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United States Environmental Protection Agency Region 6

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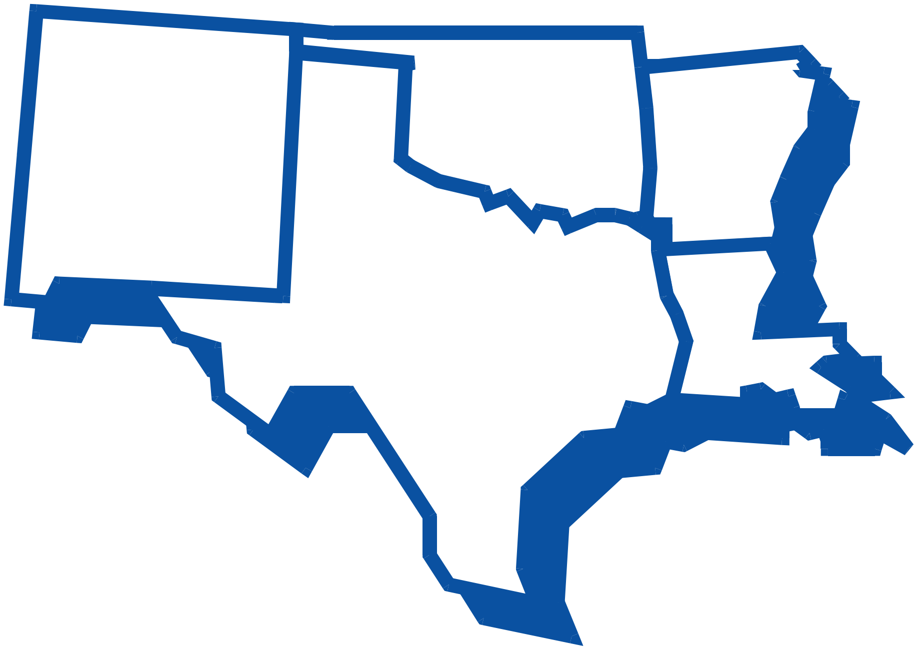
Monitored Natural Attenuation Evaluation Report
Final

Fruit Avenue Plume Superfund Site Long-Term
Remedial Action
Albuquerque, New Mexico
Task Order No. 0003-RALR-06DD
Document Control No. 0003-02091
August 2013



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Long-Term Remedial Action

Monitored Natural Attenuation Evaluation Report

Prepared for

U.S. Environmental Protection Agency

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Executive Summary

This document presents an updated evaluation of natural attenuation (NA) processes occurring in groundwater at the Fruit Avenue Plume (FAP) Superfund Site located in Albuquerque, New Mexico. This evaluation complements a previous evaluation conducted in 2005 (*Natural Attenuation Evaluation, Version 1.1, Fruit Avenue Plume Superfund Site*, U.S Environmental Protection Agency [EPA], 2005).

The evaluation was performed to determine if monitored natural attenuation (MNA) of the downgradient trichloroethene (TCE) plume, as implemented under the *Explanation of Significant Differences (ESD) for the Fruit Avenue Plume Superfund Site* (EPA, 2006), remains protective of human health and the environment. A secondary objective for the evaluation was to determine if NA processes can address other portions of the TCE plume.

Monitored natural attenuation as applied to groundwater contamination at Superfund sites may be used in conjunction with active remediation of contaminant source zones and to address low-concentration plume areas. Under the Comprehensive, Environmental Response, Compensation, and Liability Act (CERCLA), MNA is considered a remedy and, as such, is subject to periodic evaluation to confirm that NA processes are occurring in accordance with expectations and is capable of achieving cleanup levels in a reasonable timeframe compared to other alternative remedies.

The EPA has developed rigorous guidance to determine if MNA is applicable for a given site, and if so, methods for assessing its effectiveness. The evaluation presented herein was performed using the latest technical guidance cited in the references section of this report.

Background

The FAP site is identified on the National Priorities List (NPL) as a chlorinated solvent groundwater plume located in the downtown area of Albuquerque, New Mexico. The site consists of a TCE plume present within an alluvial aquifer at depths between 45 and 550 feet below ground surface (bgs). The plume was initially about 6,000 feet long with a width between 550 feet and 1,300 feet.

The City of Albuquerque (CoA) and the New Mexico Environment Department (NMED) conducted several investigations between 1989 and 1999 to characterize the distribution of TCE in groundwater and to identify the source of the contamination. In 1999, EPA placed the site on the NPL. After the NMED completed a remedial investigation (RI) and feasibility study (FS), EPA issued a Record of Decision (ROD) for the site in 2001 (EPA, 2001).

Following completion of a remedial design investigation (*Final 100% Design Deliverable*, EPA, 2003) and the 2005 NA evaluation, EPA issued an ESD (EPA, 2006), which modified the remedy selected in the ROD. The ESD authorized groundwater pump-and-treat (P&T) for the central portion of the TCE plume and MNA to treat portions of the plume (specifically the downgradient portion) not addressed by the P&T system. The ESD increased the frequency of groundwater monitoring at the site from annual to semiannual while adding periodic reviews to confirm that MNA remains effective. The ESD also eliminated soil vapor extraction, maintenance of an asphalt ground surface cap in the presumed source area, and hot-spot groundwater treatment because the remedial design investigation determined that these elements were not needed.

