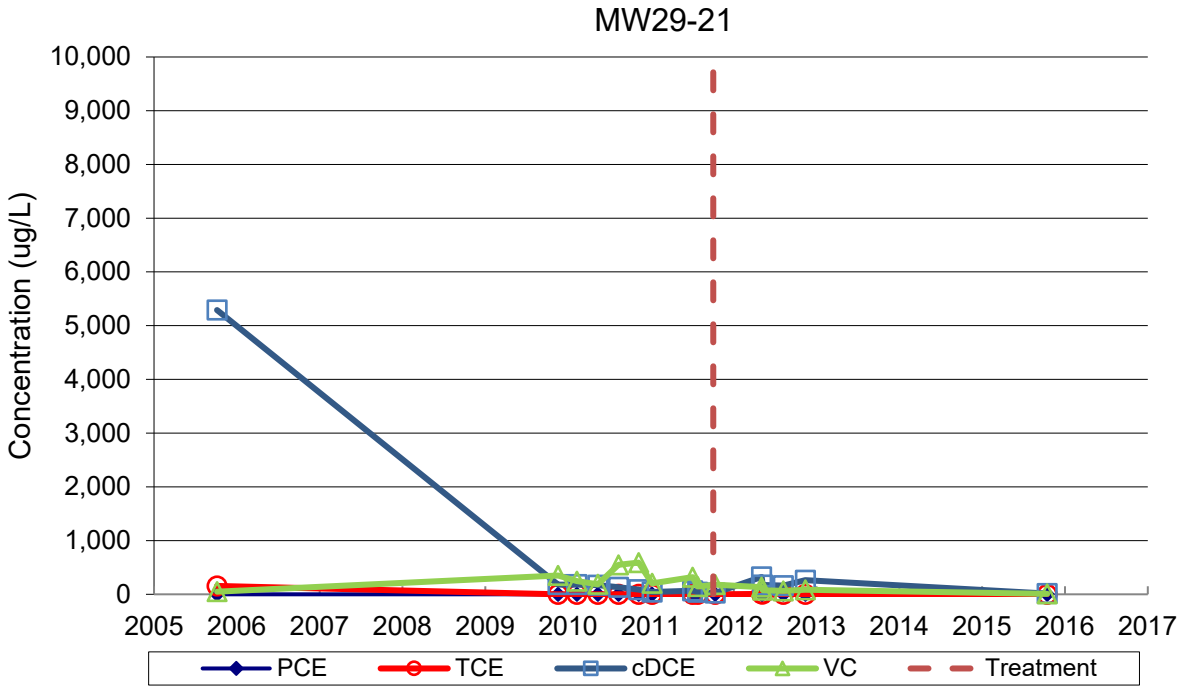


Figure 5-41. VOC Trends for MW29-21, Former Charleston Air Force Base Zone 4.

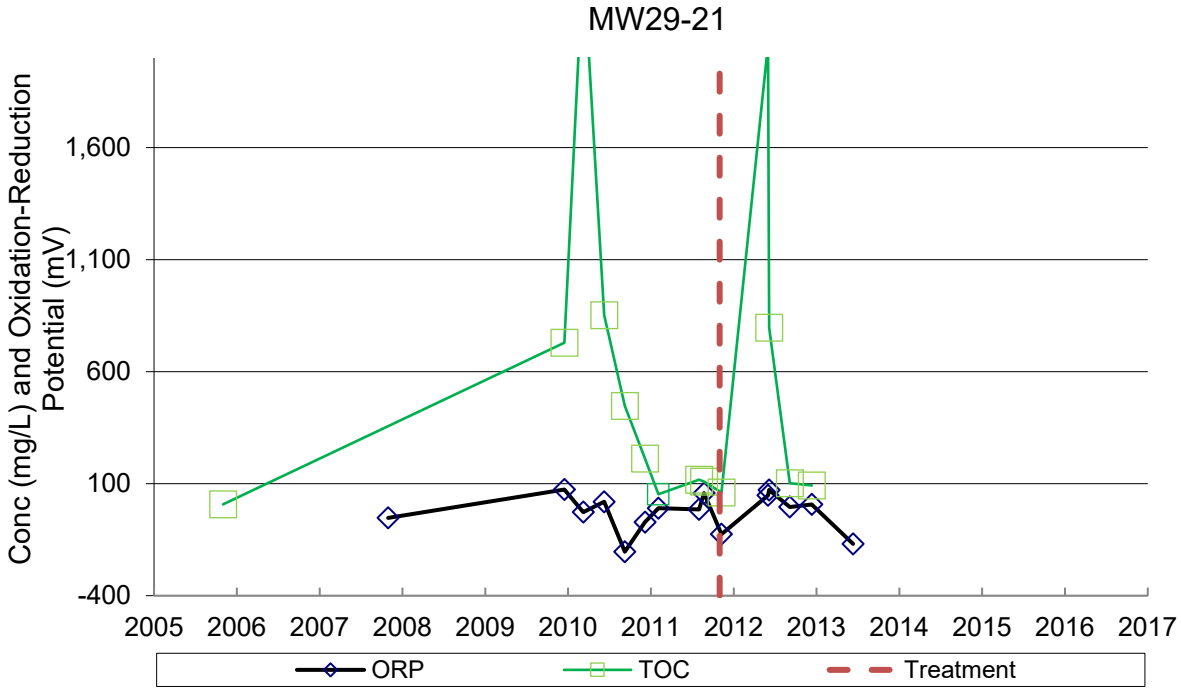


Figure 5-42. ORP and TOC for MW29-21, Former Charleston Air Force Base Zone 4.

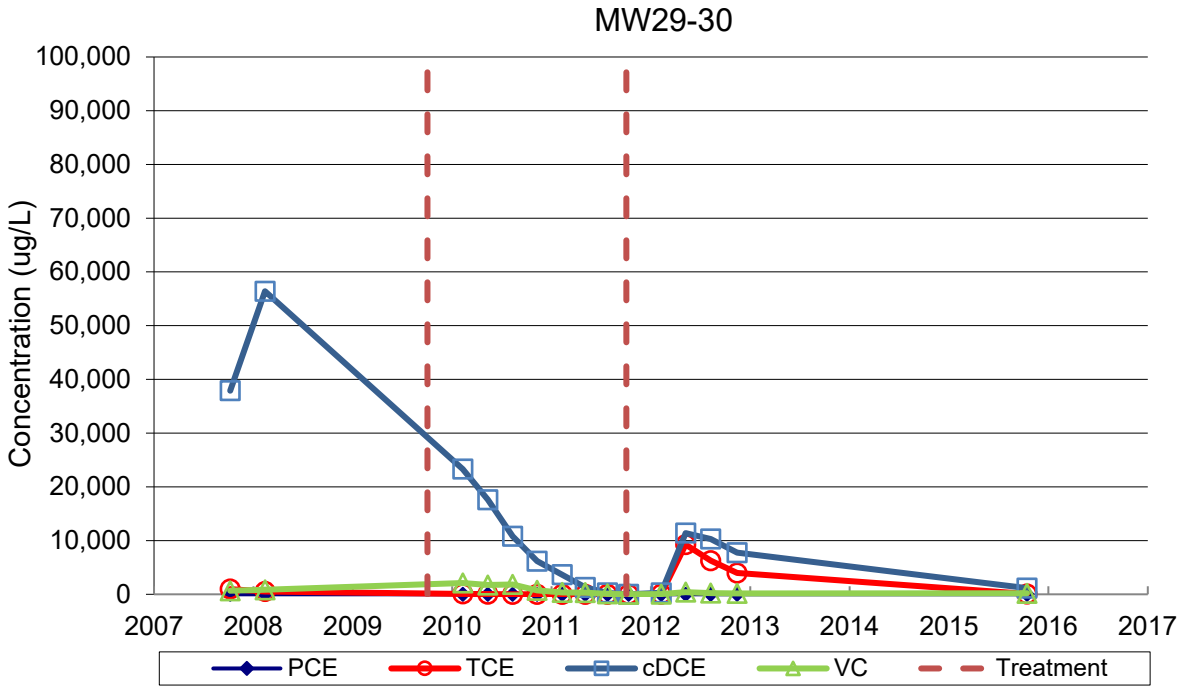


Figure 5-43. VOC Trends for MW29-30, Former Charleston Air Force Base Zone 4.

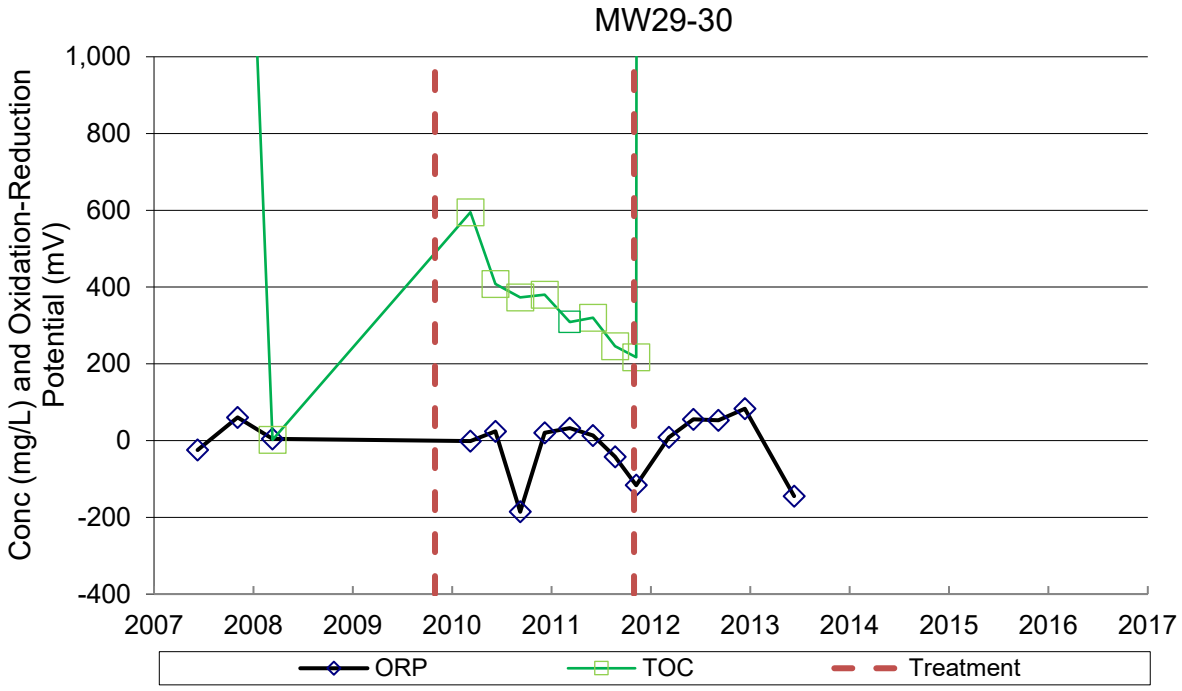


Figure 5-44. ORP and TOC for MW29-30, Former Charleston Air Force Base Zone 4.

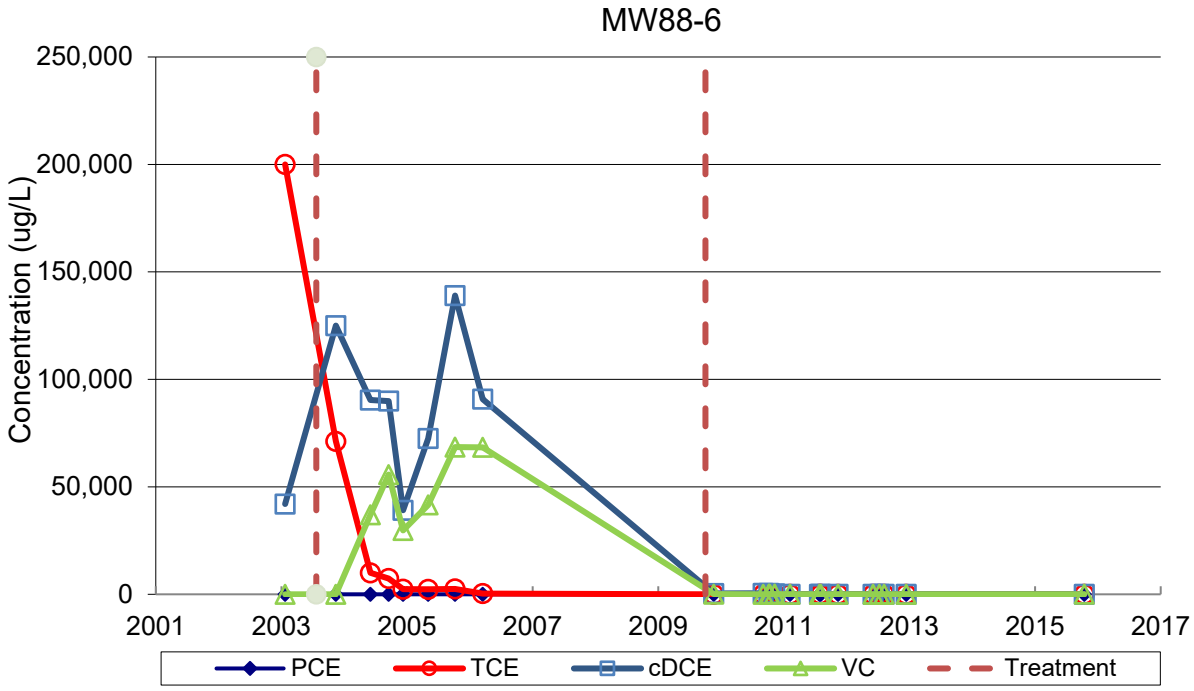


Figure 5-45. VOC Trends for MW88-6, Former Charleston Air Force Base Zone 4.

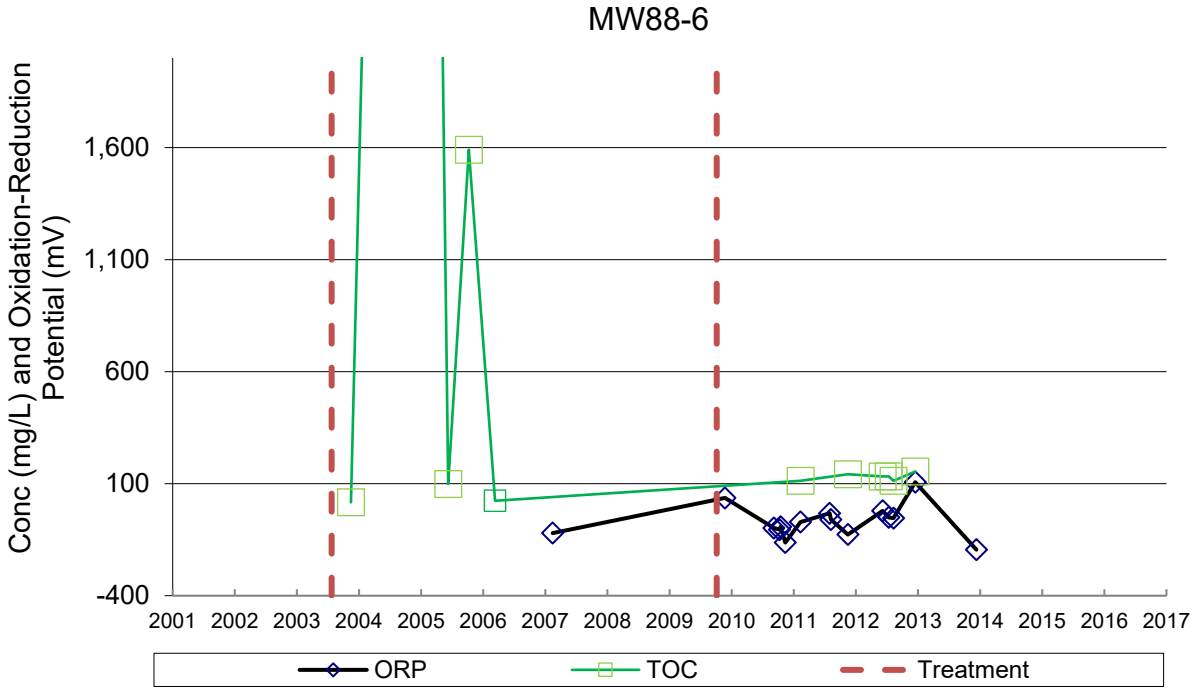


Figure 5-46. ORP and TOC for MW88-6, Former Charleston Air Force Base Zone 4.

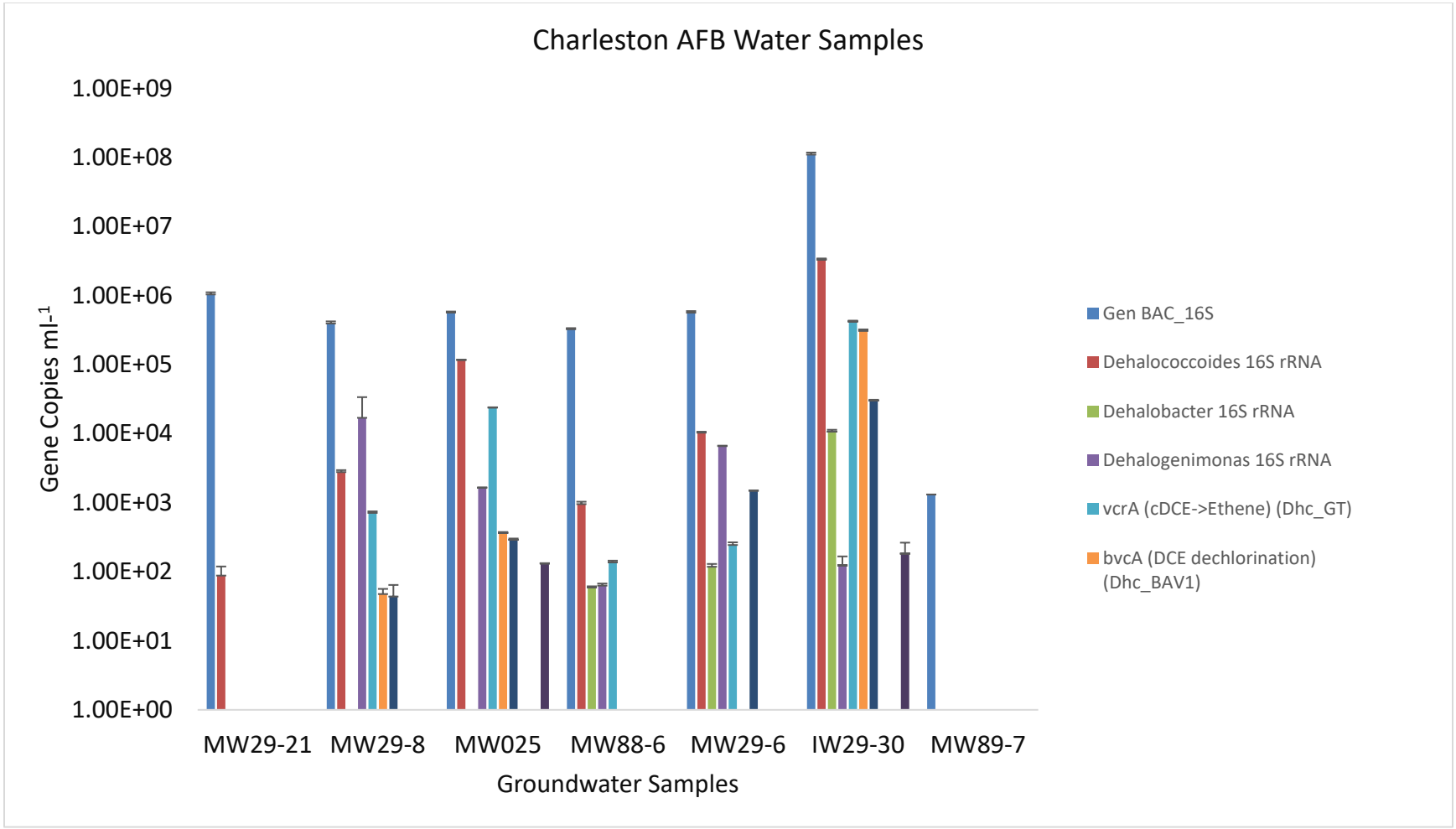


Figure 5-47. Organisms and Genes Associated with Reductive Dechlorination Detected in Wells at Charleston Air Force Base.

5.3.3.3.8. CSIA

Values of $\delta^{13}C$ were obtained for TCE in MW29-30 and MW89-7, for cis-DCE in MW29-21, MW29-30, MW29-6, MW29-8, and MW89-7, and for VC in MW29-21, MW29-30, MW29-6, MW29-8, and MW88-6 (**Table 5-16**). The $\delta^{13}C$ values are presented with VOC concentration data and well location (i.e., Plume 1 or Plume 2), with the most upgradient wells listed first in **Table 5-17**. There are not enough $\delta^{13}C$ data to prepare plots as presented for the Raritan data. However, the data do provide some insight concerning ongoing biodegradation at the Charleston site. For Plume 1, the most upgradient well MW89-7 (a source zone well),had TCE at 34,100 µg/L and a $\delta^{13}C$ value of -25.1‰, which is in the typical range for parent TCE (-34‰ to - 23‰). cis-DCE, which was detected at 6,630 µg/L, had a reported $\delta^{13}C$ value of -25.7‰, very close to TCE. No value was reported by the analytical laboratory for VC, presumably because the concentration was too low to analyze VC based on the concentration of TCE and cis-DCE in the same sample. At first view, the CSIA data suggest that biodegradation of TCE and cis-DCE is not occurring in this zone. This is supported by the general absence of dechlorinating organisms/genes in this sample (**Figure 5-47**). However, the concentration of TCE indicates that this zone may contain residual DNAPL. In this case, $\delta^{13}C$ from TCE may not be a good measure of ongoing transformation because partitioning of parent TCE from the DNAPL is likely to reduce and isotopic enrichment in parent TCE caused by degradative processes. Because $\delta^{13}C$ in cis-DCE did not exceed the typical parent value for TCE, whether or not cis-DCE degradation is ongoing also cannot be determined in this zone (see **Section 5.3.2.3.8**).

Moving downgradient in Plume 1, no $\delta^{13}C$ data were available for TCE or cis-DCE in MW025, due to low concentrations. The laboratory also did not provide data for VC despite a reported concentration of 3,130 µg/L. Inquiries concerning the analytical issue with this sample were not answered. However, it is interesting to note that only VC was detected in this well, which is downgradient of the source area with high remaining TCE and cis-DCE. Thus, ongoing VOC biodegradation is indicated by the data and supported by the previous qPCR data. The final well in this general plume transect, MW88-6, had VC detected at 68.6 µg/L, and with a $\delta^{13}C$ value of +1.20 ‰, indicative of significant ongoing biodegradation. This result is again consistent with the qPCR data, which showed the presence of *Dehalococcoides* and the *vcrA* gene.

In Plume 2, TCE was only detected in the most upgradient well (IW29-30) at 63 µg/L and with a $\delta^{13}C$ value of -21‰. In this same well cis-DCE was detected at 1,150 µg/L with a $\delta^{13}C$ of -22.0‰ and VC was observed at 179 µg/L with a $\delta^{13}C$ value of -25.6‰. The daughter products are indicative of TCE dehalogenation consistent with the high concentrations of dechlorinating organisms and reductive dehalogenase genes in this well. The $\delta^{13}C$ of the three VOCs (parent and two daughter products), however, does not conclusively support ongoing biodegradation in this region. Moving downgradient, however, a general trend is apparent for *cis*-DCE degradation based on $\delta^{13}C$, as isotopic enrichment is apparent along the flow path from -22.0‰ for IW29-30 to -7.8‰ for MW29-8, -13.2‰ for MW29-21, and -3.78 ‰ for MW29-6. The groundwater in this plume passes through two injection zones along this path (Grid #3 for the first 3 wells and Grid #4 for the last well), but cis-DCE degradation is clearly indicated by the isotopic enrichment (i.e., from -22.0‰ to -3.78‰. A large initial increase in the $\delta^{13}C$ value of VC is also observed from MW29-21 at -25.6‰ to MW29-21 at -11.9‰, with a corresponding concentration decrease of about 4-fold. The $\delta^{13}C$ value then decreases further to -9.29‰ for MW29-21. The a $\delta^{13}C$ in the final well in Grid #4 then increases slightly to -13.3‰ with a corresponding increase in concentration.

The data indicate ongoing VC biodegradation along the flow path through Grid#3, but perhaps a lack of further degradation of VC at the final well. Further sampling would be required to get a better long-term picture in this region.

5.3.3.3.9. Mass Flux

The contaminant flux profiles, as measured by the PFM deployments, are shown in **Figure 5-48** for the eight wells sampled at the Former Charleston Air Force Base, Zone 4. Because of well sizes and other variables, PFMs were, in some cases, deployed in wells not sampled for other parameters, but in the same vicinity as those companion wells. Calculated mass fluxes for each VOC in each well are provided in **Table 5-18**. As shown in **Figures 5-29** and **5-30** and previously described, the site is represented by four "Grids" Two PFMs were deployed in Plume 1, Grid #1, located to the Northwest of Building 543, in wells MW89-2 (**Figure 5-48a**) and MW89-7 (**Figure 5-48b**). Only cis-DCE was detected in MW89-2 in the shallow portion of the aquifer. TCE, cis-DCE, VC and ethene were detected in MW89-7, consistent with the analytical from this well, and as noted previously in the CSIA section, it is likely that DNAPL remained in this well. Three PFMs were deployed to the Southwest of Building 542 in Grid #2 and Transect #3 in wells MW88-6 (**Figure 5-48c**), MW025 (**Figure 5-48d**) and Z4-17 (**Figure 5-48e**). Ethene, VC, cis-DCE, and TCE were all detected in MW88-6, but cis-DCE was by far the highest with a maximum flux of 20 mg/m^2/day. These data are inconsistent with the analytical data from this well in which only VC was detected above the PQL. One potential reason for the discrepancy is diffusion of cis-DCE into the aquifer from a low permeability zone during the relatively long incubation period of the PFM. In that well samples generally pull only form the most conductive zones, cis-DCE may not have been detected during aqueous phase groundwater sampling. Cis-DCE and VC were detected in MW025 (Transect #3), but their fluxes were relatively small in comparison to the ethene flux where the average and maximum mass flux detected was 101 mg/m^2/day and 211 mg/m^2/day. The high flux of ethene (as well as the high detected concentration in this well; 5,840 µg/L) suggests high biological activity near/upgradient of this well. VC and ethene were both detected in MWZ4-17 with average mass fluxes of ~1300 mg/m^2/day and ~470 mg/m^2/day, respectively. This well was not otherwise sampled. Two PFMs were deployed in Plume 2, Grid #3, located to the Northwest of Building 532. In MW29-8 (**Figure 5-48f**), no TCE was detected, but *cis*-DCE, VC, and ethene were detected. Ethene was detected in small quantities compared to VC and *cis*-DCE, which were detected (consistent with the analytical data from this well) with maximum mass fluxes of ~28 mg/m^2/day and ~15 mg/m^2/day. Overall, contaminant mass fluxes at this well were much lower than for those in the Plume #1. Only cis-DCE was detected in MW29-21 (**Figure 5-48c**) with a relatively low average mass flux of ~2 mg/m^2/day. A final PFM was deployed in Plume #2, Grid 4 in MW29-6. Ethene, VC, and *cis*-DCE were detected consistent with the analytical data from this location. Ethene flux was relatively small compared to *cis*-DCE and VC, which had average mass fluxes of ~32 mg/m^2/day and 21 mg/m^2/day, respectively.

The flux-averaged Equiv. TCE concentration (TCE+cis-DCE+VC), estimates from the PFM results, and groundwater monitoring wells were compared **(Table 5-19**). Groundwater concentration data suggest no chlorinated ethenes were present in MW 89-2 during the time of sampling, but PFM data suggested that cis-DCE was present, but was below MCL. MW 89-7 groundwater and PFM data showed the TCE, cis-DCE, and VC were present above MCLs and free phase DNAPL is likely present since equivalent TCE concentrations were reported to be ~40 mg/L, The proportion of contaminant present in groundwater is difficult to discern since TCE was

detected at the highest concentrations in groundwater samples, whereas cis-DCE was detected at the highest concentration in PFM samples. Regardless, both measurements indicated that complete reductive dechlorination is occurring since ethene was detected in both measurement types. Downgradient of the source zone, VC and ethene were detected in MW Z4-17 with flux-averaged concentrations of ~23,300 µg/L and ~8,200 µg/L, respectively, suggesting that complete dechlorination is occurring between wells MW 89-7 and Z4-17. Groundwater samples were not taken for this well, the PFM data from Z4-17 suggest that free phase DNAPL remains in the source zone, which is similar to what was indicated by MW 89-2 data. Immediately downgradient of well Z4-17, MW-025 groundwater and PFM data concurred that VC is above its MCLs but that no TCE is present. For cis-DCE, groundwater data indicated that it was below the MCL whereas PFM data indicated the opposite. Ethene was also detected in well MW-025, indicating that complete dechlorination is occurring, but PFM data showed that ethene concentrations were 101,000 µg/L, whereas groundwater data showed a concentration of 5,840 µg/L. There high values by both methods clearly indicate ongoing degradation of chlorinated ethenes.

For Plume 2, groundwater and PFM data for MW 29-8 showed that cis-DCE and VC were present above MCLs, and ethene was detected, suggesting that complete dechlorination is ongoing. VC and cis-DCE were detected above MCLs at MW 29-21and ethane (not ethene) was present in groundwater samples. For this same well, the PFM detected cis-DCE (below the MCL) but no VC or ethane were measurable. Groundwater and PFM data for Well MW 29-6, located at the toe of the plume, both detected ethene, VC and cis-DCE. However, groundwater data showed that cis-DCE was below the MCL, whereas PFM data suggested it was above the MCL.

In some instances, groundwater and PFM data compared very well and in others they did not. Past studies have shown that flux-averaged values are better estimates than groundwater data because flux-average concentration is independent of divergence and is both a temporally and spatially average concentration as opposed to "instantaneous" measurements of groundwater data (Basu et al., 2006; Brooks et al., 2008). It is informative to have both measures to evaluate at a given site.

5.3.3.3.10. Site Summary

Results from Charleston indicate that biogeochemical conditions remained generally favorable for reductive dechlorination of chlorinated ethenes. The presence of daughter products as well as ethane and/or ethene in most wells based on both sampling and PFM data indicates ongoing biodegradation, although significant mass was still likely present in the Plume 1 source area (e.g., near MW 89-7). The microbial community analysis showed the presence of numerous different dehalogenation-associated organisms/genes in water samples from across the site with *Dehalococcoides* concentrations ranging from 9×10^1 cells/mL to 3.3×10^6 cells/mL. The overall CSIA data did not support degradation in the Plume 1 source area well (MW 89-7), but this may reflect the presence of DNAPL, and the continued resupply of unenriched TCE as biodegradation occurs. All other measures indicated ongoing degradation in this area. Moreover, CSIA clearly indicated ongoing biodegradation downgradient of this source. The same scenario was found in Plume 2: ambiguous data in the most upgradient well (MW29-30), with clear isotopic enrichment in daughter products (TCE is largely gone), downgradient of this well, indicative of ongoing biodegradation. Groundwater and PFM data showed that free-phase DNAPL was still present at the site in and or around well MW 89-7. Overall, the results suggest that biological degradation processes have persisted ~ 4 years after cessation of active bioremediation.

Table 5-17. Groundwater Sampling Locations and Rationale, Former Charleston Air Force Base Zone 4.

Well	$\delta^{13}C$ TCE (‰)	TCE (µg/L)	$\delta^{13}C$ DCE (‰)	DCE (µg/L)	$\delta^{13}C$ VC (‰)	VC (µg/L)	Grid/depth
MW89-7	-25.1	34,100	-25.7	6,630	NA	697	Plume 1, Grid 1/ Shallow
MW025	NA	< 5	NA	6.75	NA	3,130	Plume 1, Transect 3/ Deep
MW88-6	NA	< 5	NA	< 5	+ 1.20	68.6	Plume 1, Grid 2/ Deep
IW29-30	-21.0	63	-22.0	1,150	-25.6	179	Plume 2, Grid 3/ Intermediate
MW29-8	NA	< 5	-7.84	103	-11.9	51.5	Plume 2, Grid 3/ Shallow
MW29-21	NA	< 5	-13.2	13.7	-9.3	8.1	Plume 2, Grid 3/ Shallow
MW29-6	NA	< 5	-3.78	38.7	-13.3	117	Plume 2, Grid 4/ Shallow

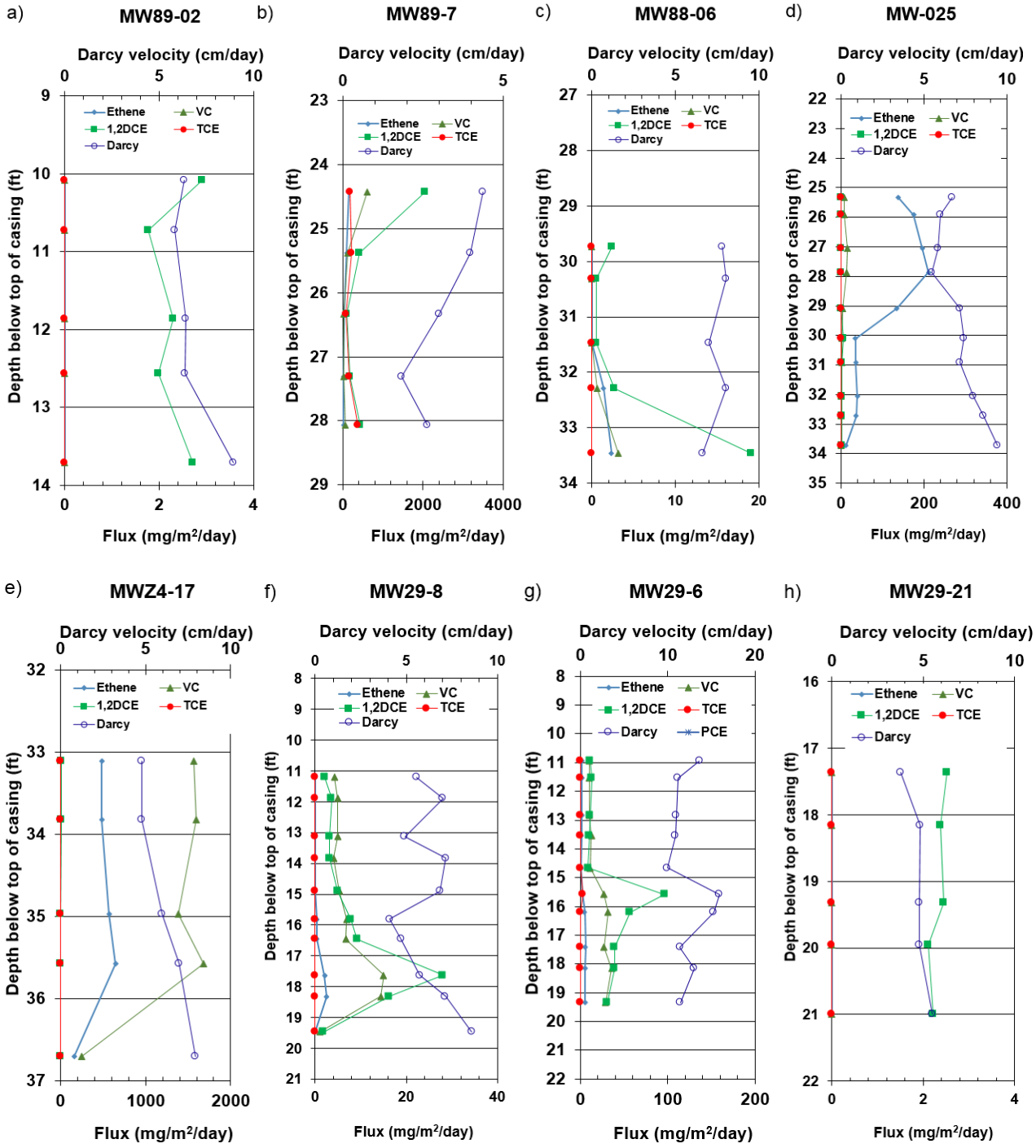


Figure 5-48. Mass Flux Profiles Measured in Select Wells using PFMs.

The solid blue diamonds represent ethene, the solid dark green triangles represent VC, the solid light green squares represent DCE, the solid red circles represent TCE, and the open purple circles represent the Darcy Velocity. Panels a-h show flux values sampled on 11/04/2016. Note the changes in scale on both axes to accommodate the data.

Table 5-18. Average Mass Discharge for Each Well.

Well_ID	Average Darcy Velocity (cm/day)	Average Ethene flux ($mg/m^2/day$)	Average VC flux ($mg/m^2/day$)	Average 1,2DCE flux ($mg/m^2/day$)	Average TCE flux ($mg/m^2/day$)
MW 89-02	6.78	0.00	0.00	2.34	0.00
MW 89-7	3.16	61.20	170.67	639.36	204.96
MW 88-06	7.51	0.74	0.75	5.05	0.00
MW 025	7.18	101.40	5.51	1.31	0.00
Z4-17	6.09	471	1296	5.01	0.00
MW 29-6	12.37	3.09	20.51	31.59	0.26
MW 29-8	6.18	0.53	6.77	8.03	0.00
MW 29-21	4.73	0.00	0.00	2.34	0.00

Table 5-19. VOC Concentration and GW and PFM Concentration Comparisons for Wells in Zone 4, Charleston Air Force Base.

Chemical	Type	MW 89-02	MW 89-7	Z4-17	MW 025	MW 88-06	IW 29-30	MW 29-8	MW 29-21	MW 29-6
Equiv. TCE	GW	na	44,640	na	6,968	145	376	249	205	299
	PFM	47	40,037	49,117	13,364	122	na	435	68	665
	% diff.	na	11	na	63	17	na	54	100	76
TCE	GW	na	34,100	na	<dl	<dl	63	<dl	<dl	<dl
	PFM	<dl	7078	<dl	<dl	<dl	na	<dl	<dl	2
	% diff.	na	131	na	na	na	na	na	na	na
cis-DCE	GW	na	6630	na	6.8	<dl	1150	103	137	39
	PFM	34.8	17498	88.5	1,307	73.2	na	139.5	50.4	237
	% diff.	na	90	na	198	na	na	na	na	n
VC	GW	na	697	na	3310	68.8	179	51.5	8.1	117
	PFM	0.0	4402	23,305	5,515	10.4	na	117	0.0	163
	% diff.	na	145	na	50	148	na	78	200	33
Ethene	GW	na	210	na	5840	82.9	55.2	6.5	<dl	17
	PFM	0.0	1665	8,245	101,396	7.51	na	8.7	0.0	24.7
	% diff.	na	155	na	178	167	na	29	na	37
Ethane	GW	na	131	na	2,180	332	23	23	4.09	4.3
	PFM	na	na	na	na	na	na	na	na	na
	% diff.	na	na	na	na	na	na	na	na	na

*PFMs only deployed in this well. VOCs, CSIA, and geochemical analysis were not performed on wells due to scheduling conflicts.

Note: na = not available

5.3.4 Seal Beach Naval Weapons Station Site 70

5.3.4.1 Site Description, Seal Beach Naval Weapons Station Site 70

Seal Beach Site 70 is also known as the Research, Testing, and Evaluation Area. TCE was used during various research and development activities that occurred at the site between 1962 and 1985. A site location map is provided in **Figure 5-49**.

Groundwater contamination is present in the source area where dense non-aqueous phase liquid (DNAPL) is suspected to occur based on the groundwater concentrations; however, DNAPL has not been observed in the various subsurface investigations. A dissolved-phase plume currently extends at least 4,000 ft downgradient to a depth of approximately 160 ft below ground surface (bgs). TCE was the primary contaminant in the plume before bioremediation (**Figure 5-50**). *cis*-DCE was detected at low concentrations throughout the plume, indicating a low level of natural biological attenuation before treatment.

The uppermost geologic material at the site contains recent alluvial sediments to a depth of approximately 60 ft bgs. This zone is designated the Upper Fines Unit and contains interbedded silts, clays, and silty clays. Heterogeneity is high in this unit, and measured hydraulic conductivities vary by an order of magnitude or more over several ft. The hydraulic conductivity value is low in the Upper Fines Unit. Water level monitoring indicates that water levels decline approximately 2.2 ft over the 45-foot saturated thickness of the Upper Fines Unit, yielding a vertical hydraulic gradient of approximately 0.05 ft per foot. The horizontal hydraulic gradient in most of the source area is generally to the south.

The Upper Fines Unit is underlain by what has been designated the First Sand, which extends from approximately 105 to 135 ft bgs. This unit is predominantly composed of well-sorted, fine-grained sand and silty sand. Gravelly coarse sand is sometimes observed at 80 to 95 ft bgs. The First Sand has a relatively high hydraulic conductivity of 68 ft per day.

Groundwater is generally anaerobic with a neutral pH. Groundwater is brackish with elevated chloride concentrations. High sulfate concentrations (>1,000 mg/L) are present throughout much of the site.

An ESTCP demonstration was implemented in the source area from 2008 to 2010 (ESTCP Project ER-200513). The primary objective of the demonstration was to compare the ability to distribute *Dehalococcoides* via passive versus active approaches. Two test cells were established in the source area, designated the Passive Cell and the Active Cell, as shown in **Figure 5-51**. Sodium lactate and the SDC-9 bioaugmentation culture were introduced into both cells. The amendments were allowed to migrate with the natural groundwater gradient in the Passive Cell. In the Active Cell, the amendments were distributed by recirculation established between two injection wells and two extraction wells. The treatment time for the ESTCP demonstration extended over a 10-month period, and significant dechlorination occurred in both test cells as a result. The results of the demonstration indicated that bacterial distribution was similar in both the Active and Passive Cells in terms of travel time and area influenced.

A full-scale bioremediation program was implemented shortly after the ESTCP demonstration, with a combination of a grid of injection wells in the source area and a series of biobarriers perpendicular to the dissolved-phase plume further downgradient. **Figure 5-51** provides the layout of the site with aerial imagery to show site features, and **Figure 5-52** shows the site plan without the aerial imagery. The Source Area Treatment Grid is an irregular shape approximately 140 ft wide and 220 ft long, containing 57 injections wells. The Source Area Biobarrier is located approximately 200 ft downgradient and contains 14 injection wells aligned roughly perpendicular to groundwater flow.

The biobarriers include permanent injection wells at a spacing of 25 ft. EVO and the KB-1 bioaugmentation culture were the amendments used in the full-scale design. The full-scale system was implemented in areas of the plume with TCE exceeding 250 μg/L. The initial injections in the biobarriers occurred in 2009 and in the source area grid in 2010. The second round of injections occurred in 2013 in the source area and all but one of the biobarriers.

The results of the bioremediation activities have been mixed, with substantial dechlorination occurring in some areas and partial dechlorination in other areas. A significant accumulation of DCE and VC was observed at many monitoring locations.

Figure 5-49. Site Location Map, Seal Beach Naval Weapons Station Site 70.

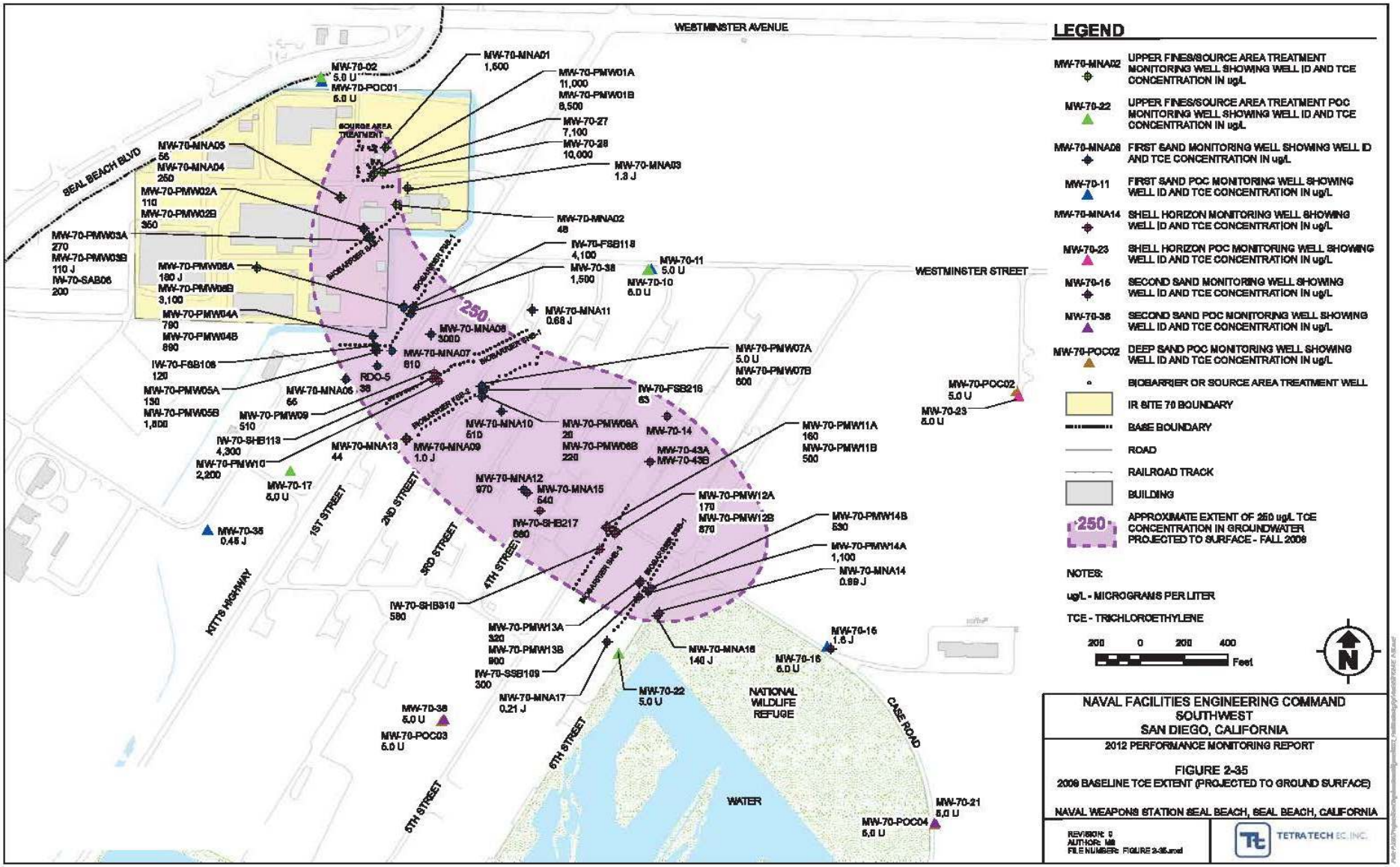


Figure 5-50. Extent of Plume Before Bioremediation, Seal Beach Naval Weapons Station Site 70.

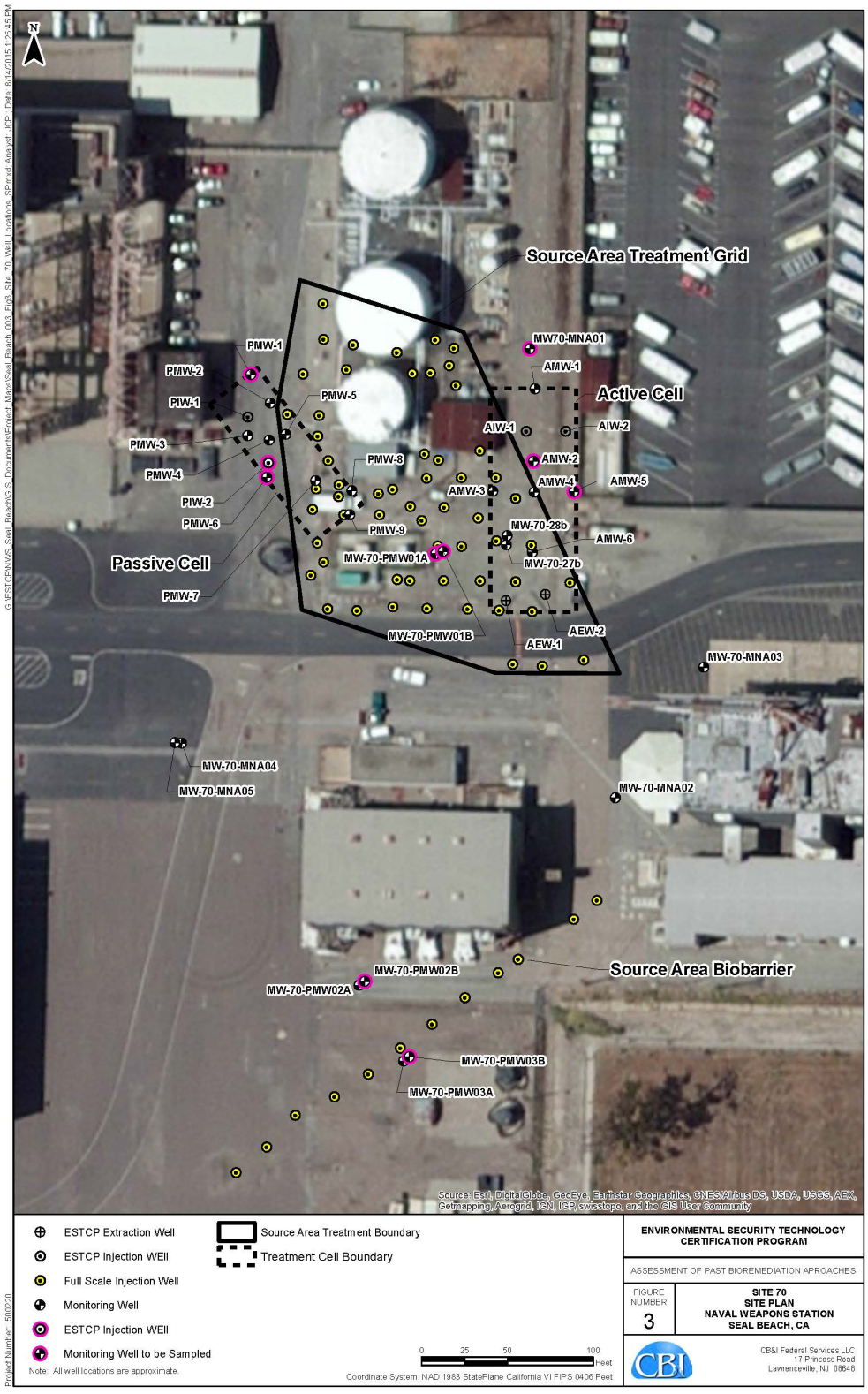


Figure 5-51. Site Plan with Aerial Imagery, Seal Beach Naval Weapons Station Site 70.

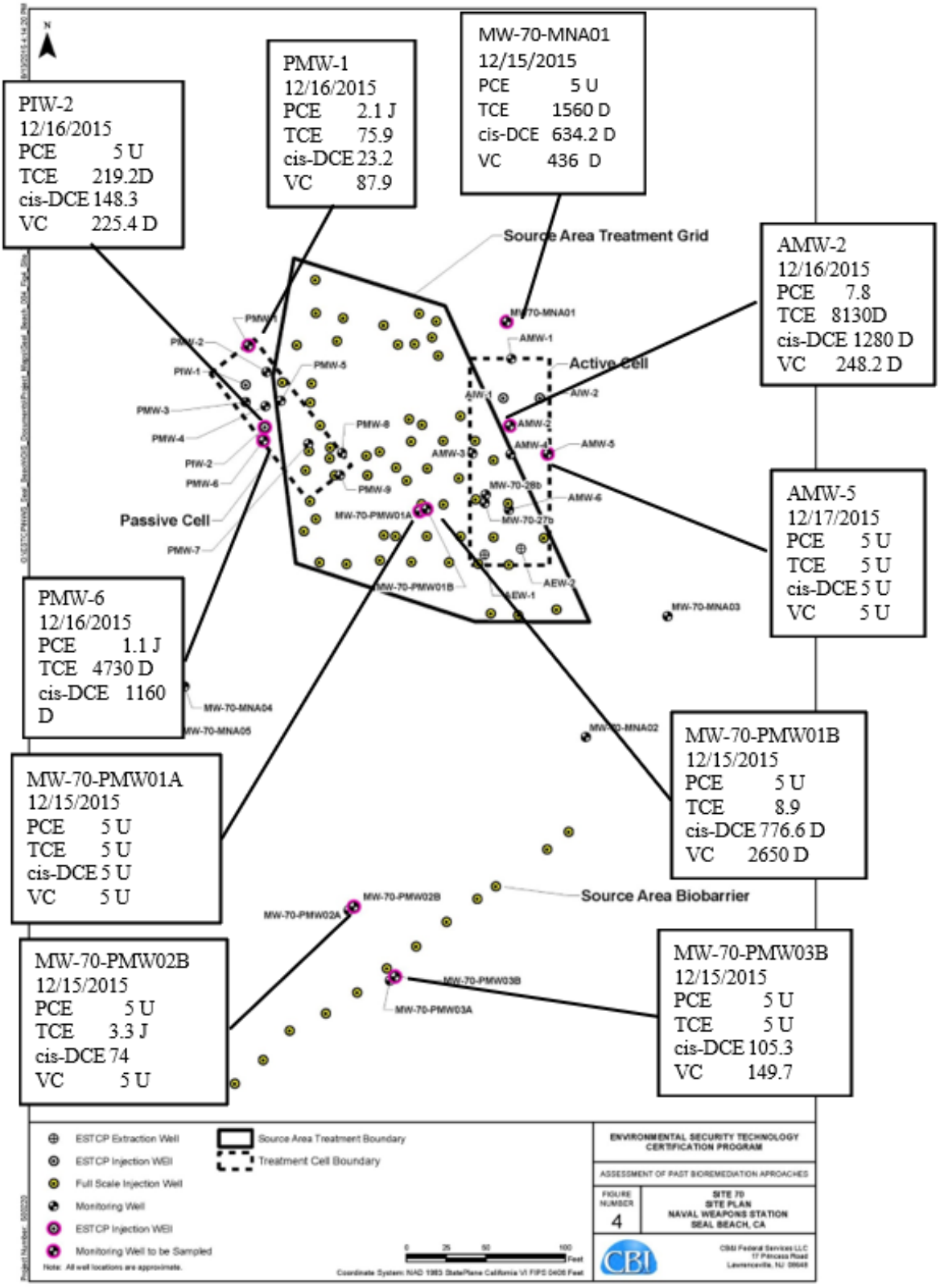


Figure 5-52. Site Plan without Aerial Imagery, Seal Beach Naval Weapons Station Site 70.

5.3.4.2 Sampling Rationale, Seal Beach Naval Weapons Station Site 70

The objective of the groundwater sampling was to assess the long-term impacts of the previously performed bioaugmentation treatment on groundwater quality and biogeochemistry. Monitoring locations upgradient, within, and downgradient of the Source Area Treatment Grid and Source Area Biobarrier were evaluated as described below. Monitoring wells that were sampled are shown in **Figures 5-52**. **Table 5-20** summarizes the monitoring locations and rationale for the sampling program.

Table 5-20. Groundwater Sampling Locations and Rationale, Seal Beach Naval Weapons Station Site 70.

Seal Beach Site 70 Monitoring Well	Sampling Rationale
MW70-MNA01	Within the source area but upgradient from both the ESTCP Active Cell and full-scale treatment zones. This well served as an untreated source area location.
AMW-2	Within the ESTCP Active Cell treatment zone but not within the full-scale treatment zone. This well represented the long-term effects of the ESTCP Active Cell treatment.
AMW-5	Similar to AMW-2 described above, this well is within the ESTCP Active Cell treatment zone, and represented the long-term effects of the ESTCP Active Cell treatment.
PMW-1	On the upgradient edge of the ESTCP Passive Cell treatment zone. This well represented the upgradient conditions associated with the ESTCP Passive Cell treatment.
PIW-2	Within the ESTCP Passive Cell treatment zone but not within the full-scale treatment zone. This well represented the long-term effects of the ESTCP Passive Cell treatment.
PMW-6	This well is also within the ESTCP Passive Cell treatment zone and represented the long-term effects of the ESTCP Passive Cell treatment
MW-70-PMW01A	Within the Source Area Treatment Grid but not within either of the ESTCP treatment zones. This well represented the long-term effects of full-scale treatment. Substantial contaminant reduction has been observed in this well.
MW-70-PMW01B	Located adjacent to MW-70-PMW01A within the Source Area Treatment Grid but screened at a deeper depth horizon. Substantial contaminant reduction has not been observed in this well.
MW-70-PMW02B	Downgradient of the ESTCP and full-scale treatment zones. This well was evaluated for downgradient effects associated with the Source Area treatment.
MW-70-PMW03B	Downgradient of the Source Area Biobarrier. This well was evaluated for downgradient effects associated with the Source Area Biobarrier treatment.

Monitoring well MW70-MNA01 is located within the source area but upgradient of both the ESTCP Active Cell and the full-scale Source Area Treatment Grid. The working assumption was that this well had not received any treatment due to its upgradient location. This well was evaluated as a source area well that did not receive treatment.

Monitoring wells AMW-2 and AMW-5 are located within the ESTCP Active Cell treatment zone but not within the Source Area Treatment Grid. The working assumption for these wells was that they only received treatment from the ESTCP Active Cell. They were evaluated for the long-term effects of the ESTCP Active Cell treatment only. During the ESTCP demonstration, significant degradation of TCE was observed in each of these wells. A significant amount of historical VOC, geochemical and microbial data are available for these wells.

Monitoring well PMW-1 is located on the upgradient edge of the ESTCP Passive Cell treatment zone and will represent upgradient conditions. Monitoring wells PIW-2 and PMW-6 are located within the ESTCP Passive Cell treatment zone but not within the Source Area Treatment Grid. The working assumption for these wells was that they only received treatment from the ESTCP Passive Cell. They were evaluated for the long-term effects of the ESTCP Passive Cell treatment that was completed in 2009.

Monitoring wells MW-70-PMW01A and MW-70-PMW01B are located at two different depths within the full-scale Source Area Treatment Grid. The initial treatment in this area included the injection of EVO and KB-1 in 2010. The second injection of EVO was conducted in 2013. Post-treatment monitoring results indicate a substantial reduction in contaminants in well MW-70PMW01A, but not in well MW-70-PMW01B. These wells were evaluated to determine what factor(s) may influence the difference in the effectiveness of the treatment between the two wells.

Monitoring well MW-70-PMW02B is located approximately 180 ft downgradient of the Source Area Treatment Grid and approximately 45 ft upgradient of the Source Area Biobarrier. This well is screened in the First Sand depth horizon and downgradient of the source area, which is located within the Upper Fines depth zone. This well was evaluated for effects downgradient of the Source Area.

Monitoring well MW-70-PMW03B is located approximately 10 ft downgradient of the Source Area Biobarrier and was used to evaluate the effects of the barrier treatment approach. This well is also screened in the First Sand depth horizon.

The monitoring well locations are shown in **Figures 5-52**. **Table 5-21** provides a summary of well construction details.

Table 5-21. Monitoring Well Construction Details, Seal Beach Naval Weapons Station Site 70.

Monitoring Well	Total Depth (bgs)	Top of Screen (bgs)	Bottom of Screen (bgs)	Diameter (inches)
MW70-MNA01	50	40	50	4
AMW-2	35	15	35	4
AMW-5 Zone 1	34	33	34	1.7
PMW-1	35	15	35	4
PIW-2	35	15	35	4
PMW-6	35	15	35	4
MW70—PMW01A	35	25	35	4
MW70—PMW01B	55	45	55	4
MW70—PMW02B	100	90	100	4
MW70—PMW03B	100	90	100	4

5.3.4.3 Sampling Results, Seal Beach Naval Weapons Station Site 70

5.3.4.3.1. VOCs

Table 5-22 provides a summary of sampling results, and **Figures 5-53** to **5-70** provide historical and current VOC data and corresponding ORP and sulfate data for the different wells sampled. The primary parent contaminant at this site was TCE, although traces of PCE were detected in a few wells. For the upgradient, untreated well, MW70-MNA01, the concentration of TCE at the time of sampling was 1560 µg/L, cis-DCE was 634 µg/L, and VC was detected at 436 µg/L. Historical data at this well showed that TCE declined substantially from the initial sampling in 2011 (2,800 µg/L) while cis-DCE and VC increased over this same timeframe (**Figure 5-53**). Thus, the data are consistent with some natural attenuation of TCE occurring at this site. The two wells that previously were treated via active addition of lactate and SDC-9 (AMW-2 and AMW-5) several years before the current sampling had very different VOC profiles. AMW-2, which had shown substantial treatment during the ESTCP study in 2008, with TCE declining from ~ 10,000 µg/L to 210 µg/L (**Figure 5-54**), showed a substantial rebound in 12/2015 when the current sample collection occurred. TCE was detected at 8,130 µg/L. Interestingly, cis-DCE showed only a modest increase over this same timeframe while VC declined substantially, from 4,200 µg/L in 2008 at the final sampling point of the demonstration to 248 µg/L in 2015. For AMW-5, TCE, cis-DCE, and VC showed an initial steep increase after treatment, likely due to the active recirculating of groundwater combined with ongoing biodegradation, with TCE reaching 6,400 µg/L from a starting concentration of 710 µg/L before treatment (**Figure 5-56**). During the final sampling event for the original ESTCP demonstration in 10/2009, this well had TCE, cis-DCE, and VC at 940 µg/L, 1400 µg/L, and 5400 µg/L, respectively. During sampling for this project in 12/2015, all three VOCs were < 5 µg /L. Interestingly, 1,2-dichloropropane, bromochloromethane, and bromomethane were all detected in this well at > 1,000 µg/L. These constituents were also observed in MW70-PMW01B at far lower concentrations, but not elsewhere.

Wells PMW-1, PIW-2, and PMW-6 were located in the ESTCP passive treatment cell, with PMW-1 being at the upgradient edge of the cell and the other two wells within the treated region. TCE in PMW-1 was ~ 1,100 µg/L at the initiation of the ESTCP demonstration in 2008, increased somewhat during the treatment period, and then remained near 1,500 µg/L for the duration of the study (final sampling event 10/2009) (**Figure 5-58**). VC and cis-DCE were generally < 100 µg/L during this same interval. In 12/2015, TCE in this well was 76 µg/L, while cis-DCE and VC were 23 µg/L and 88 µg/L, respectively. Thus. TCE showed a substantial decline after the end of the ESTCP study. It is not clear whether this represents a decline in the upgradient TCE concentrations or a longer-term impact of the ESTCP treatment. The downgradient well PMW-6 had TCE detected at 11,000 µg/L prior to substrate and culture injection and declined to a low of 470 µg/L during the field trial (**Figure 5-60**). Cis-DCE and VC reached 640 µg/L and 370 µg/L, respectively. During the 12/15 sampling event, the TCE in this well had partially rebounded to 4,730 µg/L, while cis-DCE was 1,160 µg/L, and VC was 584 µg/L, respectively. The final well sampled in this plot, PIW-2, was an injection well in which TCE declined from 20,000 µg/L to < 250 µg/L during the demonstration, with minimal formation of cis-DCE or VC (< 50 µg/L each) (**Figure 5-62**). During the 12/2015 sampling event, TCE remained low compared to historical concentrations, being detected at 219 µg/L, and cis-DCE and VC also remained relatively low at 225 µg/L and 148 µg/L, respectively. Thus, overall, well PMW-6 showed a different long-term outcome (i.e., TCE rebound) than either PMW-1 or PIW-2.

Wells MW-70-PMW01A and MW-70-PMW01B were within the full-scale Source Area Treatment Grid that received EVO and KB-1 in 2010 and a second injection of EVO was conducted in 2013. The wells were adjacent, with the former being screened at a shallower interval. Well MW70-PMW01A responded very well to treatment, with TCE declining from > 11,000 µg/L in 2011 to < 5 µg/L during sampling 12/2015 (**Figure 5-63**). Cis-DCE and VC were also below detection (< 5 µg/L). Similarly, TCE in MW-70-PMW01B declined appreciably after treatment, falling from 8,500 µg/L in 2011 to 8.9 µg/L during the 12/2015 sampling event (**Figure 5-65**). In contrast to MW-70-PMW01A, however, significant concentration of cis-DCE (777 µg/L) and VC (2,560 µg/L) were detected in this well during the 12/2015 sampling. Thus, the wells showed a somewhat different response to treatment with respect to daughter products of reductive dehalogenation.

The final two wells, MW-70-PMW02B and MW-70-PMW03B, are located approximately 45 ft upgradient and 10 ft downgradient of the Source Area Biobarrier, respectively. Both wells are appreciably downgradient of the ESTCP treatment plots. MW-70-PMW02B had TCE detected at 410 µg/L and cis-DCE at 770 µg/L in 2011, presumably the latter resulting from upgradient treatment (**Figure 5-67**). Each of these compounds showed a steady decline. By 2015, TCE was observed at < 5 µg/L, and *cis*-DCE was at 74 µg/L, an order of magnitude lower than in 2011. TCE was not detected in Well MW-70-PMW03B between 2011 and 2015 (**Figure 5-68**). Cis-DCE was present and showed an increase from 380 µg/L to 1700 µg/L between 2011 and 2013. After the second round of EVO injection in 2013, however, *cis*-DCE dropped to 12 µg/L, and then rebounded somewhat, being detected at 105 µg/L in 12/2015. VC was consistently detected < 100 µg/L in this well until the second EVO injection, after which VC increased to 240 µg/L. During the 12/2013 sampling event, the concentration of VC had declined somewhat to 140 µg/L.

5.3.4.3.2. Field Parameters

The ORP of wells across the site covered a wide range from +61 mV in AMW-2 to -351 mV in MW70-PMW01B (**Table 5-18**). The wells in the region receiving the most recent treatment with EVO (i.e., the four MW70 wells) had the lowest OPR values, ranging from -232 mV to -351 mV. DO was < 1 mg/L in 9/10 well sampled, exceeding this value (1.98 mg/L) only in PMW-6. The groundwater pH was between 6.31 and 7.61 SU, which is in a range suitable for reductive dehalogenation.

5.3.4.3.3. Anions

One of the characteristics of this site is naturally high sulfate, which can be inhibitory to reductive dehalogenation, likely due to the toxic action of hydrogen sulfide, which is the final product of sulfate reduction (Mao et al., 2017). Competition for H_2 as an electron donor between dehalogenating organisms and sulfate reducers also may contribute to issues observed at some sites (e.g., Aulenta et al., 2007). The sulfate concentrations during the 12/2015 sampling event ranged from 301 mg/L in MW70-PMW02B to 12,200 mg/L in AMW-2. The wells receiving the most recent treatment with EVO (i.e., the four MW70 wells) had the lowest sulfate values, indicative of substantial sulfate reduction. These wells also had the lowest ORP values, as previously noted. mV to -351 mV. Nitrate, nitrite, and phosphate were all below detection (< 0.2 mg/L) across the site.

5.3.4.3.4. Dissolved Iron and Manganese

As with other parameters, dissolved iron exhibited a range of concentrations across the site, from a low of <70 µg/L in AMW-2 to a high of 35,800 µg/L in MW70-PMW01B. Dissolved manganese was detected in every well ranging from 129 µg/L to 2,400 µg/L. These data are indicative of iron and manganese reduction occurring in much of the groundwater across the site, which is consistent with the general ORP and DO values.

5.3.4.3.5. Dissolved Gases

Methane was detected in groundwater across the site ranging from ~ 48 µg/L to 10,900 µg/L. The AMW and PMW wells from the early ESTCP study all had > 1,900 µg/L, with two of the wells exceeding 7,000 µg/L. Ethane was present in 5/10 wells sampled but at a maximum concentration of only 12 µg/L. Ethene was more prevalent, being detected in 9/10 wells and ranging as high as 134 µg/L. These gases (ethene and ethene) are often typically detected as final degradation products of chlorinated ethenes and are indicative of ongoing reductive dehalogenation. Hydrogen gas, the ultimate electron donor for reductive dehalogenation was below the MDL (0.0084 µg/L) in all wells.

5.3.4.3.6. Total Organic Carbon and Volatile Fatty Acids

Total organic carbon (TOC) in the different wells ranged from 6.24 mg/L in MW70-PMW02B to 37 mg/L in AMW-2. Except for two wells (MW70-PMW02B and MW70-PMW03B), all wells had at least 15 mg/L. Lactic acid was observed in all of the wells except MW70-MNA01, the well upgradient of the ESTCP active plot. The highest concentrations were present in the two wells from the historical active ESTCP Plot, AMW-2, and AMW-5 (3.76 and 11.1 mg/L, respectively, and in two wells from the historical passive ESTCP Plot, PIW-2, and PMW-1 (9.57 and 35.2 mg/L, respectively). This is interesting in that these plots had not received the carbon source for several years before this sampling event. The presence of ethene in each of these wells is also indicative of ongoing dehalogenation activity.

5.3.4.3.7. Microbial Community

The microbial community analysis indicated the presence of dehalogenation-associated organisms/genes in several water samples from the Seal Beach Site. Interestingly, no such organisms/genes were detected in upgradient well MW70-MNA01, which presumably represents non-augmented conditions at the site (**Figure 5-69**). Far downgradient wells MW-70-PMW02B and MW-70-PMW03B also showed largely non-detectable levels of dehalogenating organisms/genes. In contrast, each of the wells that were sampled from the former ESTCP passive treatment plot (PIW-1, PIW-2, and PMW-6) contained *Dehalococcoides* at ~ 9 x 10^2 to 4 x 10^3 cells/mL. These wells also had detectable *vcrA* (enzyme degrades *cis*-DCE to ethene), *tceA* (enzyme degrades TCE to VC), and *btuF* (enzyme involved in the B12 synthesis pathway in *Dehalococcoides*). The genes *bvc*A (second enzyme that degrades cis-DCE to ethene) and *cob*S (associated with the vitamin B12 pathway), also were each detected in at least one of these wells. Thus, key organisms/genes involved in reductive dehalogenation were readily detectable in this previously bioaugmented passive treatment plot, but not in upgradient or far downgradient wells. The microbial data were similar to the passive plot for the wells representing full-scale treatment (MW-70-PMW01A and MW-70-PMW01B), which received EVO and KB-1 in 2010 and a second injection of EVO in 2013. As observed for the three passive treatment plot wells, each of these wells had detectable levels (generally between 10^2 and 10^3/mL) of *Dehalococcoides*, *vcr*A, *bvc*A, *tce*A, *cob*S and *btu*F, indicating the persistence of dehalogenating organisms in this region.

Interestingly, compared to the passive treatment plot, and the wells receiving full-scale treatment with EVO, *Dehalococcoides* and most reductive dehalogenation associated genes were absent in the well sampled from the historical active ESTCP plot (AMW-2), indicating that bioaugmented organisms did not persist as long under these conditions. Well AMW-5 was not sampled for molecular analysis.

5.3.4.3.8. CSIA.

Values of $\delta^{13}C$ were obtained for TCE, cis-DCE, and VC in most of the monitoring wells where concentrations were sufficient for analysis (**Table 5-23**). It should be noted that $\delta^{13}C$ values for TCE, as well as cis-DCE and VC, were obtained for a few samples in which the concentrations were below detection at a PQL of 5 µg/L. It is assumed in these cases that, while present below the PQL, there was enough VOC present for isotopic analysis. However, in a complex matrix, the possibility exists that compounds were not adequately separated before isotopic analysis (i.e., a second compound co-eluted with the compound of interest and was analyzed). We assume this is not the case.

As noted previously, unfractionated $\delta^{13}C$ values for manufactured TCE typically range from ~ -34‰ to - 23‰, with a mean of -29‰ (USEPA, 2008). The $\delta^{13}C$ values for TCE at the Seal Beach site ranged from -25.0‰ to -0.04‰. The wells with the least fractionated TCE (i.e., closest to parent values) were AMW-2 (-23.9 ‰), AMW-5 (-22.6 ‰), MW70-MNA01 (-25.0 ‰), and PMW-6 (-22.2 ‰). Among these wells, AMW-2 and MW70-MNA01, were also noted to have very low concentrations of dehalogenating genes and organisms (AMW-5 was not tested). Consistent with these data, AMW-2, MW70-MNA01, and PMW-6 had the highest residual TCE among the wells tested. Two of the wells in the former ESTCP passive treatment plot, PIW-2, and PMW-1 had $\delta^{13}C$ values of -13.8‰ and -17.4‰, respectively, indicative of ongoing biodegradation in this zone. Similarly, wells in the full-scale treatment area, MW-70-PMW01A, and MW-70-PMW01B, had $\delta^{13}C$ values of -17.5‰ and -0.04‰, respectively, also indicative of ongoing TCE biodegradation, particularly in the latter well. Among the remaining wells, which are downgradient, TCE was below detection in MW70-PMW03B, and no $\delta^{13}C$ value was obtained, and MW70-PMW02B showed evidence of continuing dehalogenation of TCE with a $\delta^{13}C$ value of -18.6 ‰.

$\delta^{13}C$ values for cis-DCE at the Seal Beach site ranged from -26.0 ‰ to + 4.2 ‰, again indicating significant degradation of *cis*-DCE in some areas of the site. In most cases, wells in which TCE biodegradation was indicated by CSIA also showed evidence of ongoing cis-DCE biodegradation (i.e., $\delta^{13}C$ values heavier than typical parent TCE) and vice versa. A similar trend was apparent for VC, with the exception perhaps of well MW70-PMW01B, which had $\delta^{13}C$ values of -0.04‰ for TCE, + 4.2 ‰ for cis-DCE and – 25.9 ‰ for VC. The $\delta^{13}C$ data, as well as the high VC concentration in this well (2,650 µg/L), may indicate a VC stall.

5.3.4.3.9. PFMs.

Due to a scheduling conflict, PFMs were not deployed at the Seal Beach Site.

5.3.4.3.10. Site Summary

Results from the Seal Beach site varied by treatment approach and, in some instances, by well in a given treatment area. VOC concentrations in upgradient well MW70-MNA01 declined since the conclusion of the ESTCP test project and daughter products were present, but CSIA data provided no indication of ongoing degradation, and relevant dehalogenating cultures and genes were absent.

In the former ESTCP active treatment plot, one well had high concentrations of TCE and daughter products, and the second well had non-detect concentrations. CSIA data showed no clear indication of ongoing degradation of TCE or daughter products. In the former ESTCP passive treatment area, 2/3 wells appeared to have ongoing degradation based on CSIA data. Microbial community analysis indicated the presence of dehalogenation-associated organisms/genes in several but not all locations at the Seal Beach Site. Wells sampled in the passive treatment plots contained *Dehalococcoides* at ~ 9 x 10^2 to 4 x 10^3 cells/mL, whereas *Dehalococcoides* was not detected in the active treatment cell. Groundwater data in both the active and passive cell suggest that TCE rebound had occurred in some areas, but below the historically high concentration. In the full-scale treatment area, all indications suggest ongoing VOC biodegradation. Taken in sum, the data suggest that biodegradation has persisted in the former ESTCP passive treatment plot ~3 years after injection of cultures and electron donor, whereas dechlorination has largely ceased in the former ESTCP cell that underwent active treatment. The full-scale area that received EVO and bioaugmentation culture also appears to have ongoing VOC biodegradation based on all relevant measures.

Table 5-22. Sampling Results Summary AMW-2, Seal Beach Naval Weapons Station Site 70.

Class	LOCATION_CODE		AMW-2		AMW-5		MW70-MNA01		MW70-PMW01A		MW70-PMW01B		MW70-PMW02B		MW70-PMW03B		PIW-2		PMW-1		PMW-6	
	SAMPLE_DATE		12/16/15		12/17/15		12/15/15		12/15/15		12/15/15		12/15/15		12/15/15		12/16/15		12/16/15		12/16/15	
	Parameter	Units	Result		Result		Result		Result		Result		Result		Result		Result		Result		Result	
Anions	Chloride	mg/L	**1,910**	D	**2840**	D	**1590**	D	**2030**	D	**1410**	D	**185**	D	**263**	D	**1210**	D	**580**	D	**2380**	D
	Sulfate as SO4	mg/L	**12,200**	D	**6680**	D	**2730**	D	**1490**	D	**504**	D	**301**	D	**419**	D	**4040**	D	**2,370**	D	**3120**	D
CSIA	del13C cDCE	ppt	**-24.87**		**-19.16**		**-23.2**		**0.01**		**4.16**		**-26**		**2.21**		**-14.95**		**-10.51**		**-21.54**	
	del13C PCE	ppt	NA		NA		NA		NA		NA		NA		NA		NA		**-17.64**	J	NA	
	del13C TCE	ppt	**-23.89**		**-22.61**		**-25.02**		**-17.47**		**-0.04**		**-18.61**		NA		**-13.78**		**-17.35**		**-22.22**	
	del13C VC	ppt	**-22.99**		**-22.97**		**-23.72**		**-0.87**		**-25.86**		NA		**-15.88**		**-21.49**		**-20.26**		**-30.76**	
Field	DO	mg/L	**0.96**		**0.31**		**0.29**		**0.68**		**0.18**		**0.18**		**0.98**		**0.22**		**0.39**		**1.98**	
	ORP	mV	**61**		**-53**		**-141**		**-351.2**		**-232.2**		**-261.4**		**-252**		**-84**		**14.7**		**-47.1**	
	pH	su	**7**		**6.85**		**6.67**		**6.7**		**6.31**		**7.48**		**7.29**		**7.26**		**7.61**		**6.96**	
Gases	Ethane	µg/L	**4**	U	**3.02**	J	4	U	**7.79**		**12.0**		4	U	4	U	4	U	**4.58**		**1.89**	J
	Ethene	µg/L	**6.51**		**67**		**16.7**		**134**		**41.8**		5	U	**21.1**		**23.2**		**19.3**		**34.1**	
	Methane	µg/L	**3,340**	D	**7110**	D	**1270**		**5990**	D	**10900**	D	**47.9**		**6750**	D	**1970**		**7,460**	D	**4550**	D
Metals	Dissolved Iron	µg/L	**70**	U	**254**		**457**		**210**		**35800**		**256**		**3380**		**1710**		**116**		**9070**	
	Dissolved Manganese	µg/L	**491**		**1260**		**1300**		**129**		**2400**		**175**		**556**		**860**		**197**		**1830**	
TOC	Total Organic Carbon	mg/L	**37**		**21.1**		**16.1**		**39.4**		**16.5**		**6.24**		**7.26**		**28.7**		**28.6**		**23.1**	
VFA	Lactic Acid	mg/L	**3.76**		**11.1**		1	U	11.1		**0.43**	J	**1.1**		**0.77**	J	**9.57**		**35.2**		**0.57**	J
VOC	1,1,1-trichloroethane	µg/L	5	U	**4**	J	5	U	5	U	5	U	5	U	5	U	5	U	5	U	5	U
	1,1-dichloroethane	µg/L	**1.1**	J	**18.8**		5	U	15		5	U	5	U	5	U	5	U	5	U	5	U
	1,1-dichloroethylene	µg/L	**4.4**	J	5	U	**3.9**	J	5	U	**6.0**		5	U	5	U	**3.7**	J	**1.8**	J	**35.7**	
	1,2-dichloropropane	µg/L	5	U	**1010**	D	5	U	**24.4**		5	U	5	U	5	U	5	U	5	U	5	U
	1,3-dichloropropane	µg/L	5	U	**2.1**	J	5	U	5	U	5	U	5	U	5	U	5	U	5	U	5	U
	2,2-dichloropropane	µg/L	5	U	**5.4**		5	U	5	U	5	U	5	U	5	U	5	U	5	U	5	U
	2-Butanone (MEK)	µg/L	10	U	5	U	10	U	**16**		10	U	10	U	10	U	10	U	10	U	10	U
	bromochloromethane	µg/L	5	U	**1170**	D	5	U	**100**		5	U	5	U	5	U	5	U	5	U	5	U
	bromomethane	µg/L	5	U	**3280**	D	5	U	**203**		5	U	5	U	5	U	5	U	5	U	5	U
	carbon disulfide	µg/L	5	U	**10**	U	5	U	10	U	**18.5**		5	U	5	U	5	U	5	U	5	U
	chloroform	µg/L	**178**		5	U	5	U	5	U	**1.9**	J	5	U	5	U	5	U	**1.6**	J	**7.6**	
	Cis 1,2- Dichloroethylene	µg/L	**1280**	D	5	U	**634**	D	5	U	**777**	D	**74.0**		**105**		**148**		**23.2**		**1160**	D
	methylene chloride	µg/L	5	U	**5.9**		5	U	5	U	5	U	5	U	5	U	5	U	5	U	5	U
	tetrachloroethylene	µg/L	**7.8**		5	U	5	U	5	U	5	U	5	U	5	U	5	U	**2.1**	J	**1.1**	J
	trans-1,2-dichloroethylene	µg/L	**21.2**		5	U	**73.3**		5	U	**26.1**		5	U	**1.8**	J	**4.3**	J	**2.8**	J	**18.8**	
	trichloroethylene	µg/L	**8130**	D	5	U	**1560**	D	5	U	**8.9**		**3.3**	J	5	U	**219**	D	**75.9**		**4730**	D
	vinyl chloride	µg/L	**248**	D	5	U	**436**	D	5	U	**2650**	D	5	U	**150**		**225**	D	**87.9**		**584**	D

Notes:
NA - Not Analyzed
U - Compound not detected above method practical quantitation limit.
D - Sample was diluted prior to analysis
J - Estimated value above MDL and less than PQL

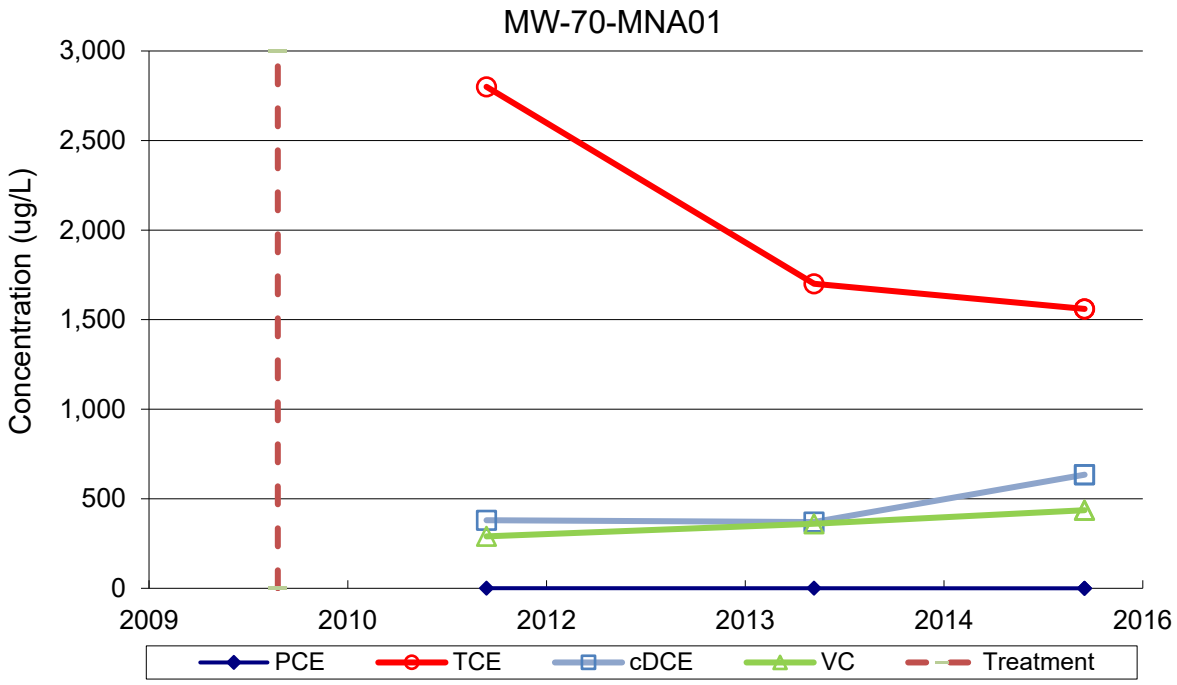


Figure 5-53. VOC Trends for MW70-MNA01, Seal Beach Naval Weapons Station Site 70.

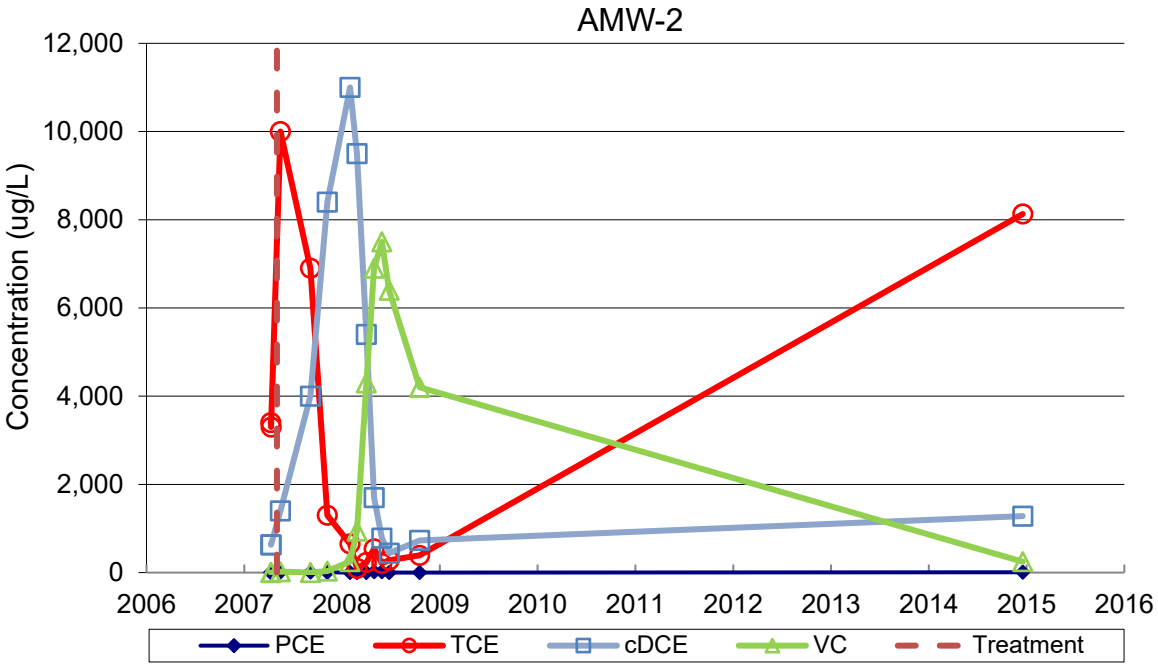


Figure 5-54. VOC Trends for AMW-2, Seal Beach Naval Weapons Station Site 70.

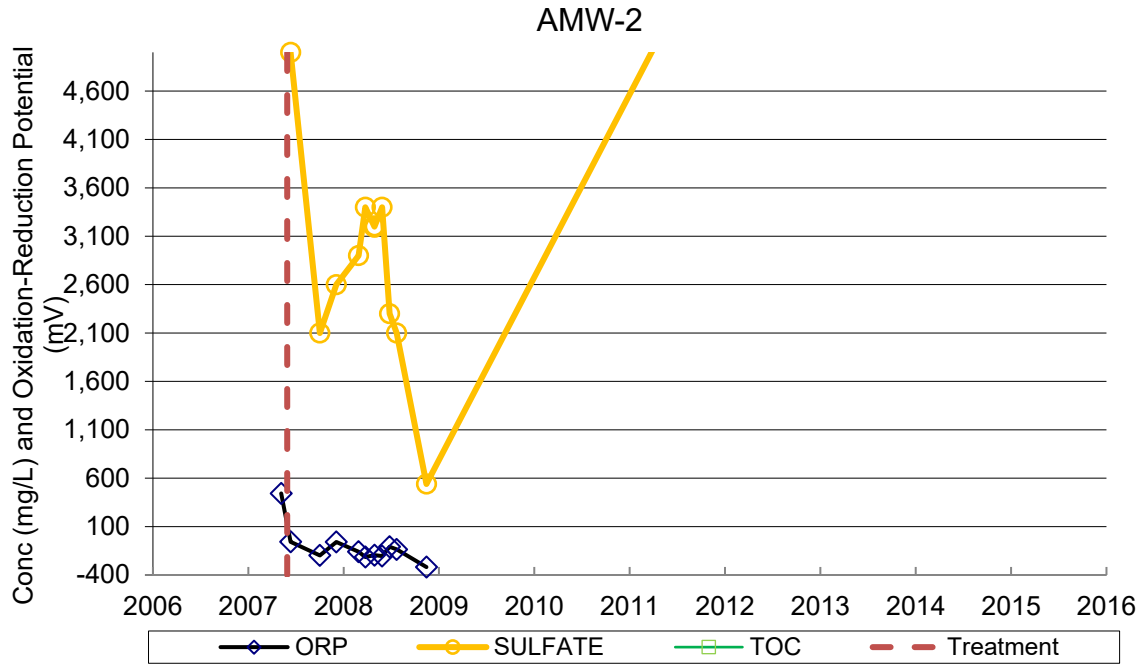


Figure 5-55. ORP and Sulfate Trends for AMW-2, Seal Beach Naval Weapons Station Site 70.

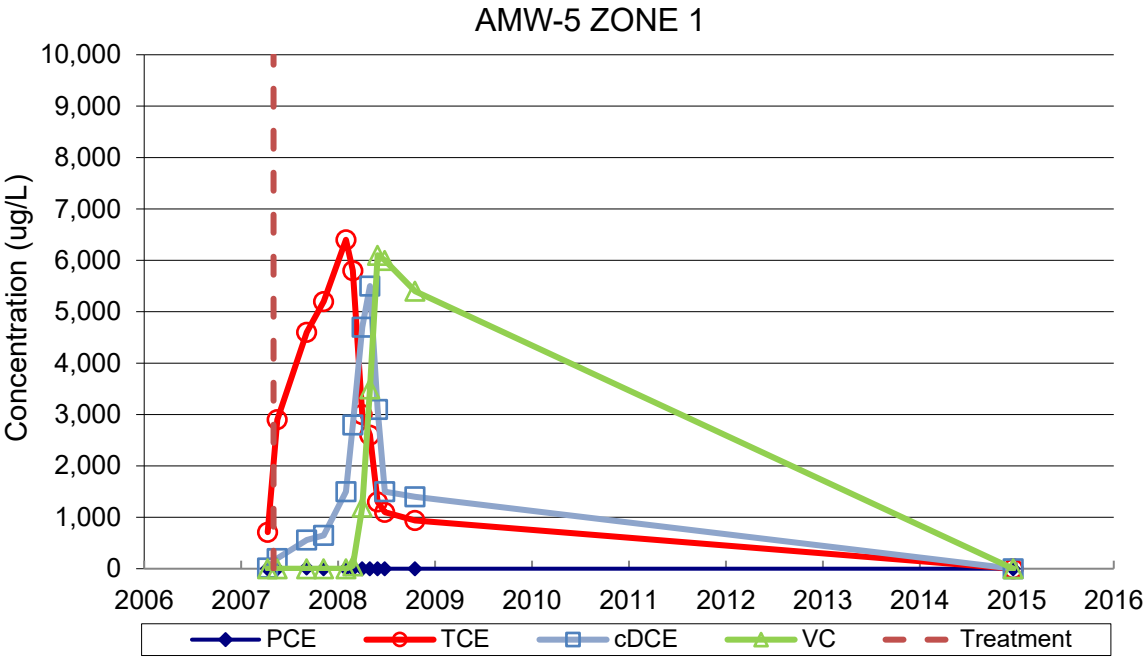


Figure 5-56. VOC Trends for AMW-5, Seal Beach Naval Weapons Station Site 70.

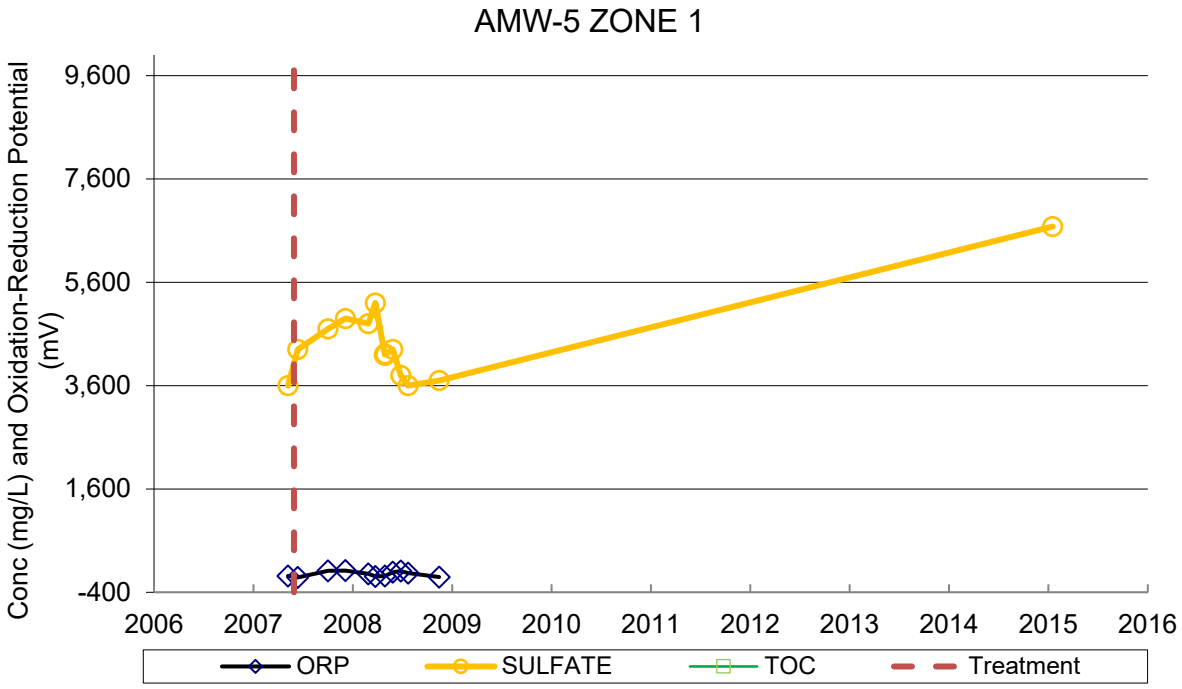


Figure 5-57. ORP and Sulfate Trends for AMW-5, Seal Beach Naval Weapons Station Site 70.

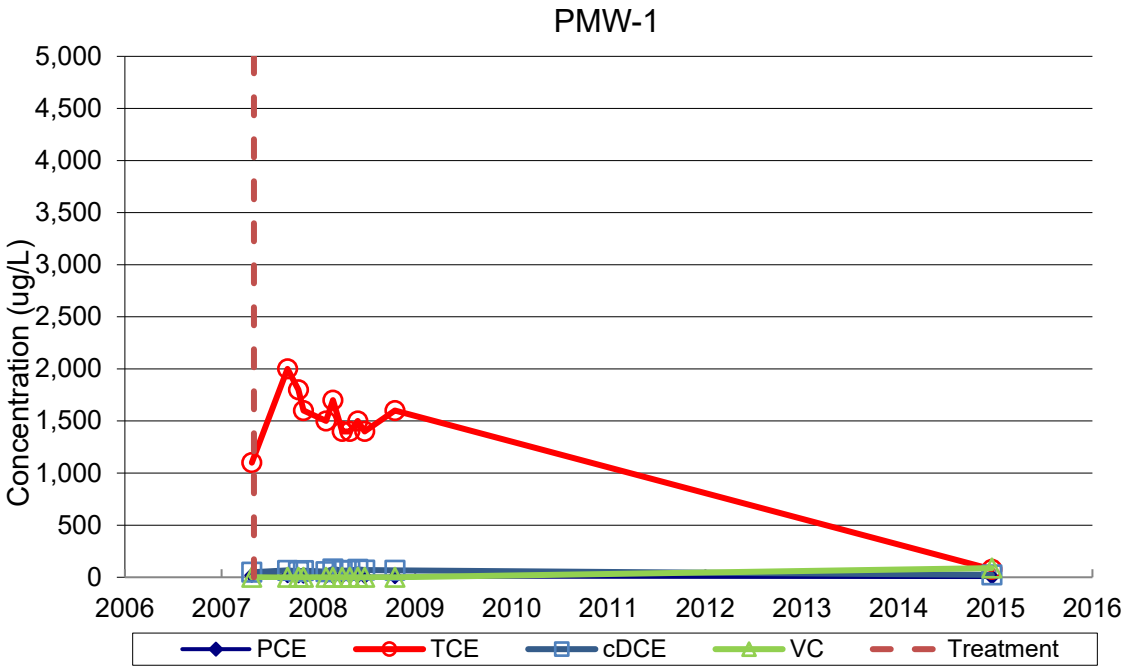


Figure 5-58. VOC Trends for PMW-1, Seal Beach Naval Weapons Station Site 70.

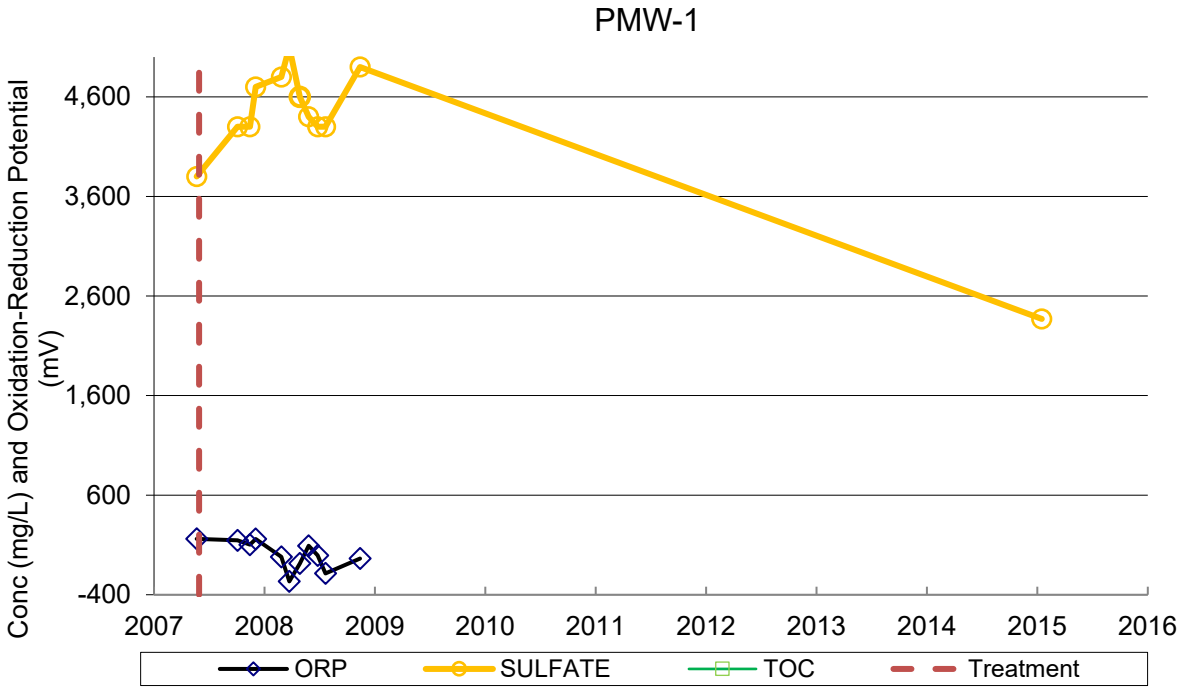


Figure 5-59. ORP and Sulfate Trends for PMW-1, Seal Beach Naval Weapons Station Site 70.

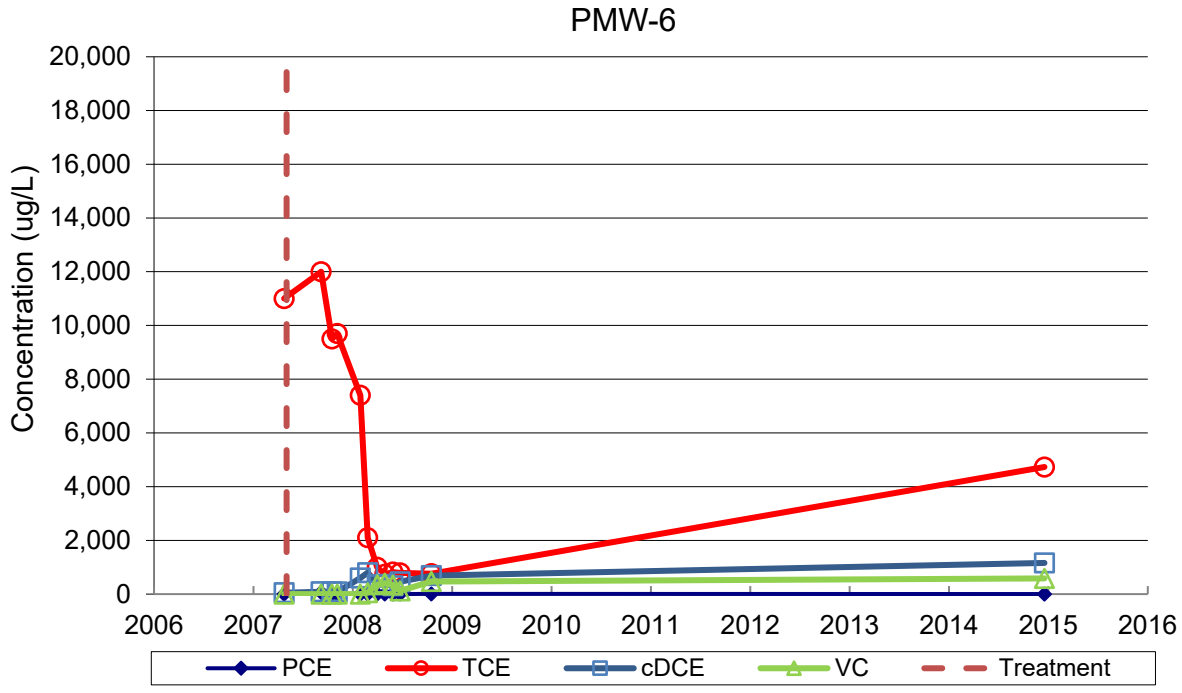


Figure 5-60. VOC Trends for PMW-6, Seal Beach Naval Weapons Station Site 70.

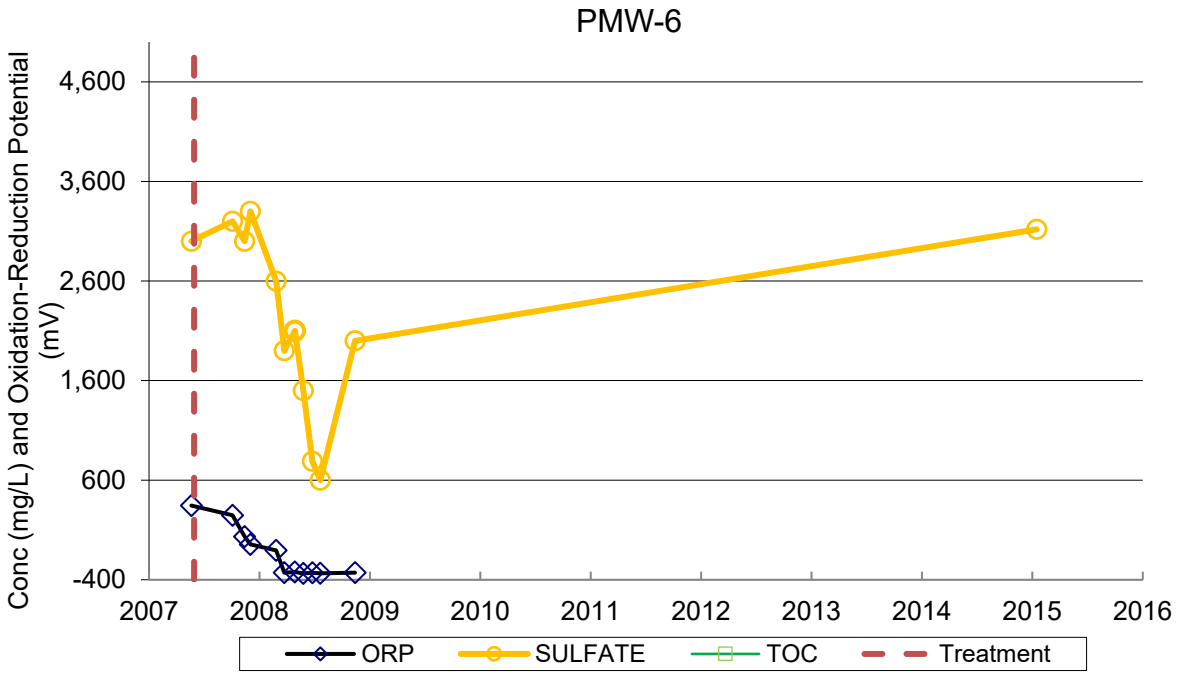


Figure 5-61. ORP and Sulfate Trends for PMW-6, Seal Beach Naval Weapons Station Site 70.

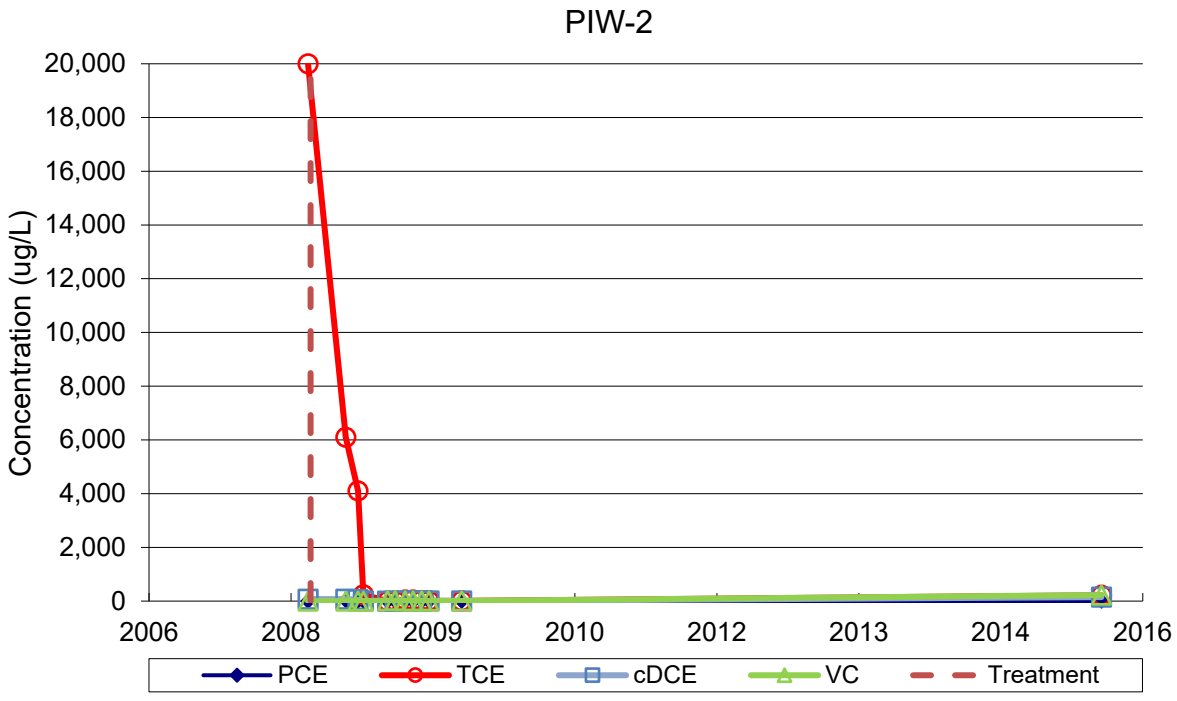


Figure 5-62. VOC Trends for PIW-2, Seal Beach Naval Weapons Station Site 70.

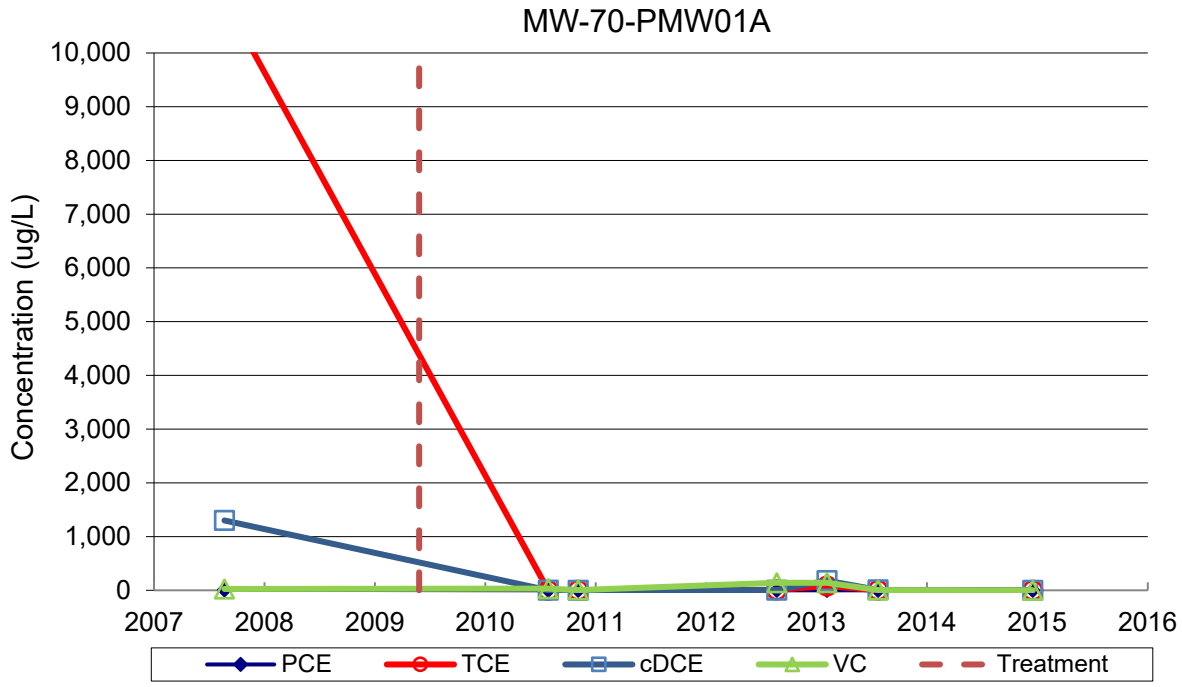


Figure 5-63. VOC Trends for MW70-PMW01A, Seal Beach Naval Weapons Station Site 70.

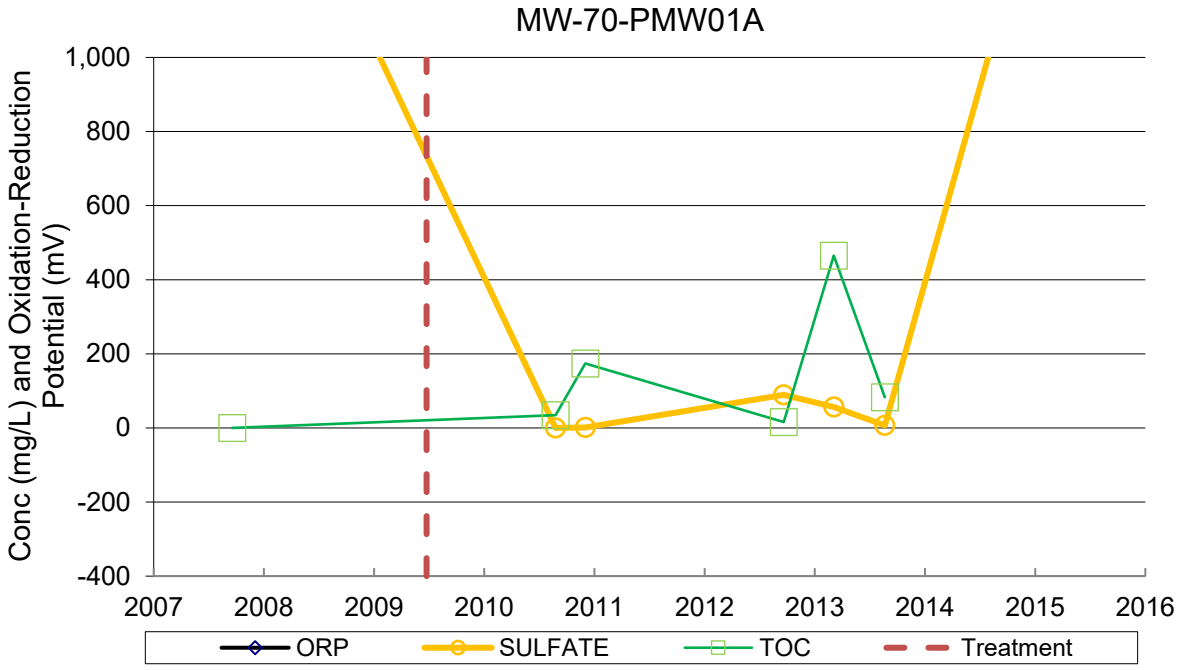


Figure 5-64. TOC and Sulfate Trends for MW70-PMW01A, Seal Beach Naval Weapons Station Site 70.

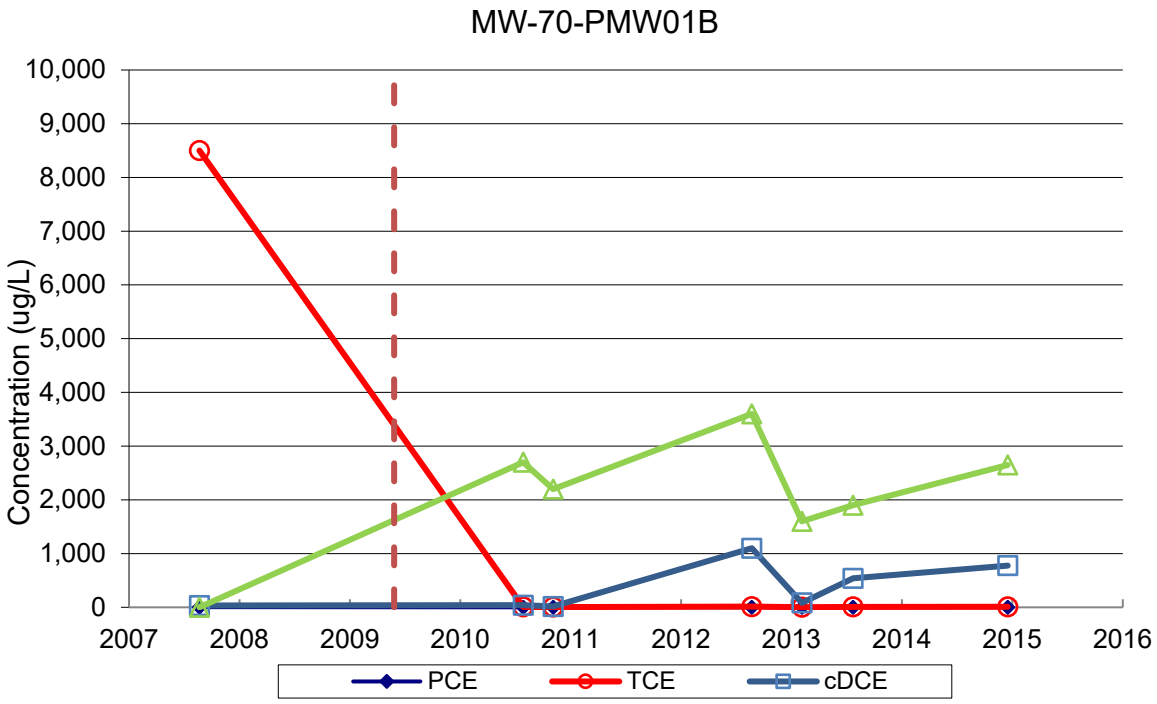


Figure 5-65. VOC Trends for MW70-PMW01B, Seal Beach Naval Weapons Station Site 70.

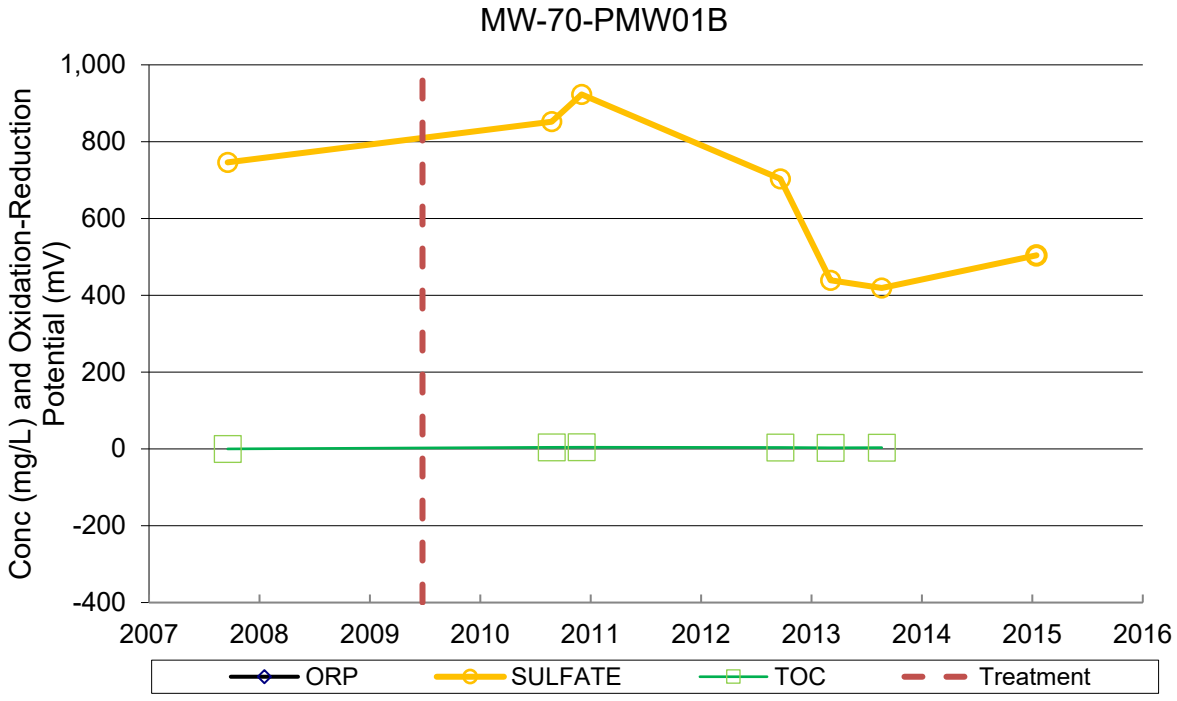


Figure 5-66. TOC and Sulfate Trends for MW70-PMW01B, Seal Beach Naval Weapons.

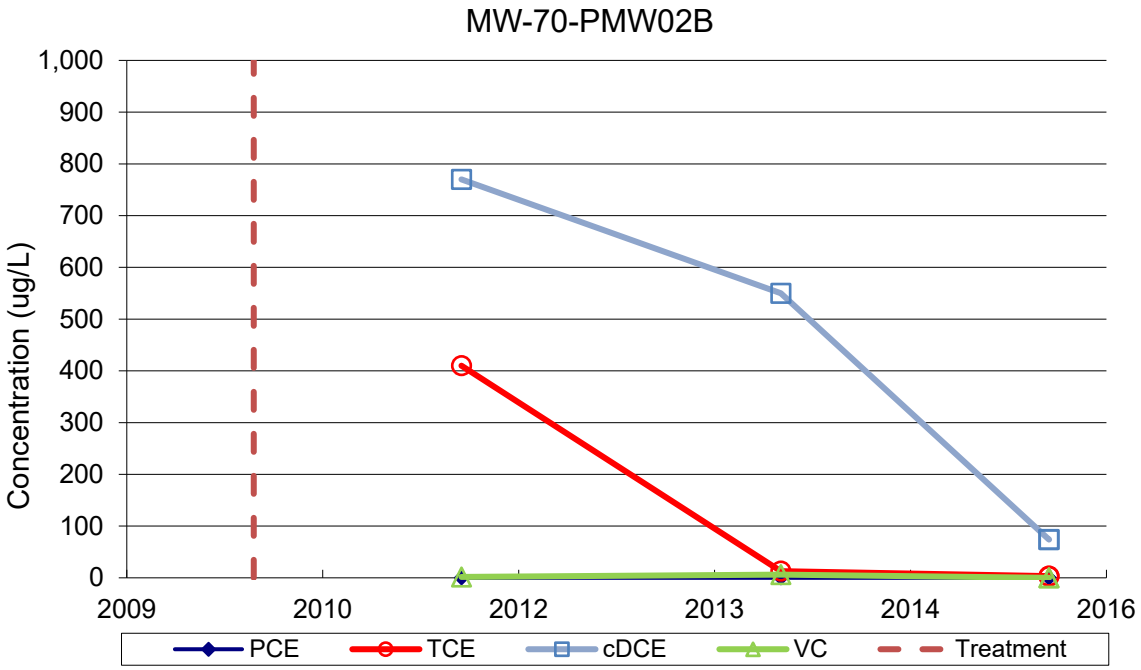


Figure 5-67. VOC Trends for MW70-PMW02B, Seal Beach Naval Weapons Station Site 70.

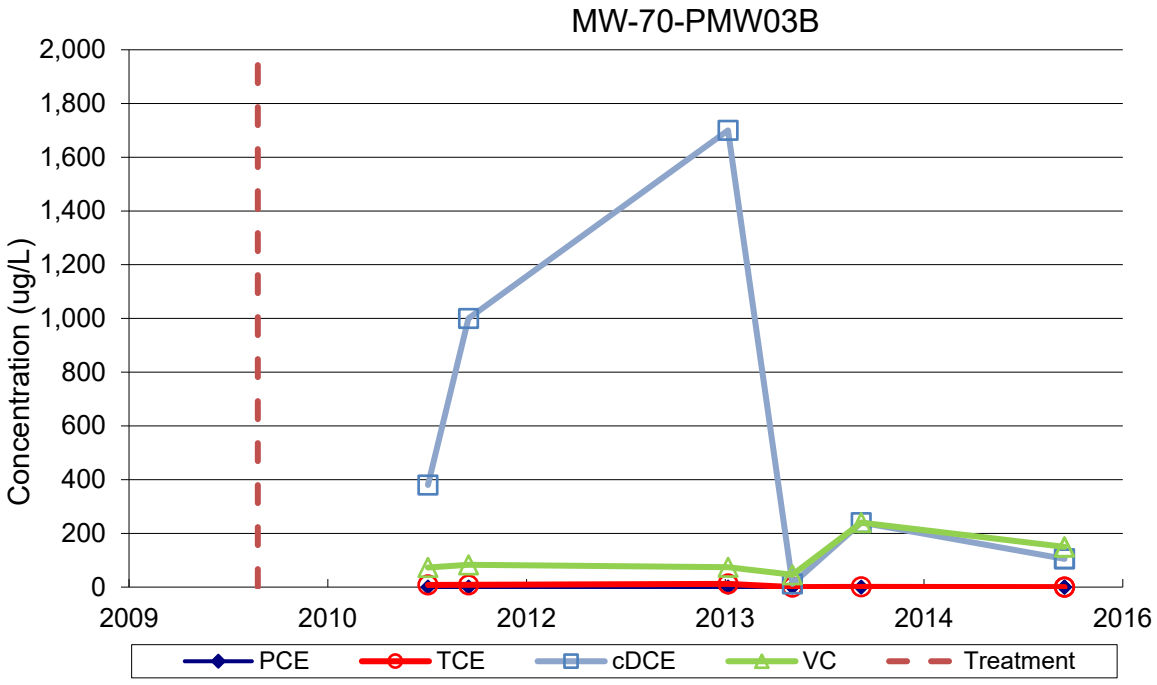


Figure 5-68. VOC Trends for MW70-PMW03B, Seal Beach Naval Weapons Station Site 70.

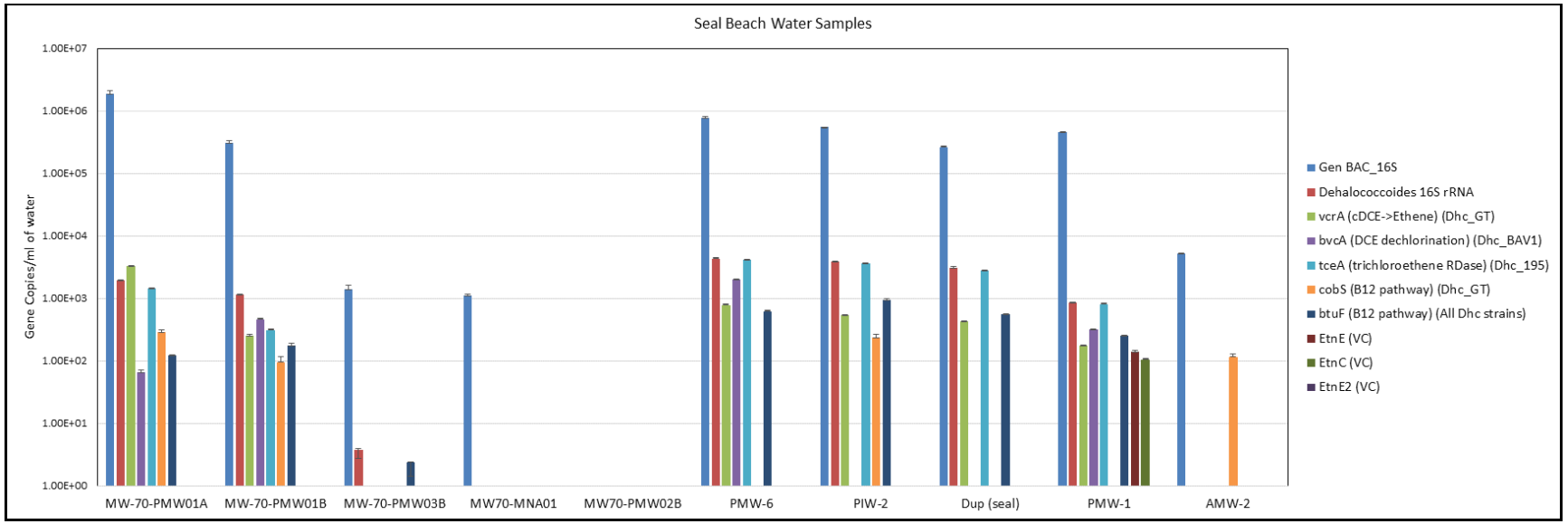


Figure 5-69. Organisms and Genes Associated with Reductive Dechlorination Detected in Wells at the Seal Beach Site.

Table 5-23. CSIA Summary Seal Beach Naval Weapons Station Site 70.

Well	$\delta^{13}C$ TCE (‰)	TCE (µg/L)	$\delta^{13}C$ DCE (‰)	DCE (µg/L)	$\delta^{13}C$ VC (‰)	VC (µg/L)	Location
MW70-MNA01	-25.0	1,560	-23.2	634	-23.7	436	Upgradient
AMW-2	-23.9	8,130	-24.9	1,280	-23.0	248	Active
AMW-5	-25.0	< 5	-23.2	< 5	-23.0	< 5	Active
PMW-1	-17.4	75.9	-10.5	23.2	-20.3	87.9	Passive
PIW-2	-13.9	219	-15.0	148	-21.	225	Passive
PMW-6	-22.2	4,730	-21.5	1,160	-30.8	584	Passive
MW70 -PMW01A	-17.5	< 5	-0.01	< 5	-0.9	< 5	Full-scale
MW70 -PMW01B	-0.04	8.9	+ 4.2	777	-25.9	2,650	Full-scale
MW70-PMW02B	-18.6	3.3	- 26.0	74	NA*	< 5	Downgradient
MW70-PMW03B	NA	< 5	+2.2	105	-15.9	150	Downgradient

*NA – Data not available because concentration was too low for CSIA analysis.

5.3.5 Treasure Island Naval Station Site 24

5.3.5.1 Site Description, Treasure Island Naval Station Site 24

Site 24 at Naval Station Treasure Island is contaminated with PCE, and a plume of contamination extends over 1,100 ft to the San Francisco Bay (**Figure 5-70)**. The main source area, Building 99, contained dry cleaning facilities that operated between 1942 and 1977. Total VOC concentrations above 1 mg/L occurred throughout much of the plume before remediation.

Treasure Island is a manmade island created from dredged fill material. The fill material contains discontinuous layers of sand, silt, clay, and shell hash to depths of up to 40 ft. The measured hydraulic conductivity of the material ranges from 5 to 16 ft per day, indicating a moderate permeability. A freshwater aquifer is present in the upper part of the fill material, but the groundwater becomes saline at depths of greater than 30 ft. The aquifer is generally anaerobic, has a neutral pH, and has relatively high sulfate concentrations.

An initial pilot study was conducted at the Building 99 source area from 2003 to 2004. The pilot study system included recirculation with three injection wells and three extraction wells arranged to provide three test loops. Sodium lactate, hydrogen gas, and SDC-9 were applied to various degrees in each of the loops. The pilot study results data showed a substantial decrease in contamination due to the treatment.

Following the successful pilot study, the full-scale treatment was implemented in three phases. Phase 1, conducted from November 2004 to May 2007, consisted of injecting and recirculating a lactic acid solution, hydrogen gas, and SDC-9 across the plume downgradient of the pilot study area. Phase 2, conducted from June 2008 to October 2010, consisted of a combination of recirculating a sodium lactate solution in some areas and injections of emulsified vegetable oil substrate in other areas.

The biotreatment was successful throughout much of the plume, but several pockets of contamination remained. Phase 3 was conducted from 2011 to 2012 to address the remaining hot spots of contamination and included additional source area recirculation with lactic acid and SDC-9, along with direct-push applications of Lactoil™ in other parts of the plume. Three areas there were targeted for additional treatment included the South Source Area Treatment Area, the EW12 Treatment Area, and the EW30 Treatment Area (**Figure 5-71**).

The bioremediation was considered effective, and no further active remediation is planned. This site was sampled to assess current conditions, including VOC and DHC concentrations, as well as a passive flux in different areas of the site. This site is an example of successful full-scale bioremediation.

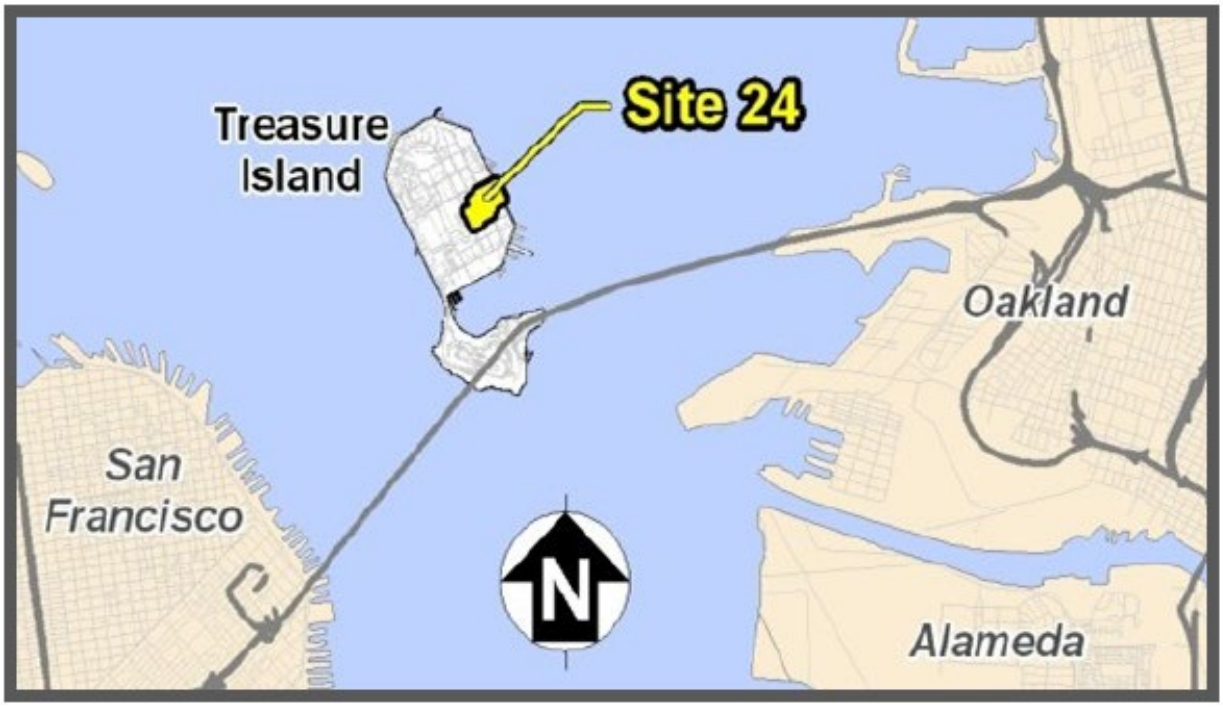


Figure 5-70. Location Map, Treasure Island Naval Station Site 24.

5.3.5.2 Sampling Rationale, Treasure Island Naval Station Site 24

The objective of the groundwater sampling was to assess the long-term impacts of the previously performed bioaugmentation treatment on groundwater quality and biogeochemistry. Monitoring locations within the various treatment areas were evaluated, as described below. **Table 5-24** summarizes the monitoring locations and rationale for the sampling program. Monitoring wells sampled are shown in **Figure 5-71**.

Table 5-24. Groundwater Sampling Locations and Rationale, Naval Station Treasure Island Site 24.

Treasure Island Monitoring Well	Sampling Rationale
24-EW04	Located in the South Source Area. Phase 1 resulted in substantial reduction followed by a rebound to pre-treatment concentrations. Phase 2 treatment caused substantial reduction but without a subsequent rebound.
24-EW12	Located in the EW-12 Treatment Area. Substantial reduction was initially achieved following Phase 1. Some rebound occurred that was substantially reduced in subsequent treatments.
24-TW-11	Located in the South Source Treatment Area. Treated in Phases 1, 2, and 3. Initial rebound followed by substantial degradation.
24-TW-14	Located in the EW30 Treatment Area. Treated in Phase 2 only. Treatment was highly effective.
24-TW-41	Located in the EW30 Treatment Area. Treated in Phase 2 only. Treatment was highly effective.
24-TW-53	Located in the EW12 Treatment Area and received treatments during Phases 1, 2, and 3. Substantial accumulation of DCE and VC after Phase 1 but then substantial reduction in Phase 3.

Monitoring wells 24-TW-11 and 24-TW-48 are located in the South Source Treatment Area. Well 24-MW-11 had repeated treatments in Phases 1, 2, and 3. Substantial rebound of contaminant concentrations occurred between treatments. Substantial degradation was observed in this well in the final treatment (Phase 3). Monitoring well 24-EW4 and 24-IW05 also had substantial reduction in Phase 1, followed by substantial rebound. Concentrations were substantially reduced in Phase 2.

Monitoring wells 24-TW-14 and 24-TW-53 are located at two other treatment areas at the site – the EW30 and EW12 Treatment Areas, respectively. Treatment was highly effective at well 24-TW-14 in the EW30 Treatment Area but not at well 24-TW-53 in the EW12 Treatment Area, where substantial accumulation of 1,2-dichloroethene and vinyl chloride was observed after treatment. Similar to the wells described above, these wells were selected to evaluate what conditions are associated with highly effective versus less effective treatment.

Table 5-25 provides monitoring well construction details.

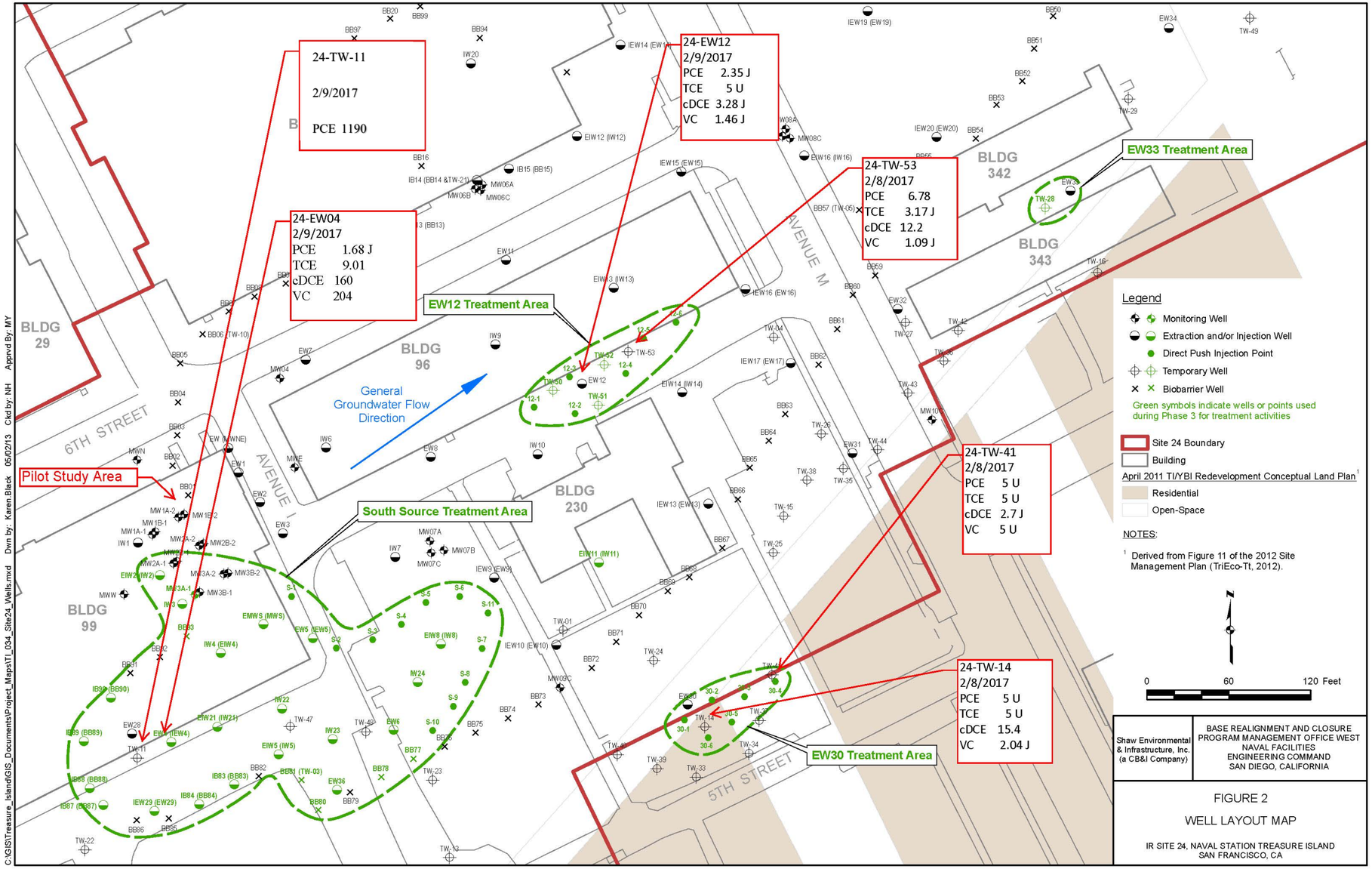


Figure 5-71. Well Layout Map, Naval Station Treasure Island Site 24.

Table 5-25. Monitoring Well Construction Details, Naval Station Treasure Island Site 24.

Monitoring Well	Top of Screen (ft bgs)	Bottom of Screen (ft bgs)	Diameter (inches)
24-EW04	10	30	4
24-EW-12	10	30	4
24-TW-11	10(e)	30(e)	1
24-TW-14	5	29.7	1
24-TW-41	5	29.7	1
24-TW-53	5	30	1

bgs = below ground surface

(d) = dual screen

(e) = estimated

5.3.5.3 Sampling Results, Treasure Island Naval Station Site 24

5.3.5.3.1. VOCs

Table 5-26 provides a summary of sampling results, and **Figures 5-72** to **5-82** provide historical and current VOC data and corresponding ORP and sulfate data for the different wells sampled. The primary parent contaminant at this site was PCE. The highest concentration of residual PCE was detected in 24-TW-11, in the South Source Treatment Area, which had 1,190 µg/L as well as 779 µg/L of TCE, 7,840 µg/L of cis-DCE and 937 µg/L of VC, respectively. This well has shown rebound of PCE after various treatment phases with levels as high as 16,000 µg/L detected in 2011, but minimal rebound was observed after treatment in 2012 until this sampling event approximately 5 years later (**Figure 5-72**). The other well in this same treatment area, 24-EW04 had much lower levels of VOCs than 24-TW-11, having PCE at 1.7 µg/L, TCE at 9.0 µg/L, and VC at 204 µg/L (**Figure 5-74**). This well had concentrations as high as 36,000 µg/L in 2005. The other 4 wells that were sampled at Site 24 had residual PCE < 7 µg/L, cis-DCE < 16 µg/L, and VC < 3 µg/L. Thus, overall treatment effectiveness in the EW-12 and EW-30 areas showed little to no rebound after treatment. These wells were primarily contaminated with *cis*-DCE and VC during previous years.

5.3.5.3.2. Field Parameters

Except for well 24-TW-53, which had a measured ORP of +66.5 mV, a negative ORP was measured in all other wells tested ranging from -257.6 mV in 24-EW04 to – 23.2 mV in 24-TW-41 (**Table 5-26**). Thus, even though the region had not presumably received any additional electron donor in ~ 5 years before this sampling event, groundwater ORP remained predominantly negative. The one well showing significant rebound, 24-TW-11 had an ORP of -145. DO was < 0.6 mg/L in all of the wells sampled. The groundwater pH was between 6.23 and 6.98 SU, which is in a range suitable for reductive dehalogenation.

5.3.5.3.3. Anions

Sulfate concentrations in groundwater at the site ranged from ~ 200 to 400 mg/L in the early 2000s (**Figures 5-73, 5-75, 5-77, 5-79, 5-81**). The sulfate concentrations during the current sampling event ranged from a low of 22.9 mg/L in 24-TW-11 to a high of 202 mg/L in 24-TW-14. Most of the wells had much lower sulfate concentrations than measured before or during the active treatment phases, indicating continued sulfate reduction across most of the site. This is consistent with the negative ORP values as well. Nitrate was detected at 0.88 mg/L in 24-TW-53, the well that also had a positive ORP, but was < 0.2 mg/L in all other wells. Interestingly, orthophosphate was detected in 4 of the 7 wells at > 1 mg/L. This is unusual since phosphate forms insoluble precipitates in most environments.

5.3.5.3.4. Dissolved Iron and Manganese

Dissolved iron ranged from <70 µg/L in 24-TW-53 (ORP +66.5) to 268,000 µg/L in 24-EW04 (ORP -257.6). Dissolved manganese was detected in every well ranging from 343 µg/L in 24-TW-53 to 7,800 µg/L in 24-EW04. These data are indicative of iron and manganese reduction occurring in much of the groundwater across the site, consistent with the general ORP values.

5.3.5.3.5. Dissolved Gases

Methane was detected in all wells ranging from 10 µg/L in 24-TW-41 to 3,920 µg/L in 24-TW-11. Ethane was present in 5/6 wells sampled, at concentrations ranging from 4.6 to 68 µg/L. Ethene was only detected > 5 µg/L in two wells, 24-EW04 (31 µg/L) and 24-TW-11 (107 µg/L), both of which are in the South Source Treatment Area, and have the highest residual VOCs overall. Ethene and ethane are indicative of ongoing reductive dehalogenation. Hydrogen gas, the ultimate electron donor for reductive dehalogenation was detected in 5/6 wells, with well 24-EW04 exceeding 1.5 µg/L.

5.3.5.3.6. Total Organic Carbon and Volatile Fatty Acids

TOC was < 11 mg/L in 4/6 wells. In the other two, 24-EW04 and 24-TW-11, TOC measured 1,520 mg/L and 212 mg/L, respectively. Each of these wells also had appreciably quantities of fatty acids present, presumably as degradation products of the Lactoil™ injected in 2012 during Phase 3 treatment. Fatty acids were not detected in any of the other wells.

5.3.5.3.7. Microbial Community

The microbial community analysis indicated the presence of quantifiable dehalogenation-associated organisms/genes only in well 24-TW-11 (**Figure 5-83**). This was one of two wells (along with 24-EW04) that showed significant residual concentrations of VOCs as well as the presence of fatty acids to support microbial growth. *Dehalococcoides* was detected in this well at ~ 1 x 10^3 cells/mL, and the *vcrA* gene was measured at approximately the same concentration. The only other organism/gene detected was the *tceA* gene at slightly > at ~ 1 x 10^2 cells/mL. Among the other wells, it is not surprising that dehalogenating organisms/genes were not detected in 24-EW12, 24-TW-53, 24-TW-14, or 24-TW-41 as concentrations of VOCs in these wells were all < 20 µg/L, and TOC was very low with no fatty acids were detected. The moderately surprising result was that no quantifiable dehalogenation-associated cells or genes were detected in 24-EW04, as this well is close to 24-TW-11 and does have some low to moderate concentrations of both cis-DCE and VC remaining (~ 160 µg/L and 204 µg/L, respectively) as well as high concentrations of fatty acids. However, overall VOC concentrations in this well were appreciably lower than in 24-TW-11, which also had TCE and PCE concentrations each exceeding 750 µg/L. PCE and TCE in 24-EW04 were each < 10 µg/L.

5.3.5.3.8. CSIA

Values of $\delta^{13}C$ were obtained for TCE, cis-DCE, and VC in monitoring wells where concentrations were sufficient for analysis (**Table 5-27**). The primary contaminant at this site was initially PCE. Unfractionated $\delta^{13}C$ values for manufactured PCE typically range from ~ -37‰ to - 24‰, with a mean of -29‰, very similar to TCE (USEPA, 2008). $\delta^{13}C$ values were not obtained for PCE at any of the well locations. The $\delta^{13}C$ values for residual TCE in the three wells where it was measurable ranged from -24.4‰ to -29.5‰. These values do not necessarily suggest that continued degradation of TCE is occurring as they are not above the range for parent PCE. It should be noted, however, that concentrations at two of the wells (24-TW-53 and 24-EW04) were < 10 µg/L at the time of sampling, and that dehalogenating organisms/genes were not detected in the wells. $\delta^{13}C$ values for cis-DCE at the Treasure Island site ranged from -24.1‰ to + 8.8‰ in the 5/6 wells where concentrations were high enough to measure. The isotope analysis shows clear evidence for continued cis-DCE biodegradation in 24-MW-41, 24-EW04, and 24-TW-14. It should be noted that the concentration of cis-DCE in two of these wells (24-MW-41 and 24-TW-14) was < 20 µg/L. The $\delta^{13}C$ value for cis-DCE in 24-TW-11 (-24.1‰), while in the general range of parent PCE, was ~ 5‰ heavier than the comparable value for TCE (-29.1 ‰.), which does indicate potential ongoing biodegradation. Finally, for VC, CSIA analysis indicated ongoing degradation in 24-EW04 ($\delta^{13}C$ of -12.9‰), and 24-EW12 ($\delta^{13}C$ of -1.1‰). The other wells for which $\delta^{13}C$ of VC was measured had values in near or lower than the parent compound (PCE in this case); thus, evidence of its continuing degradation is not provided by the analysis.

Overall, the CSIA data from this site suggest a rather complex scenario. Wells in the EW30 area, where concentrations of VOCs are very low, each show isotopic evidence of ongoing *cis*-DCE degradation. One of the two wells in the South Source Zone Treatment Area (24-EW04) showed clear evidence of both cis-DCE and VC degradation, but no measurable numbers of relevant dehalogenating organisms/genes. The other well in this region (24-TW-11) showed some evidence of ongoing cis-DCE biodegradation, and very light VC (-38.9‰) indicating that VC was being formed from cis-DCE (i.e., very light daughter product is expected initially as a parent VOC degrades), but probably not biodegrading further. This well had detectable dehalogenating organisms/genes and the highest residual VOC concentrations. For the remining wells in the EW12 area, VC is clearly still degrading in 24-EW12 but not necessarily in 24-EW-53 (although residuals are exceedingly low in both wells).

Table 5-26. Sampling Results Summary, Treasure Island Naval Station Site 24.

Class	LOCATION_CODE		24-EW04		24-EW12		24-TW-11		24-TW-14		24-TW-41		24-TW-53	
	SAMPLE_DATE		2/9/17		2/9/17		2/8/17		2/8/17		2/8/17		2/8/17	
	Parameter	Units	Result		Result		Result		Result		Result		Result	
Anions	Chloride	mg/L	**678**	D	**492**	D	**443**	D	**348**	D	**661**	D	**288**	D
	Nitrate as N	mg/L	0.2	U	0.2	U	0.2	U	0.2	U	**0.13**	J	**0.88**	
	Phosphate as P, ortho	mg/L	0.2	U	**1.51**		**1.60**		**1.76**		**0.27**		**1.54**	
	Sulfate as SO4	mg/L	**51.2**		**33.9**		**22.9**		**202**	D	**123**	D	**64.2**	D
CSIA	del13C cDCE	ppt	**-1.16**		NA		**-24.07**		**-16.18**		**8.79**		**-22.26**	
	del13C TCE	ppt	**-29.52**		NA		**-29.10**		NA		NA		**-24.43**	
	del13C VC	ppt	**-12.93**		**-1.12**		**-38.89**		**-25.19**		NA		**-28.13**	
Field	DO	mg/L	**0.01**		**0.17**		**0.12**		**0.19**		**0.23**		**0.58**	
	ORP	mV	**-257.6**		**-115.7**		**-145**		**-63.9**		**-23.2**		**66.5**	
	pH	su	**6.23**		**6.9**		**6.42**		**6.98**		**6.71**		**6.76**	
Gases	Ethane	µg/L	**10.8**		**67.9**		**27.4**		4	U	**4.59**		**9.32**	
	Ethene	µg/L	**31.4**		5	U	**107**		5	U	5	U	5	U
	Hydrogen	µg/L	**1.65**	D	**0.0046**		**0.121**		**0.0511**		**0.0559**		**0.0184**	
	Methane	µg/L	**1390**		**342**		**3920**	D	**96.5**		**10.0**		**345**	
Metals	Dissolved Iron	µg/L	**268000**		**7220**		**97100**		**1070**		**1650**		**70**	U
	Dissolved Manganese	µg/L	**7800**		**1170**		**4560**		**622**		**720**		**343**	
TOC	Total Organic Carbon	mg/L	**1520**	D	**10.9**		**121**		**9.17**		**8.90**		**7.95**	
VFA	Acetic Acid	mg/L	**1450**	D	1	U	**544**	D	1	U	1	U	1	U
	Butuyric Acid	mg/L	**4150**	D	1	U	**85.4**	D	1	U	1	U	1	U
	Lactic Acid	mg/L	20	U	1	U	20	U	1	U	0.6	J	1	U
	Propionic Acid	mg/L	**3490**	D	1	U	**527**	D	1	U	1	U	1	U
	Valeric Acid	mg/L	**1280**	D	1	U	**13.2**		1	U	1	U	1	U
VOC	1,1-dichloroethylene	µg/L	5	U	5	U	**14.5**		5	U	5	U	5	U
	2-Butanone (MEK)	µg/L	**1090**		10	U	**280**	D	10	U	10	U	10	U
	Acetone	µg/L	**9.33**		10	U	**5.72**		10	U	10	U	10	U
	carbon disulfide	µg/L	**30.9**		5	U	5	U	5	U	5	U	5	U
	Cis 1,2- Dichloroethylene	µg/L	**160**	U	**3.28**	J	**7840**	D	**15.4**		**2.70**	J	**12.2**	
	tetrachloroethylene	µg/L	**1.68**	J	**2.35**	J	**1190**	D	5	U	5	U	**6.78**	
	trans-1,2-dichloroethylene	µg/L	5	U	5	U	**52.3**		5	U	5	U	5	U
	trichloroethylene	µg/L	**9.01**		5	U	**779**	D	5	U	5	U	**3.17**	J
	vinyl chloride	µg/L	**204**		**1.46**	J	**937**	D	**2.04**	J	5	U	**1.09**	J

Notes:

NA - Not Analyzed

U - Compound not detected above method practical quantitation limit.

D - Sample was diluted prior to analysis

J - Estimated value above MDL and less than PQL

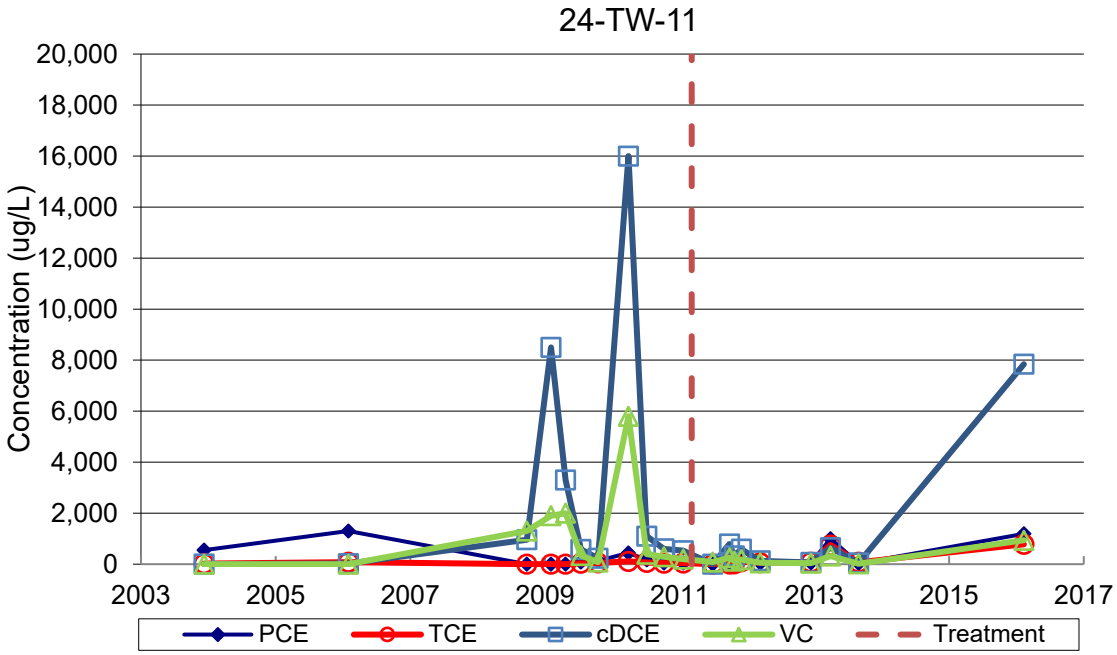


Figure 5-72. VOC Trends for 24-TW-11, Treasure Island Naval Station Site 24.

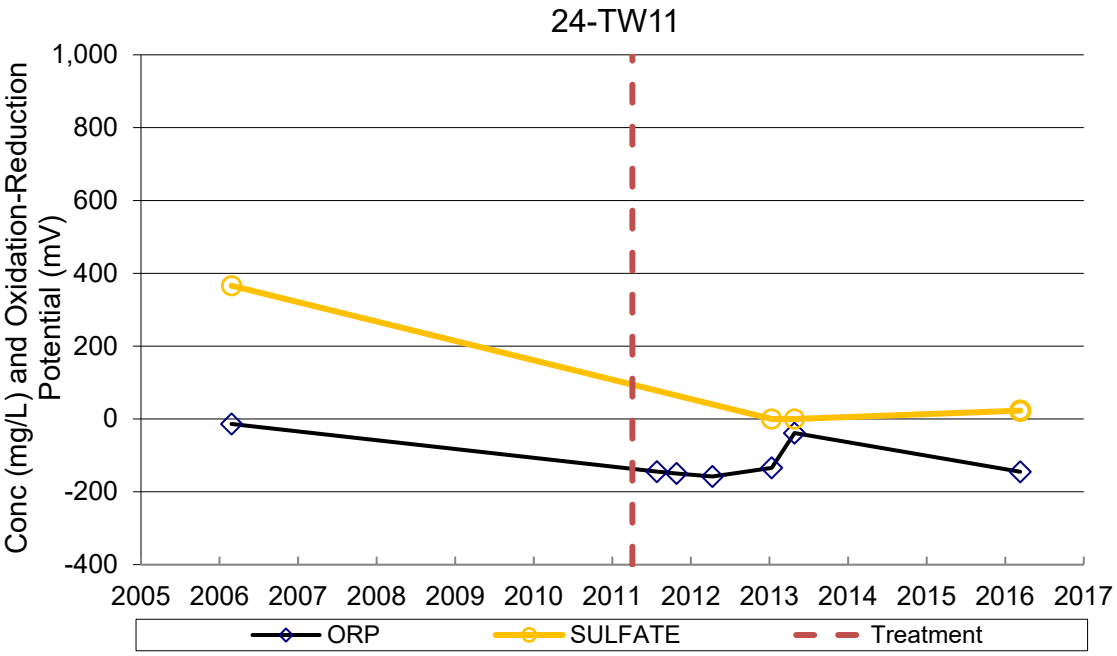


Figure 5-73. ORP and Sulfate Trends for 24-TW-11, Treasure Island Naval Station Site 24.

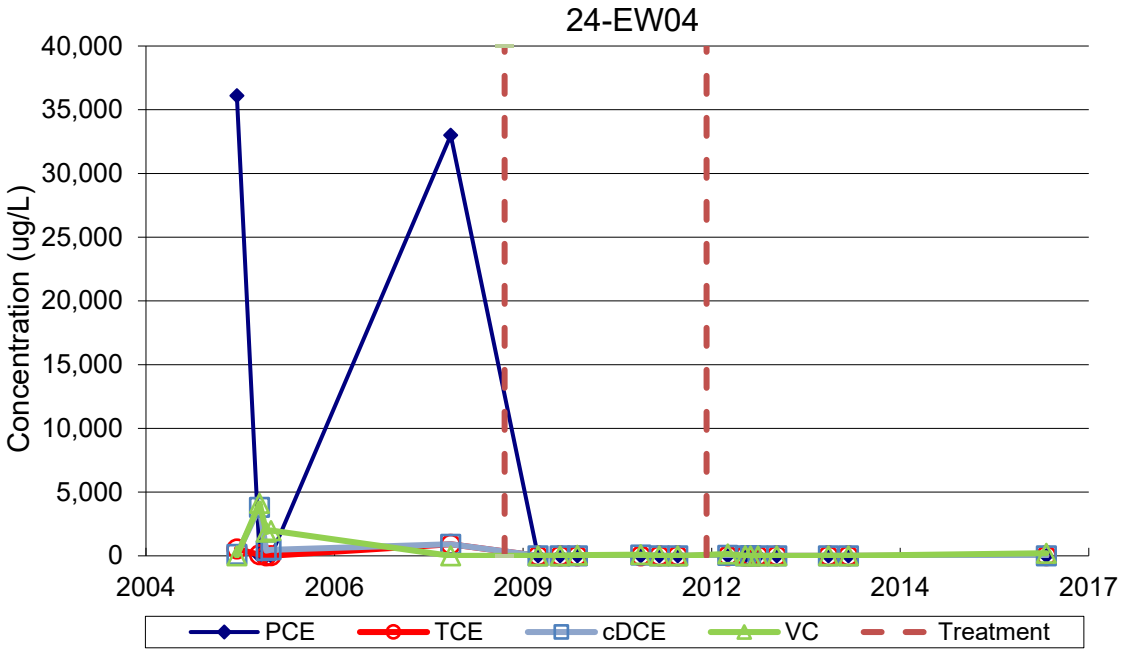


Figure 5-74. VOC Trends for 24-EW04, Treasure Island Naval Station Site 24.

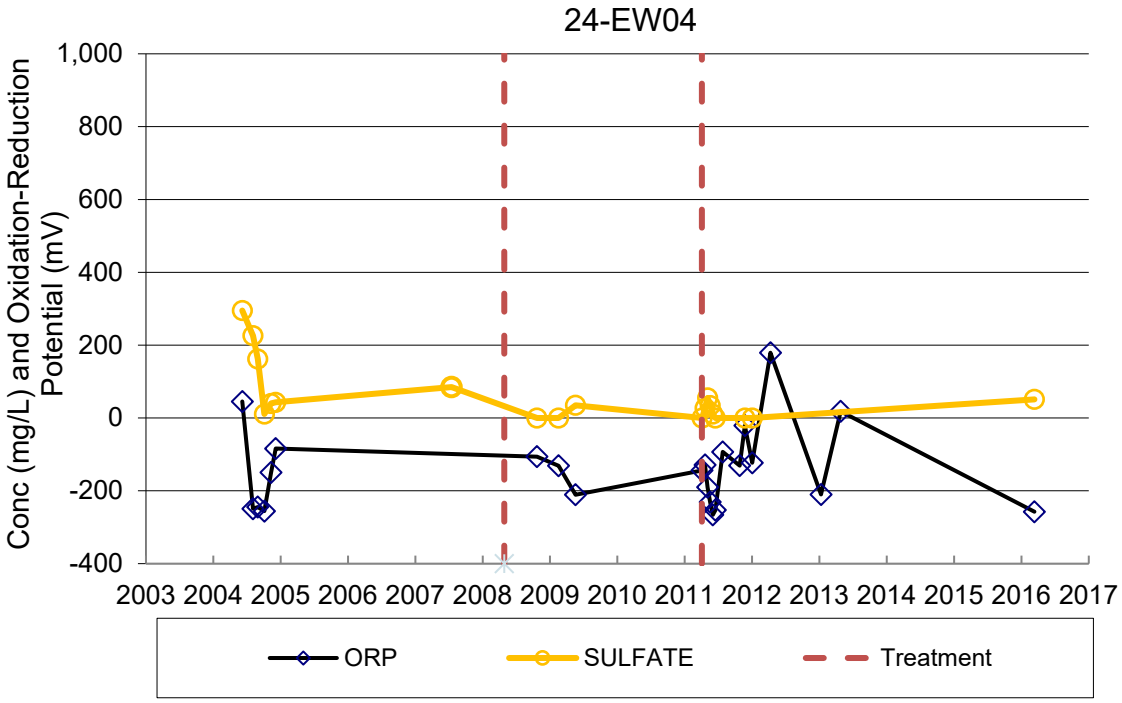


Figure 5-75. ORP and Sulfate Trends for 24-EW04, Treasure Island Naval Station Site 24.

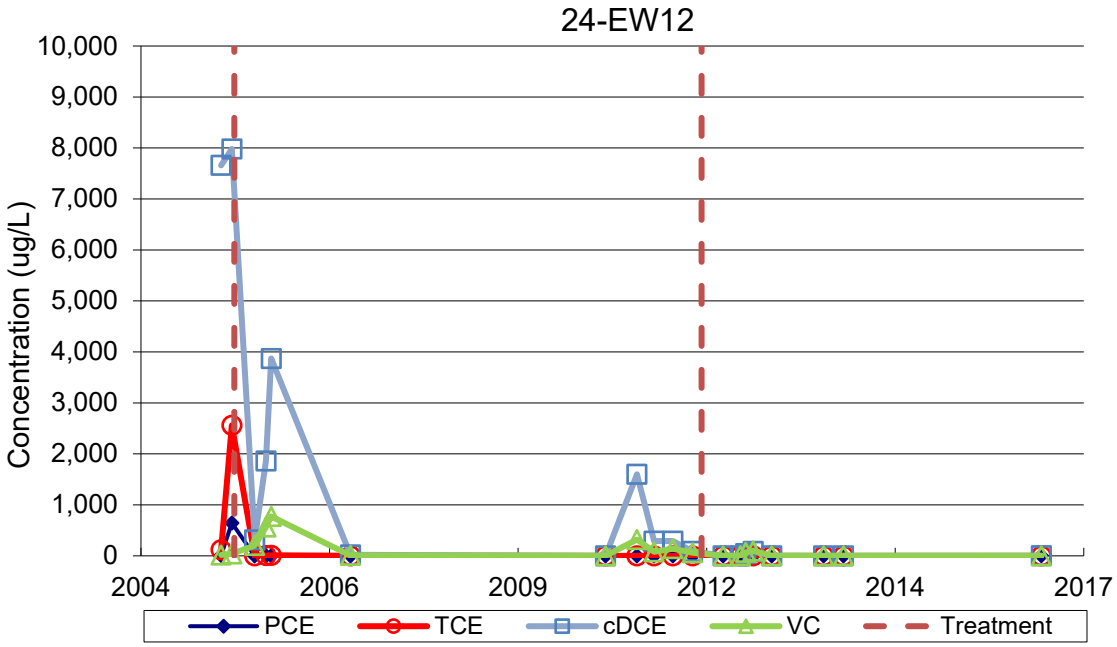


Figure 5-76. VOC Trends for 24-EW12, Treasure Island Naval Station Site 24.

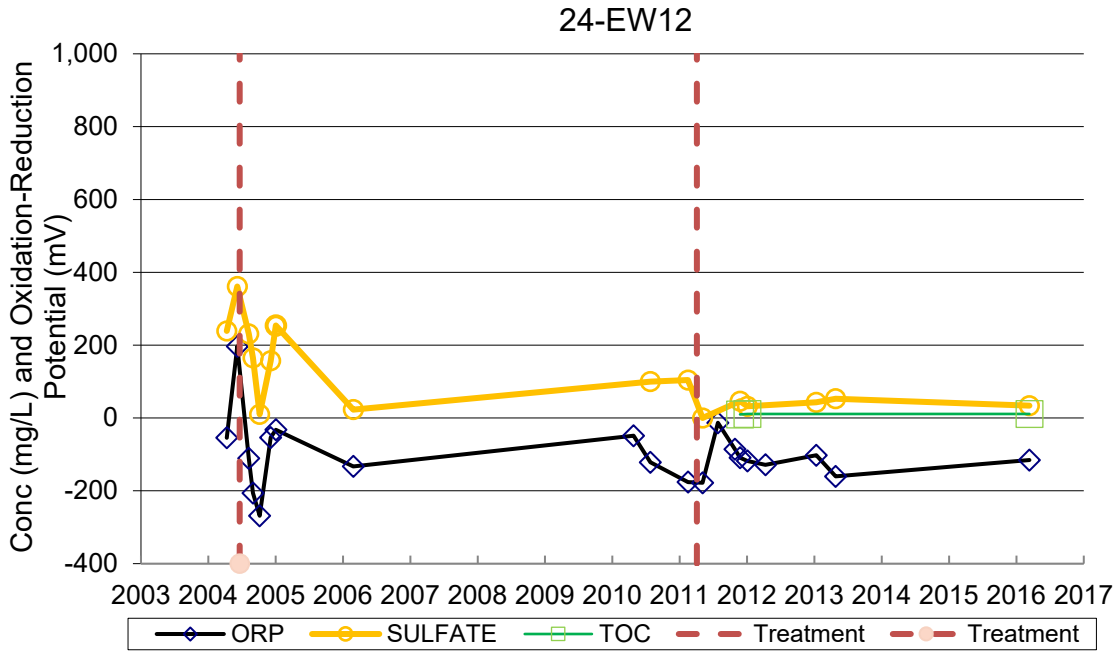


Figure 5-77. ORP and Sulfate Trends for 24-EW12, Treasure Island Naval Station Site 24.

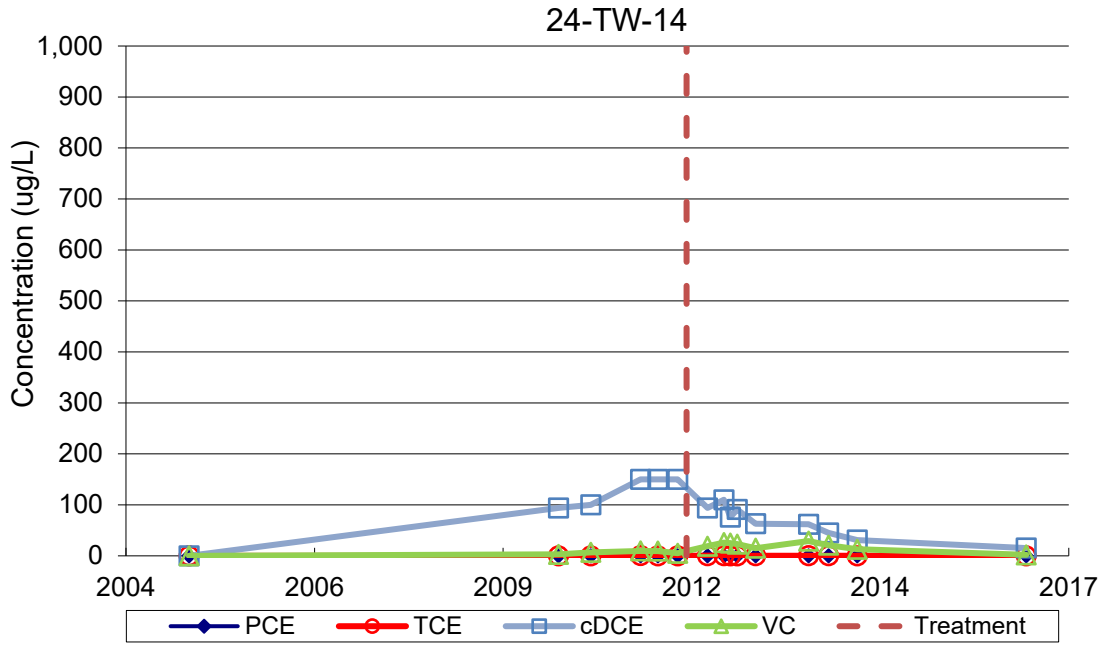


Figure 5-78. VOC Trends for 24-TW-14, Treasure Island Naval Station Site 24.

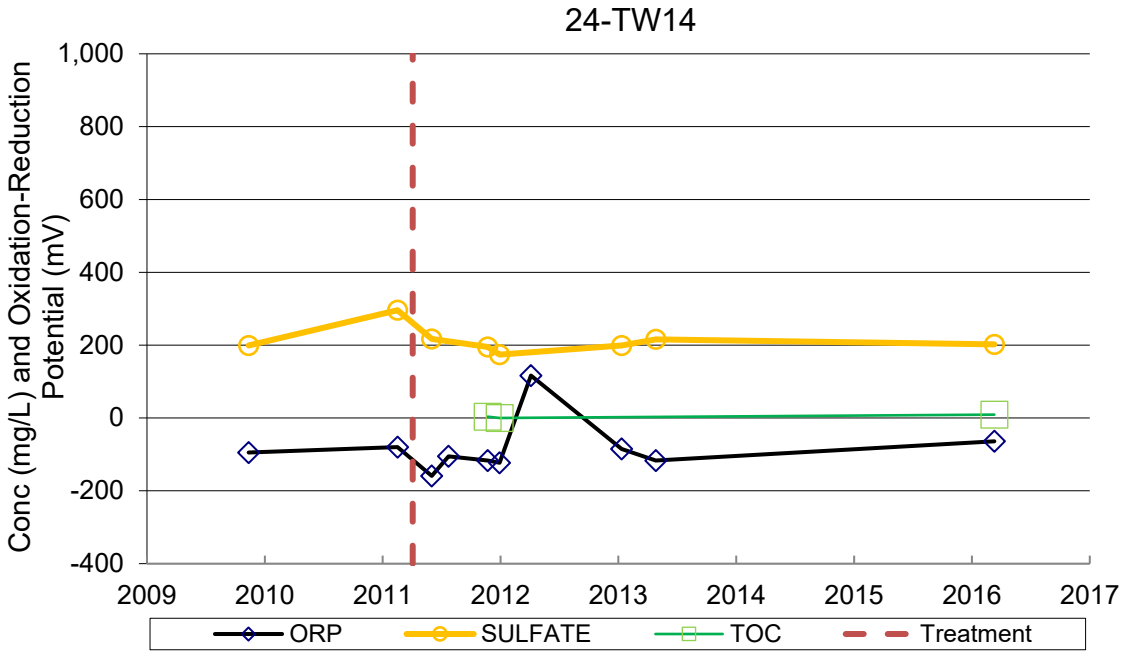


Figure 5-79. ORP and Sulfate Trends for 24-TW-14, Treasure Island Naval Station Site 24.

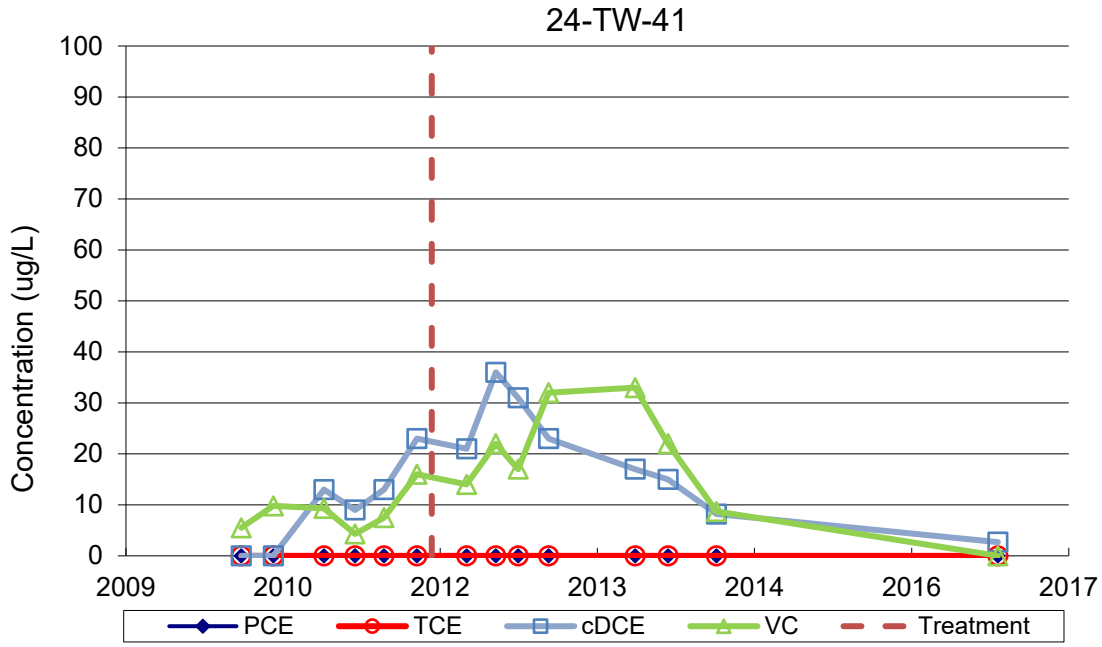


Figure 5-80. VOC Trends for 24-TW-41, Treasure Island Naval Station Site 24.

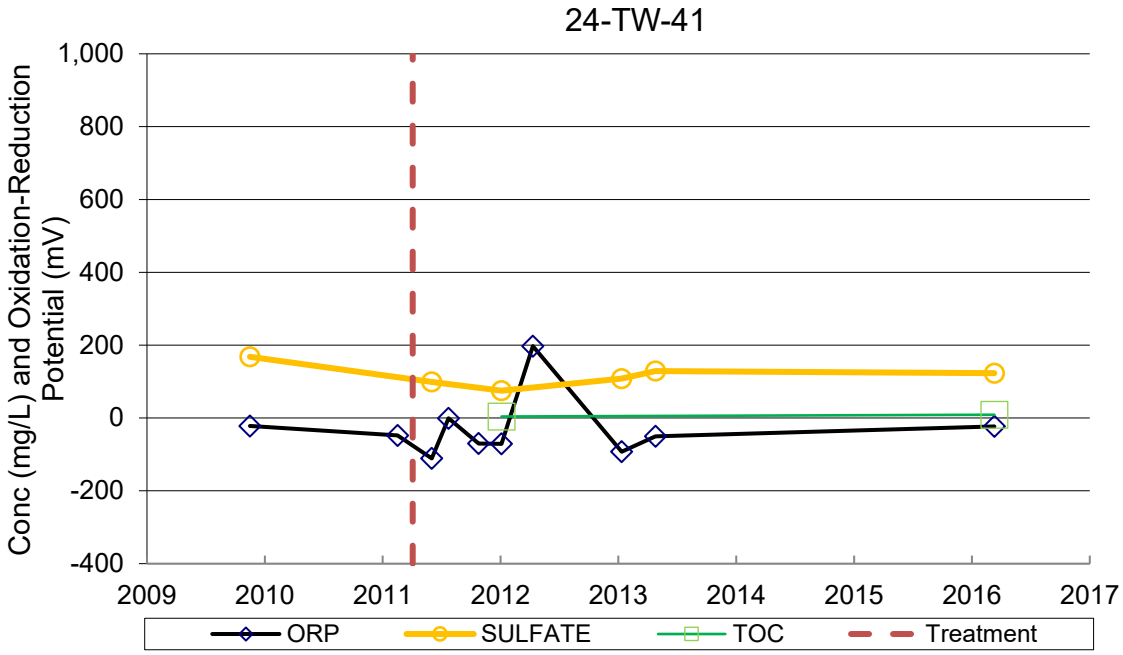


Figure 5-81. ORP and Sulfate Trends for 24-TW-41, Treasure Island Naval Station Site 24.

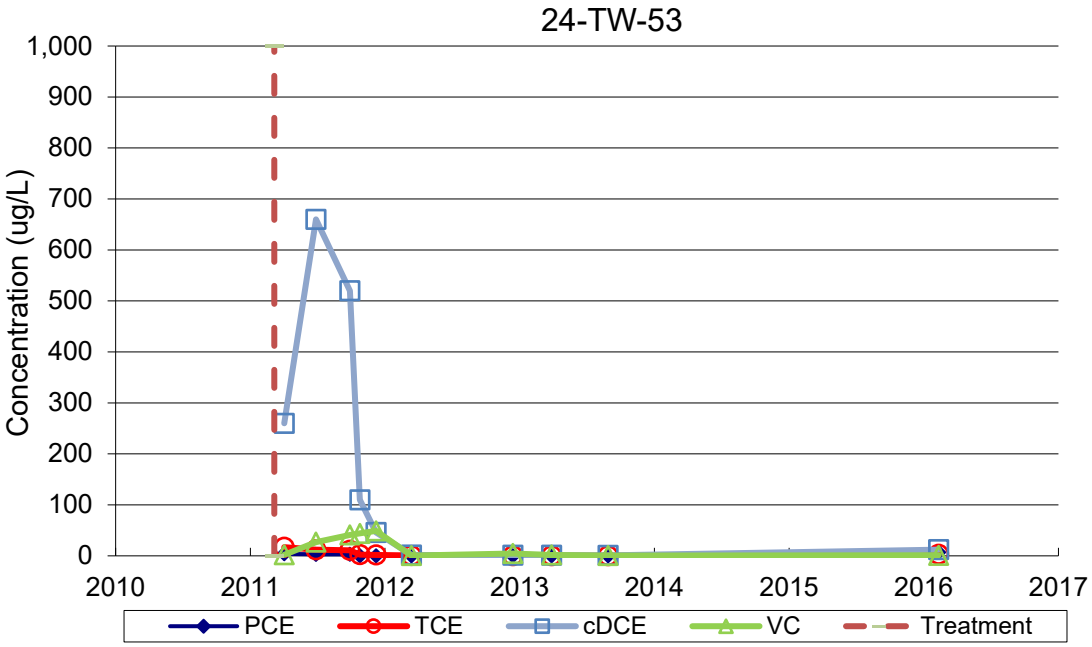


Figure 5-82. VOC Trends for 24-TW-53, Treasure Island Naval Station Site 24.

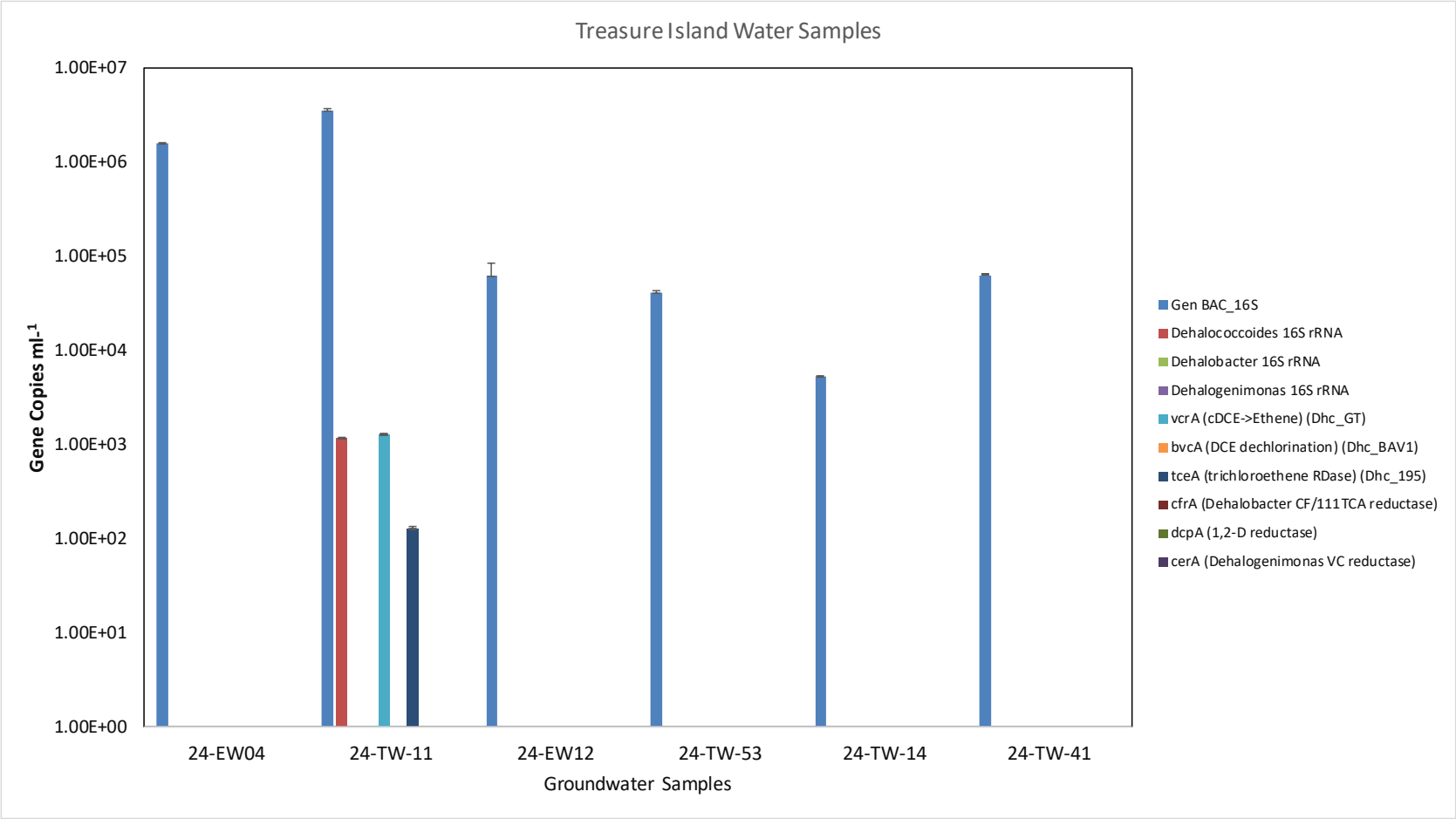


Figure 5-83. Organisms and Genes Associated with Reductive Dechlorination Detected in Wells at the Treasure Island Site.

Table 5-27. CSIA Summary Treasure Island Site.

Well	$\delta^{13}C$ TCE (‰)	TCE (µg/L)	$\delta^{13}C$ DCE (‰)	DCE (µg/L)	$\delta^{13}C$ VC (‰)	VC (µg/L)	Location
24-EW04	-29.5	9.0	-1.2	160	-12.9	204	South Source
24-TW-11	-29.1	779	-24.1	7,840	-38.9	937	South Source
24-TW-14	NA	< 5	-16.2	15.4	-25.2	2.0	EW30
24-TW-41	NA	< 5	+ 8.8	2.7	NA	< 5	EW30
24-TW-53	-24.4	3.2	-22.3	12.2	-28.1	1.1	EW12
24-EW12	NA	< 5	NA	3.3	-1.1	1.5	EW12

*NA – Data not available because concentration was too low for CSIA analysis.

5.3.5.3.9. PFMs.

PFMs were deployed in EW4, EW12, and TW-41 (**Figure 5-84** & **Table 5-28)**. No chlorinated ethenes or ethene were detected in 24-TW41 and 24-EW12. No TCE or PCE were detected in 24-EW4, but an ethene flux of 14.1 mg/m^2/day, VC flux of 11 mg/m^2/day, and cis-DCE flux of 6.9 mg/m^2/day were detected. These data suggest that complete dechlorination is occurring, but likely not at a rate fast enough to prevent the accumulation of VC and cis-DCE.

The flux-averaged equivalent TCE concentration (TCE+cis-DCE+VC), estimate from the PFM results and groundwater monitoring wells, are compared in **Table 5-29**. In well 24-TW41 groundwater concentration data detected very low cis-DCE while the PFMs found no chlorinated ethenes. For Well 24-EW4, groundwater and PFM data showed that TCE was below detection but that VC, ethene and cis-DCE were present. PFM data from Well 24-EW12 showed no detection of chlorinated ethenes whereas groundwater samples showed trace levels of (< 3.3 µg/L) of PCE, cis-DCE, and VC. Overall, data were comparable. As noted previously, for areas where there was some disagreement in results, flux-averaged values (from PFMs) may better estimate concentrations than groundwater data because flux-average concentration is independent of divergence through the well and is both temporally and spatially average concentration as opposed to "instantaneous" measurements of groundwater data (Basu et al., 2006; Brooks et al., 2008). Nonetheless, both measures suggest that reductive dechlorination is still occurring at the site.

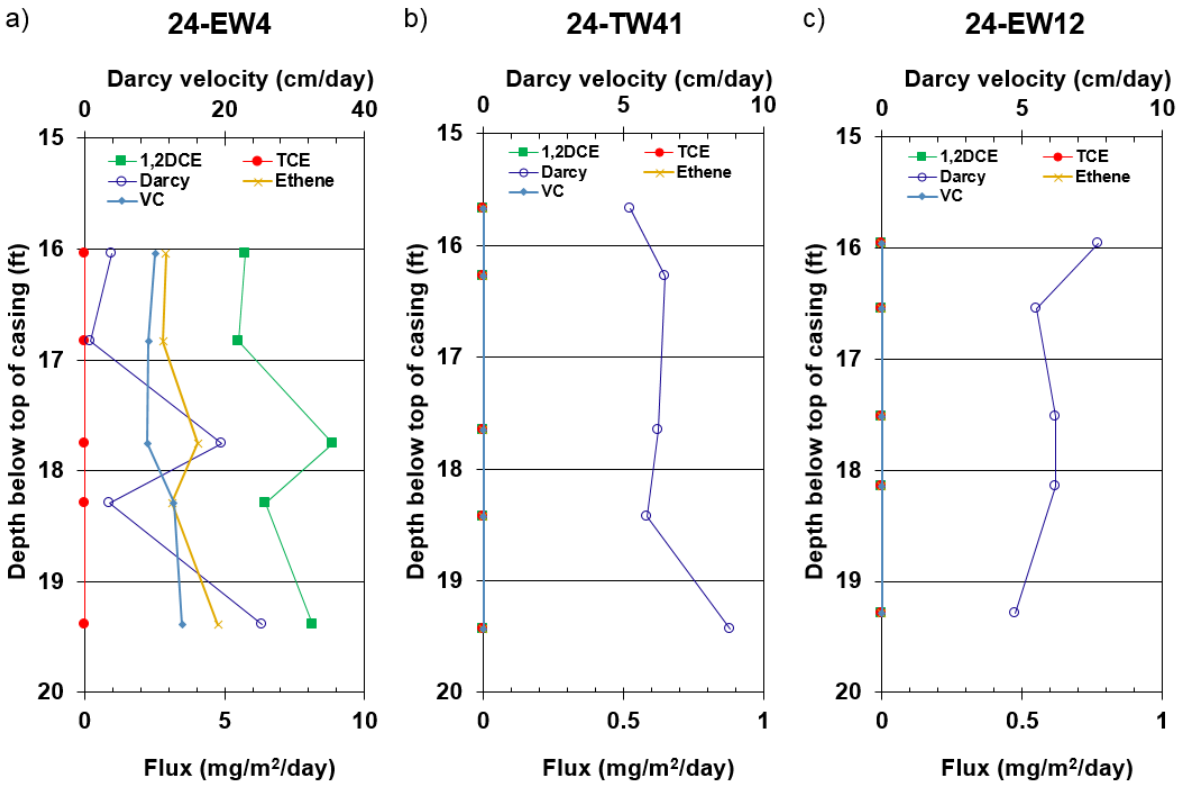


Figure 5-84. Mass Flux Profiles Measured in Select Wells Using the PFMs.

The yellow x's represents ethene, solid blue diamonds represent VC, the solid dark green squares represent DCE, the solid red circles represent TCE, and the open purple circles represent the Darcy Velocity. Panels a-e show flux values sampled on 02/24/2017. Note the changes in scale on both axes to accommodate the data.

Table 5-28. Average Mass Discharge for Each Well.

Well_ID	Average Darcy Velocity (cm/day)	Average Ethene flux (mg/m²/day)	Average VC flux (mg/m²/day)	Average 1,2-DCE flux (mg/m²/day)	Average TCE flux (mg/m²/day)
24-EW4	10.7	14.1	11.0	6.9	0.00
24-TW41	6.5	0.00	0.00	0.00	0.00
24-EW12	6.1	0.00	0.00	0.00	0.00

Table 5-29. VOC Concentration and GW and PFM Concentration Comparisons for Wells in Treasure Island.

Chemical	Type	24-TW41	24-EW4	24-EW12
Equiv. TCE	GW	3.7	433	na
	PFM	<dl	3188	<dl
	% diff.	na	152	na
TCE	GW	<dl	<dl	<dl
	PFM	<dl	0	<dl
	% diff.	na	na	na
cis-DCE	GW	2.7	3.3	3.3
	PFM	<dl	658	<dl
	% diff.	na	198	na
VC	GW	<dl	204	1.5
	PFM	<dl	1092	<dl
	% diff.	na	137	na
Ethene	GW	<dl	31	<dl
	PFM	<dl	1336	<dl
	% diff.	na	191	na
Ethane	GW	4.6	11	68
	PFM	na	na	na
	% diff.	na	na	na

Note: na = not available; <dl -= below detection

5.3.5.3.10. Site Summary

Results showed that biogeochemical conditions remained generally favorable for reductive dechlorination of chlorinated ethenes. Residual PCE was detected in 24-TW-11, in the South Source Treatment Area at 1,190 µg/L. This well also had 779 µg/L of TCE, 7,840 µg/L of cis-DCE and 937 µg/L of VC, respectively. This well showed rebound of PCE after various treatment phases with levels as high as 16,000 µg/L in 2011, but minimal rebound was observed after treatment in 2012 until this sampling event approximately 5 years later. The other well in this same treatment area, 24-EW04 had much lower levels of VOCs than 24-TW-11, with PCE at 1.7 µg/L, TCE at 9.0 µg/L, and VC at 204 µg/L. This well had concentrations as high as 36,000 µg/L in 2005. The other 4 wells that were sampled at Site 24 had residual PCE < 7 µg/L, cis-DCE < 16 µg/L, and VC < 3 µg/L. Thus, overall treatment effectiveness in the EW-12 and EW-30 areas showed little to no rebound after treatment. These wells were primarily contaminated with *cis*-DCE and VC during previous years. Both groundwater and the limited amount of PFM data detected the presence of ethene and ethane at the site, suggesting that complete biological reductive chlorination was still occurring ~5 years after the cessation of active treatment. The microbial community analysis indicated the presence of quantifiable dehalogenation-associated organisms/genes only in well 24-TW-11, which is the well with highest residual VOCs. It is likely that dehalogenators are not present in the vicinity of other wells due to the exceedingly low residual VOC concentrations. Overall, the CSIA data from this site suggest a rather complex scenario.

Wells in the EW30 area, where concentrations of VOCs are very low, each show isotopic evidence of ongoing *cis*-DCE degradation. One of the two wells in the South Source Zone Treatment Area (24-EW04) showed clear evidence of both cis-DCE and VC degradation, but no measurable numbers of relevant dehalogenating organisms/genes. The other well in this region (24-TW-11) showed some evidence of ongoing cis-DCE biodegradation, and very light VC (-38.9‰) indicating that VC was being formed from cis-DCE (i.e., very light daughter product is expected initially as a parent VOC degrades), but probably not biodegrading further. This well had detectable dehalogenating organisms/genes and the highest residual VOC concentrations. For the remining wells in the EW12 area, VC is clearly still degrading in 24-EW12 but not necessarily in 24-EW-53 (although residuals are exceedingly low in both wells).

5.4 STATISTICAL ANALYSIS

The historical data analysis included a statistical evaluation comparing measures of effectiveness to several possible factors for success. The evaluation was conducted on a well-by-well basis for each of the treatment zones and treatment phases at the 15 evaluation sites.

Measures of Effectiveness

Measures of effectiveness were developed to provide quantitative metrics for the statistical evaluation as described below:

Mass Reduction:

Mass reduction is a key measure of effectiveness and was calculated as a percent reduction of the mass concentrations of VOCs (typically presented in µg/L) from the initial to final conditions.

Dechlorination:

Dechlorination is a measure of the extent to which the dechlorination process has proceeded and for this application is equivalent to the number of chlorine atoms removed from the VOC parent molecules. Dechlorination was calculated by comparing the molar concentrations of chlorine atoms from the initial to final conditions.

Risk Reduction:

The MCL for each VOC was used as an estimator of regulatory risk. The sum of the MCL multipliers (concentration/MCL) for each VOC was compared in the initial and final conditions.

Rebound:

Rebound refers to the increase in concentrations after an initial decrease. Rebound was calculated by comparing the minimum concentration attained to the initial and final concentrations.

DCE Accumulation:

DCE accumulation was calculated by comparing the ratio of DCE to Total VOC from initial to final conditions.

VC Accumulation:

Similar to as described above for DCE Accumulation, VC Accumulation was calculated by comparing the ratio of VC to total VOC from Initial to Final conditions.

Factors for Success

The Measures of Effectiveness described above were compared to a number of potential factors for success, including those listed below.

Hydrogeologic factors:

- Percent fines
- Heterogeneity
- Hydraulic conductivity
- Hydraulic gradient
- Seepage velocity

Treatment Approach factors:

- Substrate used
- Substrate Loading (mass per treatment area volume)
- Substrate Dosing (injection fluid concentration)
- Nutrient amendments
- Treatment approach (for example recirculation, biobarrier, or direct push)
- Spacing of injection points

Geochemical factors:

- DO
- ORP
- pH
- alkalinity
- iron
- manganese
- sulfate
- sulfide
- TOC
- temperature

Biological factors:

- Abundance of DHC
- Abundance of reductase genetic markers

Table 5-30. Data Dictionary.

Data Field	Definition
Bioaug	An indication of whether bioaugmentation was used and, if so, what culture was employed.
Bioaug Rank	Y = Yes N = No
cis-DCE Accumulation	The difference between the Initial cis-DCE and Final cis-DCE concentrations as ratios for total CE at each individual well. Calculated as: (Final cis-DCE/ Final CE) – (Initial cis-DCE/ Initial CE) Where: Initial cis-DCE = Initial *cis-1,2*-dichloroethene concentration (µg/L); Initial CE = Initial total CE concentration (µg/L); Final cis-DCE = Final *cis-1,2*-dichloroethene concentration (µg/L); Final CE = Final total CE concentration (µg/L); the Initial event was pre-treatment baseline monitoring and the Final event is the latest post-treatment monitoring event. Results range from - 1.00 to + 1.00 A positive result indicates an increase in the ratio. A negative result indicates a decrease in the ratio.
cis-DCE Accumulation Rank	None = -1.0 – 0.0 Low = 0.001 – 0.1 Med = 0.1 – 0.3 High = >0.3
Conc Reduction	The greatest reduction in total chlorinated ethene (CE) concentration for each well during the treatment period prior to rebound. The concentration reduction between the *Initial CE* and *Min CE* expressed as a ratio of the *Initial CE*. Calculated as: (*Initial CE – Min CE)/Initial CE* Where: *Min CE* = Minimum total chlorinated ethene (CE) concentration (µg/L) during the treatment period; and *Initial CE* = Initial total CE concentration (µg/L). Results range from 0.00 to 1.00 (0 to 100% reduction).
Conc Reduction Rank	None = 0.0 Low = 0.01 to median Mid = median to 75th percentile High = < 75th percentile

Table 5-30. Data Dictionary (Continued).