The P&T system, which is comprised of an 80 gallon per minute (gpm) extraction well, an air stripper treatment plant (ASTP), and two treated water injection wells, has operated for 7 years (2005 through 2012) withdrawing 216 million gallons of groundwater containing 15 pounds (lbs) of TCE. This amount represents about 20 percent of the 70 lbs of TCE mass estimated to have been present in 1998. During the 14 year period (1998 through 2012) that routine groundwater monitoring has been performed at the site, NA processes have removed an estimated 33 lbs of TCE from the aquifer. Based on current information, it is estimated that 22 lbs of TCE remain within the plume boundary as defined by the remedial goal specified in the ROD (EPA, 2001). The current distribution of TCE in groundwater at the site is shown on **Figure ES-1**.

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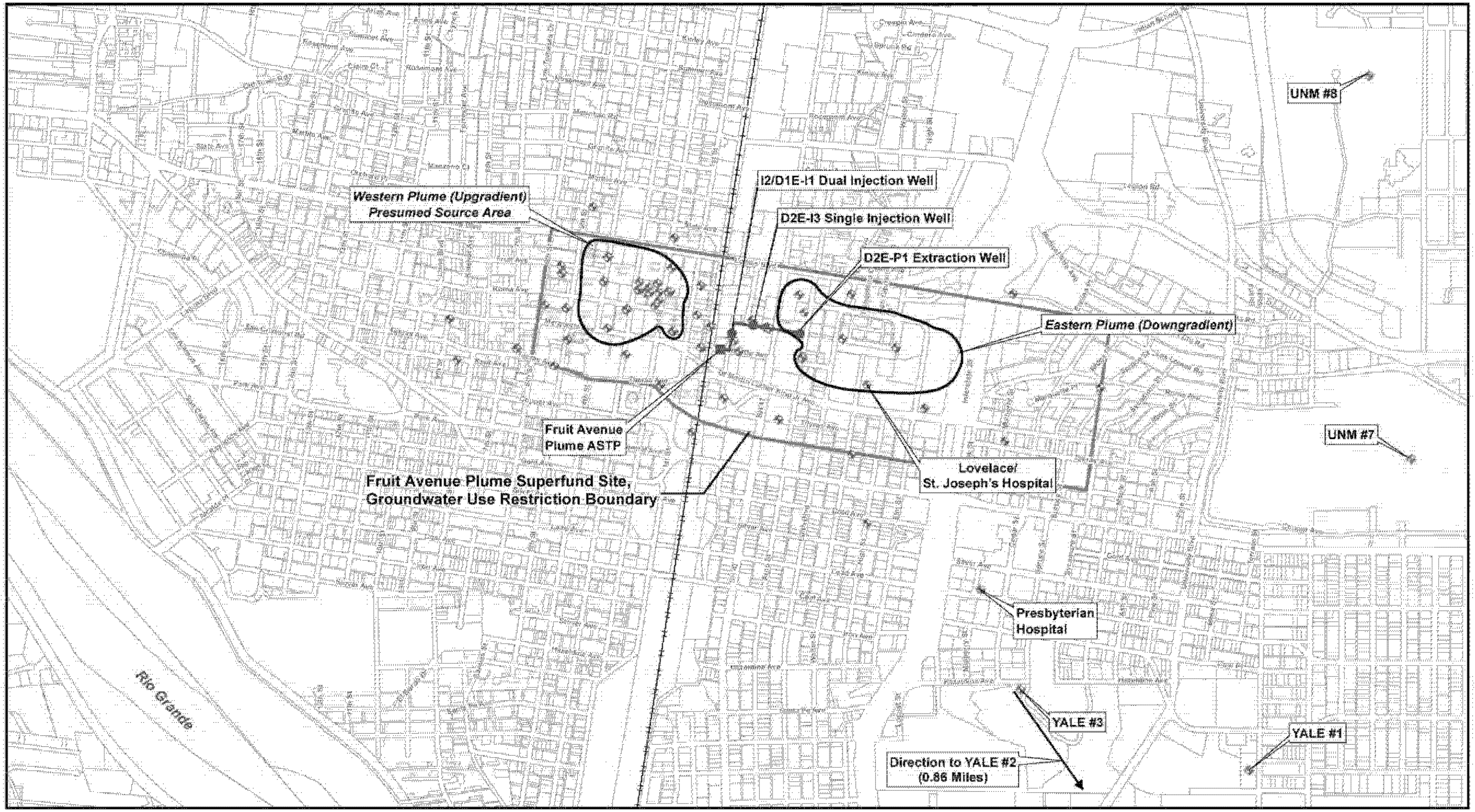

FIGURE ES-1
Site Map
Fruit Avenue Plume Superfund Site
Albuquerque, NM

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Over the past several years the mass of TCE removed from the aquifer by the P&T system has declined significantly from the levels initially observed and has reached an asymptotic level of less than 0.2 lbs per month. The TCE concentration present in the extraction well influent has remained relatively constant over the past 6 to 9 months at around 5 micrograms per liter (µg/L). This concentration corresponds to the EPA drinking water maximum contaminant level (MCL) and the remedial goal established for TCE in the ROD (EPA, 2001). Based on the levels of TCE present in the extraction well influent, and within the area of the plume influenced by groundwater extraction, continued operation of the P&T system is no longer technically practical or cost effective.