Data Field	Definition
Dechlorination	The number of chlorine atoms removed from the chlorinated ethene (CE) molecules as indicated by the change of the molar concentration of chlorine atoms. The greatest reduction is calculated for each well during the treatment period before rebound. The calculation is based on the Chlorine Number for each CE where PCE = 4, TCE = 3, cis-DCE and tDCE = 2, and VC = 1. The molar concentration of chlorine atoms [Cl] is calculated as: [Cl] = 4 x (PCE) / 166 + 3 x (TCE) / 131 + 2 x (cis-DCE) / 97 + 2 x (tDCE) / 97 + 1 x (VC)/ 62 Where: molecular weights for individual CE's are: PCE = 166, TCE = 131, cis-DCE = 97, trans-DCE = 97, and VC = 62. Brackets indicate molar concentration in micromoles per liter and parentheses indicate mass concentration in ug/L. *Dechlorination* is calculated as: (Initial [Cl] – Min [Cl])/ Initial [Cl] A positive result indicates a decrease in [Cl]. Results range from 0.00 to 1.00
Dechlorination Rank	None = 0.0 Low = 0.01 to median Mid = median to 75th percentile High = < 75th percentile
DNAPL	A Yes/No indication of whether DNAPL is present in the treatment area during the treatment period. Total chlorinated ethene (CE) concentrations greater than 10,000 µg/L are used as a presumptive indication of the presence of DNAPL. Calculated as:: IF *Initial CE* >10,000, THEN "Y", ELSE "N" Where: *CE* = the sum of the concentrations of PCE, TCE, cis-DCE, tDCE, and VC for each individual sampling event at a specific well; and The Initial event was pre-treatment baseline monitoring. Calculation output: Y = yes N = no
Dosing	The concentration of the substrate injection fluid. The substrate product diluted in water as a percent by volume.
Final CE	Total chlorinated ethene (CE) concentration for each well at the Final post-treatment monitoring event (µg/L), where the Final event is the latest post-treatment monitoring event.

Table 5-30. Data Dictionary (Continued).

Data Field	Definition
Fines	The percentage of fines (silt plus clay) within the Treatment Zone based on representative soil boring logs for each site. ASTM D2488 classifies soils based on the percentage of fines, sand, gravel, and organic matter. Each soil type contains by definition a percentage range of fines. The midpoint of the range was selected as the average. For example, silty sand contains by definition between 15% and 50% silt by definition with a midpoint mean value of 32.5%. Table 5-26 provides a listing if USCS soil names, the percentage range of fines for each soil classification, and the mean percentage of fines. Representative soil boring logs were evaluated to determine the total percent fines using a weighted average of the percent fines for each distinct soil layer. Representative boring logs are provided in **Appendix F**.
Fines Rank	H > 0.50 M > 0.15 and < 0.50 L < 0.15
Gradient	The typical hydraulic gradient (ft/foot) at the site estimated from water level data reported in site documents. *Gradient* was determined for each site by examining a typical water level contour map and measuring the change in water level elevation or hydraulic head along a typical flow path. Calculated as: dh/dl Where: dh = change in hydraulic head and dl = horizontal length along flow path.
Heterogeneity	A measure of the number of distinct soil layers within the saturated thickness of the treatment zone with units of layers per 10 ft. A representative soil boring log was evaluated for each site to determine the number of distinct layers based on the Unified Soil Classification System Standard Practice for Description and Identification of Soils Visual-Manual Procedures (ASTM D2488). Calculated as: Number of Layers/ (Measured Thickness x 10). Calculations for *Heterogeneity* for the individual sites are provided in **Appendix E**.
Heterogeneity Rank	H > 5 M > 2 and < 5 L < 2
Hydraulic Conductivity	The average hydraulic conductivity (ft/day) of the aquifer within the treatment zone as reported in site documents.
Initial	*Initial* refers to the most recent pre-treatment monitoring event.
Initial Alk	Initial alkalinity concentration (mg/L as $CaCO_3$)

Table 5-30. Data Dictionary (Continued).

Data Field	Definition
Initial CE	Initial total chlorinated ethene (CE) concentration (µg/L). Calculated as: *Initial CE* = Initial PCE + Initial TCE + Initial cis-DCE + Initial trans-DCE + Initial VC Where: PCE = tetrachloroethene TCE = trichloroethene cis-DCE = cis-1,2-dichlorethene trans-DCE = trans-1,2-dichlorethene VC = vinyl chloride
Initial DHC	Initial *Dehalococcoides* concentration (copies/L)
Initial DO	Initial dissolved oxygen concentration (mg/L)
Initial Fe	Initial iron concentration (mg/L)
Initial Methane	Initial methane concentration (µg/L)
Initial ORP	Initial oxidation-reduction potential (millivolts)
Initial PH	Initial pH value (standard pH units)
Initial Sulfide	Initial sulfide concentration (mg/L)
Initial Sulfate	Initial sulfate concentration (mg/L)
Initial TOC	Initial total organic carbon concentration (mg/L)
Loading Ratio	The Actual Loading of substrate volume compared to the Recommended Loading. Calculated as: Actual Loading/Recommended Loading Where: Actual Loading is the volume of substrate product added during the treatment period as reported in site documents. Recommended Loading is the volume of substrate product calculated using the Substrate Loading Tool developed for ESTCP Project ER-0627 "Loading Ratios and Impacts of Substrate Delivery for Enhanced Anaerobic Bioremediation" (Parsons, 2010). Inputs to the Substrate Loading Tool include the following: Treatment Zone – length, width, and thickness; Hydrogeologic – aquifer hydraulic conductivity, hydraulic gradient, and porosity; Geochemical – competing electron acceptors, DO, sulfate, and nitrate; Contaminant concentrations – average initial concentrations of PCE, TCE, cis-DCE, trans-DCE, and VC. The calculations employed in the Substrate Loading Tool use a hydrogen equivalent approach to calculate the substrate demand. A safety factor of 3 was used. The Substrate Loading Tool calculations are provided in **Appendix G.**

Table 5-30. Data Dictionary (Continued).

Data Field	Definition
Max	*Max* refers to the maximum (greatest) concentration observed during the treatment period extending from the *Initial* to *Final* monitoring events for each individual monitoring well.
Max Alk	Maximum alkalinity concentration (mg/L as $CaCO_3$).
Max CE	Maximum chlorinated ethenes (CE) = the sum of the concentrations of PCE, TCE, cis-DCE, trans-DCE, and VC for each individual sampling event at a specific well.
Max DHC	Maximum *Dehalococcoides* concentration (copies/L) observed during the treatment period.
Max DO	Maximum dissolved oxygen concentration (mg/L) observed during the treatment period.
Max Fe	Maximum iron concentration (mg/L) observed during the treatment period.
Max Methane	Maximum methane concentration (µg/L) observed during the treatment period.
Max ORP	Maximum oxidation-reduction potential (millivolts) observed during the treatment period.
Max PH	Maximum pH value (standard pH units) observed during the treatment period.
Max Sulfate	Maximum sulfate concentration (mg/L) observed during the treatment period.
Max TOC	Maximum total organic carbon concentration (mg/L) observed during the treatment period.
MCL Attained	A Yes/No indication of whether the Maximum Contaminant Level (MCL) was attained during the treatment period at each specific well. Calculated as: IF Final PCE < MCL AND Final TCE < MCL AND Final cis-DCE < MCL AND Final tDCE < MCL AND Final VC < MCL, THEN "Y", ELSE "N" Where: The Final event is the latest post-treatment monitoring event.
Method of Injection	The method substrate was introduced into groundwater, including: Recirc = recirculation with a combination of extraction and injection wells; IW = injection wells without active recirculation; and DPT = direct-push technology involving insertion of rods into the aquifer, injection of substrate through the rods followed by removal of the rods resulting in no permanent injection wells.
Method of Injection Cat	General categories: Direct or Recirc
Min	*Min* refers to the minimum (lowest) concentration observed during the treatment period extending from the *Initial* to *Final* monitoring events for each individual monitoring well.
Min Alk	Minimum alkalinity concentration (mg/L as $CaCO_3$) observed during the treatment period.
Min CE	Minimum total chlorinated ethene (CE) concentration (µg/L) during the treatment period.
Min DHC	Minimum *Dehalococcoides* concentration (copies/L) observed during the treatment period.

Table 5-30. Data Dictionary (Continued).

Data Field	Definition
Min DO	Minimum dissolved oxygen concentration (mg/L) observed during the treatment period.
Min Fe	Minimum iron concentration (mg/L) observed during the treatment period.
Min Methane	Minimum methane concentration (µg/L) observed during the treatment period.
Min ORP	Minimum oxidation-reduction potential (millivolts) observed during the treatment period.
Min PH	Minimum pH value (standard pH units) observed during the treatment period.
Min S	Minimum sulfide concentration (mg/L) observed during the treatment period.
Min Sulfate	Minimum sulfate concentration (mg/L) observed during the treatment period.
Min TOC	Minimum total organic carbon concentration (mg/L) observed during the treatment.
Nutrients	Yes/No indication of whether nutrients were added to the substrate injection. TRUE = yes; FALSE = no.
Previous Remediation	Remediation conducted in the treatment area before bioremediation. None Bio = bioremediation Bioventing Excavation ERH = electrical resistive heating SPH = six-phase heating ISCO = in situ chemical oxidation P&T = pump and treat SPH and ISCO = six phase heating combined with in situ chemical oxidation ZVI = zero valent iron
Previous Remediation Rank	Y = Yes N = No
Rebound	The difference between the Initial Decrease in concentration and Subsequent Increase in concentration expressed as a ratio of the Initial Decrease. If the Final CE concentration is greater than the Initial CE concentration, then the Rebound is set to 1.00. Calculated as: If (Final CE > Initial CE), then1.00, else ((Initial Decrease – Subsequent Increase)/Initial Decrease) Where: Initial Decrease = *Initial CE – Min CE* and Subsequent Increase = *Final CE – Min CE*.
Rebound Rank	None = 0.0 Low= 0.01 – 0.11 (median) Med= 0.11 – 0.99 High= 1.00

Table 5-30. Data Dictionary (Continued).

Data Field	Definition
Seepage Velocity	The groundwater seepage velocity (ft/year). Calculated as: (*Hydraulic Conductivity* x *Gradient*)/ (Effective Porosity x 365.25) Where: Effective Porosity is assumed to be 0.20 and days per year = 365.25.
Seepage Velocity Rank	H > 100 M > 20 and < 100 L < 20
Spacing	The horizontal distance in ft between injection points.
Substrate	The organic carbon substrate or mixture of substrates used in the Treatment. Substrates used at the various sites included: Lactate = sodium lactate EVO = emulsified vegetable oil ESO = emulsified soybean oil EOS = emulsified oil substrate HRC = hydrogen releasing compound Lactic Acid Lactoil™ = sodium lactate and emulsified oil mixture Molasses ZVI = zero valent iron
Substrate Rank	H = high viscosity substrates including molasses, EOS, EVO, Lactoil™ and HRC L = low viscosity substrates such as sodium lactate, lactic acid, and hydrogen
Sulfate Depletion	The greatest reduction in sulfate concentration for each well during the treatment period prior to rebound. The calculation is the reduction between *Initial Sulfate* and *Min Sulfate* expressed as a ratio of the *Initial Sulfate*. If the *Min Sulfate* is greater than the *Initial Sulfate*, then a value of zero is assigned (no depletion). Calculated as: If *Min Sulfate* >= *Initial Sulfate*, then 0, else (*Initial Sulfate* – *Min Sulfate)/Initial Sulfate* Where: *Min Sulfate* = Minimum sulfate concentration (µg/L) during the treatment period; and *Initial Sulfate* = Initial sulfate concentration (µg/L); Results range from 0.00 to 1.00 (0 to 100% depletion).
Temp	The average annual air temperature (°C) for the Installation as reported by NOAA for the closest city to the Installation. The average annual air temperature was assumed to approximate the average annual groundwater temperature.
Treatment ID	Identification number unique to a specific Installation, Site, Area, Depth Zone, and Phase of treatment operations.

Table 5-30. Data Dictionary (Continued).

Data Field	Definition
VC Accumulation	The difference between the Initial VC and Final VC concentrations at each individual well as ratios to the Initial CE and Final CE concentrations, respectively. Calculated as: (*Final VC*/ *Final CE*) – (*Initial VC*/ *Initial CE*) Where: *Final VC* = Final vinyl chloride concentration (µg/L); *Final CE* = Final total CE concentration (µg/L); *Initial VC* = Initial vinyl chloride concentration (µg/L); *Initial CE* = Initial total CE concentration (µg/L); and: the Initial event was pre-treatment baseline monitoring , and the Final event is the latest post-treatment monitoring event. Results range from - 1.00 to + 1.00 A positive result indicates an increase in the ratio. A negative result indicates a decrease in the ratio.
VC Accumulation Rank	None = -1.0 – 0.0 Low = 0.001 – 0.10 Mid = 0.10 – 0.4 High = >0.4

Table 5-31. USGS Soil Classification with Percent Fines.

USCS Soil Name	Minimum % Fines	Maximum % Fines	Mean % Fines
Clay	85	100	92.5
Clay with sand	75	85	80
Clay with gravel	75	85	80
Sandy clay	50	70	60
Sandy clay with gravel	50	70	60
Gravelly clay	50	70	60
Gravelly clay with sand	50	70	60
Silt	85	100	92.5
Silt with sand	75	85	80
Silt with gravel	75	85	80
Sandy silt	50	70	60
Sandy silt with gravel	50	70	60
Gravelly silt	50	70	60
Gravelly silt with sand	50	70	60
Organic soil	85	100	92.5
Organic soil with sand	75	85	80
Organic soil with gravel	75	85	80
Sandy organic soil	50	70	60
Sandy organic soil with gravel	50	70	60
Gravelly organic soil	50	70	60
Gravelly organic soil with sand	50	70	60

6.0 PERFORMANCE ASSESSMENT

The information compiled in the database (version Matrix Bio 21) is used here to perform a statistical evaluation of the correlations observed between the effectiveness measures versus site characteristics, and effectiveness measures versus remediation methods (**Table 5-25**). Such correlations, if statistically significant, may indicate specific site characteristics or remediation methods that help or hinder successful remediation. Parameters that affect measures of rebound are also evaluated here. Definitions of the parameters in the database are provided in **Section 5.4**. The methodology and results of the performance assessment are provided in the following sections.

6.1 STATISTICAL METHOD

Correlations between selected pairs of numerical parameters were evaluated using the Spearman Rank Order (SRO) procedure. This procedure calculates a Spearman correlation coefficient *R* (rho), which is a nonparametric measure of statistical dependence between two variables. It assesses how well the relationship between two variables can be described using a monotonic function. The coefficient *R* ranges from –1.0 to +1.0. The value of *R* is positive if *Y* tends to increase as *X* increases, and the value is negative if *Y* tends to decrease when *X* increases. A value of zero indicates that there is no tendency for *Y* to either increase or decrease when *X* increases. A Spearman correlation coefficient of +1.0 or −1.0 occurs when each of the variables is a perfect monotonic function of the other.

The SRO procedure also returns a *p*-value, which allows the results to be interpreted in terms of the statistical confidence in any apparent correlation. The correlations are conservatively evaluated with the null hypothesis that no correlation exists. The *p*-value, which ranges from 0.0 to 1.0, can be thought of as the probability of the null hypothesis (no correlation) being true. For this report, the test is evaluated at a 95 percent confidence level, at which there is only a five percent chance of incorrectly accepting the null hypothesis (no correlation) when a true correlation actually exists. At a confidence level of 95 percent, a correlation is considered to have statistical significance if the *p*-value is equal to or less than 0.05.

The SRO correlation method is described as being "nonparametric," meaning that a perfect SRO correlation results, when *X* and *Y* are related by any monotonic function. This is different from a linear correlation (such as Pearson product-moment), which only gives a high *R* when *X* and *Y* are related by a linear function. The nonparametric SRO approach was selected here because there is no expectation that any of the parameters considered in this evaluation will be linearly related to each other, but at least some monotonic relationships are expected.

Many of the parameters in the database are categorical (non-numeric), so their effects on performance cannot be evaluated with the SRO method. For instance, the *DNAPL Y/N*, and *Bioaug Rank* parameters contain either a Y (yes) or N (no) value for each case. Likewise, the *Seepage Velocity Rank*, *Heterogeneity Rank*, and *Fines Rank* parameters contain either an H (high), M (medium), or L (low) value for each case. The relationships between these parameters versus performance parameters are evaluated using box plots for visual comparisons of the distributions within each individual category versus a performance parameter, and the quantitative Wilcoxon Rank Sum (WRS) test or the Kruskal-Wallis (KW) test. The KW test is a multiple sample

comparison test that is equivalent to the two-sample WRS test. Both are nonparametric procedures that test the null hypothesis that the sub-groups of results that are being compared are drawn from the same population. Both tests return a *p*-value that indicates the probability of the null hypothesis (no difference between sub-groups) being true. The KW test also returns *p*-values for the individual sub-groups, which indicate which sub-group is the most different from the others.

The software package *Statistica* (version 12) was used to evaluate the correlations between selected parameters in the database using SRO correlations, KW tests, and WRS tests; and was also used to generate the box plots.

6.2 STATISTICAL EVALUATION RESULTS

The key parameters in the database are grouped as performance measures, site characteristics, and remediation methods. An Excel spreadsheet that includes the entire matrix accompanies this report**.** Evaluations of SRO correlations between performance measures versus site characteristics and performance measures versus remediation methods were performed. Identification of positive or negative correlations that are statistically significant may indicate possible factors that affect performance. A table of the SRO correlation coefficients between all pairs of numerical parameters is provided in **Table 6-1.** Statistically significant correlations ($\alpha = 0.05$) are shown in red. Non-numeric (categorical) parameters were visually compared to performance measures using box plots and quantitatively compared using either the KW test or the WRS test.

Table 6-1. SRO Results for all Pairs of Numerical Parameters SRO Correlation Coefficients.

Variable	Initial CE	Min CE	Max CE	Final CE	DNAPL 1/0	Conc Reduction	Dechlor-ination	Rebound	cDCE Accum	VC Accum	Initial pH	Max pH	Initial DO	Min DO	Initial ORP	Min ORP	Intitial SO4	Min Sulfate	Sulfate Depletion	Initial TOC	Max TOC	Initial Sulfide	Max Sulfide	Initial Fe	Max Fe	Intial DHC	Max DHC	Max Alkalinity	Max Methane	Temp	Seepage Velocity	Spacing	Dosing	Heterogeneity	Fines
Initial CE	1	0.523	0.853	0.477	0.648	0.167	0.171	-0.204	-0.095	0.193	0.124	0.088	-0.002	0.031	0.105	-0.016	0.148	0.057	0.080	0.062	0.234	-0.145	-0.232	0.072	0.222	-0.143	-0.192	0.054	0.101	0.013	-0.032	0.079	0.137	-0.086	0.304
Min CE	0.523	1	0.560	0.847	0.272	-0.655	-0.651	0.199	0.087	-0.003	-0.017	-0.055	-0.017	0.151	0.288	0.110	0.169	0.294	-0.247	-0.017	0.001	-0.192	-0.134	0.042	-0.008	-0.257	-0.570	-0.146	-0.285	0.029	-0.110	-0.092	0.220	0.051	0.409
Max CE	0.853	0.560	1	0.626	0.633	-0.030	-0.025	0.054	0.000	0.169	0.092	0.039	0.037	-0.014	0.219	-0.054	0.112	0.067	0.057	0.098	0.252	-0.103	-0.147	0.035	0.185	-0.109	-0.089	0.044	-0.048	-0.043	0.042	0.130	0.048	-0.196	0.319
Final CE	0.477	0.847	0.626	1	0.275	-0.552	-0.548	0.474	0.131	-0.032	-0.021	-0.054	0.043	0.078	0.338	0.094	0.127	0.270	-0.210	0.000	-0.002	-0.094	-0.142	0.019	0.000	-0.171	-0.484	-0.179	-0.386	0.025	-0.069	-0.023	0.199	0.017	0.408
DNAPL 1/0	0.648	0.272	0.633	0.275	1	0.130	0.132	-0.120	-0.014	0.094	0.114	0.023	-0.092	0.057	0.015	-0.018	0.076	0.017	0.007	0.155	0.193	-0.148	-0.183	0.031	0.089	0.120	-0.021	0.063	0.122	0.037	-0.022	0.106	-0.044	-0.108	0.139
Conc Reduction	0.167	-0.655	-0.030	-0.552	0.130	1	0.998	-0.515	-0.148	0.131	0.106	0.103	0.030	-0.115	-0.214	-0.148	-0.170	-0.301	0.264	0.013	0.111	0.111	-0.010	0.071	0.204	0.403	0.282	0.125	0.273	-0.026	0.118	0.116	-0.072	-0.092	-0.176
Dechlorination	0.171	-0.651	-0.025	-0.548	0.132	0.998	1	-0.513	-0.158	0.154	0.101	0.099	0.031	-0.119	-0.204	-0.153	-0.169	-0.304	0.270	0.006	0.108	0.114	-0.018	0.068	0.217	0.403	0.283	0.124	0.275	-0.029	0.124	0.117	-0.071	-0.098	-0.172
Rebound	-0.204	0.199	0.054	0.474	-0.120	-0.515	-0.513	1	0.131	-0.109	-0.025	0.017	0.044	-0.088	0.149	0.031	0.077	0.150	-0.062	-0.014	-0.059	0.112	0.063	-0.124	-0.058	-0.057	0.026	-0.055	-0.177	-0.028	-0.023	0.012	-0.001	0.003	0.107
cDCE Accum	-0.095	0.087	0.000	0.131	-0.014	-0.148	-0.158	0.131	1	-0.343	0.100	0.035	0.062	-0.057	0.151	0.007	0.172	0.208	-0.102	-0.061	0.062	0.217	0.071	-0.188	-0.088	-0.120	0.186	-0.016	-0.349	-0.067	0.048	-0.081	-0.002	-0.155	-0.091
VC Accum	0.193	-0.003	0.169	-0.032	0.094	0.131	0.154	-0.109	-0.343	1	-0.015	0.024	0.064	-0.069	0.025	-0.112	-0.011	-0.126	0.172	-0.141	0.074	-0.050	-0.022	-0.029	0.124	-0.237	0.299	0.063	0.083	-0.018	0.132	0.052	-0.082	-0.120	0.011
Initial pH	0.124	-0.017	0.092	-0.021	0.114	0.106	0.101	-0.025	0.100	-0.015	1	0.629	-0.046	-0.129	-0.291	-0.105	0.617	0.404	-0.023	0.176	0.064	0.365	0.095	-0.162	0.040	0.186	0.105	0.602	0.208	-0.279	-0.173	0.158	0.037	-0.281	-0.035
Max pH	0.088	-0.055	0.039	-0.054	0.023	0.103	0.099	0.017	0.035	0.024	0.629	1	0.044	-0.159	-0.175	-0.181	0.468	0.305	-0.073	0.095	0.121	0.230	0.200	-0.105	0.216	0.121	0.271	0.534	0.310	-0.280	-0.085	0.059	0.186	-0.208	0.122
Initial DO	-0.002	-0.017	0.037	0.043	-0.092	0.030	0.031	0.044	0.062	0.064	-0.046	0.044	1	0.056	0.274	-0.065	-0.070	-0.162	0.068	-0.146	0.004	0.000	0.213	-0.037	-0.179	-0.148	-0.313	-0.017	-0.246	-0.128	0.175	-0.051	-0.088	-0.098	0.000
Min DO	0.031	0.151	-0.014	0.078	0.057	-0.115	-0.119	-0.088	-0.057	-0.069	-0.129	-0.159	0.056	1	0.012	0.422	-0.030	0.049	-0.136	-0.175	-0.004	-0.150	-0.328	0.100	-0.317	0.127	0.187	-0.048	-0.291	0.125	-0.218	-0.056	-0.162	0.298	-0.080
Initial ORP	0.105	0.288	0.219	0.338	0.015	-0.214	-0.204	0.149	0.151	0.025	-0.291	-0.175	0.274	0.012	1	0.184	0.005	0.126	-0.079	-0.404	-0.059	-0.035	0.007	-0.250	0.046	-0.321	-0.311	-0.197	-0.349	-0.165	0.148	0.016	0.129	0.009	0.273
Min ORP	-0.016	0.110	-0.054	0.094	-0.018	-0.148	-0.153	0.031	0.007	-0.112	-0.105	-0.181	-0.065	0.422	0.184	1	-0.133	0.129	-0.304	-0.303	-0.259	-0.192	-0.466	0.133	-0.391	-0.013	-0.450	-0.154	-0.031	-0.035	0.006	0.142	-0.017	0.021	-0.001
Intitial SO4	0.148	0.169	0.112	0.127	0.076	-0.170	-0.169	0.077	0.172	-0.011	0.617	0.468	-0.070	-0.030	0.005	-0.133	1	0.702	0.098	-0.094	-0.020	0.270	0.171	-0.398	-0.031	-0.589	-0.501	0.441	-0.155	-0.211	-0.336	0.081	-0.015	-0.060	-0.091
Min Sulfate	0.057	0.294	0.067	0.270	0.017	-0.301	-0.304	0.150	0.208	-0.126	0.404	0.305	-0.162	0.049	0.126	0.129	0.702	1	-0.455	-0.144	-0.327	0.281	0.026	-0.213	-0.166	-0.650	-0.677	0.127	-0.381	-0.148	-0.213	0.103	0.048	0.097	-0.158
Sulfate Depletion	0.080	-0.247	0.057	-0.210	0.007	0.264	0.270	-0.062	-0.102	0.172	-0.023	-0.073	0.068	-0.136	-0.079	-0.304	0.098	-0.455	1	-0.006	0.343	0.046	0.240	-0.190	0.154	0.194	0.577	0.147	0.173	-0.031	0.153	0.016	-0.049	-0.177	-0.068
Initial TOC	0.062	-0.017	0.098	0.000	0.155	0.013	0.006	-0.014	-0.061	-0.141	0.176	0.095	-0.146	-0.175	-0.404	-0.303	-0.094	-0.144	-0.006	1	0.477	0.069	0.237	0.314	0.293	0.116	-0.556	0.156	-0.154	0.244	-0.286	-0.220	0.076	0.177	0.267
Max TOC	0.234	0.001	0.252	-0.002	0.193	0.111	0.108	-0.059	0.062	0.074	0.064	0.121	0.004	-0.004	-0.059	-0.259	-0.020	-0.327	0.343	0.477	1	0.003	0.450	0.146	0.399		0.179	0.413	0.315	0.135	-0.125	-0.085	0.073	0.085	0.073
Initial Sulfide	-0.145	-0.192	-0.103	-0.094	-0.148	0.111	0.114	0.112	0.217	-0.050	0.365	0.230	0.000	-0.150	0.270	0.281	0.046	0.069	0.003	1	0.318	-0.427	-0.310	0.400	-0.816	0.111	0.174	0.001	-0.238	-0.021	0.145	0.034	-0.280
Max Sulfide	-0.232	-0.134	-0.147	-0.142	-0.183	-0.010	-0.018	0.063	0.071	-0.022	0.095	0.200	0.213	-0.328	0.007	-0.466	0.171	0.026	0.240	0.237	0.450	0.318	1	-0.118	-0.024	-0.056	0.089	0.205	-0.260	-0.013	-0.156	-0.114	0.154	-0.144	-0.127
Initial Fe	0.072	0.042	0.035	0.019	0.031	0.071	0.068	-0.124	-0.188	-0.029	-0.162	-0.105	-0.037	0.100	-0.250	0.133	-0.398	-0.213	-0.190	0.314	0.146	-0.427	-0.118	1	0.149	-0.949		-0.140	0.135	0.274	-0.112	-0.014	-0.024	0.253	0.151
Max Fe	0.222	-0.008	0.185	0.000	0.089	0.204	0.217	-0.058	-0.088	0.124	0.040	0.216	-0.179	-0.317	0.046	-0.391	-0.031	-0.166	0.154	0.293	0.399	-0.310	-0.024	0.149	1		-0.400	0.183	0.297	-0.115	0.147	-0.180	0.184	0.048	0.203
Intial DHC	-0.143	-0.257	-0.109	-0.171	0.120	0.403	0.403	-0.057	-0.120	-0.237	0.186	0.121	-0.148	0.127	-0.321	-0.013	-0.589	-0.650	0.194	0.116		0.400	-0.056	-0.949		1	0.211	-0.050		-0.478	0.421	-0.375	0.196	-0.421	-0.478
Max DHC	-0.192	-0.570	-0.089	-0.484	-0.021	0.282	0.283	0.026	0.186	0.299	0.105	0.271	-0.313	0.187	-0.311	-0.450	-0.501	-0.677	0.577	-0.556	0.179	-0.816	0.089		-0.400	0.211	1	0.041	-0.632	-0.475	0.613	-0.639	-0.517	-0.545	0.407
Max Alkalinity	0.054	-0.146	0.044	-0.179	0.063	0.125	0.124	-0.055	-0.016	0.063	0.602	0.534	-0.017	-0.048	-0.197	-0.154	0.441	0.127	0.147	0.156	0.413	0.111	0.205	-0.140	0.183	-0.050	0.041	1	0.211	-0.596	0.006	0.491	-0.400	-0.213	-0.397
Max Methane	0.101	-0.285	-0.048	-0.386	0.122	0.273	0.275	-0.177	-0.349	0.083	0.208	0.310	-0.246	-0.291	-0.349	-0.031	-0.155	-0.381	0.173	-0.154	0.315	0.174	-0.260	0.135	0.297		-0.632	0.211	1	0.131	-0.029	0.447	-0.022	-0.317	-0.274
Temp	0.013	0.029	-0.043	0.025	0.037	-0.026	-0.029	-0.028	-0.067	-0.018	-0.279	-0.280	-0.128	0.125	-0.165	-0.035	-0.211	-0.148	-0.031	0.244	0.135	0.001	-0.013	0.274	-0.115	-0.478	-0.475	-0.596	0.131	1	-0.526	-0.349	0.295	0.511	0.085
Seepage Velocity	-0.032	-0.110	0.042	-0.069	-0.022	0.118	0.124	-0.023	0.048	0.132	-0.173	-0.085	0.175	-0.218	0.148	0.006	-0.336	-0.213	0.153	-0.286	-0.125	-0.238	-0.156	-0.112	0.147	0.421	0.613	0.006	-0.029	-0.526	1	0.227	-0.247	-0.598	-0.149
Spacing	0.079	-0.092	0.130	-0.023	0.106	0.116	0.117	0.012	-0.081	0.052	0.158	0.059	-0.051	-0.056	0.016	0.142	0.081	0.103	0.016	-0.220	-0.085	-0.021	-0.114	-0.014	-0.180	-0.375	-0.639	0.491	0.447	-0.349	0.227	1	-0.477	-0.394	-0.349
Dosing	0.137	0.220	0.048	0.199	-0.044	-0.072	-0.071	-0.001	-0.002	-0.082	0.037	0.186	-0.088	-0.162	0.129	-0.017	-0.015	0.048	-0.049	0.076	0.073	0.145	0.154	-0.024	0.184	0.196	-0.517	-0.400	-0.022	0.295	-0.247	-0.477	1	0.129	0.589
Heterogeneity	-0.086	0.051	-0.196	0.017	-0.108	-0.092	-0.098	0.003	-0.155	-0.120	-0.281	-0.208	-0.098	0.298	0.009	0.021	-0.060	0.097	-0.177	0.177	0.085	0.034	-0.144	0.253	0.048	-0.421	-0.545	-0.213	-0.317	0.511	-0.598	-0.394	0.129	1	0.133
Fines	0.304	0.409	0.319	0.408	0.139	-0.176	-0.172	0.107	-0.091	0.011	-0.035	0.122	0.000	-0.080	0.273	-0.001	-0.091	-0.158	-0.068	0.267	0.073	-0.280	-0.127	0.151	0.203	-0.478	0.407	-0.397	-0.274	0.085	-0.149	-0.349	0.589	0.133	1

6.2.1 Evaluation of Performance Measures

The first step was to evaluate correlations between the various performance measures themselves to select key performance measures that can be evaluated with respect to site characteristics and remediation methods. Formal database parameter names are shown in italics in the following text.

The *R* values for the SRO correlations between performance measures are provided in **Table 6-2.** All of the correlations considered in the Table are statistically significant at a 95 percent confidence level (shown in red) except for the correlation between *Rebound* versus *VC Accumulation*. Definitions of the parameters in the database are provided in **Section 5.4.**

Table 6-2. SRO Correlation Coefficients for Performance Measures.

Variable	Conc Reduction	Dechlor-ination	Rebound	cDCE Accum	VC Accum
Conc Reduction	1	0.998	-0.515	-0.148	0.131
Dechlorination	0.998	1	-0.513	-0.158	0.154
Rebound	-0.515	-0.513	1	0.131	-0.109
cDCE Accum	-0.148	-0.158	0.131	1	-0.343
VC Accum	0.131	0.154	-0.109	-0.343	1

It is important to note that the *Concentration Reduction* performance parameter is based on the difference between the initial and minimum chlorinated ethene (CE) concentrations divided by the initial CE concentration and is unaffected by any rebound that may occur after the minimum CE concentrations are reached. Likewise, the *Dechlorination* parameter is based on the extent of dechlorination that occurs between the initial and minimum CE concentration and is also unaffected by any subsequent rebound that may occur after the minimum is reached. The *Rebound* performance parameter is based on the difference between the initial decrease in CE concentration and any subsequent increase in CE concentrations after the minimum is reached.

Concentration Reduction has significant Spearman Rank Order (SRO) correlations with:

Dechlorination – A very high positive correlation (*R*= +0.998) is observed, indicating that *Dechlorination* and *Concentration Reduction* are equivalent measures of CE reduction, but both parameters do not consider any subsequent rebound in concentrations if it occurs.

Rebound – A negative correlation (*R*= –0.515) is observed, suggesting that better concentration reduction is a predictor of less rebound after the minimum CE concentration is reached.

cis-DCE Accumulation – A negative correlation (*R*= –0.148) suggests that better concentration reduction is a predictor of less cis-DCE accumulation after the minimum CE concentration is reached.

VC Accumulation – A low but positive correlation (R= +0.131) suggests that large initial reductions in CE concentrations are not a good predictor of VC accumulation after the minimum CE concentrations are reached. In addition, the negative correlation between *VC Accumulation* and *cis-DCE Accumulation* suggests that these two parameters may be controlled by different processes.

The parameters *cis-DCE Accumulation* and *Rebound* were positively correlated with each other because cis-DCE is often the main contributor to rebound. However, *VC Accumulation* is not significantly correlated with *Rebound*, and is negatively correlated with *cis-DCE Accumulation*, suggesting that factors that affect VC accumulation are different from those affecting rebound. These results show that the *Concentration Reduction*, *Rebound*, and *cis-DCE Accumulation* performance parameters are useful indicators of performance and can be used to determine the effects of site characteristics and remediation methods on treatment system performance.

6.2.2 Numerical Site Characteristics

Table 6-3 provides the SRO correlation coefficients for the 22 numerical site characteristics parameters versus the performance parameter *Concentration Reduction*, and **Figure 6-1** shows these results graphically. The relationships between categorical parameters versus *Concentration Reduction* are shown with box plots and Kruskal Wallis test results. *Concentration Reduction* has statistically significant SRO correlations with the following numerical parameters:

Initial ORP – Negatively correlated with *Concentration Reduction*. Low initial ORP is a favorable condition for CE degradation. If ORP is low at the start of treatment, then it is likely that redox conditions are favorable for degradation during the treatment period.

Minimum ORP – Negatively correlated with *Concentration Reduction*. Low minimum ORP is a favorable condition for CE degradation. If ORP reached low values during treatment, then CE degradation is maximized. This parameter is also negatively correlated with Sulfate Depletion, indicating that low redox potentials are required for sulfate reduction, which is a key factor in CE degradation.

Initial Sulfate – Negatively correlated with *Concentration Reduction.* High initial sulfate interferes with degradation by providing competition for hydrogen between anaerobes that are involved in sulfate reduction and dechlorination. High sulfate also acts as a redox buffer that maintains Eh-pH conditions at or above the sulfate/sulfide equilibrium, which is above the optimal region of Eh-pH space for reductive dechlorination processes.

Min Sulfate – Negatively correlated with *Concentration Reduction*. Low or non-detectable sulfate during treatment indicates the establishment of sulfate-reducing conditions under which CE degradation rates are maximized. Persistently high sulfate concentrations can cause a "stall" as the redox conditions are prevented from entering the sulfide Eh-pH stability field, which is a field that is favorable for reductive dechlorination.

Sulfate Depletion – Positively correlated with *Concentration Reduction.* Sulfate Depletion is also significantly correlated with *Min CE* (-) and *Final CE* (-). The depletion of sulfate is a key step for the successful degradation of CEs. The inability to reduce sulfate concentrations can be caused by insufficiently reducing conditions, or by a continual source of sulfate, which can occur in coastal sites, arid sites with high-sulfate groundwater, or the presence of gypsum layers in the treatment zone.

Maximum Iron – Positively correlated with *Concentration Reduction.* High dissolved iron concentration is an indicator of iron-reducing conditions, which is a favorable condition for CE degradation. *Max Fe* is also significantly correlated with *Min DO* (-) and *Min ORP* (-), which are also indicators of favorable conditions for CE degradation.

Fines – Negatively correlated with *Concentration Reduction*. This may be due to the diffusion of CEs into and out of the fine-grained layers within the treatment zone, which can limit the effectiveness and/or extend the time required for *in situ* treatment. Fines are also positively correlated with *Min CE* and *Final CE*, also demonstrating that the presence of fines can limit the effectiveness of remediation.

Max DHC – This parameter is not correlated with *Concentration Reduction* or any of the rebound parameters, but it is significantly correlated with *Min CE* (-) and *Final CE* (-), indicating that elevated DHC counts contribute to lowered CE concentrations during remediation. In addition, *Max DHC* is significantly correlated with *Min ORP* (-), *Min Sulfate* (-), and *Sulfate Depletion* (+), which are all reliable indicators of performance. It should be noted that only 26 of the 256 cases have values for *Max DHC*, so these results may not be representative of its overall effect.

Table 6-3. SRO Correlation Coefficients for Site Characteristics.

Variable	Conc Reduction	Dechlor-ination	Rebound	cDCE Accum	VC Accum	Initial pH	Max pH	Initial DO	Min DO	Initial ORP	Min ORP	Intitial SO4	Min Sulfate	Sulfate Depletion	Initial TOC	Max TOC	Initial Sulfide	Max Sulfide	Initial Fe	Max Fe	Intial DHC	Max DHC	Max Alkalinity	Max Methane	Temp	Seepage Velocity	Heterogeneity	Fines
Conc Reduction	1	0.998	-0.515	-0.148	0.131	0.106	0.103	0.030	-0.115	-0.214	-0.148	-0.170	-0.301	0.264	0.013	0.111	0.111	-0.010	0.071	0.204	0.403	0.282	0.125	0.273	-0.026	0.118	-0.092	-0.176
Dechlorination	0.998	1	-0.513	-0.158	0.154	0.101	0.099	0.031	-0.119	-0.204	-0.153	-0.169	-0.304	0.270	0.006	0.108	0.114	-0.018	0.068	0.217	0.403	0.283	0.124	0.275	-0.029	0.124	-0.098	-0.172
Rebound	-0.515	-0.513	1	0.131	-0.109	-0.025	0.017	0.044	-0.088	0.149	0.031	0.077	0.150	-0.062	-0.014	-0.059	0.112	0.063	-0.124	-0.058	-0.057	0.026	-0.055	-0.177	-0.028	-0.023	0.003	0.107
cDCE Accum	-0.148	-0.158	0.131	1	-0.343	0.100	0.035	0.062	-0.057	0.151	0.007	0.172	0.208	-0.102	-0.061	0.062	0.217	0.071	-0.188	-0.088	-0.120	0.186	-0.016	-0.349	-0.067	0.048	-0.155	-0.091
VC Accum	0.131	0.154	-0.109	-0.343	1	-0.015	0.024	0.064	-0.069	0.025	-0.112	-0.011	-0.126	0.172	-0.141	0.074	-0.050	-0.022	-0.029	0.124	-0.237	0.299	0.063	0.083	-0.018	0.132	-0.120	0.011
Initial pH	0.106	0.101	-0.025	0.100	-0.015	1	0.629	-0.046	-0.129	-0.291	-0.105	0.617	0.404	-0.023	0.176	0.064	0.365	0.095	-0.162	0.040	0.186	0.105	0.602	0.208	-0.279	-0.173	-0.281	-0.035
Max pH	0.103	0.099	0.017	0.035	0.024	0.629	1	0.044	-0.159	-0.175	-0.181	0.468	0.305	-0.073	0.095	0.121	0.230	0.200	-0.105	0.216	0.121	0.271	0.534	0.310	-0.280	-0.085	-0.208	0.122
Initial DO	0.030	0.031	0.044	0.062	0.064	-0.046	0.044	1	0.056	0.274	-0.065	-0.070	-0.162	0.068	-0.146	0.004	0.000	0.213	-0.037	-0.179	-0.148	-0.313	-0.017	-0.246	-0.128	0.175	-0.098	0.000
Min DO	-0.115	-0.119	-0.088	-0.057	-0.069	-0.129	-0.159	0.056	1	0.012	0.422	-0.030	0.049	-0.136	-0.175	-0.004	-0.150	-0.328	0.100	-0.317	0.127	0.187	-0.048	-0.291	0.125	-0.218	0.298	-0.080
Initial ORP	-0.214	-0.204	0.149	0.151	0.025	-0.291	-0.175	0.274	0.012	1	0.184	0.005	0.126	-0.079	-0.404	-0.059	-0.035	0.007	-0.250	0.046	-0.321	-0.311	-0.197	-0.349	-0.165	0.148	0.009	0.273
Min ORP	-0.148	-0.153	0.031	0.007	-0.112	-0.105	-0.181	-0.065	0.422	0.184	1	-0.133	0.129	-0.304	-0.303	-0.259	-0.192	-0.466	0.133	-0.391	-0.013	-0.450	-0.154	-0.031	-0.035	0.006	0.021	-0.001
Intitial SO4	-0.170	-0.169	0.077	0.172	-0.011	0.617	0.468	-0.070	-0.030	0.005	-0.133	1	0.702	0.098	-0.094	-0.020	0.270	0.171	-0.398	-0.031	-0.589	-0.501	0.441	-0.155	-0.211	-0.336	-0.060	-0.091
Min Sulfate	-0.301	-0.304	0.150	0.208	-0.126	0.404	0.305	-0.162	0.049	0.126	0.129	0.702	1	-0.455	-0.144	-0.327	0.281	0.026	-0.213	-0.166	-0.650	-0.677	0.127	-0.381	-0.148	-0.213	0.097	-0.158
Sulfate Depletion	0.264	0.270	-0.062	-0.102	0.172	-0.023	-0.073	0.068	-0.136	-0.079	-0.304	0.098	-0.455	1	-0.006	0.343	0.046	0.240	-0.190	0.154	0.194	0.577	0.147	0.173	-0.031	0.153	-0.177	-0.068
Initial TOC	0.013	0.006	-0.014	-0.061	-0.141	0.176	0.095	-0.146	-0.175	-0.404	-0.303	-0.094	-0.144	-0.006	1	0.477	0.069	0.237	0.314	0.293	0.116	-0.556	0.156	-0.154	0.244	-0.286	0.177	0.267
Max TOC	0.111	0.108	-0.059	0.062	0.074	0.064	0.121	0.004	-0.004	-0.059	-0.259	-0.020	-0.327	0.343	0.477	1	0.003	0.450	0.146	0.399		0.179	0.413	0.315	0.135	-0.125	0.085	0.073
Initial Sulfide	0.111	0.114	0.112	0.217	-0.050	0.365	0.230	0.000	-0.150	-0.035	-0.192	0.270	0.281	0.046	0.069	0.003	1	0.318	-0.427	-0.310	0.400	-0.816	0.111	0.174	0.001	-0.238	0.034	-0.280
Max Sulfide	-0.010	-0.018	0.063	0.071	-0.022	0.095	0.200	0.213	-0.328	0.007	-0.466	0.171	0.026	0.240	0.237	0.450	0.318	1	-0.118	-0.024	-0.056	0.089	0.205	-0.260	-0.013	-0.156	-0.144	-0.127
Initial Fe	0.071	0.068	-0.124	-0.188	-0.029	-0.162	-0.105	-0.037	0.100	-0.250	0.133	-0.398	-0.213	-0.190	0.314	0.146	-0.427	-0.118	1	0.149	-0.949		-0.140	0.135	0.274	-0.112	0.253	0.151
Max Fe	0.204	0.217	-0.058	-0.088	0.124	0.040	0.216	-0.179	-0.317	0.046	-0.391	-0.031	-0.166	0.154	0.293	0.399	-0.310	-0.024	0.149	1		-0.400	0.183	0.297	-0.115	0.147	0.048	0.203
Intial DHC	0.403	0.403	-0.057	-0.120	-0.237	0.186	0.121	-0.148	0.127	-0.321	-0.013	-0.589	-0.650	0.194	0.116		0.400	-0.056	-0.949		1	0.211	-0.050		-0.478	0.421	-0.421	-0.478
Max DHC	0.282	0.283	0.026	0.186	0.299	0.105	0.271	-0.313	0.187	-0.311	-0.450	-0.501	-0.677	0.577	-0.556	0.179	-0.816	0.089		-0.400	0.211	1	0.041	-0.632	-0.475	0.613	-0.545	0.407
Max Alkalinity	0.125	0.124	-0.055	-0.016	0.063	0.602	0.534	-0.017	-0.048	-0.197	-0.154	0.441	0.127	0.147	0.156	0.413	0.111	0.205	-0.140	0.183	-0.050	0.041	1	0.211	-0.596	0.006	-0.213	-0.397
Max Methane	0.273	0.275	-0.177	-0.349	0.083	0.208	0.310	-0.246	-0.291	-0.349	-0.031	-0.155	-0.381	0.173	-0.154	0.315	0.174	-0.260	0.135	0.297		-0.632	0.211	1	0.131	-0.029	-0.317	-0.274
Temp	-0.026	-0.029	-0.028	-0.067	-0.018	-0.279	-0.280	-0.128	0.125	-0.165	-0.035	-0.211	-0.148	-0.031	0.244	0.135	0.001	-0.013	0.274	-0.115	-0.478	-0.475	-0.596	0.131	1	-0.526	0.511	0.085
Seepage Velocity	0.118	0.124	-0.023	0.048	0.132	-0.173	-0.085	0.175	-0.218	0.148	0.006	-0.336	-0.213	0.153	-0.286	-0.125	-0.238	-0.156	-0.112	0.147	0.421	0.613	0.006	-0.029	-0.526	1	-0.598	-0.149
Heterogeneity	-0.092	-0.098	0.003	-0.155	-0.120	-0.281	-0.208	-0.098	0.298	0.009	0.021	-0.060	0.097	-0.177	0.177	0.085	0.034	-0.144	0.253	0.048	-0.421	-0.545	-0.213	-0.317	0.511	-0.598	1	0.133
Fines	-0.176	-0.172	0.107	-0.091	0.011	-0.035	0.122	0.000	-0.080	0.273	-0.001	-0.091	-0.158	-0.068	0.267	0.073	-0.280	-0.127	0.151	0.203	-0.478	0.407	-0.397	-0.274	0.085	-0.149	0.133	1

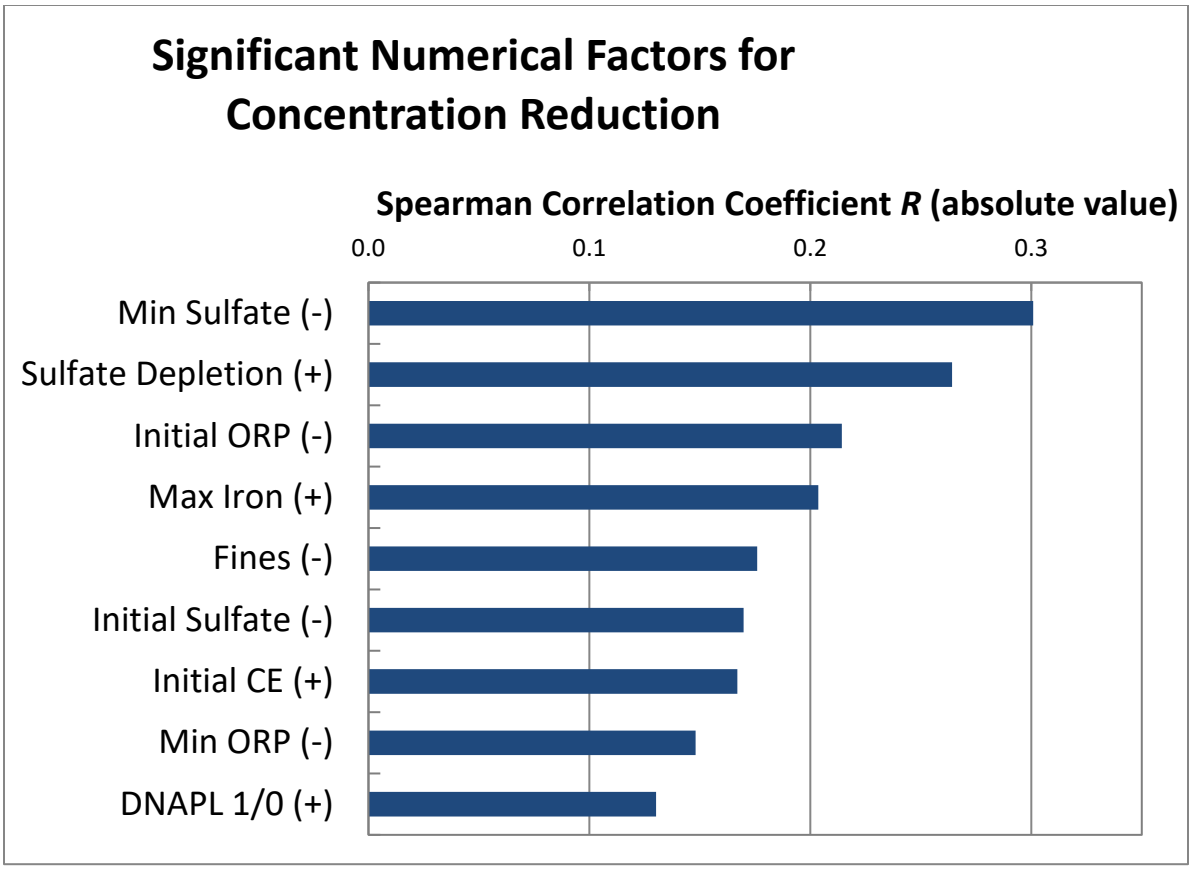


Figure 6-1. Significant Numerical Factors for Predicting Concentration Reduction.

6.2.3 Categorical Site Characteristics Parameters

Presence of DNAPL – Cases where DNAPL was present were assigned a "Yes" and sites without DNAPL were assigned a "No" for the parameter DNAPL Y/N. **Figure 6-2** shows a pair of box plots that compare the distributions of Concentration Reduction for the two categories of cases. These plots provide a summary view of the entire data set, including the overall location and degree of symmetry. The box encloses the central 50 percent of the data points so that the top of the box represents the 75th percentile, and the bottom of the box represents the 25th percentile. The median of the data set is represented by a small box within the larger box. The upper whisker extends outward from the box to the maximum point, and the lower whisker extends to the minimum point. **Figure 6-2** shows similar distribution ranges for the two categories, but the median and the 25th and 75th percentiles of the distribution with DNAPL (n= 43) are shifted higher relative to the distribution without DNAPL (n= 213).

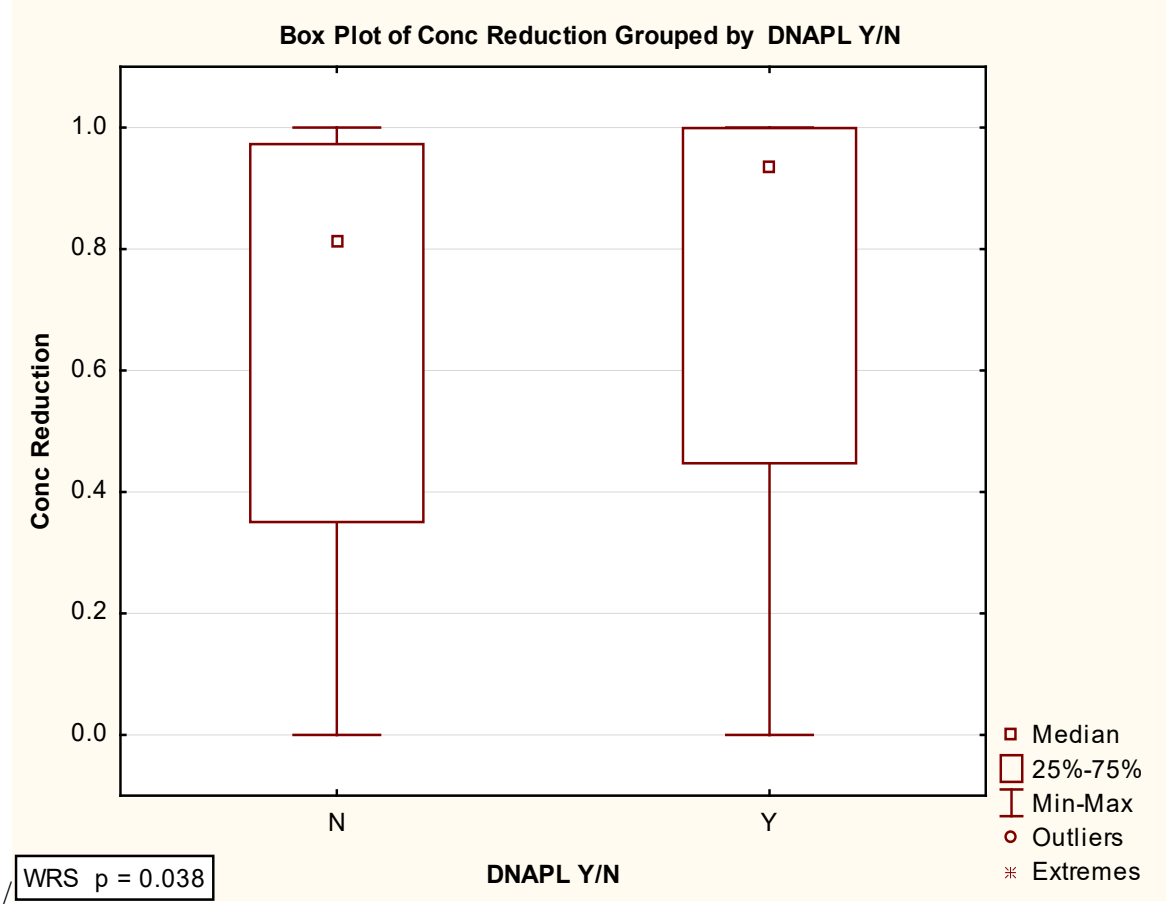


Figure 6-2. Box Plots of Concentration Reduction by the Presence or Absence of DNAPL.

Cases with and without DNAPL (parameter *DNAPL Y/N*) were also compared with respect to *Concentration Reduction* using the Wilcoxon rank sum test. The test result *p*-level, shown on the lower left corner of the Figure of 0.038 is less than the critical value of 0.05, indicating that there is a statistically significant difference between the two categories with respect to *Concentration Reduction*. The upward shift in the cases with DNAPL is likely due to the fact that sites with DNAPL usually have higher initial CE concentrations relative to sites without DNAPL, so the sites with DNAPL tend to show a greater decrease during remediation.

The parameter *DNAPL 1/0* assigns a "1" if DNAPL is present and a "0" if it is absent. This allows the SRO procedure to be used to evaluate correlations with other numerical parameters. *DNAPL 1/0* has the highest significant positive SRO correlations with *Initial CE* and *Max CE* (**Table 6-2**), supporting the theory that cases where DNAPL is present have higher initial concentrations that allow greater decreases during remediation. These results also suggest that the presence of DNAPL at a site does not interfere with reductions in CE concentrations during remediation. The *DNAPL 1/0* parameter is not correlated with *Rebound*, *cis-DCE Accumulation*, or *VC Accumulation*, so its presence is not a predictor of rebound, which is somewhat surprising.

Fines Rank – Cases were assigned a high (H), medium (M), or low (L) based on the percent fines (silt plus clay) present in the treated zone. **Figure 6-3** shows box plot comparisons of these three categories of cases as a function of *Concentration Reduction*. The box plots show a clear progression of medians, with the low fines cases (*n*= 102) performing better than the medium fines cases (*n*= 115), which in turn, perform better than the high fines cases (*n*= 39). The KW test p-level of 0.035 indicates that there is a statistically significant difference between one or more of the three categories. High fines in the treatment zone can absorb CE and then slowly release it, and it can also limit the ability to adequately distribute reagents in the subsurface.

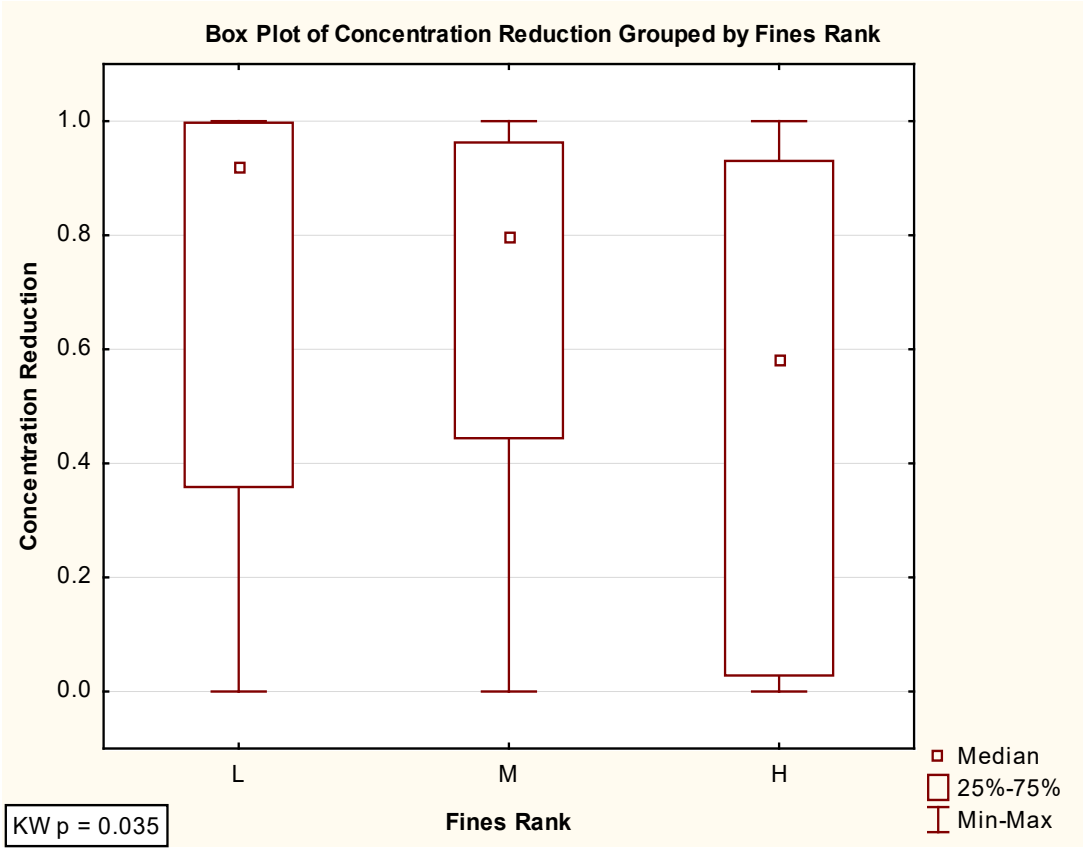


Figure 6-3. Box Plots of Concentration Reduction by Fines Rank.

Previous Remediation Rank – Cases were assigned a Yes or No, depending on whether remediation had previously been performed at that location. A box plot comparing these two categories is shown in **Figure 6-4.** The Yes category (n= 191) has a higher median and percentiles relative to the No category (n= 57). The very low WRS test *p*-level (0.0008) indicates a statistically significant difference between the categories. A history of previous remediation at a site is a strong predictor of successful CE concentration reduction.

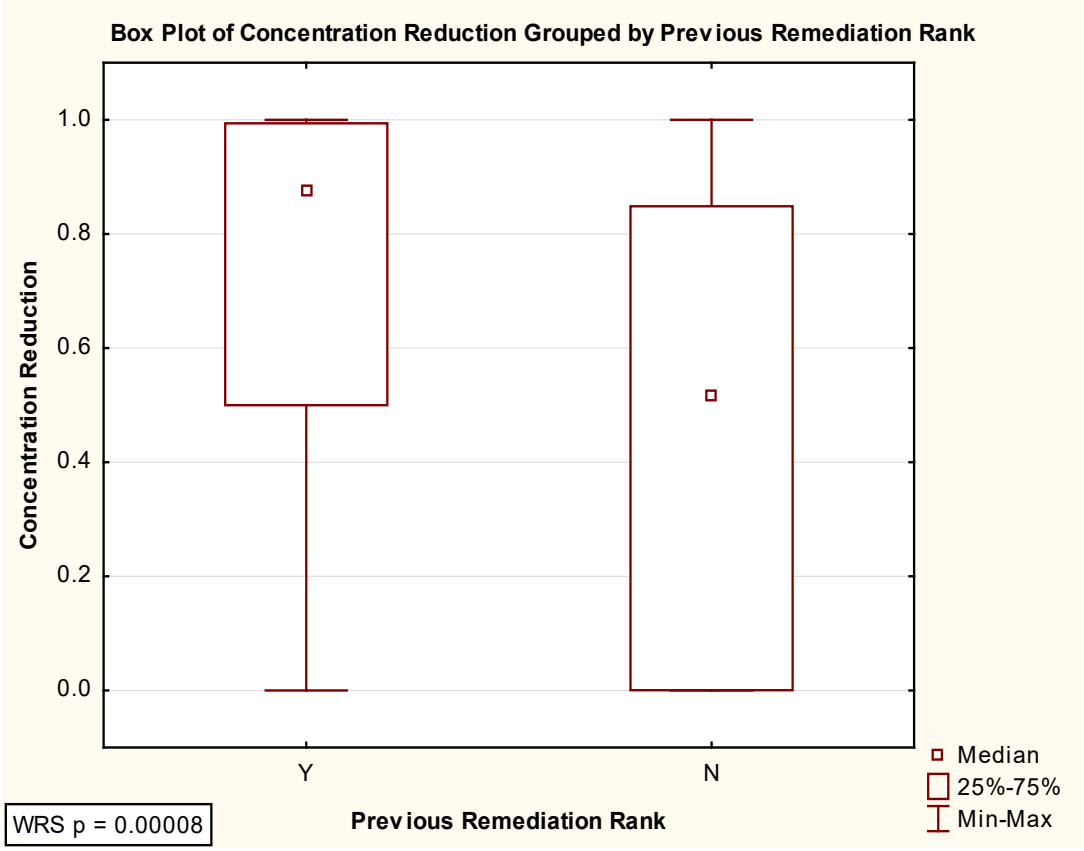


Figure 6-4. Box Plots of Concentration Reduction by Previous Remediation Rank.

Initial pH – It is recognized that the groundwater pH needs to be in the circum-neutral range for optimal degradation. Sites with pH conditions that are either too high or too low may, therefore, have lower amounts of CE reduction. The relationship between *Concentration Reduction* versus a broad range of pH values is thus expected to be a peaking function rather than a monotonic function, so a SRO correlation approach would not be appropriate. To address the dependence of *Concentration Reduction* on pH, the initial pH conditions at 229 cases where results are available were divided into four categories (<5, 5 to 6, 6 to 7, and >7). The *Concentration Reduction* results for these four categories were then compared using box plots (**Figure 6-5**) and the KW test. The KW *p*-value of 0.042 indicates that one or more of the four groups of pH ranges are likely drawn from a different distribution of *Concentration Reduction* values. The box plot shows a gradual increase in the *Concentration Reduction* medians as the pH increases. The lowest median, 25th, and 75th percentiles are observed in the lowest pH (<5.0) category. The 23 pH values in this group range from 3.67 to 4.96, with a mean of 4.45. These cases are from five different installations, so the results do not appear to be driven by location. Most of the cases in the low pH category likely had inhibited the degradation of CEs.

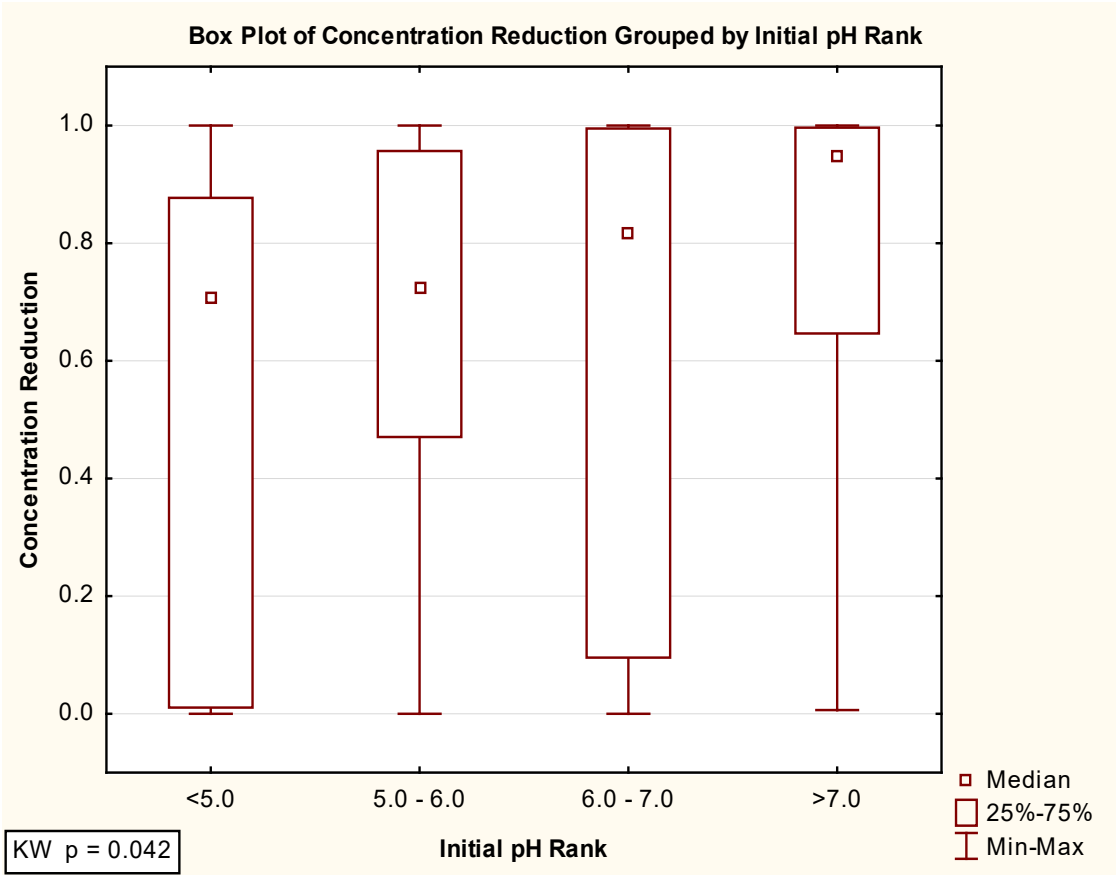


Figure 6-5. Box Plots of Performance by Initial pH.

6.2.4 Remediation Methods

Table 6-4 provides the SRO correlation coefficients for the two numerical site characteristics parameters *Spacing* and *Dosing* versus the performance parameter *Concentration Reduction*. Neither of these parameters is significantly correlated with *Concentration Reduction*. The relationships between categorical remediation methods parameters versus *Concentration Reduction* are shown with box plots and WRS or KW test results and are discussed below.

***Bioaug Rank* –** Bioaugmentation methods involve the injection of specific strains or consortia of live microbes such as KB-1 or SDC-9. Cases where bioaugmentation was used (*n*= 122) were compared with cases where it was not used (*n*= 134) in **Figure 6-6**. The Figure shows little difference in *Concentration Reduction* between the two groups, and the WRS *p*-value of 0.467 confirms that there is no significant difference. However, a likely confounding factor is that bioassessments (e.g., qPCR and/or treatability studies) may have been performed at some of these sites, resulting in the use of bioaugmentation primarily at sites where it was considered to be needed due to the lack of indigenous microbes and/or treatability study evidence that CE degradation was likely to occur via biostimulation alone.

Table 6-4. SRO Correlation Coefficients for Remediation Methods.

Variable	Conc Reduction	Dechlor-ination	Rebound	cDCE Accum	VC Accum	Spacing	Dosing
Conc Reduction	1	0.998	-0.515	-0.148	0.131	0.116	-0.072
Dechlorination	0.998	1	-0.513	-0.158	0.154	0.117	-0.071
Rebound	-0.515	-0.513	1	0.131	-0.109	0.012	-0.001
cDCE Accum	-0.148	-0.158	0.131	1	-0.343	-0.081	-0.002
VC Accum	0.131	0.154	-0.109	-0.343	1	0.052	-0.082
Spacing	0.116	0.117	0.012	-0.081	0.052	1	-0.477
Dosing	-0.072	-0.071	-0.001	-0.002	-0.082	-0.477	1

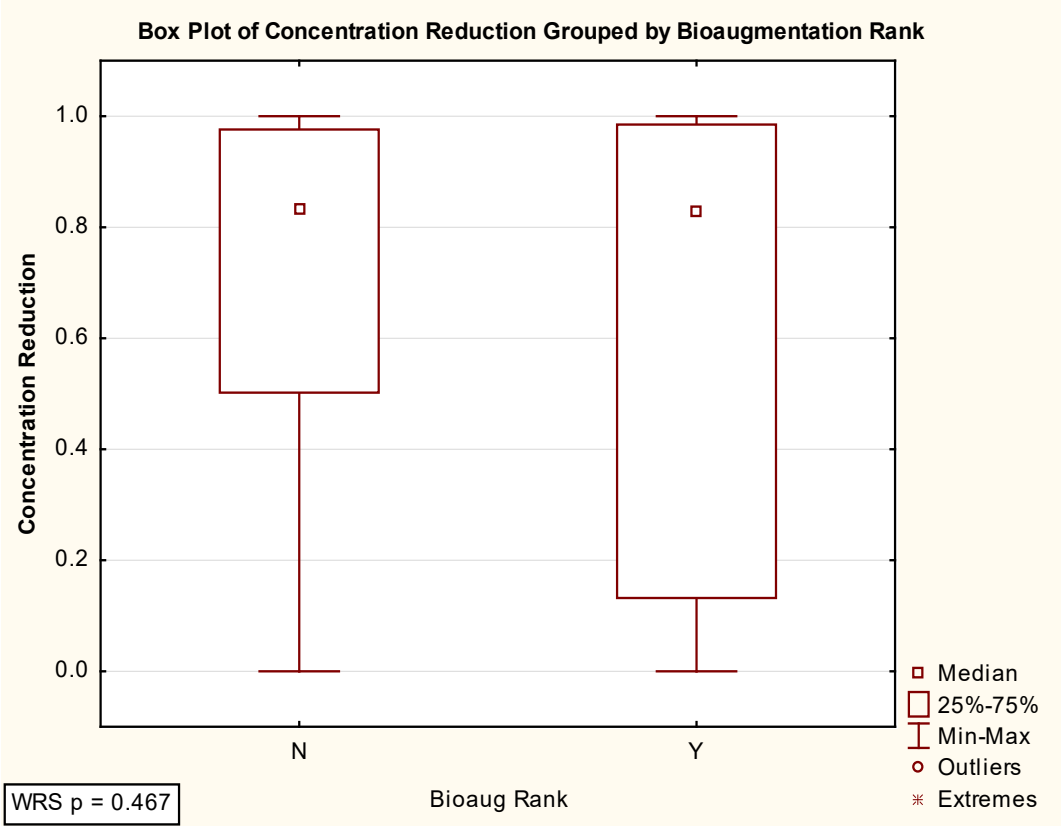


Figure 6-6. Box Plots of Performance by Bioaugmentation Rank.

Substrate Rank – This parameter ranks high viscosity carbon substrates, including molasses, EOS, EVO, Lactoil™, and HRC as "H" (*n*= 148), and low viscosity substrates such as sodium lactate, lactic acid, and hydrogen as "L" (*n*= 106). The box plot comparison (**Figure 6-7**) shows very similar distributions of Concentration Reduction in the two categories, and the WRS *p*-value test result of 0.743 indicates no significant differences between the two categories. These results indicate that the viscosity of the substrate is not a key factor in predicting performance.

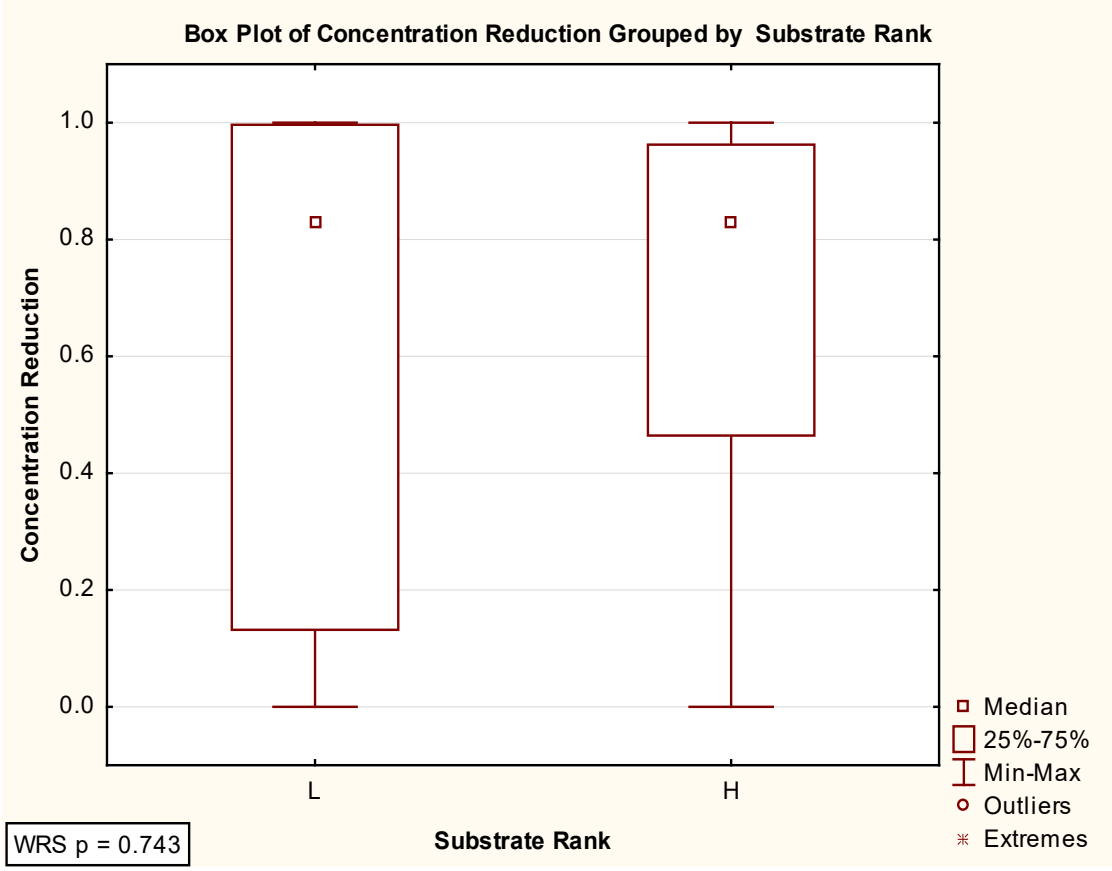


Figure 6-7. Box Plots of Performance by Carbon Substrate Rank.

Method of Injection Category **–** Cases where direct application of amendments via injection wells or direct push (*n*= 170) was used versus recirculation loops (*n*= 86) were compared with respect to *Concentration Reduction*. A box plot comparison of the two groups is shown in **Figure 6-8.** The WRS *p*-value of 0.276 indicates that there are no significant differences in *Concentration Reduction* between the two groups. A confounding factor in this comparison may be that sites with permeable treatment zones do not need recirculation, which is an added expense and is a regulatory issue in some states. If recirculation is only used at sites where it is required for adequate amendment delivery, then these sites would be expected to have similar performance as the sites with more permeable treatment zones where recirculation is not required and was not used.

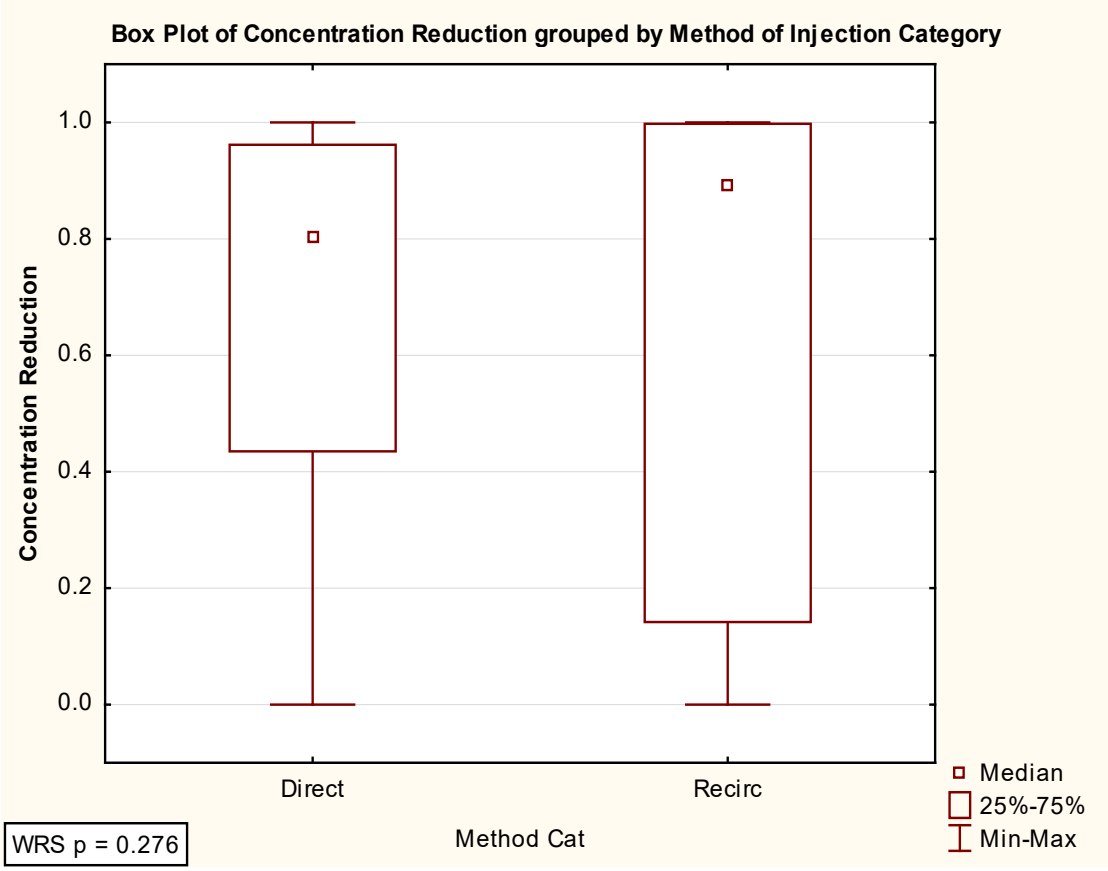


Figure 6-8. Box Plots of Performance by Method of Injection Category.

***Use of Nutrients* –** Sites where inorganic nutrients were used were assigned a "Yes" (n= 25), and sites where nutrients were not used were assigned a "No" (n= 231) for this parameter. A box plot comparing the distributions of *Concentration Reduction* for each group is provided in **Figure 6-9**. The plot shows little difference in performance between the two groups, which is confirmed by the high WRS test p-value of 0.816. These results suggest that the addition of nutrients has little effect on *Concentration Reduction*. However, as was the case with bioaugmentation, laboratory or field assessments are performed at some sites to determine if nutrients are needed. If nutrients were only used where needed, then these results would be expected.

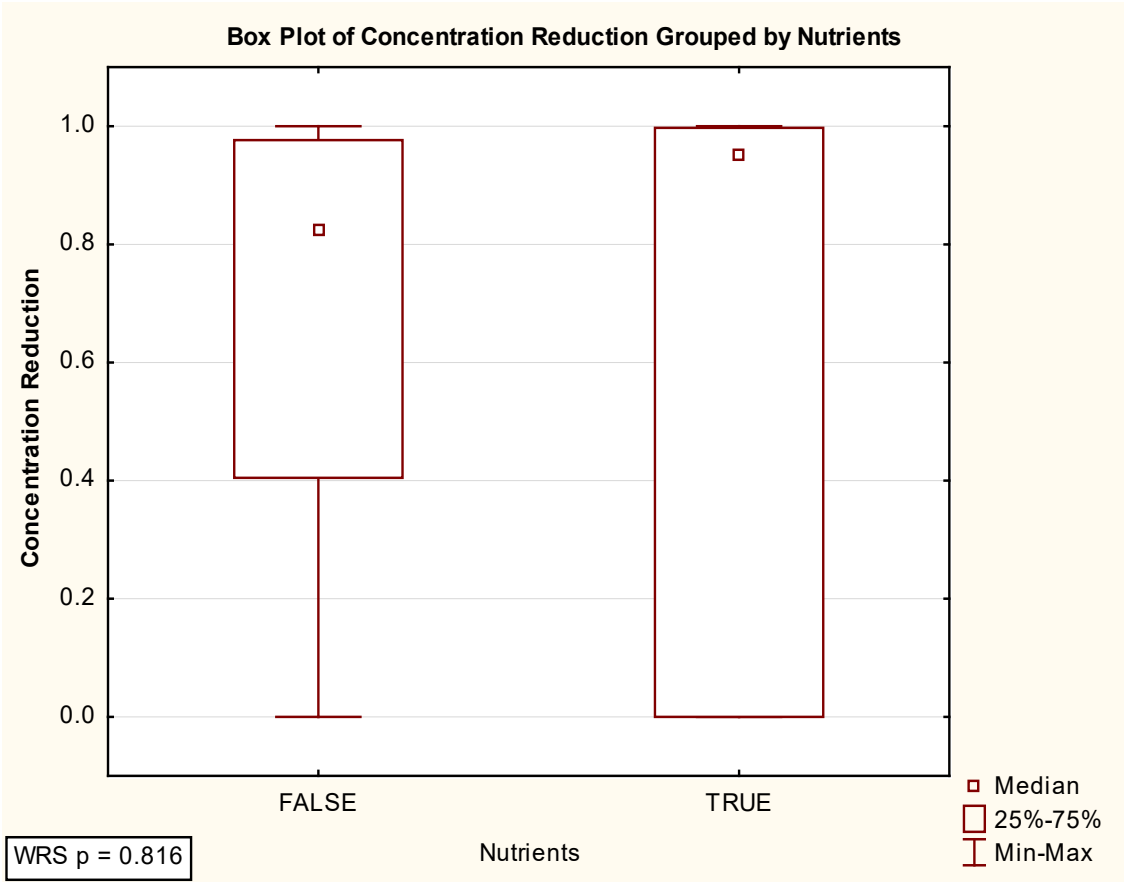


Figure 6-9. Box Plots of Performance by Use of Nutrients.

6.2.5 Factors Affecting Rebound, cis-DCE Accumulation, and VC Accumulation

The *Concentration Reduction* and *Dechlorination* parameters are measures of the initial decrease in CE concentrations to the minimum values, irrespective of any subsequent increases. The rebound parameters *Rebound*, *cis-DCE Accumulation*, and *VC Accumulation* are measures of any increases after the minimum CE concentrations are reached during and after remediation activities. Factors that affect these numerical and categorical parameters are discussed in this section.

Rebound – This parameter is negatively correlated (R= -0.515) with *Concentration Reduction*, in part because a greater initial decrease in CE concentrations allows a greater subsequent increase. It is also negatively correlated with *Dechlorination*, which is an alternate measure of initial concentration reduction. *Rebound* is positively correlated with *cis-DCE Accumulation* because cis-DCE is often a major contributor to rebound.

Numerical site characteristics that have significant correlations with *Rebound* include *Min Sulfate* (+) and *Initial ORP* (+) (**Figure 6-10**). These correlations suggest that high initial ORP is a predictor of rebound. In addition, failure to adequately reduce sulfate to low concentrations in the groundwater may also lead to rebound.

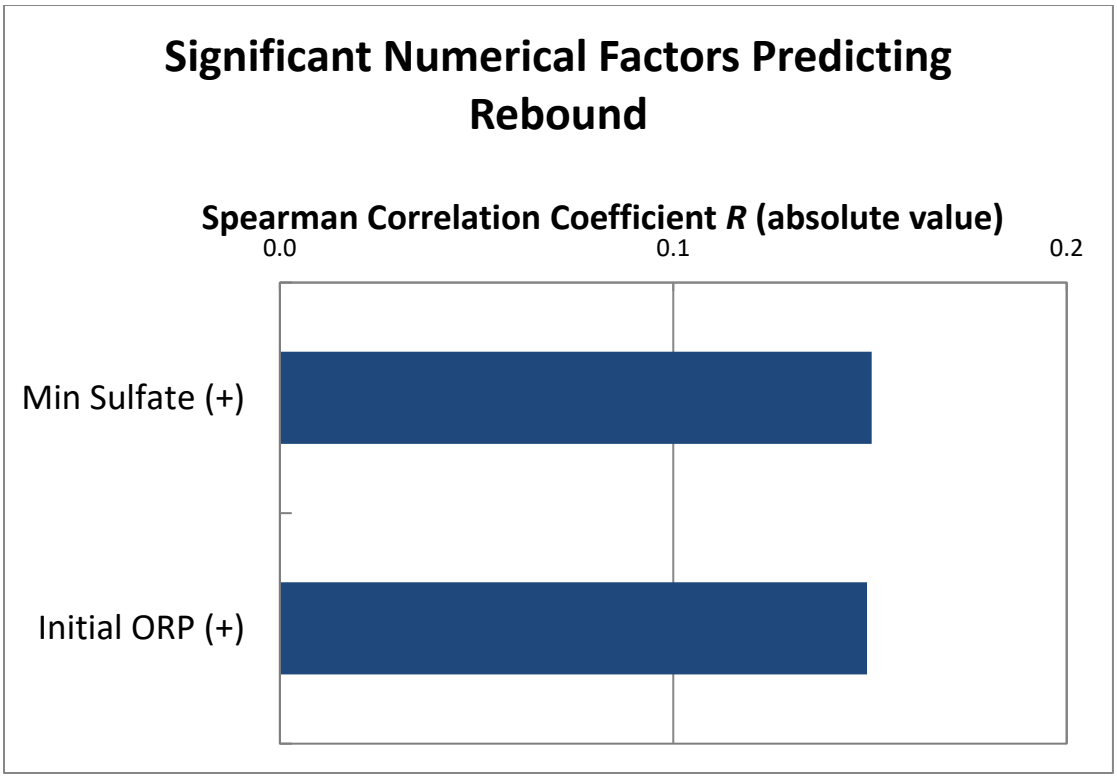


Figure 6-10. Significant Numerical Factors Predicting Rebound.

The proportion of fines in the treated zone may also be an important parameter. For the categorical *Fines Rank* parameter, cases were assigned a high (H), medium (M), or low (L) based on the percent fines (silt plus clay) present in the treatment zone. **Figure 6-11** shows box plot comparisons of these three categories of cases as a function of *Rebound*. The box plots show a clear progression of increasing medians, with the low fines cases (n= 102) showing less rebound than the medium fines cases (n= 115), which in turn, have less rebound than the high fines cases (n= 39). The KW test p-level of 0.160 indicates that there is not a statistically significant difference between the three categories. However, the increasing progression of the medians in the figure suggests that a high proportion of fines may be a predictor of *Rebound*. The mass of CE absorbed by the fine layers can then slowly diffuse out of the layers after CE concentrations have decreased during remediation, leading to a reversal of local CE concentration gradients. In addition, a large proportion of fines in the treatment zone can limit the ability to distribute amendments. Note that **Figure 6-11** is a near mirror image of **Figure 6-3**, which shows *Fine Rank* versus *Concentration Reduction*.

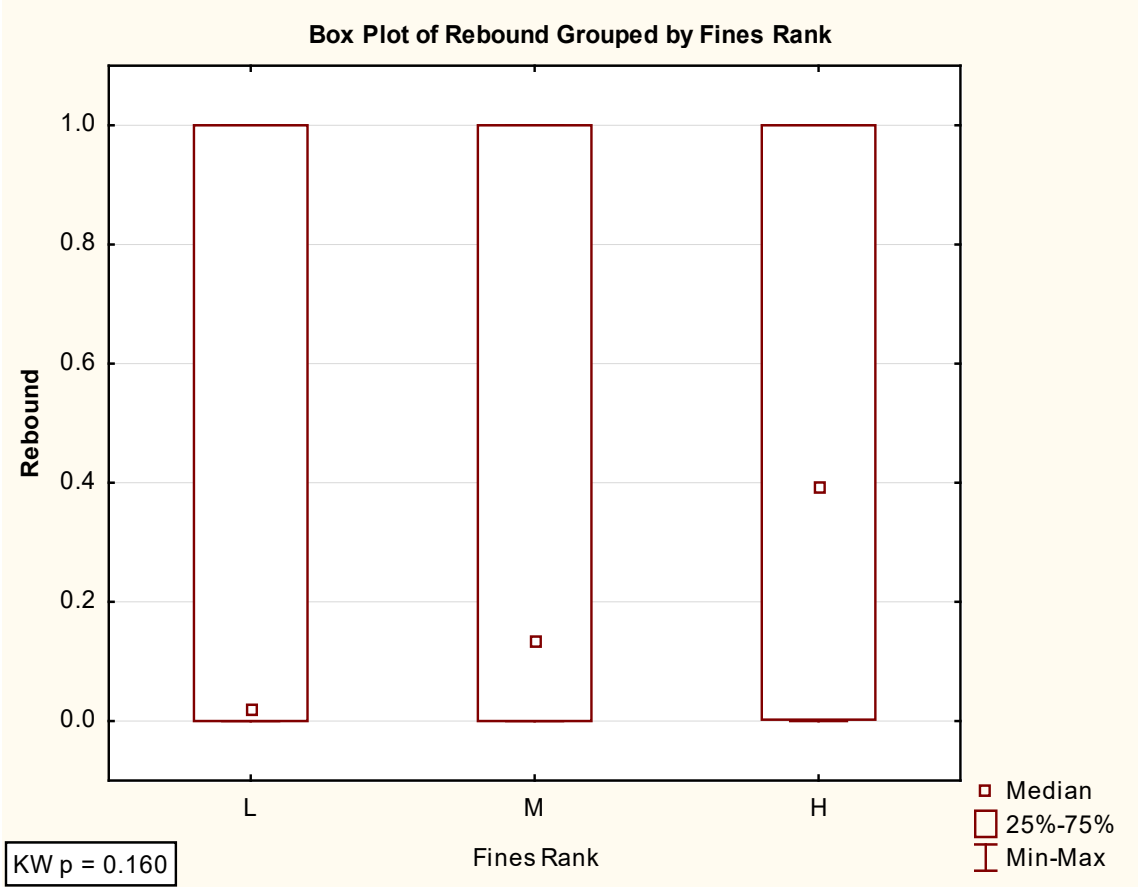


Figure 6-11. Box Plots of Rebound by Fines Rank.

Sites that have undergone previous remediation show significantly less rebound than sites that have not had previous remediation. **Figure 6-12** shows *Previous Remediation Rank* versus *Rebound*. Sites without previous remediation (n= 57) have a much higher median rebound than sites with previous remediation (n= 191). The WRS p-value of 0.018 indicates that the differences between the two *Previous Remediation Rank* categories have a statistically significant effect on *Rebound*.

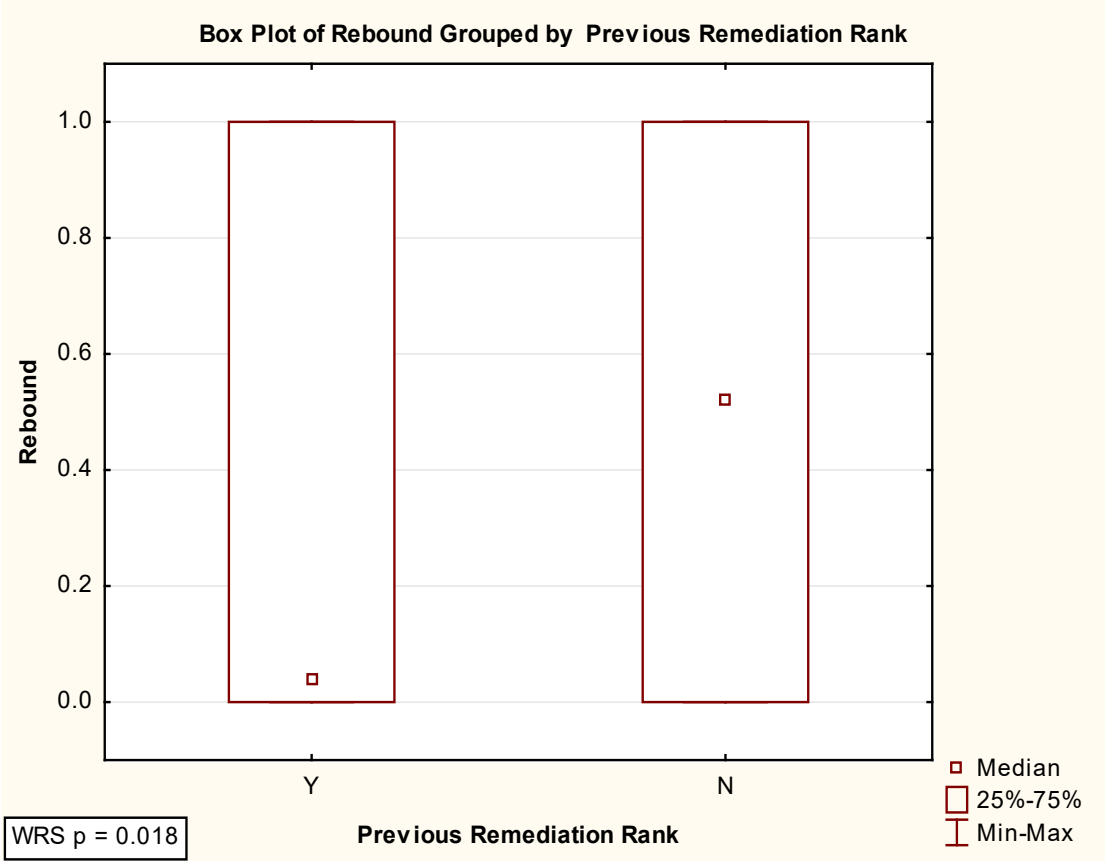


Figure 6-12. Box Plots of Rebound by Previous Remediation Rank.

cis-DCE Accumulation – This performance parameter is positively correlated with *Rebound* because cis-DCE is a frequent contributor to rebound. Numerical site characteristics that have significant correlations with *cis-DCE Accumulation* are *Minimum Sulfate* (+), *Initial Fe* (-), *Initial Sulfate* (+), Heterogeneity (-), and *Initial ORP* (+) in decreasing order (**Figure 6-13**). These results suggest that high initial redox conditions, as indicated by high initial ORP and low initial iron, are predictors of cis-DCE accumulation.

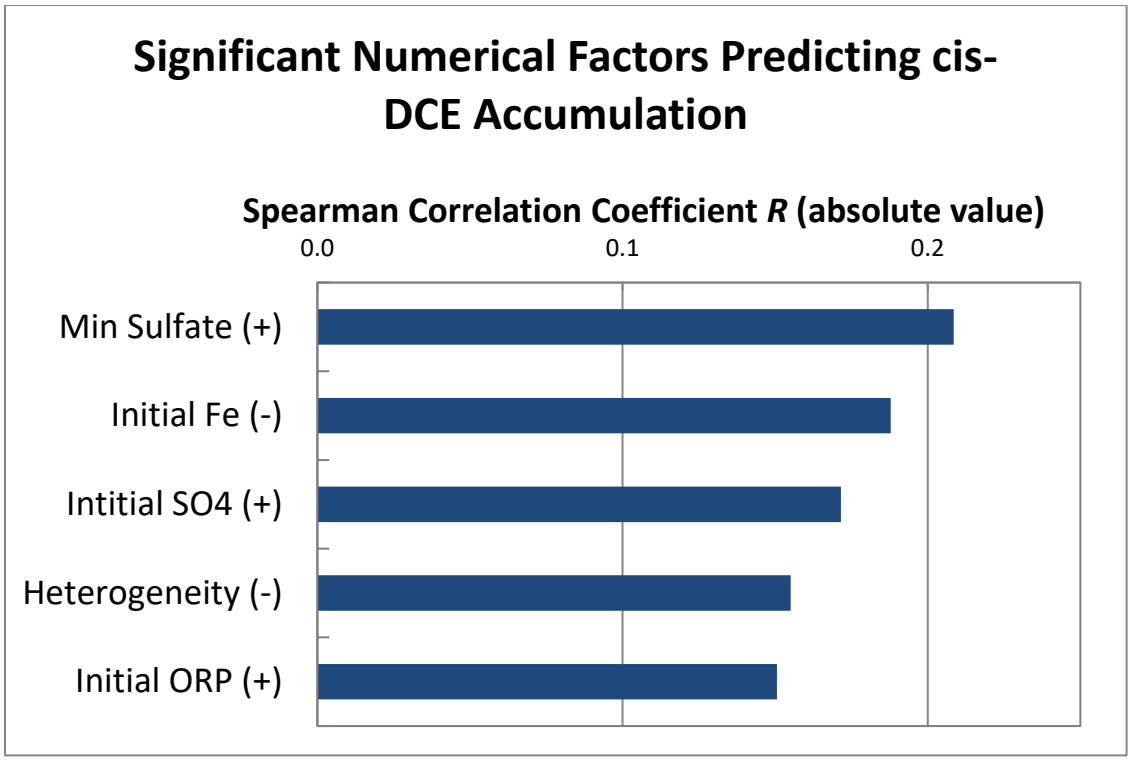


Figure 6-13. Significant Numerical Factors for Predicting cis-DCE Accumulation.

A significant positive correlation with *Min Sulfate* suggests that sulfate concentrations need to be lowered during remediation to avoid accumulation of cis-DCE. This can be a challenge if the site is in a coastal area (such as Seal Beach) or an arid region where naturally high-sulfate groundwater is common. These areas may have on-going sources of sulfate (such as the presence of gypsum layers) that can make it difficult to effectively lower sulfate concentrations, thus leading to cis-DCE accumulation.

A box plot comparison of cases with recirculation loops (*n*= 86) versus direct injection (n= 170) with respect to *cis-DCE Accumulation* is provided in **Figure 6-14**. The accumulation of cis-DCE at sites where recirculation loops were used was minor, but less than 25 percent of the sites where direct injection was used experienced a large amount of cis-DCE accumulation. The WRS p-value of 0.022 indicates that these differences are statistically significant. These results may be driven by a small fraction of sites where the permeability of the treatment zone was low and/or the well spacing was high, and recirculation was not used.

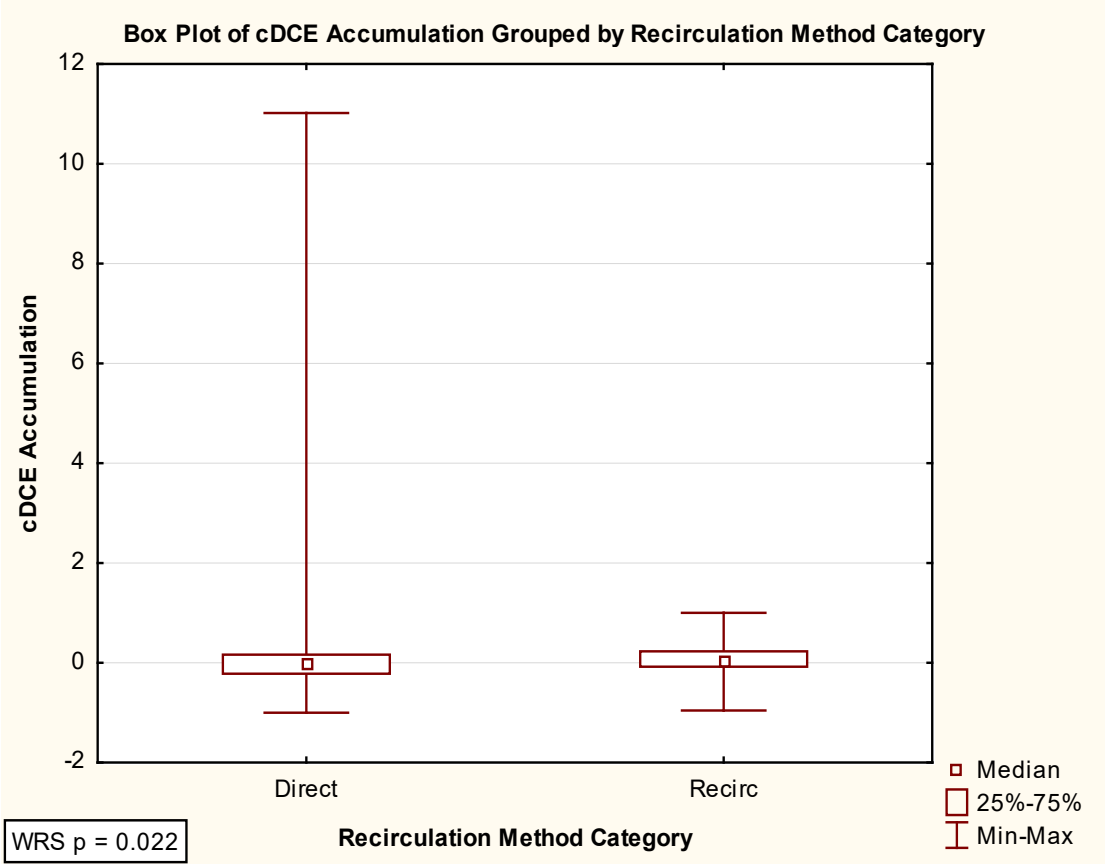


Figure 6-14. Box Plots of cis-DCE Accumulation by Recirculation Method Category.

Initial pH Rank also appears to be an important factor at pH conditions below pH 5.0. **Figure 6-15** shows a box plot of *cis-DCE Accumulation* for the four pH ranges. The initial pH does not seem to be a critical factor controlling *cis-DCE Accumulation* except in a small fraction (less than 25 percent) of the cases that have an initial pH below 5.0. These are the only cases of the 229 cases with available initial pH that showed a large degree of *cis-DCE Accumulation*.

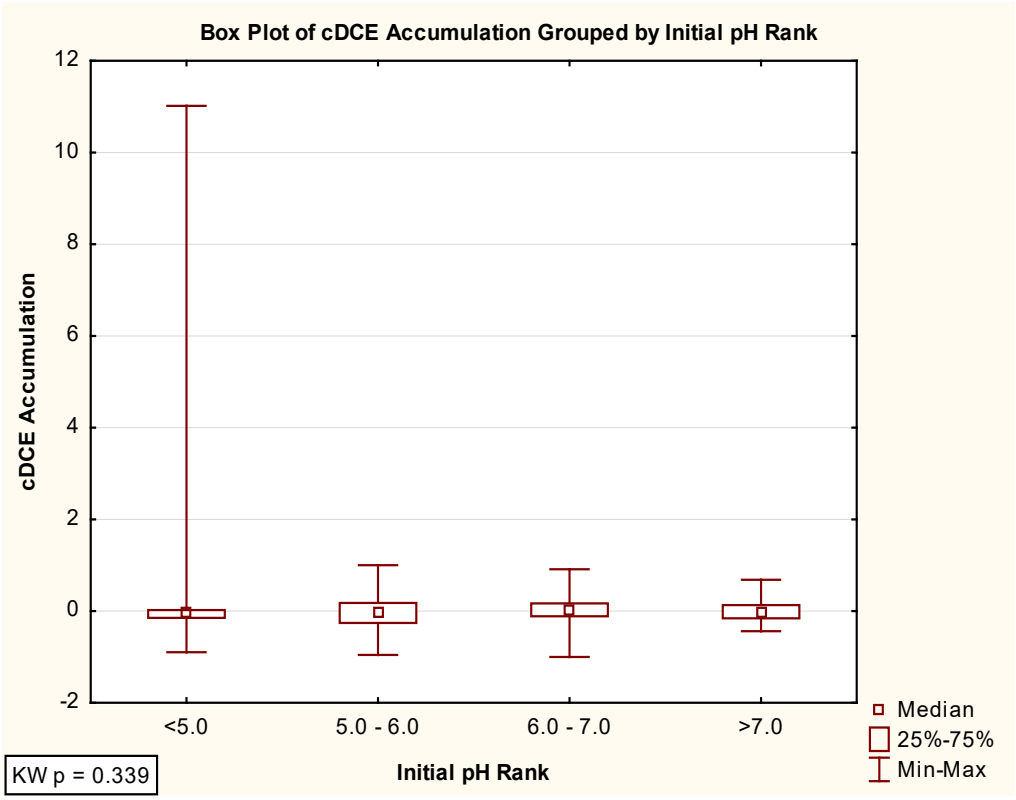


Figure 6-15. Box Plots of cis-DCE Accumulation by Initial pH Rank.

6.3 SUMMARY AND CONCLUSIONS

The parameter *Concentration Reduction*, equal to the greatest reduction in total CE concentration for each well during the treatment period before any rebound, was selected as the performance parameter for the majority of the evaluations. Rebound parameters (*Rebound* and *cis-DCE Accumulation*) were also evaluated.

Numerical site characteristics that showed statistically significant ($\alpha = 0.05$) positive (+) or negative (-) correlations with *Concentration Reduction* include *Min Sulfate* (-), *Sulfate Depletion* (+), *Initial ORP* (-), *Max Iron* (+), *Fines* (-), *Initial Sulfate* (-), *Initial CE* (+), *Min ORP* (-), and *DNAPL 1/0* (+) in decreasing order (**Figure 6-1**). The strongest correlations were with *Min Sulfate* (-) and *Sulfate Depletion* (+), suggesting that creating strongly reducing redox conditions (that reduce sulfate concentrations as low as possible) will contribute to successful remediation.

The third and fourth most significant correlations were with *Initial ORP* (-) and *Max Iron* (+), demonstrating that either initial or minimum redox potentials are strong predictors of successful CE concentration reductions. These first four strongest correlations provide independent evidence that creating redox conditions corresponding to sulfate-reducing (or lower) redox potentials is beneficial for reducing CE concentrations.

Initial Sulfate had a significant negative correlation with *Concentration Reduction*, indicating that high initial sulfate is a predictor of poor performance. High initial sulfate may be present at coastal sites or at arid sites where gypsum layers are present in the treatment zone.

Fines have a significant negative correlation with *Concentration Reduction.* This observation suggests that it may be more challenging to lower CE concentrations in treatment zones that have a high proportion of fine-grained sediments. Diffusion of CEs into the fine-grained units over time within the treatment zone may extend the time required for treatment, and may also increase the likelihood of rebound as the CE compounds slowly diffuse back out of the fine-grained units after treatment has stopped. The presence of fine-grained layers can also prevent the adequate distribution of amendments in the subsurface.

Cases where DNAPL is present show significantly greater concentration reduction than cases where DNAPL is not present. This is likely caused by higher initial CE concentrations were DNAPL is present. The significant correlations between *Concentration Reduction* versus *Initial CE* (+) and *DNAPL 1/0* (+) likely reflect the fact that CE concentrations can only show strong decreases if they are initially high.

Numerical parameters that contribute to *Rebound* include *Min Sulfate* (+) and *Initial ORP* (+), suggesting that high initial ORP is a predictor of rebound. In addition, failure to adequately reduce sulfate to low concentrations in the groundwater during treatment may also lead to rebound.

A positive correlation with the categorical *Fines Rank* parameter indicates that a high proportion of fines in the treatment zone is a predictor of rebound, as well as poor reduction of CE concentrations, as noted above. Also, sites that have undergone previous remediation show significantly less rebound than sites that have not had previous remediation.

Numerical site characteristics that have significant correlations with *cis-DCE Accumulation* are *Minimum Sulfate* (+), *Initial Iron* (-), *Initial Sulfate* (+), Heterogeneity (-), and *Initial ORP* (+) in decreasing order. These results suggest that high initial redox conditions, as indicated by high initial ORP and low initial iron, are predictors of cis-DCE accumulation.

The use of recirculation loops avoids accumulation of cis-DCE, most likely by allowing more effective mixing of amendments in the subsurface. Initial pH below 5.0 is a predictor of cis-DCE accumulation by inhibiting microbial degradation rates, especially the final stages of cis-DCE reduction.

In summary, the key parameters that control CE reduction are similar to the parameters that control rebound. These parameters are:

- **Redox conditions –** The strongest predictors of CE concentration reduction and rebound are *Initial Sulfate*, *Min Sulfate*, and *Sulfate Depletion*. These results demonstrate that it is essential to establish sulfate-reducing (or lower) redox potentials for successful remediation. Correlations of these performance measures with other redox-related parameters such as *Initial ORP*, *Min ORP*, and *Initial Iron* provide independent evidence for these predictors. High initial sulfate or lack of sufficient sulfate depletion may prevent successful remediation if there is an ongoing source of sulfate during the treatment period that prevents redox conditions from falling below sulfate-reducing potentials. Sources of sulfate may include seawater intrusion, arid climate (where sulfate groundwater concentrations are typically high), or the presence of gypsum in the treatment zone.

- **Fines –** The presence of fines in the treatment zone is correlated with poor concentration reduction, as well as rebound and DCE accumulation. These results provide independent evidence that the presence of fine-grained layers in the treatment zone interfere with performance, likely by allowing diffusion of CE into the fine layers over time. During remediation, when the CE concentrations decrease in groundwater along interconnected flow paths, the local concentration gradients reverse, and CE that had diffused into the fine layers slowly diffuses back out, thus contributing to rebound. Also, the presence of fine-grained layers can interfere with the distribution of amendments in the subsurface.
- **Initial pH –** Initial pH below 5.0 is a predictor of poor CE concentration reduction and is also a predictor of cis-DCE accumulation. These effects are likely caused by inhibition of microbial activity.
- **Previous remediation –** Cases that have undergone previous remediation have significantly higher CE reduction and significantly less rebound and cis-DCE accumulation. These results highlight the need for multiple rounds of remediation at some locations.
- **Presence of DNAPL –** One surprising result was that cases where DNAPL was present had significantly greater reductions in CE concentrations than cases where DNAPL was absent. This result is likely due to the fact that sites with DNAPL usually have higher initial CE concentrations relative to sites without DNAPL, so the sites with DNAPL tend to show a greater decrease during remediation. (The presence of DNAPL as the parameter *DNAPL 1/0* is positively correlated with *Initial CE*, *Min CE*, *Max CE,* and *Final CE*.) These results also suggest that the presence of DNAPL at a site does not interfere with reductions in CE concentrations during remediation. The degree of rebound and cis-DCE accumulation were insensitive to the presence or absence of DNAPL.

7.0 COST ASSESSMENT

The nature of this project does not allow for a traditional ESTCP cost assessment, where one remediation or other technology is evaluated against traditional alternatives. However, this section is intended to provide a reasonable cost estimate for the different assessment technologies utilized during this demonstration. The cost includes labor and per diem for field sampling and PFM installation personnel, materials for sample collection, CSIA, molecular analysis, PFM analysis, and basic geochemistry and VOC analysis. The assessment does not include monies spent on the development of the site database and statistical analysis of the database results.

For the cost assessment, we assume that a total of 8 groundwater wells will be sampled by a single field technician using low-flow sampling and that the technician can sample 4 wells per day. For each well, basic field parameters (dissolved oxygen, oxidation-reduction potential, pH, conductivity) will be determined using a field meter, and samples will subsequently be collected for (1) VOC concentrations (EPA Method 8260); (2) anions (EPA Method 300); (3) C stable isotope analysis of TCE, cis-DCE and VC (4) molecular analysis of important dehalogenating organisms and genes. For the PFM analysis, it is assumed that pricing includes installation, removal, and data analysis on a per PFM basis (Dr. Mike Annable; University of Florida). Shipping of coolers will occur at the end of the second day of sample collection. Based on this scenario, the following cost assumptions were made:

1) Rental of required sampling pumps and meters: 1 week ($400);
2) Field labor $70 per hr x 32 hrs (including travel time) for sampling ($2,240);
3) Vehicle rental: 1 week ($375);
4) Hotel (3 nights) and per diem (2 full days; 2 travel days), Virginia default rate $96/$55/$41 ($480);
5) Shipping samples to laboratories: $50 ea x 4 ($200);
6) Other miscellaneous materials including ice, coolers, etc ($300);
7) EPA Method 300 anions (5): 8 x $55 ($440);
8) EPA Method 8260 VOCs: 8 x $131 ($1,048);
9) C stable isotope analysis for TCE, cis-DCE and VC: 8 x $600 ($5,200);
10) PFM Analysis (EnviroFlux): 16 (2 PFMs per well) x $1,700 ($27,200).

Analytical costs for EPA Method 300 ($55 per sample for analysis of 5 anions) and EPA Method 8260 ($131 per sample) represent GSA pricing from a national analytical laboratory. Stable isotope analysis of C and Cl in VOCs is the analytical price provided by a vendor for this project, which for C is $500 for the first compound in a sample and then $50 each for every compound after that. For Cl, the price is $600 for the first compound in a sample and then $50 each for every compound after that. The price for PFM installation, sampling, and analysis (a service that can be provided commercially by EnviroFlux (Enviroflux.com), was provided by Dr. Mike Annable at the University of Florida, who was a founder of the company. The price assumes 2-5 ft PFMs installed in each well. Based on all assumptions provided above, the estimated cost of sampling and analysis of 8 wells in support of complete biodegradation evaluation of PCE/TCE and daughter products is $37,883.

8.0 IMPLEMENTATION ISSUES

The primary end-users of these technologies (MBT, PFM, CSIA) are expected to be DoD site managers and their contractors, consultants, and engineers. The general concerns of these end users are likely to include the following: (1) technology availability and cost; (2) appropriate application of the technology at DoD sites; and (3) interpretation of CSIA, MBT, and PFM data. These implementation issues are addressed in the following sections. The database developed during this project will also be made available via the ESTCP website.

8.1 TECHNOLOGY AVAILABILITY

The C and Cl stable isotope analyses of VOCs described herein as well as the general qPCR analysis of important organisms and genes responsible for VOC biodegradation are commercially available and conducted in multiple university laboratories. Commercial laboratories conducting these analyses include Microbial Insights (Knoxville, TN) and Pace Analytical (Pittsburgh, PA). PFM installation, sampling, and analysis is also commercially available from EnviroFlux (Gainsville, Fl) as previously described in **Section 7**. Thus, the key technologies used in this ESTCP project are commercially available. The database developed during this project will also be made available via the ESTCP website.

8.2 APPROPRIATE APPLICATION OF THE TECHNOLOGY AT DOD SITES

Appropriate application of the technologies used in this project will vary by site depending on specific conditions and the questions to be answered. During this project, our primary question was the long-term effectiveness of bioremediation and the different tools were combined toward this end and to assess whether biodegradation was still occurring at select sites a few to several years after active treatment.

8.3 INTERPRETATION OF CSIA, MBT AND PFM DATA

8.3.1 CSIA

CSIA data gathered on environmental pollutants has been utilized to (1) document biological and abiotic contaminant degradation, (2) estimate or constrain rates of contaminant degradation; (3) identify dominant degradation mechanisms; and (4) forensically determine dominant sources of a specific contaminant in the environment, as well as various other specific applications for individual contaminants. The application and interpretation of CSIA data for the above purposes have been thoroughly reviewed in a US Environmental Protection Agency (EPA) document entitled “A Guide for Assessing Biodegradation and Source Identification of Organic Groundwater Contaminants Using Compound Specific Isotope Analysis (CSIA)” This document is available online through the EPA NEPIS Site (https://nepis.epa.gov/Exe/ZyPDF.cgi/P1002VAI.PDF?Dockey=P1002VAI.PDF). The readers of this ESTCP report are referred to Chapter 4 in this document entitled “Interpretation of Stable Isotope Data from Field Sites,” which clearly describes and provides examples of how CSIA data can be utilized to document and quantify the biodegradation of organic contaminants in groundwater aquifers. The Interstate Technology and Regulatory Council (ITRC) Environmental Molecular Diagnostics (EMD) team has also developed online guidance and instruction on CSIA (https://www.itrcweb.org/Team/Public?teamID=3). The C isotope data for TCE, cis-DCE, and VC

gathered during this project provide information on ongoing degradation of these contaminants at 5 different sites and, for the Raritan Site, where samples were collected along a flow path (**Section 5.3.1.3.8**), an ability to estimate field rates.

8.3.2 MBT

The molecular analysis conducted during this project (qPCR of key dehalogenating organisms and genes) is now conducted routinely at VOC sites. Guidance concerning the application of this technique and interpretation of results is available at the ITRC EMD website (https://www.itrcweb.org/Team/Public?teamID=3) and via Microbial Insights, who provide information on the relative abundance of different gene markers at groundwater sites (https://microbe.com/quantarray/).

8.3.3 PFMs

The PFM analysis conducted was initially developed in 2004 as part of SERDP/ESTCP project ER-200114. Since then, PFM technology has been deployed at over 100+ contaminated sites and is commercially available from companies such as EnviroFlux® (Gainesville, FL, USA) and iFlux® (Boom, Belgium). Additionally, SERDP/ESTCP has funded various iterations of the passive sampling technology, which most recently include a PFM for measuring low partitioning organic contaminants such as 1,4-dioxane (ER-2304) and the colorimetric PFM which use a colorimetric response to assess Darcy fluxes (ER-2420). PFM data interpretation must be carefully performed, as the Darcy velocity varies spatially and temporally, which can have an impact on contaminant flux rates. Contaminant fluxes must be normalized to the groundwater flux in order to assess changes in contaminant mass discharge due to source removal.

Guidance concerning the application of this technology and interpretations is available in a ITRC document entitled “Use and Measurement of Mass Flux and Mass Discharge,” which can be found at ITRC EMD website (https://www.itrcweb.org/Guidance/ListDocuments?TopicID=5&SubTopicID=11). Also, guidance document “ER-0144-PR: Demonstration and Validation of Water and Solute Flux Measuring Device” provides additional and more in-depth overview of the PFM technology employed in this project and the guidance document can be found on SERDP/ESTCP website (https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Monitoring/ER-200114/ER-200114-TR).

9.0 REFERENCES

9.1 GENERAL REFERENCES

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Appendix A: Points of Contact

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APPENDIX B: SITE DESCRIPTIONS

Sites used for statistical data analysis but not described in the final report.

B.1 Former Alameda Naval Air Station, Site 4

Former Alameda Naval Air Station is located on the northwestern tip of Alameda Island along the eastern margin of the San Francisco Bay and south of the City of Oakland, California. The northern portion of Alameda Island was formerly tidelands, marshlands, and sloughs adjacent to the historical San Antonio Channel, now known as the Oakland Inner Harbor. Alameda Point was created by filling sub tidal areas, natural tidelands, marshlands, and sloughs with dredge spoils from the surrounding San Francisco Bay, Seaplane Lagoon, and Oakland Inner Harbor.

Site 4 at former Alameda Naval Air Station has been the subject of environmental investigations due to historical documentation of fuel, oil, and solvent usage related to ship and aircraft maintenance. The site includes Building 360, a former Aircraft Engine Facility that contained process shops for blast testing, cleaning, painting, welding, and plating; various aircraft component repair rooms; and nondestructive testing facilities (Arcadis 2014).

Prior to 1975, wastes generated by plating operations in Building 360 were discharged directly to the Seaplane Lagoon via the industrial waste sewer system. Between 1975 to April 1997, plating wastes were treated at an industrial waste treatment facility located north of Building 360. Chemical contaminants from the various industrial processes inside Building 360 are believed to have been released to the subsurface at Site 4 by leaks in the sanitary, industrial waste, and storm sewer lines from the building (Shaw 2013).

Site 4 contains multiple hot sports of chlorinated volatile organic compound (VOC) contamination due to the presence of multiple contamination sources. Three of the hot spots are present and have been referred to as Hot Spot 4-1, Hot Spot 4-2 and Hot Spot 4-3. Two additional hot spots were identified at a utility corridor an at an oil/water separator.

Hot Spot 4-1 and associated Plume 4-1 contains VOCs at concentrations greater than 10,000 μg/L and is a presumed dense non-aqueous phase liquid (DNAPL) site. Trichloroethene (TCE) concentrations up to 200,000 μg/L were previously obtained from groundwater samples (Shaw 2010). Plume 4-1 extends from Hot Spot 4-1 over 1400 ft and discharges to Seaplane Lagoon in San Francisco Bay. Total VOC concentrations exceed 10,000 μg/L throughout much of the plume. Plume 4-1 contains several hot spots of contamination, one of which is identified as Hot Spot 4-1. The predominant groundwater contaminants are TCE and vinyl chloride (VC).

The stratigraphy beneath Plume 4-1 consists of two geologic units: the Merritt Sand Formation and overlying artificial fill (Shaw 2013). The Merritt Sand Formation extends from roughly 10 to 70 ft below ground surface (bgs), and contains fine-grained, silty sand and fine-grained clayey sand. The top of the Merritt Sand is composed of dense, well-consolidated, clayey sand, between 1 and 5 ft thick and has a low hydraulic conductivity. Additionally, a contact zone divides the Merritt Sand into an upper eolian and a lower alluvial section. The eolian section of the Merritt Sand represents sediment deposition by airborne processes, and the alluvial section of the Merritt Sand represents sediment deposition by fluvial or water processes. The contact zone between the eolian sand and alluvial sand sections ranges from 5 to 15 ft thick, consisting of a dense to well-consolidated clayey sand. This clayey sand has a low hydraulic conductivity (Shaw 2013).

Overlying the Merritt Sand Formation is the artificial fill that extends from the surface down to 10 ft bgs. The artificial fill consists of a light to dark brown, fine-grained, silty sand with trace amounts of gravel and brick fragments. The fill is composed of dredge spoils from the San Francisco Bay. Percent fines are estimated to be 66% based on examination of representative soil boing and the treatment zone contains

1.8 layers per 10 ft. Groundwater at Plume 4-1 is encountered between 2 and 8 ft bgs within the artificial fill.

Aquifer pumping tests indicate an average hydraulic conductively of 4.8 ft per day (Arcadis 2014) and hydraulic gradient of 0.005 ft per ft. The groundwater flow directions are affected by local recharge from precipitation, seasonal variation in groundwater elevations, and tidal influences. For Alameda Point, the groundwater has been found to generally flow from southeast to northwest.

Previous pilot studies at Hot Spot 4-1 included bioremediation in 1999 to 2000, low temperature thermal treatment in 2002 (IT 2003) and *in situ* chemical oxidation in 2003 to 2004 (Shaw 2004).

A field-scale bioremediation treatability study was conducted between July 2011 and June 2013. The main objectives of the treatability study were to evaluate the effectiveness of enhanced bioremediation to reduce dense nonaqueous phase liquid in the groundwater within the target treatment zone and to provide a technical basis for expanding bioremediation to the extended plume (Shaw 2013).

The bioremediation treatability study included a pilot recirculation system that was operated for a 60-day period from September to November 2012. The bioremediation system included a groundwater recirculation system with four extraction wells and three injection wells. Each extraction well and injection well operated at a constant rate to distribute sodium lactate substrate across the treatment area. The injected groundwater was bioaugmented with SDC-9™ bacteria after reducing conditions were created. Approximately 730 gallons of sodium lactate product was introduced into the injection stream at a dosing concentration of approximately 1.5%.

Multi-level sampling wells and the extraction wells were used to monitor the performance of the system. Baseline sampling was performed during July 2012, prior to system operations to assess the existing groundwater concentrations. Treatment progress sampling occurred regularly over the lactate recirculation and fermentation periods and quarterly thereafter. Post-treatment sampling also was performed to assess contaminated treatment effectiveness and rebound. The final sampling event occurred June 12, 2013.

Multilevel sampling wells and the extraction wells were used to monitor the performance of the system. The wells were closely spaced, with six monitoring wells located within a 10 ft by 10 ft area. Each monitoring location had multiple depth zones (either three or four). The system of multilevel sampling points provides a means to observe the variability of treatment effects on a small scale.

The results of this study show that bioremediation at the site was highly effective. During active treatment and groundwater re-circulation, groundwater concentrations were reduced up to 99 percent in one location and on average by greater than 70 percent across all extraction and monitoring wells. Complete dechlorination of TCE, as evidenced by generation of ethene, was observed in all four extraction wells. Post-treatment monitoring initially showed very little rebound of chlorinated ethenes. While substantial decreases in the chlorinated ethene concentrations were observed, evaluation of the mass balance indicates that only a small fraction (less than 1 percent) of the estimated initial DNAPL mass present (11 to 55 kg) was removed. The range of the initial DNAPL mass present, as well as the uncertainty in correlating DNAPL mass removal to changes in groundwater quality, highlights the challenges in evaluating and treating DNAPL source areas (Shaw 2013).

Based on the results obtained from this pilot study, a full-scale bioremediation approach was selected as a remedy for the site (NAVFAC 2014). The design for the full-scale system included a grid of injection

wells in the source area with a spacing of 15 ft and 20 deep/shallow well couplets (Arcadis 2014). Further information on the effectiveness of the full-scale treatment was not available as of this writing.

B.2 Moody Air Force Base, Site FT-07

Moody Air Force Base (MAFB) is located in central Georgia. FT-07 encompasses approximately 10 acres located in the central portion of MAFB, west of Grand Bay Swamp and east of the Flight line Area (SS-38). The FT-07 site has historically been separated into two areas. Area 1 is located west of the current fire training area and encompasses areas that are east and west of Perimeter Road. Area 2 is located east of the hot cargo pad and encompasses the area east of Perimeter Road. The data collected from Area 2 were used in the statistical analysis described in this report.

The site formerly included seven burn pits along with a building and mock aircraft for fire training exercises. Waste fuel, solvents, paints, and Jet Propellant-4 (JP-4) were used as fuel for fire training purposes. Currently, the majority of the land surface at FT-07 consists of cleared grassy areas and unimproved, piney woods and forested wetlands adjacent to Great Bay Swamp.

The FT-07 site contains groundwater impacted with dissolved-phase chlorinated solvents and hydrocarbon compounds, including 1,2-dichloroethane (DCA), TCE, cis-DCE, and VC. The plume of groundwater contamination at Source 1 extends approximately 600 ft from the source area to the wetland adjacent to Great Bay Swamp. The predominant contaminant is overwhelmingly cis-DCE rather than TCE, and this constituent exceeds 1 mg/L extends throughout the plume. The presence of high cis-DCE concentrations indicates resistance to dechlorinate to VC and then completely to ethene ("DCE Stall"). Concentrations of cis-DCE in excess of 1 mg/L extend over 500 ft from the source area. Source 2, located on the southeastern portion of the site, consisted primarily of cis-DCE contamination at somewhat lower concentrations.

Groundwater at the site has a low pH with pH values ranging between 3.8 and 5.3 prior to treatment, and the low pH is suspected to be the primary factor in the DCE Stall observed. The aquifer contains alternating layers of sand, silt and clay (CDM 2001). The treatment zone contains an estimated 58% fines and is highly heterogeneous with 18 layers per 10 ft. The core of the plume extends into a wetland area with low permeability soils, and the bioremediation injections were within the wetlands at this site.

Three major phases of bioremediation were implemented using three different substrates:

- Hydrogen-Releasing Compound® (HRC®) in 2002;
- Sodium Lactate in 2005; and
- EOS in 2008.

In each of the treatment phases, amendments were injected via either direct push or temporary well points. Sodium bicarbonate was added in 2008 for pH control.

HRC Treatment

An interim measure (IM) involving the injection of HRC® to serve as an organic carbon electron donor was implemented within the Source Area 2 in November 2002 (Shaw 2003-10). A total of 18,600 pounds of HRC® was injected using Direct Push Technology (DPT) during three events (November 2002, November 2003 and March 2004). Injections were conducted in four areas (areas A, B, C, and D) with a total of 167 injection points. Spacing was 10 ft.

Lactate Treatment

The second phase of bioremediation was implemented in June 2005 (Shaw 2003b). Injections were performed within an expanded area (Locations A and B) using sodium lactate as the primary carbon source to support reductive dechlorination. The injections were performed using a total of 57 injection

wells installed in Locations A and B. Spacing was 20 ft. A total of 1,078 gallons of lactate were injected at a dosing of 1 to 6% (Shaw 2005-11).

Lactate was delivered using a passive gravity-feed method rather than an active injection under pressure, a unique approach among the sites evaluated. Totes were set up at each injection well head and flexible hose extended from the bottom of the tote to the injection well head. The valve was opened at the bottom of the tote and the lactate solution drained by gravity into the well. Bioaugmentation was employed for the first time in this phase with injection of the SDC-9™ culture.

Emulsified Vegetable Oil (EVO) Treatment

A third phase of treatment was implemented in October 2008 with the installation of 73 additional injection wells in Area 2. Spacing was 40 ft. Injections were initiated in November 2008. A total of 19,800 pounds of sodium bicarbonate, 38,100 pounds of 50 percent sodium hydroxide, and 5,115 gallons of EVO product were injected.

The bioremediation at FT-07 had limited effectiveness. Overall decreasing trends were observed at many wells; however cis-DCE remained resistant to degradation. Additional injections were planned in 2015 but the status of this work is unknown at this writing.

B.3 Myrtle Beach Air Force Base, Site FT-11

The former Myrtle Beach Air Force Base (MBAFB) is located in the Coastal Plain of South Carolina approximately 2.5 miles inland from the Atlantic Ocean near Myrtle Beach, South Carolina. FT-11 at MBAFB is located in the north-central portion of the base, approximately one-half mile west of the flight line. FT-11 was formerly used as a practice area to conduct fire training exercises from 1965 through 1969. The FT-11 area consisted of a 100-ft-diameter earthen burn ring with a low-relief berm. Fire training involved soaking the ground within the berm with jet petroleum grade-4 fuel, waste oil, and/or solvents, igniting the fuel, and then extinguishing the fire (CB&I 2014).

Topography at the FT-11 site is fairly flat and ranges from 18 to 20 ft above mean sea level. Surface water runoff from FT-11 flows east and southwest into two drainage ditches that carry the flow to the storm drainage system. The unconsolidated sediments underlying FT-11 consist of fine to medium-grained sand and silty sands with interbedded clay layers with the layers being relatively continuous across the site (Shaw 2008). Groundwater contamination is confined to two zones, a shallow zone (8 to approximately 15 ft bgs) and an intermediate zone (approximately 19 to 26 ft bgs). These zones correspond to coarser-grained layers in the sediment deposits at the site.

The historical area of contaminated groundwater is relatively small, being ~500 ft long and 200 ft wide. The original TCE was observed to have partially reduced to cis-DCE and VC, and these two compounds were observed in the highest concentrations. Concentrations of cis-DCE over 90 µg/L were detected; VC was detected at over 5,000 µg/L (Shaw 2008).

Hydraulic conductivities calculated from the site range from 0.5 to 21.7 ft per day with a geometric mean of 2.4 ft per day (Shaw 2008). The estimated percent fines is relatively low at 2.5%. The heterogeneity of the treatment zone is 13 layers per 10 ft of aquifer. Drainage ditches at the site control shallow groundwater flow, and groundwater flow directions fluctuate based on whether the ditches are full or empty.

Remediation at FT-07 has included a combination of technologies including excavation, *in situ* chemical oxidation, and groundwater extraction. Two source areas in soil have been identified and removed in two separate events. Soils were excavated in 2000 and 2006, and a potassium permanganate *In Situ* Chemical Oxidation (ISCO) pilot test was implemented in 2002.

Multiple phases of bioremediation treatment have been applied at the site including:

- Phase I and II using sodium lactate via injection wells;
- Phase III in 2007 using sodium lactate via injection wells;
- Phase IV in 2008 using sodium lactate via injection wells and direct push;
- Phase V in 2009 using LactOil®, via injection wells and direct push; and
- Phase VI in 2012 using sodium lactate via direct push.

The approach included injection of substrates and extraction of groundwater, however the extracted groundwater was not recirculated. Instead, the extracted groundwater was removed for *ex situ* treatment off-site. Each treatment phase is summarized below.

Phase I and II (2006)

The initial two phases of bioremediation treatment occurred in two steps – Phase I in June 2006 and Phase II in November 2006. Sodium lactate was injected in 50 temporary injection wells laid out in an irregular grid. Approximately 2,350 gallons of sodium lactate product were injected during these two events (Shaw 2008).

Phase III (2007)

A follow-up injection event was conducted in the same area in July 2007. Approximately 900 gallons of sodium lactate product were injected. Injections were conducted in existing injection wells and also via direct push (Shaw 2009).

Phase IV (2008)

The next phase of injections occurred in March and April of 2008 with injection of an additional 670 gallons of sodium lactate product. The injections were all via DPT in this phase. Injections were conducted at ~ 280 locations. Bioaugmentation was used for the first time in this phase with introduction of the SDC-9™ culture (Shaw 2009).

Phase V (2009)

LactOil®, rather than sodium lactate, was used in Phase V in 2009. Approximately 2,280 gallons of LactOil® were injected into 59 injection wells and 2333 DPT locations. The dosing concentration was approximately 1.6% (Shaw 2011).

Phase VI (2012)

The injections conducted in 2012 targeted a smaller portion of the previous treatment areas. Sodium lactate was applied at 64 locations. Sodium bicarbonate was added for pH control (Shaw 2013). This series of treatments was highly successful at reducing the concentrations of VOCs. VC and cis-DCE were the most recalcitrant of the VOCs, but eventually these were successful degraded. Six phases of bioremediation were used at the site. Based on the results achieved, no further active bioremediation is planned just natural attenuation of remining µg/L concentrations of cis-DCE and VC.

B.4 North Island Naval Air Station, OU 24

Naval Air Station North Island (NAS North Island) is located in San Diego County, California, on the tip of the Silver Strand peninsula that separates San Diego Bay and the Pacific Ocean. OU 24 at NAS North Island is identified as the groundwater plume near Building 653 in the northeastern part of the installation. It consists of shallow groundwater impacted with TCE, cis-DCE and VC, likely the result of leaks from the industrial wastewater lines located south of Building 653 (Trevet 2014). Other investigations indicated that releases were associated with an acid waste pump station located south of Building 653 (Geosyntec 2006). The plume of groundwater contamination historically extended approximately 500 ft where it discharged to San Diego Bay.

Groundwater is primarily anoxic with DO less than 1 mg/L and ORP is low or negative. Sulfate is elevated at the site with concentrations exceeding 1,000 mg/L in the source area. NAS North Island is located on generally flat land with an average elevation of approximately 20 ft above mean sea level. The shape and size of NAS North Island has been modified considerably, primarily as a result of the addition of artificial fill derived from the dredging of San Diego Bay. The uppermost 30 ft of sediments are designated "Zone A" and "Zone B" monitoring zones at the site. The uppermost unit, the hydraulic fill material, consists primarily of silty fine sand. The artificial fill material can be up to 20 ft thick and is discontinuous across the island. Beach sand is located below the artificial fill (Trevet 2014).

Water level monitoring data indicates the groundwater gradient is minimal at 0.0004 to 0.0007 ft per ft, and the flow direction is radial. The rate of groundwater movement was estimated to be between 19 and 33 ft per year (Trevet 2014). The hydraulic conductivities in the A and B monitoring zones are about 10 ft per day (Geosyntec 2006).

The bioremediation system at the site included a recirculation system in the source area and a series of six downgradient biobarriers aligned perpendicular to the plume (Geosyntec 2006). Remediation began in December 2006 with the installation of monitoring wells and recirculation wells for an active treatment system in the source area near Building 653. Full operation of the active system began in May 2007. The active system is combined with a series of biobarriers in the downgradient portion of the plume. Biobarrier installation was completed in November 2007. In 2008 and 2009, the source-area system was optimized to target a smaller area and the biobarriers were recommended to stimulate additional degradation.

The remedial design included sodium lactate introduced once per week for a 2-hour pulse at a minimum flow rate of 0.3 gpm to provide a minimum loading of 36 gallons of sodium lactate product per week. With a designed recirculation flow rate of 1.5 gpm, the dosing concentration for the sodium lactate solution was 20%.

The treatment resulted in substantial reduction in VOC concentrations in most of the monitoring wells. In January 2010, the active recirculation system was shut down because performance monitoring results demonstrated that concentrations in the source area had been reduced to below project action levels.

Additional upgradient contamination was subsequently discovered and the remediation was expanded in 2012 to the upgradient areas. The expansion was completed in December 2011 and treatment commenced in March 2012. In March 2013 the upgradient recirculation system was shut down because performance monitoring results demonstrated that concentrations in the upgradient area had been reduced to below project action levels. The remediation at the Building 653 source area is considered complete. However, additional bioremediation treatment has continued in the upgradient areas and the downgradient system of biobarriers.

B.5 Orlando National Training Center, Study Area 17

The former Orlando National Training Center is a former U.S. Navy facility located in the city of Orlando in north-central Florida. Study Area 17 (SA 17) is a former motor pool area at the installation. Previous site activities related to a motor pool area have contributed to subsurface soil and groundwater contamination from TCE. The specific source of the contamination is unknown.

VOCs adversely impacted groundwater throughout the surficial aquifer and in isolated areas within the upper part of the intermediate aquifer of the Hawthorn Group sediments. Given the contaminant distribution pattern, the plume appeared to have originated from two release points at the surface located in the western and central parts of the former motor pool area. In the western source area, compounds detected at the highest concentrations were cis-DCE and VC, with a combined maximum concentration of 400 µg/L. In the eastern source area, TCE was the predominant compound detected, with a maximum concentration of 577,000 µg/L. The highest contaminant concentrations were detected at the water table interface in the source areas and along the upper surface of a silty sand layer that is located between 15 and 25 ft bgs. This layer and another somewhat deeper layer of silty sand act as apparent aquitards that divide the surficial aquifer into three units – shallow, intermediate, and deep.

The VOC contamination within the Target Treatment Zone (TTZ-1) extended vertically through the surficial aquifer from the water table (approximately 5 ft bgs) to the top of a confining layer at an approximate depth of 50 ft bgs. The historical lateral footprint of the source area is approximately 50 ft long and 50 ft wide. The vertical treatment zone is approximately 45 ft deep.

The plume dives downward at the site (Solutions 2011). The plume extends at the water table interface from both source areas for a distance of approximately 50 to 100 ft in the direction of groundwater flow (east-southeast). In the intermediate unit of the surficial aquifer, the plume extended to a distance of approximately 250 ft downgradient, and in the deep unit of the aquifer, the plume extended approximately 300 ft from the source areas.

The surficial aquifer at the site contains interbedded sand and silty sand to a depth of approximately 25 ft. The surficial aquifer is underlain by sediments of the Hawthorn Group consisting of interbedded sand, silty sand and clay. The highest contamination is in the surficial aquifer. The water table is at approximately 6 ft below ground surface (bgs) across the site, with a variation of 2 ft. The surficial aquifer extends to a depth of about 50 ft bgs with its lower extent defined by the uppermost Hawthorn clay layer. Zone A (5 to 15 ft bgs), Zone B (15 to 30 ft bgs), and Zone C (30 to 50 ft bgs) were monitored. Monitoring Zone C is within the Hawthorn Group sediments at a depth of approximate 45 to 50 ft (Solutions 2011).

The horizontal gradient ranges from 0.003 to 0.004 ft/ft. A downward vertical hydraulic gradient of 0.007 to 0.020 ft/ft exists within the surficial aquifer except near the drainage ditch, where groundwater discharges to the ditch and an upward gradient of approximately 0.25 ft/ft exists. Hydraulic conductivity was calculated based on the August 2005 aquifer pump test to be 4.7 ft/day in the surficial aquifer, and 6.9 ft/day in the deeper intervals of the surficial aquifer (Solutions 2011).

Prior to bioremediation, *In Situ* Chemical Oxidation (ISCO) with hydrogen peroxide was conducted from November 2000 through September 2002 (CH2M 2003). Several phases of ISCO injections occurred through that time period. A total of 69 injection wells were installed within the three vertical depth horizons (Zones A, B, and C) in the first phase. Additional direct-push injections were added in subsequent injection phases. An evaluation of the pre-and post-treatment monitoring data indicated an

average VOC concentration decrease of over 80%. However, VOC concentrations remained above 1,000 µg/L in some areas (CH2M 2003).

Multiple phases of subsequent bioremediation treatment with different treatment approaches have included:

- Phase 1 in 2006 which included recirculation in Zones B and C with EOS injections;
- Phase 2 in 2008 which included direct push injections of EOS in Zone B only; and
- Phase 3 in 2012 which included injection into Zones B and C wells without circulation. These phases are briefly described below.

Phase 1 Recirculation (2006)

The recirculation system included twelve injection wells arranged in a circular pattern around the target treatment zone. Two extraction wells were installed in the center of the circle in Zones B and C. Zone A was not targeted for treatment.

The recirculation equipment was housed in a mobile process trailer. The approach included recirculation of Emulsified Vegetable Oil (EVO), an approach not commonly employed with this substrate. The other evaluation sites with recirculation systems used high solubility substrates such as sodium lactate rather than EVO with a low solubility. EVO was metered into the recirculation stream at a concentration dosing of about 10%. The total loading was 990 gallons of EVO product. Bioaugmentation was not used.

Phase 2 Direct Push Technology (DPT) (2008)

Based on post-treatment monitoring results for Phase 1, additional polishing injections were implemented for Zone B. The injections included 50 gallons of EVO product injected at six DPT locations. The injection water was diluted to a 6% dosing concentration prior to injection.

Phase 3 Injections (2012)

A third phase of injections occurred in 2012. The twelve injection wells installed for Phase 1 were used for the injections. A total of 456 gallons of EVO product were injected. Phase 3 included the addition of a buffering agent for pH control.

The treatments resulted in a significant reduction in TCE in most of the monitoring wells, however, cis-DCE accumulation was significant in many wells. The site has switched to a long-term monitoring program with reliance on natural attenuation processes for further degradation.

B.6 Naval Base Ventura County Point Mugu, Site 24

The Naval Base Ventura County (NBVC) Point Mugu facility is located in Ventura County, California, approximately 50 miles northwest of Los Angeles. Site 24 at NBVC Point Mugu consists of two former Underground Storage Tanks (USTs): UST 23 and UST 55. In 1970 a single 550-gallon concrete tank (UST Site 23) was installed at the Site and was used as an oil/water separator, and the suspected source of groundwater contamination is associated operations.

Much of the developed land of NBVC Point Mugu was formed from mechanically compacted fill material. Fill thickness and composition vary widely (TtEMI 2004).

Upon investigation of the site, VC was reported as the predominant VOC in the plume. The specific chlorinated solvent that constituted the original source is uncertain, but presumed to be TCE and/or PCE. The predominance of VC at this site is presumed to be due to extensive reductive dehalogenation with relatively little and or slow degradation to ethene. The treatments at this site provide information to evaluate bioremediation of a plume with VC as the principal initial constituent.

Three general lithologic units are present at the site: (1) a coarse to fine sand, mostly fill, from ground surface to about 5 ft bgs; (2) a clay layer from about 5 to 10 ft bgs; and (3) primarily sand with some silty sand and silt from about 10 to 90 ft bgs (AIS-TN 2014).

Two separate monitoring zones were established at the site, designated Zone A and Zone B. Zone A extends from 4 to 12 ft bgs and Zone B extends from 20 to 35 ft bgs. These two zones are within the same shallow unconfined aquifer. A laterally-continuous clay layer is encountered in Zone A at a depth of approximately 8 ft bgs. This clay layer acts as an aquitard locally, but its thickness is highly variable, pinching out totally in some areas; it has also been compromised by excavation and well installation activities. Zone B includes a relatively homogeneous sand/silt unit (AIS-TN 2012).

The Navy completed pilot testing at Site 24 in 2002 to evaluate the effectiveness of a bioremediation system to degrade chlorinated solvents in groundwater (Shaw 2003). In 2006, a phase I pilot test was designed and implemented to evaluate the effectiveness of substrate injection/delivery using Direct Push Technology (DPT). Phase 1 substrates included emulsified soybean oil and lactic acid. Phase 2 batch injections of soybean oil and lactic acid were conducted between September and December 2006 as detailed below.

<u>Phase 1 (2006)</u>

The phase I pilot test was designed and implemented to evaluate effectiveness of substrate injection/delivery using direct-push technology and the use of emulsified soybean oil (EOS) as a longer-term electron donor (TN&A 2006). The approach used a substrate of mixture of EOS and lactic acid. A total of approximately 2,000 gallons of EOS and 1,000 gallons of lactic acid were injected. The injections were completed over a one-week period in July 2006. Twelve DPT locations were used with a spacing of 20 ft.

<u>Phase 2 (2006)</u>

Phase 2 batch injections of EOS and lactic acid in Zone B were initiated on September 2006 and were completed in December 2006. Groundwater was extracted from a central extraction well, amended with substrate and re-injected to the surrounding injection wells. Approximately 8,000 gallons of EOS and 4,500 gallons of lactic acid were injected via 8 injection wells. The groundwater extraction and treatment system processed approximately 1.7 million gallons of groundwater from September 2006 to February 2007 (TN&A 2007).

DPT Injections (2013)

EOS, sodium lactate, and microbes (BAC-9; same culture designated SDC-9) were injected into the Zone A and B groundwater through 18 DPT injection points covering an area of approximately 10,800 square ft using a portable mixing and injection system in January 2013. The system consisted of trailer mounted equipment and a substrate/groundwater mixing and storage tank. The total volumes of EOS and sodium lactate injected were 1,050 and 210 gallons, respectively.

The electron donor substrates, sodium lactate and EOS, were diluted approximately 10 to 1 with anoxic groundwater and injected in 5-ft intervals. The distance between the injection points was approximately 20 ft within each injection row and the injection point rows were approximately 20 ft apart. Substrate and microbes were delivered to the subsurface in Zones A and B between 5 and 35 ft bgs.

The results of the treatment were mixed. Substantial reduction of all VOC constituents were observed in many of the wells, however substantial VC accumulation remained in other monitoring wells. Upon completion of the bioremediation operations, the site entered into a long-term monitoring program to evaluate the long term effectiveness of the treatments.

B.7 St Juliens Creek Annex, Site 21

The Navy's St Juliens Creek Annex (SJCA) is located near Chesapeake, VA. Site 21 is in the south-central portion of the installation. Most of Site 21's ground surface, with the exception of a few small, unconnected grassy areas, is covered with asphalt. The general topography of the area is flat, with elevations ranging from 7 to 9 ft above msl.

Site 21 is associated with Building 187, a locomotive maintenance facility where TCE was used. The site encompasses a number of nearby industrial buildings, which historically were used as maintenance shops, electrical shops, and munitions-loading facilities. Waste oils and degreasers (including TCE) were reportedly disposed of on the ground surface and around the railroad tracks in this industrial area (CH2M 2015). Multiple isolated sources of contamination are suspected.

Historical contamination in groundwater was distributed unevenly due presumably due to the multiple sources of contamination. Contamination contour maps show an amoeba-like pattern to the outlines of the plume with higher concentrations scattered with the plume. The contaminant distribution maps lack the elongate plume pattern typical of sites with a relatively constant groundwater flow direction. Ten sub-areas of the site were treated, designated Group 1 through Group 10.

The subsurface geology at the site consists of the fine to coarse silty and clayey sands of the Columbia aquifer underlain by the high-plasticity clay of the Yorktown Formation. The Columbia aquifer extends to a depth of between 13.5 and 20 ft bgs. Shallow groundwater flow velocity has been calculated to be approximately 72 ft per year. Shallow groundwater at Site 21 is encountered from 2 to 7 ft bgs and flows southwest in the eastern portions of the site and southeast in the western portion of the site, toward the storm sewer system east of Building 1556 (CH2M 2015). Shallow groundwater is fresh, but becomes brackish at depths greater than 30 ft.

Groundwater contour maps show an irregular pattern of groundwater elevations. In general, groundwater elevations decrease in a southwestern direction toward St Juliens Creek (Tidewater 2014). Surface water drainage ditches may have a role in distorting groundwater flow along with tidal effects.

Previous remediation at Site 21 included a small-scale pilot study to evaluate the ability to enhance natural attenuation through bioaugmentation with aerobic bacteria that degrade cis-DCE (ESTCP 2010). Zero-valent iron (ZVI) injections were initiated in December 2010 with injection DPT at three areas of the site (designated North, South and East Areas).

EVO injections were initiated in April 2011 and completed in September 2011. A total of 10,758 gallons of EVO was injected into ten treatment areas of the site (designated Group 1 through Group 10). Nine of the ten EVO treatment areas received EVO only without ZVI. One of the ten areas received treatment with both ZVI and EVO.

The bioremediation at Site 21 was generally successful with substantial reduction of contamination. Arsenic was monitored throughout the treatment and arsenic concentrations substantially increased after treatment was initiated. Monitoring indicates several areas resistant to treatment and requiring follow-up action. Additional EVO injections were conducted in May 2014 (CB&I, 2014).

B.8 Vandenberg Air Force Base (VAFB), Site 15A/15B

VAFB Site 15A

Vandenberg Air Force Base is located near the Pacific Ocean near Oxford, California. Site 15 at was active from 1960 to 1967 and used to launch Atlas D and Atlas F missiles. Prior to launches, TCE was used to degrease rocket motors. As part of the launch process, TCE along with deluge water was discharged to the drainage channels and subsequently to the ground surface. Site 15A is associated with Launch Pad 1 and Channel A extends about 800 ft northwest from the launch pad.

Groundwater in the Site 15 area has been impacted by dissolved TCE and its degradation products. Two TCE source plumes with concentrations greater than 1,000 µg/L have been identified (AECOM, 2009). These source areas are located at the discharge point of Channel A and near the 90-degree bend in Channel B. TCE concentrations greater than 5 µg/L extend almost 2,000 to 3,000 ft toward San Antonio Creek.

Site 15 is located on Pleistocene sand dune deposits derived from the Pacific Ocean beaches located 1.5 miles west of the site. Surface topography of the site consists of sand dune hills with small closed depressions. The overall surface slopes southwest to San Antonio Creek, which flows west-northwest, passing about 3,000 ft southwest of the launch pads. The dune sand overlies the Orcutt Formation which consists of wind-deposited sand and local gravel deposits near the base. The combined deposits above the bedrock are typically 25 to 50 ft thick.

The plume of contamination occurs in the unconfined groundwater in the unconsolidated dune sand and underlying coarse sand and gravel and deposits. AECOM (2009) noted that the saturated thickness of the aquifer varied from approximately 4 to 45 ft. The depth to groundwater at the site varies from a few ft bgs in some areas to almost 50 ft bgs in places. Slug test and aquifer tests at the site provide highly variable results for hydraulic conductivity. A value of 50 ft per day is a representative value (Shaw 2009).

Active bioremediation was performed in several phases. Phase I of the recirculation operations extended from May 2011 to January 2012 and included operation with five extraction wells and four injection wells. Phase II included conversion of the five extraction wells to injection wells and installation of additional well points for both injection and extraction. Phase II operation extended from February 2012 to March 2013. The Phase II system included four injection wells and six extraction wells (Shaw 2014).

Alkalinity monitoring was used to evaluate distribution of amendments from the injection well to the extraction wells, a rarely used method to obtain real-time results.

The workplan called for injection of 12,140 gallons of sodium lactate product in Phase I and 3,000 gallons in Phase II. The SDC-9 bioaugmentation culture was introduced directly into injection wells during Phase II. The sodium lactate was diluted with water to provide a dosing concentration of approximately 0.2%.

The recirculation system was initially composed of five downgradient extraction wells and four upgradient injection wells. The system included an additional five extraction wells and conversion of the original extraction wells to injection wells, thereby “sweeping” across the source area westward. The average injection rate was estimated to be 9 gpm per well or 35 gpm total, with injections of sodium lactate at concentrations up to 10,000 mg/L. The average groundwater extraction rate was estimated to be 7 gpm per well or 35 gpm total. Hydrogen gas was also added as a gaseous electron donor. A total of 5,640 standard cubic ft (~29.5 pounds) was added during the two phases

Substantial declines in VOC concentrations were noted while recirculation was ongoing in Phase I and II. Many wells had sustained VOC declines post treatment; however substantial rebound was observed in some wells after the recirculation operations had ceased (CB&I 2015). Additional injections were planned for 2015 but the details concerning these injections and the results were not available at the time of this project.

VAFB Site 15B

Similar to the previously described Site 15A, Site 15B at VAFB was active from 1960 to 1967 and used to launch missiles; prior to launches TCE was used to degrease rocket motors. Site 15B had a separate drainage channel for wash-down water - Channel B. Investigations at Channel B indicate the entry point for groundwater contamination was at a 90-degree bend mid-way in the channel. The plume of contamination at Site 15B is shorter that that at Site 15A and extends approximately 2,000 ft from the launch pad area to San Antonio Creek. TCE and it daughter products are the primary contaminants. (Shaw 2009). TCE concentrations greater than 5 µg/L extend almost 2,000 to 3,000 ft toward San Antonio Creek.

As was the case previously described for Site 15A, the impacted shallow aquifer at Site 15B consists of unconfined groundwater in the unconsolidated dune sand and underlying coarse sand and gravel and deposits.

A groundwater recirculation system was initially planned for Site 15B, however the approach was modified due to the low expected extraction rates (Shaw 2013). The approach was modified to include 24 temporary injection well points. Twelve additional injection well points were added in the course of the operation. Injection and recirculation operations occurred in two phases, the first in July 2011 and the second in May 2012 as summarized below.

Initial remediation activities included injection of EVO and lactate (4,000 gals each) into 24 well points at Channel B in July 2011. Additional injections were conducted in May 2012. The bioremediation resulted in significant reduction of concentrations in the source area although the *cis*-1,2-dichloroethene (cis-DCE) concentrations remained in the downgradient areas at concentrations greater than 1 mg/L.

B.9 Vandenberg Air Force Base, Site 19

Site 19 at Vandenberg Air Force Base is an active NASA facility and is largely occupied by buildings and parking lots. Improper disposal of waste oils and solvents reportedly occurred in the storm water drainage ditch located to the south of Building 836 during the years that the facility was operated. Reportedly waste solvents were also disposed of by pouring the liquids into a storm drainage grating at the southeast corner of the site. In the past, TCE was used as a degreasing agent for parts cleaning and was likely discharged to the ground surface (MWH 2008-02).

Investigations conducted since the mid-1980s have indicated that the primary groundwater contaminants at the site are PCE and TCE along with their daughter products. Other VOCs and petroleum-related compounds including benzene have also been detected at low levels. TCE was considered the main VOC of concern, because it was detected at substantially high concentrations in the subsurface media. TCE-impacted soil was found mainly between two buildings (830 and 836) at 10 to 11 ft bgs in soil near the groundwater table interface.

Two plumes of contamination have been identified – the "TCE Plume" and the "PCE Plume". The TCE Plume is approximately 250 ft in length and 110 ft in width. The highest TCE concentrations are observed in the Building 836 source area (3,300 µg/L), and the contamination is mostly in the upper 35 ft at the site. However, contamination has been observed near monitoring wells at a depth of 70 to 85 ft (MWH 2008-02).

Site 19 is underlain by Quaternary alluvial deposits of the Santa Ynez River floodplain. The upper 5 ft of sediments consists of sand, silty sand, and sandy silt. Between 5 and 20 ft bgs, plastic clay and silty clay were encountered. These unconsolidated sediments are underlain by medium to coarse grained sand and gravelly sand to an approximate depth of 30 to 35 ft. Below this sand unit, the unconsolidated sediments consist of interbedded plastic clayey silt and silty sand. Treatments have occurred in both the upper Clay Zone and the lower Sand Zone. Based on groundwater elevation data collected since 1987, the average groundwater gradient is approximately 0.002 to 0.003; site groundwater flows north-northeast toward the Santa Ynez River.

Phases of bioremediation at the site included:

- Pilot Study with Hydrogen Release Compound® (HRC®) and dehalogenating culture BDI in 2006;
- Reinjection of HRC® and BDI in 2008;
- Injection of LactOil® in 2009;
- Injection of LactOil® in 2011; and
- Additional injections in 2014.

HRC® Pilot Study 2006

The pilot study included the use of HRC® and BDI. Injections were performed in the TCE treatment area in May 2006 and again in the immediate vicinity of monitoring well 19-MW-17A in July 2008. The treatment included injection via DPT of HRC® and BDI in both the shallow Clay Zone and deeper Sand Zone. A total of 17,364 pounds of HRC® and 126 L of BDI were injected. Spacing was 5 ft in the Clay Zone and 10 ft in the Sand Zone. The HRC® and BDI injections had limited success in maintaining reducing conditions in the TCE treatment area.

LactOil®/Lactate Injections 2009

ISB injections (8 ft spacing) occurred between December 2009 and January 2010 and consisted of injections of emulsified vegetable oil (LactOil®), lactate and the dechlorinating microbial culture SDC-9 in the TCE treatment areas (Shaw, 2011). The injections included a mixture of LactOil® (500 gallons) and lactate (20 gallons) delivered at a dose of about 8%. The injections targeted the shallow Clay Zone only. The bioaugmentation cultures BDI and SDC-9 are the same culture.

The data collected during subsequent groundwater monitoring events occurring over the 5 years following the ISB treatment injections showed significantly reduced TCE concentrations in some areas. Ethene and ethane were observed indicating compleete reductive dechlorination in some locations, however, TCE continued to persist in other regions. Additional injections were conducted in 2011 and 2014.

B.10 Vandenberg Air Force Base, Site 35

Site 35 at Vandenberg Air Force Base, also known as Missile Silo 576-G, is a rocket launch facility. Atlas F missiles, fueled with a combination of rocket propellant and liquid oxygen, were launched from the site in the 1960s. Mixed solvents, lubrication oils, hydraulic fluids and TCE were typically used at the dry pad launch facilities (Tetra Tech, 2005).

The plume is long and narrow with TCE concentrations above 1 mg/L extending over 0.5 mile from the source. Investigations at the site indicate that the plume occurs within unconsolidated sediments in a paleo-channel incised into the underlining bedrock. Groundwater is moderately aerobic with DO of 1 to 3 mg/L and a positive ORP.

The subsurface is composed of loosely consolidated deposits of the Orcutt Formation, consisting of beds of sand, gravel, and clay of predominantly continental origin, with the upper zone representing eolian and beach sand. Shale bedrock of the Sisquoc Formation underlies the Orcutt Formation sediments at a depth of approximately 40 ft.

Groundwater beneath the site is unconfined and the water table surface is approximately 20 ft below ground surface. Groundwater appears to flow following the bedrock topography to the southwest at a relatively high hydraulic gradient of 0.05 ft per ft (Tetra Tech, 2005). Aquifer tests estimated the hydraulic conductivity between 1.1 and 5.8 ft/day (Tetra Tech, 2008b).

Source area remediation included soil excavation prior to bioremediation activities. In April 2010, source area soils were excavated and in September 2011 additional source area treatment included injection of EHC, a combination of zero-valent-iron and carbon-substrate product.

Biobarriers have been employed as a bioremediation approach at two locations, one located near the source and one farther downgradient. These are named the ISB Biobarrier and the Distal Biobarrier, respectively. The near-source ISB Biobarrier is a subject of evaluation in the statistical analysis.

Initial pilot studies were conducted from 2001 to 2003 were followed by a full-scale application in 2009. The system included nine injection wells extending approximately 180 ft aligned perpendicular to the plume. The spacing was approximately 25 ft. A total of 1,600 gallons of LactOil® and 385 gallons of sodium lactate product were injected. Bioaugmentation included 1546 L of SDC-9 culture. The substrates were diluted prior to injection to provide a dosing concentration of approximately 1.5%.

Post injection monitoring indicated substantial decreases in VOC concentrations within the first 2 years in downgradient monitoring wells followed by a rebound in concentrations. Additional injections were planned.

Appendix C: Groundwater Sampling for Nucleic Acid Biomarker Analysis

2 Groundwater Sampling for Nucleic Acid Biomarker Analysis

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Abstract: Microbes catalyze relevant transformation processes in aquifers (e.g., contaminant detoxification) and monitoring microbial biomarkers in groundwater yields valuable information regarding their presence, abundance and activity as well as their spatial and temporal dynamics. This chapter provides protocols for *on-site* and *off-site* biomass collection from groundwater for biomarker analysis.

1 Introduction

Freshwater-saturated subsurface environments (aquifers) play a pivotal role in supplying drinking water for a growing human population (Gleick, 1996). Unfortunately, anthropogenic contamination impairs groundwater quality, and supplying clean drinking water has become increasingly challenging. Common groundwater contaminants include organic compounds such as gasoline constituents and chlorinated solvents, as well as inorganic compounds including metals, radionuclides, metalloids, nitrate, and perchlorate, to name a few (www.epa.gov/ogwdw/hfacts.html).

A wealth of information has accrued over recent years about the microbiology contributing to the detoxification of common groundwater pollutants such as chlorinated ethenes (Bradley, 2003; Freedman and Gossett, 1989; He et al., 2003; Holliger et al., 1993; Maymó-Gatell et al., 1997; Sung et al., 2006). A productive pathway leading to detoxification is the stepwise reductive dechlorination of tetrachloroethene (PCE) to trichloroethene (TCE), dichloroethenes (DCEs), vinyl chloride (VC) and ethene catalyzed by bacteria capable of respiratory reductive dechlorination ([de]chlororespiration) (Futagami et al., 2008; Löffler and Edwards, 2006).

The key microbes with the ability to efficiently dechlorinate chlorinated ethenes, including DCEs and VC, to ethene are *Dehalococcoides* (*Dhc*) spp., and a link between *Dhc* presence and detoxification has been established (Ellis et al., 2000; He et al., 2003; Hendrickson et al., 2002; Lu et al., 2006). Bioremediation of contaminated aquifers using both biostimulation (i.e., electron donor additions) and bioaugmentation with *Dhc*-containing consortia or groundwater were successfully implemented (Lendvay et al., 2003; Lookman et al., 2007; Major et al., 2002; Ritalahti et al., 2005; Scheutz et al., 2008). A critical site assessment component prior to technology implementation is knowledge of the presence, abundance and potential for activity of the microbiology contributing to the process of interest (i.e., detoxification). Further, monitoring microbial abundance after technology implementation provides site managers with information on how to control (i.e., enhance) and sustain process performance (i.e., detoxification rates). A few *Dhc* biomarkers to indicate *Dhc* presence and abundance have been identified and *Dhc*-specific prognostic and diagnostic tool kits targeting the *Dhc* 16S rRNA gene and three reductive dehalogenase genes (i.e., *tceA*, *vcrA*, *bvcA*) (See Chapter 26, Vol. 5, Part 2) have been designed (Cupples, 2008; Holmes et al., 2006; Löffler et al., 2000; Regeard et al., 2004; Ritalahti et al., 2006, 2005).

Sampling aquifers for microbial and geochemical analyses in support of bioremediation applications faces several constraints and the ideal sampling regime with regard to sampling locations, sampling frequency and sample type can typically not be achieved. For example, site access limitations, obstruction by existing infrastructure, lack of sampling wells, and shortage of funds for well installation, sample collection and analysis constrain sampling efforts. For practical reasons, sampling focuses on groundwater, and solid aquifer samples are typically not included in routine analyses. The focus on groundwater is justified for the analysis of targets like *Dhc* that distribute in the aqueous phase (e.g., planktonic microbial cells) (Lendvay et al.,

2003; Major et al., 2002); however, the distribution of organisms between solid and aqueous phases in different aquifer matrices is poorly understood for most microbial populations (Amos et al., 2008). Hence, the factors controlling attached versus planktonic growth of target microbes warrants further investigation so that the value added by performing microbial analysis with aquifer solids can be evaluated.

This chapter provides protocols for groundwater collection and biomass recovery for subsequent nucleic acid extraction and biomarker analysis. These procedures are currently applied to *Dhc* biomarker analysis in support of bioremediation at chlorinated solvent sites but the protocols are universal and should be applicable for monitoring other planktonic populations of interest.

2 Approach

2.1 General Considerations

Prior to sampling, the expected outcomes (goals) of the analysis should be clearly defined. What information should the analysis provide? Does qualitative information (i.e., *Dhc* presence) suffice or is quantitative information (i.e., *Dhc* abundance) desired? Will samples be collected only once or will the site be monitored over time? A crucial consideration is that the sampling protocol for a given well (or site) is maintained for the duration of the monitoring efforts. Changes to the protocol during long-term monitoring will complicate data interpretation and should be avoided. Aseptic techniques should be employed to the extent possible when handling groundwater destined for laboratory analysis. An appropriate canopy or cover is recommended to protect sample equipment and samples from direct sunlight or rain, and samples should be packed in a cooler with ice without delay.

Since the filtration method is expected to trap the majority of microbial cells, the amount of groundwater collected determines the number of biomarker genes available for subsequent PCR analysis. Hence, filtering large volumes of groundwater seems beneficial, but for practical purposes (e.g., time constraints, slow well recharge), 0.5–2 L of water are typically collected; however, depending on groundwater characteristics (e.g., fines that clog the membrane filter), as little as 10 mL may be gathered, which may or may not be sufficient for subsequent biomarker analysis. Whether sufficient biomass was captured depends on the abundance of the target biomarker(s) and the types and concentrations of inhibitory compounds. A typical quantitative real-time PCR (qPCR) quantification threshold is 20 gene targets per qPCR reaction. Assuming 1,000 target gene copies in 1 L of groundwater were concentrated to a 100 μL volume of DNA, then 10 target genes would be added to the qPCR reaction tube per μL of template. Consequently, as the volume of groundwater filtered decreases, the detection threshold increases, and a 100 mL groundwater sample will yield a positive result only if more than 1×10^4 target gene copies are present per liter of groundwater (Cupples, 2008; Rahm et al., 2006; Ritalahti et al., 2006).

2.2 Selection of Sampling Wells

Dhc abundance data are valuable throughout the remedial investigation and feasibility study process, and samples for *Dhc* analysis should certainly be collected prior to designing a

bioremediation system (Stroo et al., 2006). Following implementation of remedial action, temporal *Dhc* data from a treated aquifer zone are critical for evaluating and managing the bioremediaton system's performance.

Groundwater samples for *Dhc* analysis should be collected from source area(s) and down gradient plume locations where biodegradation products may have been observed or are anticipated, and where geochemical conditions are favorable for anaerobic bioremediation. If available, samples from a well outside (i.e., upstream) of the contaminated zone(s) should be included, at least in the initial site assessment efforts. Wells should produce sufficient water for adequate purging and collecting at least a 500 mL groundwater sample. Well screen depths and lengths should be considered when selecting a sampling location. Ideally, wells installed for establishing vertical profiles of contaminant (i.e., chlorinated ethenes) concentrations are used to establish a similar profile for *Dhc* distribution. Discrete sampling zones in intervals with dechlorination daughter products (i.e., DCEs, VC) are preferred for *Dhc* analysis, although zones where primarily parent compounds (i.e., PCE, TCE) are present may provide additional information regarding the rate-limiting factors controlling contaminant transformation. Wells with extended screens used for injection of substrates (e.g., electron donor) or bioaugmentation culture should not be used for monitoring performance of the bioremediation system.

2.3 Groundwater Sampling Procedures

Groundwater sampling for microbial analysis typically utilizes methods established for evaluating groundwater chemistry. Selecting a method depends on a number of site-specific conditions including sampling depth, well construction, and aquifer permeability, as well as historic site data and regulatory requirements. Groundwater sampling approaches employ a variety of purging and sampling devices and applicable procedures have been described (reviewed in Yeskis and Zavala, 2002). The goal of these procedures is to generate a sample representative of the formation groundwater of the well vicinity. However, geochemical variations in the water column within a well and geochemical and contaminant stratification within a screened interval are affected by seasonal changes (e.g., rain events, temperature changes) and can lead to variation in biomarker abundance and confound data interpretation (Stroo et al., 2006).

The traditional "well volume" groundwater sampling method involves bailers or high speed pumps (>500 mL min^{-1}) to purge 3–5 well casing volumes prior to collecting groundwater samples. Alternatively, low-flow purging methods (100–500 mL min^{-1}) with a peristaltic or submersible bladder pump are generally recommended to collect groundwater samples for volatile organic compounds (VOCs) and/or geochemical analysis (Puls and Barcelona, 1996). These approaches also apply to microbial (e.g., *Dhc*) analysis, which should occur after geochemical parameters have stabilized. Surging the monitoring well with a surge block or disposable bailer can increase particulate matter in the sample and recovery of associated (i.e., attached) biomass. Whether using traditional "well volume" methods or "low-flow" methods, it is imperative that the same protocol is applied for every sampling event.

This chapter describes two different procedures for sample collection following well preparation (i.e., purging and surging). Procedure 1 (see 3.5.1) relies on collection of groundwater for *off-site* laboratory filtration and biomass collection whereas Procedure 2 (see 3.5.2) collects biomass *on-site* by field filtration using Sterivex-GP 0.22 μm polyethersulfone membrane filter cartridges (Millipore Corporation, Billerica, MA). For analysis of DNA

biomarkers, both approaches provide valuable information (Ritalahti et al., 2009); however, *on-site* filtration using Sterivex cartridges has several advantages. The cartridges are easy to ship, the addition of nucleic acid preservatives to enhance biomarker stability is feasible, and, depending on the aquifer characteristics, larger volumes of groundwater can be collected. In addition, bottle breakage and the disposal of contaminated groundwater in the analytical laboratory are avoided. The primary advantages of laboratory filtration are that the method is commonly used, field personnel are accustomed to the procedure, and the analytical laboratory has greater control over the filtration process (e.g., can prepare replicate filters from the same groundwater sample).

3 Protocol for Groundwater Sampling

3.1. Connect a flow-through cell (e.g., the YSI 556 Handheld Multiparameter Instrument, www.ysi.com) to the tubing of the peristaltic pump. Record the sample start time and the field measurements for pH, oxidation-reduction potential (ORP), specific conductance, temperature, dissolved oxygen, and turbidity.

3.2. Disconnect the flow-through cell.

3.3. Lower a polyethylene disposable bailer into the well to the midpoint of the screen and move the bailer up and down in the water column to surge the well. It is important to agitate at the midpoint of the well screen as this step is not intended to stir up sediment in the sump and/or the bottom of the well.

3.4. While continuing to surge the well with the bailer, re-connect the flow-through cell and record the field measurements for pH, ORP, specific conductance, temperature, dissolved oxygen, and turbidity. Disconnect the flow-through cell but continue to surge the well with the bailer through the sample collection process. Surge the well with steady motion avoiding rigorous mixing of sediment from the bottom of the well.

3.5.1. In order to sample groundwater for *off-site* biomass collection, fill the appropriate sample containers (e.g., clean, sterile 1 L amber glass or plastic bottles with Teflon-lined caps) directly from the effluent end of the pump. No preservatives (e.g., acid) routinely used for stabilizing cations and anions in groundwater samples should be added. The bottles should be filled with groundwater from tubing that has already been used to withdraw one to two well volumes of groundwater to ensure that a representative sample of aquifer water, rather than well water, is collected. The bottles should be filled to capacity (i.e., minimal headspace) to minimize air exposure. Apply the Teflon-lined caps and ensure a tight seal.

3.5.2. For *on-site* biomass collection, use sterile Sterivex-GP 0.22 μm membrane filter cartridges. Attach 1/4–5/16 in. polyethylene tubing to the inlet of the Sterivex cartridge and secure with a clamp. Place the cartridge over a graduated cylinder that can accurately measure the volume of water filtered. Using a 10 mL syringe filled with air, push any remaining liquid out of the Sterivex cartridge. Close the inlet and the outlet of the Sterivex cartridge with male and female Luer Lock plugs, respectively. Sterivex cartridges without a Luer Lock closure on the outlet end are not recommended. Replicate samples should be collected consecutively without flow interruption. Record the volume of filtered groundwater on the chain-of-custody form (see below) and on the Sterivex cartridge barrel with a black permanent marker, and transfer each capped Sterivex cartridge to a separate, new 50 mL Falcon conical plastic tube. The Sterivex cartridges may clog during field filtration before the target volume of

groundwater could be filtered. When membrane fouling occurs, record the volume of groundwater collected so that subsequent data normalization is possible.

4 *On-Site* Sample Handling and Shipping

Since the stability of microbial biomarkers is of concern, the samples (i.e., bottles filled with groundwater and/or Sterivex cartridges) should be transferred to coolers with ice immediately after sampling and shipped using an overnight carrier to the analytical laboratory.

4.1. Chain-of-custody forms. Immediately following sample collection, record the sampling well location, the well ID, notes on individual samples (e.g., the volume of water that passed through each Sterivex cartridge), date and time of sampling, the handler's name and contact information, and the type of analyses requested. Chain-of-custody forms are either provided by the analytical laboratory or the consulting firm, and must accompany each sample shipment.

4.2. Sample shipping. The coolers with samples are shipped for next day delivery to the analytical laboratory. It is important to notify analytical laboratories when samples are shipped to avoid delays in handling and processing that could affect biomarker integrity.

4.2.1. Groundwater-filled containers: Apply several layers of bubble wrap to protect against breakage and double bag each container in separate Ziploc plastic bags. Transfer the bottles to a cooler and use ice packs and/or blue ice (in Ziploc bags) to ensure refrigeration until arrival at the analytical laboratory. Use additional packing material, as appropriate, to prevent movement and breakage during shipping.

4.2.2. Sterivex cartridges: Place each Falcon plastic tube with one enclosed cartridge into a separate Ziploc bag and transfer to an appropriately sized cooler with ice packs and/or blue ice (in Ziploc bags).

5 Sample Handling in the Analytical Laboratory

Upon arrival, transfer containers with groundwater immediately to a 4°C incubator and Sterivex cartridges to a −80°C freezer. Collect biomass from groundwater samples (see 5.1) as soon as possible to minimize biomarker loss and formation of iron precipitates, which interfere with the filtration process and downstream sample processing.

5.1. Biomass collection from groundwater.

5.1.1. Connect a 47 mm diameter, polyethersulfone membrane filter (0.22 μm pore size) unit (MO BIO Ultraclean™ Water DNA Isolation Kit, MO BIO Laboratories Inc.) to a vacuum filtration system. Use a vacuum manifold for simultaneously filtering multiple samples.

5.1.2. Working aseptically inside a fume hood, filter 100 mL aliquots of the groundwater. Repeat with additional 100 mL aliquots until 1 L of groundwater has been filtered. If less than one liter passes through the filter, record the final filtered volume.

5.1.3. Use flame-sterilized forceps to transfer the membrane filter with the biomass cake to a sterile Petri dish. Following biomass collection, the membrane filters can be stored at −80°C or processed immediately.

5.1.4. Cut the membrane filter into strips with a sterile razor blade. Remove the strips aseptically with sterile forceps and place them into a sterile tube appropriately sized for the DNA extraction method to be used.

5.2. Biomass collection for nucleic acid extraction from Sterivex cartridges.

5.2.1. If stored at −80°C, thaw the Sterivex cartridges at room temperature.

5.2.2. Remove the cartridge from the Falcon plastic tube and record any information written on the cartridge barrel. Wipe the exterior of the cartridge with ethanol and place in a sterile Petri dish.

5.2.3. Remove the plugs from both ends of the cartridge and connect a 10 mL syringe to the cartridge outlet and remove any remaining liquid from inside the cartridge barrel.

5.2.4. Place the cartridge in an appropriately sized pipe cutter that has been cleaned with 70% ethanol. Fit the blade of the pipe cutter into the seam near the outlet end of the filter cartridge (*Fig. 1*).

5.2.5. Remove the exterior portion of the cartridge housing by slowly tightening the blade and rotating the cartridge until the cartridge barrel holding the membrane and the housing come apart (*Fig. 1*). The membrane filter remains attached to the interior barrel of the cartridge.

5.2.6. Use a sterile razor blade to cut the membrane filter into 4–12 strips while leaving one end of each strip attached to the housing (*Fig. 2*). The size, shape and the number of strips cut depends on the tube size (e.g., 2.0 or 15 mL) required for subsequent DNA extraction procedures.

5.2.7. Remove the filter strips including the 0.1 μm membrane filter at the end of the barrel (*Fig. 2*) aseptically with sterile forceps and place them into an appropriate tube for DNA extraction. Add any liquid remaining in the cartridge to the same tube.

5.2.8. Standard protocols described elsewhere are applied to extract DNA from the biomass collected on the membrane filters. Protocols for RNA extraction from Sterivex cartridges are described in Chapter 26, Vol. 5, Part 2.

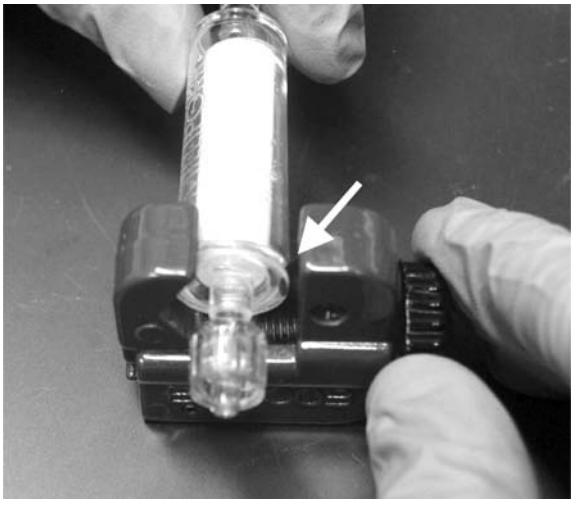

Figure 1

The blade of the pipe cutter (white arrow) is fit into the seam near the output end of the Sterivex cartridge. By rotating the cartridge while slowly tightening the pipe cutter, the cartridge housing opens and the membrane filter is exposed.

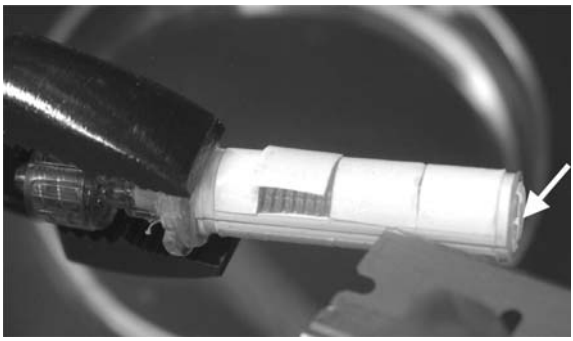

Figure 2

A flame-sterilized razor blade is used to cut the membrane filter into 4–12 strips while leaving each strip attached to the housing. The arrow points to the 0.1 μm membrane filter at the end of the barrel. The filter strips, including the round end piece, are removed aseptically with forceps, placed into sterile 2.0 or 15 mL plastic tubes and used for DNA extraction.

6 Equipment and Supplies

Microbial (e.g., *Dhc*) analysis requires the standard equipment and supplies used for groundwater sampling to perform VOC and geochemical analyses.

For *on-site* filtration:

- Sterivex-GP 0.22 μm polyethersulfone membrane filter cartridges (Catalog # SVGPL10RC), Millipore Corporation, Billerica, MA.
- Male and female Luer Lock plugs (Catalog # EW-45503–58 and EW-45500–28, respectively), Cole-Parmer, Vernon Hills, IL.
- Falcon tubes (50 mL) or equivalent plastic containers for protecting Sterivex cartridges during shipping and storage, standard laboratory suppliers such as Fisher Scientific, Pittsburgh, PA and VWR International, West Chester, PA.

Sample processing in the laboratory:

- Standard Duty Dry Vacuum Pump (Catalog #2511B-01), Gardner Denver Thomas, Welch Vacuum Technology Inc., Nile, IL.
- Filtering manifold (Catalog # 02924–20), Cole-Parmer, Vernon Hills, IL.
- MO BIO UltraClean™ Water DNA Isolation Kit (Catalog # 14880–10, 14880–25), MO BIO Laboratories, Inc., Solana Beach, CA for collecting and processing biomass from groundwater.
- MO BIO PowerSoil™ DNA Isolation Kit (Catalog # 12888–50, 12888–100), MO BIO Laboratories, Inc., Solana Beach, CA. for processing Sterivex Filters
- Vortex Genie 2 (Catalog # 13111-V), and adapters for 15 mL Falcon tubes (Catalog # 13000-V1–15), and/or 2 mL bead tubes (Catalog # 13000-V1), MO BIO Laboratories, Inc., Solana Beach, CA.
- Small tubing cutter, local hardware store.

Petri dishes, forceps, razors, 10 mL syringes, and 2.0 or 15 mL plastic tubes from standard laboratory suppliers (Fisher Scientific, Pittsburgh, PA and VWR International, West Chester, PA)

7 Time Considerations

Low-flow purging and sampling methods typically can be completed in 1–2 h per well. Field filtration procedures (i.e., Sterivex cartridges) may add up to 30 min per well, along with additional training of personnel.

An important consideration is the shipment of samples to the analytical laboratory, which should occur without delay to minimize biomarker loss. Overnight carrier delivery is commonly used and the samples should be processed and/or preserved as soon as possible upon arrival. Biomass from groundwater should be harvested as soon as possible after receipt of samples. Filtration of groundwater samples greatly depends on the amount of particulates present and could require from a few min to several hours for each sample. Immediate filtration of groundwater samples is recommended because iron precipitates formed when dissolved ferrous iron is oxidized following air exposure can significantly reduce the volumes of groundwater that can be filtered in acceptable time periods. With practice, processing a Sterivex cartridge will require 5–10 min.

8 Quality Assurance/Quality Control

A one-size-fits-all approach to biomarker analysis has not been adopted, and different analytical laboratories use different PCR primers, qPCR detection chemistries and analytical equipment. Since all of the factors that affect the analysis of environmental samples cannot be accounted for, and repeating the analysis of a particular sample may not be feasible (e.g., if only one Sterivex cartridge was available), good record keeping is key, and begins in the field. The analytical laboratory benefits from having as much information as possible available, in particular with regard to volume filtered, and whether problems were associated with collecting the sample. As with any analytical method, the laboratory must follow standard operating procedures (e.g., for DNA extraction and qPCR). Standard curves should be performed with each qPCR run to verify proper instrument performance and operation. Each sample should include at least three replicate qPCR reactions and multiple (e.g., at least two) dilutions of the extracted DNA solution should be analyzed. Preferably, two or more Sterivex cartridges or groundwater samples are available for each well, so that quantitative results from replicate DNA extractions can be compared. The skilled technical specialist must be able to reproducibly perform the assays, assess data quality and interpret the qPCR results by analyzing the amplification plots. If qPCR data suggest inhibition (e.g., deviation from exponential amplification or poor amplification in undiluted samples), this information should accompany target gene quantification estimates.

9 Trouble Shooting

Negative results (i.e., no *Dhc* biomarker genes detected) suggest that the target microbes (e.g., *Dhc*) are absent and that reductive dechlorination of DCEs and VC to ethene cannot be

expected. Negative results should be interpreted cautiously because the target organisms may be heterogeneously distributed in aquifer formations or the analysis may erroneously fail to detect *Dhc* biomarker genes. For example, false negative results may be caused by several factors including:

- Very low numbers of *Dhc* bacteria are present.
- The characteristics of the groundwater or sampling well(s) limit the volume of groundwater that can be withdrawn or filtered (and hence the amount of biomass that can be analyzed).
- The presence of inhibitors that interfere with biomarker analysis (e.g., via qPCR).
- The loss of biomarkers during sample handling, transport and storage.

To minimize false negative results, samples from multiple wells in different areas within the contaminant zone(s) should be collected and analyzed for the presence and abundance of *Dhc* biomarker genes, in particular during initial site analysis.

DNA extracted from groundwater may contain substances that interfere with PCR analysis either by affecting PCR amplification or by impacting the intensity of the fluorescence signal in qPCR. This effect is not predictable and typically leads to underestimation of the actual biomarker gene copy numbers (Stults et al., 2001). To detect possible PCR inhibition, template DNA should be used undiluted and at a 1:10 or appropriate higher dilution. PCR inhibition is indicated when the undiluted DNA sample yields fewer copies per µl of template DNA than the dilutions, when adjusted for the dilution factor. Another indication of inhibition is obtained from the qPCR fluorescence plot on the real-time thermocycler. Inhibition is indicated when undiluted samples do not display the expected sigmoid, exponentially increasing fluorescence curve. Since dilution may result in too few copies to be detectable with qPCR, it may be prudent to perform a nested PCR that avoids inhibition and provides unsurpassed sensitivity (but quantitative information is lost) (Löffler et al., 2000).

A prerequisite for a meaningful application of the analytical approach is that the biomarkers of interest are stable from the time of sample collection until the actual analysis occurs. Biomarker stability cannot be predicted, varies between organisms, and is influenced by environmental conditions. *Dhc* biomarker genes are considered to be stable for at least 24 h at 4°C, and no differences have been observed between Sterivex cartridges prepared in the field and shipped to the analytical laboratory, as compared with groundwater shipped from the field with the filters prepared in the lab (Ritalahti et al., 2009). Hence, *Dhc* DNA biomarker loss should be negligible with proper sample handling procedures and short-term refrigeration. RNA is generally less stable than DNA and prone to degradation and integrity of biomarker transcripts during sample shipping is of concern. Procedures to obtain RNA from Sterivex membrane filters are presented in Chapter 26, Vol. 5, Part 2.

10 Research Needs

To advance microbial groundwater monitoring, the integrity of the target biomarkers (DNA, RNA, proteins, fatty acids) and preservation methods should be explored in detail so that the loss of analyte(s) during sampling and sample handling can be quantified and appropriately considered for data interpretation. The search for process-specific biomarkers, including DNA (genes) RNA (transcripts), proteins, and fatty acids, must continue to enhance information richness and resolution of the analytical process. To reduce analysis costs, even with a broader

suite of biomarker targets, site-tailored multiplex qPCR assays that only enumerate biomarkers that are informative for a given site should replace the current "shotgun" approaches that probe all available biomarkers. Further, the contemporary biomass collection and sample handling procedures should be compared, and if needed, standardized to facilitate comparative analyses between sites. In addition, standard analytical procedures should be developed and applied so that data generated in different laboratories can be directly compared. Groundwater analysis for chemical analytes (i.e., contaminants) routinely uses internal standards to quantify losses and provide accurate quantitative measurements. Internal standards for microbial analysis are currently not available but the development of such internal standards would be a major advance for microbial biomarker quantification. Further, implementing standard analytical procedures would allow direct comparison of data generated in different laboratories. Since groundwater analysis for monitoring microbial processes in the subsurface requires that some fraction of the target microbes is planktonic, the factors controlling the switch from sessile (e.g., attached growth in biofilms) to a planktonic lifestyle must be explored. Unfortunately, the effects of changing geochemical conditions on the physiological status (ecophysiology) (e.g., attached vs. planktonic growth) of the target populations are poorly understood, which confounds quantitative assessment of groundwater samples and data interpretation. Addressing these research needs and technical challenges will advance microbial groundwater analysis to a routine procedure that informs about microbial processes of interest in aquifers.

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Appendix D: Passive Flux Meter Protocol Report

Environmental Security Technology Certification Program (ESTCP)

Final Protocol Report

Field Demonstration and Validation of a New Device for Measuring Water and Solute Fluxes CU-0114

November 2005

University of Florida
&
Purdue University

Table of Contents

List of Acronyms

AC	activated carbon
ACGIH	American Conference of Governmental Industrial Hygienists
CAR	corrective action report
CF	chloroform
CM	chloromethane
CPVC	chlorinated poly (vinyl chloride)
CV	coefficient of variation
DMP	2,4-dimethyl-3-pentanol
DNAPL	dense nonaqueous phase liquid
DO	dissolved oxygen
DoD	Department of Defense
ED	electrochemical detector
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FID	flame-ionization detector
FRTR	Federal Remediation Technology Roundtable
FTL	field team leader
GC	gas chromatography
HASP	health and safety plan
HPLC	high pressure liquid chromatography
IBA	isobutyl alcohol
IC	ion chromatography
I.D.	inner diameter
IDL	instrument detection limit
IDLH	immediately dangerous to life or health
IPA	isopropyl alcohol
MDL	minimum detection level
MeCl	methylene chloride
MLS	multilevel samplers
MS	matrix spike
MSD	matrix spike duplicate
MSDS	materials safety data sheets
MTBE	methyl tertiary butyl ether
NAPL	non-aqueous phase liquid
NBS	national bureau of standards
NIOSH	National Institute for Occupational Safety and Health
NITS	National Institute of Standards and Testing
O.D.	outer diameter
OSHA	Occupational Safety and Health Administration
PCE	perchloroethylene
PEL	permissible exposure limit

PFM	Passive Fluxmeter
PPE	personal protective equipment
PSO	project safety officer
PVC	poly (vinyl chloride)
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RPD	relative percent difference
RRF	relative response factors
RRT	relative retention times
SD	standard deviation
SOP	Standard operating procedure
SRM	Standard Reference Materials
SS	stainless steel
SSO	site safety officer
TBA	tert-butyl alcohol
TCE	trichloroethylene
TLV	threshold limit value
TWA	time weighted averages
VOA	volatile organic acid

1.0. PFM Construction, Storage, and Transport

1.1. Description of PFM

The PFM is a self-contained permeable unit that is inserted into a well or boring such that it intercepts groundwater flow but does not retain it (See Figure 1-1).

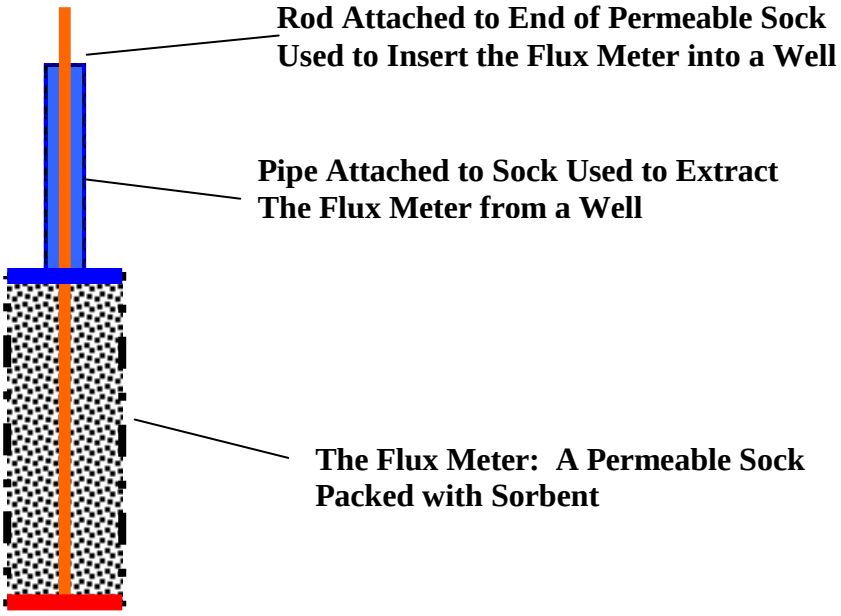


Figure 1-1. Schematic of a Flux meter comprised of a permeable sock filled with a selected sorbent.

The interior composition of the flux meter is a matrix of hydrophobic and hydrophilic permeable sorbents that retain dissolved organic and/or inorganic contaminants present in fluid intercepted by the unit. The sorbent matrix is also impregnated with known amounts of one or more fluid soluble 'resident tracers'. These tracers are leached from the sorbent at rates proportional to fluid flux.

After a specified period of exposure to groundwater flow, the flux meter is removed from the well or boring. Next, the sorbent is carefully extracted to quantify the mass of all contaminants intercepted by the flux meter and the residual masses of all resident tracers. The contaminants masses are used to calculate cumulative and time-averaged contaminant mass fluxes, while residual resident tracer masses are used to calculate cumulative or time- average fluid flux. Depth variations of both water and contaminant fluxes can be measured in an aquifer from a single flux meter by vertically segmenting the exposed sorbent packing, and analyzing for resident tracers and contaminants. Thus, at any specific well depth, an extraction from the locally exposed sorbent yields the mass of resident tracer remaining and the mass of contaminant intercepted. Note that multiple tracers with a range of partitioning coefficients are used to determine variability in groundwater flow with depth that could range over orders of magnitude. This data is used to estimate local cumulative water and contaminant fluxes.

1.2. Preparation of Sorbent (Activated Carbon) and Tracers

Table 1-1 provides a complete list of equipment items need to prepare the PFM sorbent, while Table 1-2 lists all required parts. A tracer mixture is prepared by combining appropriate ratios of all tracers used for the test. Tracer volumes are measured in graduated cylinders and transferred to a volumetric flask for mixing. The flask is manually mixed. The sample mixture includes 100 ml of methanol, 100 ml of ethanol, 200 ml of isopropylalcohol (IPA), 200 ml of tert-butyl alcohol (TBA) and 66 ml of 2, 4-dimethyl-3-pentanol. A volume of the tracer mixture is transferred to a 22L plastic jar containing water (190 ml of tracer solution is added to 15 L of water). The jar cap is tightened with several layers of Teflon tape to provide a seal. This is mixed manually agitating occasionally over a period of a few hours until all immiscible liquids have dissolved.

Dry activated carbon (AC) is added to the aqueous solution containing tracers. 15 L of AC is slowly added to the 22L jar. Each jar is weighted before transfer. Significant gas is generated by adding the AC to water so this process requires addition of AC with gentle agitation until the AC is completely wet. Note a dust mask should be worn during this process. After all AC is added the jar is again sealed using several layers of Teflon tape.

The jars containing AC, water and tracers are mixed by rotating. The jars are placed in a 55 gallon drum and secured using foam packing. The 55 gallon drum is rotated or rolled for a period of 6 hours to homogenize the AC tracer mixture. Following mixing, the 22 L jars are placed in a cooler until shipping or packing.

1.3. Assembly of PFMs

Table 1-1 provides a complete list of equipment items need to prepare for PFM assembly, while Table 1-2 lists all required parts. The passive flux meters are constructed in a pipe having the same diameter as the well screen. The exception is for stainless steel well screen nylon for which a red mesh material is added. In this case the pipe used for construction should be slightly (0.1 inch) smaller diameter than the well screen. The pipe length is 5 feet. A table is used as a work area for packing of the flux meters. All materials needed for packing the PFMs are listed in Section 3-0. Nitrile protective gloves and protective clothing are worn during construction.

Prior to packing the PFMs with AC, the sock is attached to the center tube of the PMF. The center tube for 2 inch wells consists of 1/2 inch CPVC pipe cut to 5 feet lengths. The bottom of the sock is clamped to the CPVC pipe using a SS worm drive clam (pipe band clamp). The sock is protected from the clamp by wrapping the CPVC pipe with electrical tape (4 wraps) prior to attaching the sock and between the sock and the SS clamp. This is important to avoid sharp edges of the clamp tearing the sock material. The sock and tube are then placed in the packing pipe and the top of the sock is pulled back over the outside of the packing pipe (note the ends of the packing pipe should be sanded to remove sharp edges capable of tearing the sock material). Prior to adding AC to the PFM a thick (1/8 inch) viton washer is inserted to the bottom of the sock. The viton washers used should have an OD of the packing pipe and a center hole the same

as the center tube (for 2 inch wells, 2 inch OD with a 5/8 inch hole). The viton washers are pushed to the bottom of the PFM using a 3/4 inch CPVC pipe.

Prior to packing, the top of the center tube must be plugged to avoid AC entering the center tube. Any method of plugging is appropriate (cork, rubber stopper, cap, electrical tape). At this point the PFM is ready for packing with AC. A funnel is used to drop the AC lifts into the PFM. The funnel should be cut to have an opening slightly smaller than the packing pipe. AC is transferred to a 400 ml beaker using a large spoon and the AC poured into the funnel attached to the top of the packing pipe. The funnel is tapped to slide the AC into the sock and packing pipe. A vibrator (or manual tapping) is applied to the packing pipe to help settle the AC to the bottom of the sock. After adding the required amount of AC (this will depend on the desired sampling interval), a thin (1/16 inch) viton washer is pushed down the sock to pack the AC in place. This process is continued until the sock is filled. During this period, an initial AC sample is collected and placed in a 40ml vial containing 20 ml of extraction solvent (IBA). For 5 foot long socks typically 4 to 6 lifts are packed. At the top of the PFM a thick viton washer is added followed by a sponge cut to the same size as the viton washer. The sponge is used to minimize AC loss from the top of the PFM since the connection between the top of the sock and the center tube must be loose.

At this point the top of the sock is attached to the retrieval wire and short section of PVC pipe. The outside of the PVC pipe section should be wrapped with electrical tape to protect the sock from the wire rope. The PVC pipe section is then slid over the center tube down to the position of the sponge. The sock is pulled up over this section. Electrical tape is applied over the sock attaching it to the PVC pipe section (4 or 5 wraps). This is critical to protect the sock from the SS clamp. A SS clamp is attached to the sock ensuring that the clamp is securely over the PVC pipe section and electrical tape is protecting the sock. This step is very critical since failure of this attachment will make PFM retrieval extremely difficult. This clamp should be well tightened but not stripping the worm drive clamp. Electrical tape is then wrapped around the outside of the clamp to prevent the clamp from catching on joints in the well screen and casing.

1/16 inch stainless steal wire rope is used to retrieve the PFMs. These need to be constructed prior to PFM assembly. The wires are fastened using wire crimps with a crimping tool. The wires are connected to the sock at the top of the PFM using a short section of PVC pipe (approximately 1.5 inch section of 3/4 inch PVC) with the wire looped through holes drilled in the short section of pipe. Four holes (1/8 inch) are used to thread the wire though the pipe and is crimped to the entry wire using two crimps. The other end of the wire is formed into a loop at the end of the wire either the length needed for deep deployment or a short section (6 inches) that is attached to a second wire rope using a coupler. The short wire is required if the PFM will be stored in tubes for storage and shipping.

The PFM construction process is visualized in pictures below.

1) Place empty PFM sock into PVC packing tube.



2) Take a C_0 sample of the sorbent for each PFM created.


3) Scoop sorbent mixture into 400mL beaker. Pour sorbent mixture from beaker into PFM sock using a funnel placed inside the packing tube.


4) Slide a neoprene washer onto center tube after each one-foot segment of sorbent is poured into sock (for vertical separation of segments). Use pipe with a larger I.D. than the O.D. of the PFM center pipe to push the washer into the mesh sock.


5) Repeat steps 3 and 4 until all of the sorbent has been loaded into the PFM.

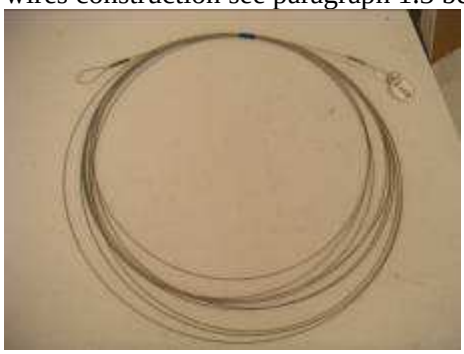
6) Attach retrieval mechanism to top of PFM

7) Push newly constructed PFM out of packing tube and into transport tube.

8) Screw on Teflon lined end caps to both ends of transport tube.

9) PFM is ready for transport.

10) Cut retrieval cable for each PFM to correct length. Use stainless steel compression sleeves to form loops at both ends. Label the wire with the appropriate PFM ID. For detailed description of wires construction see paragraph 1.3 below.



Equipment items and materials needed to construct and sample PFM are summarized in Table 1-1.

Table 1-1. Equipment Items Needed to Construct and Sample PFM(task based).

Preparing Activated Carbon and Tracers
Prepare tracer solution in water:
Graduated cylinders (50, 100, 500 ml, 1, 2 L)
1L volumetric flask
Glass funnel
Stir bars
Stir plate
Pipettes (10, 25, 50, 100 ml)
Pipette bulb
22L plastic jars (Cole-Parmer)
Adding AC to 22L jars:
2L plastic jars
Balance (2 decimal place up to 4Kg)
Dust masks
Teflon Tape (3/4 inch heavy duty)
Mixing AC:
55 gallon drum roller
55 gallon drum with removable top
Dense foam pieces to hold 22L jars in place
Preparing wire lines for PFMs:
Wire cutters
PVC pipe cutter
Pliers
Wire Crimper (McMaster Carr 3582T5 Multi Groove Hand Tool For All 3/64" Sleeves & 3/32" Alum Oval Sleeves)

200 ft tape measure
Drill with 1/8in bit
Dremel tool
Constructing PFMs:
Nut drivers (5/16”)
400 ml beakers
Work table
Constructing PFM carrying tubes:
Hack Saw
Sand paper
PVC glue
Teflon tape
Sampling PFMs
Preparing sample vials:
Balance
Syringe dispenser (for IBA) (Fisher item}
Sampling in the field:
Spatulas
Scissors
Mixing bowls
Buckets

All parts used for PFM construction and their costs are listed in Table 1-2.

Table 1-2. PFM Parts List 10/3/05

Part	Supplier	Part Number	Cost
Silver Impregnated Granular Activated Carbon	Eric R. Hasis Inside Sales Representative Site Services/Remediation Calgon Carbon Corporation PH: 800-422-7266 x 4770 Fax 412-787-4523 website: www.calgoncarbon.com		50 – 200 lbs...$7.22/lb
IBA 2.5L	Fisher Scientific	15828-0025	$95
40 ml VOA vials Max=300 (432) Ordered direct to site (222 left)	Fisher Scientific	03-339-14A	
60+ 5.5 ft long socks	Lili’s Alterations		$4/sock
330 feet of red mesh (only needed for SS wells)	Cole-Parmer	U-09405-30	$95/164ft
½ inch CPVC tube	Hardware Store		
Rubber Washers	Servalite	RT258	$0.52 each

	1-800-477-6760	RM258	
Hose clamps	McMaster-Carr www.mcmaster.com	54155K15 5415K32	$0.56 $0.39
Threaded rod for pushing wells in	GeoProbe		$500
Wire lines.	McMaster-Carr www.mcmaster.com	3461T9 3883T39	Wire $0.08/ft
PFM Parts List **(Need to have on site)**			
1.8" PVC pipe (to pack socks in)	Hardware Store		
3/4 in PVC pipe for packing	Hardware Store		
Funnels	Hardware Store		
Vibrator			
Power cord	Hardware Store		
Bucket for fluid leakage	Hardware Store		
Large spoon for transferring			
Calibrated jar	Fisher Scientific		
Spatula for Co sampling	Fisher Scientific	14-357	$6.06
Electrical tape **order more**	Hardware Store		
Wrenches	Hardware Store		
Pipe cutter	Hardware Store		
Hack-saw	Hardware Store		
Tape measure	Hardware Store		
Balance **on-site**	Fisher Scientific		
Cooler			
Blue Ice			
Syringe dispenser	Fisher Scientific	13-689-135D	$274
Field notebook	UF Bookstore		
Gloves	Fisher Scientific		
Rope	Hardware Store		
Hard Hats			
Copper caps			
Safety vests			
Steel toe boots			
Methanol	Fisher Scientific	A452-4	$174.41
Ethanol	Fisher Scientific		
IPA	Fisher Scientific		
TBA	Fisher Scientific		
2,4-dimethyl-3-pentanol	Fisher Scientific		

1.4. PFM Storage

Table 1-1 provides a complete list of equipment items need to prepare PFMs for storage, while Table 1-2 lists all required parts. If the PFMs are constructed for transport to the field site, the PFMs will be stored in tubes and cooled. PFM storage tubes are constructed using PVC pipe the same diameter as the packing tube. The ends have threaded caps that are sealed using Teflon tape. In the bottom of the storage tube a spacer is place to stop the PFM from sliding past the end of the PVC pipe (usually a gap exists between the pipe and end cap in which the PFM can expand during transport). A rubber stopper (#10) works well. The PFM is then extruded from the packing tube into the storage tube. A section of threaded rod or PVC pipe is used to push the PFM out of the packing tube and into the storage tube. The top of the storage tube is then sealed. The PFMs are then placed in cold storage (5 °C) until transport.

1.5. PFM Transport

Table 1-1 provides a complete list of equipment items need to prepare for PFM transport, while Table 1-2 lists all required parts. The PFMs are transported in insulated containers to the site. Cardboard boxes (5ft by 8x8in) with foam insulation (1 inch) forming the walls has been used for FedEx shipments. Blue ice is added to the box for cooling. For vehicle transport appropriate insulation for the travel time can be constructed.

2.0. PFM Deployment

2.1. PFM Insertion

Table 1-1 provides a complete list of equipment items need for PFM deployment, while Table 1-2 lists all required parts. At the field site the PFM in the packing tube or storage tube is prepared for PFM insertion into the well casing. A wire rope is attached to the top of the PFM using a safety carabineer (or if packing on-site the required wire has been attached to the PFM). The tube is lined up with the top of the well casing and a section of push rod is used to push the PFM from the tube into the top section of well casing. Additional push rods are attached to continue pushing the PFM to the screen interval. If multiple PFMs are deployed in a single well, the wires from PFMs currently in place are held taught to avoid the wire catching on the PFM being inserted. When inserting the PFM some back pressure may build since the water in the well casing must flow through the center tube as the PFM is inserted. Proceed slowly is pressure builds. The flux meter steel cable attached to the sock assembly is then secured to an exterior 2” segment of PVC pipe to ensure that it will not be lost to the well head.

Step-by-step instructions are provided below.

1) Transport PFMs to site using PVC transport tubes (either by vehicle or FedEx Overnight). Once onsite, organize the flux meters for deployment.

2) Setup a workstation at the first deployment location by laying the PFMs for the first well across two portable sawhorses.

3) Remove end caps from PVC transport tubes.

4) Remove well lid and cap.

5) Attach retrieval cable to the top of each PFM.

6) Install PFM by setting the transport tube on top of the monitoring well casing and using Geoprobe rods to push the PFM out of the transport tube and into the well.

7) Push PFM into position in the well using Geoprobe rods while maintaining tension on the retrieval cable.

8) Repeat steps 5 through 7 for each PFM that is to be installed in the well.

9) Replace well lid and cap (wire cables are cut to a length such that two feet of each retrieval cable will remain outside the well).

10) Repeat steps 2 through 9 for each well.

2.2. PFM Retrieval and Sampling

Table 1-1 provides a complete list of equipment items need to retrieve and sample PFM, while Table 1-2 lists all required parts. PFMs are retrieved using the wire rope. The top PFM in the well is extracted first by gently pulling up on the wire (heavy work gloves should be worn when pulling on 1/16 inch cable). The PFM should be pulled to the top of the well casing. The PFM will occasionally catch on joints in the well screen. Simply apply more pressure to overcome. If the PFM will not move look at troubleshooting options below. When the PFM is at the top of the well casing untangle any wires that are twisted at the well head. Thread the retrieval cable through a 5' x 2" I.D. PVC pipe and place the pipe over the well to guide and contain the extruded PFM. Move the PFM to the sampling work station.

A tarpaulin acts as a 'protective flooring' for the work zone. A portable table is used as a work zone for sampling the PFMs. All material listed in Table 1 will be contained in this area during the retrieval stage. Nitrile protective gloves and necessary other protective clothing will be worn by all samplers. A lined bucket is placed under the work area to capture un-sampled residual activated carbon from the retrieved PFM. The sock is extruded from the PVC pipe to the sampling interval extent. The flexible mesh and cotton packing materials are cut and the sorbent captured in plastic bowls for homogenization using a stainless steel spatula. A sub-sample is then transferred into 40 mL VOA vials each containing the extraction solvent. 10 grams of sample or 1.5 cm sample depth is added to the vials. The vials are stored in a cooler containing blue ice prior to transport back to the laboratory for analysis. The center tube and viton washers are measured to obtain the sample interval lengths in the PFM. Sampling materials, spatula, scissors, mixing bowls are wiped cleaned of AC grains prior to retrieval of the next PFM.

40 ml VOA vials are used for AC sampling. The vials are weighed empty (nearest 0.01 g) and recorded. The vials are then filled with IBA (extraction solvent) using a fixed volume dispenser (20 ml syringe dispenser) and sealed. The vials weights are then recorded. Following addition of AC (approximately 2cm depth) the vials are weighed.

The PFM retrieval and sampling procedure is visualized in pictures below.

1) Retrieve PFM from well by pulling up on the attached wire cable. The PFM is pulled from the well pipe directly into a PVC tube of the same diameter.

2) Place tube on table and expose the first segment by pulling on the bottom end of the PFM.

3) Using scissors, cut open the nylon mesh covering the first segment and pour the exposed sorbent into a bowl.

4) Stir the sorbent to homogenize

5) Sub-sample the mixture and place into 40mL vial containing IBA

6) Measure the interval length of the PFM segment

7) Repeat for steps 3-8 for remaining segments of PFM

8) After all PFMs are sampled, place 40mL vials into cooler(s) and ship back for analysis

9) Excess sorbent is collected in a plastic-lined container for proper hazardous waste disposal.

All equipment items and materials needed for deployment and retrieval of PFM in the field are listed in Table 2-1.

Table 2-1. Field Equipment and Materials

Item	Used During Deployment	Used During Retrieval
Field notebook	X	X
Cotton Flux Socks	X	
Stainless Steel Rods	X	
Flexible Plastic mesh	X	
Plastic funnel	X	
Tracer loaded Activated Carbon	X	
Rubber washers	X	
Steel-wire retrieval cable	X	
Medium threaded stainless steel clamps	X	
Small stainless steel threaded clamps	X	
Electrical tape	X	X
Spoon/scoop	X	
Paper towels	X	X
Clean cloth	X	X
Garbage bags	X	X
20L Carboy containing Deionized water	X	X
Portable workbench	X	X
Tarpaulin	X	X
Latex gloves	X	X
Protective work gloves	X	X
Wire crimper	X	
40 mL VOA vials containing 20mL solvent	X	X
1” I.D. PVC packing rod	X	
1.8” I.D. PVC packing pipe	X	
2” I.D. PVC Transporting pipe	X	X
4’ Plastic attachable insertion rods	X	
Tape measure		X
Stainless steel spatulas		X
Tool box	X	X
Plastic homogenizing bowls		X
Scissors	X	X
Bucket	X	X
Alconox solution	X	X
20L Carboy for liquid waste	X	X
Nitrile protective gloves	X	X

2.3. Troubleshooting PFM extraction

In the event that the PFM is difficult to remove from the well the following steps might be considered. Using the rods used to insert the PFM, push down to move the PFM below the obstruction. In this case it is useful to attach a viton 2 inch washer at the end of the push rod to center the rod in the well. Holding both the retrieval wire and the push rod, surge the PFM up and down to attempt to overcome the obstacle.

In the event that the wire breaks or becomes detached from the PFM, a corkscrew attachment can be added to the rod to attempt to "grab" the top of the PFM and advance it upwards. If this fails the corkscrew can be used to dig into the AC and viton washers again in an attempt to "grab" the PFM. Finally, a pump with tubing lowered to the top of the PFM can be used to extract the AC. This slow process obviously destroys the PFM, but can be successful in clearing the well.

3.0 Analytical Methods Supporting the Experimental Design and Sampling Plan

Details of, or references to, the analytical methods employed in sampling and analysis to determine the results of the application (i.e. performance) of the technology.

3.1. Standard operating procedure for extraction of analytes from flux device sorbents (October 10, 2001)

3.1.1. Scope and application

1. This SOP describes the procedures used by the Department of Environmental Engineering Sciences, University of Florida, for extraction of target analytes (including tracers) from sorbents used in flux devices inserted in monitoring wells.

2. This SOP was written by M.D. Annable, Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL.

3. The selected constituents are TCE, PCE, and alcohol tracers:

Methanol
Ethanol
2-propanol (IPA)
2-methyl-1-propanol (IBA)
2-methyl-2-propanol (TBA)
n-propanol
n-butanol
n-pentanol

n-hexanol
n-heptanol
3-heptanol
n-octanol
2-octanol
2,4-dimethyl-3-pentanol
2-ethyl-1-hexanol
3,5,5-trimethyl-1-hexanol
6-methyl-2-heptanol
2,6-dimethyl-2-heptanol
n-decane

Potential Sorbents include:

Liquid (mixed in a sand matrix at a pore volume saturation of 10%)
Tetradecane
Heptadecane
Hexadecane

Solid
Activated Carbon
Surfactant modified zeolytes

4. The method involves liquid extraction in 20 or 40 ml VOA vials using organic solvents.

3.1.2. Purpose

The purpose of this SOP is to insure reliable and reproducible analytical results. Extracted constituents will be quantified suing analytical methods described in other SOPs.

3.1.3. Procedures

1. Sample Containers, Collection, Transportation and Storage

Sample Containers: Field samples will be collected in 20-mL or 40-ml glass sample vials (Fisher Catalog # 03-340-121) with teflon-faced rubber backed caps.

Sample Collection: Each field sample vial will be partially filled with the extraction solvent (alcohol IPA, IBA, etc. or Methylenechloride) using a pipet or repeating volume dispenser. Typically 10 or 20-ml of solvent will be used.

Transportation and Storage: Field samples will be stored in coolers containing "blue ice", and later stored in refrigerators in a trailer located on the site. Samples will be sent to UF labs packed in coolers and shipped via overnight air express (e.g., FedEx). The samples will be stored in the cold

storage room or refrigerator at 4C, until GC analysis. After sub-sampling, the samples are returned to cold storage.

For lab studies, samples will be collected directly in 20 mL Headspace vials whenever possible and stored in a refrigerator if analysis is expected to take more than a day.

2. In the laboratory, samples will be rotated for a minimum of 8 hours on a rotator (Glas-Col model RD 4512).

3. Sub-sampling and Dilution

Field samples will be sub-sampled into 2 ml GC vials. Pipets will be used to transfer samples from 20-mL sample vials to the 2-mL GC vials.

3. Apparatus and Materials

Glassware: Glass pipets are required for sub-sampling.

4. Safety

Gloves and eye protection will be worn during all extraction activities.

Reference to the Materials Safety Data Sheets (MSDS) will be made for information on toxicity, flammability, and other hazard data.

3.2. Standard operating procedure for analysis of alcohol tracers (November 15, 1995) utilized at the University of Florida

3.2.1. Scope and application

1. This SOP describes the analytical procedures utilized by the Soil and Water Science Department, University of Florida, IFAS, for analysis of alcohols used as partitioning tracers in both lab and field studies in order to quantify the amount and distribution of residual non-aqueous phase liquids (NAPLs) present in the saturated zone.

2. This SOP was written by R.D. Rhue, Soil and Water Science Department, University of Florida, Gainesville, Fl. It is a modification of SOP-UF-Hill-95-07-0010-v.2, prepared by D.P. Dai, H.K. Kim, and P.S.C. Rao, Soil and Water Science Department, University of Florida. The SOP of Dai, Kim, and Rao was modified from a protocol provided to them by Professor Gary Pope at the University of Texas-Austin.

3. The alcohol tracers used in the UF lab and field studies are ethanol, n-butanol, n-pentanol, n-hexanol, n-heptanol, 2,2-dimethyl-3-pentanol, and 6-methyl-2-heptanol.

4. The method involves gas chromatography (GC) analysis for alcohol concentrations in aqueous samples. A flame-ionization detector (FID) is used to quantify the analyte concentrations in the sample. The method has been found to provide reliable and reproducible quantitation of alcohols for concentrations > 1 ug/mL. This value may be considered the minimum detection level (MDL). The standard calibration curve for FID response has been found to be linear up to 3,000 ug/mL for ethanol.

5. Samples selected for GC-FID analysis may be chosen on the basis of preliminary screening which will provide approximate concentration ranges and appropriate sample injection volumes, standard concentrations, etc.

3.2.2. Purpose

The purpose of this SOP is to insure reliable and reproducible analytical results for alcohols in aqueous samples for laboratory-based or on-site (field-based) GC-FID analyses, and to permit tracing sources of error in analytical results.

3.2.3. Procedures

1. Sample Containers, Collection, Transportation and Storage

Sample Containers: Field samples will be collected in 5-mL glass sample vials (Fisher Catalog # 06-406-19F) with teflon-faced septa caps. Glass vials and caps are not reused.

Sample Collection: Each field sample vial will be completely filled with liquid, such that no gas headspace exists, and capped. The vials will not be opened until the time for analysis.

Transportation and Storage: Field samples will be stored in coolers containing "blue ice", and later stored in refrigerators in a trailer located on the site. Samples may be subjected to on-site GC analysis, and/or shipped back to UF labs; samples will be packed in coolers and shipped via overnight air express (e.g., FedEx). The samples will be stored in the cold storage room or refrigerator at 4C, until GC analysis. After sub-sampling, the samples are returned to cold storage.

For lab studies, samples will be collected directly in 2 mL GC vials whenever possible and stored in a refrigerator if analysis is expected to take more than a day.

2. Sub-sampling and Dilution

Field samples will be sub-sampled into 2-ml vials for automated GC analysis. Disposable, Pasture glass pipets (Fisher Catalog # 13-678-20B) will be used to transfer samples from 5-mL sample vials to the 2-mL GC vials.

For samples needing dilution prior to GC analysis, a dilution of 1:10 should be sufficient. Dilutions will be made using double-distilled, deionized water.

3. Apparatus and Materials

Glassware: Disposable micro-pipets (100 uL; Fisher Catalog # 21-175B; 21-175F) and Class A volumetric pipets (1 or 2 mL) are required for sample dilution.

Disposable Pasteur glass pipets (Fisher Catalog # 13-678-20B) are required for sub-sampling.

GC vials (2-mL) with Teflon-faced caps (Fisher Catalog # 03-375-16A) are required for GC analysis.

Volumetric class A pipets and volumetric class A flasks are required for preparations of the calibration standards.

Gas Chromatograph System: An analytical GC system with a temperature-programmable oven, auto-injector capable of on-column injection, and either an integrator or a PC-based data acquisition/analysis software system are required. Also required are other accessories, including analytical columns and the gases required for GC-FID operation.

A Perkin Elmer Autosystem with an FID and an integrated autosampler are suitable for analysis of field and laboratory samples. The Perkin Elmer system is linked to an IBM-compatible PC loaded with Turbochrom (version 4.01) software.

A J&W Scientific DB-624 capillary column (30m x 0.53mm, 3um film thickness) are required. Zero-grade air and ultra-high purity hydrogen are required for the FID. Ultra-high purity nitrogen or helium are required for carrier gas.

4. Reagents

Deionized, Double-Distilled Water: Deionized, double distilled water is prepared by double distillation of deionized water in a quartz still. This water will be referred to as reagent water.

Alcohols: Certified ACS grade alcohols are required for analysis.

5. Standard Solutions

Stock Standard Solution: Analytical standards are prepared from reagent chemicals in the laboratory. Stock standards each contain a single alcohol dissolved in reagent water and stored in 20 mL glass vials (Fisher Catalog # 03-393-D) with teflon-lined caps. These stock solutions are kept in a refrigerator at 4 C. Fresh stock standards are prepared every six months. The procedure for making stock standard solutions is essentially that given in the Federal Register, Rules and Regulations, Thursday, November 29, 1979, Part III, Appendix C, Section 5.10,

"Standard Stock Solutions". The only modification of the procedure for the current study is that reagent water is used as the solvent in place of methanol.

Calibration Standards: Calibration standards are prepared by diluting the stock standards in reagent water. Each calibration standard contains each of the alcohols listed above. Five concentrations should be prepared that cover the approximate concentration range utilized in the partitioning tracer experiments.

6. QC blank Spike/Matrix Spike

Two 1 mL aliquots of the sample to be spiked are transferred to clean vials. To one vial, 1 mL of reagent water is added. To the second vial, 1 mL of a calibration standard is added. The spike recovery is calculated using the difference between the two measured concentrations and the known spike concentration.

7. Quality Control

GC injector septa should be changed every 80 to 100 injections, or sooner if any related problems occur.

Injector liner should be cleaned or changed every 80 to 100 injections or sooner if any related problems occur.

A method blank should be included in every 50 samples

A complete set of calibration standards (5) should be run at the beginning of each day and after every fiftieth sample.

One standard and a blank should be included in every 25 samples.

A sample spike and a blank spike should be included in every 50 samples.

8. Instrumental Procedures

Gas Chromatography: For J&W DB-624 Column:

Injection port temperature 200C
FID detector temperature 225C

Temp Program: Isothermal at 60C for 0 min; Ramp to 120C at 5 C/min.

9. Sample Preparation

Sub-sampling: Field samples are transferred from the 5 mL sample vials to the 2 mL GC vials and capped with open-top, teflon-lined septa caps.

Dilution: Samples are diluted if chromatographic peak areas for any of the alcohols exceed those of the highest calibration standard. One mL of sample is added to an appropriate amount of reagent water to make the dilution.

10. Sample Analysis

Analysis: The samples should be allowed to reach ambient temperature prior to GC analysis.

Sample vials (2 mL) are loaded onto the Perking Elmer GC auto-injector. A one uL injection volume should be used for both samples and standards.

Analyte Identification: Analyte identification should be based on absolute retention times. The analytes of interest should elute at their characteristic retention times within 0.1 minute for the automated GC system.

Analyte Quantitation: When an analyte has been identified, the concentration should be based on the peak area, which is converted to concentration using a standard calibration curve.

11. Interferences

Contamination by carry-over can occur whenever high-level and low-level samples are sequentially analyzed. To reduce carry over, the injector syringe should rinsed with reagent water between samples.

Potential carry-over should be checked by running a highly concentrated sample, but one still within the standard concentration range, followed by a blank. A negligible reading for the blank will insure that carry-over has been minimized.

12. Safety

The main safety issue concerning the use of the GC at a field site relates to the compressed gases. The FID gases (hydrogen and air) form explosive mixtures. It is important to keep this in mind at all times, and be aware of the hazard potential in the event of an undetected hydrogen leak. All gas connections will be properly leak tested at installation.

High-pressure compressed-gas cylinders will be secured to a firm mounting point, whether they are located internally or externally.

Gas cylinders should preferably be located outside the trailer on a flat, level base, and the gas lines run inside through a duct or window opening. If the gases are located outside, then some form of weatherproofing for the gauges will be necessary. As a temporary measure, heavy-duty

polyethylene bags, secured with tie-wraps, have been used successfully; this may not be very elegant but it is very effective for short-term use of the GC. A more permanent protective housing must be built if the GC is located at the trailer for an extended time period.

The main operating drawback to locating the gas cylinders externally is that it is not easy to monitor the cylinder contents from inside. The gas which could be used up most quickly is air for the FID, particularly if two instruments are hooked up to the same supply and they are running continuously. A reserve cylinder of air should be available at all times to prevent down time.

If it is not possible to arrange external citing easily, the gas cylinders should be secured to a wall inside the trailer.

It is a good laboratory operating practice to make sure the flame is attended at all times.

When it is necessary to change the injection liner on the GC, the detector gases should be shut off.

The column must be connected to the detector before igniting the flame.

The trailer should be kept well ventilated when using the GC.

Reference to the Materials Safety Data Sheets (MSDS) will be made for information on toxicity, flammability, and other hazard data.

3.3. Standard operating procedure for the sampling, collection, extraction and analysis of Alcohol Tracers utilized at Purdue University

The following described Standard Operating Procedures (SOP) are currently utilized by the Environmental Engineering area of the School of Civil Engineering at Purdue University, West Lafayette, Indiana.

This SOP was updated March 3, 2004 by I.C. Poyer, School of Civil Engineering, Purdue University, West Lafayette, Indiana. It is a modification of SOP-UF-Hill-95-07-0010-v.2, prepared by D.P. Dai, H.K. Kim, and P.S.C. Rao, Soil and Water Science Department, University of Florida.

3.3.1. Scope and application

1. This Standard Operating Procedure (SOP) describes the extraction and analytical procedures of alcohol tracers from a sorbent (Silver-impregnated Activated Carbon) packed into borehole flux meters. Some of the alcohols have been used as partitioning tracers in both laboratory and field studies to quantify the amount and distribution of DNAPLs in source zones. Here, these alcohols are used as “resident” tracers that are pre-loaded on to the sorbent packed into the flux

meter sock; loss of tracers via desorption and advective/diffusive/dispersive transport resulting from groundwater flow under natural hydraulic gradients is measured to estimate cumulative groundwater and contaminant fluxes.

2. The alcohol tracers used in the Purdue University field studies are methanol, ethanol, iso-propanol, t-butanol, and 2,4-dimethyl-3-pentanol.

3. The established analytical method to determine and quantify alcohol concentrations in extracted samples is direct injection of 1 μL of sample into a Shimadzu GC17A gas chromatograph (GC) equipped with a flame-ionization detector (FID). This method provides reliable and reproducible quantitation of alcohols at concentrations greater than or equal to 1 μg/mL, which is the reportable minimum detection limit (MDL). The linear standard calibration range for the FID response is from the reported MDL up to a concentration of approximately 1500 μg/mL per analyte of interest.

3.3.2. Purpose

The purpose of this SOP is to: (1) insure reliable and reproducible results, and (2) track possible sources of error in the extraction of alcohols from a sorbent and the subsequent analysis by GC-FID analytical methodology.

3.3.3. Procedures

1. Sample Containers, Collection, Transportation and Storage

Sample Containers: Sorbent samples should be collected in 40mL VOA vials (Fisher Scientific Catalog # 05-719-106) sealed with Teflon-lined septa caps. Vials should contain 20mL of extraction solvent (*iso*-butanol), prepared previously in the laboratory. All vials and caps are non-reusable.

Sample Collection: Sorbent aliquots collected over 1-foot increments from an exfiltrated Flux meter should be transferred to a mixing bowl and homogenized with a metal spatula. Approximately 10 to 20 grams of mixed sorbent should be placed into the 40 mL VOA vials containing extracting solvent.

Transportation and Storage: Field samples should be stored, on site, in coolers containing "blue ice" then shipped via overnight air express (e.g., FedEx) to the Purdue University laboratory. Samples should be stored in a cold storage room or refrigerator at 4^{o} C until extraction and GC analysis.

2. Laboratory Supplies and Materials

Volumetric class ‘A’ pipettes and volumetric class ‘A’ flasks for preparation of calibration standards and sample dilutions.

Disposable Pasteur glass pipettes (Fisher Catalog # 13-678-6A) for sub-sampling.

GC vials (2 mL) with Teflon-faced caps (Fisher Catalog # 03-375-16A) for GC analysis.

3. Reagents

Deionized water prepared by filtration of potable water through a Barnstead Ultrapure Deionization Unit. This water should be referred to as ‘reagent water’.

Certified ACS grade pure alcohols purchased from one or more of the following vendors; Fisher Scientific, VWR and/or Sigma-Aldrich and used as received.

4. Calibration and Stock Standard Solutions

Individual alcohol stock standard solutions should be prepared in reagent water using volumetric glassware and stored in 20 mL glass vials with Teflon-lined caps. Stock solutions should be kept in a refrigerator at 4^{o} C. Fresh stock standards should be prepared every six months and follow protocols outlined in the Federal Register, Rules and Regulations, Thursday, November 29, 1979, Part III, Appendix C, Section 5.10, "Standard Stock Solutions". The single modification from the cited procedure is the use of reagent water instead of methanol as the solvent.

Mixed calibration standards should be prepared by diluting stock standards in reagent water using volumetric glassware. A minimum of five standards should be prepared and should bracket the expected concentration range.

5. Quality Control (QC) Blank Spike/Matrix Spike

A blank spike should be prepared by the addition of 1 mL of calibration standard to 1mL of extraction solvent. A matrix spike should be prepared by the addition of 1mL of calibration standard to 1 mL of extracted sample. Spike recoveries should be calculated using the difference between the two measured concentrations and the known spike concentration.

6. Analytical Instrumentation

A Shimadzu GC17A Gas Chromatograph equipped with an AOC17 Autosampler, a temperature-programmable oven, heated auto-injector and detector zones, a 30 meter or greater capillary separations column, nitrogen carrier gas, standard compressed air and hydrogen flame gases and controlled by a PC-based data acquisition/analysis software system.

7. GC Procedure

Column dimensions	J&W DB-624 Column, 75m X 0.53um X 3um
Injection port temperature	180C
FID detector temperature	220C
Column Temperature Program	Isothermal at 60C for 3 min; ramp to 120C at 5 C/min, hold 1min; ramp at 20C/min to 200C, hold 1 min.
Carrier gas	Nitrogen 99.995% purity
Flame gases	Air, 99.995% purity; Hydrogen, 99.995% purity

8. Quality Control of GC System

GC injector septa shoudl be changed every 100 to 150 injections, or sooner if instrument performance deteriorates.

Injection port glass liner should be cleaned or changed after 100 to 150 injections or sooner if instrument performance deteriorates.

A method blank should be analyzed at the beginning of each sample set and after every 25 samples to monitor instrument background.

A complete set of calibration standards (minimum 5) should be analyzed at the beginning of each day with a mid-range continuing calibration standard analyzed after every 25 samples.

A matrix spike and a blank spike, and up to 5 sample duplicates should be analyzed with each daily sample set.

10. Extraction of Alcohol Tracers from Sorbent Matrix

The collected sorbent samples should be rotated for a period not to exceed 24 hours on a Glas-Col Rotator, centrifuged for 5 minutes at 2000 rpm (Jouan, Inc., centrifuge), and sub-sampled into a 2 mL vial for GC analysis. Extraction vials will be stored at 4^{o} C.

11. Sample Analysis

Individual alcohol identification should be based on absolute retention times compared to calibration standards.

Alcohol concentrations should be calculated on chromatographic peak area response converted to units of concentration in mg/L based on standard calibration curves.

12. Interferences

Contamination by carry-over may occur when high-level and low-level samples are sequentially analyzed. Subsequent dilution and reanalysis should be completed on samples identified as

outside the standard concentration bracket. Samples analyzed immediately following a ‘high-concentration sample’ should be reanalyzed.

In an attempt to minimize carryover, samples suspected of being in a higher concentration range should be isolated and bracketed by the analysis of reagent water samples.

13. Safety

Reference to the Materials Safety Data Sheets (MSDS) should be made for information on toxicity, flammability, and other hazard data.

3.4. Standard operating procedure for analysis of Target Analytes in groundwater samples (February 20, 1996)

3.4.1. Scope and application

1. This SOP describes the analytical procedures utilized by the Department of Environmental Engineering Sciences, University of Florida, for analysis of target analytes in groundwater samples from both lab and field studies. This analysis provides characterization of existing site and lab column aqueous contamination both before and following flushing technology applications.

2. This SOP was written by M.D. Annable, Department of Environmental Engineering Sciences, University of Florida, Gainesville, FL. It is a modification of SOP-UF-Hill-95-07-0012-v.2, prepared by D.P. Dai and P.S.C. Rao, Soil and Water Science Department, University of Florida.

3. The selected constituents are benzene, toluene, o-xylene, 1,1,1-trichloroethane, 1,3,5,-trimethylbenzene, 1,2-dichlorobenzene, decane, and naphthalene.

4. The method involves gas chromatography (GC) analysis for target analyte concentrations in aqueous samples. Headspace analysis with a flame-ionization detector (FID) is used to quantify the analyte concentrations in the sample. The method has been found to provide reliable and reproducible quantitation of the above constituents for concentrations > 5 ug/L. This value may be considered the minimum detection level (MDL).

5. Samples selected for GC-FID analysis may be chosen on the basis of preliminary screening which will provide approximate concentration ranges and appropriate sample injection times, and standard concentrations, etc.

3.4.2. Purpose

The purpose of this SOP is to insure reliable and reproducible analytical results for soluble NAPL constituents in aqueous samples for laboratory-based GC-FID analyses, and to permit tracing sources of error in analytical results.

3.4.3. Procedures

1. Sample Containers, Collection, Transportation and Storage

Sample Containers: Field samples will be collected in 20-mL glass sample vials (Fisher Catalog # 03-340-121) with teflon-faced rubber backed caps. Glass vials and caps are not reused.

Sample Collection: Each field sample vial will be completely filled with liquid, such that no gas headspace exists, and capped. The vials will not be opened until the time for analysis.

Transportation and Storage: Field samples will be stored in coolers containing "blue ice", and later stored in refrigerators in a trailer located on the site. Samples will be sent to UF labs packed in coolers and shipped via overnight air express (e.g., FedEx). The samples will be stored in the cold storage room or refrigerator at 4C, until GC analysis. After sub-sampling, the samples are returned to cold storage.

For lab studies, samples will be collected directly in 20 mL Headspace vials whenever possible and stored in a refrigerator if analysis is expected to take more than a day.

2. Sub-sampling and Dilution

Field samples will be sub-sampled placing 10-ml into 20-ml headspace vials containing 2 g of sodium chloride for automated GC analysis. Pipets will be used to transfer samples from 20-mL sample vials to the 20-mL GC headspace vials.

3. Apparatus and Materials

Glassware: Glass pipets are required for sub-sampling.

GC headspace vials (20-mL) with Teflon-faced caps are required for GC analysis.

Volumetric class A pipets and volumetric class A flasks are required for preparations of the calibration standards

Gas Chromatograph System: An analytical GC system with a temperature-programmable oven, headspace sample injection system, and either an integrator or a PC-based data acquisition/analysis software system are required. Also required are other accessories, including analytical columns and the gases required for GC-FID operation.

A Perkin Elmer Autosystems with an HS40 Auto-headspace sampler and a FID will be used for analysis of field and laboratory samples. The Perkin Elmer system will be linked to an IBM-compatible PC loaded with Turbochrom (version 4.01) software.

A J&W Scientific DB-624 capillary column (50m X 0.53mm, 3□m film thickness) will be used. Zero-grade air and high purity hydrogen will be used for the FID. Ultra-high purity nitrogen or helium will be used for carrier gas.

4. Reagents

Deionized, Double-Distilled Water: Deionized, double distilled water is prepared by double distillation of deionized water in a quartz still. This water will be referred to as reagent water.

5. Standard Solutions

Stock Standard Solution: Analytical standards will be prepared from reagent chemicals by the laboratory. Stock standards will each contain a single analyte dissolved in methanol and stored in 20 mL glass vials (Fisher Catalog # 03-393-D) with teflon-lined caps. These stock solutions will be kept in a refrigerator at 4 C. Fresh stock standards will be prepared every six months. The procedure for making stock standard solutions is essentially that given in the Federal Register, Rules and Regulations, Thursday, November 29, 1979, Part III, Appendix C, Section 5.10, "Standard Stock Solutions".

Calibration Standards: Calibration standards will be prepared by diluting the stock standards in water. Each calibration standard will contain each of the eight analytes listed above. Five concentrations will be prepared that cover the approximate concentration range from 0 to 20 mg/L.

6. QC blank Spike/Matrix Spike

Two 1 mL aliquots of the sample to be spiked will be transferred to clean vials. To one vial, 1 mL of reagent water will be added. To the second vial, 1 mL of a calibration standard will be added. The spike recovery will be calculated using the difference between the two measured concentrations and the known spike concentration.

7. Quality Control

A method blank will be included in every 50 samples

A complete set of calibration standards (5) will be run at the beginning of each day and after every fiftieth sample.

One standard and a blank will be included in every 25 samples.

A sample spike and a blank spike will be included in every 50 samples.

8. Instrumental Procedures

Gas Chromatography: For J&W DB-624 Column:

Headspace sample temperature	90C
Injection needle temperature	100C
Transfer line Temperature	110C
FID detector temperature	225C
Carrier gas pressure	8psi

Temp Program: Isothermal at 50C for 0 min; Ramp to 200C at 5 C/min; hold for 10 min.

9. Sample Preparation

Sub-sampling: Field samples will be transferred from the 20 mL sample vials to the 20 mL GC headspace vials and capped with open-top, teflon-lined septa caps.

Dilution: Samples will be diluted if chromatographic peak areas for any of the analytes exceed those of the highest calibration standard. One mL of sample will be added to an appropriate amount of reagent water to make the dilution.

10. Sample Analysis

Analysis: Sample headspace vials (20 mL) will be loaded onto the Perking Elmer HS40 auto-sampler. Samples will be pressurized for 1 min followed by a 0.1 minute injection time and a withdrawal time of 0.5 minute.

Analyte Identification: Analyte identification will be based on absolute retention times. The analytes of interest should elute at their characteristic retention times within ±0.1 minute for the automated GC system.

Analyte Quantitation: When an analyte has been identified, the concentration will be based on the peak area, which is converted to concentration using a standard calibration curve.

11. Interferences

Contamination by carry-over can occur whenever high-level and low-level samples are sequentially analyzed. To reduce carry over, the injector needle should purged with carrier gas between samples.

Potential carry-over will be checked by running a highly concentrated sample, but one still within the standard concentration range, followed by a blank. A negligible reading for the blank will insure that carry-over has been minimized.

12. Safety

The main safety issue concerning the use of the GC relates to the compressed gases. The FID gases (hydrogen and air) form explosive mixtures. It is important to keep this in mind at all times, and be aware of the hazard potential in the event of an undetected hydrogen leak. All gas connections will be properly leak tested at installation.

High-pressure compressed-gas cylinders will be secured to a firm mounting point, whether they are located internally or externally.

When it is necessary to change the injection liner on the GC, the detector gases should be shut off.

The column must be connected to the detector before igniting the flame.

Reference to the Materials Safety Data Sheets (MSDS) will be made for information on toxicity, flammability, and other hazard data.

3.5. Standard operating procedure for the sampling, collection, extraction and analysis of Perchlorate from sorbents packed in borehole flux meters

3.5.1. Scope and application

1. This Standard Operating Procedure (SOP) describes the extraction and analytical procedures of perchlorate from sorbent (Silver-impregnated Activated Carbon) packed into the borehole flux meters. The mass of perchlorate accumulated by sorption on the sorbent from the groundwater passing through the flux meter is used to estimate the cumulative contaminant flux.

2. The established analytical method to determine and quantify perchlorate concentrations in extracted samples is direct injection of 1 μL of sample into a Dionex DX600 Ion Chromatograph equipped with an Electrochemical Detector (ED). This method provides reliable and reproducible quantitation of perchlorate at concentrations greater than or equal to 2 μg/L, which is the reportable minimum detection limit (MDL). The linear standard calibration range for the ED response is from the reported MDL up to a concentration of approximately 100 mg/L for the analyte of interest.

3.5.2. Purpose

The purpose of this SOP is to: (1) insure reliable and reproducible results, and (2) track possible sources of error in the extraction of perchlorate from a sorbent and the subsequent analysis by IC-ED analytical methodology.

3.5.3. Procedures

1. Sample Containers, Collection, Transportation and Storage

Sample Containers: Field samples will be collected in 250mL wide-mouth jars, sealed with Teflon-lined septa caps.

Sample Collection: Sorbent aliquots collected over 1 foot increments from an exfiltrated Flux meter, will be transferred to a mixing bowl and homogenized with a metal spatula. Approximately 100 grams of mixed sorbent will be placed into the wide-mouth jar. Excess sorbent will be collected in a plastic-lined container for proper hazardous waste disposal.

Transportation and Storage: Sorbent samples will be stored, on site, in coolers containing "blue ice" then shipped via overnight air express (e.g., FedEx) to the Purdue University laboratory. Samples will be stored in a cold storage room or refrigerator at 4^{o}C until extraction and IC-ED analysis.

2. Laboratory Supplies and Materials

Volumetric class 'A' pipets and volumetric class 'A' flasks for preparations of calibration standards and sample dilutions.

Disposable Pasteur glass pipets (Fisher Catalog # 13-678-6A) for sub-sampling.

IC vials (2mL) with Teflon-faced caps (Fisher Catalog # 03-375-16A) for IC analysis.

3. Reagents

Deionized water prepared by filtration of potable water through a Barnstead Ultrapure Deionization Unit. This water will be referred to as reagent water.

Certified ACS grade granular ammonium perchlorate purchased from Sigma-Aldrich.

4. Calibration and Stock Standard Solutions

A stock standard solution will be prepared in reagent water using volumetric glassware and stored in 20mL glass vials with Teflon-lined caps. The stock solution will be refrigerated at $4^{o}C$. Two concentration ranges will be prepared. The higher concentration range will be 100mg/L to 1mg/L. The low concentration range will be 2ug/L to 100ug/L. A minimum of five standards per range will be prepared.

5. Quality Control (QC) Blank Spike/Matrix Spike

A blank spike will be prepared by the addition of 1 mL of calibration standard to 1mL of reagent water. A matrix spike will be prepared by the addition of 1mL of calibration standard to 1 mL of sample. Spike recoveries will be calculated using the difference between the two measured concentrations and the known spike concentration.

6. Analytical Instrumentation

A Dionex DX600 Ion Chromatograph (IC) Autosystem equipped with an ED50 Electrochemical Detector, a GP50 Gradient Pump, a GD40 Eluent Generator, an AS50 Thermal Compartment, and an AS50 Autosampler will be used for analysis of all perchlorate samples. The Dionex IC system is linked to an IBM-compatible PC loaded with Peaknet (version 6.00) software for acquisition, analysis interpretation and quantitation.

A Dionex IonPac AS11 column and guard column will be used and the analyte perchlorate eluted with 35mM potassium hydroxide solution.

7. IC Parameters and Analytical Conditions

Analytical & Guard Column	Dionex IonPac AS11, 4mm
Column temperature	30C
Suppressor Current	104 mV
Eluent Concentration	35mM potassium hydroxide
Column flow rate	1.2 mL/min

Injection loop volume 50ul (high concentration range); 950ul (low concentration range)

8. Quality Control of IC System

Nanopure water is used to provide ion-free solvent for the Eluent Generator and eliminate high background signal

A method blank will be analyzed at the beginning of each sample set and after every 25 samples to monitor instrument background.

A complete set of calibration standards (minimum 5) will be analyzed at the beginning of each day with a mid-range continuing calibration standard analyzed after every 25 samples.

A matrix spike and a blank spike, and up to 5 sample duplicates will be analyzed with each daily sample set.

9. Extraction of Perchlorate from Sorbent Matrix

Perchlorate extraction from the sorbent will be completed utilizing a Dionex ASE300 Accelerated Solvent Extractor, with hot reagent water as the solvent. Glass fiber filters and Ottowa 40 mesh sand will be used to filter and as a filler respectively, in the extraction cell.

10. Sample Analysis

Perchlorate identification will be based on the absolute retention time compared to calibration standards.

Perchlorate concentrations will be calculated on a chromatographic peak area response converted to units of concentration in ug/L or mg/L based on the standard calibration range of analysis.

11. Interferences

Contamination by carry-over may occur when high-level and low-level samples are sequentially analyzed. Subsequent dilution and reanalysis will be completed on samples identified as outside the standard concentration bracket. Samples analyzed immediately following a ‘high-concentration sample’ will be reanalyzed.

In an attempt to minimize carryover, samples suspected of being in a higher concentration range will be isolated and bracketed by the analysis of reagent water samples.

12. Safety

Reference to the Materials Safety Data Sheets (MSDS) will be made for information on toxicity, flammability, and other hazard data.

4.0. Quality Assurance Project Plan

4.1. Purpose and Scope of the Plan

This Quality Assurance plan focuses on field installation, sampling and processing of data from the Flux Meters.

4.2. Quality Assurance Responsibilities

The responsibility for QA were shared by Kirk Hatfield and Mike Annable at the University of Florida. During field activities one of the PI's will be present to oversee QA procedures. Other personnel present during field sampling activities will include graduate students or post-doctoral researchers from the University of Florida, Purdue University, and the University of Waterloo.

4.3. Data Quality Parameters

This section discusses measures to be taken to ensure the representativeness, completeness, comparability, accuracy, and precision of the data.

Accuracy

Accuracy is defined as the closeness of the results to the true value.

The percent recoveries of surrogates, QC check standards, and matrix-spiked analytes are used to evaluate the accuracy of an analysis. The percent recovery represented by X can be calculated using the following equations:

For surrogates and QC check standards:

$$X = \frac{SSR}{SA} x\,100 \qquad 1$$

For matrix spikes:

$$X = \frac{SSR - SS}{SA} \times 100$$

where:

SSR = Spiked sample result
SS = Sample result
SA = Spike added from spiking mix

The mean percent recovery (X) is defined by:

$$\overline{X} = \frac{\sum_{i=1}^{N} X_i}{N} \qquad 2$$

where:

X_i = The percent recovery value of a spike replicate
N = Number of spikes

Precision

Precision is a measure of the mutual agreement among individual measurements of the same parameters under prescribed similar conditions.

The analytical precision is determined using results from duplicate or replicate analyses of samples and from matrix spike results for a given matrix. The Relative Percent Difference (RPD) is used to evaluate the precision of duplicate analyses. Relative Percent Difference is defined in the following equation:

$$\%RPD = \frac{2(X1 - X2)}{\overline{x}} \, x\, 100 \qquad 3$$

X1 = First duplicate value
X2 = Second duplicate value

When replicate analyses are performed, precision is measured in terms of the Standard Deviation (SD) which is defined in the following equation:

$$S = \sum_{i=1}^{N} \left[\frac{(X_i - \overline{X})^2}{N - 1} \right]^{‰} \qquad 4$$

where:

X_i = The recovery value of a spike replicate
X = Arithmetic average of the replicate values
N = Number of spikes

Completeness

Completeness is defined as the percent of parameters falling within acceptance criteria and the results subsequently reported. A goal of 95 percent completeness has been set for all samples.

The general requirement of this quality assurance program is to analyze a sufficient number of standards, replicates, blanks, and spike samples to evaluate results adequately against numerical QA objectives.

4.4. Calibration Procedures, Quality Control Checks, and Corrective Action

The focus of the following section is to describe initial and continuing calibration procedures for analytical instrumentation, duplicate and control testing and data reduction, validation, and reporting.

Supplies and Quality Control Materials

All supplies (i.e., glassware, chemicals, reagents) used will be of the best possible quality to ensure proper instrument calibration and avoid contamination. All reagents used are prepared from Analytical Reagent Grade (AR) chemicals or higher purity grades, unless such purity is not available. The preparation of all reagents will be documented, including source, mass, and dilutions. Each reagent will be clearly labeled with the composition, concentration, date prepared, initials of preparer, expiration date, and special storage requirements, if any.

Reagents

Reagent solutions are stored in appropriate glass, plastic, or metal containers. Reagents are stored under conditions designed to maintain their integrity (refrigerated, dark, etc.). Shelf life is listed on the label and the reagent is discarded after it has expired. Dry reagents such as sodium sulfate, silica gel, alumina, and glass wool are either muffled at 400°C or extracted with solvent before use for organic chemical analyses. Water used in the laboratory is glass distilled or deionized, and periodically checked for purity. In addition, water used in the organics area is carbon-filtered or purchased as HPLC grade. All organic solvents used are either glass-distilled or pesticide grade. Solvents and reagent solutions are checked for contamination by employing reagent blanks, before use in any analysis.

Quality Control Reference Materials

All Quality Control Reference Materials are acquired only from authorized vendors or sources commonly used by U.S. EPA Regional Laboratories.

Standards Traceability

When standard reference materials arrive at the laboratory, they are registered in a bound log book, "Standards Notebook for Neat Materials and Primary Solutions." An example of a logging sequence is used to illustrate this process.

(1-S-XXX-12-4) (label and log sequence)

where:
1 = Notebook log number
S = Standard Notebook--"Neat and Primary Standards"
XXX = Receiving analyst's initials
12 = Notebook page
4 = Entry number on notebook page

All working standards prepared at the site lab are logged in the "Standards Notebook for Intermediate and Working Standards." A similar labeling convention has been adopted for classifying these working standard materials. An example is given below.

1-W-XXX-6-5 (label and log)
Where:
1 = Number of notebook
W = Standards notebook - "Intermediate and Working" Standard
XXX = Analyst's initial
6 = Page Number
5 = Page entry number in sequence

Instrument Calibration

Every instrument used to analyze samples must pass the calibration criteria established in the appropriate SOP. Initial calibration criteria for instrument linearity, sensitivity, resolution, and deactivation must be met before samples can be analyzed. Sustained performance is monitored periodically during sample analyses by the use of continuing calibration check standards.

GC Section

Initial Calibration

The linear calibration range of the instrument must be determined before the analysis of any samples. Gas chromatographic conditions used for sample analyses are used during calibration.

The calibration is performed in accordance with the SOP derived from the methods used. For most GC analyses, a 5-level calibration is run. The concentrations of the standards must bracket the linear range of the instrument. Calibration using fewer than 5-levels is done only when specifically allowed by the method.

Relative Retention Times and Relative Response Factors

Instrument calibration and sample analysis must be performed using appropriate internal standards to establish relative retention times (RRT) and relative response factors (RRF) where required. Internal standards appearing in a chromatogram will establish primary search windows for those target compounds nearby in the chromatogram. RRT are calculated using this equation:

$$RRT = \frac{RT^{target}}{RT^{is}} \qquad 5$$

The RRF may be calculated as follows:

$$\text{Absolute Response Factor} = RF = \frac{\text{Area}}{\text{Amount}}$$

Note: Amount in this equation refers to the mass (e.g. ug) of compound mixed into the solution injected.

Each calibration standard is analyzed and the RRF is calculated for each analyte according to the following equation:

$$RRF = \frac{A_s \, x \, C_{is}}{A_{is} \, x \, C_s} \qquad 6$$

A_s = Area of analyte
A_{is} = Area of internal standard
C_{is} = Concentration of internal standard
C_s = Concentration of analyte

Note: Certain data processors may calculate the RRF differently.

The standard deviation (SD) and the % coefficient of variation (CV) of RRFs for the compounds are calculated using the following equations:

$$S = \sum_{i=1}^{N} \left[\frac{(RRF_i - RRF_m)^2}{N - 1} \right]^{\%o} \qquad 7$$

Where:

RRF_i = Individual RRF
RRF_m = Mean RRF

N = Number of RRFs

and

$$\%CV = \frac{S \times 100}{RRF_m} \qquad 8$$

Coefficient of Variation

The %CV of each compound must be less than 30 percent. This criterion must be achieved for the calibration to be valid.

If the %CV is less than 20 percent, the RRF of the compound can be assumed to be invariant, and the average RRF can be used for calculations.

If the %CV is between 20 percent and 30 percent, calculations must be made from the calibration curve. Both the slope and the intercept of the curve must be used to perform calculations.

Initial Calibration Verification

The calibration curve must be validated further by analyzing a QC check sample. The QC check sample must be obtained from EPA, another vendor, or it must be from another lot number. The QC check sample verifies the validity of the concentrations of the standards used to obtain the initial calibration.

All analytes in the QC check standard must be recovered within 80 to 100 percent. If any analyte exceeds this criterion, then a new calibration curve must be established. All sample results for a target analyte can be reported only from valid initial calibrations.

Continuing Calibration

The working calibration curve or RRF for each analyte must be verified daily by the analysis of a continuing calibration standard. The ongoing daily continuing calibration must be compared to the initial calibration curve to verify that the operation of the measurement system is in control.

The continuing calibration check must be performed during each day of analysis to verify the continuing calibration of the instrument. A day is defined as 24 hours from the start run time of the last valid continuing calibration. Generally, a continuing calibration check sample is injected every 10 samples.

Verification of continuing calibration is performed by the analysis of a midpoint standard containing all of the analytes of interest. Verification of continuing calibration of the measurement system is done by calculating the percent difference (%D) of the continuing calibration RRF from the mean RRF from the initial calibration curve using the following equation:

$$\%D = \frac{(RRF_m - RRF) \times 100}{RRF_m} \qquad 9$$

where:

RRF_m = The mean relative response factor from the initial calibration curve

RRF = The relative response factor from the continuing calibration standard

The %D must meet the acceptance criteria established in the appropriate SOP. If these criteria are exceeded, a new calibration curve must be established.

Other Calibrations

Weekly calibrations are performed for equipment such as balances, thermometers, ovens, incubators, and dissolved oxygen (D.O.) meters that are required in analytical methods, but which are not recorded in a dedicated QA instrument log.

Balances

Balances are checked with Class S weights on a daily basis. Before a weighing session, the analyst is required to perform at least one calibration check in the range of the material to be weighed. This value is also recorded on the specific balance control chart and must be within the control limit. The criteria for calibration checks are given in Table 4.1.

Table 4-1.

CRITERIA FOR BALANCE CALIBRATION CHECKS

Class S Weight (grams)	Warning Level (grams)	Control Level (grams)
Analytical Balances		
0.0100	0.0098-0.0102	0.0097-0.0103
0.1000	0.098-0.102	0.097-0.103
1.000	0.995-1.005	0.990-1.010
10.000	9.995-10.005	9.990-10.010
50.00	49.98-50.02	49.95-50.05
Top Loading Balances		
1.00	0.95-1.05	0.90-1.10
10.0	9.9-10.1	9.8-10.2
50.0	49.7-50.3	49.5-50.5

Incubators, ovens, and waterbaths

Temperatures are checked daily with an NBS grade thermometer and necessary adjustments made as required. All temperature readings are recorded and posted on the appropriate equipment.

DO meters

DO meter is calculated daily using a modified Winkler technique. The Winkler solution is titrated against 0.025N sodium thiosulfate.

Conductivity bridges

Conductivity meter is standardized daily against a solution of KCl to obtain a new cell constant.

pH meters

The pH meter is standardized daily using buffers at pH of 4, 7, and 10.

Refrigerators

Refrigerators are maintained at 4°C, with control levels ranging from 1°C to 10°C. A temperature reading is taken each workday morning immediately after unlocking the refrigerator. The temperature reading is recorded and entered on the control chart posted on the door of the refrigerator. If a trend is apparent or if the temperature is outside the acceptable range, the Lab Manager is notified so that corrective action can be initiated if required.

Freezers

Freezers are maintained at -10°C, with control levels ranging from 0°C to -35°C. A temperature reading is taken each workday morning immediately after unlocking the freezer. The temperature reading is recorded and entered on the control chart posted on the door of the freezer. If a trend is apparent, or if the temperature is outside the acceptable range, the Lab Manager is notified so that corrective action can be initiated if required.

Calibration Standards

All calibration standards, including internal standards used in LMG, are obtained from chemical suppliers with certificates of high purity and concentration.

Traceability

All standards are traceable to the National Institue of Standards and Testing (NITS) Standard Reference Materials (SRM) or to the U.S. EPA Reference Standards.

Working Standards

The commercial standards are used as stock standards. Working standards are made from the stock standards at appropriate concentrations to cover the linear range of the calibration curve. The working standards are used for initial calibration curves, continuing calibration checks, and preparation of analyte spiking solutions as appropriate for a particular analysis. All stock and working solutions are uniquely identified, dated, labeled, and initialed.

Standards Logbook

All stock solutions are given a unique code number and are entered into a bound "Primary Standards" logbook. The name of the compound and other pertinent information, including concentration, date of receipt, and analyst's name, are also entered.

Working standards are given a unique code number that allows them to be traced to a specific stock solution. The working standard is entered in a "Working Standards" logbook with analyst's name, date and method of preparation, and other pertinent information.

CORRECTIVE ACTIONS

Laboratory Imposed

Corrective actions will be initiated if the quality control criteria indicate an analysis is out of control.

- Check calculations for accuracy
- Check instrumentation to ensure it is operating properly. Recalibrate if necessary.
- Remake standards and reagents and reanalyze samples.
- Re-prep and re-analyze samples.

The analyst is responsible for initiating corrective actions for analytical problems encountered during analysis of samples. Most problems which occur and are corrected during the analytical run will be explained in the run log or analytical bench sheet for that run. A corrective action report (CAR) may be necessary for some problems encountered, such as complete system failure, chronic calibration failure, or severe matrix interferences.

During data review, the reviewer may initiate corrective actions based on problems or questions arising from the review. A CAR will be initiated.

The Laboratory Manager may initiate corrective actions if a problem is noticed during a QC review of data, a system audit, or a performance audit. A CAR will be initiated.

CARs are signed and dated by Project Manager, and by the Laboratory Manager. CARs will be filed in appropriate department files and in the Lab Manger's files.

Agency Imposed

Any actions deemed necessary by regulatory agencies, such as EPA, will be taken. These actions are most likely to arise from a systems or performance audit, or from data review conducted by the agency.

Corrective Action Reports

The field laboratory will have a Corrective Action System that ensures the proper documentation and dispositions of conditions requiring corrective action. The system will also ensure that the proper corrective action is implemented to prevent recurrence of the condition.

Situations Requiring Corrective Action Reports

The Corrective Action System applies to all situations that affect data quality. These situations include, but are not limited to, quality control criteria being exceeded, statistically out-of-control events, deviations from normally expected results, suspect data, deviations from the standard operating procedure, and special sample handling requirements. Corrective actions may also be initiated as a result of other QA activities, such as performance audits, systems audits, laboratory/interfield comparison studies, and QA project-related requirements of certifying agencies such as EPA.

Corrective Action Procedures

The procedure requires documenting the condition requiring corrective action on a Corrective Action Report and implementing corrective action based on the results of the investigation performed to determine the cause of the condition (Tables 4-2 and 4-3).

When a condition requiring corrective action arises, the Corrective Action Report is initiated. The initiator describes the condition requiring corrective action. An investigation, if necessary, is conducted to determine the cause of the condition. A corrective action is recommended based on the results of the investigation. The Corrective Action Report is reviewed by the Project Manager and the Field Site Manager who either approve the recommended corrective action or indicate a different corrective action. The originator has the responsibility of following up to be sure that the corrective action is implemented. Implementation of the corrective action is documented by the Corrective Action Report being signed and dated by the person who implemented the corrective action.

Table 4-2. Corrective Actions

QC Activity	Acceptance Criteria	Recommended Corrective Action
Initial instrument blank	Instrument response <MDL response	Prepare another blank, if same response, determine cause of contamination: reagents, environment, instrument equipment failure, etc.
Initial calibration standards	Coefficient of variation >0.99995 or standard concentration value ± 10% of expected value	Reanalyze standards. If still unacceptable, then remake standards
QC Check Standard	± 10% of expected value	Reanalyze standard. if still unacceptable, then remake standards, or use new primary standards if necessary
Continuing calibration Standards	± of expected value	Reanalyze standard. If still unacceptable, then recalibrate and rerun samples from the last cc stnd. Check
Method blank	<MDL	Reanalyze blank. If still positive, determine source of contamination. If necessary, reprocess (i.e., digest or extract) sample set
Initial calibration Standards (GC/MS)	RRF <30%	Reanalyze standards. If still unacceptable, prepare new standards.
Surrogate recovery (GC/MS Semivolatiles)	0 or 1 outside CLP criteria	Re-extract and/or re-analyze
Surrogate recovery (GC/MS volatiles)	0 outside criteria	Re-analyze

Table 4-3. Corrective Action Report Criteria for Control Charts

Criteria	Corrective Action
A point outside ±3 standard deviations	Attempt to determine the source of the problem. Verbally report the deviation and results of preliminary investigation to the Field Site Manager, who will decide jointly what action to take. After implementing corrective action, complete the Corrective Action Report and submit it to the Project Manager and the Field Site Manager for approval.
Three consecutive points accuracy outside ± standard deviation	Conduct investigation. Check accuracy of data input, calculations, instrument, standards, etc., to locate the source of the problem. Document results in a Corrective Action Report. Have the report approved by the supervisor. No results can be reported until the Corrective Action Report has been approved. Send a copy of the Corrective Action Report and a copy of the QC chart to the Field Site Manager.
Obvious outlier.	Conduct investigation. Check accuracy of data input, calculations, dilutions, instrument, standard, etc.. present initial findings to the Field Site Manager. They will jointly decide what actions need to be taken. Document the results in a Corrective Action Report and have it approved by the Field Site Manager. No results can be reported until the Corrective Action Report is approved. Send a copy of the Corrective Action report and a copy of the control chart to the Field Site Manager.
Obvious shift in the mean.	Conduct investigation. Check calculations, data entry, standards, instrument, calibrations, etc. Document results in a Corrective Action Report. Have the Corrective Action Report approved by the Field Site Manager. No results can be reported until the report is approved. Send a copy of the Corrective Action Report and a copy of the QC chart to the Field Site Manager.

4.5. Demonstration Procedures

Initiating the flux meter experiments will involve limited field effort. All of the components of the device can be prepared prior to field activities. In the field, the primary activity will be assembly of the flux meters which can be completed with two people in a mater of minutes. Extraction and sub-sampling also required fairly minimal time and personnel. Only the controlled flow flume experiments will require establishing steady flow from one end of the flume using peristaltic pumps. These pumps will be calibrated in the field using simple time and volume measurements. Periodic flow measurements will be made to determine total average flow.

Samples collected at the Borden site will be sent to the University of Florida for analysis. In the laboratory, instrument maintenance will include the following.

Maintenance Schedule

Preventive maintenance, such as lubrication, source cleaning, and detector cleaning, is performed according to the procedures delineated in the manufacturer's instrument manuals.

The frequency of preventive maintenance varies with different instruments. Routine maintenance performed includes cleaning and/or replacement of various instrument components. In general, the frequency recommended by the manufacturer is followed. In addition to the regular schedule, maintenance is performed as needed. Precision and accuracy data are examined for trends and excursions beyond control limits to determine evidence of instrument malfunction. Maintenance is performed when an instrument begins to degrade as evidenced by the degradation of peak resolution, shift in calibration curves, decreased ion sensitivity, or failure to meet one or another of the quality control criteria. Table 4-4 lists routine equipment maintenance procedures and frequency.

Instrument maintenance logbooks are maintained in the laboratory at all times. The logbook contains a complete history of past maintenance, both routine and nonroutine. The nature of work performed, the date, and the signature of the person who performed the work are recorded in the logbook. Preventive maintenance is scheduled according to each manufacturer's recommendation. Instrument downtime is minimized by keeping adequate supplies of all expendable items on hand. Expendable items are those with an expected lifetime of less than one year. Routine instrument preventive maintenance is handled by the instrument operator. Repair maintenance is performed by a full-time electronics technician, or by the manufacturer's service personnel.

Table 4-4. PREVENTIVE MAINTENANCE		
Instrument	Activity	Frequency
Gas Chromatograph	Change septum Check carrier gas Change carrier gas Change in-line filters Perform ECD wipe test Clean ECO Check system for leaks Clean/replace injection point liner Clean/replace jet tip Service flame photomeric detector	As needed Daily As needed As needed As license requires Return to vendor as needed As needed As needed As needed As needed
IR	Change desiccant Electronics maintenance	Every six months Every six months
UV	Clean and align optics Replace lamp Calibrate	Annually As needed Weekly
pH Meter	Calibrate Check fluid in probe	Daily Daily
D.O. Meter	Clean and replace membrane and HCl solution Calibrate	Daily Daily
Balance	Calibrate Maintenance	Daily Annually
Ovens	Temperature checks	Daily
Refrigerators and Freezers	Temperature checks	Daily
COD Heating Block	Check temperature with NBS thermometer	As needed
Conductivity Meter	Standardize with KCl Check probe visually	Daily Daily

4.6. Calculation of Data Quality Indicators

The focus of this section is to present methods of calculating data quality that will be used for this project.

Control Samples

The laboratory will employ control samples to assess the validity of the analytical results of the field samples. Determination of the validity of field sample results is based on the acceptance criteria being met by the control sample. The acceptance criteria for each type of control sample

are delineated in the appropriate SOP. These acceptance criteria are based on the laboratory's statistical process capabilities determined from historical data, and meet the EPA CLP acceptance criteria as a minimum. Often, in-house criteria are more stringent than required by CLP. The control samples are analyzed in the same manner as the field samples. They are interspersed with the field samples at frequencies that are specified by the appropriate SOP.

Method Blank Analyses

A method blank is a "clean" sample (i.e., containing no analyte of concern), most often deionized water, to which all reagents are added and analytical procedures are performed. Method blanks are analyzed at a rate of one per sample lot or at least every 20 samples. The blank is analyzed in order to assess possible contamination from the laboratory or the procedure. If the analyte of interest is found in the blank at above reporting levels, inorganic analysis is suspended until the source of contamination is found and corrective action is taken. The Laboratory Manager is notified when blank results are unacceptably high, and may assist in the investigation.

Surrogate Spike Analyses

For certain analyses such as those performed by GC/MS, each sample and blank is spiked with one or more surrogate compounds before preparatory operations such as purging or extraction. These surrogate standards are chosen for properties similar to sample analytes of interest, but are usually absent from the natural sample.

Surrogate spikes evaluate the efficiency of the analytical procedure in recovering the true amount of a known compound.

The results of surrogate standard determinations are compared with the true values spiked into the sample matrix prior to extraction and analysis, and the percent recoveries of the surrogate standards are determined. Recoveries should meet the upper and lower control limits as specified for each compound. If control limits are exceeded for surrogate standards, the following sequence of actions is taken:

a. The sample is re-injected.

b. Raw data and calculations are checked for errors.

c. Internal standards and surrogate spiking solutions are checked for degradation, contamination, or solvent evaporation.

d. Instrument performance is checked.

e. If a, b, and c fail to reveal the cause of the noncompliance surrogate recoveries, the sample is re-purged or re-extracted.

f. If all the measures listed above fail to correct the problem for laboratory blank surrogate analyses, the analytical system is considered out of control, and the instrument must be recalibrated and examined for mechanical faults.

g. If all the measures listed above fail to correct the problem for field sample surrogate analyses, the deficiency probably is due to sample interferences, and not due to any procedural or mechanical problems in the laboratory. The surrogate spike recovery data and the sample data from both extractions are reported and are flagged. The Laboratory Manager is notified with an exceptions report and the corrective actions taken.

Matrix Spike/Matrix Spike Duplicate Analyses

To evaluate the effect of the sample matrix on the analytical methodology, two separate aliquot samples may be spiked with a standard mix of compounds appropriate to a given analysis. The matrix spike and the matrix spike duplicate (MS/MSD) are analyzed at a frequency of one per lot or one per 20 samples, whichever is more frequent. The percent recovery for each of the spiking compounds is calculated. The relative percent difference (RPD) between the MS/MSD is also calculated.

The observed percent recoveries (%R) and relative percent differences (RPD) between the MS/MSD are used to determine the accuracy and the precision of the analytical method for the sample matrix. If the percent recovery and RPD results exceed the control limits as specified for each spiking compound, the sample is not reanalyzed. Poor recovery in matrix spiked samples does not necessarily represent an analytical system out of control. It is possible that unavoidable interferences and matrix effects from the sample itself preclude efficient recoveries. The poor recovery is documented for the Project Manager.

Internal Standards Analysis

Once an instrument has been calibrated, it is necessary to confirm periodically that the analytical system remains in calibration. The continuing calibration and precision of the organics analytical system are checked for each sample analysis by monitoring the instrument response to internal standards. When internal standard addition is not appropriate to a particular method, other means of accuracy checks, such as standard addition, are used. Results from internal standard analyses are compared to the mean calibrated value. Deviation from this mean beyond a predetermined magnitude, depending on the type of analysis, defines an out-of-control condition. The system must then be brought back into control by:

- Checking the quality of the internal standards and reanalyzing the sample
- Recalibrating the system
- Correcting the malfunctions causing the instrument to fall out of calibration

Duplicate Sample Analyses

Duplicate analyses are performed for cations analyses and upon special request for selected other parameters to evaluate the reproducibility of the method. Results of the duplicate analyses are used to determine the RPD between replicate samples. For each parameter analyzed, at least one duplicate sample is run per group of 20 samples.

The precision value, RPD, is reviewed by the section supervisor and the division manager. If the precision value exceeds the control limit or the established protocol criteria for the given parameter, the sample set is reanalyzed for the parameter in question unless it is determined that heterogeneity of the sample has caused the high RPD.

QC Check Standard Analyses

Analysis of QC check standards is used to verify the preparation process or the standard curve, and is performed with each group of samples. Results of these data are summarized, evaluated, and presented to the section supervisor and the division manager for review.

The results of the QC check standard analysis are compared with the true values, and the percent recovery of the check standard is calculated. If correction of a procedure or instrument repair is done, the check standard is reanalyzed to demonstrate that the corrective action has been successful.

At least twice a year, a QC check standard for each parameter group is analyzed as a double-blind sample. Samples are prepared, submitted, and evaluated by the Laboratory Manager.

Other Quality Control Samples

Under some sampling analysis, additional quality control samples may be required. These may include:

a. **Blank/Spike--**Analyte of interest or surrogate is spiked into blank water rather than into a sample. The blank/spike goes through the entire analytical procedure, and percent recovery is calculated with no likelihood of matrix effect. For many contracts, an externally provided LCS sample (EPA) serves as a blank/spike sample.

b. **Trip Blank--**A sample bottle filled with laboratory blank water travels with the sample kit to the sampling site, and is sent back to the laboratory packed in the same container as any volatile samples collected. Trip blank analyses check for possible volatile contamination during shipping or sampling.

c. **Field Blank--**A field blank can be a sample container filled with laboratory blank water and sent to the sampling site, or it may be filled at the site with purchased distilled water or

decontamination water. The field blank analysis checks for possible contamination by the sampling team.

d. **Equipment Rinsates**--After equipment has been cleaned in the field, many contracts require that the equipment be rinsed and the rinsate analyzed for the same parameters requested on the samples. The rinsate analysis proves the equipment has been cleaned properly and will not contaminate the next samples taken.

Control Charts

The laboratory will use control charts to monitor for out-of-control conditions.

Control Charting Process

The control chart program uses a series of Lotus (or equivalent) macros to perform data processing and control charting. These macros also perform statistical decisions on the acceptability of the data.

The control chart used is a variation of the Shewart control chart of averages. The chart plots individual quantitative results against the order of time measurement. The plotted values are compared with control limits determined by the variability about the mean of the standard "in control" process. The control chart estimates the process mean and the variability from a moving window of 50 to 200 samples, depending upon the analytical parameters involved. The mean is estimated from the arithmetic average of the samples in the current window. The variability is estimated as the sample SD of the sample values in the current window. The program calculates the 2 SD and the 3 SD limits and displays them on the chart. The t-statistic is used to estimate the 99.7 percent tolerance limits for the degrees of freedom in the current window. Values outside the t-statistic limits are unconditionally rejected from inclusion in the sample window and automatically documented in a Corrective Action Report (CAR). The CAR prompts the analyst to initiate investigation and corrective action.

When the maximum number of samples has accumulated in the current window, the summary statistics of the mean and SD are written to the long-term data base. The last 20 samples in the old window are then transferred to a new window for continued use in the charting process.

The long-term data base charts the mean 1 SD error bars.

<u>Instrument Detection Limits, Method Detection Limits, and Reporting Limits</u>

Instrument Detection Limits (IDL)

Instrument Detection Limit (IDL) studies are performed for inorganic parameters when an instrument is installed, when major maintenance or repair work has been done, and routinely once per calendar quarter.

To determine IDL, seven consecutive measurements per day are made on a prepared standard solution (in reagent water) of an analyte at a concentration 3 to 5 times the instrument manufacturer's suggested IDL. Each measurement is performed as though it were a separate analytical sample. This procedure is repeated on three nonconsecutive days. The standard deviation is calculated for each set of seven replicates and the average of the standard deviations is obtained. This average is multiplied by 3 to give the instrument detection limit (IDL).

Method Detection Limits (MDL)

The Method Detection Limit (MDL) is the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the value is above zero. The sample must be carried through the entire method under ideal conditions. MDL is determined according to the method outlined in 40 CFR 136, Appendix B. MDLs are determined at least annually for all parameters. MDL studies are also conducted for new methods introduced in the lab, after major maintenance or modification to an instrument, and as part of the training of new analysts.

To determine MDL, seven replicate analyses are made of analytes spiked into blank water at 1 to 5 times the estimated method detection limit. The spiked samples must be carried through the entire analytical procedure, including any extraction, digestion, or distillation process, for MDL calculation. The SD of these replicates is calculated. Where:t = The student t value for a 99% confidence interval

$$MDL = t \times S \qquad 10$$

S = Standard deviation of the replicate analyses

Reporting Limits

In most cases, final report forms list reporting limits rather than either IDL or MDL. Reporting limits are taken from EPA SW846 published limits or from historical data. Matrixes or analyte concentrations which require dilution will change the detection limits for that sample.

4.7. Performance and System Audits

In this section information is provided on performance audits and onsite system audits.

Performance Evaluation Samples

Performance evaluation samples are analyzed throughout the project for all parameters, as a constant check on accuracy and precision for all analyses.

Audits

Internal audits of the laboratory are conducted in two phases. The first phase is conducted by the Laboratory Quality Assurance Coordinator during the fourth quarter of the year. This is usually a 2-day systems audit which covers all sections of the laboratory. An audit report is issued within 2 weeks of completion. The Field Site Manager has the responsibility for coordinating all responses to the audit finding and for following up on the required corrective action. A followup audit is made when deemed necessary by the by the Field Site Manager or the Laboratory Manager. A quality assurance review questionnaire is provided in the Appendix.

The second phase consists of quarterly audits performed by the Field Site Manager. These are half-day or day-long audits, and are concentrated on specific areas that are deemed problem areas by the Field Site Manager. An audit report is issued at the completion of the audit. Responses and followup corrective action to the audit findings are required, and are monitored by the Field Site Manager.

All audit reports are issued to management and circulated to all staff. Copies are filed with the Field Site Manager and the Laboratory Manager.

4.8. Quality Assurance Reports

The performance of the field laboratory as assessed by the quality monitoring systems in place is reported by the Field Site Manager to management quarterly and as needed. Copies of all quality reports are maintained in the Field Site Manager and Laboratory Manager files.

Quality assurance reports to management include, but are not limited to, the following:

- Results of performance and systems audits
- Status of corrective actions
- Periodic assessment of data accuracy, precision, and completeness
- Significant QA problems and recommended solutions

In addition to the quarterly reports, a final report summarizing items covered in the quarterly reports is provided by the Field Site Manager to the Project Manager.

4.9. Data Format

Introduction

In order to provide analytical data which is technically sound and defensible, a system of data management will be implemented in the laboratory. All activities which pertain to a sample are documented.

All data generated during the demonstration, except those that are generated by automated data collection systems, will be recorded directly, promptly, and legibly in ink. All data entries will be dated on the day of entry and signed or initialed by the person entering the data. Any change in entries will not obscure the original entry, will indicate the reason for such change, and will be dated and signed or identified at the time of the change.

In automated data collection systems, the individual responsible for direct data input will be identified at the time of data input. Any change in automated data entries will not obscure the original entry. Updated entries will indicate the reason for the change, the date, and the person responsible for making the change.

Data Tracking in the Laboratory

The Field Site Manager is responsible for developing a system for tracking and maintaining sample identity between the collection point, analysis and reporting. This process will be periodically reviewed by the Project Manager.

Analyses and Data Reduction

The Field Site Manager is responsible for the reduction of raw data when such steps are required to produce the correct data format for reporting. Data reduction may be done manually or through one of a number of computer programs used in the laboratory.

Chromatogram Identification

In the GC section computer software is used to identify chromatograms. A system-supplied file name (a hexadecimal date-time) and a user-supplied file name (related to an entry in the injection log) identify each acquisition.

Data Reduction Formulas

Linear regression formulas are used in a computer software system to calculate samples values for many general inorganic parameters and metals analyses. These programs use the general formula for linear regression:

$$Y' = a + bx \qquad 11$$

where:

Y'	=	The predicted value of y for a selected value of x
a	=	The value of y when x = 0
b	=	The slope of the straight line
x	=	Any value of x selected

Sample values for GC/MS parameters are calculated by systems software using the general formula:

$$\frac{Area_{Target} \; x \; Amount_{IS}}{Area_{IS} \; x \; Response\ Factor} \qquad 12$$

GC data is calculated using either an internal or an external standard. For internal standards:

$$Concentration = \left(\frac{A_x^{sample}}{A_x^{standard}}\right)\left(\frac{A_{IS}^{standard}}{A_{IS}^{sample}}\right)\left(amt_x^{standard}\right)\left(\frac{P}{T}\right)\left(\frac{amt_{IS}^{Sample}}{Amt_{IS}^{standard}}\right) \qquad 13$$

where: P = 1/fraction of extract to which IS is added

For calculations using an external standard:

$$Concentration = \left(\frac{A_x^{sample}}{A_x^{standard}}\right)\left(C_x^{standard}\right)\left(\frac{V}{T}\right) \qquad 14$$

where: C = concentration of x in standard
V = volume of final extract
T = total sample extracted

4.10. Data Storage and Archiving Procedures.

Data from GC's will be saved and archived in P&E Turbochrom format. All data will be backed-up on ZIP disks. This data will be batch processed into an Excel .csv file that can be easily converted to an Excel Worksheet. These files will be backed-up and transferred to individuals responsible for calculating flux results. All data related to the project will be organized for rapid retrieval and transfer to other interested parties.

Appendix E: Fines Calculations

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
Alameda							
PP41IW01	0.0	4.5	gravel				
	4.5		water table				top of treatment zone
	4.5	6.0	gravel	0.025	1.5	0.038	
	6.0	10.0	clay	0.925	4.0	3.700	
	10.0	15.0	silt with sand	0.800	5.0	4.000	
	15.0	27.0	sandy silt	0.600	12.0	7.200	
	27.0						bottom of treatment zone
	27.0	35.0	sandy clay				
			subtotal		22.5	14.938	
			average fraction fines			0.664	
			number of layers			4.000	
			layers per 10 feet			1.778	
			treatment zone thickness			22.500	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
Charleston							
MW-7	0.0	1.0	gravel with sand fill				
	1.0	2.0	sand				
	2.0	3.0	clayey sand				
	3.0	5.0	sand				
	5.0	6.0	silty sand				
	6.0	7.5	sand				
	7.5		water table				top of treatment zone
	7.5	11.3	sand	0.025	3.8	0.095	
	11.3	15.0	sandy clay	0.600	3.7	2.220	
	15.0	20.0	clay	0.925	5.0	4.625	
	20.0	22.8	sandy clay	0.600	2.8	1.680	
	22.8	27.5	silty sand	0.325	4.7	1.528	
	27.5	28.0	gravel	0.025	0.5	0.013	
	28.0						bottom of treatment zone
	28.0	29.0	sandy clay marl				
			subtotal		20.5	10.160	
			average fraction fines			0.496	
			number of layers			6.000	
			layers per 10 feet			2.927	
			treatment zone thickness			20.500	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
Dover							
MW211D	0.0	1.0	silty sand				
	1.0	10.0	sand				
	10.0		water table				top of treatment zone
	10.0	17.0	sand	0.025	7.0	0.175	
	17.0	19.5	clay with sand	0.800	2.5	2.000	
	19.5	41.5	sand	0.025	22.0	0.550	
	41.5	42.5	clay	0.925	1.0	0.925	
	42.5	44.0	clay with sand	0.800	1.5	1.200	
	46.5						bottom of treatment zone
	46.5	48.0	clay				
			subtotal		34.0	4.850	
			average fraction fines			0.143	
			number of layers			5.000	
			layers per 10 feet			1.471	
			treatment zone thickness			36.500	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
Moody							
FT07-DPS111-65	0.0	2.7	silty sand				
	2.7	3.7	sandy silt				
	5.0	9.5	sandy silt				
	10.0	14.4	sandy silt				
	15.0	15.5	sandy silt				
	15.5		water table				top of treatment zone
	15.5	16.5	silty sand	0.325	1.0	0.325	
	16.5	17.7	clay	0.925	1.2	1.110	
	17.7	19.6	sandy clay	0.600	1.9	1.140	
	20.0	20.4	silty sand	0.325	0.4	0.130	
	20.4	20.9	clay	0.925	0.5	0.463	
	20.9	21.2	sandy silt	0.600	0.3	0.180	
	21.2	22.8	sandy clay	0.600	1.6	0.960	
	25.0	25.4	clay	0.925	0.4	0.370	
	25.4	26.1	sand	0.025	0.7	0.018	
	26.1	26.5	sandy clay	0.600	0.4	0.240	
	26.5	27.0	sandy silt	0.600	0.5	0.300	
	27.0	27.2	silty sand	0.325	0.2	0.065	
	27.2	27.3	clay	0.925	0.1	0.093	
	27.3	27.4	silty sand	0.325	0.1	0.032	
	27.4	27.5	clay	0.925	0.1	0.093	
	27.5	27.8	silty sand	0.325	0.3	0.098	
	27.8	27.9	clay	0.925	0.1	0.092	
	27.9	28.0	silty sand	0.325	0.1	0.033	
	28.0						bottom of treatment zone
	28.0	28.2	clay				
	30.0	30.5	sandy clay				
	30.5	30.9	clay				
	30.9	31.9	silty sand				
	31.9	32.4	sandy silt				
	35.0	35.9	clay				
	35.9	37.0	silty sand				
	40.0	41.9	silty sand				
	45.0	47.8	silty sand				
	50.0	51.5	silty sand				
	55.0	57.0	clay				
	60.0	63.4	clay				
			subtotal		9.9	5.740	
			average fraction fines			0.580	
			number of layers			18.000	
			layers per 10 feet			18.182	
			treatment zone thickness			12.500	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
Myrtle							
FT11-MW04	0.0	1.0	clay				
	1.0	2.0	silty sand				
	2.0	4.0	sandy silt				
	4.0	7.5	clay				
	7.5		water table				top of shallow treatment zone
	7.5	8.0	sand	0.025	0.5	0.013	
	14.0	15.0	sand	0.025	1.0	0.025	
	15.0						bottom of shallow treatment zone
	15.0	16.0	clay				
	16.0	18.0	sandy clay				
	23.0	25.0	clay				
	28.0	30.0	clay				
	33.0	33.5	clay				
	33.5	34.6	silty sand				
	34.6	35.0	sand with silt				
	38.0	40.0	sand				
	43.0	44.0	sand				
	44.0	45.0	clay with sand				
			subtotal		1.5	0.038	
			average fraction fines			0.025	
			number of layers			2.000	
			layers per 10 feet			13.333	
			treatment zone thickness			7.500	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
North Island							
General			silty sand	0.325			no log
Orlando							
OLD-17-04A/10C	0.0	0.5	gravel				
	0.5	1.5	sand				
	1.5	6.0	silty sand				
	6.0		water table				top of A/B treatment zone
	6.0	22.0	silty sand	0.325	16.0	5.200	
	22.0						bottom of A/B treatment zone
	22.0	46.0	silty sand	0.325	24.0	7.800	
	46.0	55.0	sandy silt	0.600	9.0	5.400	
	55.0						bottom of C treatment zone
	55.0	60.0	clay	0.925	5.0		
	A/B treatment zone		subtotal		16.0	5.200	
			average fraction fines			0.325	
			number of layers			1.000	
			layers per 10 feet			0.625	
			treatment zone thickness			16.000	
	C treatment zone		subtotal		33.0	13.200	
			average fraction fines			0.400	
			number of layers			2.000	
			layers per 10 feet			0.606	
			treatment zone thickness			33.000	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
Point Mugu 23W26B							
	0.0		asphalt				
	0.2	5.1	sand				
	5.1		water table				top of Zone A
	5.1	9.5	sand	0.025	4.4	0.109	
	9.5	13.0	silt	0.925	3.5	3.238	
	13.0	15.0	sand	0.025	2.0	0.050	
	15.0	18.0	silt	0.925	3.0	2.775	
	18.0	23.0	sand	0.025	5.0	0.125	
	23.0	26.0	sand	0.025	3.0	0.075	
	26.0	28.0	clay	0.925	2.0	1.850	
	28.0	34.5	sand	0.025	6.5	0.163	
	34.5	35.3	silt	0.925	0.8	0.740	
	35.3	35.4	sand	0.025	0.1	0.003	
	35.4						bottom of Zone B
	A/B treatment zone		subtotal		30.3	9.127	
			average fraction fines			0.302	
			number of layers			10.000	
			layers per 10 feet			3.304	
			treatment zone thickness			30.270	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
Raritan							
MW304D	0.0	5.0	sand with silt				
	5.0	10.0	sand with gravel				
	10.0		water table				top of Upper Sand
	10.0	11.0	sand with gravel	0.025	1.0	0.025	
	11.0						bottom of Upper Sand
	11.0	21.5	clay	0.925	10.5	9.713	
	21.5						top of Lower Sand
	21.5	23.0	silt with sand	0.800	1.5	1.200	
	23.0	25.0	sand	0.025	2.0	0.050	
	25.0	30.0	sand with silt	0.100	5.0	0.500	
	30.0						bottom of Lower Sand
	30.0		clay	0.925			
	Upper Sand		subtotal		1.0	0.025	
			average fraction fines			0.025	
			number of layers			1.000	
			layers per 10 feet			10.000	
			treatment zone thickness			1.000	
	Lower Sand		subtotal		8.5	1.750	
			average fraction fines			0.206	
			number of layers			3.000	
			layers per 10 feet			3.529	
			treatment zone thickness			8.500	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
Seal Beach							
AMW1	0.0	0.2	aphalt				
	0.2	5.0	silty sand				
	5.0	15.0	clay				
	15.0		water table				top of treatment zone
	15.0	23.0	clayey sand	0.325	8.0	2.600	
	23.0	28.0	silty sand	0.325	5.0	1.625	
	28.0	28.4	sandy clay	0.600	0.4	0.240	
	28.4	29.5	silty sand	0.325	1.1	0.358	
	29.5	31.0	sandy clay	0.600	1.5	0.900	
	31.0	32.0	silty sand	0.325	1.0	0.325	
	32.0	33.0	sandy clay	0.600	1.0	0.600	
	33.0	34.0	silty sand	0.325	1.0	0.325	
	34.0	35.1	sandy silt	0.600	1.1	0.660	
	35.1	37.0	silty sand	0.325	1.9	0.618	
	37.0						bottom of treatment zone
			subtotal		22.0	8.250	
			average fraction fines			0.375	
			number of layers			10.000	
			layers per 10 feet			4.545	
			treatment zone thickness			22.000	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
St Juliens							
IW1	0.0	1.0	concrete				
	1.0	2.0	gravel				
	2.0	5.0	sandy silt				
	5.0	6.0	silt				
	6.0		water table				top of treatment zone
	6.0	10.0	silt with sand	0.800	4.0	3.200	
	10.0	17.0	sand with silt	0.100	7.0	0.700	
	17.0	18.0	sand	0.025	1.0	0.025	
	18.0						bottom of treatment zone
	18.0	20.0	clay				
			subtotal		12.0	3.925	
			average fraction fines			0.327	
			number of layers			3.000	
			layers per 10 feet			2.500	
			treatment zone thickness			12.000	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
Treasure Island							
EW-29	0.0	0.0	asphalt				
	0.0	2.0	sandy clay				
	2.0	5.0	clay with sand				
	5.0	6.0	clay				
	6.0	9.0	sand with silt				
	9.0	10.0	clay with sand				
	10.0	18.0	sand with silt				
	18.0		water table				top of treatment zone
	18.0	30.0	sand with silt	0.100	12.0	1.200	
	30.0						bottom of treatment zone
			subtotal		12.0	1.200	
			average fraction fines			0.100	
			number of layers			1.000	
			layers per 10 feet			0.833	
			treatment zone thickness			12.000	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
VAFB Site 15A							
15MW10	0.0	10.9	sand				
	10.9		water table				top of treatment zone
	10.9	26.5	sand	0.025	15.6	0.390	
	26.5	28.0	clay	0.925	1.5	1.388	
	28.0	39.0	sand	0.025	11.0	0.275	
	39.0						bottom of treatment zone
	39.0		bedrock				
			subtotal		28.1	2.053	
			average fraction fines			0.073	
			number of layers			3.000	
			layers per 10 feet			1.068	
			treatment zone thickness			28.100	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
VAFB Site 15B							
15MW16	0.0	8.0	sand				
	8.0		water table				top of treatment zone
	8.0	42.0	sand	0.025	34.0	0.850	
	42.0	45.0	clay	0.925	3.0	2.775	
	45.0		bedrock				bottom of treatment zone
			subtotal		37.0	3.625	
			average fraction fines			0.098	
			number of layers			2.000	
			layers per 10 feet			0.541	
			treatment zone thickness			37.000	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
VAFB Site 19							
19-MW-17A/B	0.0	0.5	asphalt				
	0.5	2.5	sand				
	2.5	5.0	sand with silt				
	5.0	8.0	clay				
	8.0		water table				top of Clay Zone
	8.0	10.0	silt	0.925	2.0	1.850	
	10.0	13.5	clay	0.925	3.5	3.238	
	13.5	14.5	silt	0.925	1.0	0.925	
	14.5	15.0	clay	0.925	0.5	0.463	
	15.0	17.0	silty sand	0.325	2.0	0.650	
	17.0	19.5	clay	0.925	2.5	2.313	
	19.5						top of Sand Zone
	19.5	21.0	silty sand	0.325	1.5	0.488	
	21.0	30.0	sand	0.025	9.0	0.225	
	30.0						bottom of Sand Zone
	30.0		gravel				
	Clay Zone		subtotal		11.5	9.438	
			average fraction fines			0.821	
			number of layers			6.000	
			layers per 10 feet			5.217	
			treatment zone thickness			11.500	
	Sand Zone		subtotal		10.5	0.713	
			average fraction fines			0.068	
			number of layers			2.000	
			layers per 10 feet			1.905	
			treatment zone thickness			10.500	

Well Log	Top	Bottom	Description	Fraction Fines	Measured Thickness	Weighted Fraction	Notes
VAFB Site 35							
35-MW-30	0.0	13.0	sand				
	13.0	20.0	sand with silt				
	20.0	26.5	clayey sand				
	26.5		water table				top of treatment zone
	26.5	29.0	clayey sand	0.325	2.5	0.813	
	29.0	29.5	clayey gravel	0.325	0.5	0.163	
	29.5	30.5	clayey sand	0.325	1.0	0.325	
	30.5	31.5	clayey gravel	0.325	1.0	0.325	
	31.5	33.0	clayey sand	0.325	1.5	0.488	
	33.0						bottom of treatment zone
	33.0	36.5	bedrock				
			subtotal		6.5	2.113	
			average fraction fines			0.325	
			number of layers			5.000	
			layers per 10 feet			7.692	
			treatment zone thickness			6.500	

Appendix F: Representative Soil Boring Logs

Drilling Log

Monitoring Well **PP41IW01**

Project *Alameda CTO 107* Owner *US Navy*

Location *Alameda, CA* Proj. No. *844918*

Surface Elev. *NG=11.33 ft* Total Hole Depth *35.4 ft.* North *470798.61 ft.* East *1481761.1 ft.*

Top of Casing *11.14 ft.* Water Level Initial *NA* Static ▼ *4.4 ft.* Diameter *8 in.*

Screen: Dia *2 in.* Length *10 ft.* Type/Size *Fiberglass/slotted 0.020 in.*

Casing: Dia *2 in.* Length *24.5 ft.* Type *Fiberglass*

Fill Material *See Comments* Rig/Core *8" Hollow Stem*

Drill Co. *BC 2* Method *Hollow Stem Auger*

Driller *Diego Rivera* Log By *Jim Teo* Date *11/5/03* Permit # *W03-0978*

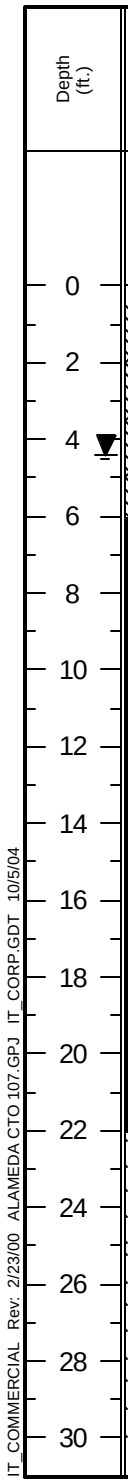
Checked By *Gene Mullenmeister* License No. *Driller License C57# 686255*

COMMENTS

Water ~10 gallons; #2/12 Sand ~5 bags (100 lb bags); Bentonite ~5 bags (60 lb bags)

NG = Natural Ground

Static Water Level: 1/26/04



Description

(Color, Texture, Structure)

Soil Descriptions are Based on the USCS.

@ ~2-5 ft, Well graded gravel, dry, pebbles, rocks and cobbles, dense to very dense (95% gravel; 5% sand) (next to railroad tie)

@ ~8-10 ft, Lean clay, yellowish brown (10YR 5/4), very moist, many pebbles and rocks, firm, coarse grained fraction is dense (40% gravel; 10% sand; 10% silt; 40% clay)

@ ~10-15 ft, Silt with sand, dark olive gray (5Y 3/2), wet/saturated, with small interspersed clay aggregates (30-50 mm) and gravel, liquid but slightly sticky, loose, soft (10% gravel; 10% sand; 50% silt; 20% clay)

@ ~15-20 ft, Sandy silt, olive brown (5Y 4/3), wet/saturated, cohesive, massive with few silty clay aggregates interspersed, soft, slightly plastic, sticky (20% sand; 50% silt; 30% clay)

@ ~20-25 ft, Sandy silt, as above, color change to light olive brown (2.5Y 5/3)

@ ~30 ft, Sandy lean clay, olive (2.5Y 5/4), wet/saturated, no aggregates,

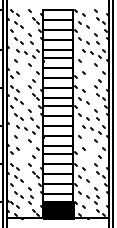
Continued Next Page

Drilling Log

Monitoring Well **PP41IW01**

Project *Alameda CTO 107* Owner *US Navy*

Location *Alameda, CA* Proj. No. *844918*

Depth (ft.)	Well Completion	PID (ppm)	Sample ID / % Recovery / Blow Count Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Soil Descriptions are Based on the USCS.
30						*Continued*
32					CL	frequent medium grained black sand, soft to firm, slightly plastic, slightly sticky (50% sand; 25% silt; 25% clay)
34						@ ~35 ft, Sandy lean clay, as above
36						TD = 35.4 ft
38						Survey Datum: Horizontal: NAD 27, Vertical: NAVD 88
40						Note: Soil descriptions were generated from soil grab sample specimens collected from the veins of hollow stem auger flytes. As a result, the depths of all descriptions and soil horizon boundaries are approximate.
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AIS-TN&A JOINT VENTURE
AIS-TN&A JV
317 E Main St
Ventura, CA 93001
Telephone: (805) 585-2110
Fax: (805) 585-2111

WELL NUMBER 23W26B

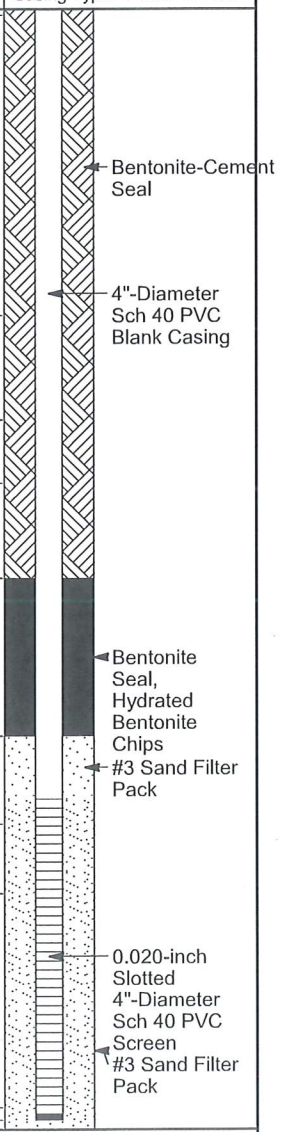
CLIENT US Dept of the Navy
PROJECT NAME IRP Site 24
PROJECT NUMBER 2009044
PROJECT LOCATION NBVC Point Mugu, CA
DATE STARTED 12/17/12 **COMPLETED** 12/17/12
GROUND ELEVATION 10.13 ft **HOLE SIZE** 12" OD
DRILLING CONTRACTOR ABC Liovin
GROUND WATER LEVELS:
DRILLING METHOD Hollow Stem Auger
AT TIME OF DRILLING 4.60 ft / Elev 5.53 ft
LOGGED BY M Wanek **CHECKED BY** J Harting, PE
AT END OF DRILLING ---
NOTES MC-Modified Cal Sampler; AU-Hand Auger
AFTER DRILLING 5.13 ft / Elev 5.00 ft

DEPTH (ft)	SAMPLE TYPE NUMBER	RECOVERY %	PID	U.S.C.S.	GRAPHIC LOG	MATERIAL DESCRIPTION
0	AU	96	0.0	SP		2" ASPHALT Brown (7.5YR, 5/4) fine SAND with trace silt. Moist. Medium dense.
5	MC	80	0.0	SP		- Becomes gray (7.5YR, 5/1) - Becomes very dark gray (7.5YR, 3/1), wet with fining upward sequences ~0.2' each. Grades to fine-medium sand with trace shell hash at bottom of each sequence.
10	MC	93	0.0	ML		Black (7.5YR, 2.5/1) SILT with trace fine sand. Wet. Medium dense. Root inclusions approx. 1.5" diameter. - Becomes very dark gray (5Y, 3/1) with no sand and no organic inclusions. - Becomes dark yellowish-brown (10YR, 4/4) with strong brown (7.5YR, 4/6) secondary mineralization
				SW		Dark gray (10YR, 4/1) well-graded (fine to coarse) SAND with trace shell hash. Wet. Medium dense.
15	MC	87	0.0	ML		Very dark gray (10YR, 3/1) SILT. Wet. Medium dense. Finely laminated - Becomes sandy - Becomes dark yellowish brown (10YR, 3/4)
20	MC	100	2.2 9.2	SW		Dark gray (10YR, 4/1) poorly graded SAND with trace silt and gravel to 1" diameter. Wet. Medium dense.
25	MC	73	2.1	SP		Dark gray (10YR, 4/1) fine SAND. Wet. Medium dense.
				CL		Brown (10YR, 4/3) CLAY. Moist. Medium stiff.
30	MC	93	9.2	SP		Gray (10YR, 5/1) fine SAND. Wet. Medium dense - Becomes dark gray (10YR, 4/1), very fine sand.
35	MC	100	0.0	ML		- Becomes fine to medium-grained sand with trace shell hash.
				SP		Very dark gray (5Y, 3/1) SILT. Moist. Medium dense Dark grayish-brown (2.5Y, 4/2) fine SAND. Wet. Medium dense.

Bottom of borehole at 35.5 feet.

WELL DIAGRAM

Casing Top Elev: 9.35 (ft)
Casing Type: 4" Sch 40 PVC



Drilling Log

Monitoring Well PP41IW01

Project: Alameda CTO 107 | Owner: US Navy
Location: Alameda, CA | Proj. No.: 844918
Surface Elev.: NG=11.33 ft | Total Hole Depth: 35.4 ft. | North: 470798.61 ft. | East: 1481761.1 ft.
Top of Casing: 11.14 ft. | Water Level Initial: NA | Static: ▽ 4.4 ft. | Diameter: 8 in.
Screen: Dia: 2 in. | Length: 10 ft. | Type/Size: Fiberglass/slotted 0.020 in.
Casing: Dia: 2 in. | Length: 24.5 ft. | Type: Fiberglass
Fill Material: See Comments | Rig/Core: 8" Hollow Stem
Drill Co.: BC 2 | Method: Hollow Stem Auger
Driller: Diego Rivera | Log By: Jim Teo | Date: 11/5/03 | Permit #: W03-0978
Checked By: Gene Mullenmeister | License No.: Driller License C57# 686255

COMMENTS
Water ~10 gallons; #2/12 Sand ~5 bags (100 lb bags); Bentonite ~5 bags (60 lb bags)

NG = Natural Ground

Static Water Level: 1/26/04

Depth (ft.)	Well Completion	PID (ppm)	Sample ID / % Recovery	Blow Count / Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) — Soil Descriptions are Based on the USCS.
0–4							
4–6						GW	@ ~2-5 ft, Well graded gravel, dry, pebbles, rocks and cobbles, dense to very dense (95% gravel; 5% sand) (next to railroad tie)
6–10						CL	@ ~8-10 ft, Lean clay, yellowish brown (10YR 5/4), very moist, many pebbles and rocks, firm, coarse grained fraction is dense (40% gravel; 10% sand; 10% silt; 40% clay)
10–18						ML	@ ~10-15 ft, Silt with sand, dark olive gray (5Y 3/2), wet/saturated, with small interspersed clay aggregates (30-50 mm) and gravel, liquid but slightly sticky, loose, soft (10% gravel; 10% sand; 50% silt; 20% clay) @ ~15-20 ft, Sandy silt, olive brown (5Y 4/3), wet/saturated, cohesive, massive with few silty clay aggregates interspersed, soft, slightly plastic, sticky (20% sand; 50% silt; 30% clay)
18–28						ML	@ ~20-25 ft, Sandy silt, as above, color change to light olive brown (2.5Y 5/3)
28–30						CL	@ ~30 ft, Sandy lean clay, olive (2.5Y 5/4), wet/saturated, no aggregates,

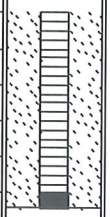
Continued Next Page

Drilling Log

Monitoring Well **PP41IW01**

Project *Alameda CTO 107* Owner *US Navy*

Location *Alameda, CA* Proj. No. *844918*

Depth (ft.)	Well Completion	PID (ppm)	Sample ID / % Recovery / Blow Count Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Soil Descriptions are Based on the USCS.
30						*Continued* frequent medium grained black sand, soft to firm, slightly plastic, slightly sticky (50% sand; 25% silt; 25% clay)
32					CL	
34						@ ~35 ft, Sandy lean clay, as above
36						TD = 35.4 ft Survey Datum: Horizontal: NAD 27, Vertical: NAVD 88 Note: Soil descriptions were generated from soil grab sample specimens collected from the veins of hollow stem auger flytes. As a result, the depths of all descriptions and soil horizon boundaries are approximate.
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1036 213

Well #: MW-7

Page 1 of 2

RADIAN INTERNATIONAL

LOG OF DRILLING OPERATIONS

PROJECT Zone 4 RFI/CMS LOCATION Charleston AFB
TOTAL DEPTH 31.00' START DATE 4/21/01 FINISH DATE 4/21/01
GEOLOGIST Rhoda Willis APPROVED BY Jim Narkunas R.G.# 385
DRILLING COMPANY MacCall Hill Brothers DRILLER Thomas Whitehead
DRILLING METHOD Hollow Stem Auger EQUIPMENT Mobile Drill B-57
DRILL BIT TYPE AND SIZE 8" Carbide Bit
BORING LOCATION (Coordinates or Description)

Depth Below Surface (ft)	Screening Results (ppm)	Blow Counts	Lithologic Description Color, Texture, Moisture, etc.	Graphic Log	Elevation (ft MSL)
0			0-1.0' Gravel with silty sand fill material.		
			1.0-2.0' Sand, fine grainded, subrounded, moist to damp, brownish yellow (10YR 6/8).		
			2.0-3.0' Clayey sand, fine grained subrounded moist, light yellowish brown (10YR 6/4).		
	0		3.0-5.0' Sand with >10% clay and silt, fine to coarse subangular, moist, strong brown (7.5YR 5/6).		
5			5.0-6.0' Silty fine sand, moist to wet becoming less silty at 6.0' bgs, strong brown (7.5YR 5/8).		
			6.0-11.3' Sand, mica flakes, little to no matics, saturated at 7.5' bgs, light brownish gray (10YR 6/2).		
10	0		11.3-15.0' Sandy clay, fine sand grains with minor silt, saturated.		
15	0		15.0-20.0' Clay with >20% silt, little to no sand, same color as above.		
20			20.0-22.8' Tight sandy clay, fine to coarse sand grains, color grades from dark gray with orange mottling (7.5YR N4) to gray (7.5YR N6/0) then greenish gray (5GY 6/1).		
			22.8-27.5' Silty sand with a little clay, same color as above (distinctive greenish gray), sand becoming coarser with depth.		
25					

Well Construction Details

Casing elevation=

0
5
10
19.5
21.5

NOTES
ppm=parts per million

RADIAN INTERNATIONAL
A DAMES & MOORE GROUP COMPANY

Well #: MW-7

LOG OF DRILLING OPERATIONS

PROJECT Zone 4 RFI/CMS LOCATION Charleston AFB

Depth Below Surface (ft)	Screening Results (ppm)	Blow Counts	Lithologic Description Color, Texture, Moisture, etc.	Graphic Log	Elevation (ft MSL)	Well Construction Details
			27.5-28.0' Gravel layer. 28.0-29.0' Cooper Marl. Bottom of the hole at 29.0' bgs.			29.0 29.3 31.0

30
35
40
45
50
55
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C C JOHNSON & MALHOTRA, P.C.

SOIL BORING LOG

WELL INSTALLATION AND COMPLETION DATA

Client : DOVER AFB
Well No. : MW 211D
Total Depth : 48.5'
Casing Size & Type : 2' PVC

Site : T-1
Location : 100' SW OF SIT
Screen Length : 10'
Field Geo./Eng. : KL

Job No. : 5152-00
Driller : MATHES
Ground Elev. : 21.92'
Org. Vap. Instr. : HNU

Date Drilled : 04/19&20/90
Method : HS AUGERS
Top of Casing Elev. : 25.00'
03/21/90

Depth (feet)	CLP Sample	Blows per 6" 140 lbs.	Screened Interval	Adv./ Recov.	Org. Vap. PPM	Sample Description	Soil Class	Color
0								Very dark
						Br silt, sand & pebbles; org mat & coal; dry	SW	Greyish
		4,18,16,12		75 %	bkg			Brown
								10YR 3/2
2						Grey f to med sand with gradationally more		
						clay at depth (trace), trace pebbles; dry	SP	Olive brown
		6,8,12,14		100 %	bkg			2.5Y 4/4
4								
						Orange and grey mottled med to crs sand with		Light gray
		na		83 %	bkg	trace clay and vc sand grading to crs sand	SW	2.5Y 7/2
						with some vc sand; dry		
6								
								Dark yellow.
		10,9,9,10		83 %	.2			Brown
						Greyish-orange med to crs round to subang		10YR 4/6
8						uniform sand with trace clay; moist	SP	
								Light grey
		6,9,8,7		83 %	.6			2.5Y 7/2
10								
						Tan f to med sand coarsening with depth		
		3,3,4,5		79 %	.6	to med to crs sand with f sand lenses, trace	SW	
						to little clay; wet		
12								
								Light
		1,3,3,9		88 %	.2			Brownish
								Grey
14						Grey med to crs round to subround sand		2.5Y 6/2
						coarsening to crs to vc sand with occ		
		4,5,6,12		na	4	med sand and trace clay lenses; wet	SP	
16								
								Light grey
		2,2,12,12		58 %	8			10YR 7/2
18						Very poorly sorted clay, sand, and pebbles.		
						Clay is in green chunks, sand and pebbles	SW	Brown
		4,2,4,6		58 %	12	are maroon; wet		7.5YR 7/2
20								

CONTINUED ON NEXT PAGE

C C JOHNSON & MALHOTRA, P.C.

Well No. : MW 211D Site : T-1 Job No. : 5152-00 Date Drilled : 04/19&20/98

Depth (feet)	CLP Sample	Blows per 6" 140 lbs.	Screened Interval	Adv./ Recov.	Org. Vap. PPM	Sample Description	Soil Class	Color
20								
		2,6,5,9		66 %	30			Yellow 10YR 7/8
22						Brown uniform round to subround crs sand coarsening to crs to vc sand with trace pebbles; wet		
		3,6,7,7		50 %	30			Yellowish Brown 10YR 5/8
24								
		5,8,6,5		58 %	20			Strong brown 7.5YR 5/8
26								
		2,5,7,11		63 %	31	Brown and orange med to crs sand with trace clay; wet		
28								
		4,4,5,7		63 %	10		SP	
30								
		3,4,6,9		63 %	15			Yellow 10YR 7/6
32						Orange fine to med sand with trace clay; wet		
		3,3,4,8		71 %	15			Strong brown 7.5YR 5/8
34								
		1,4,7,9		66 %	60			Brownish Yellow 10YR 7/6
36								
		2,8,11,14		58 %	30			Yellow 10YR 7/6
38						Orange med to crs sand with trace clay and pebbles becoming crs sand with depth; wet		
	SB 211D 38	5,8,14,12		58 %	20			
40								
		1,7,15,12		50 %	15.4			Strong brown 7.5YR 5/8
42						Orange silty clay with grey-brn lam; moist		
		2,4,5,6		71 %	bkg	Charcoal grey silty clay with light grey v fine sand lenses; moist	CL	
44								

CONTINUED ON NEXT PAGE

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C C JOHNSON & MALHOTRA, P.C.

Well No. : MW 211D Site : T-1 Job No. : 5152-00 Date Drilled : 04/19&20/98

Depth (feet)	CLP Sample	Blows per 6" 140 lbs.	Screened Interval	Adv./ Recov.	Org. Vap. PPM	Sample Description	Soil Class	Color
44						- -		
		Shelby tube				Not recorded		- -
46							CL	
	SB 211D 46	3,3,5,7		92 %	bkg	Charcoal grey silty clay with light grey v fine sand lenses; moist		Very dark Grey 10YR 3/1
48								

BOTTOM OF BORE HOLE

HTRW DRILLING LOG

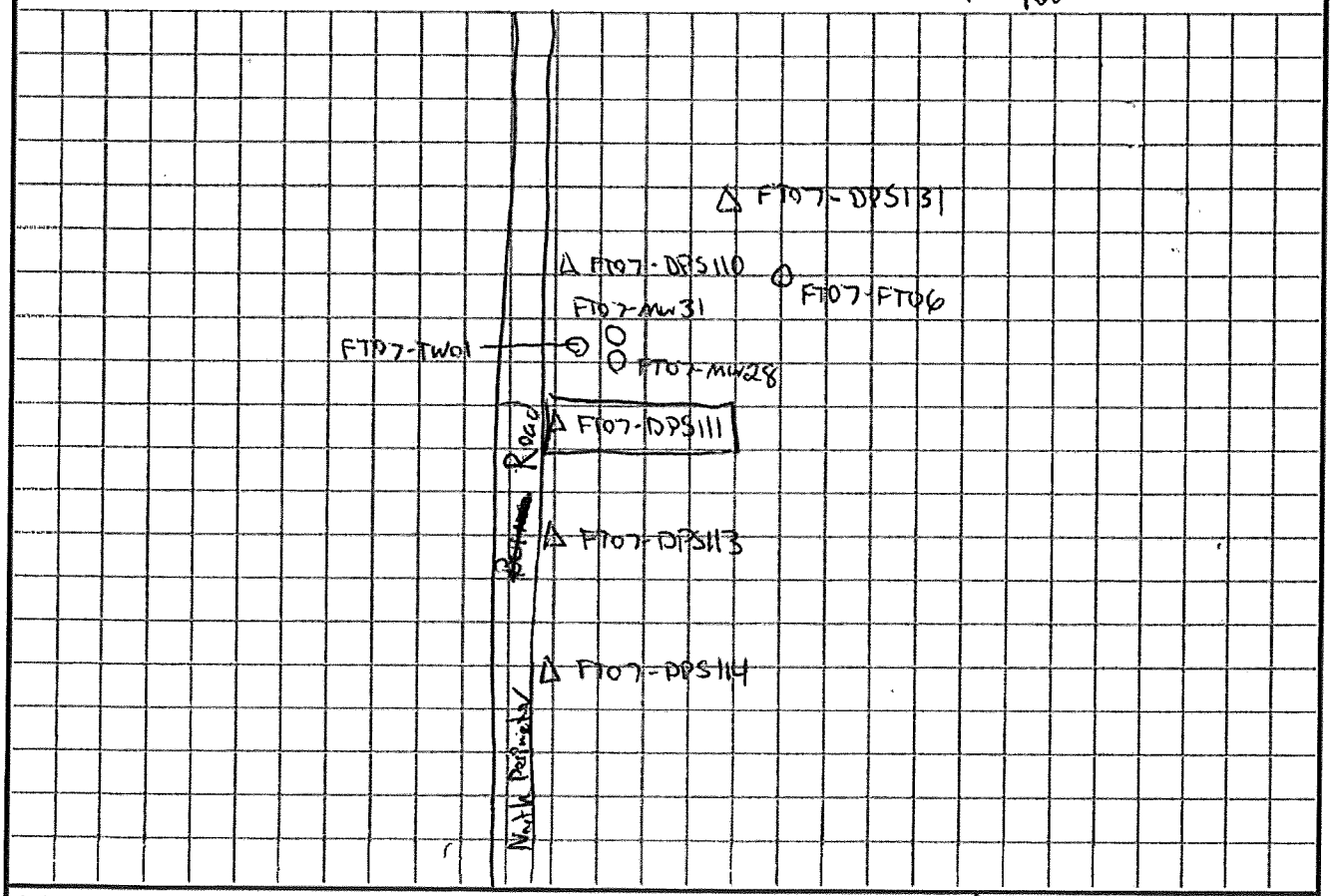
DISTRICT: Omaha		HOLE NUMBER: FT07-DPS111-65
1. COMPANY NAME: URS	2. DRILLING SUBCONTRACTOR: Columbia Technologies	SHEET 1 OF 8 SHEETS
3. PROJECT: Moody AFB Data Gaps Investigation		4. LOCATION: Moody AFB, Valdosta, Georgia
5. NAME OF DRILLER: B. Starr, B. Cochran		6. MANUFACTURER'S DESIGNATION OF DRILL: 6610 DT Geoprobe
7. SIZES AND TYPES OF DRILLING AND SAMPLING EQUIPMENT: Direct Push; 1.5" ID 2.5" OD		8. HOLE LOCATION: see sketch
		9. SURFACE ELEVATION
		10. DATE STARTED: 2/3/12 — 11. DATE COMPLETED: 2/3/12
12. OVERBURDEN THICKNESS: NA		15. DEPTH GROUNDWATER ENCOUNTERED: 15.5'
13. DEPTH DRILLED INTO ROCK: NA		16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING: NA
14. TOTAL DEPTH OF HOLE: 65.0'		17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY): NA

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES
1	NA	(1)	NA

20. SAMPLES FOR CHEMICAL	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY
6	(2) VOC	NA	(2) PH	(2) TOC	(2) Bulk Cap	N/A %

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
Abandoned	Bentonite	NA	(2) % Moisture	

LOCATION SKETCH/COMMENTS — SCALE: 1" = 100'



PROJECT	HOLE
Moody AFB Data Gaps Investigation	FT07-DPS111-65

ENG FORM 5056-R, AUG 94 (Proponent: CECW-EG)

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE: FT07-DPS111-65

PROJECT: Moody AFB Data Gaps Investigation

Inspector: Kevin Myers

SHEET 2 OF 4 SHEETS

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO. e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
	1	Silty SAND (SM) - Loose, moist, brownish grey fine grained sand, trace organics (roots) (top 6")	Field Screening (FS) = ND				Time: 0823
		- Becomes, tan and grey 10'	Breathing Zone (BZ) = ND				Recovery (R) = 38"/60"
							Pocket Penetrometer (N) =
	2	- Becomes with clay ~ 10%	FS: 0.0 ppm ↓ 14.7 168 202 373				Hydrocarbon odor (Strong)
	3	Sandy SILT (ML) Very silt, wet, grey, fine grained sand, trace clay ~ 15%, low plastic	545 285 502				N = <500 Perched water @ 2.9' to 10.45'
	4						
	5	- Becomes light brown					
		- Becomes black and grey					
	6	- Becomes light brownish grey,	FS: 50 ppm ↓ 243 821 108 513 327		FT07-DPS111-6 + (FT07-DPS111-0) (2) %M TOC		Time = 0831
		- Becomes with more clay (~ 25%)					R = 54"/60"
							Hydrocarbon odor (Strong)
	7	Sandy and Clayey SILT (ML) Very soft, wet, grey and tan, low plastic, fine grained sand	126 809 92				N = <500
	8	- Becomes soft	77 192				N = 600
		- Becomes moist to wet	0.0 13				
	9	- Becomes moist, medium stiff	0.0				N = 1200
		- Becomes stiff, with dark reddish and grey color	7.2				N = 2500
	10		0.0 BZ = ND				

Project: Moody AFB Data Gaps Investigation

HOLE NO. FT07-DPS111-65

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE: FT07-DPS111-65

PROJECT: Moody AFB Data Gaps Investigation

Inspector: Kevin Meyer

SHEET 3 OF 8 SHEETS

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO. e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
		Sandy SILT(ML) Soft, wet, grey, fine grained sand, low plastic, trace clay (≈ 12%)	FS= 100 ppm ↓ 783 ↓				Time: 0840 N= 700 R= 58"/60"
	11	Sandy and clayey SILT(ML) very stiff, moist, grey, low plastic, fine grained sands, some dark reddish banding,	95 82 49 51 71				Strong hydrocarbon odor
	12	-Becomes grey and tan	70 102				
		-Becomes grey	295 29 22 26 49				
	13		14.6 35.6 42				
	14	Becomes with SILT pockets reddish tan, non plastic Becomes with no SILT pockets @ 14.45'	BZ=ND				
	15	-Becomes moist to wet					
▽		Silty SAND (SM) Loose, ~~moist~~ wet, grey, fine grained sand, trace clay (≈ 12%)	FS= 78 ppm 215 70		FT07-DPS111-17 FT07-DPS611-17 PH TOC Bulking Capacity		Time: 0849
	16	-Becomes with clay (≈ 15%)	14.5 6.8 324				R= 56"/60"
	17	CLAY (CH) Stiff, moist, grey and greenish grey, highly plastic, trace silt ≈ 10%, trace fine grained sand (≈ 10%)	109 1.4 0.0 BZ=ND				N= 3300
	18	Silty and Sandy CLAY (CL) Soft, moist, grey, fine grained sand, low plastic Pockets/Seams with more sand ≈ 40%	5.8 113 27.3				N= 600
		-Becomes medium stiff	22.9 11.4				N= 1200
	19	-Becomes grey and reddish brown	79.2 37.9				
		-Becomes with Iron staining (dark reddish)	0.0				
	20		↓				

Project: Moody AFB Data Gaps Investigation

HOLE NO. FT07-DPS111-65

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE: FT07-DPSIII-65

PROJECT: Moody AFB Data Gaps Investigation

Inspector: Kevin Meyer

SHEET 4 OF 8 SHEETS

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO. e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
	21	Silty SAND (SM) Dense, moist, gray brown, fine to medium grained; trace clay (≤ 5%)	FS = 10 ppm				Time = 0855
		Silty CLAY (CL) - stiff, moist, gray and greenish gray, medium Plastic, trace fine grained sand (≤ 5%) with Hard - Becomes highly plastic (CH)	6% ↓ 15 34				N = 3100
		Sandy SILT (ML) - Stiff, moist, dark reddish and brown, non plastic fine to medium grained sand	0.0 ↓				R = 34"/60"
	22	Sandy CLAY (SC) - stiff, moist, gray, reddish brown / medium grained, fractured, low plastic	BZ = ND	FT07-DPSIII-22 Geotech			N = 2700
		~~Sandy SILT (ML) - Same as 20.5' to 21.2', with more sand~~					Changes based on geotechnical results for FT07.
		~~Silty SAND (SM) - Same as 20.00' to 20.35', grayish brown~~					
		~~Sandy SILT (ML) - Same as 20.5' to 21.2', slightly fractured, red brown~~					
	23						
	24						
	25	CLAY (CH) Stiff, moist, tan to brown, highly plastic, trace fine grained sand (≤ 5%)	FS = ND				N = 3100 Time = 0911
		SAND (SP) Dense, wet, fine to medium grained, whitish gray	BZ = ND				R = 38"/60"
	26	Sandy CLAY (SC) - Stiff, moist, gray, greenish gray, and tan, medium plastic					N = 2800
		Sandy SILT (ML) - stiff, moist, reddish brown,					
	27	Silty SAND (SM) and CLAY (CH) (SM-CH) stiff clay, medium dense sand, moist, greenish gray clay, white and tan sand, fine to medium grained sand, highly plastic clay					N = 2900
	28	(CH) layers					
	29						
	30						

Project: Moody AFB Data Gaps Investigation

HOLE NO. FT07-DPSIII-65

ENG FORM 5056-R, AUG 94

(Proponent: CECW-EG)

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE: FT07-DBSIII-65

PROJECT: Moody AFB Data Gaps Investigation

Inspector: Kevin Meyer

SHEET 5 OF 8 SHEETS

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO. e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
	31	Sandy CLAY(SC) - Medium stiff, moist, greenish grey to tan, dark red; fine to medium grained, mottled, banded, laminated	FS=ND BZ=ND				Time = 0938 N=1400 R=27"/60" N=3000
		CLAY(CH) Stiff, moist, tannish brown, highly plastic, trace silt (≤2%), trace fine grained sand (≈2%)					
	32	Silty SAND (SM) - Medium dense, moist, tannish grey, fine to medium grained sand, trace clay (≈8%)					
		- Becomes reddish brown, with more clay (≈12%), mottled and laminated					
		Sandy SILT (ML) Medium stiff, moist, reddish brown, fine grained sand, low plastic, stratified layers					N=1400
	33						
	34						
	35						
		CLAY(CH) Stiff, moist, tan and greenish grey, highly plastic	FS=ND BZ=ND				Time=0957 N=2800 R=24"/60"
	36						
		Silty SAND (SM) Dense, moist, tannish grey, fine to medium grained, with clay (≈15%)					
		- Becomes grey, with no clay					
	37						
	38						
	39						
	40						

Project: Moody AFB Data Gaps Investigation

HOLE NO. FT07-DBSIII-65

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE: FT07-DPSIII-65

PROJECT: Moody AFB Data Gaps Investigation

Inspector: Kevin Meyer

SHEET 6 OF 8 SHEETS

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO. e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
	41	Silty SAND (SM) Medium dense, wet, grey and brown, fine to medium grained sand	PS=ND BZ=ND				Time = 1015 R= 23"/60"
		-Becomes grey					
	42	-Becomes with black staining					
	43						
	44						
	45	-Becomes medium grained, trace fine grained sand (≈ 10%), with less silt (≈ 15%)	PS=ND BZ=ND				Time = 1030 R= 34"/60"
	46						
	47						
	48						
	49						
	50						

Project: Moody AFB Data Gaps Investigation

HOLE NO. FT07-DPSIII-65

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE: FT07-DPSIII-65

PROJECT: Moody AFB Data Gaps Investigation

Inspector: Kevin Meyer

SHEET 7 OF 8 SHEETS

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO. e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
	51	Silty SAND (Sm) - Medium dense, wet, light reddish brown, fine to medium grained	BZ=ND PS=ND				Time = 1104 R= 18"/60"
		-Becomes dark reddish brown, with more SILT ≈40%, trace clay (≈10%)					
	52						
	53						
	54						
	55						
		~~Clayey silty SILT (ML)~~ / Silty CLAY (CL) - Soft, moist, greenish gray to redd sh brown, low to medium plastic, mottled	FS=ND BZ=ND				Time = 1118 N=500 R= 24"/60"
	56						
	57						
	58						
	59						
	60						

Project: Moody AFB Data Gaps Investigation

HOLE NO. FT07-DPSIII-65

ENG FORM 5056-R, AUG 94

(Proponent: CECW-EG)

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE: FT07-DPSIII-G5

PROJECT: Moody AFB Data Gaps Investigation

Inspector: Kevin Mayer

SHEET 8 OF 8 SHEETS

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO. e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
	61	Silty CLAY (CL) soft, moist, reddish light tan/greenish gray	FS = ND BZ = ND				Time = 1148 N = 700 R = 39"/60"
	62	- Becomes medium stiff, medium plastic - Becomes mottled, with SILTY (CH) fat clay nodules					
	63	Basal CLAY (CH) stiff, moist, greenish gray, highly plastic, with reddish iron staining (~~mottled~~) (speckled)					N = 3300
	64						
	65						Bottom of boring @ 65.0'
	66						
	67						
	68						
	69						
	70						

Project: Moody AFB Data Gaps Investigation

HOLE NO. FT07-DPSIII-G5

ENG FORM 5056-R, AUG 94

(Proponent: CECW-EG)

443 103

HTW DRILLING LOG

HOLE NO. FT11-MW04

1. COMPANY NAME: Ebasco	2. DRILLING SUBCONTRACTOR: ATEC	SHEET 1 OF 6 SHEETS
3. PROJECT: MYRTLE BEACH AIR FORCE BASE	4. LOCATION: FT 11	
5. NAME OF DRILLER: JEFF REID	6. MANUFACTURER'S DESIGNATION OF DRILL: Mobile B-57	
7. SIZES AND TYPES OF DRILLING AND SAMPLING EQUIPMENT: 2" S.S. Split Spoons	8. HOLE LOCATION: 15' North of MW05 (N 255090.60, E 2626005.25)	
	9. SURFACE ELEVATION: 19.97	
	10. DATE STARTED: 12/17/93	11. DATE COMPLETED: 1/5/94
12. OVERBURDEN THICKNESS: NA	15. DEPTH GROUNDWATER ENCOUNTERED	
13. DEPTH DRILLED INTO ROCK: NA	16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED	
14. TOTAL DEPTH OF HOLE: 45	17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY)	

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES
1	X		NA

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %
NA						

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
		X		

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS PID d. PPM	GEOTECH SAMPLE OR CORE BOX NO. e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
19	1	Medium to dark brown silty clay. (SC)	AH = 21.1 BZ = 0 Sam = 2.7	NS	NS	2 7 10 8	Moist 80% Rec
18	2	Tan to brown, rounded, fine grained silty sand. Fe streaks. (SM)					
17	3	Tan to brown to orange clayey, sandy silt. 20% clay (ML)	AH = 15.3 BZ = 0 Sam = 3.8	NS	NS	7 8 9 12	Moist 50% Rec
16	4						
15	5	Gray to rust to orange silty clay. (ML)	AH = 10.9 BZ = 0 Sam = 4.4	NS	NS	7 12	Moist

HTW DRILLING LOG 443 101

HOLE NO. FT11-MW04

PROJECT MBAFB

INSPECTOR James F. Allen Sr.

SHEET 2 OF 6 SHEETS

ELEV.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
						14	
				NS	NS		
4	6	AS ABOVE				11	70% Rec.
			AH: 17.9			6	WET
		(ML)	BZ = 0				50% Rec
			Sam = 29.7			8	
13	7			NS	NS		
						10	
							▽ WL
		Medium Gray, fine grained, subrounded SAND. (SM)				8	
2	8						
	9						
11							
	10						
0							
	11						
9							
	12						
8							
	13						
7							
	14	DARK GRAY COARSE SAND, with shells		NS	NS	2	WET

PROJECT MBAFB HOLE NO. FT11-MW04

HTW DRILLING LOG 443 105

HOLE NO. FT11-MW04

PROJECT MBAFB

INSPECTOR

SHEET 3 OF 6 SHEETS

EL. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
5	15	(SW)	AH = 6.4 BZ = 0 Sam = 3.4	NS	NS	0 1 1	100% Rec
-4	16	GRAY, very sticky clay High Plast., 30% silt (MH)					
-3	17	GRAY, very sticky, silty, sandy clay (MH)	AH = 8.1 BZ = 0 Sam = 4.7	NS	NS	1 2 3 7	WET 100% Rec
2	18						
	19						
0	20						
-1	21						
-2	22						
-3	23						
-4	24	Olive gray, high Plasticity, silty clay. (MH)	AH = 6.2 BZ = 0 Sam = 13.2			4 4	WET

HTW DRILLING LOG 443 106

HOLE NO. FT11-MW04

PROJECT MBAFB

INSPECTOR [illegible]

SHEET 4 OF 6 SHEETS

F.V.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
		AS ABOVE		NS	NS	5 7	100% Rec
-5	25						
-6	26						
-7	27						
-8	28	Olive gray, highly plastic clay; minor silt zones of 20-30% silty SAND. (CH)	AH = 7.2 BZ = 0 Sam = 13.2	NS	NS	2 3 8 6	WET 100% Rec
-9	29						
-10	30						
-11	31						
-12	32						
-13	33						
		DARK GRAY CLAY		NS	NS	7	WET

HTW DRILLING LOG 443 107

PROJECT: MBAFB | INSPECTOR: James D. Anderson | HOLE NO.: FT11-MW04 | SHEET 5 OF 6 SHEETS

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
-14	34	AND VFG SILTY SAND (CL)	AH = 50.2 BZ = 0 Sam = 13.2	NS	NS	8 5	
		GRAY, VFG QUARTZ SAND, some SILT (SM)				7	100% Rec
-15	35						
-16	36						
-17	37						
	38	Light gray, fine to v.f.g. quartz sand, rounded, slightly silty, some shell fragments. (SP-SM)	AH = 189 BZ = 0 Sam = 83.0	FT11-MW04 (38-40)	NS	12 12 25 35	WET 80% Rec
-19	39						
-20	40						
-21	41						
-22	42						
-23	43						

PROJECT: MBAFB | HOLE NO.: FT11-MW04

HTW DRILLING LOG 443 108

HOLE NO. FT11-MW04

PROJECT MBAFB

INSPECTOR [illegible]

SHEET 6 OF 6 SHEETS

ELEV. a.	DEPTH b.	DESCRIPTION OF MATERIALS c.	FIELD SCREENING RESULTS d.	GEOTECH SAMPLE OR CORE BOX NO e.	ANALYTICAL SAMPLE NO. f.	BLOW COUNTS g.	REMARKS h.
		Light gray, f.g., quartz sand, rounded, minor shell frag. and mica. (SM)	AH = 50.4 BZ = 0 Sam = 98.6	NS	NS	11 10	WET
-24	44	Olive gray, clay with lenses of silty sand. Bottom High Plastic clay. (OH				11 10	80% Rec
-25	45	Total Depth = 45'					

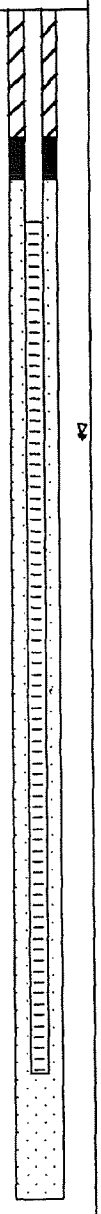
AH = Auger Hole

BZ = Breathing Zone

Sam = Split Spoon Sample

Project: BRAC NTC Orlando	**Site:** S.A. 17		**Boring No.:** OLD-17-04A
Client: SOUTHDIVNAVFACENGCOM			**Job No.:** CTO-107
Contractor: GEOTEK		**Date started:** 05/18/95	**Complted:** 05/18/95
Method: Hollow stem auger	**Casing Size:** 2 in.	**Screen Int.:** 10 ft.	**Protection level:** D
Ground Elev.:	**Type of OVM.:** Porta FID	**Total depth:** 14Ft.	**Dpth to ▽** 5 Ft.
Logged by: M. Hawes	**Well Development Date:**		**Well ID:** OLD-17-04A

Depth Ft.	Sample ID (Depth) (Type)	Split Spoon	Recovery	Headspace (ppm)	Soil/Rock Description and comments	Lithologic symbol	Soil class.	Blows/6-In.
					Limestone rock			
					QUARTZ SAND: Dark brown, fine		SP	
					QUARTZ SAND: Tan, fine, silty, good to moderate rounding		SM	
	17B00401 (4-8')							12,20
5			70%	0				24,22
								5,8
			80%	0				7,13
								4,4
			80%	0				8,9
10								4,7
			90%	0				6,7
								5,7
			90%	10				9,0
					TD			
15								



HLA-ES

Project: BRAC NTC Orlando	**Site:** S.A. 17	**Boring No.:** OLD-17-10C
Client: SOUTHDIVNAVFACENGCOM		**Job No.:** CTO 107
Contractor: Custom	**Date started:** 02/04/97	**Compltd:** 02/04/97
Method: SPT	**Casing Size:** 2 in. / **Screen Int.:** 5 ft.	**Protection level:** D
Ground Elev.:	**Type of OVM.:** FID / **Total depth:** 60Ft.	**Dpth to ▽** 8 Ft.
Logged by: JN	**Well Development Date:**	**Well ID:** OLD-17-10C

Depth Ft.	Sample ID (Depth) (Type)	Split Spoon	Recovery	Headspace (ppm)	Soil/Rock Description and comments	Lithologic symbol	Soil class.	Blows/6-in.
					Begin sample collection at base of existing OLD-17-04 boring/well.			
10			95%	0	Light gray silty fine sand, wet.		SP	7,7,8,5
			95%	0				4,4,3,2
15			10%	0				3,2,2,10
			60%	0				2,2,8,4
20			100%	0				2,2,5,5
			95%	0				8,8,2,1
			70%	0				1,1,1,2
25			100%	0	Light gray silty fine sand with clay, dry.		SP/SC	2,2,1,1
			90%	0				5,8,7,11
30			50%	0	Light gray silty fine sand, wet.		SP	4,4,8,7
			50%	0				2,4,6,8
35			45%	0				5,4,5,10

HLA-ES

Project: BRAC NTC Orlando	**Site:** S.A. 17		**Boring No.:** OLD-17-10C
Client: SOUTHDIVNAVFACENGCOM			**Job No.:** CTO 107
Contractor: Custom		**Date started:** 02/04/97	**Compltd:** 02/04/97
Method: SPT	**Casing Size:** 2 in.	**Screen Int.:** 5 ft.	**Protection level:** D
Ground Elev.:	**Type of OVM.:** FID	**Total depth:** 60Ft.	**Dpth to ▽** 8 Ft.
Logged by: JN	**Well Development Date:**		**Well ID:** OLD-17-10C

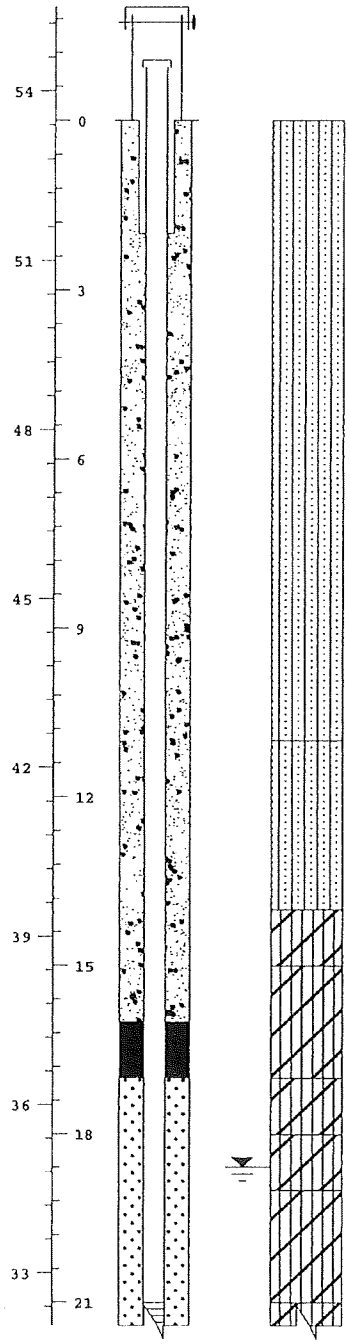
Depth Ft.	Sample ID (Depth) (Type)	Split Spoon Recovery	Headspace (ppm)	Soil/Rock Description and comments	Lithologic symbol	Soil class.	Blows/6-in.
				Continued from PAGE 1			
		45%	0			SP	8,10,14,13
		60%	0				5,4,2,4
40		70%	0				5,4,5,5
		70%	0				8,8,7,4
		60%	0				NS
45		0	0				1,2,2,4
		100%	0	Dark gray wandy clay, soft, low plasticity, hard brown nodules after 3".		SC	1,0,0,1
		100%	0				NS
50		0	0				0,0,0,0
		100%					3,2,2,1
		100%					
55		100%		Green silty clay, stiff, low plasticity (Hawthorne).		CL	8,10,13,13
		100%					
		100%		Green silty clay.		CL/SC	2,3,4,8
60				TD			
65							
70							

HLA-ES

DRILL HOLE LOG
DRILL HOLE NO.: MW-304D

PROJECT: Former Raritan Arsenal
CLIENT/OWNER: Army Corp of Engineers
HOLE LOCATION: Area 18C N:612049.71' E:534456.4'
DRILLER: SGS Drilling Services
DRILL RIG: Mobile Drill Hollow Stem Augers
DEPTH TO WATER: 18.59' (5-12-08)

PROJECT NO.: 108797
DATE: 4-29-08
GS ELEV.: 53.48'
LOGGED BY: Christopher R. Jones, Shaw E&I
HOLE DIAMETER: 6 inch, 2 inch pvc well



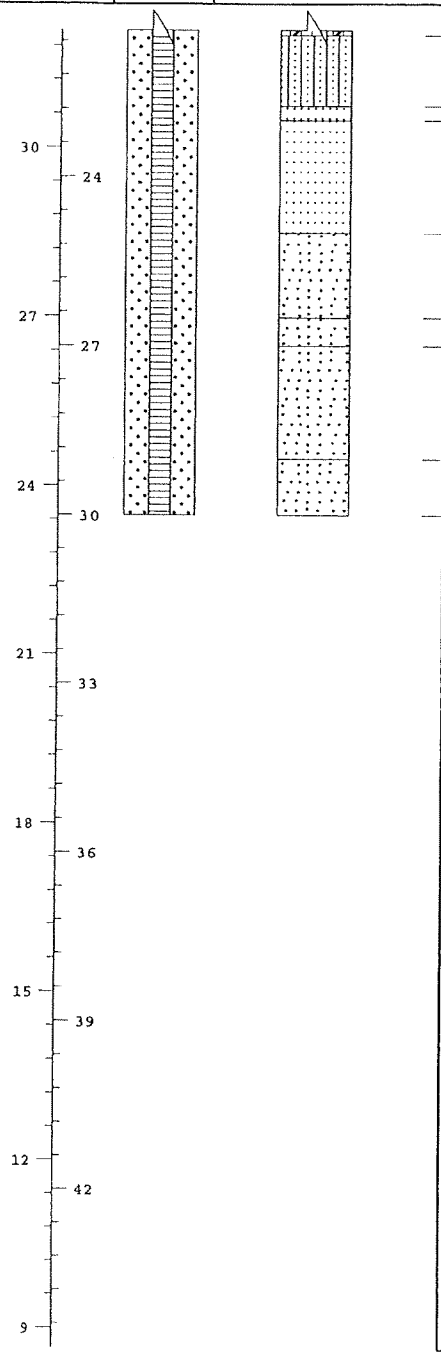
ELEVATION / DEPTH	WELL DETAILS	SOIL SYMBOLS, SAMPLER SYMBOLS AND FIELD TEST DATA	USCS	DESCRIPTION	PID	Recovery	Blow Counts
				Locking protective casing.			
				0			
			SM	Air Knife for UXO and utility clearance. Tan brown, fine to course grain sand with some silt.			
				Tan brown, fine to medium grain sand with trace coarse grain and some gravel.			
				11			
			sm	Gray silty clay.			
				14			
			CL-ML	Gray silty clay.			
				15			
			cl-ml	Collect Shelby tube from 15 to 17 feet.			
				Top of bentonite seal.			
				17			
			cl-ml	Start split spoons. Gray very stiff silty clay.	0	12 in	18.43.50.53
				18			
			cl-ml	Top of #00 sand (1 bag).			
				19			
			cl-ml	SAA. Top of #1 sand (6 bags).		16 in	7.16.26.33
				21			
						16 in	20.18.15.17

FIGURE NO.

DRILL HOLE LOG
DRILL HOLE NO.: MW-304D

PROJECT: Former Raritan Arsenal
CLIENT/OWNER: Army Corp of Engineers
HOLE LOCATION: Area 18C N:612049.71' E:534456.4'
DRILLER: SGS Drilling Services
DRILL RIG: Mobile Drill Hollow Stem Augers
DEPTH TO WATER: 18.59' (5-12-08)

PROJECT NO.: 108797
DATE: 4-29-08
GS ELEV.: 53.48'
LOGGED BY: Christopher R. Jones, Shaw E&I
HOLE DIAMETER: 6 inch, 2 inch pvc well



ELEVATION / DEPTH	WELL DETAILS	SOIL SYMBOLS, SAMPLER SYMBOLS AND FIELD TEST DATA	USCS	DESCRIPTION	PID	Recovery	Blow Counts
			cl-ml	SAA. Top of well screen (10 slot). 21.5			
			SM	Black-gray, silt with fine grain sand and little clay. 22.75			
			SW	Fine sand. 23	4		
			SW	SAA	0	5 in	14.10.11.9
			sp	White-gray fine to medium grain sand with gray silt. 25	0	14 in	4.9.17.25
			SP	SAA with some trace gravel. 26.5			
			sp	SAA. 27 Black wood layer.	0	20 in	27.19.15.29
			sp	White-gray fine to medium grain sand with gray silt. 29 30	0	15 in	15.27.18.36
			ch	Start of Fire clay layer. Bottom of well.			

FIGURE NO.

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP
PROJECT NAME Naval Weapons Station-Seal Beach, Site 70
LOCATION Naval Weapons Station-Seal Beach
DRILLING METHOD CME 75 Hollow Stem Auger
SAMPLING METHOD 1.5' CA-Modified Split Spoon
GROUND SURFACE ELEVATION (FT MSL)
TOP OF CASING ELEVATION (FT MSL)
LOGGED BY Kristeen Bennett
REMARKS

BORING/WELL NUMBER AMW1
DATE DRILLED 9/5/07
CASING TYPE/DIAMETER 4" Schedule 40 PVC
SCREEN TYPE/SLOT 4" Schedule 40 PVC 0.010-slot Slotted Screen
GRAVEL PACK TYPE #2/16 Monterey Sand
GROUT TYPE/QUANTITY Neat Cement Grout / Medium Bentonite Chips
STATIC WATER LEVEL (FT BELOW TOC)
GROUND WATER ELEVATION (FT MSL)

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH
						3" Asphalt cored (18" diameter)	0.2
						Hand augered to 5 feet bgs for utility clearance.	0.7
						~0.5' of road base (Silty Sand-Gravel mixture)	
				SP		1-4: SILTY SAND: Olive brown (2.5Y3/1); 60% fine to coarse, poorly graded, angular to subround sand; 30% micaceous silt; 10% clay, in "balls".	
			5				5.0
0.0/0.0	1,1, 3,4	20.4"/24"				5-7: CLAY: Very dark gray (2.5Y3/1); 95% moderately plastic clay; 5% micaceous silt; wet.	
0.0/0.0	8,8, 7,13	24"/24"		CH		7-8: Similar to above with plant and wood fragments.	
						8-9: Similar to above with Dark gray clay "balls"	
0.0/0.0	1,1, 3,4	24"/24"				9-9.6: Similar to above with layer of fine sand.	9.6
			10			9.6-11.2: Similar to above with transition to Dark grayish brown Silty Clay with worm casings.	
0.0/0.0	5,5, 6,9	18"/24"		CL ML		11.2-13: VERY SILTY CLAY: Light olive brown (2.5Y5/4); 60% moderately plastic clay; 30% micaceous silt; 10% fine to coarse, subangular to subround sand; <1% fine gravel; iron oxide mottling; wet; worm casings.	
0.0/0.0	3,5,7, 7,8	6"/24"				13-15: SImilar to above; wet to saturated in center.	
			15				15.0
0.0/0.0	3,5, 6,8	24"/24"				15-16.5: CLAYEY SAND: Dark olive brown (2.5Y3/3) to dark greenish gray (GLEY4/5GY); 70% fine to medium, subround sand; 20% stiff clay; 10% micaceous silt.	
0.1/0.0	11,13, 17,17	24"/24"				16.5-23: Similar to above with increasing fine sand and predominantly dark greenish gray in color. Similar to 15'-16.5'.	
0.0/0.0	3,5, 10,9	18"/24"		SP			
			20				
0.0/0.0	11,14, 11,13	20.4"/24"					
							23.0
0.4/0.0	7,10,5, 8,11	24"/24"				23-23.5: SILTY SAND: Olive brown (2.5Y4/3); 70% well graded, subangular to subround, fine sand; 30% micaceous silt; saturated.	
0.0/0.0	11,15, 17,22	24"/24"	25	SP		23.5-23.7: Dark brown (10YR3/3) sandy clay layer. 23.7-28: Similar to 23'-23.5' with some iron oxide mottling concentrated at bottom of section.	
0.0/0.0	NM	24"/24"					
							28.0
				SP			28.4
				SC		28-28.4: VERY SANDY CLAY: Light brownish gray (2.5Y6/2); 55% plastic clay; 30% fine to coarse, subangular to subround sand; 10% micaceous silt; 5%	
0.0/0.0	5,10, 11,11	24"/24"		SP SM			29.5
			30				

Continued Next Page

WELL DIAGRAM
- 4" PVC slip cap
- Concrete
- Annular Seal Borehole Diameter = 11"
- Neat Cement Grout
- 15 feet of 4" Sch 40 PVC Blank Riser
- Hydrated PureGold Medium Bentonite Chips
- #2/16 Monterey Sand Filter Pack
- 20 feet of 4" SCH 40 PVC 0.010-slot Slotted Screen with Threaded Couplings
- #2/16 Monterey Sand Filter Pack

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

CDM
111 Academy, Suite 150
Irvine, CA 92617
Phone: (949) 752-5452
Fax: (949) 725-3907

BORING/WELL CONSTRUCTION LOG

PROJECT NUMBER 50999-56254-6225.001.TK4.EQUIP **BORING/WELL NUMBER** AMW1

PROJECT NAME Naval Weapons Station-Seal Beach, Site 70 **DATE DRILLED** 9/5/07

Continued from Previous Page

PID (ppm)	BLOW COUNTS	RECOVERY (inches)	DEPTH (feet bgs)	U.S.C.S.	GRAPHIC LOG	LITHOLOGIC DESCRIPTION	CONTACT DEPTH	WELL DIAGRAM
				SP		subangular, fine gravel; saturated.		
				SC		28.4-29.5: Similar to 23.7'-28'.	31.0	
0.0/0.0	11,12, 15,17	24"/24"		SP		29.5-31: Similar to 28'-28.4', but heavilty bioturbated.		#2/16 Monterey Sand Filter Pack
				SM		31-32: Similar to 23.7'-28'.	32.0	
				SP		32-33: SImilar to 29.5'-31'.		
				SC			33.0	
0.0/0.0	4,7, 11,21	20.4"/24"		SP		33-34: Similar to 31'-32'.		
				SM			34.0	
				SP		34-34.2: Similar to above with fine to medium, subangular to subround gravel.	34.2	
0.0/0.0	4,5, 7,11	24"/24"	35	ML		34.2-35.1: VERYSANDY SILT: Olive (5Y4/3); 60% micaceous silt; 35% well graded, subround, fine sand; <10% clay; wet to saturated.	35.1	Threaded SCH 40 PVC Bottom Cap
				SP SM		35.1-37: Similar to 33'-34' with iron oxide mottling.	37.0	Slough
			40			Total Depth of Boring = 36.5 feet bgs (with slough) Total Depth of Well = 35.1 feet bgs		
			45					
			50					
			55					
			60					

SEALBEACH SEALBEACH.GPJ NEWGINT.GDT 10/24/07

VISUAL CLASSIFICATION OF SOILS

BORING NUMBER	**IW1**	PROJECT NAME	SJCA Site 21						
PROJECT NUMBER	136517	COORDINATES	N 3453248.969 E 12122836.2219				DATE		
ELEVATION	9.85	GWL	Depth		Date/Time		STARTED	5/3/2014	
LOG BY	B. Roberts		Depth		Date/Time		COMPLETED	5/3/2014	
DRILLING METHOD	Direct Push						PAGE/PAGES	1/1	

DEPTH (ft)	SAMPLE TYPE & NUMBER	RECOVERY (ft)	PID (ppm)	DESCRIPTION	USCS SYMBOL	REMARKS
1	1	2.5	0	Concrete floor		Cored
2				Gravel subbase material		
3				sandy SILT - brown	ML/SM	
4						
5						
6	2	3.0	0	clayey SILT/silty CLAY - brown, stiff, dry	ML-CL	
7				SILT and SAND - brown, wet	ML-SM	
8						
9						
10						
11	3	4.0	0	SAND - brownish orange, little silt, wet	SM/ML	
12						
13						
14						
15						
16	4	5.0	0	SAND - brown, little silt		
17						
18				SAND - gray, wet	SP	
19				CLAY - gray	CL	
20						

End of boring = 20 ft.

NOTES:

c = coarse
m = medium
f = fine
vf = very fine

ft = feet
NA= not applicable
ppm = parts per million

Drilling Contractor: Parratt Wolff
Drilling Equipment: Geoprobe 7822 DT Track Rig
Driller: A. Chapel

*The free Adobe Reader may be used to view and complete this form. However, software must be purchased to complete, save, and reuse a saved form.

File Original with DWR

State of California

Well Completion Report

Refer to Instruction Pamphlet

No. e0085465

Page 1 of 1

Owner's Well Number EW-29

Date Work Began 10/21/2008 Date Work Ended 10/22/2008

Local Permit Agency

Permit Number Permit Date

DWR Use Only – Do Not Fill In

State Well Number/Site Number

Latitude N Longitude W

APN/TRS/Other

Geologic Log

Orientation ◉ Vertical ○ Horizontal ○ Angle Specify

Drilling Method Hollow Stem Auger Drilling Fluid

Depth from Surface Feet	to Feet	Description Describe material, grain size, color, etc
0	0	Asphalt
0	2	Sandy clay - yellowish brown
2	5	Silty clay with sand - brown
5	6	Clay with silt - brown
6	9	Poorly graded sand with silt - olive brown
9	10	Clay with sand and silt - dark greenish gray
10	30	Poorly graded sand with silt - olive brown

Total Depth of Boring 30 Feet

Total Depth of Completed Well 30 Feet

Well Owner

Name US Navy Caretaker Site Office

Mailing Address Palm Avenue B-1, Suite 161

City San Francisco State CA Zip 94130

Well Location

Address Treasure Island (former naval base), EW-29

City San Francisco County San Francisco

Latitude Deg. Min. Sec. N Longitude Deg. Min. Sec. W

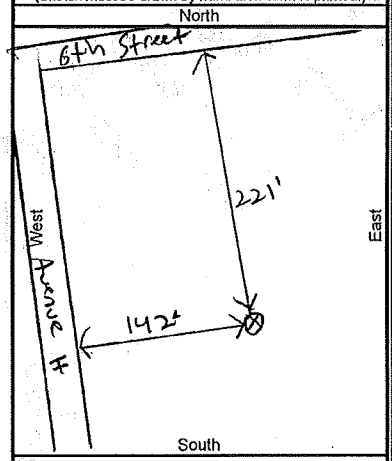
Datum Decimal Lat. Decimal Long.

APN Book Page Parcel

Township Range Section

Location Sketch

(Sketch must be drawn by hand after form is printed.)



Illustrate or describe distance of well from roads, buildings, fences, rivers, etc. and attach a map. Use additional paper if necessary. Please be accurate and complete.

Activity

◉ New Well
○ Modification/Repair
○ Deepen
○ Other
○ Destroy
Describe procedures and materials under "GEOLOGIC LOG"

Planned Uses

○ Water Supply
☐ Domestic ☐ Public
☐ Irrigation ☐ Industrial
○ Cathodic Protection
○ Dewatering
○ Heat Exchange
○ Injection
○ Monitoring
◉ Remediation
○ Sparging
○ Test Well
○ Vapor Extraction
○ Other

Water Level and Yield of Completed Well

Depth to first water 18 (Feet below surface)

Depth to Static Water Level (Feet) Date Measured

Estimated Yield * (GPM) Test Type

Test Length (Hours) Total Drawdown (Feet)

*May not be representative of a well's long term yield.

Casings

Depth from Surface Feet	to Feet	Borehole Diameter (Inches)	Type	Material	Wall Thickness (Inches)	Outside Diameter (Inches)	Screen Type	Slot Size if Any (Inches)
0	10	10	Blank	PVC Sch. 40				
10	30	10	Screen	PVC Sch. 40			slots	0.020

Annular Material

Depth from Surface Feet	to Feet	Fill	Description
0	4	Cement	
4	7	Bentonite	
7	30	Filter Pack	2/12 sand

Attachments

☑ Geologic Log
☐ Well Construction Diagram
☐ Geophysical Log(s)
☐ Soil/Water Chemical Analyses
☑ Other Site Map

Attach additional information, if it exists.

Certification Statement

I, the undersigned, certify that this report is complete and accurate to the best of my knowledge and belief

Name Shaw Environmental Inc. / WDC Exploration & Wells
Person, Firm or Corporation

4005 Port Chicago Highway Concord CA 94520
Address City State Zip

Signed CHRIS TATUM 1/29/09 283326
C-57 Licensed Water Well Contractor Date Signed C-57 License Number

DWR 188 REV. 1/2006

IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

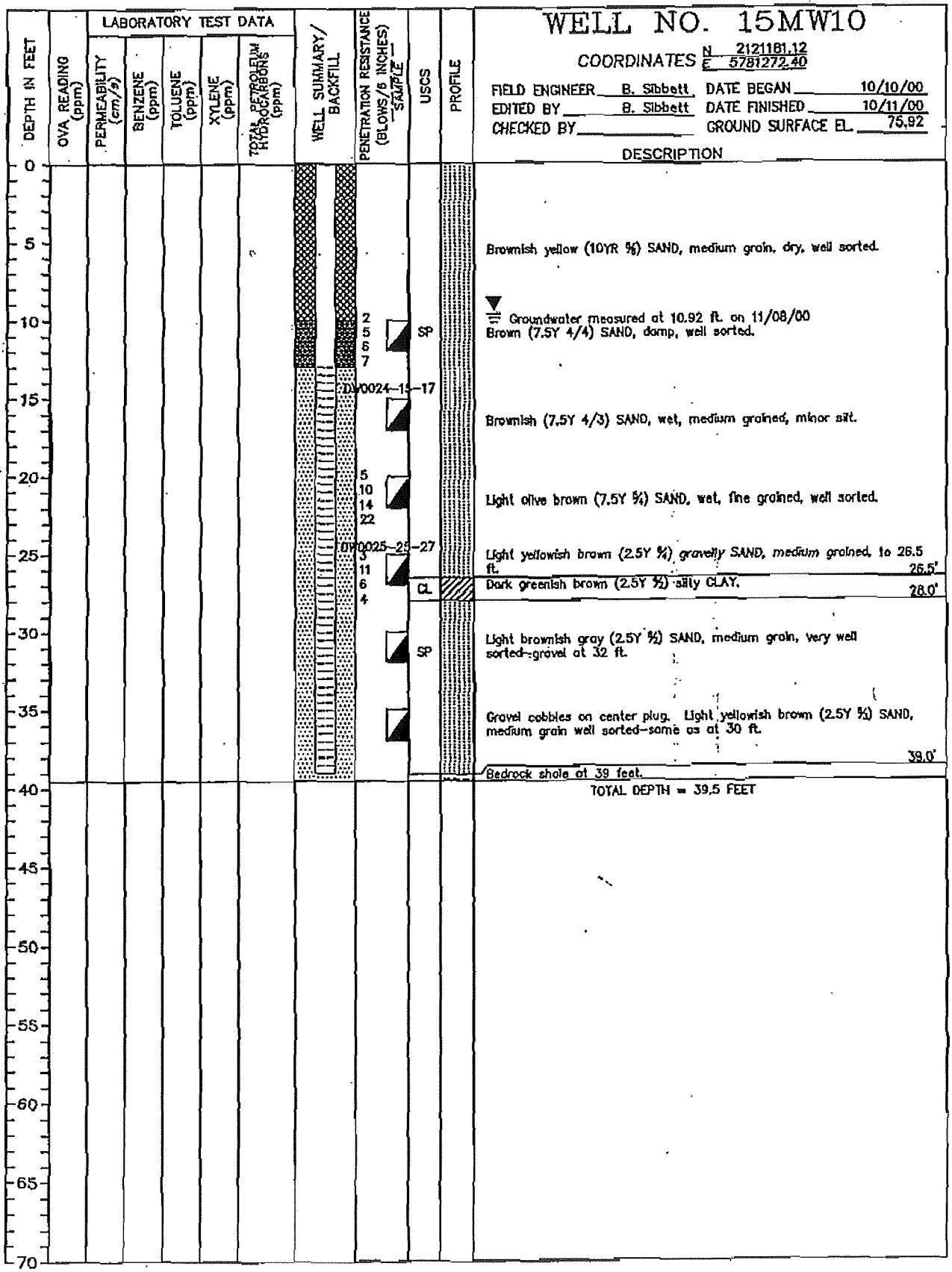
WELL NO. 15MW10

COORDINATES N 2121181.12 E 5781272.40

FIELD ENGINEER B. Sibbett DATE BEGAN 10/10/00

EDITED BY B. Sibbett DATE FINISHED 10/11/00

CHECKED BY _____ GROUND SURFACE EL. 75.92



PROJECT NO. 779480-3D210691
CLIENT: Site 15 Vandenberg AFB

SEE LEGEND FOR LOGS AND TEST PITS
FOR EXPLANATION OF SYMBOLS AND TERMS

INTERNATIONAL TECHNOLOGY CORPORATION

WELL NO. 15MW16

Project Name: Vandenberg AFB
Location: Site 15
Drill Company: Tri County Drilling
Driller: Michael Flerguson
Rig/Core: —
Method: Auger
Init. H_2O Level: —
Static H_2O Level: 9.9'
Total Hole Depth: 45'
Borehole Dia.: 12"
Fill Material: Bentonite–Cement grout
Screen Dia.: 4" Sch.40 PVC/0.02" slot
Depth Interval: 8'–43'
Casing Dia.: 4" Sch.40 PVC
Depth Interval: 0–18'
Filter Pack/Depth: #2/12 Lonestar sand/ 5.9'–45'
Seal/Depth/Type: Bentonite chips/ 1.5'–5.9'

NOTE:

COORDINATES: N 2,118,481.00 E 5,780,442.00

FIELD GEOLOGIST: B. Sibbett — DATE BEGAN: 12-3-01
EDITED BY: B. Sibbett — DATE FINISHED: 12-3-01
CHECKED BY: B. Sibbett — GROUND SURFACE EL.: 47.40'
R.G. NO.: 4443

DEPTH IN FEET	PID READING (ppm)	WELL SUMMARY/ BACKFILL	PENETRATION RESISTANCE (BLOWS/6 INCHES) — SAMPLE	USCS	PROFILE	DESCRIPTION
0–10				sp		Loose, dark brown (7.5YR 4/4) SAND, dry, medium grained, very well-sorted top soil zone to 3 ft. ▽ 8.9 ft. to water on 12-6-01 10.0'
10–20				sp		Loose, light brown (7.5YR 6/4) SAND, dry, medium grained, very well sorted, dune sand. 20.0'
20–42				sp		Loose, yellowish brown (10YR 5/4) SAND, dry, medium grained, very well sorted well rounded quartz grains. Loose, very dark grayish brown (10YR 3/2) SAND, wet, medium grained well rounded, very well sorted, quartz grains. Pet organics in the sand. 42.0'
42–45				cl		(Top of clay uncertain) Very soft, very dark gray (5Y 3/1) CLAY, strong sulfur smell. Medium dense, Gray (5Y 5/1) SHALE, thinly bedded, possibly crushed.
45–70						TOTAL DEPTH = 45.0 FEET

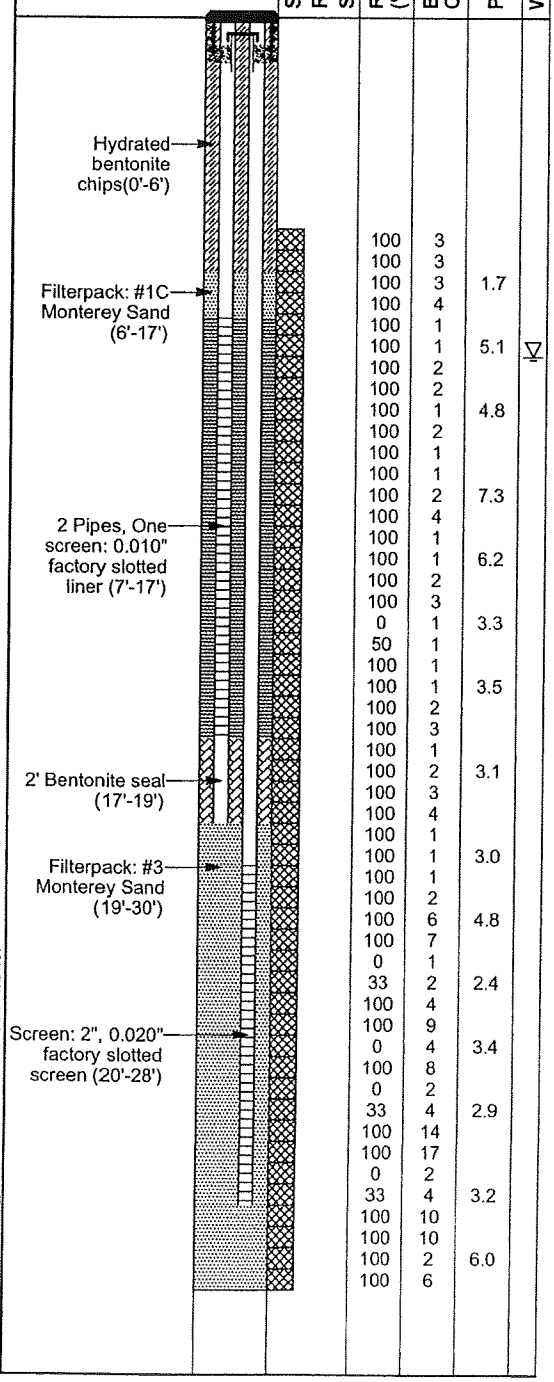
Jul 09, 2002 — 16:08:11 I:\IT CORP\VandenbergAFB\779480\LOGS\15MW16.dwg

PROJECT NO. 779480
CLIENT: VANDENBERG AFB
SEE LEGEND FOR LOGS AND TEST PITS
FOR EXPLANATION OF SYMBOLS AND TERMS

IT CORPORATION

MWH

Boring ID: **19-MW-17A/B**		Well ID: **19-MW-17A/B**	
Borehole Diam. (in.): **10.0**	Total Depth (ft): **30.0**	Project: **VAFB TO 106**	
Northing (ft):	Easting (ft):	Job Number: **1950986.06010707**	Site: **IRP Site 19**
Drill Start Date: **03-28-2006**	Start Time: **09:40**	Logged By: **GMB**	Reviewed By:
Drill Finish Date: **03-28-2006**	Finish Time: **12:00**	Drilling Contractor: **S & G Drilling**	Field Instrumentation: **PID**
Depth 1st H_2O (ft): **8.0** ▽	Date / Time: **03-28-2006 09:57**	Drill Rig Type/Method: **Hollow Stem Auger**	
Depth H_2O After Drilling (ft): **N/A**	Date / Time: **N/A**	Driller's Name: **Tim Blakeboro, Tim McNally**	
Comments:		Well Comp. Date: **03-28-2006**	Completion Time: **13:50**
Samplers: **continuous CA-modified split-spoon**		Soil Backfill Date: **N/A**	Backfill Time: **N/A**



Depth (feet)	USCS Soil Classification	Description	Recovery (%)	Blow Count/6"	PID (ppm)	Water Level	Est. % of Soil: Gravel	Coarse Sand	Med. Sand	Fine Sand	Silt/Clay
0		Surface: asphalt									
	SP	Poorly Graded Sand, reddish brown (5YR 4/3), loose, moist, no odors							70	30	
	SP-SM	Poorly Graded Sand with Silt, reddish brown (5YR 4/3), loose, moist, no odors							60	30	10
5	CL-ML	Silty Clay, black (GLEY1 2.5/N), medium stiff, moist, no odors	100	3							100
			100	3							
			100	3	1.7						
	CH	Fat Clay, yellowish brown (10YR 5/4), very soft, moist, plastic, no odors	100	4							100
			100	1							
			100	1	5.1	▽					
	MH	Elastic Silt, yellowish brown (10YR 5/4), very soft, wet, plastic, no odors	100	2							100
			100	2							
	MH	Elastic Silt, yellowish brown (10YR 5/4), very soft, plastic, no odors	100	1	4.8						100
			100	2							
10	CH	Fat Clay, dark grayish brown (10YR 4/2), very soft, moist, fat CLay, sticky, no odors	100	1							100
			100	1							
			100	2	7.3						
	CH	Fat Clay, brown (10YR 4/3), very soft, wet, no odors	100	4							100
			100	1							
			100	1	6.2						
			100	2							
	MH	Elastic Silt, brown (10YR 4/3), very soft, wet, no odors	100	3							100
			0	1	3.3						
15	CH	Fat Clay, brown (10YR 4/3), very soft, wet, no odors	50	1							100
	SM	Silty Sand, brown (10YR 4/3), loose, wet, no odors	100	1						70	30
			100	1	3.5						
			100	2							
	CH	Fat Clay, yellowish brown (10YR 5/4), medium stiff, moist, no odors	100	3							100
			100	1							
			100	2	3.1						
			100	3							
			100	4							
20	SM	Silty Sand, yellowish brown (10YR 5/4), very loose, wet, no odors	100	1						70	30
			100	1	3.0						
			100	1							
			100	2							
	SW	Well Graded Sand, light yellowish brown (10YR 6/4), medium dense, wet, no odors, trace Gravel	100	6	4.8		tr	65	25	10	
			100	7							
			0	1							
			33	2	2.4						
		Becomes finer grained at 23'	100	4				55	40	5	
			100	9							
		Becomes dark grayish brown (10YR 4/2), with occasional large Gravel at 24'	0	4	3.4			50	45	5	
25			100	8							
			0	2							
			33	4	2.9						
		Becomes dense at 26'	100	14							
			100	17							
			0	2							
			33	4	3.2						
			100	10							
			100	10							
		Becomes very coarse grained at 29'	100	2	6.0		tr	60	35	5	
		Becomes more Gravely at 30'	100	6			5	60	30	5	
30		Total depth 30'									

LOG OF BORING VAFB_TO106.GPJ MWH WC.GDT 3/21/07

DRAFT Sheet 1 of 1

Tetra Tech, Inc.
4213 State Street, Suite 100
Santa Barbara, CA 93110-2847
VOICE (805) 681-3100 FAX (805) 681-3108

Project: Site 32 Cluster Groundwater Investigation
Log of Boring No. 35-MW-30
Location: OU4, Site 32C, approximately 120 feet northwest of soil boring location 35-MIP-6.
Northing: 2130769.74 Easting: 5791152.77

Date Started: 1/19/07 Completed: 1/19/07	2" Sch. 80 PVC Blank Casing: from 23.0 ft bgs to 0.0 ft bgs
Logged By: M. Houlahan Checked By: DJH PG#6962	2" Sch. 80 PVC Screening Casing: from 33.0 ft bgs to 23.0 ft bgs
Drilled By: Ramon Zepeda / BC[2] Environmental Corp.	Bentonite/Cement Grout: from 19.0 ft bgs to 1.0 ft bgs
Drilling Equipment: CME 95 HSA	Bentonite Transitional Seal: from 21.0 ft bgs to 19.0 ft bgs
Sampling Equipment: 2" Stainless Steel CA Split Spoon Sampler	Sand Filter Pack: from 36.5 ft bgs to 21.0 ft bgs
GS Elev.: 311.68 ft above MSL TD: 36.5 ft bgs	TOC Elevation: 313.63 ft above MSL

Depth (ft. bgs)	MATERIAL DESCRIPTION	Material Symbol	Material Type	Well Construction	Sample	Blow Counts per 6"	Percent Recovery	PID (ppm) Amb/Smp	REMARKS
			SP						1330 Begin drilling.
5	Sand, pale brown (10YR 6/3), fine grained, subrounded, poorly graded, medium dense, trace silt, trace gravel [<10 mm], cemented, dry.					10 12 14	100	0.0/ 0.0	
10	As above, few clay.					12 14 18	100	0.0/ 0.0	
			SP-SC						
15	Sand with silt, brown (10YR 5/3), fine grained, subrounded, poorly graded, 10 percent silt, trace clay, dry.					16 18 21	100	0.0/ 0.0	
20									

30 ft bgs ▼ Groundwater depth during drilling.
26.5 ft bgs ▽ Groundwater depth after well development on: 03/08/2007

Graphics:\ZBORLOGS\Vandenberg\Site 32 Cluster\99062-06\35-MW-30.ai

Tetra Tech, Inc.
4213 State Street, Suite 100
Santa Barbara, CA 93110-2847
VOICE (805) 681-3100 FAX (805) 681-3108

Project: Site 32 Cluster Groundwater Investigation
Log of Boring No. 35-MW-30

Location: OU4, Site 32C, approximately 120 feet northwest of soil boring location 35-MIP-6.
Northing: 2130769.74 Easting: 5791152.77

Depth (ft. bgs)	MATERIAL DESCRIPTION	Material Symbol	Material Type	Well Construction	Sample	Blow Counts per 6"	Percent Recovery	PID (ppm) Amb/Smp	REMARKS
20	Clayey sand, dark grayish brown (10YR 4/2), fine grained, subrounded, poorly graded, 10 percent silt, slightly moist.		SC			10 12 14	100	0.0/ 0.5	
									Note - screen slot size is 0.020".
25	As above.					13 16 18	100	0.0/ 0.0	
	As above.		▽			14 18 20	100	0.0/ 0.0	
	As above. 40 percent fragments of fractured shale.						75		
	Clayey gravel with sand, grayish brown (10YR 5/2), fine gravel, subrounded, poorly graded, 25 percent clay, 15 percent sand, slightly moist.		GC						
30			SC ▽						
	Clayey sand, grayish brown (10YR 5/2), fine grained, subrounded, poorly graded, 30 percent clay, wet.		GC			50	33	0.0/ 0.2	
	Clayey gravel with sand, grayish brown (10YR 5/2), fine gravel, subrounded, poorly graded, dense, 25 percent clay, 15 percent sand, slightly moist.		SC			22 50	67		
	Clayey sand, grayish brown (10YR 5/2), fine grained, subrounded, poorly graded, 30 percent clay, wet.								
	Shale, very pale brown (10YR 7/3), dry, Sisquoc Shale.		Shale			33 50	67		
35	As above.								1510 End drilling.
40									
45									

30 ft bgs ▽ Groundwater depth during drilling.

26.5 ft bgs ▽ Groundwater depth after well development on: 03/08/2007

Appendix G: Loading Calculations

SUBSTRATE ESTIMATING TOOL FOR ENHANCED ANAEROBIC BIOREMEDIATION OF CHLORINATED SOLVENTS

Version 1.2
November 2010

Site Data Input Table

TABLE S.1 - INPUT TABLE

Calculation Tables

Table S.2 - Substrate Calculations in Hydrogen Equivalents

Table S.3 - Hydrogen Produced by Common Substrates

Table S.4 - Estimated Substrate Requirements for Hydrogen Demand

Output Summary Table

TABLE S.5 - OUTPUT TABLE

PRINT SUMMARY TABLE

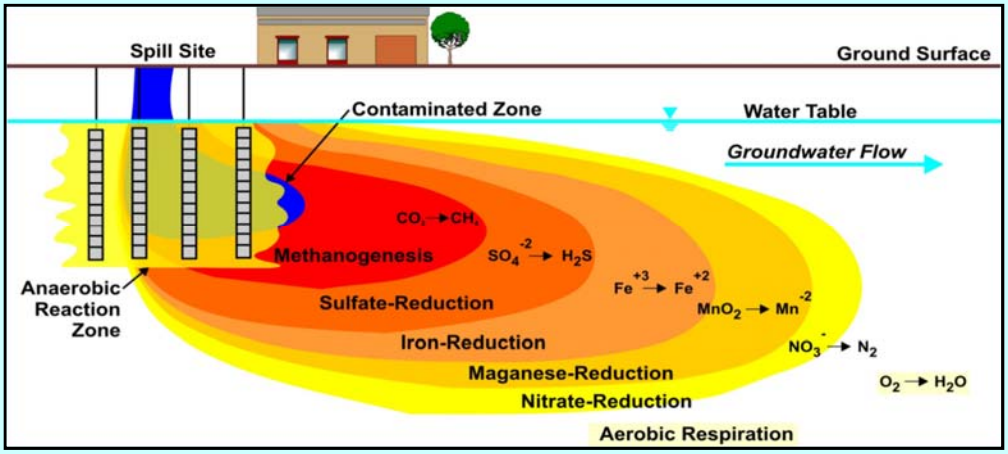


Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 1

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	60	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	140	1-1,000	feet	
Saturated Thickness	22	1-100	feet	
Treatment Zone Cross Sectional Area	1320	--	ft^2	
Treatment Zone Volume	184,800	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	345,668	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	276,535	--	gallons	
Design Period of Performance	1.4	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	0.01	.01-1000	ft/day	
Average Hydraulic Gradient	0.05	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.00	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	0.9	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	1,802	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.3	0.01 to 10	mg/L	Default = 5
Nitrate	0.22	0.1 to- 20	mg/L	Default = 1
Sulfate	5920	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.022	--	mg/L	
Trichloroethene (TCE)	15.146	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.393	--	mg/L	
Vinyl Chloride (VC)	0.004	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 1

RETURN TO COVER PAGE

1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	60	feet	18	meters
Length (parallel to groundwater flow)	140	feet	42.7	meters
Saturated Thickness	22	feet	6.7	meters
Design Period of Performance	1.42	years	1.42	years

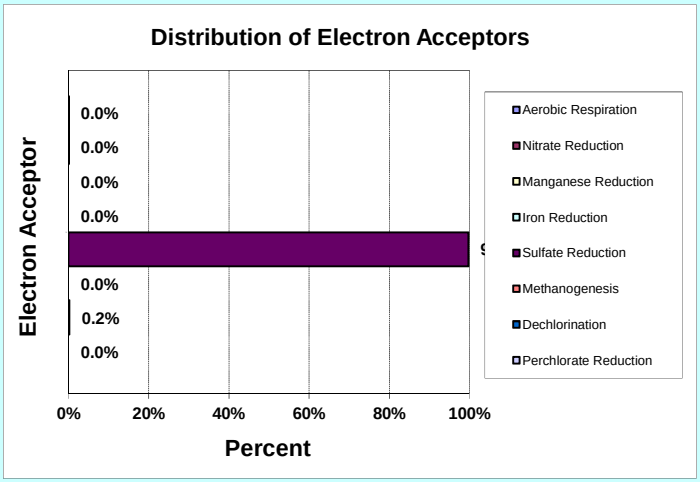
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	0.01	ft/day	3.5E-06	cm/sec
Average Hydraulic Gradient	0.05	ft/ft	0.05	m/m
Average Groundwater Seepage Velocity	0.00	ft/day	7.6E-02	cm/day
Average Groundwater Seepage Velocity	1	ft/yr	0.3	m/yr
Effective Treatment Zone Pore Volume	276,535	gallons	1,046,769	liters
Groundwater Flux (per year)	1,802	gallons/year	6,823	liters/year
Total Groundwater Volume Treated (over entire design period)	279,094	gallons total	1,056,457	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.0%	0.384
Nitrate Reduction	0.0%	0.042
Sulfate Reduction	99.8%	1157.612
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.2%	2.406
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**1160.44**

Hydrogen demand in pounds/gallon:	4.16E-03
Hydrogen demand in grams per liter:	4.98E-01



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	161,364	14,669	33,395	as lactic acid
2. Molasses Product	123,146	10,262	31,724	as sucrose
3. Fructose Product	97,243	8,682	33,402	as fructose
4. Ethanol Product	49,723	7,206	17,079	as ethanol
5. Sweet Dry Whey (lactose)	76,699	sold by pound	23,052	as lactose
6. HRC®	58,960	sold by pound	20,252	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	30,274	3,881	12,998	as soybean oil
8. Emulsified Vegetable Oil	50,456	6,469	12,998	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 1

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		14669.43659
2. Molasses Product		10262.16968
3. Fructose Product		8682.435413
4. Ethanol Product		7206.160231
5. Sweet Dry Whey (lactose)	76699.08034	
6. HRC®	58959.61468	
7. Linoleic Acid (Soybean Oil)		3881.262855
8. Emulsified Vegetable Oil		6468.771425
9. Lactoil Product		3105.010284
10. Lactic Acid Product		0
11. Hydrogen Gas	1160.44	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 2

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	180	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	40	1-1,000	feet	
Saturated Thickness	22	1-100	feet	
Treatment Zone Cross Sectional Area	3960	--	ft^2	
Treatment Zone Volume	158,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	296,287	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	237,030	--	gallons	
Design Period of Performance	1.4	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	0.01	.01-1000	ft/day	
Average Hydraulic Gradient	0.05	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.00	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	0.9	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	5,407	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.8	0.01 to 10	mg/L	Default = 5
Nitrate	0.10	0.1 to- 20	mg/L	Default = 1
Sulfate	3643	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.077	--	mg/L	
Trichloroethene (TCE)	14.646	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.087	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 2

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	180	feet	55	meters
Length (parallel to groundwater flow)	40	feet	12.2	meters
Saturated Thickness	22	feet	6.7	meters
Design Period of Performance	1.42	years	1.42	years

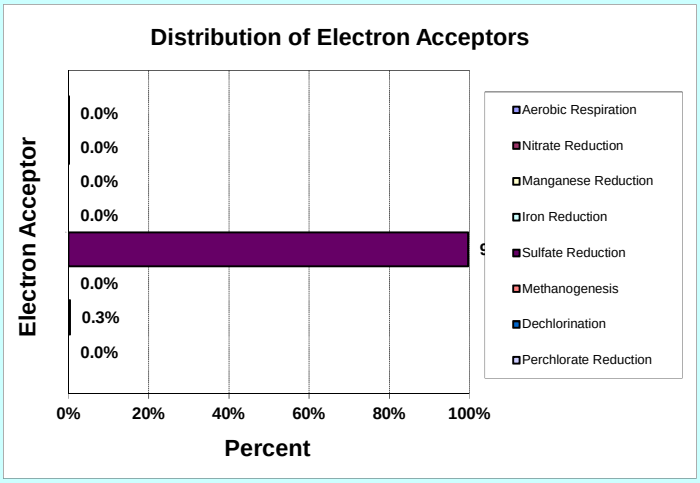
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	0.01	ft/day	3.5E-06	cm/sec
Average Hydraulic Gradient	0.05	ft/ft	0.05	m/m
Average Groundwater Seepage Velocity	0.00	ft/day	7.6E-02	cm/day
Average Groundwater Seepage Velocity	1	ft/yr	0.3	m/yr
Effective Treatment Zone Pore Volume	237,030	gallons	897,230	liters
Groundwater Flux (per year)	5,407	gallons/year	20,468	liters/year
Total Groundwater Volume Treated (over entire design period)	244,708	gallons total	926,295	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.0%	0.198
Nitrate Reduction	0.0%	0.017
Sulfate Reduction	99.6%	624.570
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.3%	2.007
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**626.79**

Hydrogen demand in pounds/gallon:	2.56E-03
Hydrogen demand in grams per liter:	3.07E-01



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	87,158	7,923	20,572	as lactic acid
2. Molasses Product	66,515	5,543	19,543	as sucrose
3. Fructose Product	52,524	4,690	20,577	as fructose
4. Ethanol Product	26,857	3,892	10,521	as ethanol
5. Sweet Dry Whey (lactose)	41,428	sold by pound	14,201	as lactose
6. HRC®	31,846	sold by pound	12,476	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	16,352	2,096	8,007	as soybean oil
8. Emulsified Vegetable Oil	27,253	3,494	8,007	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 2

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		7923.419618
2. Molasses Product		5542.917488
3. Fructose Product		4689.653803
4. Ethanol Product		3892.271595
5. Sweet Dry Whey (lactose)	41427.56228	
6. HRC®	31845.92434	
7. Linoleic Acid (Soybean Oil)		2096.39096
8. Emulsified Vegetable Oil		3493.984933
9. Lactoil Product		1677.112768
10. Lactic Acid Product		0
11. Hydrogen Gas	626.79	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 3

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	200	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	320	1-1,000	feet	
Saturated Thickness	22	1-100	feet	
Treatment Zone Cross Sectional Area	4400	--	ft^2	
Treatment Zone Volume	1,408,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	2,633,664	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	2,106,931	--	gallons	
Design Period of Performance	3.2	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	0.01	.01-1000	ft/day	
Average Hydraulic Gradient	0.05	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.00	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	0.9	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	6,008	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.46	0.1 to- 20	mg/L	Default = 1
Sulfate	1975	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.063	--	mg/L	
Trichloroethene (TCE)	9.150	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	1.649	--	mg/L	
Vinyl Chloride (VC)	0.019	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.002	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 3

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	200	feet	61	meters
Length (parallel to groundwater flow)	320	feet	97.5	meters
Saturated Thickness	22	feet	6.7	meters
Design Period of Performance	3.18	years	3.18	years

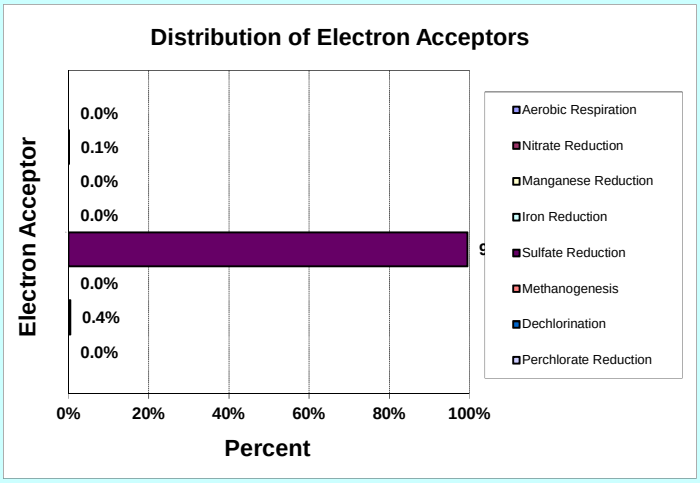
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	0.01	ft/day	3.5E-06	cm/sec
Average Hydraulic Gradient	0.05	ft/ft	0.05	m/m
Average Groundwater Seepage Velocity	0.00	ft/day	7.6E-02	cm/day
Average Groundwater Seepage Velocity	1	ft/yr	0.3	m/yr
Effective Treatment Zone Pore Volume	2,106,931	gallons	7,975,379	liters
Groundwater Flux (per year)	6,008	gallons/year	22,742	liters/year
Total Groundwater Volume Treated (over entire design period)	2,126,037	gallons total	8,047,700	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.0%	0.000
Nitrate Reduction	0.1%	2.108
Sulfate Reduction	99.5%	2941.904
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.4%	12.412
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**2956.42**

Hydrogen demand in pounds/gallon:	1.39E-03
Hydrogen demand in grams per liter:	1.67E-01



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	411,101	37,373	11,169	as lactic acid
2. Molasses Product	313,735	26,145	10,610	as sucrose
3. Fructose Product	247,744	22,120	11,171	as fructose
4. Ethanol Product	126,676	18,359	5,712	as ethanol
5. Sweet Dry Whey (lactose)	195,404	sold by pound	7,710	as lactose
6. HRC®	150,209	sold by pound	6,773	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	77,128	9,888	4,347	as soybean oil
8. Emulsified Vegetable Oil	128,546	16,480	4,347	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 3

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		37372.84436
2. Molasses Product		26144.59445
3. Fructose Product		22119.95706
4. Ethanol Product		18358.899
5. Sweet Dry Whey (lactose)	195403.7413	
6. HRC®	150209.4842	
7. Linoleic Acid (Soybean Oil)		9888.166579
8. Emulsified Vegetable Oil		16480.27763
9. Lactoil Product		7910.533263
10. Lactic Acid Product		0
11. Hydrogen Gas	2956.42	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 9

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	22	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	14	1-1,000	feet	
Saturated Thickness	22.5	1-100	feet	
Treatment Zone Cross Sectional Area	495	--	ft^2	
Treatment Zone Volume	6,930	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	12,963	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	10,370	--	gallons	
Design Period of Performance	1.3	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	4.8	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.12	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	43.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	32,443	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	3.2	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	186	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.001	--	mg/L	
Trichloroethene (TCE)	18.394	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	21.345	--	mg/L	
Vinyl Chloride (VC)	7.627	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.001	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 9

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	22	feet	7	meters
Length (parallel to groundwater flow)	14	feet	4.3	meters
Saturated Thickness	22.5	feet	6.9	meters
Design Period of Performance	1.29	years	1.29	years

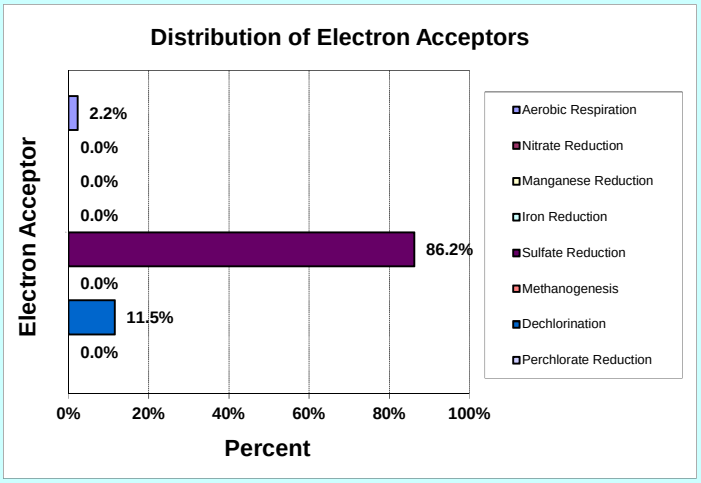
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	4.8	ft/day	1.7E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.12	ft/day	3.7E+00	cm/day
Average Groundwater Seepage Velocity	44	ft/yr	13.4	m/yr
Effective Treatment Zone Pore Volume	10,370	gallons	39,254	liters
Groundwater Flux (per year)	32,443	gallons/year	122,808	liters/year
Total Groundwater Volume Treated (over entire design period)	52,222	gallons total	197,677	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	2.2%	0.177
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	86.2%	6.809
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	11.5%	0.911
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**7.90**

Hydrogen demand in pounds/gallon:	1.51E-04
Hydrogen demand in grams per liter:	1.81E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	1,098	100	1,215	as lactic acid
2. Molasses Product	838	70	1,154	as sucrose
3. Fructose Product	662	59	1,215	as fructose
4. Ethanol Product	338	49	621	as ethanol
5. Sweet Dry Whey (lactose)	522	sold by pound	838	as lactose
6. HRC®	401	sold by pound	737	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	206	26	473	as soybean oil
8. Emulsified Vegetable Oil	343	44	473	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 9

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		99.82835101
2. Molasses Product		69.83604797
3. Fructose Product		59.08565096
4. Ethanol Product		49.03931304
5. Sweet Dry Whey (lactose)	521.9520646	
6. HRC®	401.2315725	
7. Linoleic Acid (Soybean Oil)		26.41274382
8. Emulsified Vegetable Oil		44.02123971
9. Lactoil Product		21.13019506
10. Lactic Acid Product		0
11. Hydrogen Gas	7.90	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 10

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	22	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	14	1-1,000	feet	
Saturated Thickness	22.5	1-100	feet	
Treatment Zone Cross Sectional Area	495	--	ft^2	
Treatment Zone Volume	6,930	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	12,963	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	10,370	--	gallons	
Design Period of Performance	0.3	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	4.8	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.12	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	43.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	32,443	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	273	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.024	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.404	--	mg/L	
Vinyl Chloride (VC)	0.204	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 10

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	22	feet	7	meters
Length (parallel to groundwater flow)	14	feet	4.3	meters
Saturated Thickness	22.5	feet	6.9	meters
Design Period of Performance	0.29	years	0.29	years

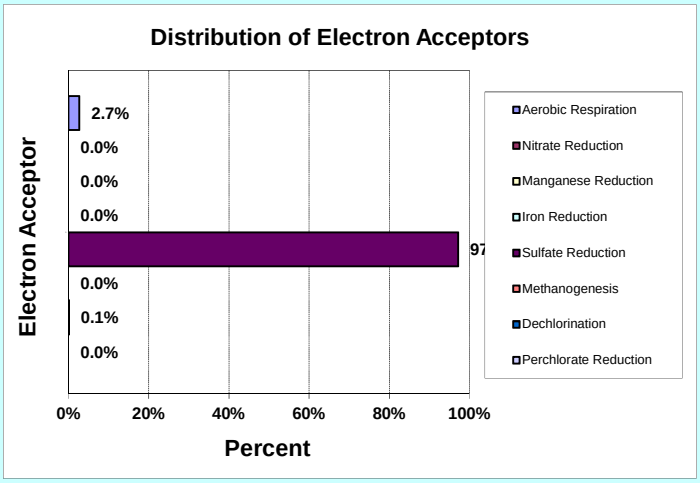
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	4.8	ft/day	1.7E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.12	ft/day	3.7E+00	cm/day
Average Groundwater Seepage Velocity	44	ft/yr	13.4	m/yr
Effective Treatment Zone Pore Volume	10,370	gallons	39,254	liters
Groundwater Flux (per year)	32,443	gallons/year	122,808	liters/year
Total Groundwater Volume Treated (over entire design period)	19,779	gallons total	74,868	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	2.7%	0.104
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	97.2%	3.776
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.1%	0.004
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**3.88**

Hydrogen demand in pounds/gallon:	1.96E-04
Hydrogen demand in grams per liter:	2.35E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	540	49	1,577	as lactic acid
2. Molasses Product	412	34	1,499	as sucrose
3. Fructose Product	326	29	1,578	as fructose
4. Ethanol Product	166	24	807	as ethanol
5. Sweet Dry Whey (lactose)	257	sold by pound	1,089	as lactose
6. HRC®	197	sold by pound	957	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	101	13	614	as soybean oil
8. Emulsified Vegetable Oil	169	22	614	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 10

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		49.10475666
2. Molasses Product		34.35178591
3. Fructose Product		29.06375276
4. Ethanol Product		24.12204057
5. Sweet Dry Whey (lactose)	256.7439897	
6. HRC®	197.3625581	
7. Linoleic Acid (Soybean Oil)		12.99221459
8. Emulsified Vegetable Oil		21.65369098
9. Lactoil Product		10.39377167
10. Lactic Acid Product		0
11. Hydrogen Gas	3.88	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 11

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	20	1-1,000	feet	
Saturated Thickness	20.5	1-100	feet	
Treatment Zone Cross Sectional Area	3485	--	ft^2	
Treatment Zone Volume	69,700	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	130,374	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	104,299	--	gallons	
Design Period of Performance	3.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	523,451	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	3	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	43.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	120.560	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	4.400	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.380	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 11

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	20	feet	6.1	meters
Saturated Thickness	20.5	feet	6.2	meters
Design Period of Performance	3.8	years	3.8	years

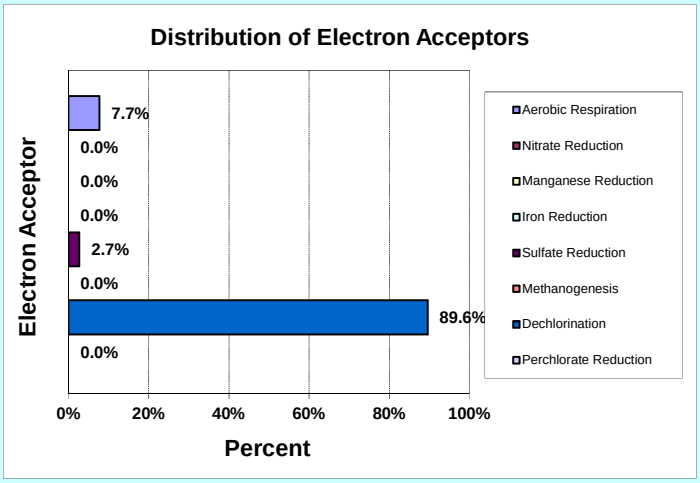
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	104,299	gallons	394,804	liters
Groundwater Flux (per year)	523,451	gallons/year	1,981,422	liters/year
Total Groundwater Volume Treated (over entire design period)	2,093,413	gallons total	7,924,208	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	7.7%	11.000
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	2.7%	3.813
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	89.6%	127.587
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**142.40**

Hydrogen demand in pounds/gallon:	6.80E-05
Hydrogen demand in grams per liter:	8.15E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	19,801	1,800	546	as lactic acid
2. Molasses Product	15,112	1,259	519	as sucrose
3. Fructose Product	11,933	1,065	546	as fructose
4. Ethanol Product	6,102	884	279	as ethanol
5. Sweet Dry Whey (lactose)	9,412	sold by pound	377	as lactose
6. HRC®	7,235	sold by pound	331	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	3,715	476	213	as soybean oil
8. Emulsified Vegetable Oil	6,192	794	213	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 11

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		1800.120235
2. Molasses Product		1259.294397
3. Fructose Product		1065.441578
4. Ethanol Product		884.2844624
5. Sweet Dry Whey (lactose)	9411.920197	
6. HRC®	7235.069649	
7. Linoleic Acid (Soybean Oil)		476.2786737
8. Emulsified Vegetable Oil		793.7977895
9. Lactoil Product		381.0229389
10. Lactic Acid Product		0
11. Hydrogen Gas	142.40	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 12

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	30	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	4080	--	ft^2	
Treatment Zone Volume	122,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	228,949	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	183,159	--	gallons	
Design Period of Performance	0.9	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	612,821	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	12	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.001	--	mg/L	
Trichloroethene (TCE)	21.560	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	6.109	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 12

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	30	feet	9.1	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	0.92	years	0.92	years

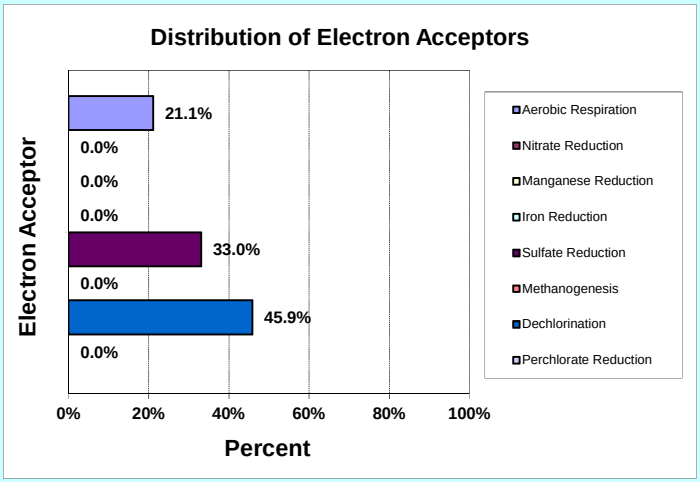
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	183,159	gallons	693,314	liters
Groundwater Flux (per year)	612,821	gallons/year	2,319,714	liters/year
Total Groundwater Volume Treated (over entire design period)	746,954	gallons total	2,827,451	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	21.1%	3.925
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	33.0%	6.149
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	45.9%	8.532
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**18.61**

Hydrogen demand in pounds/gallon:	2.49E-05
Hydrogen demand in grams per liter:	2.98E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	2,587	235	200	as lactic acid
2. Molasses Product	1,974	165	190	as sucrose
3. Fructose Product	1,559	139	200	as fructose
4. Ethanol Product	797	116	102	as ethanol
5. Sweet Dry Whey (lactose)	1,230	sold by pound	138	as lactose
6. HRC®	945	sold by pound	121	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	485	62	78	as soybean oil
8. Emulsified Vegetable Oil	809	104	78	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 12

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		235.2040596
2. Molasses Product		164.5396506
3. Fructose Product		139.2108037
4. Ethanol Product		115.5407797
5. Sweet Dry Whey (lactose)	1229.763322	
6. HRC®	945.3356061	
7. Linoleic Acid (Soybean Oil)		62.23066404
8. Emulsified Vegetable Oil		103.7177734
9. Lactoil Product		49.78453124
10. Lactic Acid Product		0
11. Hydrogen Gas	18.61	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 23

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	50	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	1200	--	ft^2	
Treatment Zone Volume	60,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	112,230	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	89,784	--	gallons	
Design Period of Performance	1.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	180,241	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	2.40	0.1 to- 20	mg/L	Default = 1
Sulfate	2	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	105.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	81.460	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	1.650	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 23

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	50	feet	15.2	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.78	years	1.78	years

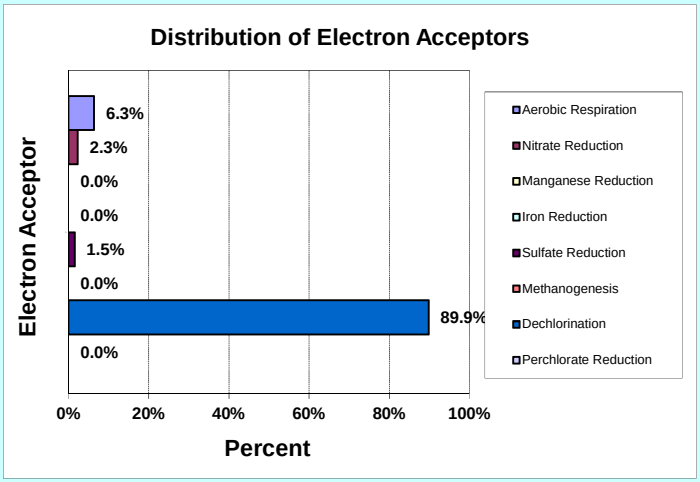
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	89,784	gallons	339,860	liters
Groundwater Flux (per year)	180,241	gallons/year	682,269	liters/year
Total Groundwater Volume Treated (over entire design period)	410,614	gallons total	1,554,298	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	6.3%	2.158
Nitrate Reduction	2.3%	0.773
Sulfate Reduction	1.5%	0.518
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	89.9%	30.575
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**34.02**

Hydrogen demand in pounds/gallon:	8.29E-05
Hydrogen demand in grams per liter:	9.93E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	4,731	430	666	as lactic acid
2. Molasses Product	3,611	301	632	as sucrose
3. Fructose Product	2,851	255	666	as fructose
4. Ethanol Product	1,458	211	340	as ethanol
5. Sweet Dry Whey (lactose)	2,249	sold by pound	459	as lactose
6. HRC®	1,729	sold by pound	404	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	888	114	259	as soybean oil
8. Emulsified Vegetable Oil	1,479	190	259	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 23

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		430.0997841
2. Molasses Product		300.881151
3. Fructose Product		254.5642141
4. Ethanol Product		211.2806406
5. Sweet Dry Whey (lactose)	2248.774702	
6. HRC®	1728.66336	
7. Linoleic Acid (Soybean Oil)		113.7964847
8. Emulsified Vegetable Oil		189.6608078
9. Lactoil Product		91.03718775
10. Lactic Acid Product		0
11. Hydrogen Gas	34.02	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 24

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	220	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	140	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	5280	--	ft^2	
Treatment Zone Volume	739,200	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,382,674	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,106,139	--	gallons	
Design Period of Performance	2.6	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	793,062	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	50	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	83.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	80.580	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 24

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	220	feet	67	meters
Length (parallel to groundwater flow)	140	feet	42.7	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	2.61	years	2.61	years

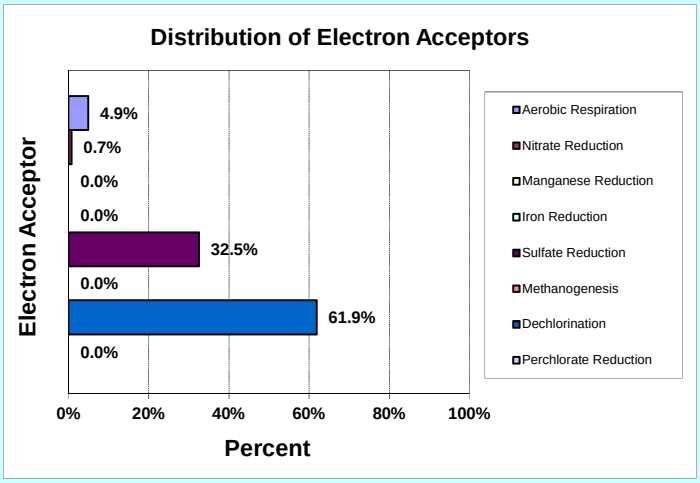
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	1,106,139	gallons	4,187,074	liters
Groundwater Flux (per year)	793,062	gallons/year	3,001,983	liters/year
Total Groundwater Volume Treated (over entire design period)	3,176,031	gallons total	12,022,249	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	4.9%	16.689
Nitrate Reduction	0.7%	2.436
Sulfate Reduction	32.5%	111.262
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	61.9%	211.976
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**342.36**

Hydrogen demand in pounds/gallon:	1.08E-04
Hydrogen demand in grams per liter:	1.29E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	47,607	4,328	866	as lactic acid
2. Molasses Product	36,331	3,028	822	as sucrose
3. Fructose Product	28,689	2,562	866	as fructose
4. Ethanol Product	14,669	2,126	443	as ethanol
5. Sweet Dry Whey (lactose)	22,628	sold by pound	598	as lactose
6. HRC®	17,395	sold by pound	525	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	8,932	1,145	337	as soybean oil
8. Emulsified Vegetable Oil	14,886	1,908	337	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 24

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		4327.878067
2. Molasses Product		3027.615876
3. Fructose Product		2561.551807
4. Ethanol Product		2126.01095
5. Sweet Dry Whey (lactose)	22628.29016	
6. HRC®	17394.671	
7. Linoleic Acid (Soybean Oil)		1145.07686
8. Emulsified Vegetable Oil		1908.461433
9. Lactoil Product		916.0614879
10. Lactic Acid Product		0
11. Hydrogen Gas	342.36	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 25

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	20	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	4080	--	ft^2	
Treatment Zone Volume	81,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	152,633	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	122,106	--	gallons	
Design Period of Performance	2.6	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	612,821	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	2.40	0.1 to- 20	mg/L	Default = 1
Sulfate	2	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	14.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	170.820	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	5.200	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 25

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	20	feet	6.1	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	2.61	years	2.61	years

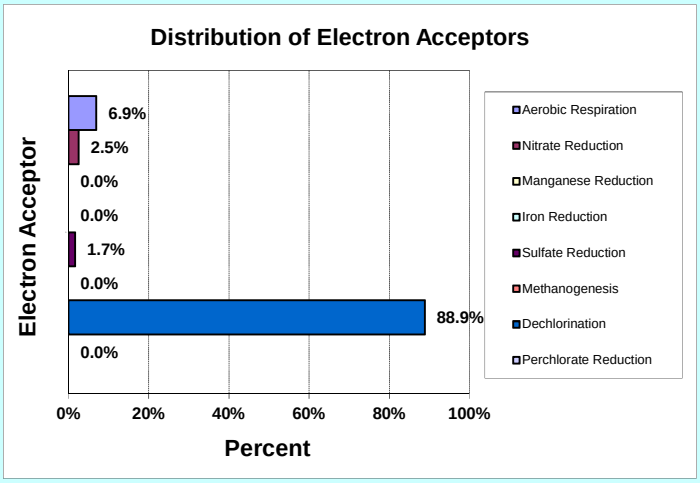
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	122,106	gallons	462,209	liters
Groundwater Flux (per year)	612,821	gallons/year	2,319,714	liters/year
Total Groundwater Volume Treated (over entire design period)	1,721,568	gallons total	6,516,663	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	6.9%	9.046
Nitrate Reduction	2.5%	3.324
Sulfate Reduction	1.7%	2.171
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	88.9%	116.467
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**131.01**

Hydrogen demand in pounds/gallon:	7.61E-05
Hydrogen demand in grams per liter:	9.12E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	18,217	1,656	611	as lactic acid
2. Molasses Product	13,903	1,159	581	as sucrose
3. Fructose Product	10,978	980	611	as fructose
4. Ethanol Product	5,613	814	313	as ethanol
5. Sweet Dry Whey (lactose)	8,659	sold by pound	422	as lactose
6. HRC®	6,656	sold by pound	371	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	3,418	438	238	as soybean oil
8. Emulsified Vegetable Oil	5,696	730	238	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 25

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		1656.107331
2. Molasses Product		1158.548547
3. Fructose Product		980.2043078
4. Ethanol Product		813.5400916
5. Sweet Dry Whey (lactose)	8658.949406	
6. HRC®	6656.250874	
7. Linoleic Acid (Soybean Oil)		438.1755106
8. Emulsified Vegetable Oil		730.2925177
9. Lactoil Product		350.5404085
10. Lactic Acid Product		0
11. Hydrogen Gas	131.01	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 26

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	20	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	4080	--	ft^2	
Treatment Zone Volume	81,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	152,633	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	122,106	--	gallons	
Design Period of Performance	2.6	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	612,821	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	0.50	0.1 to- 20	mg/L	Default = 1
Sulfate	6	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.037	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	32.196	--	mg/L	
Vinyl Chloride (VC)	10.001	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.001	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 26

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	20	feet	6.1	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	2.61	years	2.61	years

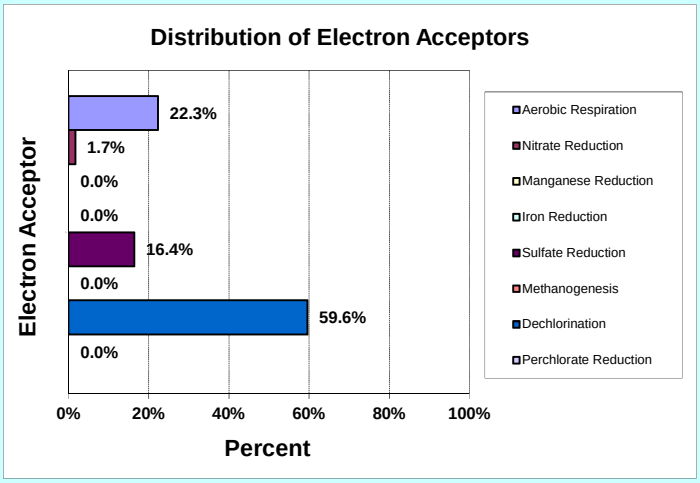
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	122,106	gallons	462,209	liters
Groundwater Flux (per year)	612,821	gallons/year	2,319,714	liters/year
Total Groundwater Volume Treated (over entire design period)	1,721,568	gallons total	6,516,663	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	22.3%	9.046
Nitrate Reduction	1.7%	0.692
Sulfate Reduction	16.4%	6.634
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	59.6%	24.157
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**40.53**

Hydrogen demand in pounds/gallon:	2.35E-05
Hydrogen demand in grams per liter:	2.82E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	5,636	512	189	as lactic acid
2. Molasses Product	4,301	358	180	as sucrose
3. Fructose Product	3,396	303	189	as fructose
4. Ethanol Product	1,737	252	97	as ethanol
5. Sweet Dry Whey (lactose)	2,679	sold by pound	131	as lactose
6. HRC®	2,059	sold by pound	115	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	1,057	136	74	as soybean oil
8. Emulsified Vegetable Oil	1,762	226	74	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 26

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		512.3481708
2. Molasses Product		358.4189369
3. Fructose Product		303.2447685
4. Ethanol Product		251.6840365
5. Sweet Dry Whey (lactose)	2678.810006	
6. HRC®	2059.237282	
7. Linoleic Acid (Soybean Oil)		135.5578936
8. Emulsified Vegetable Oil		225.9298227
9. Lactoil Product		108.4463149
10. Lactic Acid Product		0
11. Hydrogen Gas	40.53	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 62

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	54	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	34	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	1296	--	ft^2	
Treatment Zone Volume	44,064	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	82,422	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	65,937	--	gallons	
Design Period of Performance	2.5	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	194,661	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	50	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	1.928	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	3.535	--	mg/L	
Vinyl Chloride (VC)	0.029	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 62

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	54	feet	16	meters
Length (parallel to groundwater flow)	34	feet	10.4	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	2.5	years	2.5	years

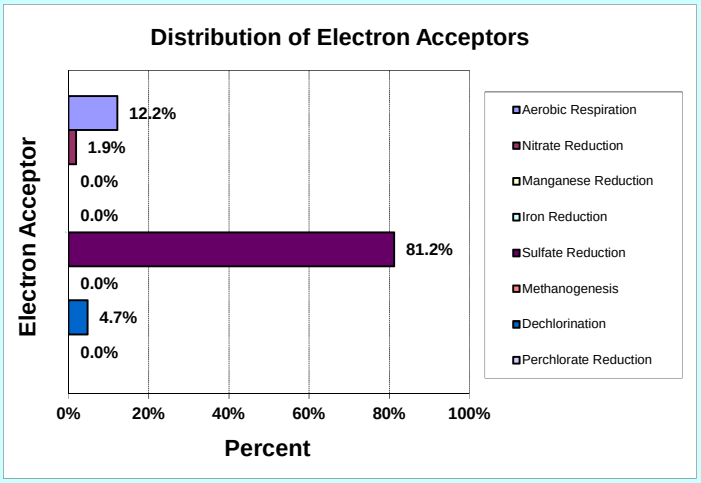
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	65,937	gallons	249,593	liters
Groundwater Flux (per year)	194,661	gallons/year	736,850	liters/year
Total Groundwater Volume Treated (over entire design period)	552,589	gallons total	2,091,719	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	12.2%	2.904
Nitrate Reduction	1.9%	0.441
Sulfate Reduction	81.2%	19.358
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	4.7%	1.129
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**23.83**

Hydrogen demand in pounds/gallon:	4.31E-05
Hydrogen demand in grams per liter:	5.17E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	3,314	301	346	as lactic acid
2. Molasses Product	2,529	211	329	as sucrose
3. Fructose Product	1,997	178	346	as fructose
4. Ethanol Product	1,021	148	177	as ethanol
5. Sweet Dry Whey (lactose)	1,575	sold by pound	239	as lactose
6. HRC®	1,211	sold by pound	210	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	622	80	135	as soybean oil
8. Emulsified Vegetable Oil	1,036	133	135	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 62

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		301.2610426
2. Molasses Product		210.7505575
3. Fructose Product		178.3081122
4. Ethanol Product		147.9903697
5. Sweet Dry Whey (lactose)	1575.141947	
6. HRC®	1210.832801	
7. Linoleic Acid (Soybean Oil)		79.70812562
8. Emulsified Vegetable Oil		132.846876
9. Lactoil Product		63.7665005
10. Lactic Acid Product		0
11. Hydrogen Gas	23.83	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 71

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	50	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	1200	--	ft^2	
Treatment Zone Volume	60,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	112,230	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	89,784	--	gallons	
Design Period of Performance	1.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	180,241	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.6	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	0	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.143	--	mg/L	
Trichloroethene (TCE)	143.467	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	35.286	--	mg/L	
Vinyl Chloride (VC)	1.965	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.002	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 71

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	50	feet	15.2	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.75	years	1.75	years

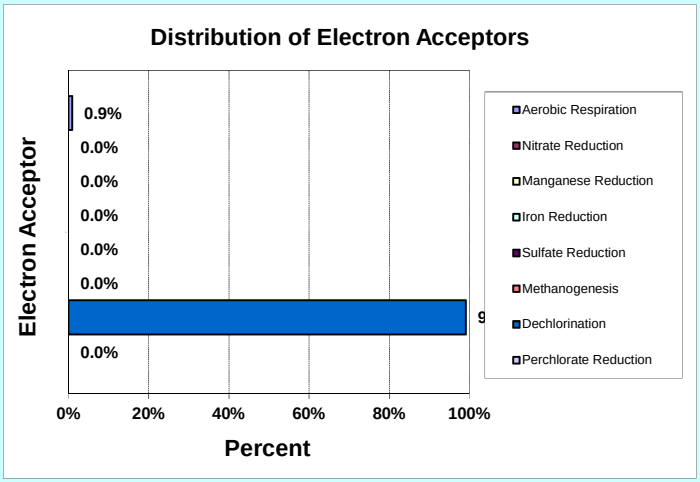
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	89,784	gallons	339,860	liters
Groundwater Flux (per year)	180,241	gallons/year	682,269	liters/year
Total Groundwater Volume Treated (over entire design period)	405,206	gallons total	1,533,830	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.9%	0.274
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	0.0%	0.000
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	99.1%	29.989
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**30.26**

Hydrogen demand in pounds/gallon:	7.47E-05
Hydrogen demand in grams per liter:	8.95E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	4,208	383	600	as lactic acid
2. Molasses Product	3,212	268	570	as sucrose
3. Fructose Product	2,536	226	600	as fructose
4. Ethanol Product	1,297	188	307	as ethanol
5. Sweet Dry Whey (lactose)	2,000	sold by pound	414	as lactose
6. HRC®	1,538	sold by pound	364	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	790	101	233	as soybean oil
8. Emulsified Vegetable Oil	1,316	169	233	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 71

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		382.5641124
2. Molasses Product		267.6270362
3. Fructose Product		226.4291595
4. Ethanol Product		187.9293916
5. Sweet Dry Whey (lactose)	2000.234666	
6. HRC®	1537.607292	
7. Linoleic Acid (Soybean Oil)		101.2194211
8. Emulsified Vegetable Oil		168.6990352
9. Lactoil Product		80.97553688
10. Lactic Acid Product		0
11. Hydrogen Gas	30.26	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 72

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	220	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	140	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	5280	--	ft^2	
Treatment Zone Volume	739,200	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,382,674	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,106,139	--	gallons	
Design Period of Performance	2.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	793,062	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	50	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.169	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	49.818	--	mg/L	
Vinyl Chloride (VC)	48.800	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 72

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	220	feet	67	meters
Length (parallel to groundwater flow)	140	feet	42.7	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	2.03	years	2.03	years

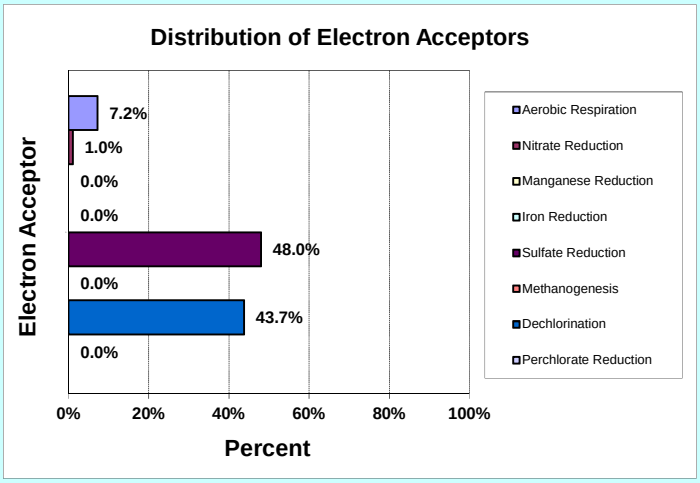
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	1,106,139	gallons	4,187,074	liters
Groundwater Flux (per year)	793,062	gallons/year	3,001,983	liters/year
Total Groundwater Volume Treated (over entire design period)	2,716,055	gallons total	10,281,099	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	7.2%	14.272
Nitrate Reduction	1.0%	2.061
Sulfate Reduction	48.0%	95.148
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	43.7%	86.677
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**198.16**

Hydrogen demand in pounds/gallon:	7.30E-05
Hydrogen demand in grams per liter:	8.74E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	27,555	2,505	586	as lactic acid
2. Molasses Product	21,028	1,752	557	as sucrose
3. Fructose Product	16,605	1,483	586	as fructose
4. Ethanol Product	8,491	1,231	300	as ethanol
5. Sweet Dry Whey (lactose)	13,097	sold by pound	404	as lactose
6. HRC®	10,068	sold by pound	355	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	5,170	663	228	as soybean oil
8. Emulsified Vegetable Oil	8,616	1,105	228	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 72

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		2504.957422
2. Molasses Product		1752.371194
3. Fructose Product		1482.615293
4. Ethanol Product		1230.526097
5. Sweet Dry Whey (lactose)	13097.15812	
6. HRC®	10067.96161	
7. Linoleic Acid (Soybean Oil)		662.7656173
8. Emulsified Vegetable Oil		1104.609362
9. Lactoil Product		530.2124938
10. Lactic Acid Product		0
11. Hydrogen Gas	198.16	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 73

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	80	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	130	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	1920	--	ft^2	
Treatment Zone Volume	249,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	466,877	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	373,501	--	gallons	
Design Period of Performance	1.3	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	288,386	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	2.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	12	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.089	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.079	--	mg/L	
Vinyl Chloride (VC)	0.023	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 73

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	80	feet	24	meters
Length (parallel to groundwater flow)	130	feet	39.6	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.26	years	1.26	years

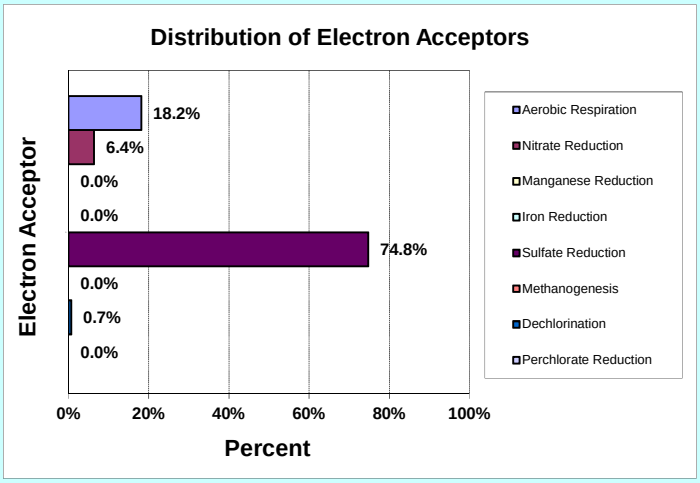
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	373,501	gallons	1,413,817	liters
Groundwater Flux (per year)	288,386	gallons/year	1,091,630	liters/year
Total Groundwater Volume Treated (over entire design period)	736,868	gallons total	2,789,271	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	18.2%	1.568
Nitrate Reduction	6.4%	0.549
Sulfate Reduction	74.8%	6.451
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.7%	0.058
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**8.63**

Hydrogen demand in pounds/gallon:	1.17E-05
Hydrogen demand in grams per liter:	1.40E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	1,199	109	94	as lactic acid
2. Molasses Product	915	76	89	as sucrose
3. Fructose Product	723	65	94	as fructose
4. Ethanol Product	370	54	48	as ethanol
5. Sweet Dry Whey (lactose)	570	sold by pound	65	as lactose
6. HRC®	438	sold by pound	57	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	225	29	37	as soybean oil
8. Emulsified Vegetable Oil	375	48	37	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 73

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		109.0443343
2. Molasses Product		76.28319291
3. Fructose Product		64.54033756
4. Ethanol Product		53.56653885
5. Sweet Dry Whey (lactose)	570.1377898	
6. HRC®	438.2725875	
7. Linoleic Acid (Soybean Oil)		28.85112332
8. Emulsified Vegetable Oil		48.08520554
9. Lactoil Product		23.08089866
10. Lactic Acid Product		0
11. Hydrogen Gas	8.63	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 74

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	80	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	40	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	1920	--	ft^2	
Treatment Zone Volume	76,800	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	143,654	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	114,924	--	gallons	
Design Period of Performance	2.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	288,386	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.8	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	2	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.241	--	mg/L	
Vinyl Chloride (VC)	0.057	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 74

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	80	feet	24	meters
Length (parallel to groundwater flow)	40	feet	12.2	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	2	years	2	years

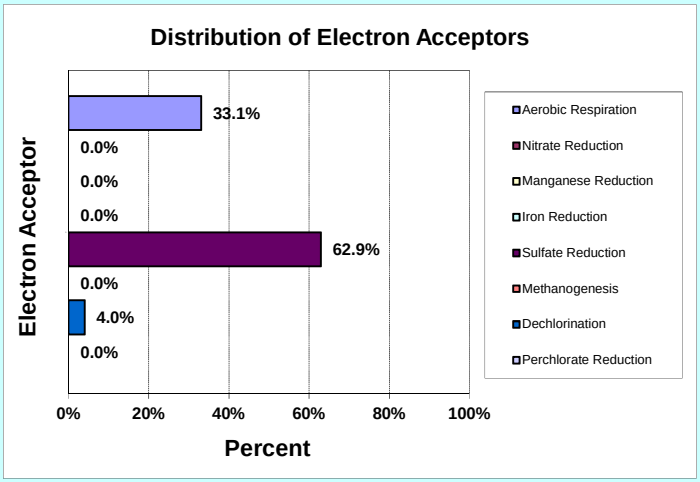
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	114,924	gallons	435,021	liters
Groundwater Flux (per year)	288,386	gallons/year	1,091,630	liters/year
Total Groundwater Volume Treated (over entire design period)	691,696	gallons total	2,618,281	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	33.1%	0.582
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	62.9%	1.107
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	4.0%	0.070
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**1.76**

Hydrogen demand in pounds/gallon:	2.54E-06
Hydrogen demand in grams per liter:	3.05E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	245	22	20	as lactic acid
2. Molasses Product	187	16	19	as sucrose
3. Fructose Product	147	13	20	as fructose
4. Ethanol Product	75	11	10	as ethanol
5. Sweet Dry Whey (lactose)	116	sold by pound	14	as lactose
6. HRC®	89	sold by pound	12	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	46	6	8	as soybean oil
8. Emulsified Vegetable Oil	76	10	8	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 74

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		22.2402854
2. Molasses Product		15.55844229
3. Fructose Product		13.16341227
4. Ethanol Product		10.92523623
5. Sweet Dry Whey (lactose)	116.2832278	
6. HRC®	89.38848125	
7. Linoleic Acid (Soybean Oil)		5.88437007
8. Emulsified Vegetable Oil		9.807283449
9. Lactoil Product		4.707496056
10. Lactic Acid Product		0
11. Hydrogen Gas	1.76	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 75

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	20	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	4080	--	ft^2	
Treatment Zone Volume	81,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	152,633	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	122,106	--	gallons	
Design Period of Performance	2.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	612,821	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	50	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	4.050	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	48.334	--	mg/L	
Vinyl Chloride (VC)	0.349	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.925	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 75

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	20	feet	6.1	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	2	years	2	years

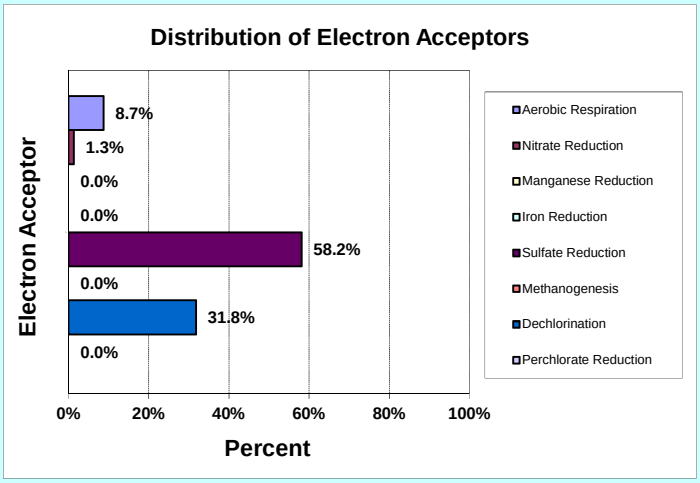
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	122,106	gallons	462,209	liters
Groundwater Flux (per year)	612,821	gallons/year	2,319,714	liters/year
Total Groundwater Volume Treated (over entire design period)	1,347,748	gallons total	5,101,637	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	8.7%	7.082
Nitrate Reduction	1.3%	1.081
Sulfate Reduction	58.2%	47.214
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	31.8%	25.794
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**81.17**

Hydrogen demand in pounds/gallon:	6.02E-05
Hydrogen demand in grams per liter:	7.22E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	11,287	1,026	484	as lactic acid
2. Molasses Product	8,614	718	460	as sucrose
3. Fructose Product	6,802	607	484	as fructose
4. Ethanol Product	3,478	504	247	as ethanol
5. Sweet Dry Whey (lactose)	5,365	sold by pound	334	as lactose
6. HRC®	4,124	sold by pound	293	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	2,118	271	188	as soybean oil
8. Emulsified Vegetable Oil	3,529	452	188	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 75

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		1026.090543
2. Molasses Product		717.8132032
3. Fructose Product		607.3147265
4. Ethanol Product		504.0529554
5. Sweet Dry Whey (lactose)	5364.909589	
6. HRC®	4124.078161	
7. Linoleic Acid (Soybean Oil)		271.4846673
8. Emulsified Vegetable Oil		452.4744455
9. Lactoil Product		217.1877338
10. Lactic Acid Product		0
11. Hydrogen Gas	81.17	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 76

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	30	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	4080	--	ft^2	
Treatment Zone Volume	122,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	228,949	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	183,159	--	gallons	
Design Period of Performance	2.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	612,821	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.8	0.01 to 10	mg/L	Default = 5
Nitrate	0.50	0.1 to- 20	mg/L	Default = 1
Sulfate	6	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.001	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	11.036	--	mg/L	
Vinyl Chloride (VC)	24.655	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 76

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	30	feet	9.1	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	2	years	2	years

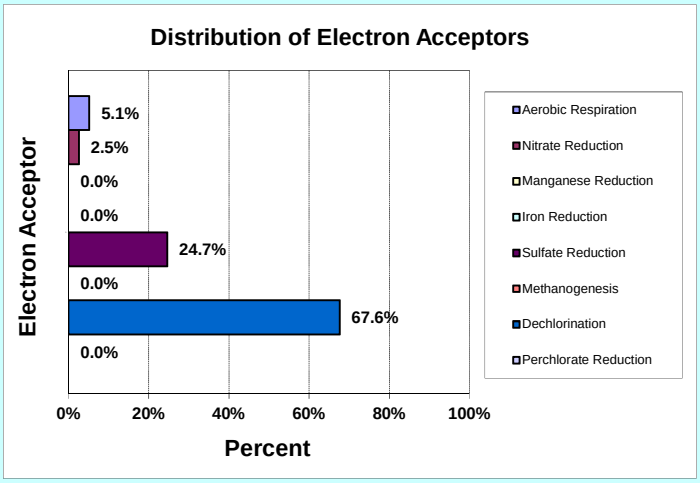
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	183,159	gallons	693,314	liters
Groundwater Flux (per year)	612,821	gallons/year	2,319,714	liters/year
Total Groundwater Volume Treated (over entire design period)	1,408,801	gallons total	5,332,742	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	5.1%	1.133
Nitrate Reduction	2.5%	0.561
Sulfate Reduction	24.7%	5.429
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	67.6%	14.894
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**22.02**

Hydrogen demand in pounds/gallon:	1.56E-05
Hydrogen demand in grams per liter:	1.87E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	3,062	278	126	as lactic acid
2. Molasses Product	2,336	195	119	as sucrose
3. Fructose Product	1,845	165	126	as fructose
4. Ethanol Product	943	137	64	as ethanol
5. Sweet Dry Whey (lactose)	1,455	sold by pound	87	as lactose
6. HRC®	1,119	sold by pound	76	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	574	74	49	as soybean oil
8. Emulsified Vegetable Oil	957	123	49	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 76

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		278.3193682
2. Molasses Product		194.7014505
3. Fructose Product		164.7295671
4. Ethanol Product		136.7205857
5. Sweet Dry Whey (lactose)	1455.19151	
6. HRC®	1118.625286	
7. Linoleic Acid (Soybean Oil)		73.63818092
8. Emulsified Vegetable Oil		122.7303015
9. Lactoil Product		58.91054473
10. Lactic Acid Product		0
11. Hydrogen Gas	22.02	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 77

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	200	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	20	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	4800	--	ft^2	
Treatment Zone Volume	96,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	179,568	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	143,654	--	gallons	
Design Period of Performance	2.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	720,966	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	0.60	0.1 to- 20	mg/L	Default = 1
Sulfate	13	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	2.993	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	13.467	--	mg/L	
Vinyl Chloride (VC)	17.592	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 77

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	200	feet	61	meters
Length (parallel to groundwater flow)	20	feet	6.1	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	2	years	2	years

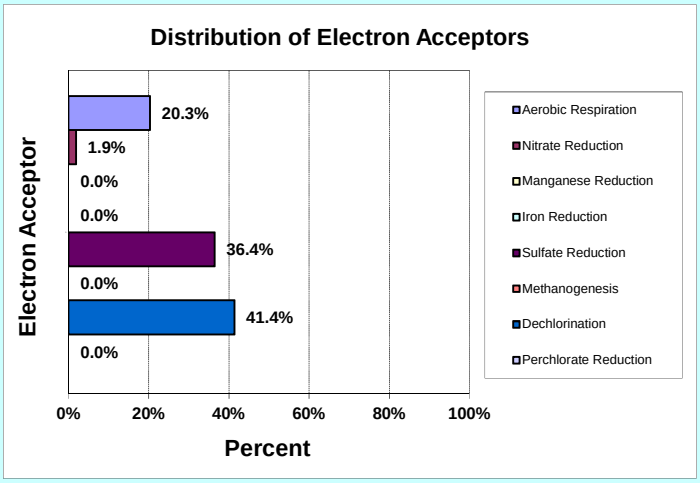
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	143,654	gallons	543,776	liters
Groundwater Flux (per year)	720,966	gallons/year	2,729,075	liters/year
Total Groundwater Volume Treated (over entire design period)	1,585,585	gallons total	6,001,926	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	20.3%	8.332
Nitrate Reduction	1.9%	0.763
Sulfate Reduction	36.4%	14.920
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	41.4%	16.952
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**40.97**

Hydrogen demand in pounds/gallon:	2.58E-05
Hydrogen demand in grams per liter:	3.10E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	5,696	518	208	as lactic acid
2. Molasses Product	4,347	362	197	as sucrose
3. Fructose Product	3,433	307	208	as fructose
4. Ethanol Product	1,755	254	106	as ethanol
5. Sweet Dry Whey (lactose)	2,708	sold by pound	143	as lactose
6. HRC®	2,081	sold by pound	126	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	1,069	137	81	as soybean oil
8. Emulsified Vegetable Oil	1,781	228	81	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 77

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		517.859732
2. Molasses Product		362.2746116
3. Fructose Product		306.5069097
4. Ethanol Product		254.3915156
5. Sweet Dry Whey (lactose)	2707.627178	
6. HRC®	2081.38943	
7. Linoleic Acid (Soybean Oil)		137.0161512
8. Emulsified Vegetable Oil		228.3602521
9. Lactoil Product		109.612921
10. Lactic Acid Product		0
11. Hydrogen Gas	40.97	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 92

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	50	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	1200	--	ft^2	
Treatment Zone Volume	60,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	112,230	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	89,784	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	180,241	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.5	0.01 to 10	mg/L	Default = 5
Nitrate	0.04	0.1 to- 20	mg/L	Default = 1
Sulfate	4	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.168	--	mg/L	
Trichloroethene (TCE)	8.090	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	60.938	--	mg/L	
Vinyl Chloride (VC)	5.220	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.002	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 92

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	50	feet	15.2	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.12	years	1.12	years

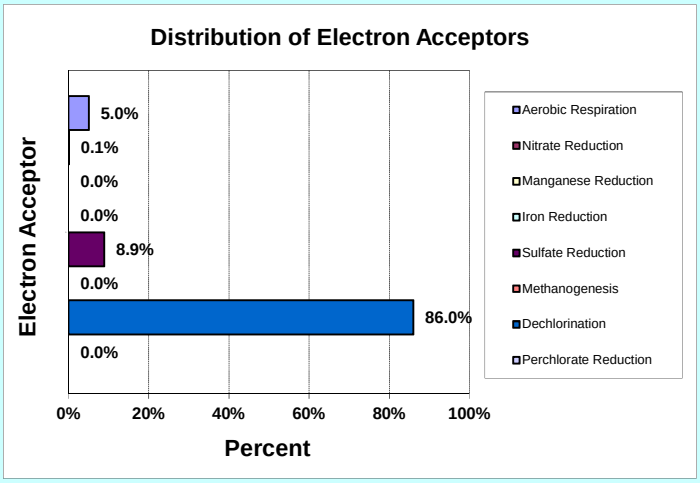
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	89,784	gallons	339,860	liters
Groundwater Flux (per year)	180,241	gallons/year	682,269	liters/year
Total Groundwater Volume Treated (over entire design period)	291,654	gallons total	1,104,001	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	5.0%	0.469
Nitrate Reduction	0.1%	0.009
Sulfate Reduction	8.9%	0.826
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	86.0%	8.001
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**9.30**

Hydrogen demand in pounds/gallon:	3.19E-05
Hydrogen demand in grams per liter:	3.82E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	1,294	118	256	as lactic acid
2. Molasses Product	987	82	243	as sucrose
3. Fructose Product	780	70	256	as fructose
4. Ethanol Product	399	58	131	as ethanol
5. Sweet Dry Whey (lactose)	615	sold by pound	177	as lactose
6. HRC®	473	sold by pound	155	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	243	31	100	as soybean oil
8. Emulsified Vegetable Oil	405	52	100	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 92

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		117.6203182
2. Molasses Product		82.28261916
3. Fructose Product		69.61622624
4. Ethanol Product		57.77937377
5. Sweet Dry Whey (lactose)	614.9772818	
6. HRC®	472.7413082	
7. Linoleic Acid (Soybean Oil)		31.1201708
8. Emulsified Vegetable Oil		51.86695134
9. Lactoil Product		24.89613664
10. Lactic Acid Product		0
11. Hydrogen Gas	9.30	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 93

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	220	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	140	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	5280	--	ft^2	
Treatment Zone Volume	739,200	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,382,674	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,106,139	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	793,062	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.6	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	0	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.003	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.621	--	mg/L	
Vinyl Chloride (VC)	0.457	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 93

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	220	feet	67	meters
Length (parallel to groundwater flow)	140	feet	42.7	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.11	years	1.11	years

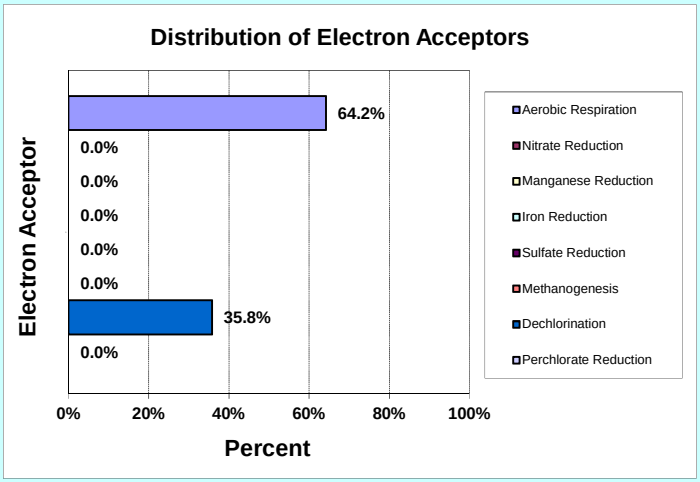
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	1,106,139	gallons	4,187,074	liters
Groundwater Flux (per year)	793,062	gallons/year	3,001,983	liters/year
Total Groundwater Volume Treated (over entire design period)	1,986,438	gallons total	7,519,275	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	64.2%	1.294
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	0.0%	0.000
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	35.8%	0.723
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**2.02**

Hydrogen demand in pounds/gallon:	1.02E-06
Hydrogen demand in grams per liter:	1.22E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	280	25	8	as lactic acid
2. Molasses Product	214	18	8	as sucrose
3. Fructose Product	169	15	8	as fructose
4. Ethanol Product	86	13	4	as ethanol
5. Sweet Dry Whey (lactose)	133	sold by pound	6	as lactose
6. HRC®	102	sold by pound	5	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	53	7	3	as soybean oil
8. Emulsified Vegetable Oil	88	11	3	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 93

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		25.49610943
2. Molasses Product		17.83609068
3. Fructose Product		15.09044482
4. Ethanol Product		12.52461529
5. Sweet Dry Whey (lactose)	133.3062885	
6. HRC®	102.4743369	
7. Linoleic Acid (Soybean Oil)		6.745801168
8. Emulsified Vegetable Oil		11.24300195
9. Lactoil Product		5.396640934
10. Lactic Acid Product		0
11. Hydrogen Gas	2.02	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 94

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	80	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	130	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	1920	--	ft^2	
Treatment Zone Volume	249,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	466,877	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	373,501	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	288,386	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.9	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	0	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.090	--	mg/L	
Vinyl Chloride (VC)	0.243	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 94

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	80	feet	24	meters
Length (parallel to groundwater flow)	130	feet	39.6	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.11	years	1.11	years

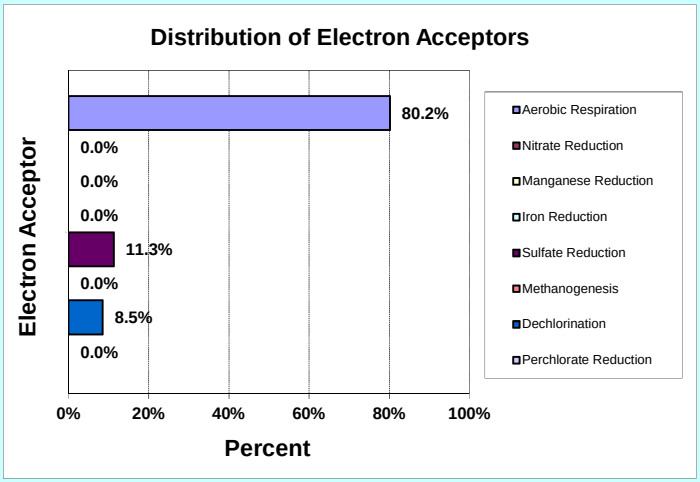
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	373,501	gallons	1,413,817	liters
Groundwater Flux (per year)	288,386	gallons/year	1,091,630	liters/year
Total Groundwater Volume Treated (over entire design period)	693,610	gallons total	2,625,527	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	80.2%	0.656
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	11.3%	0.092
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	8.5%	0.070
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**0.82**

Hydrogen demand in pounds/gallon:	1.18E-06
Hydrogen demand in grams per liter:	1.41E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	114	10	9	as lactic acid
2. Molasses Product	87	7	9	as sucrose
3. Fructose Product	69	6	9	as fructose
4. Ethanol Product	35	5	5	as ethanol
5. Sweet Dry Whey (lactose)	54	sold by pound	7	as lactose
6. HRC®	42	sold by pound	6	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	21	3	4	as soybean oil
8. Emulsified Vegetable Oil	36	5	4	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 94

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		10.34036957
2. Molasses Product		7.233722062
3. Fructose Product		6.120179897
4. Ethanol Product		5.079565223
5. Sweet Dry Whey (lactose)	54.06457374	
6. HRC®	41.56016502	
7. Linoleic Acid (Soybean Oil)		2.73587142
8. Emulsified Vegetable Oil		4.559785699
9. Lactoil Product		2.188697136
10. Lactic Acid Product		0
11. Hydrogen Gas	0.82	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 95

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	80	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	40	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	1920	--	ft^2	
Treatment Zone Volume	76,800	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	143,654	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	114,924	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	288,386	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.6	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	1	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.172	--	mg/L	
Vinyl Chloride (VC)	0.132	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 95

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	80	feet	24	meters
Length (parallel to groundwater flow)	40	feet	12.2	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.08	years	1.08	years

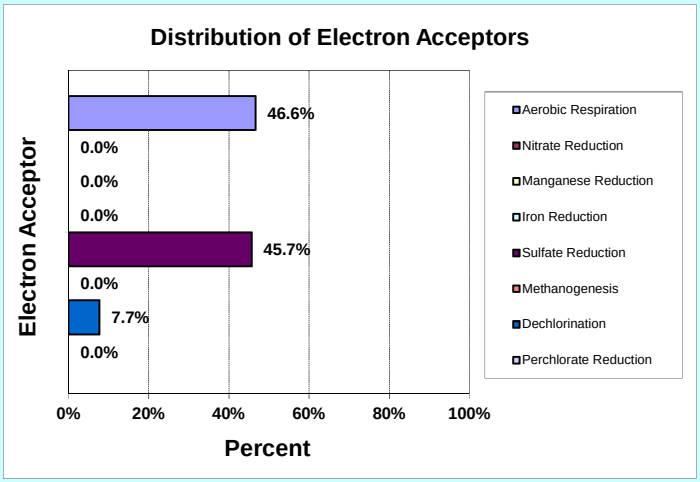
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	114,924	gallons	435,021	liters
Groundwater Flux (per year)	288,386	gallons/year	1,091,630	liters/year
Total Groundwater Volume Treated (over entire design period)	426,381	gallons total	1,613,981	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	46.6%	0.253
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	45.7%	0.248
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	7.7%	0.042
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**0.54**

Hydrogen demand in pounds/gallon:	1.27E-06
Hydrogen demand in grams per liter:	1.53E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	76	7	10	as lactic acid
2. Molasses Product	58	5	10	as sucrose
3. Fructose Product	46	4	10	as fructose
4. Ethanol Product	23	3	5	as ethanol
5. Sweet Dry Whey (lactose)	36	sold by pound	7	as lactose
6. HRC®	28	sold by pound	6	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	14	2	4	as soybean oil
8. Emulsified Vegetable Oil	24	3	4	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 95

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		6.865323417
2. Molasses Product		4.802714366
3. Fructose Product		4.063395809
4. Ethanol Product		3.372496297
5. Sweet Dry Whey (lactose)	35.89531126	
6. HRC®	27.59320857	
7. Linoleic Acid (Soybean Oil)		1.816438185
8. Emulsified Vegetable Oil		3.027396974
9. Lactoil Product		1.453150548
10. Lactic Acid Product		0
11. Hydrogen Gas	0.54	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 96

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	30	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	4080	--	ft^2	
Treatment Zone Volume	122,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	228,949	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	183,159	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	612,821	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.5	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	25	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.007	--	mg/L	
Trichloroethene (TCE)	0.006	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	1.051	--	mg/L	
Vinyl Chloride (VC)	0.211	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.014	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.007	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 96

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	30	feet	9.1	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.08	years	1.08	years

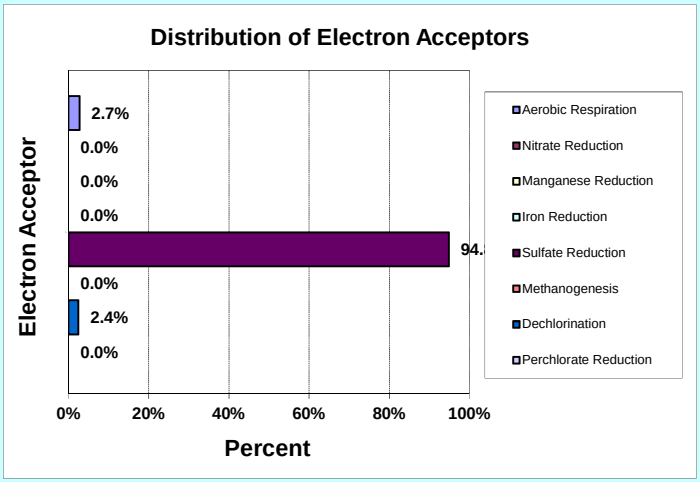
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	183,159	gallons	693,314	liters
Groundwater Flux (per year)	612,821	gallons/year	2,319,714	liters/year
Total Groundwater Volume Treated (over entire design period)	845,006	gallons total	3,198,605	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	2.7%	0.426
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	94.8%	14.860
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	2.4%	0.381
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**15.67**

Hydrogen demand in pounds/gallon:	1.85E-05
Hydrogen demand in grams per liter:	2.22E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	2,179	198	149	as lactic acid
2. Molasses Product	1,663	139	141	as sucrose
3. Fructose Product	1,313	117	149	as fructose
4. Ethanol Product	671	97	76	as ethanol
5. Sweet Dry Whey (lactose)	1,036	sold by pound	103	as lactose
6. HRC®	796	sold by pound	90	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	409	52	58	as soybean oil
8. Emulsified Vegetable Oil	681	87	58	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 96

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		198.0575349
2. Molasses Product		138.5533806
3. Fructose Product		117.224799
4. Ethanol Product		97.2930571
5. Sweet Dry Whey (lactose)	1035.542892	
6. HRC®	796.0357491	
7. Linoleic Acid (Soybean Oil)		52.40237747
8. Emulsified Vegetable Oil		87.33729579
9. Lactoil Product		41.92190198
10. Lactic Acid Product		0
11. Hydrogen Gas	15.67	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 97

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	30	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	4080	--	ft^2	
Treatment Zone Volume	122,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	228,949	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	183,159	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	612,821	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.2	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	4	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	3.623	--	mg/L	
Vinyl Chloride (VC)	18.884	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 97

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	30	feet	9.1	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.08	years	1.08	years

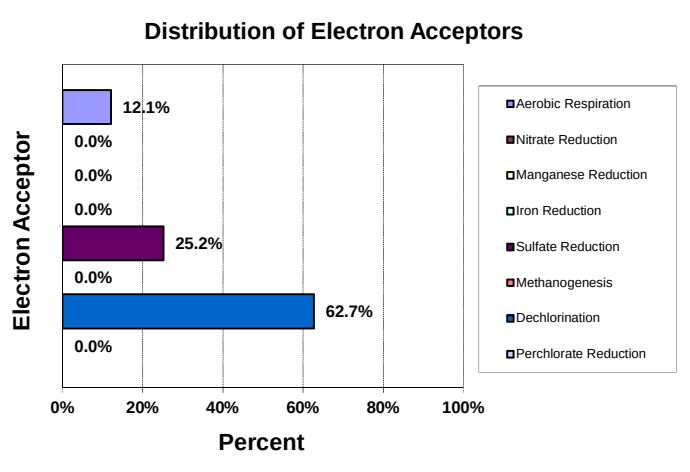
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	183,159	gallons	693,314	liters
Groundwater Flux (per year)	612,821	gallons/year	2,319,714	liters/year
Total Groundwater Volume Treated (over entire design period)	845,006	gallons total	3,198,605	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	12.1%	1.043
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	25.2%	2.173
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	62.7%	5.414
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**8.63**

Hydrogen demand in pounds/gallon:	1.02E-05
Hydrogen demand in grams per liter:	1.22E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	1,200	109	82	as lactic acid
2. Molasses Product	916	76	78	as sucrose
3. Fructose Product	723	65	82	as fructose
4. Ethanol Product	370	54	42	as ethanol
5. Sweet Dry Whey (lactose)	570	sold by pound	57	as lactose
6. HRC®	438	sold by pound	50	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	225	29	32	as soybean oil
8. Emulsified Vegetable Oil	375	48	32	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 97

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		109.0919564
2. Molasses Product		76.31650751
3. Fructose Product		64.56852379
4. Ethanol Product		53.58993257
5. Sweet Dry Whey (lactose)	570.3867818	
6. HRC®	438.463991	
7. Linoleic Acid (Soybean Oil)		28.86372326
8. Emulsified Vegetable Oil		48.10620543
9. Lactoil Product		23.09097861
10. Lactic Acid Product		0
11. Hydrogen Gas	8.63	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 98

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	30	1-1,000	feet	
Saturated Thickness	24	1-100	feet	
Treatment Zone Cross Sectional Area	4080	--	ft^2	
Treatment Zone Volume	122,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	228,949	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	183,159	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	11	.01-1000	ft/day	
Average Hydraulic Gradient	0.005	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.28	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	100.4	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	612,821	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.4	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	7	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.014	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	1.240	--	mg/L	
Vinyl Chloride (VC)	4.357	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 98

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	30	feet	9.1	meters
Saturated Thickness	24	feet	7.3	meters
Design Period of Performance	1.12	years	1.12	years

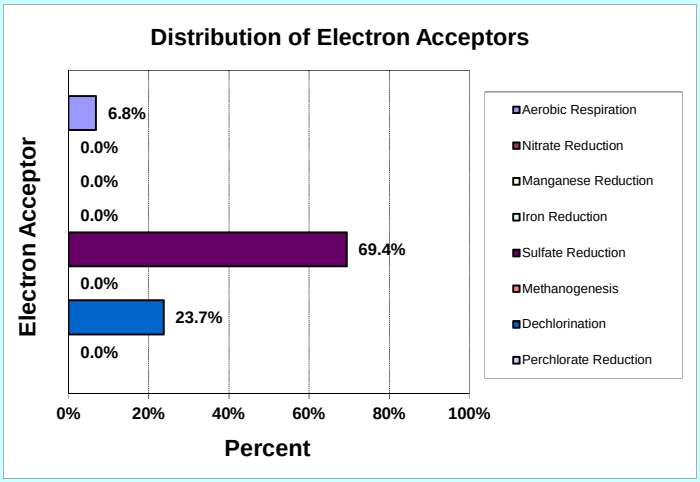
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	11	ft/day	3.9E-03	cm/sec
Average Hydraulic Gradient	0.005	ft/ft	0.005	m/m
Average Groundwater Seepage Velocity	0.28	ft/day	8.4E+00	cm/day
Average Groundwater Seepage Velocity	100	ft/yr	30.6	m/yr
Effective Treatment Zone Pore Volume	183,159	gallons	693,314	liters
Groundwater Flux (per year)	612,821	gallons/year	2,319,714	liters/year
Total Groundwater Volume Treated (over entire design period)	869,519	gallons total	3,291,394	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	6.8%	0.408
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	69.4%	4.143
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	23.7%	1.417
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**5.97**

Hydrogen demand in pounds/gallon:	6.86E-06
Hydrogen demand in grams per liter:	8.22E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	830	75	55	as lactic acid
2. Molasses Product	633	53	52	as sucrose
3. Fructose Product	500	45	55	as fructose
4. Ethanol Product	256	37	28	as ethanol
5. Sweet Dry Whey (lactose)	394	sold by pound	38	as lactose
6. HRC®	303	sold by pound	33	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	156	20	21	as soybean oil
8. Emulsified Vegetable Oil	259	33	21	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 98

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		75.44217219
2. Molasses Product		52.77642176
3. Fructose Product		44.65214349
4. Ethanol Product		37.05993599
5. Sweet Dry Whey (lactose)	394.4490432	
6. HRC®	303.2182849	
7. Linoleic Acid (Soybean Oil)		19.96060986
8. Emulsified Vegetable Oil		33.2676831
9. Lactoil Product		15.96848789
10. Lactic Acid Product		0
11. Hydrogen Gas	5.97	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 115

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	120	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	165	1-1,000	feet	
Saturated Thickness	36.5	1-100	feet	
Treatment Zone Cross Sectional Area	4380	--	ft^2	
Treatment Zone Volume	722,700	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,351,810	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,081,448	--	gallons	
Design Period of Performance	5.5	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	60	.01-1000	ft/day	
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.60	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	219.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	1,435,377	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.1	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	13	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.358	--	mg/L	
Trichloroethene (TCE)	0.437	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	2.157	--	mg/L	
Vinyl Chloride (VC)	0.056	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.785	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.865	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 115

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	120	feet	37	meters
Length (parallel to groundwater flow)	165	feet	50.3	meters
Saturated Thickness	36.5	feet	11.1	meters
Design Period of Performance	5.48	years	5.48	years

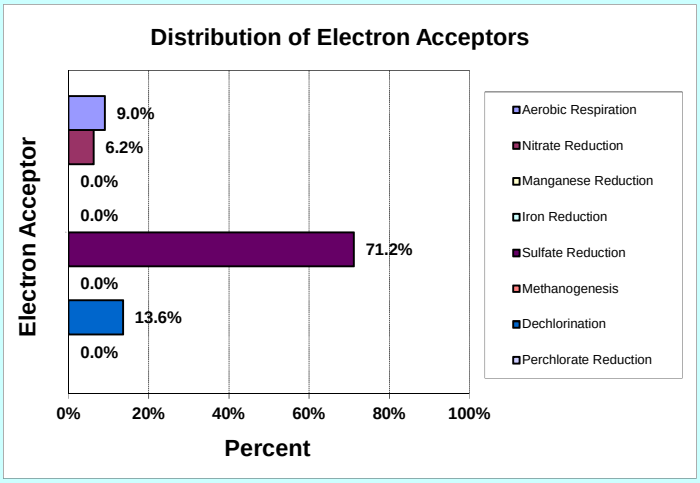
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	60	ft/day	2.1E-02	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	0.60	ft/day	1.8E+01	cm/day
Average Groundwater Seepage Velocity	219	ft/yr	66.8	m/yr
Effective Treatment Zone Pore Volume	1,081,448	gallons	4,093,613	liters
Groundwater Flux (per year)	1,435,377	gallons/year	5,433,340	liters/year
Total Groundwater Volume Treated (over entire design period)	8,947,313	gallons total	33,868,318	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	9.0%	10.306
Nitrate Reduction	6.2%	7.137
Sulfate Reduction	71.2%	81.337
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	13.6%	15.516
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**114.30**

Hydrogen demand in pounds/gallon:	1.28E-05
Hydrogen demand in grams per liter:	1.53E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	15,893	1,445	103	as lactic acid
2. Molasses Product	12,129	1,011	97	as sucrose
3. Fructose Product	9,578	855	103	as fructose
4. Ethanol Product	4,897	710	52	as ethanol
5. Sweet Dry Whey (lactose)	7,554	sold by pound	71	as lactose
6. HRC®	5,807	sold by pound	62	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	2,982	382	40	as soybean oil
8. Emulsified Vegetable Oil	4,970	637	40	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 115

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		1444.855042
2. Molasses Product		1010.764627
3. Fructose Product		855.1698974
4. Ethanol Product		709.7652919
5. Sweet Dry Whey (lactose)	7554.417804	
6. HRC®	5807.182575	
7. Linoleic Acid (Soybean Oil)		382.2820441
8. Emulsified Vegetable Oil		637.1367402
9. Lactoil Product		305.8256353
10. Lactic Acid Product		0
11. Hydrogen Gas	114.30	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 117

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	165	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	120	1-1,000	feet	
Saturated Thickness	36	1-100	feet	
Treatment Zone Cross Sectional Area	5940	--	ft^2	
Treatment Zone Volume	712,800	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,333,292	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,066,634	--	gallons	
Design Period of Performance	2.4	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	60	.01-1000	ft/day	
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.60	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	219.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	1,946,607	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.12	0.1 to- 20	mg/L	Default = 1
Sulfate	14	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.085	--	mg/L	
Trichloroethene (TCE)	0.394	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	2.499	--	mg/L	
Vinyl Chloride (VC)	0.038	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 117

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	165	feet	50	meters
Length (parallel to groundwater flow)	120	feet	36.6	meters
Saturated Thickness	36	feet	11.0	meters
Design Period of Performance	2.41	years	2.41	years

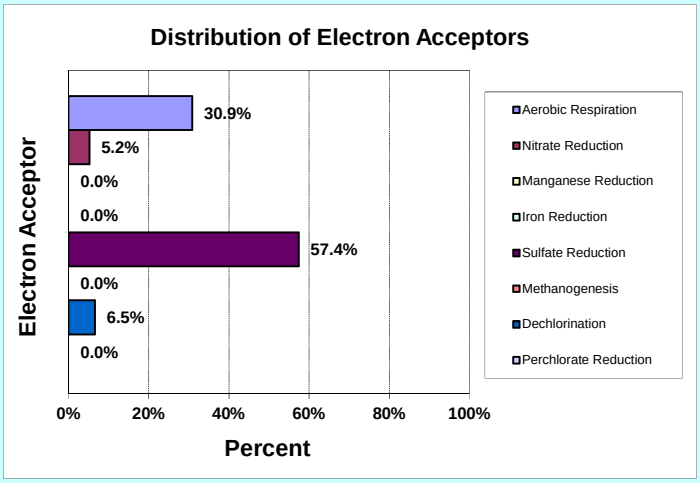
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	60	ft/day	2.1E-02	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	0.60	ft/day	1.8E+01	cm/day
Average Groundwater Seepage Velocity	219	ft/yr	66.8	m/yr
Effective Treatment Zone Pore Volume	1,066,634	gallons	4,037,536	liters
Groundwater Flux (per year)	1,946,607	gallons/year	7,368,503	liters/year
Total Groundwater Volume Treated (over entire design period)	5,757,957	gallons total	21,795,628	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	30.9%	30.257
Nitrate Reduction	5.2%	5.088
Sulfate Reduction	57.4%	56.277
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	6.5%	6.413
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**98.03**

Hydrogen demand in pounds/gallon:	1.70E-05
Hydrogen demand in grams per liter:	2.04E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	13,632	1,239	137	as lactic acid
2. Molasses Product	10,403	867	130	as sucrose
3. Fructose Product	8,215	733	137	as fructose
4. Ethanol Product	4,201	609	70	as ethanol
5. Sweet Dry Whey (lactose)	6,480	sold by pound	94	as lactose
6. HRC®	4,981	sold by pound	83	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	2,558	328	53	as soybean oil
8. Emulsified Vegetable Oil	4,263	546	53	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 117

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		1239.278001
2. Molasses Product		866.9508915
3. Fructose Product		733.4945098
4. Ethanol Product		608.7783801
5. Sweet Dry Whey (lactose)	6479.559209	
6. HRC®	4980.924316	
7. Linoleic Acid (Soybean Oil)		327.8901437
8. Emulsified Vegetable Oil		546.4835728
9. Lactoil Product		262.312115
10. Lactic Acid Product		0
11. Hydrogen Gas	98.03	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 119

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	165	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	120	1-1,000	feet	
Saturated Thickness	36	1-100	feet	
Treatment Zone Cross Sectional Area	5940	--	ft^2	
Treatment Zone Volume	712,800	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,333,292	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,066,634	--	gallons	
Design Period of Performance	2.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	60	.01-1000	ft/day	
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.60	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	219.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	1,946,607	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.58	0.1 to- 20	mg/L	Default = 1
Sulfate	3	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.398	--	mg/L	
Trichloroethene (TCE)	0.046	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.206	--	mg/L	
Vinyl Chloride (VC)	0.065	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 119

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	165	feet	50	meters
Length (parallel to groundwater flow)	120	feet	36.6	meters
Saturated Thickness	36	feet	11.0	meters
Design Period of Performance	2.75	years	2.75	years

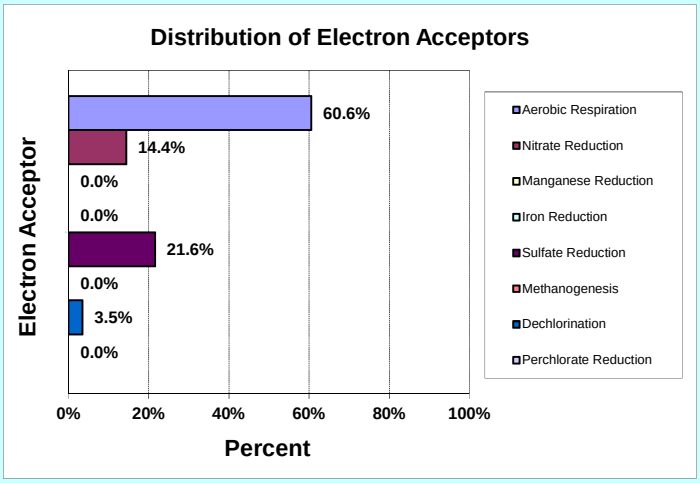
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	60	ft/day	2.1E-02	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	0.60	ft/day	1.8E+01	cm/day
Average Groundwater Seepage Velocity	219	ft/yr	66.8	m/yr
Effective Treatment Zone Pore Volume	1,066,634	gallons	4,037,536	liters
Groundwater Flux (per year)	1,946,607	gallons/year	7,368,503	liters/year
Total Groundwater Volume Treated (over entire design period)	6,419,803	gallons total	24,300,918	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	60.6%	33.734
Nitrate Reduction	14.4%	8.029
Sulfate Reduction	21.6%	12.009
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	3.5%	1.937
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**55.71**

Hydrogen demand in pounds/gallon:	8.68E-06
Hydrogen demand in grams per liter:	1.04E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	7,747	704	70	as lactic acid
2. Molasses Product	5,912	493	66	as sucrose
3. Fructose Product	4,668	417	70	as fructose
4. Ethanol Product	2,387	346	36	as ethanol
5. Sweet Dry Whey (lactose)	3,682	sold by pound	48	as lactose
6. HRC®	2,830	sold by pound	42	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	1,453	186	27	as soybean oil
8. Emulsified Vegetable Oil	2,422	311	27	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 119

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		704.2417907
2. Molasses Product		492.6602812
3. Fructose Product		416.8213159
4. Ethanol Product		345.9491545
5. Sweet Dry Whey (lactose)	3682.124897	
6. HRC®	2830.498934	
7. Linoleic Acid (Soybean Oil)		186.3294126
8. Emulsified Vegetable Oil		310.5490211
9. Lactoil Product		149.0635301
10. Lactic Acid Product		0
11. Hydrogen Gas	55.71	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 123

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	165	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	120	1-1,000	feet	
Saturated Thickness	36	1-100	feet	
Treatment Zone Cross Sectional Area	5940	--	ft^2	
Treatment Zone Volume	712,800	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,333,292	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,066,634	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	60	.01-1000	ft/day	
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.60	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	219.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	1,946,607	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.36	0.1 to- 20	mg/L	Default = 1
Sulfate	6	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.161	--	mg/L	
Trichloroethene (TCE)	0.020	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.094	--	mg/L	
Vinyl Chloride (VC)	0.019	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 123

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	165	feet	50	meters
Length (parallel to groundwater flow)	120	feet	36.6	meters
Saturated Thickness	36	feet	11.0	meters
Design Period of Performance	1.14	years	1.14	years

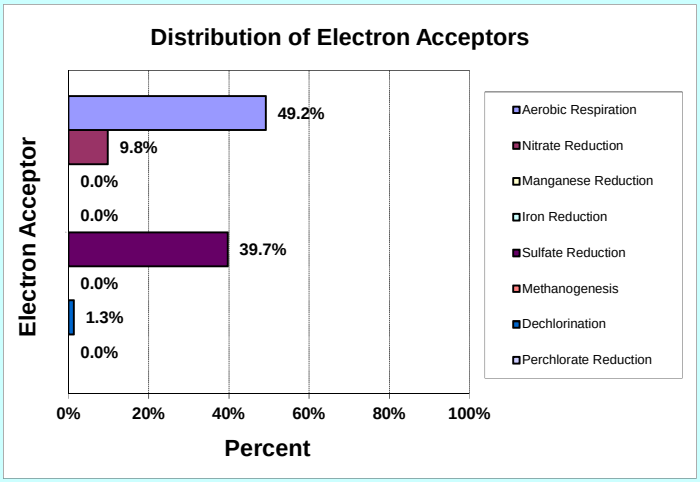
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	60	ft/day	2.1E-02	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	0.60	ft/day	1.8E+01	cm/day
Average Groundwater Seepage Velocity	219	ft/yr	66.8	m/yr
Effective Treatment Zone Pore Volume	1,066,634	gallons	4,037,536	liters
Groundwater Flux (per year)	1,946,607	gallons/year	7,368,503	liters/year
Total Groundwater Volume Treated (over entire design period)	3,285,766	gallons total	12,437,629	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	49.2%	17.266
Nitrate Reduction	9.8%	3.441
Sulfate Reduction	39.7%	13.928
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	1.3%	0.452
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**35.09**

Hydrogen demand in pounds/gallon:	1.07E-05
Hydrogen demand in grams per liter:	1.28E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	4,879	444	86	as lactic acid
2. Molasses Product	3,723	310	81	as sucrose
3. Fructose Product	2,940	263	86	as fructose
4. Ethanol Product	1,503	218	44	as ethanol
5. Sweet Dry Whey (lactose)	2,319	sold by pound	59	as lactose
6. HRC®	1,783	sold by pound	52	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	915	117	33	as soybean oil
8. Emulsified Vegetable Oil	1,526	196	33	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 123

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		443.5417101
2. Molasses Product		310.2846018
3. Fructose Product		262.5201198
4. Ethanol Product		217.883803
5. Sweet Dry Whey (lactose)	2319.055749	
6. HRC®	1782.689346	
7. Linoleic Acid (Soybean Oil)		117.3529708
8. Emulsified Vegetable Oil		195.5882847
9. Lactoil Product		93.88237666
10. Lactic Acid Product		0
11. Hydrogen Gas	35.09	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 125

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	165	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	120	1-1,000	feet	
Saturated Thickness	36	1-100	feet	
Treatment Zone Cross Sectional Area	5940	--	ft^2	
Treatment Zone Volume	712,800	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,333,292	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,066,634	--	gallons	
Design Period of Performance	1.9	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	60	.01-1000	ft/day	
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.60	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	219.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	1,946,607	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.90	0.1 to- 20	mg/L	Default = 1
Sulfate	3	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.490	--	mg/L	
Trichloroethene (TCE)	0.031	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.166	--	mg/L	
Vinyl Chloride (VC)	0.057	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 125

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	165	feet	50	meters
Length (parallel to groundwater flow)	120	feet	36.6	meters
Saturated Thickness	36	feet	11.0	meters
Design Period of Performance	1.91	years	1.91	years

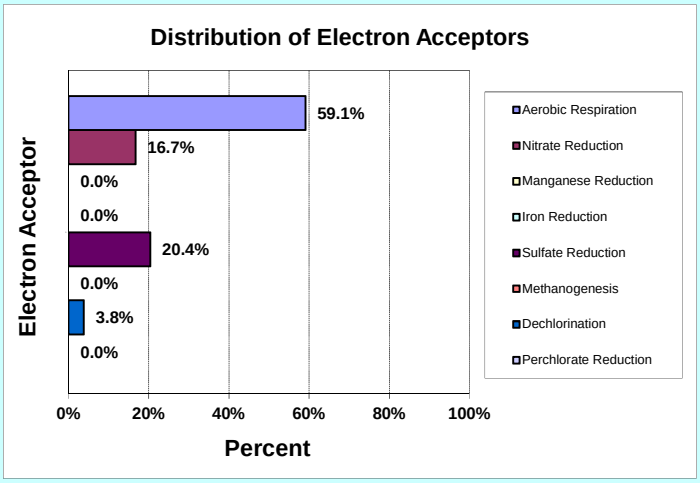
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	60	ft/day	2.1E-02	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	0.60	ft/day	1.8E+01	cm/day
Average Groundwater Seepage Velocity	219	ft/yr	66.8	m/yr
Effective Treatment Zone Pore Volume	1,066,634	gallons	4,037,536	liters
Groundwater Flux (per year)	1,946,607	gallons/year	7,368,503	liters/year
Total Groundwater Volume Treated (over entire design period)	4,784,653	gallons total	18,111,376	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	59.1%	25.142
Nitrate Reduction	16.7%	7.126
Sulfate Reduction	20.4%	8.682
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	3.8%	1.612
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**42.56**

Hydrogen demand in pounds/gallon:	8.90E-06
Hydrogen demand in grams per liter:	1.07E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	5,918	538	71	as lactic acid
2. Molasses Product	4,517	376	68	as sucrose
3. Fructose Product	3,567	318	71	as fructose
4. Ethanol Product	1,824	264	37	as ethanol
5. Sweet Dry Whey (lactose)	2,813	sold by pound	49	as lactose
6. HRC®	2,162	sold by pound	43	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	1,110	142	28	as soybean oil
8. Emulsified Vegetable Oil	1,851	237	28	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 125

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		538.038964
2. Molasses Product		376.3912207
3. Fructose Product		318.4504412
4. Ethanol Product		264.3042875
5. Sweet Dry Whey (lactose)	2813.134197	
6. HRC®	2162.494095	
7. Linoleic Acid (Soybean Oil)		142.3552045
8. Emulsified Vegetable Oil		237.2586742
9. Lactoil Product		113.8841636
10. Lactic Acid Product		0
11. Hydrogen Gas	42.56	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 128

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	80	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	180	1-1,000	feet	
Saturated Thickness	12.5	1-100	feet	
Treatment Zone Cross Sectional Area	1000	--	ft^2	
Treatment Zone Volume	180,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	336,690	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	269,352	--	gallons	
Design Period of Performance	2.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.3	.01-1000	ft/day	
Average Hydraulic Gradient	0.01	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.12	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	42.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	62,811	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.2	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	1	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.006	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	1.513	--	mg/L	
Vinyl Chloride (VC)	0.008	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.044	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 128

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	80	feet	24	meters
Length (parallel to groundwater flow)	180	feet	54.9	meters
Saturated Thickness	12.5	feet	3.8	meters
Design Period of Performance	2.14	years	2.14	years

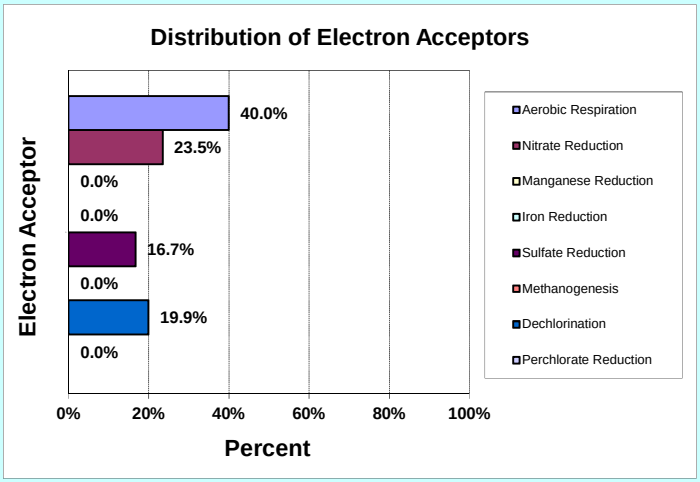
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.3	ft/day	8.1E-04	cm/sec
Average Hydraulic Gradient	0.01	ft/ft	0.01	m/m
Average Groundwater Seepage Velocity	0.12	ft/day	3.5E+00	cm/day
Average Groundwater Seepage Velocity	42	ft/yr	12.8	m/yr
Effective Treatment Zone Pore Volume	269,352	gallons	1,019,580	liters
Groundwater Flux (per year)	62,811	gallons/year	237,760	liters/year
Total Groundwater Volume Treated (over entire design period)	403,768	gallons total	1,528,387	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	40.0%	0.498
Nitrate Reduction	23.5%	0.292
Sulfate Reduction	16.7%	0.208
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	19.9%	0.248
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**1.25**

Hydrogen demand in pounds/gallon:	3.08E-06
Hydrogen demand in grams per liter:	3.70E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	173	16	25	as lactic acid
2. Molasses Product	132	11	24	as sucrose
3. Fructose Product	104	9	25	as fructose
4. Ethanol Product	53	8	13	as ethanol
5. Sweet Dry Whey (lactose)	82	sold by pound	17	as lactose
6. HRC®	63	sold by pound	15	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	32	4	10	as soybean oil
8. Emulsified Vegetable Oil	54	7	10	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 128

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		15.740936
2. Molasses Product		11.01174917
3. Fructose Product		9.316626398
4. Ethanol Product		7.732519673
5. Sweet Dry Whey (lactose)	82.30140999	
6. HRC®	63.26620084	
7. Linoleic Acid (Soybean Oil)		4.164761873
8. Emulsified Vegetable Oil		6.941269789
9. Lactoil Product		3.331809499
10. Lactic Acid Product		0
11. Hydrogen Gas	1.25	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 130

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	70	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	355	1-1,000	feet	
Saturated Thickness	12.5	1-100	feet	
Treatment Zone Cross Sectional Area	875	--	ft^2	
Treatment Zone Volume	310,625	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	581,024	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	464,819	--	gallons	
Design Period of Performance	2.4	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.3	.01-1000	ft/day	
Average Hydraulic Gradient	0.01	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.12	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	42.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	54,960	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.2	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	6	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.005	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	1.174	--	mg/L	
Vinyl Chloride (VC)	0.056	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.041	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 130

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	70	feet	21	meters
Length (parallel to groundwater flow)	355	feet	108.2	meters
Saturated Thickness	12.5	feet	3.8	meters
Design Period of Performance	2.36	years	2.36	years

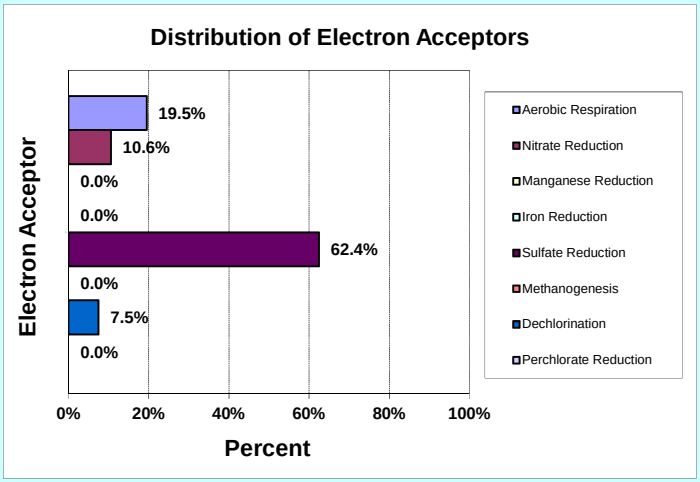
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.3	ft/day	8.1E-04	cm/sec
Average Hydraulic Gradient	0.01	ft/ft	0.01	m/m
Average Groundwater Seepage Velocity	0.12	ft/day	3.5E+00	cm/day
Average Groundwater Seepage Velocity	42	ft/yr	12.8	m/yr
Effective Treatment Zone Pore Volume	464,819	gallons	1,759,483	liters
Groundwater Flux (per year)	54,960	gallons/year	208,040	liters/year
Total Groundwater Volume Treated (over entire design period)	594,525	gallons total	2,250,458	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	19.5%	0.778
Nitrate Reduction	10.6%	0.421
Sulfate Reduction	62.4%	2.487
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	7.5%	0.298
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**3.98**

Hydrogen demand in pounds/gallon:	6.70E-06
Hydrogen demand in grams per liter:	8.03E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	554	50	54	as lactic acid
2. Molasses Product	423	35	51	as sucrose
3. Fructose Product	334	30	54	as fructose
4. Ethanol Product	171	25	28	as ethanol
5. Sweet Dry Whey (lactose)	263	sold by pound	37	as lactose
6. HRC®	202	sold by pound	33	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	104	13	21	as soybean oil
8. Emulsified Vegetable Oil	173	22	21	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 130

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		50.35879722
2. Molasses Product		35.22906412
3. Fructose Product		29.80598483
4. Ethanol Product		24.73807086
5. Sweet Dry Whey (lactose)	263.3007349	
6. HRC®	202.4028164	
7. Linoleic Acid (Soybean Oil)		13.32401063
8. Emulsified Vegetable Oil		22.20668439
9. Lactoil Product		10.65920851
10. Lactic Acid Product		0
11. Hydrogen Gas	3.98	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 131

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	200	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	590	1-1,000	feet	
Saturated Thickness	12.5	1-100	feet	
Treatment Zone Cross Sectional Area	2500	--	ft^2	
Treatment Zone Volume	1,475,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	2,758,988	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	2,207,190	--	gallons	
Design Period of Performance	5.3	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.3	.01-1000	ft/day	
Average Hydraulic Gradient	0.01	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.12	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	42.0	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	157,028	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.5	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	8	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.003	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.805	--	mg/L	
Vinyl Chloride (VC)	0.073	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.019	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 131

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	200	feet	61	meters
Length (parallel to groundwater flow)	590	feet	179.8	meters
Saturated Thickness	12.5	feet	3.8	meters
Design Period of Performance	5.32	years	5.32	years

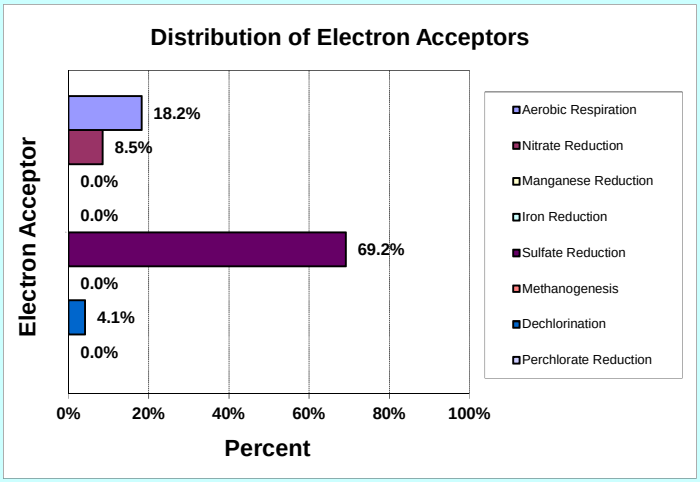
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.3	ft/day	8.1E-04	cm/sec
Average Hydraulic Gradient	0.01	ft/ft	0.01	m/m
Average Groundwater Seepage Velocity	0.12	ft/day	3.5E+00	cm/day
Average Groundwater Seepage Velocity	42	ft/yr	12.8	m/yr
Effective Treatment Zone Pore Volume	2,207,190	gallons	8,354,890	liters
Groundwater Flux (per year)	157,028	gallons/year	594,401	liters/year
Total Groundwater Volume Treated (over entire design period)	3,042,581	gallons total	11,517,102	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	18.2%	4.659
Nitrate Reduction	8.5%	2.177
Sulfate Reduction	69.2%	17.693
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	4.1%	1.054
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**25.58**

Hydrogen demand in pounds/gallon:	8.41E-06
Hydrogen demand in grams per liter:	1.01E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	3,558	323	68	as lactic acid
2. Molasses Product	2,715	226	64	as sucrose
3. Fructose Product	2,144	191	68	as fructose
4. Ethanol Product	1,096	159	35	as ethanol
5. Sweet Dry Whey (lactose)	1,691	sold by pound	47	as lactose
6. HRC®	1,300	sold by pound	41	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	667	86	26	as soybean oil
8. Emulsified Vegetable Oil	1,112	143	26	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 131

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		323.4130151
2. Molasses Product		226.2472195
3. Fructose Product		191.4192545
4. Ethanol Product		158.8722235
5. Sweet Dry Whey (lactose)	1690.963431	
6. HRC®	1299.866334	
7. Linoleic Acid (Soybean Oil)		85.56912973
8. Emulsified Vegetable Oil		142.6152162
9. Lactoil Product		68.45530378
10. Lactic Acid Product		0
11. Hydrogen Gas	25.58	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 135

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	120	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	360	1-1,000	feet	
Saturated Thickness	7.5	1-100	feet	
Treatment Zone Cross Sectional Area	900	--	ft^2	
Treatment Zone Volume	324,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	606,042	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	484,834	--	gallons	
Design Period of Performance	0.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.4	.01-1000	ft/day	
Average Hydraulic Gradient	0.004	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.05	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	17.5	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	23,595	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.5	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	1	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.014	--	mg/L	
Trichloroethene (TCE)	0.100	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	2.283	--	mg/L	
Vinyl Chloride (VC)	0.997	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.015	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.199	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 135

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	120	feet	37	meters
Length (parallel to groundwater flow)	360	feet	109.7	meters
Saturated Thickness	7.5	feet	2.3	meters
Design Period of Performance	0.83	years	0.83	years

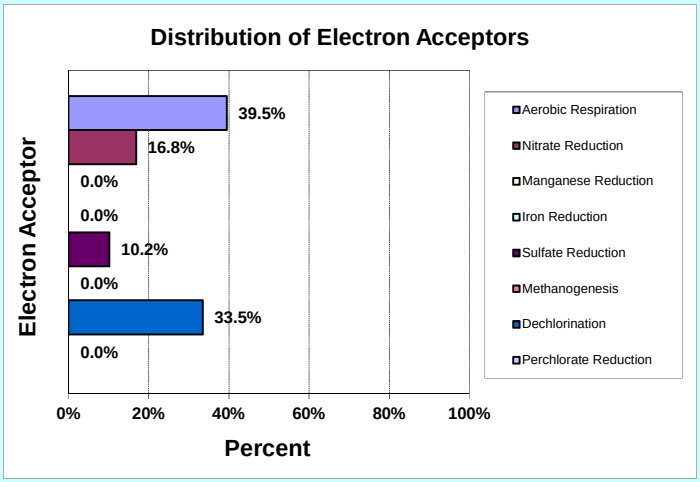
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.4	ft/day	8.5E-04	cm/sec
Average Hydraulic Gradient	0.004	ft/ft	0.004	m/m
Average Groundwater Seepage Velocity	0.05	ft/day	1.5E+00	cm/day
Average Groundwater Seepage Velocity	18	ft/yr	5.3	m/yr
Effective Treatment Zone Pore Volume	484,834	gallons	1,835,244	liters
Groundwater Flux (per year)	23,595	gallons/year	89,315	liters/year
Total Groundwater Volume Treated (over entire design period)	504,418	gallons total	1,909,375	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	39.5%	0.808
Nitrate Reduction	16.8%	0.345
Sulfate Reduction	10.2%	0.209
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	33.5%	0.686
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**2.05**

Hydrogen demand in pounds/gallon:	4.06E-06
Hydrogen demand in grams per liter:	4.87E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	285	26	33	as lactic acid
2. Molasses Product	217	18	31	as sucrose
3. Fructose Product	172	15	33	as fructose
4. Ethanol Product	88	13	17	as ethanol
5. Sweet Dry Whey (lactose)	135	sold by pound	23	as lactose
6. HRC®	104	sold by pound	20	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	53	7	13	as soybean oil
8. Emulsified Vegetable Oil	89	11	13	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 135

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		25.88954797
2. Molasses Product		18.11132505
3. Fructose Product		15.32331026
4. Ethanol Product		12.7178866
5. Sweet Dry Whey (lactose)	135.36338	
6. HRC®	104.0556509	
7. Linoleic Acid (Soybean Oil)		6.849897763
8. Emulsified Vegetable Oil		11.41649627
9. Lactoil Product		5.47991821
10. Lactic Acid Product		0
11. Hydrogen Gas	2.05	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 139

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	320	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	115	1-1,000	feet	
Saturated Thickness	7	1-100	feet	
Treatment Zone Cross Sectional Area	2240	--	ft^2	
Treatment Zone Volume	257,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	481,841	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	385,473	--	gallons	
Design Period of Performance	0.5	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.4	.01-1000	ft/day	
Average Hydraulic Gradient	0.004	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.05	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	17.5	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	58,726	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	1	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.017	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.181	--	mg/L	
Vinyl Chloride (VC)	0.476	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 139

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	320	feet	98	meters
Length (parallel to groundwater flow)	115	feet	35.1	meters
Saturated Thickness	7	feet	2.1	meters
Design Period of Performance	0.5	years	0.5	years

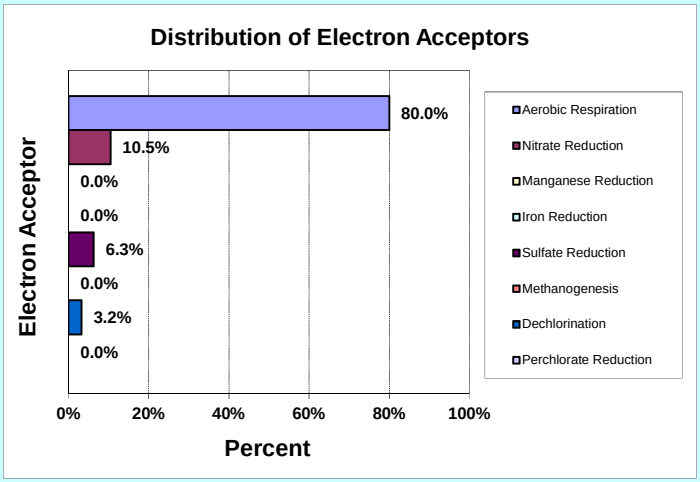
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.4	ft/day	8.5E-04	cm/sec
Average Hydraulic Gradient	0.004	ft/ft	0.004	m/m
Average Groundwater Seepage Velocity	0.05	ft/day	1.5E+00	cm/day
Average Groundwater Seepage Velocity	18	ft/yr	5.3	m/yr
Effective Treatment Zone Pore Volume	385,473	gallons	1,459,132	liters
Groundwater Flux (per year)	58,726	gallons/year	222,296	liters/year
Total Groundwater Volume Treated (over entire design period)	414,836	gallons total	1,570,280	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	80.0%	2.180
Nitrate Reduction	10.5%	0.285
Sulfate Reduction	6.3%	0.171
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	3.2%	0.088
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**2.73**

Hydrogen demand in pounds/gallon:	6.57E-06
Hydrogen demand in grams per liter:	7.87E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	379	34	53	as lactic acid
2. Molasses Product	289	24	50	as sucrose
3. Fructose Product	228	20	53	as fructose
4. Ethanol Product	117	17	27	as ethanol
5. Sweet Dry Whey (lactose)	180	sold by pound	36	as lactose
6. HRC®	138	sold by pound	32	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	71	9	21	as soybean oil
8. Emulsified Vegetable Oil	118	15	21	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 139

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		34.44826384
2. Molasses Product		24.09867119
3. Fructose Product		20.38897841
4. Ethanol Product		16.92223879
5. Sweet Dry Whey (lactose)	180.1125858	
6. HRC®	138.4549673	
7. Linoleic Acid (Soybean Oil)		9.114376415
8. Emulsified Vegetable Oil		15.19062736
9. Lactoil Product		7.291501132
10. Lactic Acid Product		0
11. Hydrogen Gas	2.73	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 141

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	213	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	466	1-1,000	feet	
Saturated Thickness	7.5	1-100	feet	
Treatment Zone Cross Sectional Area	1597.5	--	ft^2	
Treatment Zone Volume	744,435	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,392,466	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,113,973	--	gallons	
Design Period of Performance	0.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.4	.01-1000	ft/day	
Average Hydraulic Gradient	0.004	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.05	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	17.5	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	41,882	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.8	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	1	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.430	--	mg/L	
Vinyl Chloride (VC)	10.300	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.134	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 141

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	213	feet	65	meters
Length (parallel to groundwater flow)	466	feet	142.0	meters
Saturated Thickness	7.5	feet	2.3	meters
Design Period of Performance	0.84	years	0.84	years

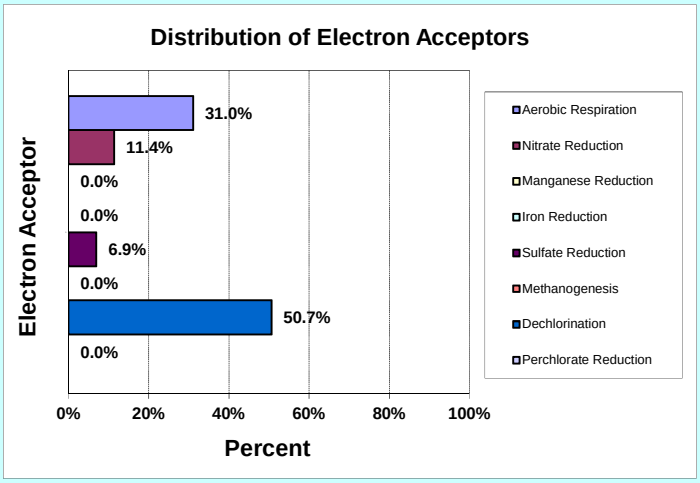
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.4	ft/day	8.5E-04	cm/sec
Average Hydraulic Gradient	0.004	ft/ft	0.004	m/m
Average Groundwater Seepage Velocity	0.05	ft/day	1.5E+00	cm/day
Average Groundwater Seepage Velocity	18	ft/yr	5.3	m/yr
Effective Treatment Zone Pore Volume	1,113,973	gallons	4,216,727	liters
Groundwater Flux (per year)	41,882	gallons/year	158,534	liters/year
Total Groundwater Volume Treated (over entire design period)	1,149,153	gallons total	4,349,896	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	31.0%	2.138
Nitrate Reduction	11.4%	0.784
Sulfate Reduction	6.9%	0.475
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	50.7%	3.488
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**6.88**

Hydrogen demand in pounds/gallon:	5.99E-06
Hydrogen demand in grams per liter:	7.18E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	957	87	48	as lactic acid
2. Molasses Product	731	61	46	as sucrose
3. Fructose Product	577	52	48	as fructose
4. Ethanol Product	295	43	25	as ethanol
5. Sweet Dry Whey (lactose)	455	sold by pound	33	as lactose
6. HRC®	350	sold by pound	29	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	180	23	19	as soybean oil
8. Emulsified Vegetable Oil	299	38	19	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 141

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		87.02912294
2. Molasses Product		60.88220374
3. Fructose Product		51.51014045
4. Ethanol Product		42.75186718
5. Sweet Dry Whey (lactose)	455.0313608	
6. HRC®	349.7887273	
7. Linoleic Acid (Soybean Oil)		23.02630371
8. Emulsified Vegetable Oil		38.37717285
9. Lactoil Product		18.42104297
10. Lactic Acid Product		0
11. Hydrogen Gas	6.88	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 143

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	200	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	520	1-1,000	feet	
Saturated Thickness	7.5	1-100	feet	
Treatment Zone Cross Sectional Area	1500	--	ft^2	
Treatment Zone Volume	780,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,458,990	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,167,192	--	gallons	
Design Period of Performance	2.9	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.4	.01-1000	ft/day	
Average Hydraulic Gradient	0.004	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.05	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	17.5	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	39,325	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.5	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	1	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.148	--	mg/L	
Vinyl Chloride (VC)	1.650	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.024	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 143

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	200	feet	61	meters
Length (parallel to groundwater flow)	520	feet	158.5	meters
Saturated Thickness	7.5	feet	2.3	meters
Design Period of Performance	2.91	years	2.91	years

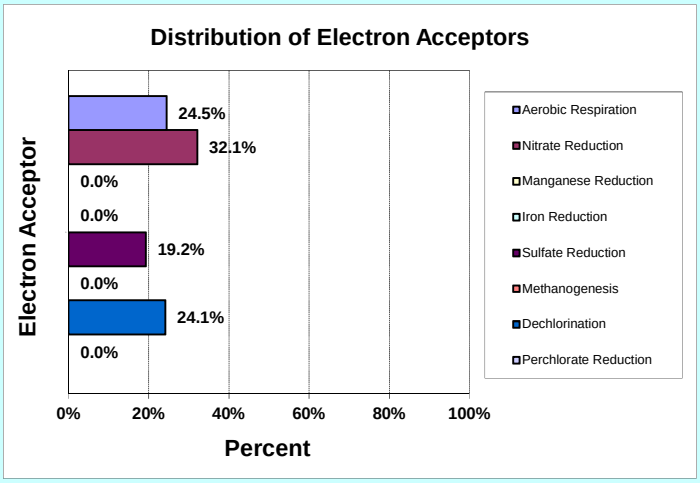
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.4	ft/day	8.5E-04	cm/sec
Average Hydraulic Gradient	0.004	ft/ft	0.004	m/m
Average Groundwater Seepage Velocity	0.05	ft/day	1.5E+00	cm/day
Average Groundwater Seepage Velocity	18	ft/yr	5.3	m/yr
Effective Treatment Zone Pore Volume	1,167,192	gallons	4,418,179	liters
Groundwater Flux (per year)	39,325	gallons/year	148,859	liters/year
Total Groundwater Volume Treated (over entire design period)	1,281,629	gallons total	4,851,358	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	24.5%	0.673
Nitrate Reduction	32.1%	0.885
Sulfate Reduction	19.2%	0.530
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	24.1%	0.665
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**2.75**

Hydrogen demand in pounds/gallon:	2.15E-06
Hydrogen demand in grams per liter:	2.57E-04



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	383	35	17	as lactic acid
2. Molasses Product	292	24	16	as sucrose
3. Fructose Product	231	21	17	as fructose
4. Ethanol Product	118	17	9	as ethanol
5. Sweet Dry Whey (lactose)	182	sold by pound	12	as lactose
6. HRC®	140	sold by pound	10	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	72	9	7	as soybean oil
8. Emulsified Vegetable Oil	120	15	7	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 143

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		34.80191225
2. Molasses Product		24.34606992
3. Fructose Product		20.59829316
4. Ethanol Product		17.09596374
5. Sweet Dry Whey (lactose)	181.9616348	
6. HRC®	139.8763561	
7. Linoleic Acid (Soybean Oil)		9.207945273
8. Emulsified Vegetable Oil		15.34657545
9. Lactoil Product		7.366356218
10. Lactic Acid Product		0
11. Hydrogen Gas	2.75	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 145

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	540	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	75	1-1,000	feet	
Saturated Thickness	7	1-100	feet	
Treatment Zone Cross Sectional Area	3780	--	ft^2	
Treatment Zone Volume	283,500	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	530,287	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	424,229	--	gallons	
Design Period of Performance	0.4	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.4	.01-1000	ft/day	
Average Hydraulic Gradient	0.004	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.05	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	17.5	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	99,100	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	50	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.005	--	mg/L	
Vinyl Chloride (VC)	0.022	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 145

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	540	feet	165	meters
Length (parallel to groundwater flow)	75	feet	22.9	meters
Saturated Thickness	7	feet	2.1	meters
Design Period of Performance	0.38	years	0.38	years

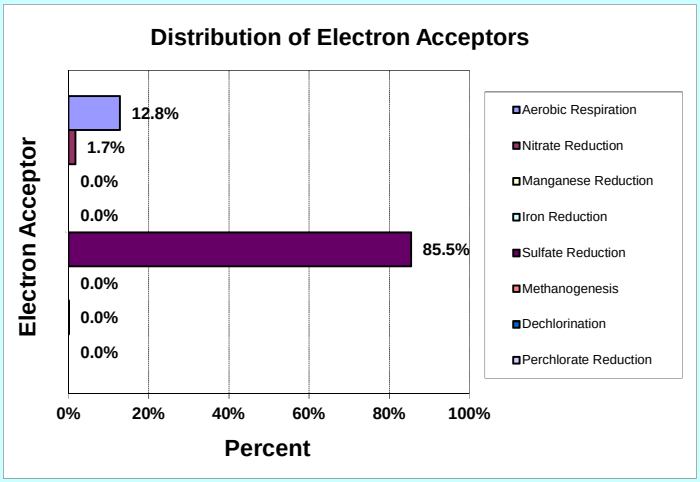
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.4	ft/day	8.5E-04	cm/sec
Average Hydraulic Gradient	0.004	ft/ft	0.004	m/m
Average Groundwater Seepage Velocity	0.05	ft/day	1.5E+00	cm/day
Average Groundwater Seepage Velocity	18	ft/yr	5.3	m/yr
Effective Treatment Zone Pore Volume	424,229	gallons	1,605,838	liters
Groundwater Flux (per year)	99,100	gallons/year	375,124	liters/year
Total Groundwater Volume Treated (over entire design period)	461,887	gallons total	1,748,385	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	12.8%	2.427
Nitrate Reduction	1.7%	0.318
Sulfate Reduction	85.5%	16.181
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.0%	0.004
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**18.93**

Hydrogen demand in pounds/gallon:	4.10E-05
Hydrogen demand in grams per liter:	4.91E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	2,632	239	329	as lactic acid
2. Molasses Product	2,009	167	313	as sucrose
3. Fructose Product	1,586	142	329	as fructose
4. Ethanol Product	811	118	168	as ethanol
5. Sweet Dry Whey (lactose)	1,251	sold by pound	227	as lactose
6. HRC®	962	sold by pound	200	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	494	63	128	as soybean oil
8. Emulsified Vegetable Oil	823	106	128	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 145

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		239.2979247
2. Molasses Product		167.40356
3. Fructose Product		141.6338496
4. Ethanol Product		117.5518349
5. Sweet Dry Whey (lactose)	1251.168076	
6. HRC®	961.7897286	
7. Linoleic Acid (Soybean Oil)		63.31382537
8. Emulsified Vegetable Oil		105.5230423
9. Lactoil Product		50.6510603
10. Lactic Acid Product		0
11. Hydrogen Gas	18.93	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 147

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	90	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	75	1-1,000	feet	
Saturated Thickness	23	1-100	feet	
Treatment Zone Cross Sectional Area	2070	--	ft^2	
Treatment Zone Volume	155,250	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	290,395	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	232,316	--	gallons	
Design Period of Performance	6.4	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	10	.01-1000	ft/day	
Average Hydraulic Gradient	0.001	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.05	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	18.3	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	56,530	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	2.2	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	336	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.361	--	mg/L	
Vinyl Chloride (VC)	1.058	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 147

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	90	feet	27	meters
Length (parallel to groundwater flow)	75	feet	22.9	meters
Saturated Thickness	23	feet	7.0	meters
Design Period of Performance	6.42	years	6.42	years

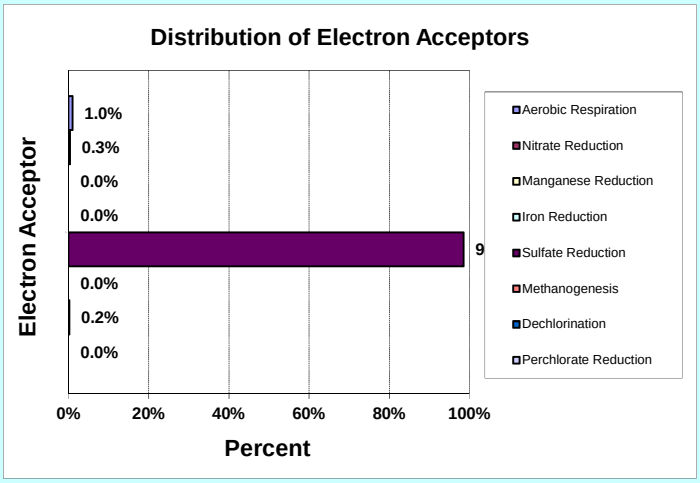
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	10	ft/day	3.5E-03	cm/sec
Average Hydraulic Gradient	0.001	ft/ft	0.001	m/m
Average Groundwater Seepage Velocity	0.05	ft/day	1.5E+00	cm/day
Average Groundwater Seepage Velocity	18	ft/yr	5.6	m/yr
Effective Treatment Zone Pore Volume	232,316	gallons	879,388	liters
Groundwater Flux (per year)	56,530	gallons/year	213,984	liters/year
Total Groundwater Volume Treated (over entire design period)	595,240	gallons total	2,253,167	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	1.0%	1.356
Nitrate Reduction	0.3%	0.453
Sulfate Reduction	98.6%	140.258
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.2%	0.251
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**142.32**

Hydrogen demand in pounds/gallon:	2.39E-04
Hydrogen demand in grams per liter:	2.87E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	19,790	1,799	1,920	as lactic acid
2. Molasses Product	15,103	1,259	1,824	as sucrose
3. Fructose Product	11,926	1,065	1,921	as fructose
4. Ethanol Product	6,098	884	982	as ethanol
5. Sweet Dry Whey (lactose)	9,406	sold by pound	1,326	as lactose
6. HRC®	7,231	sold by pound	1,165	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	3,713	476	747	as soybean oil
8. Emulsified Vegetable Oil	6,188	793	747	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 147

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		1799.067384
2. Molasses Product		1258.557863
3. Fructose Product		1064.818425
4. Ethanol Product		883.7672638
5. Sweet Dry Whey (lactose)	9406.415372	
6. HRC®	7230.838015	
7. Linoleic Acid (Soybean Oil)		476.0001087
8. Emulsified Vegetable Oil		793.3335145
9. Lactoil Product		380.800087
10. Lactic Acid Product		0
11. Hydrogen Gas	142.32	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 151

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	50	1-1,000	feet	
Saturated Thickness	16	1-100	feet	
Treatment Zone Cross Sectional Area	800	--	ft^2	
Treatment Zone Volume	40,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	74,820	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	59,856	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	4.7	.01-1000	ft/day	
Average Hydraulic Gradient	0.003	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.07	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	25.7	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	30,805	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	32	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	3.032	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.172	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 151

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	50	feet	15.2	meters
Saturated Thickness	16	feet	4.9	meters
Design Period of Performance	1.08	years	1.08	years

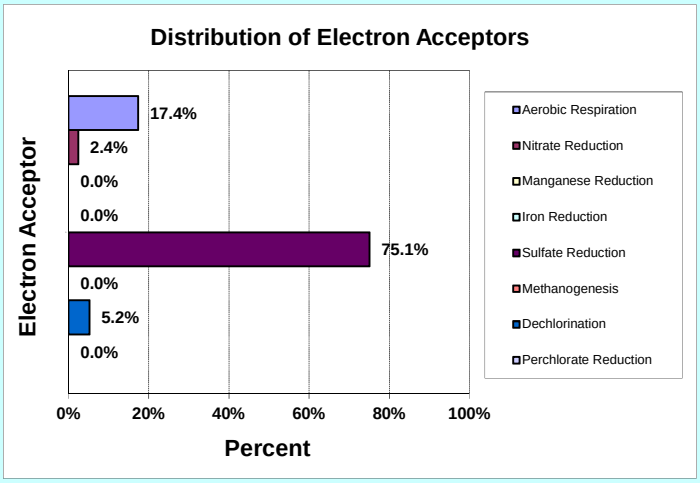
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	4.7	ft/day	1.7E-03	cm/sec
Average Hydraulic Gradient	0.003	ft/ft	0.003	m/m
Average Groundwater Seepage Velocity	0.07	ft/day	2.1E+00	cm/day
Average Groundwater Seepage Velocity	26	ft/yr	7.8	m/yr
Effective Treatment Zone Pore Volume	59,856	gallons	226,573	liters
Groundwater Flux (per year)	30,805	gallons/year	116,606	liters/year
Total Groundwater Volume Treated (over entire design period)	93,125	gallons total	352,508	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	17.4%	0.489
Nitrate Reduction	2.4%	0.068
Sulfate Reduction	75.1%	2.116
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	5.2%	0.146
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**2.82**

Hydrogen demand in pounds/gallon:	3.03E-05
Hydrogen demand in grams per liter:	3.63E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	392	36	243	as lactic acid
2. Molasses Product	299	25	231	as sucrose
3. Fructose Product	236	21	243	as fructose
4. Ethanol Product	121	18	124	as ethanol
5. Sweet Dry Whey (lactose)	186	sold by pound	168	as lactose
6. HRC®	143	sold by pound	147	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	74	9	95	as soybean oil
8. Emulsified Vegetable Oil	123	16	95	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 151

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		35.64258716
2. Molasses Product		24.93417353
3. Fructose Product		21.09586548
4. Ethanol Product		17.5089338
5. Sweet Dry Whey (lactose)	186.3570997	
6. HRC®	143.2552091	
7. Linoleic Acid (Soybean Oil)		9.430372378
8. Emulsified Vegetable Oil		15.7172873
9. Lactoil Product		7.544297903
10. Lactic Acid Product		0
11. Hydrogen Gas	2.82	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 152

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	50	1-1,000	feet	
Saturated Thickness	33	1-100	feet	
Treatment Zone Cross Sectional Area	1650	--	ft^2	
Treatment Zone Volume	82,500	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	154,316	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	123,453	--	gallons	
Design Period of Performance	1.5	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	6.9	.01-1000	ft/day	
Average Hydraulic Gradient	0.003	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.10	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	37.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	93,275	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	207	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	31.596	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.005	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 152

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	50	feet	15.2	meters
Saturated Thickness	33	feet	10.1	meters
Design Period of Performance	1.5	years	1.5	years

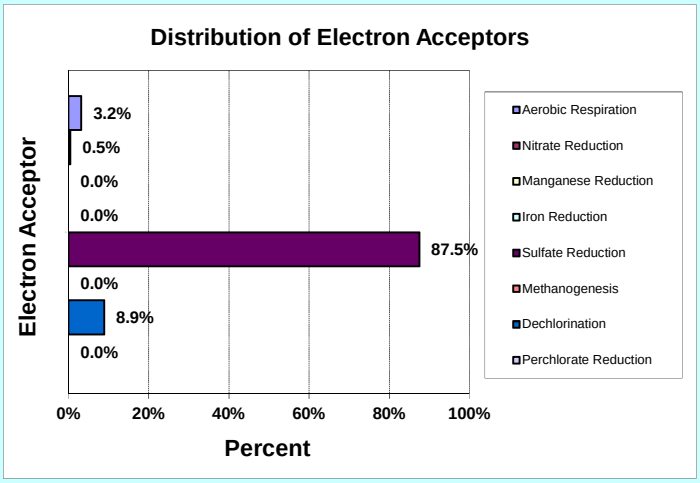
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	6.9	ft/day	2.4E-03	cm/sec
Average Hydraulic Gradient	0.003	ft/ft	0.003	m/m
Average Groundwater Seepage Velocity	0.10	ft/day	3.2E+00	cm/day
Average Groundwater Seepage Velocity	38	ft/yr	11.5	m/yr
Effective Treatment Zone Pore Volume	123,453	gallons	467,307	liters
Groundwater Flux (per year)	93,275	gallons/year	353,074	liters/year
Total Groundwater Volume Treated (over entire design period)	263,365	gallons total	996,919	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	3.2%	1.384
Nitrate Reduction	0.5%	0.198
Sulfate Reduction	87.5%	38.196
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	8.9%	3.877
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**43.65**

Hydrogen demand in pounds/gallon:	1.66E-04
Hydrogen demand in grams per liter:	1.99E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	6,070	552	1,331	as lactic acid
2. Molasses Product	4,633	386	1,265	as sucrose
3. Fructose Product	3,658	327	1,332	as fructose
4. Ethanol Product	1,871	271	681	as ethanol
5. Sweet Dry Whey (lactose)	2,885	sold by pound	919	as lactose
6. HRC®	2,218	sold by pound	807	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	1,139	146	518	as soybean oil
8. Emulsified Vegetable Oil	1,898	243	518	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 152

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		551.8519082
2. Molasses Product		386.0542216
3. Fructose Product		326.6259424
4. Ethanol Product		271.0897075
5. Sweet Dry Whey (lactose)	2885.355112	
6. HRC®	2218.011283	
7. Linoleic Acid (Soybean Oil)		146.0098553
8. Emulsified Vegetable Oil		243.3497588
9. Lactoil Product		116.8078842
10. Lactic Acid Product		0
11. Hydrogen Gas	43.65	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 154

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	50	1-1,000	feet	
Saturated Thickness	30	1-100	feet	
Treatment Zone Cross Sectional Area	1500	--	ft^2	
Treatment Zone Volume	75,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	140,288	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	112,230	--	gallons	
Design Period of Performance	3.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	6.9	.01-1000	ft/day	
Average Hydraulic Gradient	0.003	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.10	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	37.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	84,795	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	50	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.001	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.002	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 154

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	50	feet	15.2	meters
Saturated Thickness	30	feet	9.1	meters
Design Period of Performance	3.75	years	3.75	years

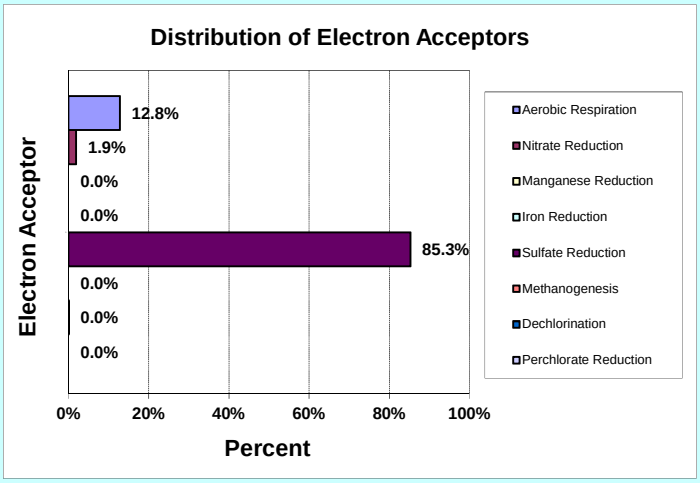
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	6.9	ft/day	2.4E-03	cm/sec
Average Hydraulic Gradient	0.003	ft/ft	0.003	m/m
Average Groundwater Seepage Velocity	0.10	ft/day	3.2E+00	cm/day
Average Groundwater Seepage Velocity	38	ft/yr	11.5	m/yr
Effective Treatment Zone Pore Volume	112,230	gallons	424,825	liters
Groundwater Flux (per year)	84,795	gallons/year	320,976	liters/year
Total Groundwater Volume Treated (over entire design period)	430,213	gallons total	1,628,487	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	12.8%	2.261
Nitrate Reduction	1.9%	0.335
Sulfate Reduction	85.3%	15.071
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.0%	0.000
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**17.67**

Hydrogen demand in pounds/gallon:	4.11E-05
Hydrogen demand in grams per liter:	4.92E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	2,457	223	330	as lactic acid
2. Molasses Product	1,875	156	313	as sucrose
3. Fructose Product	1,480	132	330	as fructose
4. Ethanol Product	757	110	169	as ethanol
5. Sweet Dry Whey (lactose)	1,168	sold by pound	228	as lactose
6. HRC®	898	sold by pound	200	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	461	59	128	as soybean oil
8. Emulsified Vegetable Oil	768	98	128	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 154

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		223.3355198
2. Molasses Product		156.2368798
3. Fructose Product		132.1861419
4. Ethanol Product		109.7105217
5. Sweet Dry Whey (lactose)	1167.708717	
6. HRC®	897.6333967	
7. Linoleic Acid (Soybean Oil)		59.0904669
8. Emulsified Vegetable Oil		98.4841115
9. Lactoil Product		47.27237352
10. Lactic Acid Product		0
11. Hydrogen Gas	17.67	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 162

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	40	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	50	1-1,000	feet	
Saturated Thickness	30.3	1-100	feet	
Treatment Zone Cross Sectional Area	1212	--	ft^2	
Treatment Zone Volume	60,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	113,352	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	90,682	--	gallons	
Design Period of Performance	5.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	3	.01-1000	ft/day	
Average Hydraulic Gradient	0.001	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.02	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	5.5	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	9,930	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.1	0.01 to 10	mg/L	Default = 5
Nitrate	2.55	0.1 to- 20	mg/L	Default = 1
Sulfate	50	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.103	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	1.216	--	mg/L	
Vinyl Chloride (VC)	0.791	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.001	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 162

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	40	feet	12	meters
Length (parallel to groundwater flow)	50	feet	15.2	meters
Saturated Thickness	30.3	feet	9.2	meters
Design Period of Performance	5.75	years	5.75	years

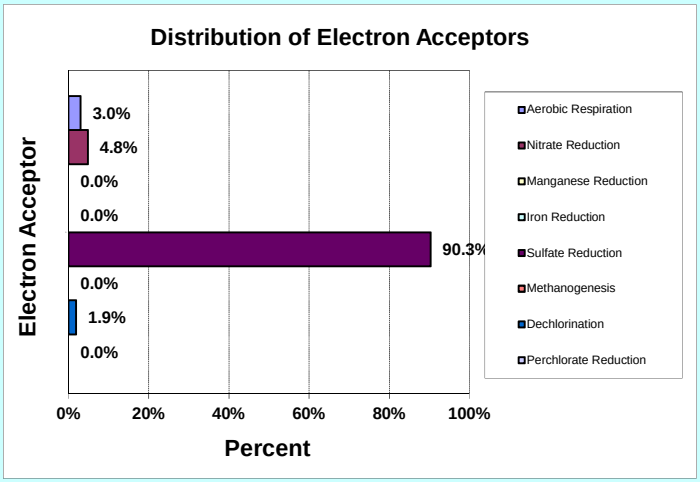
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	3	ft/day	1.1E-03	cm/sec
Average Hydraulic Gradient	0.001	ft/ft	0.001	m/m
Average Groundwater Seepage Velocity	0.02	ft/day	4.6E-01	cm/day
Average Groundwater Seepage Velocity	5	ft/yr	1.7	m/yr
Effective Treatment Zone Pore Volume	90,682	gallons	343,259	liters
Groundwater Flux (per year)	9,930	gallons/year	37,587	liters/year
Total Groundwater Volume Treated (over entire design period)	147,777	gallons total	559,383	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	3.0%	0.171
Nitrate Reduction	4.8%	0.275
Sulfate Reduction	90.3%	5.177
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	1.9%	0.109
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**5.73**

Hydrogen demand in pounds/gallon:	3.88E-05
Hydrogen demand in grams per liter:	4.65E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	797	72	312	as lactic acid
2. Molasses Product	608	51	296	as sucrose
3. Fructose Product	480	43	312	as fructose
4. Ethanol Product	246	36	159	as ethanol
5. Sweet Dry Whey (lactose)	379	sold by pound	215	as lactose
6. HRC®	291	sold by pound	189	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	150	19	121	as soybean oil
8. Emulsified Vegetable Oil	249	32	121	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading
Treatment 162

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		72.5
2. Molasses Product		50.7
3. Fructose Product		42.9
4. Ethanol Product		35.6
5. Sweet Dry Whey (lactose)	378.9	
6. HRC®	291.3	
7. Linoleic Acid (Soybean Oil)		19.2
8. Emulsified Vegetable Oil		32.0
9. Lactoil Product		15.3
10. Lactic Acid Product		47.0
11. Hydrogen Gas	5.7	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 174

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	110	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	55	1-1,000	feet	
Saturated Thickness	30.3	1-100	feet	
Treatment Zone Cross Sectional Area	3333	--	ft^2	
Treatment Zone Volume	183,315	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	342,891	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	274,313	--	gallons	
Design Period of Performance	0.7	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	3	.01-1000	ft/day	
Average Hydraulic Gradient	0.001	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.02	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	5.5	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	27,307	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.2	0.01 to 10	mg/L	Default = 5
Nitrate	0.70	0.1 to- 20	mg/L	Default = 1
Sulfate	562	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.112	--	mg/L	
Vinyl Chloride (VC)	0.350	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.001	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 174

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	110	feet	34	meters
Length (parallel to groundwater flow)	55	feet	16.8	meters
Saturated Thickness	30.3	feet	9.2	meters
Design Period of Performance	0.71	years	0.71	years

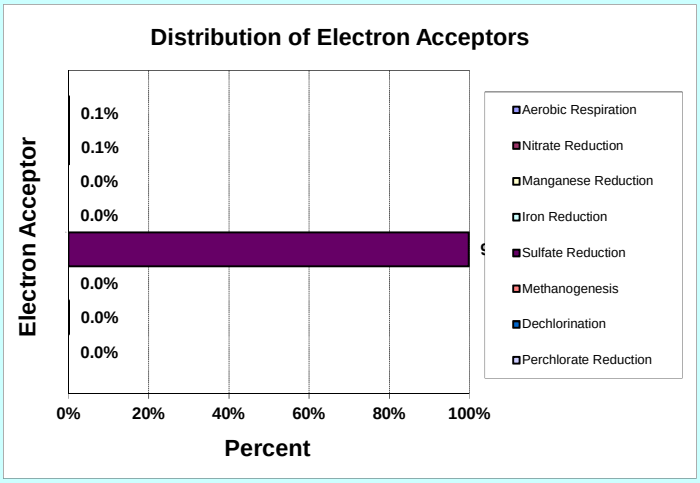
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	3	ft/day	1.1E-03	cm/sec
Average Hydraulic Gradient	0.001	ft/ft	0.001	m/m
Average Groundwater Seepage Velocity	0.02	ft/day	4.6E-01	cm/day
Average Groundwater Seepage Velocity	5	ft/yr	1.7	m/yr
Effective Treatment Zone Pore Volume	274,313	gallons	1,038,357	liters
Groundwater Flux (per year)	27,307	gallons/year	103,364	liters/year
Total Groundwater Volume Treated (over entire design period)	293,700	gallons total	1,111,745	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.1%	0.074
Nitrate Reduction	0.1%	0.141
Sulfate Reduction	99.8%	115.543
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.0%	0.042
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**115.80**

Hydrogen demand in pounds/gallon:	3.94E-04
Hydrogen demand in grams per liter:	4.72E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	16,102	1,464	3,167	as lactic acid
2. Molasses Product	12,289	1,024	3,008	as sucrose
3. Fructose Product	9,704	866	3,167	as fructose
4. Ethanol Product	4,962	719	1,620	as ethanol
5. Sweet Dry Whey (lactose)	7,654	sold by pound	2,186	as lactose
6. HRC®	5,884	sold by pound	1,920	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	3,021	387	1,233	as soybean oil
8. Emulsified Vegetable Oil	5,035	646	1,233	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 174

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		1463.857672
2. Molasses Product		1024.058131
3. Fructose Product		866.4170305
4. Ethanol Product		719.1000741
5. Sweet Dry Whey (lactose)	7653.772964	
6. HRC®	5883.558223	
7. Linoleic Acid (Soybean Oil)		387.3097901
8. Emulsified Vegetable Oil		645.5163168
9. Lactoil Product		309.8478321
10. Lactic Acid Product		0
11. Hydrogen Gas	115.80	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 181

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	180	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	200	1-1,000	feet	
Saturated Thickness	1	1-100	feet	
Treatment Zone Cross Sectional Area	180	--	ft^2	
Treatment Zone Volume	36,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	67,338	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	53,870	--	gallons	
Design Period of Performance	1.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.3	.01-1000	ft/day	
Average Hydraulic Gradient	0.054	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.62	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	226.7	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	61,053	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.4	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	50	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.060	--	mg/L	
Trichloroethene (TCE)	0.048	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.007	--	mg/L	
Vinyl Chloride (VC)	0.011	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 181

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	180	feet	55	meters
Length (parallel to groundwater flow)	200	feet	61.0	meters
Saturated Thickness	1	feet	0.3	meters
Design Period of Performance	0.97	years	0.97	years

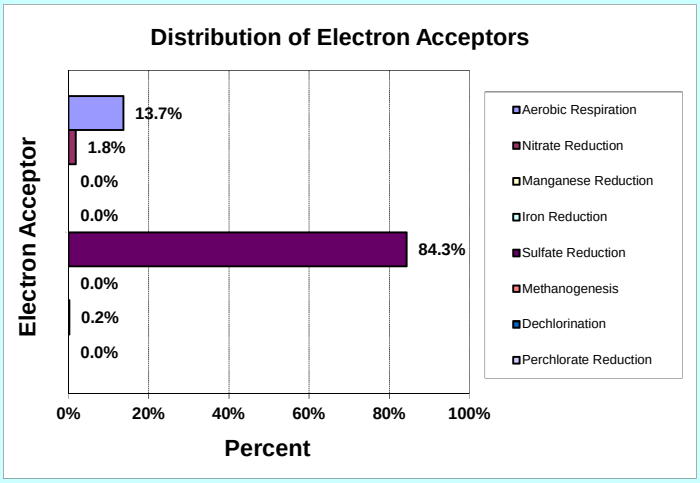
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.3	ft/day	8.1E-04	cm/sec
Average Hydraulic Gradient	0.054	ft/ft	0.054	m/m
Average Groundwater Seepage Velocity	0.62	ft/day	1.9E+01	cm/day
Average Groundwater Seepage Velocity	227	ft/yr	69.1	m/yr
Effective Treatment Zone Pore Volume	53,870	gallons	203,916	liters
Groundwater Flux (per year)	61,053	gallons/year	231,103	liters/year
Total Groundwater Volume Treated (over entire design period)	113,091	gallons total	428,086	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	13.7%	0.644
Nitrate Reduction	1.8%	0.085
Sulfate Reduction	84.3%	3.962
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.2%	0.007
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**4.70**

Hydrogen demand in pounds/gallon:	4.15E-05
Hydrogen demand in grams per liter:	4.98E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	653	59	334	as lactic acid
2. Molasses Product	499	42	317	as sucrose
3. Fructose Product	394	35	334	as fructose
4. Ethanol Product	201	29	171	as ethanol
5. Sweet Dry Whey (lactose)	310	sold by pound	230	as lactose
6. HRC®	239	sold by pound	202	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	123	16	130	as soybean oil
8. Emulsified Vegetable Oil	204	26	130	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 181

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		59.38248016
2. Molasses Product		41.54168321
3. Fructose Product		35.14685418
4. Ethanol Product		29.17083177
5. Sweet Dry Whey (lactose)	310.4810187	
6. HRC®	238.6709352	
7. Linoleic Acid (Soybean Oil)		15.71151101
8. Emulsified Vegetable Oil		26.18585168
9. Lactoil Product		12.56920881
10. Lactic Acid Product		0
11. Hydrogen Gas	4.70	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 182

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	80	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	280	1-1,000	feet	
Saturated Thickness	8.5	1-100	feet	
Treatment Zone Cross Sectional Area	680	--	ft^2	
Treatment Zone Volume	190,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	356,143	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	284,915	--	gallons	
Design Period of Performance	0.4	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	50	.01-1000	ft/day	
Average Hydraulic Gradient	0.011	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	2.75	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	1003.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	1,021,368	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.5	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	40	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.014	--	mg/L	
Trichloroethene (TCE)	0.044	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.968	--	mg/L	
Vinyl Chloride (VC)	0.174	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 182

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	80	feet	24	meters
Length (parallel to groundwater flow)	280	feet	85.3	meters
Saturated Thickness	8.5	feet	2.6	meters
Design Period of Performance	0.35	years	0.35	years

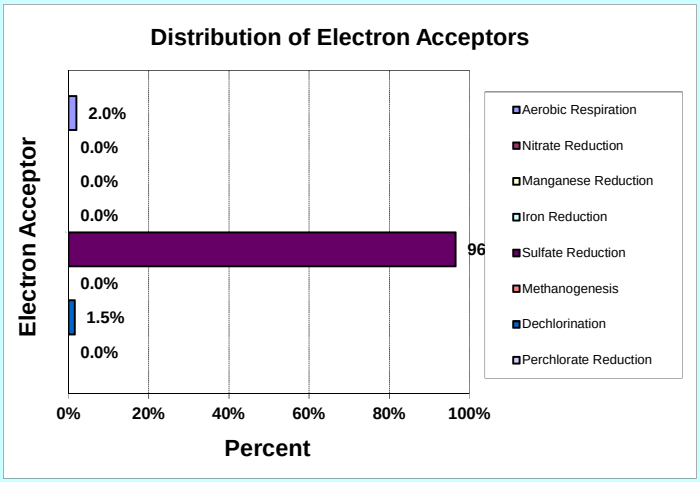
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	50	ft/day	1.8E-02	cm/sec
Average Hydraulic Gradient	0.011	ft/ft	0.011	m/m
Average Groundwater Seepage Velocity	2.75	ft/day	8.4E+01	cm/day
Average Groundwater Seepage Velocity	1004	ft/yr	305.9	m/yr
Effective Treatment Zone Pore Volume	284,915	gallons	1,078,489	liters
Groundwater Flux (per year)	1,021,368	gallons/year	3,866,190	liters/year
Total Groundwater Volume Treated (over entire design period)	642,393	gallons total	2,431,655	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	2.0%	0.361
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	96.5%	17.778
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	1.5%	0.283
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**18.42**

Hydrogen demand in pounds/gallon:	2.87E-05
Hydrogen demand in grams per liter:	3.44E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	2,562	233	230	as lactic acid
2. Molasses Product	1,955	163	219	as sucrose
3. Fructose Product	1,544	138	230	as fructose
4. Ethanol Product	789	114	118	as ethanol
5. Sweet Dry Whey (lactose)	1,218	sold by pound	159	as lactose
6. HRC®	936	sold by pound	140	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	481	62	90	as soybean oil
8. Emulsified Vegetable Oil	801	103	90	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 182

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		232.8799049
2. Molasses Product		162.9137619
3. Fructose Product		137.8352005
4. Ethanol Product		114.3990704
5. Sweet Dry Whey (lactose)	1217.611489	
6. HRC®	935.9943291	
7. Linoleic Acid (Soybean Oil)		61.61573547
8. Emulsified Vegetable Oil		102.6928925
9. Lactoil Product		49.29258838
10. Lactic Acid Product		0
11. Hydrogen Gas	18.42	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 195

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	150	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	180	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	1800	--	ft^2	
Treatment Zone Volume	324,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	606,042	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	484,834	--	gallons	
Design Period of Performance	0.4	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	72	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	2.52	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	919.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	2,477,500	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	25	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	3.770	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.662	--	mg/L	
Vinyl Chloride (VC)	0.034	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 195

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	150	feet	46	meters
Length (parallel to groundwater flow)	180	feet	54.9	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	0.41	years	0.41	years

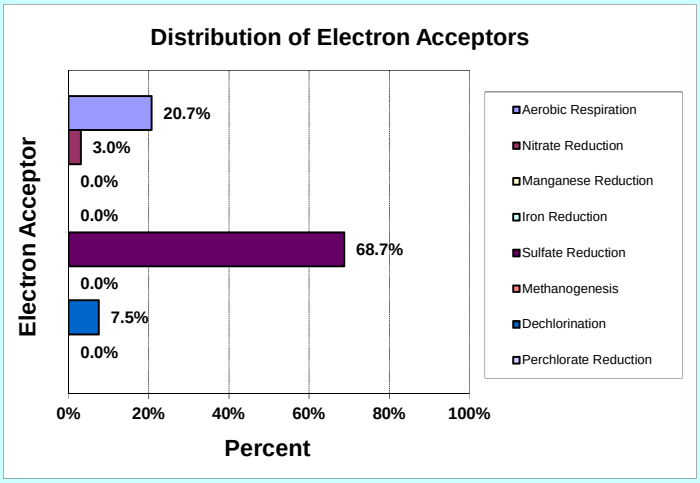
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	72	ft/day	2.5E-02	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	2.52	ft/day	7.7E+01	cm/day
Average Groundwater Seepage Velocity	920	ft/yr	280.4	m/yr
Effective Treatment Zone Pore Volume	484,834	gallons	1,835,244	liters
Groundwater Flux (per year)	2,477,500	gallons/year	9,378,094	liters/year
Total Groundwater Volume Treated (over entire design period)	1,500,608	gallons total	5,680,262	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	20.7%	7.885
Nitrate Reduction	3.0%	1.156
Sulfate Reduction	68.7%	26.179
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	7.5%	2.871
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**38.09**

Hydrogen demand in pounds/gallon:	2.54E-05
Hydrogen demand in grams per liter:	3.04E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	5,297	482	204	as lactic acid
2. Molasses Product	4,042	337	194	as sucrose
3. Fructose Product	3,192	285	204	as fructose
4. Ethanol Product	1,632	237	104	as ethanol
5. Sweet Dry Whey (lactose)	2,518	sold by pound	141	as lactose
6. HRC®	1,935	sold by pound	124	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	994	127	79	as soybean oil
8. Emulsified Vegetable Oil	1,656	212	79	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 195

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		481.5284322
2. Molasses Product		336.8586414
3. Fructose Product		285.0034142
4. Ethanol Product		236.5442611
5. Sweet Dry Whey (lactose)	2517.669148	
6. HRC®	1935.366137	
7. Linoleic Acid (Soybean Oil)		127.4035582
8. Emulsified Vegetable Oil		212.3392636
9. Lactoil Product		101.9228465
10. Lactic Acid Product		0
11. Hydrogen Gas	38.09	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 197

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	164	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	750	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	1968	--	ft^2	
Treatment Zone Volume	1,476,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	2,760,858	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	2,208,686	--	gallons	
Design Period of Performance	2.6	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	72	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	2.52	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	919.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	2,708,733	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	35	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.907	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	1.086	--	mg/L	
Vinyl Chloride (VC)	0.019	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 197

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	164	feet	50	meters
Length (parallel to groundwater flow)	750	feet	228.6	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	2.56	years	2.56	years

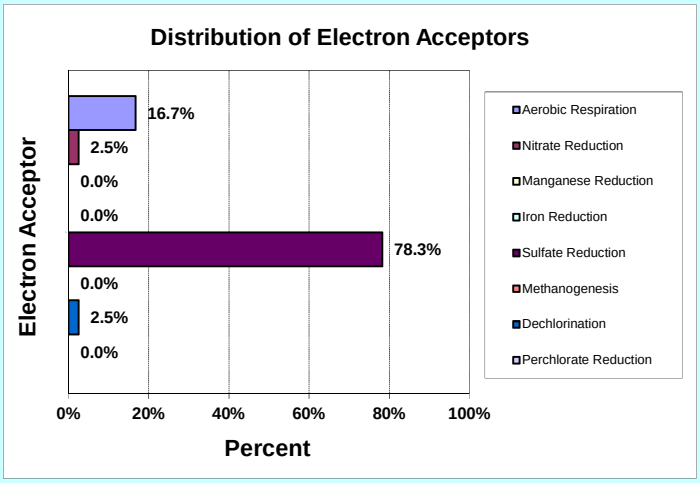
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	72	ft/day	2.5E-02	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	2.52	ft/day	7.7E+01	cm/day
Average Groundwater Seepage Velocity	920	ft/yr	280.4	m/yr
Effective Treatment Zone Pore Volume	2,208,686	gallons	8,360,554	liters
Groundwater Flux (per year)	2,708,733	gallons/year	10,253,383	liters/year
Total Groundwater Volume Treated (over entire design period)	9,143,043	gallons total	34,609,215	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	16.7%	48.044
Nitrate Reduction	2.5%	7.144
Sulfate Reduction	78.3%	224.700
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	2.5%	7.186
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**287.07**

Hydrogen demand in pounds/gallon:	3.14E-05
Hydrogen demand in grams per liter:	3.76E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	39,919	3,629	252	as lactic acid
2. Molasses Product	30,464	2,539	240	as sucrose
3. Fructose Product	24,056	2,148	252	as fructose
4. Ethanol Product	12,301	1,783	129	as ethanol
5. Sweet Dry Whey (lactose)	18,974	sold by pound	174	as lactose
6. HRC®	14,586	sold by pound	153	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	7,489	960	98	as soybean oil
8. Emulsified Vegetable Oil	12,482	1,600	98	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading
Treatment 197

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		3628.96978
2. Molasses Product		2538.686706
3. Fructose Product		2147.887244
4. Ethanol Product		1782.681806
5. Sweet Dry Whey (lactose)	18974.05146	
6. HRC®	14585.60856	
7. Linoleic Acid (Soybean Oil)		960.1585939
8. Emulsified Vegetable Oil		1600.264323
9. Lactoil Product		768.1268751
10. Lactic Acid Product		0
11. Hydrogen Gas	287.07	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 220

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	120	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	210	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	1440	--	ft^2	
Treatment Zone Volume	302,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	565,639	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	452,511	--	gallons	
Design Period of Performance	1.9	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	10	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.35	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	127.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	275,278	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.6	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	403	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.905	--	mg/L	
Trichloroethene (TCE)	0.103	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.082	--	mg/L	
Vinyl Chloride (VC)	0.007	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 220

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	120	feet	37	meters
Length (parallel to groundwater flow)	210	feet	64.0	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	1.94	years	1.94	years

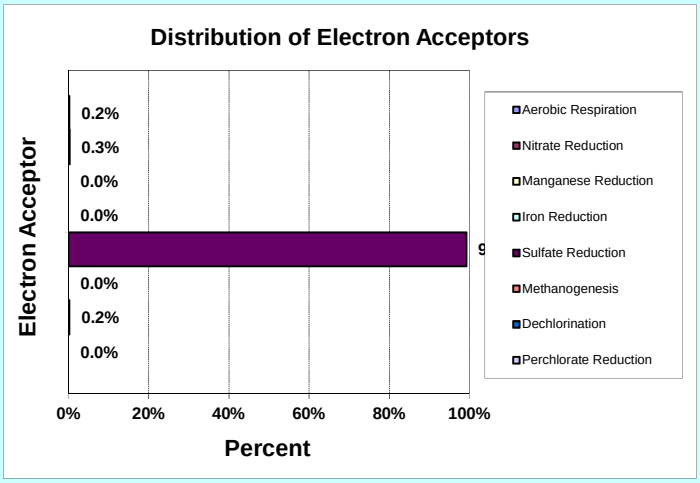
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	10	ft/day	3.5E-03	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	0.35	ft/day	1.1E+01	cm/day
Average Groundwater Seepage Velocity	128	ft/yr	38.9	m/yr
Effective Treatment Zone Pore Volume	452,511	gallons	1,712,894	liters
Groundwater Flux (per year)	275,278	gallons/year	1,042,010	liters/year
Total Groundwater Volume Treated (over entire design period)	986,550	gallons total	3,734,394	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.2%	0.643
Nitrate Reduction	0.3%	0.742
Sulfate Reduction	99.3%	278.212
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.2%	0.627
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**280.22**

Hydrogen demand in pounds/gallon:	2.84E-04
Hydrogen demand in grams per liter:	3.40E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	38,966	3,542	2,281	as lactic acid
2. Molasses Product	29,737	2,478	2,167	as sucrose
3. Fructose Product	23,482	2,097	2,282	as fructose
4. Ethanol Product	12,007	1,740	1,167	as ethanol
5. Sweet Dry Whey (lactose)	18,521	sold by pound	1,575	as lactose
6. HRC®	14,238	sold by pound	1,384	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	7,311	937	888	as soybean oil
8. Emulsified Vegetable Oil	12,184	1,562	888	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 220

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		3542.375818
2. Molasses Product		2478.108924
3. Fructose Product		2096.634663
4. Ethanol Product		1740.143705
5. Sweet Dry Whey (lactose)	18521.29533	
6. HRC®	14237.56884	
7. Linoleic Acid (Soybean Oil)		937.2474258
8. Emulsified Vegetable Oil		1562.079043
9. Lactoil Product		749.7979406
10. Lactic Acid Product		2296.048482
11. Hydrogen Gas	280.22	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 221

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	90	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	170	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	1080	--	ft^2	
Treatment Zone Volume	183,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	343,424	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	274,739	--	gallons	
Design Period of Performance	1.6	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	10	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.35	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	127.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	206,458	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	361	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	6.450	--	mg/L	
Trichloroethene (TCE)	2.560	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	8.047	--	mg/L	
Vinyl Chloride (VC)	0.039	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 221

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	90	feet	27	meters
Length (parallel to groundwater flow)	170	feet	51.8	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	1.61	years	1.61	years

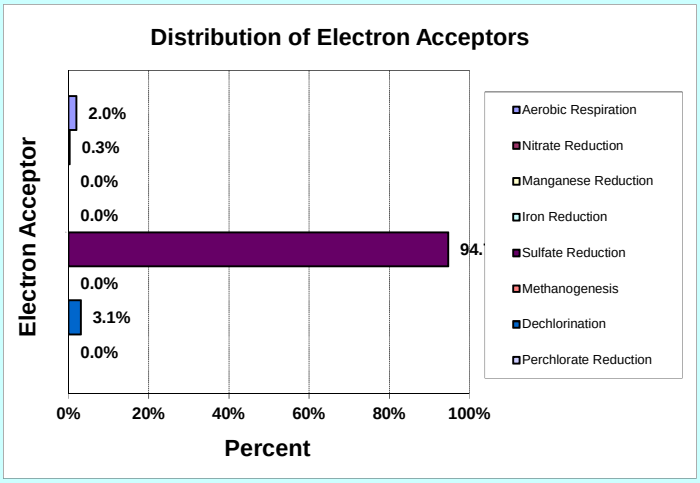
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	10	ft/day	3.5E-03	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	0.35	ft/day	1.1E+01	cm/day
Average Groundwater Seepage Velocity	128	ft/yr	38.9	m/yr
Effective Treatment Zone Pore Volume	274,739	gallons	1,039,971	liters
Groundwater Flux (per year)	206,458	gallons/year	781,508	liters/year
Total Groundwater Volume Treated (over entire design period)	607,137	gallons total	2,298,199	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	2.0%	3.190
Nitrate Reduction	0.3%	0.457
Sulfate Reduction	94.7%	153.562
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	3.1%	4.960
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**162.17**

Hydrogen demand in pounds/gallon:	2.67E-04
Hydrogen demand in grams per liter:	3.20E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	22,550	2,050	2,145	as lactic acid
2. Molasses Product	17,209	1,434	2,038	as sucrose
3. Fructose Product	13,590	1,213	2,146	as fructose
4. Ethanol Product	6,949	1,007	1,097	as ethanol
5. Sweet Dry Whey (lactose)	10,719	sold by pound	1,481	as lactose
6. HRC®	8,239	sold by pound	1,301	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	4,231	542	835	as soybean oil
8. Emulsified Vegetable Oil	7,051	904	835	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 221

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		2050.025539
2. Molasses Product		1434.118469
3. Fructose Product		1213.353644
4. Ethanol Product		1007.047028
5. Sweet Dry Whey (lactose)	10718.54891	
6. HRC®	8239.492714	
7. Linoleic Acid (Soybean Oil)		542.3990165
8. Emulsified Vegetable Oil		903.9983608
9. Lactoil Product		433.9192132
10. Lactic Acid Product		1328.757385
11. Hydrogen Gas	162.17	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 223

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	120	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	210	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	1440	--	ft^2	
Treatment Zone Volume	302,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	565,639	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	452,511	--	gallons	
Design Period of Performance	0.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	10	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.35	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	127.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	275,278	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.6	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	476	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	165.011	--	mg/L	
Trichloroethene (TCE)	0.457	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.456	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 223

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	120	feet	37	meters
Length (parallel to groundwater flow)	210	feet	64.0	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	0	years	0	years

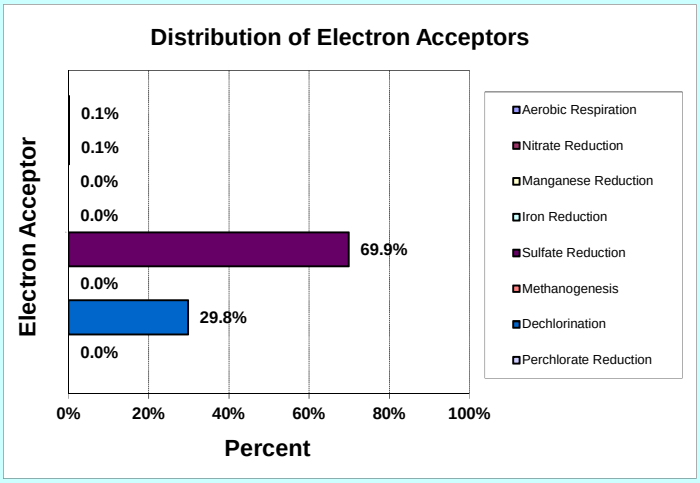
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	10	ft/day	3.5E-03	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	0.35	ft/day	1.1E+01	cm/day
Average Groundwater Seepage Velocity	128	ft/yr	38.9	m/yr
Effective Treatment Zone Pore Volume	452,511	gallons	1,712,894	liters
Groundwater Flux (per year)	275,278	gallons/year	1,042,010	liters/year
Total Groundwater Volume Treated (over entire design period)	452,511	gallons total	1,712,894	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.1%	0.295
Nitrate Reduction	0.1%	0.307
Sulfate Reduction	69.9%	150.913
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	29.8%	64.352
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**215.87**

Hydrogen demand in pounds/gallon:	4.77E-04
Hydrogen demand in grams per liter:	5.72E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	30,017	2,729	3,831	as lactic acid
2. Molasses Product	22,908	1,909	3,640	as sucrose
3. Fructose Product	18,089	1,615	3,832	as fructose
4. Ethanol Product	9,249	1,341	1,960	as ethanol
5. Sweet Dry Whey (lactose)	14,268	sold by pound	2,645	as lactose
6. HRC®	10,968	sold by pound	2,324	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	5,632	722	1,491	as soybean oil
8. Emulsified Vegetable Oil	9,386	1,203	1,491	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 223

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		2728.830464
2. Molasses Product		1908.984104
3. Fructose Product		1615.119579
4. Ethanol Product		1340.500669
5. Sweet Dry Whey (lactose)	14267.67727	
6. HRC®	10967.75542	
7. Linoleic Acid (Soybean Oil)		721.9983025
8. Emulsified Vegetable Oil		1203.330504
9. Lactoil Product		577.598642
10. Lactic Acid Product		0
11. Hydrogen Gas	215.87	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 224

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	75	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	30	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	900	--	ft^2	
Treatment Zone Volume	27,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	50,504	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	40,403	--	gallons	
Design Period of Performance	1.6	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	10	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.35	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	127.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	172,049	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen		0.01 to 10	mg/L	Default = 5
Nitrate		0.1 to- 20	mg/L	Default = 1
Sulfate		10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)		0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)		--	mg/L	
Trichloroethene (TCE)		--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)		--	mg/L	
Vinyl Chloride (VC)		--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 224

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	75	feet	23	meters
Length (parallel to groundwater flow)	30	feet	9.1	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	1.57	years	1.57	years

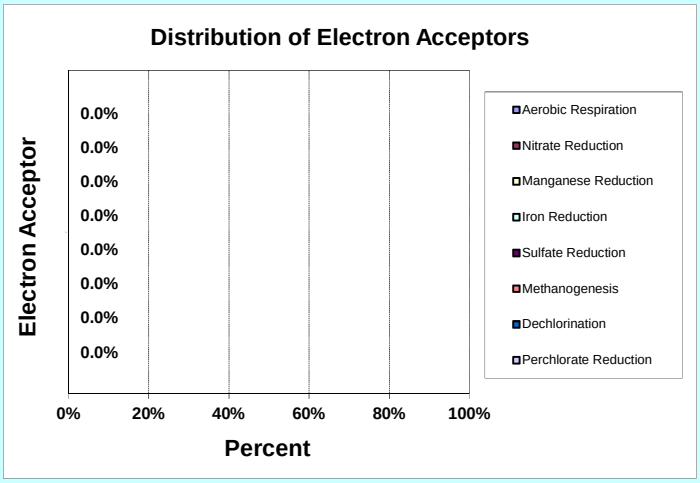
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	10	ft/day	3.5E-03	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	0.35	ft/day	1.1E+01	cm/day
Average Groundwater Seepage Velocity	128	ft/yr	38.9	m/yr
Effective Treatment Zone Pore Volume	40,403	gallons	152,937	liters
Groundwater Flux (per year)	172,049	gallons/year	651,257	liters/year
Total Groundwater Volume Treated (over entire design period)	310,519	gallons total	1,175,410	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	#DIV/0!	0.000
Nitrate Reduction	#DIV/0!	0.000
Sulfate Reduction	#DIV/0!	0.000
Manganese Reduction	#DIV/0!	0.000
Iron Reduction	#DIV/0!	0.000
Methanogenesis	#DIV/0!	0.000
Dechlorination	#DIV/0!	0.000
Perchlorate Reduction	#DIV/0!	0.000
Totals:	**#DIV/0!**	**0.00**

Hydrogen demand in pounds/gallon:	0.00E+00
Hydrogen demand in grams per liter:	0.00E+00



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	0	0	0	as lactic acid
2. Molasses Product	0	0	0	as sucrose
3. Fructose Product	0	0	0	as fructose
4. Ethanol Product	0	0	0	as ethanol
5. Sweet Dry Whey (lactose)	0	sold by pound	0	as lactose
6. HRC®	0	sold by pound	0	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	0	0	0	as soybean oil
8. Emulsified Vegetable Oil	0	0	0	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading
Treatment 224

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		0
2. Molasses Product		0
3. Fructose Product		0
4. Ethanol Product		0
5. Sweet Dry Whey (lactose)	0	
6. HRC®	0	
7. Linoleic Acid (Soybean Oil)		0
8. Emulsified Vegetable Oil		0
9. Lactoil Product		0
10. Lactic Acid Product		0
11. Hydrogen Gas	0.00	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 229

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	170	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	340	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	2040	--	ft^2	
Treatment Zone Volume	693,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,297,379	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	1,037,903	--	gallons	
Design Period of Performance	2.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	10	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.35	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	127.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	389,977	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	215	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.157	--	mg/L	
Trichloroethene (TCE)	0.015	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.486	--	mg/L	
Vinyl Chloride (VC)	0.227	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 229

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	170	feet	52	meters
Length (parallel to groundwater flow)	340	feet	103.6	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	1.99	years	1.99	years

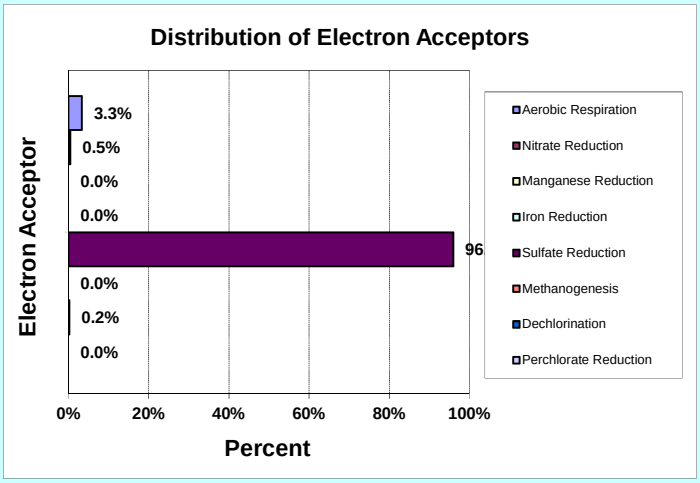
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	10	ft/day	3.5E-03	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	0.35	ft/day	1.1E+01	cm/day
Average Groundwater Seepage Velocity	128	ft/yr	38.9	m/yr
Effective Treatment Zone Pore Volume	1,037,903	gallons	3,928,781	liters
Groundwater Flux (per year)	389,977	gallons/year	1,476,182	liters/year
Total Groundwater Volume Treated (over entire design period)	1,813,957	gallons total	6,866,382	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	3.3%	9.532
Nitrate Reduction	0.5%	1.336
Sulfate Reduction	96.0%	273.565
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.2%	0.653
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**285.09**

Hydrogen demand in pounds/gallon:	1.57E-04
Hydrogen demand in grams per liter:	1.88E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	39,642	3,604	1,262	as lactic acid
2. Molasses Product	30,253	2,521	1,199	as sucrose
3. Fructose Product	23,890	2,133	1,263	as fructose
4. Ethanol Product	12,215	1,770	646	as ethanol
5. Sweet Dry Whey (lactose)	18,843	sold by pound	871	as lactose
6. HRC®	14,485	sold by pound	765	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	7,437	954	491	as soybean oil
8. Emulsified Vegetable Oil	12,396	1,589	491	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading
Treatment 229

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		3603.840667
2. Molasses Product		2521.107352
3. Fructose Product		2133.014014
4. Ethanol Product		1770.337472
5. Sweet Dry Whey (lactose)	18842.66401	
6. HRC®	14484.60926	
7. Linoleic Acid (Soybean Oil)		953.5098932
8. Emulsified Vegetable Oil		1589.183155
9. Lactoil Product		762.8079146
10. Lactic Acid Product		2335.887924
11. Hydrogen Gas	285.09	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 230

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	75	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	30	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	900	--	ft^2	
Treatment Zone Volume	27,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	50,504	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	40,403	--	gallons	
Design Period of Performance	0.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	10	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.35	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	127.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	172,049	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	174	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.060	--	mg/L	
Vinyl Chloride (VC)	0.009	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 230

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	75	feet	23	meters
Length (parallel to groundwater flow)	30	feet	9.1	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	0.81	years	0.81	years

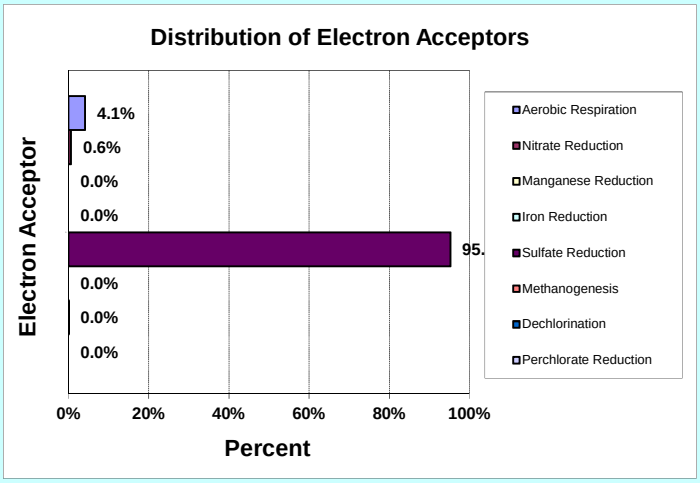
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	10	ft/day	3.5E-03	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	0.35	ft/day	1.1E+01	cm/day
Average Groundwater Seepage Velocity	128	ft/yr	38.9	m/yr
Effective Treatment Zone Pore Volume	40,403	gallons	152,937	liters
Groundwater Flux (per year)	172,049	gallons/year	651,257	liters/year
Total Groundwater Volume Treated (over entire design period)	179,762	gallons total	680,455	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	4.1%	0.945
Nitrate Reduction	0.6%	0.141
Sulfate Reduction	95.3%	21.873
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.0%	0.004
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**22.96**

Hydrogen demand in pounds/gallon:	1.28E-04
Hydrogen demand in grams per liter:	1.53E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	3,193	290	1,026	as lactic acid
2. Molasses Product	2,437	203	975	as sucrose
3. Fructose Product	1,924	172	1,026	as fructose
4. Ethanol Product	984	143	525	as ethanol
5. Sweet Dry Whey (lactose)	1,518	sold by pound	708	as lactose
6. HRC®	1,167	sold by pound	622	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	599	77	399	as soybean oil
8. Emulsified Vegetable Oil	998	128	399	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 230

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		290.2815873
2. Molasses Product		203.0697557
3. Fructose Product		171.809675
4. Ethanol Product		142.5968624
5. Sweet Dry Whey (lactose)	1517.735916	
6. HRC®	1166.704013	
7. Linoleic Acid (Soybean Oil)		76.80316387
8. Emulsified Vegetable Oil		128.0052731
9. Lactoil Product		61.4425311
10. Lactic Acid Product		0
11. Hydrogen Gas	22.96	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 231

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	170	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	600	--	ft^2	
Treatment Zone Volume	102,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	190,791	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	152,633	--	gallons	
Design Period of Performance	2.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	10	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.35	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	127.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	114,699	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	104	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.090	--	mg/L	
Vinyl Chloride (VC)	0.060	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 231

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	170	feet	51.8	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	1.99	years	1.99	years

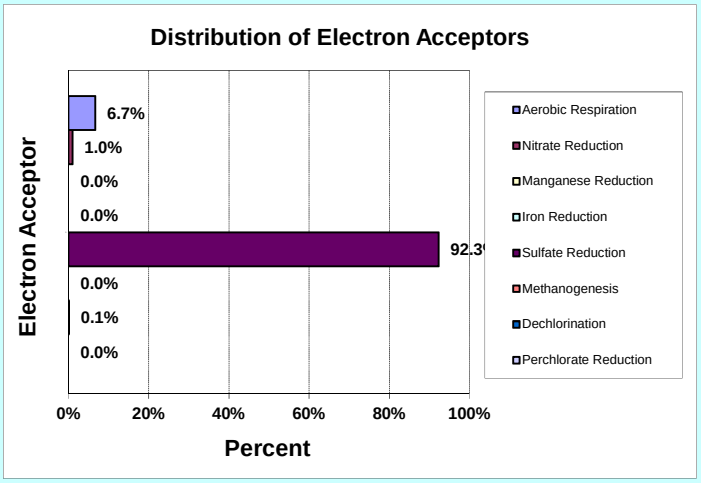
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	10	ft/day	3.5E-03	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	0.35	ft/day	1.1E+01	cm/day
Average Groundwater Seepage Velocity	128	ft/yr	38.9	m/yr
Effective Treatment Zone Pore Volume	152,633	gallons	577,762	liters
Groundwater Flux (per year)	114,699	gallons/year	434,171	liters/year
Total Groundwater Volume Treated (over entire design period)	380,884	gallons total	1,441,762	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	6.7%	2.001
Nitrate Reduction	1.0%	0.289
Sulfate Reduction	92.3%	27.753
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.1%	0.019
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**30.06**

Hydrogen demand in pounds/gallon:	7.89E-05
Hydrogen demand in grams per liter:	9.46E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	4,180	380	634	as lactic acid
2. Molasses Product	3,190	266	602	as sucrose
3. Fructose Product	2,519	225	634	as fructose
4. Ethanol Product	1,288	187	324	as ethanol
5. Sweet Dry Whey (lactose)	1,987	sold by pound	438	as lactose
6. HRC®	1,527	sold by pound	384	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	784	101	247	as soybean oil
8. Emulsified Vegetable Oil	1,307	168	247	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 231

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		380.0375407
2. Molasses Product		265.8595445
3. Fructose Product		224.9337513
4. Ethanol Product		186.6882477
5. Sweet Dry Whey (lactose)	1987.024498	
6. HRC®	1527.452457	
7. Linoleic Acid (Soybean Oil)		100.5509367
8. Emulsified Vegetable Oil		167.5848945
9. Lactoil Product		80.44074938
10. Lactic Acid Product		0
11. Hydrogen Gas	30.06	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 233

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	420	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	655	1-1,000	feet	
Saturated Thickness	28.1	1-100	feet	
Treatment Zone Cross Sectional Area	11802	--	ft^2	
Treatment Zone Volume	7,730,310	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	14,459,545	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	11,567,636	--	gallons	
Design Period of Performance	4.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	50	.01-1000	ft/day	
Average Hydraulic Gradient	0.023	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	5.75	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	2098.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	37,065,001	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	4.1	0.01 to 10	mg/L	Default = 5
Nitrate	5.40	0.1 to- 20	mg/L	Default = 1
Sulfate	102	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.002	--	mg/L	
Trichloroethene (TCE)	5.087	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.020	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 233

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	420	feet	128	meters
Length (parallel to groundwater flow)	655	feet	199.6	meters
Saturated Thickness	28.1	feet	8.6	meters
Design Period of Performance	3.99	years	3.99	years

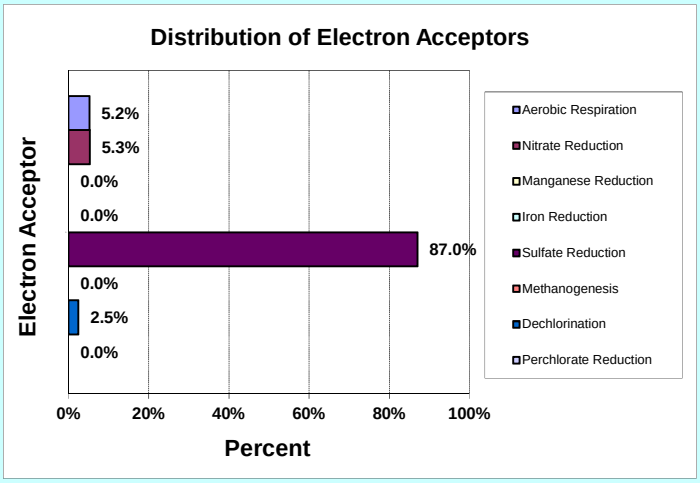
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	50	ft/day	1.8E-02	cm/sec
Average Hydraulic Gradient	0.023	ft/ft	0.023	m/m
Average Groundwater Seepage Velocity	5.75	ft/day	1.8E+02	cm/day
Average Groundwater Seepage Velocity	2099	ft/yr	639.7	m/yr
Effective Treatment Zone Pore Volume	11,567,636	gallons	43,787,042	liters
Groundwater Flux (per year)	37,065,001	gallons/year	140,302,372	liters/year
Total Groundwater Volume Treated (over entire design period)	159,456,991	gallons total	603,593,504	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	5.2%	683.732
Nitrate Reduction	5.3%	692.521
Sulfate Reduction	87.0%	11406.698
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	2.5%	323.034
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**13105.99**

Hydrogen demand in pounds/gallon:	8.22E-05
Hydrogen demand in grams per liter:	9.85E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	1,822,434	165,676	660	as lactic acid
2. Molasses Product	1,390,804	115,900	627	as sucrose
3. Fructose Product	1,098,260	98,059	660	as fructose
4. Ethanol Product	561,563	81,386	338	as ethanol
5. Sweet Dry Whey (lactose)	866,235	sold by pound	456	as lactose
6. HRC®	665,887	sold by pound	400	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	341,911	43,835	257	as soybean oil
8. Emulsified Vegetable Oil	569,852	73,058	257	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 233

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		165675.7964
2. Molasses Product		115900.3705
3. Fructose Product		98058.93996
4. Ethanol Product		81385.97063
5. Sweet Dry Whey (lactose)	866235.1238	
6. HRC®	665886.5908	
7. Linoleic Acid (Soybean Oil)		43834.76562
8. Emulsified Vegetable Oil		73057.94269
9. Lactoil Product		35067.81249
10. Lactic Acid Product		0
11. Hydrogen Gas	13105.99	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 234

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	200	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	240	1-1,000	feet	
Saturated Thickness	37	1-100	feet	
Treatment Zone Cross Sectional Area	7400	--	ft^2	
Treatment Zone Volume	1,776,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	3,322,008	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	2,657,606	--	gallons	
Design Period of Performance	0.7	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	50	.01-1000	ft/day	
Average Hydraulic Gradient	0.023	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	5.75	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	2098.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	23,240,214	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.7	0.01 to 10	mg/L	Default = 5
Nitrate	2.44	0.1 to- 20	mg/L	Default = 1
Sulfate	214	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.004	--	mg/L	
Trichloroethene (TCE)	12.580	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.037	--	mg/L	
Vinyl Chloride (VC)	0.002	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 234

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	200	feet	61	meters
Length (parallel to groundwater flow)	240	feet	73.2	meters
Saturated Thickness	37	feet	11.3	meters
Design Period of Performance	0.67	years	0.67	years

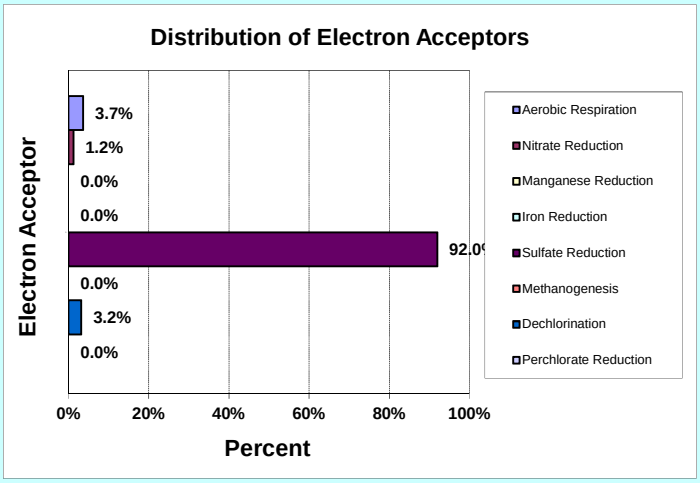
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	50	ft/day	1.8E-02	cm/sec
Average Hydraulic Gradient	0.023	ft/ft	0.023	m/m
Average Groundwater Seepage Velocity	5.75	ft/day	1.8E+02	cm/day
Average Groundwater Seepage Velocity	2099	ft/yr	639.7	m/yr
Effective Treatment Zone Pore Volume	2,657,606	gallons	10,059,853	liters
Groundwater Flux (per year)	23,240,214	gallons/year	87,971,323	liters/year
Total Groundwater Volume Treated (over entire design period)	18,228,550	gallons total	69,000,640	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	3.7%	108.239
Nitrate Reduction	1.2%	35.329
Sulfate Reduction	92.0%	2727.359
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	3.2%	94.183
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**2965.11**

Hydrogen demand in pounds/gallon:	1.63E-04
Hydrogen demand in grams per liter:	1.95E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	412,309	37,483	1,306	as lactic acid
2. Molasses Product	314,657	26,221	1,241	as sucrose
3. Fructose Product	248,471	22,185	1,307	as fructose
4. Ethanol Product	127,049	18,413	668	as ethanol
5. Sweet Dry Whey (lactose)	195,978	sold by pound	902	as lactose
6. HRC®	150,651	sold by pound	792	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	77,354	9,917	509	as soybean oil
8. Emulsified Vegetable Oil	128,924	16,529	509	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 234

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		37482.64734
2. Molasses Product		26221.40836
3. Fructose Product		22184.94641
4. Ethanol Product		18412.83821
5. Sweet Dry Whey (lactose)	195977.8457	
6. HRC®	150650.8059	
7. Linoleic Acid (Soybean Oil)		9917.218425
8. Emulsified Vegetable Oil		16528.69738
9. Lactoil Product		7933.77474
10. Lactic Acid Product		0
11. Hydrogen Gas	2965.11	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 235

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	200	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	240	1-1,000	feet	
Saturated Thickness	37	1-100	feet	
Treatment Zone Cross Sectional Area	7400	--	ft^2	
Treatment Zone Volume	1,776,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	3,322,008	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	2,657,606	--	gallons	
Design Period of Performance	3.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	50	.01-1000	ft/day	
Average Hydraulic Gradient	0.023	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	5.75	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	2098.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	23,240,214	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	2.9	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	47	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	7.509	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	4.877	--	mg/L	
Vinyl Chloride (VC)	0.004	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 235

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	200	feet	61	meters
Length (parallel to groundwater flow)	240	feet	73.2	meters
Saturated Thickness	37	feet	11.3	meters
Design Period of Performance	2.99	years	2.99	years

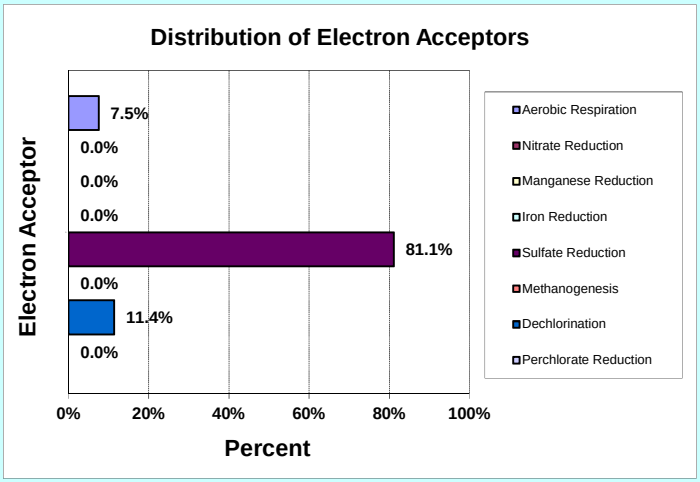
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	50	ft/day	1.8E-02	cm/sec
Average Hydraulic Gradient	0.023	ft/ft	0.023	m/m
Average Groundwater Seepage Velocity	5.75	ft/day	1.8E+02	cm/day
Average Groundwater Seepage Velocity	2099	ft/yr	639.7	m/yr
Effective Treatment Zone Pore Volume	2,657,606	gallons	10,059,853	liters
Groundwater Flux (per year)	23,240,214	gallons/year	87,971,323	liters/year
Total Groundwater Volume Treated (over entire design period)	72,145,847	gallons total	273,094,108	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	7.5%	220.641
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	81.1%	2383.327
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	11.4%	334.540
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**2938.51**

Hydrogen demand in pounds/gallon:	4.07E-05
Hydrogen demand in grams per liter:	4.88E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	408,610	37,146	327	as lactic acid
2. Molasses Product	311,834	25,986	311	as sucrose
3. Fructose Product	246,242	21,986	327	as fructose
4. Ethanol Product	125,909	18,248	167	as ethanol
5. Sweet Dry Whey (lactose)	194,220	sold by pound	226	as lactose
6. HRC®	149,299	sold by pound	198	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	76,660	9,828	127	as soybean oil
8. Emulsified Vegetable Oil	127,767	16,380	127	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 235

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		37146.36247
2. Molasses Product		25986.15649
3. Fructose Product		21985.90866
4. Ethanol Product		18247.64287
5. Sweet Dry Whey (lactose)	194219.5818	
6. HRC®	149299.2048	
7. Linoleic Acid (Soybean Oil)		9828.243639
8. Emulsified Vegetable Oil		16380.40607
9. Lactoil Product		7862.594912
10. Lactic Acid Product		0
11. Hydrogen Gas	2938.51	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 237

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	80	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	80	1-1,000	feet	
Saturated Thickness	11.5	1-100	feet	
Treatment Zone Cross Sectional Area	920	--	ft^2	
Treatment Zone Volume	73,600	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	137,669	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	110,135	--	gallons	
Design Period of Performance	2.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.4	.01-1000	ft/day	
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.02	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	8.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	12,060	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.5	0.01 to 10	mg/L	Default = 5
Nitrate	0.13	0.1 to- 20	mg/L	Default = 1
Sulfate	803	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.968	--	mg/L	
Trichloroethene (TCE)	0.185	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.068	--	mg/L	
Vinyl Chloride (VC)	0.001	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.050	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 237

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	80	feet	24	meters
Length (parallel to groundwater flow)	80	feet	24.4	meters
Saturated Thickness	11.5	feet	3.5	meters
Design Period of Performance	2.04	years	2.04	years

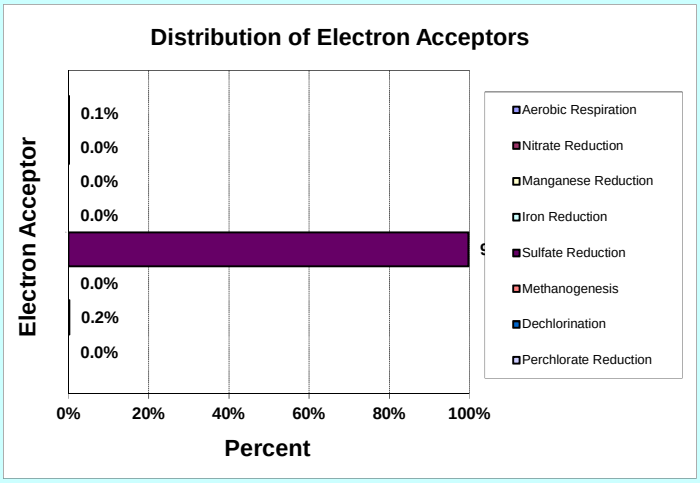
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.4	ft/day	8.5E-04	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	0.02	ft/day	7.3E-01	cm/day
Average Groundwater Seepage Velocity	9	ft/yr	2.7	m/yr
Effective Treatment Zone Pore Volume	110,135	gallons	416,895	liters
Groundwater Flux (per year)	12,060	gallons/year	45,650	liters/year
Total Groundwater Volume Treated (over entire design period)	134,737	gallons total	510,021	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.1%	0.077
Nitrate Reduction	0.0%	0.012
Sulfate Reduction	99.7%	75.804
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.2%	0.121
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**76.01**

Hydrogen demand in pounds/gallon:	5.64E-04
Hydrogen demand in grams per liter:	6.76E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	10,570	961	4,531	as lactic acid
2. Molasses Product	8,067	672	4,305	as sucrose
3. Fructose Product	6,370	569	4,532	as fructose
4. Ethanol Product	3,257	472	2,317	as ethanol
5. Sweet Dry Whey (lactose)	5,024	sold by pound	3,128	as lactose
6. HRC®	3,862	sold by pound	2,748	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	1,983	254	1,764	as soybean oil
8. Emulsified Vegetable Oil	3,305	424	1,764	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 237

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		960.9157161
2. Molasses Product		672.2194183
3. Fructose Product		568.7395417
4. Ethanol Product		472.0367123
5. Sweet Dry Whey (lactose)	5024.143311	
6. HRC®	3862.126539	
7. Linoleic Acid (Soybean Oil)		254.2406079
8. Emulsified Vegetable Oil		423.7343465
9. Lactoil Product		203.3924863
10. Lactic Acid Product		0
11. Hydrogen Gas	76.01	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 238

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	105	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	110	1-1,000	feet	
Saturated Thickness	11.5	1-100	feet	
Treatment Zone Cross Sectional Area	1207.5	--	ft^2	
Treatment Zone Volume	132,825	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	248,449	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	198,759	--	gallons	
Design Period of Performance	1.4	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.4	.01-1000	ft/day	
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.02	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	8.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	15,828	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.8	0.01 to 10	mg/L	Default = 5
Nitrate	0.12	0.1 to- 20	mg/L	Default = 1
Sulfate	485	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	2.000	--	mg/L	
Trichloroethene (TCE)	0.411	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.395	--	mg/L	
Vinyl Chloride (VC)	0.001	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.052	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 238

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	105	feet	32	meters
Length (parallel to groundwater flow)	110	feet	33.5	meters
Saturated Thickness	11.5	feet	3.5	meters
Design Period of Performance	1.42	years	1.42	years

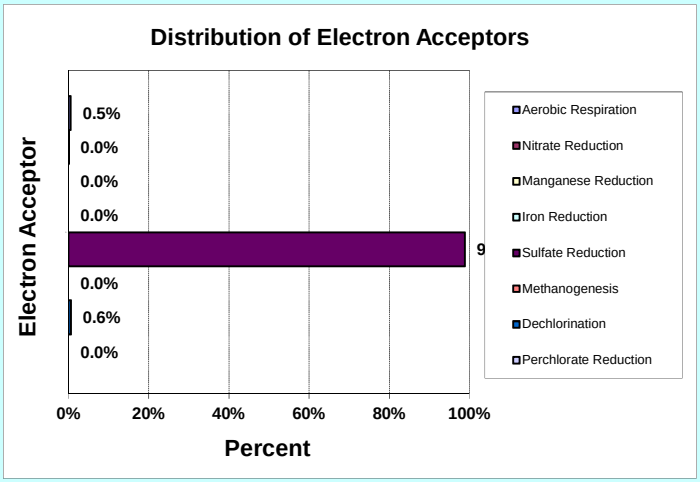
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.4	ft/day	8.5E-04	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	0.02	ft/day	7.3E-01	cm/day
Average Groundwater Seepage Velocity	9	ft/yr	2.7	m/yr
Effective Treatment Zone Pore Volume	198,759	gallons	752,365	liters
Groundwater Flux (per year)	15,828	gallons/year	59,916	liters/year
Total Groundwater Volume Treated (over entire design period)	221,236	gallons total	837,445	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.5%	0.409
Nitrate Reduction	0.0%	0.018
Sulfate Reduction	98.8%	75.139
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.6%	0.449
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**76.01**

Hydrogen demand in pounds/gallon:	3.44E-04
Hydrogen demand in grams per liter:	4.12E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	10,570	961	2,760	as lactic acid
2. Molasses Product	8,067	672	2,622	as sucrose
3. Fructose Product	6,370	569	2,760	as fructose
4. Ethanol Product	3,257	472	1,411	as ethanol
5. Sweet Dry Whey (lactose)	5,024	sold by pound	1,905	as lactose
6. HRC®	3,862	sold by pound	1,674	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	1,983	254	1,074	as soybean oil
8. Emulsified Vegetable Oil	3,305	424	1,074	as soybean oil

Notes:
1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 238

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		960.9142187
2. Molasses Product		672.2183708
3. Fructose Product		568.7386554
4. Ethanol Product		472.0359767
5. Sweet Dry Whey (lactose)	5024.135482	
6. HRC®	3862.120521	
7. Linoleic Acid (Soybean Oil)		254.2402117
8. Emulsified Vegetable Oil		423.7336862
9. Lactoil Product		203.3921694
10. Lactic Acid Product		0
11. Hydrogen Gas	76.01	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 239

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	77	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	48	1-1,000	feet	
Saturated Thickness	11.5	1-100	feet	
Treatment Zone Cross Sectional Area	885.5	--	ft^2	
Treatment Zone Volume	42,504	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	79,504	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	63,603	--	gallons	
Design Period of Performance	4.3	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	2.4	.01-1000	ft/day	
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.02	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	8.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	11,608	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.8	0.01 to 10	mg/L	Default = 5
Nitrate	0.00	0.1 to- 20	mg/L	Default = 1
Sulfate	138	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	1.417	--	mg/L	
Trichloroethene (TCE)	0.276	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.435	--	mg/L	
Vinyl Chloride (VC)	0.008	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.040	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 239

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	77	feet	23	meters
Length (parallel to groundwater flow)	48	feet	14.6	meters
Saturated Thickness	11.5	feet	3.5	meters
Design Period of Performance	4.29	years	4.29	years

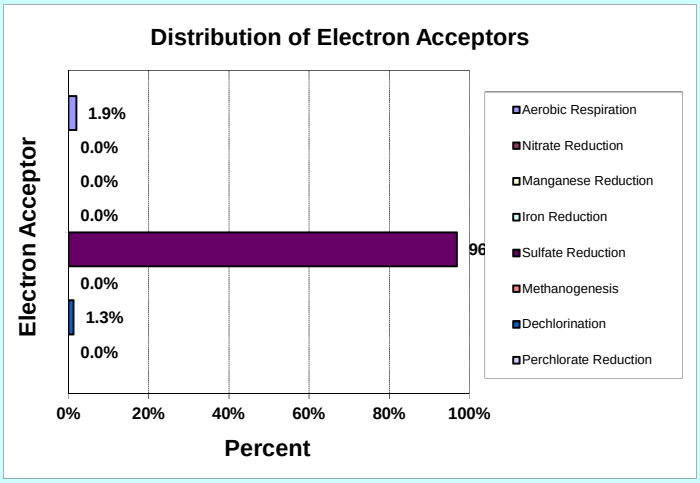
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	2.4	ft/day	8.5E-04	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	0.02	ft/day	7.3E-01	cm/day
Average Groundwater Seepage Velocity	9	ft/yr	2.7	m/yr
Effective Treatment Zone Pore Volume	63,603	gallons	240,757	liters
Groundwater Flux (per year)	11,608	gallons/year	43,938	liters/year
Total Groundwater Volume Treated (over entire design period)	113,399	gallons total	429,251	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	1.9%	0.217
Nitrate Reduction	0.0%	0.000
Sulfate Reduction	96.8%	10.964
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	1.3%	0.142
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**11.32**

Hydrogen demand in pounds/gallon:	9.99E-05
Hydrogen demand in grams per liter:	1.20E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	1,575	143	802	as lactic acid
2. Molasses Product	1,202	100	762	as sucrose
3. Fructose Product	949	85	802	as fructose
4. Ethanol Product	485	70	410	as ethanol
5. Sweet Dry Whey (lactose)	748	sold by pound	554	as lactose
6. HRC®	575	sold by pound	486	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	295	38	312	as soybean oil
8. Emulsified Vegetable Oil	492	63	312	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 239

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		143.1374265
2. Molasses Product		100.1333998
3. Fructose Product		84.71909968
4. Ethanol Product		70.31430444
5. Sweet Dry Whey (lactose)	748.3933624	
6. HRC®	575.3000438	
7. Linoleic Acid (Soybean Oil)		37.87152787
8. Emulsified Vegetable Oil		63.11921311
9. Lactoil Product		30.29722229
10. Lactic Acid Product		0
11. Hydrogen Gas	11.32	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 241

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	80	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	130	1-1,000	feet	
Saturated Thickness	12	1-100	feet	
Treatment Zone Cross Sectional Area	960	--	ft^2	
Treatment Zone Volume	124,800	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	233,438	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	186,751	--	gallons	
Design Period of Performance	2.9	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	72	.01-1000	ft/day	
Average Hydraulic Gradient	0.007	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	2.52	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	919.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	1,321,333	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	46	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	12.500	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	1.010	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)		--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 241

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	80	feet	24	meters
Length (parallel to groundwater flow)	130	feet	39.6	meters
Saturated Thickness	12	feet	3.7	meters
Design Period of Performance	2.92	years	2.92	years

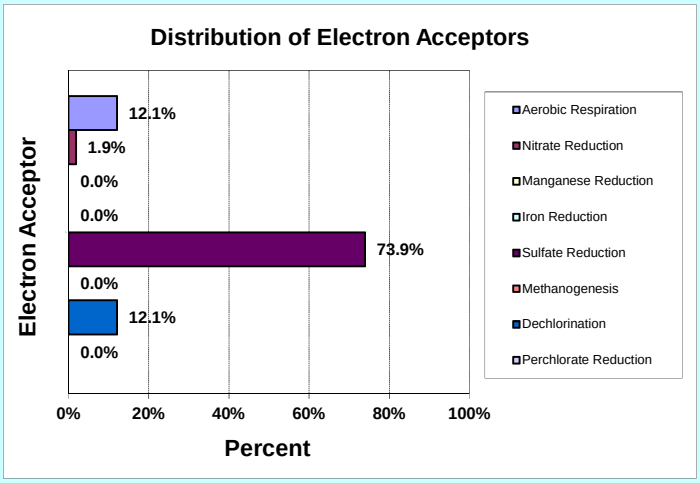
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	72	ft/day	2.5E-02	cm/sec
Average Hydraulic Gradient	0.007	ft/ft	0.007	m/m
Average Groundwater Seepage Velocity	2.52	ft/day	7.7E+01	cm/day
Average Groundwater Seepage Velocity	920	ft/yr	280.4	m/yr
Effective Treatment Zone Pore Volume	186,751	gallons	706,909	liters
Groundwater Flux (per year)	1,321,333	gallons/year	5,001,650	liters/year
Total Groundwater Volume Treated (over entire design period)	4,045,044	gallons total	15,311,728	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	12.1%	21.256
Nitrate Reduction	1.9%	3.268
Sulfate Reduction	73.9%	129.801
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	12.1%	21.254
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**175.58**

Hydrogen demand in pounds/gallon:	4.34E-05
Hydrogen demand in grams per liter:	5.20E-03



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	24,415	2,220	349	as lactic acid
2. Molasses Product	18,632	1,553	331	as sucrose
3. Fructose Product	14,713	1,314	349	as fructose
4. Ethanol Product	7,523	1,090	178	as ethanol
5. Sweet Dry Whey (lactose)	11,605	sold by pound	241	as lactose
6. HRC®	8,921	sold by pound	211	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	4,581	587	136	as soybean oil
8. Emulsified Vegetable Oil	7,634	979	136	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 241

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		2219.538179
2. Molasses Product		1552.702947
3. Fructose Product		1313.683506
4. Ethanol Product		1090.317795
5. Sweet Dry Whey (lactose)	11604.84495	
6. HRC®	8920.800402	
7. Linoleic Acid (Soybean Oil)		587.2489402
8. Emulsified Vegetable Oil		978.7482337
9. Lactoil Product		469.7991522
10. Lactic Acid Product		0
11. Hydrogen Gas	175.58	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 243

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	180	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	25	1-1,000	feet	
Saturated Thickness	6.5	1-100	feet	
Treatment Zone Cross Sectional Area	1170	--	ft^2	
Treatment Zone Volume	29,250	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	54,712	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	43,770	--	gallons	
Design Period of Performance	5.3	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	1	.01-1000	ft/day	
Average Hydraulic Gradient	0.026	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.13	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	47.5	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	83,075	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	2.1	0.01 to 10	mg/L	Default = 5
Nitrate	0.11	0.1 to- 20	mg/L	Default = 1
Sulfate	382	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	0.134	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.010	--	mg/L	
Vinyl Chloride (VC)	0.133	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 243

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	180	feet	55	meters
Length (parallel to groundwater flow)	25	feet	7.6	meters
Saturated Thickness	6.5	feet	2.0	meters
Design Period of Performance	5.28	years	5.28	years

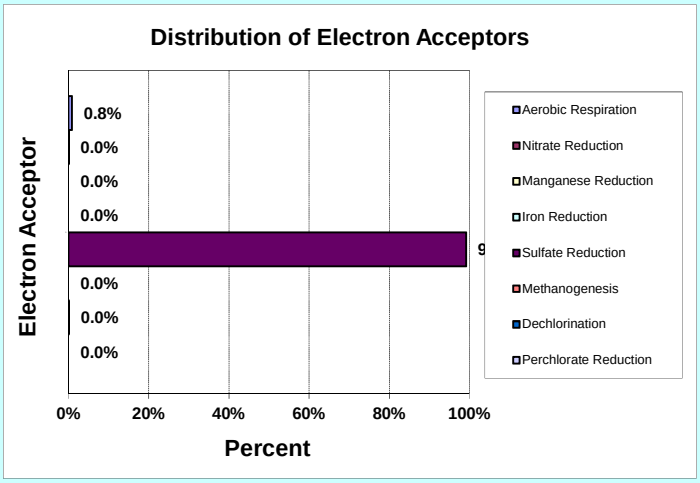
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	1	ft/day	3.5E-04	cm/sec
Average Hydraulic Gradient	0.026	ft/ft	0.026	m/m
Average Groundwater Seepage Velocity	0.13	ft/day	4.0E+00	cm/day
Average Groundwater Seepage Velocity	47	ft/yr	14.5	m/yr
Effective Treatment Zone Pore Volume	43,770	gallons	165,682	liters
Groundwater Flux (per year)	83,075	gallons/year	314,464	liters/year
Total Groundwater Volume Treated (over entire design period)	482,405	gallons total	1,826,051	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.8%	1.039
Nitrate Reduction	0.0%	0.043
Sulfate Reduction	99.1%	129.112
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.0%	0.045
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**130.24**

Hydrogen demand in pounds/gallon:	2.70E-04
Hydrogen demand in grams per liter:	3.24E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	18,110	1,646	2,168	as lactic acid
2. Molasses Product	13,821	1,152	2,060	as sucrose
3. Fructose Product	10,914	974	2,169	as fructose
4. Ethanol Product	5,580	809	1,109	as ethanol
5. Sweet Dry Whey (lactose)	8,608	sold by pound	1,497	as lactose
6. HRC®	6,617	sold by pound	1,315	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	3,398	436	844	as soybean oil
8. Emulsified Vegetable Oil	5,663	726	844	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 243

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		1646.375036
2. Molasses Product		1151.740211
3. Fructose Product		974.4440307
4. Ethanol Product		808.7592349
5. Sweet Dry Whey (lactose)	8608.064148	
6. HRC®	6617.134692	
7. Linoleic Acid (Soybean Oil)		435.6005246
8. Emulsified Vegetable Oil		726.0008743
9. Lactoil Product		348.4804197
10. Lactic Acid Product		0
11. Hydrogen Gas	130.24	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 245

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	50	1-1,000	feet	
Saturated Thickness	33	1-100	feet	
Treatment Zone Cross Sectional Area	1650	--	ft^2	
Treatment Zone Volume	82,500	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	154,316	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	123,453	--	gallons	
Design Period of Performance	1.1	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	6.9	.01-1000	ft/day	
Average Hydraulic Gradient	0.003	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.10	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	37.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	93,275	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	5.0	0.01 to 10	mg/L	Default = 5
Nitrate	1.00	0.1 to- 20	mg/L	Default = 1
Sulfate	293	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	3.910	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.013	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 245

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	50	feet	15.2	meters
Saturated Thickness	33	feet	10.1	meters
Design Period of Performance	1.08	years	1.08	years

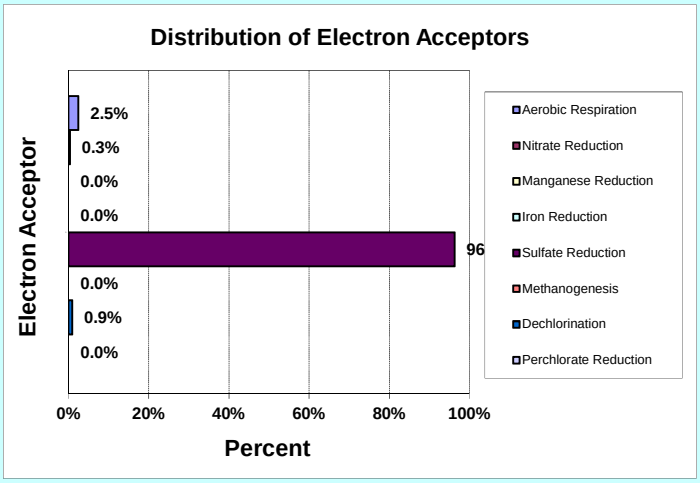
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	6.9	ft/day	2.4E-03	cm/sec
Average Hydraulic Gradient	0.003	ft/ft	0.003	m/m
Average Groundwater Seepage Velocity	0.10	ft/day	3.2E+00	cm/day
Average Groundwater Seepage Velocity	38	ft/yr	11.5	m/yr
Effective Treatment Zone Pore Volume	123,453	gallons	467,307	liters
Groundwater Flux (per year)	93,275	gallons/year	353,074	liters/year
Total Groundwater Volume Treated (over entire design period)	224,190	gallons total	848,627	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	2.5%	1.178
Nitrate Reduction	0.3%	0.166
Sulfate Reduction	96.3%	46.023
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.9%	0.422
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**47.79**

Hydrogen demand in pounds/gallon:	2.13E-04
Hydrogen demand in grams per liter:	2.55E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	6,645	604	1,712	as lactic acid
2. Molasses Product	5,071	423	1,626	as sucrose
3. Fructose Product	4,005	358	1,712	as fructose
4. Ethanol Product	2,048	297	876	as ethanol
5. Sweet Dry Whey (lactose)	3,159	sold by pound	1,182	as lactose
6. HRC®	2,428	sold by pound	1,038	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	1,247	160	666	as soybean oil
8. Emulsified Vegetable Oil	2,078	266	666	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 245

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		604.1092497
2. Molasses Product		422.6114337
3. Fructose Product		357.5556233
4. Ethanol Product		296.7604123
5. Sweet Dry Whey (lactose)	3158.582376	
6. HRC®	2428.044756	
7. Linoleic Acid (Soybean Oil)		159.8361857
8. Emulsified Vegetable Oil		266.3936429
9. Lactoil Product		127.8689486
10. Lactic Acid Product		0
11. Hydrogen Gas	47.79	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 246

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NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	80	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	80	1-1,000	feet	
Saturated Thickness	10.5	1-100	feet	
Treatment Zone Cross Sectional Area	840	--	ft^2	
Treatment Zone Volume	67,200	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	125,698	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	100,558	--	gallons	
Design Period of Performance	1.8	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	Default = 3
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	25%	.05-50	percent	Default = 25%
Effective Porosity	20%	.05-50	percent	Default = 20%
Average Aquifer Hydraulic Conductivity	29.5	.01-1000	ft/day	
Average Hydraulic Gradient	0.002	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.30	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	107.7	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	135,345	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	Default = 1.7
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	Default = 0.05%
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.4	0.01 to 10	mg/L	Default = 5
Nitrate	0.05	0.1 to- 20	mg/L	Default = 1
Sulfate	524	10 to 5,000	mg/L	Default = 50
Carbon Dioxide (estimated as the amount of Methane produced)	0.0	0.1 to 20	mg/L	Default = 0
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)		0.1 to 20	mg/L	Default = 0
Iron (III) (estimated as the amount of Fe (II) produced)		0.1 to 20	mg/L	Default = 0

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.002	--	mg/L	
Trichloroethene (TCE)	0.109	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.010	--	mg/L	
Vinyl Chloride (VC)	0.000	--	mg/L	
Carbon Tetrachloride (CT)		--	mg/L	
Trichloromethane (or chloroform) (CF)		--	mg/L	
Dichloromethane (or methylene chloride) (MC)		--	mg/L	
Chloromethane		--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane		--	mg/L	
Perchlorate		--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)		-400 to +500	mV	
Temperature		5.0 to 30	ºC	
pH		4.0 to 10.0	su	
Alkalinity		10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)		10 to 1,000	mg/L	
Specific Conductivity		100 to 10,000	µs/cm	
Chloride		10 to 10,000	mg/L	
Sulfide - Pre injection		0.1 to 100	mg/L	
Sulfide - Post injection		0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	Default = 10,000
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	Default = 10%

NOTES:

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: Treatment 246

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1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	80	feet	24	meters
Length (parallel to groundwater flow)	80	feet	24.4	meters
Saturated Thickness	10.5	feet	3.2	meters
Design Period of Performance	1.83	years	1.83	years

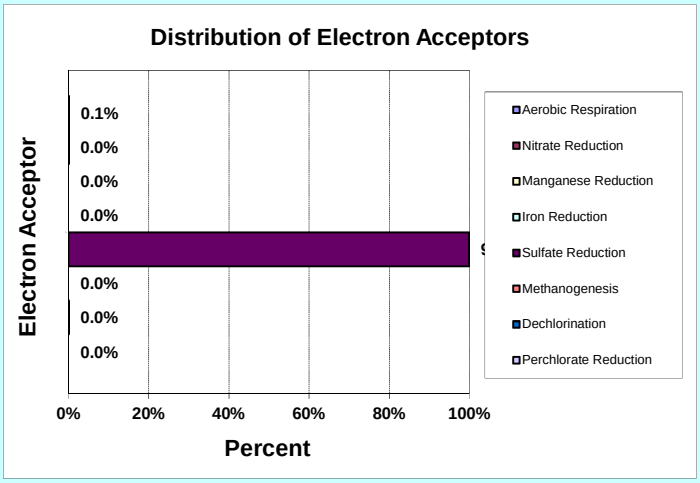
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.25	percent	0.25	percent
Effective Porosity	0.2	percent	0.2	percent
Average Aquifer Hydraulic Conductivity	29.5	ft/day	1.0E-02	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	0.30	ft/day	9.0E+00	cm/day
Average Groundwater Seepage Velocity	108	ft/yr	32.8	m/yr
Effective Treatment Zone Pore Volume	100,558	gallons	380,643	liters
Groundwater Flux (per year)	135,345	gallons/year	512,322	liters/year
Total Groundwater Volume Treated (over entire design period)	348,239	gallons total	1,318,192	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.1%	0.139
Nitrate Reduction	0.0%	0.013
Sulfate Reduction	99.9%	127.728
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	0.0%	0.000
Dechlorination	0.0%	0.018
Perchlorate Reduction	0.0%	0.000
Totals:	**100.00%**	**127.90**

Hydrogen demand in pounds/gallon:	3.67E-04
Hydrogen demand in grams per liter:	4.40E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	17,785	1,617	2,950	as lactic acid
2. Molasses Product	13,573	1,131	2,802	as sucrose
3. Fructose Product	10,718	957	2,950	as fructose
4. Ethanol Product	5,480	794	1,509	as ethanol
5. Sweet Dry Whey (lactose)	8,453	sold by pound	2,036	as lactose
6. HRC®	6,498	sold by pound	1,789	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	3,337	428	1,148	as soybean oil
8. Emulsified Vegetable Oil	5,561	713	1,148	as soybean oil

Notes:
1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

Recommended Loading

Treatment 246

Substrate	Quantity(lb)	Quantity (gallons)
1. Sodium Lactate Product		1616.794802
2. Molasses Product		1131.047025
3. Fructose Product		956.9363051
4. Ethanol Product		794.2283492
5. Sweet Dry Whey (lactose)	8453.404034	
6. HRC®	6498.245382	
7. Linoleic Acid (Soybean Oil)		427.7741393
8. Emulsified Vegetable Oil		712.9568988
9. Lactoil Product		342.2193114
10. Lactic Acid Product		0
11. Hydrogen Gas	127.90	

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.
9. Quantity assumes commercial product is 80% soybean oil by weight.
10. Quantity assumes commercial product is 88% lactic acid by weight.
11. Quantity assumes hydrogen gas substrate is 100% by weight.