Approach

The updated MNA evaluation presented in this report used a multiple lines of evidence approach to identify the processes and degree of NA affecting the fate and transport of TCE at the site. The key lines of evidence that were assessed included:

- Field and laboratory analysis of groundwater samples for TCE, TCE degradation products, and geochemical parameters associated with different NA processes. These data provide direct and indirect evidence of the degradation processes operating at the FAP site.
- Statistical evaluation of monitoring well TCE and cis-1,2-dichloroethene (cis-1,2-DCE) concentration data using the Mann-Kendall statistic to determine where concentrations are increasing, decreasing or stable.
- Compound-specific isotope[1] analysis (CSIA) to confirm the presence of biotic/abiotic degradation processes. The results of the CSIA evaluation were also used to develop a degradation rate used in TCE fate and transport modeling.
- Laboratory analysis to identify the presence of microorganisms associated with biodegradation processes.
- Magnetic susceptibility measurements at selected monitor well locations to identify the presence of reactive minerals associated with abiotic degradation processes.
- Statistical evaluation of TCE and cis-1,2-DCE concentration data using linear regression methods to estimate decay rates and remediation timeframes for the range of conditions present at the FAP site.
- Numerical modeling to simulate future groundwater flow patterns and TCE fate and transport for a range of potential site conditions. The model simulations were used to estimate TCE remediation timeframes with and without P&T system operation.

The above approach was developed using the latest EPA and Interstate Technical and Regulatory Council (ITRC) technical guidance and in consultation with EPA and NMED technical experts based in Ada, Oklahoma; Dallas, Texas; Washington D.C; and Santa Fe, New Mexico.

Summary of Findings

This MNA evaluation concluded that within the aquifer zones monitored by the existing monitoring well network geochemical conditions are indicative of Type 3[2] plume behavior; a category that is deemed less favorable for biodegradation processes. Within the fine-grained portions of the aquifer, geochemical conditions are expected to be more supportive of biodegradation and abiotic degradation processes. The evaluation also determined that injection of treated groundwater from the ASTP is inhibiting degradation processes within the central and downgradient portions of the TCE plume because the treated water contains elevated concentrations of dissolved oxygen and sulfate, and low concentrations of carbon dioxide, which interfere with TCE biodegradation processes.

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[1] Isotope = two or more forms of the same compound having the same number of protons but with a different number of neutrons in the nucleus.

[2] Aquifer conditions with low, and potentially inadequate, native and/or anthropogenic organic carbon concentrations and dissolved oxygen concentrations greater than 1.0 milligram per liter (mg/L).

NA processes contributing to TCE degradation at the FAP site include anaerobic reductive dechlorination and abiotic degradation. Although site conditions do not favor rapid TCE degradation, the rate of degradation is sufficient such that these processes provide a significant contribution to the overall reduction of TCE concentrations in groundwater. The laboratory analysis and CSIA evidence indicates that TCE is degrading to cis-1,2 DCE. Decreasing cis-1,2 DCE concentrations are likely caused by aerobic oxidation, aerobic cometabolism, or abiotic degradation, as indicated by the lack of vinyl chloride (VC).

Based on the findings of this evaluation, TCE concentrations present downgradient of the P&T system are expected to attenuate to concentrations below the 5 µg/L remedial goal specified in the ROD before the plume reaches the groundwater use restriction boundary. Furthermore, this report finds that site-related TCE present upgradient of the P&T system is also expected to naturally attenuate below the 5 µg/L remedial goal specified in the ROD *even if the P&T system is shutdown* (**Figure ES-2** and **ES-3**). That is, MNA, acting as the sole remedy at the site, is expected to maintain the concentration of TCE below the 5 µg/L remedial goal at the groundwater use restriction boundary and to achieve the remedial goal throughout the plume boundary by approximately the year 2030.

Uncertainties remain concerning the specific biodegradation processes responsible for TCE and cis-1,2 DCE degradation in groundwater at the site, and the impact migration of an un-related TCE plume located west of the FAP site will have on cleanup timeframe projections. Past microbial analyses were not capable of identifying specific bacteria, enzymes, or microbial processes. However, new microbiological analysis methods are now available to ascertain the specific bacteria, enzymes, and/or microbial processes responsible for degradation of TCE and cis-1,2 DCE in groundwater. Fate and transport modeling, and existing groundwater monitoring results, indicate that the offsite plume has migrated onto the FAP site. Future groundwater monitoring and data evaluations will be used to update cleanup timeframe projections to reflect offsite plume impacts if warranted.

Recommendations

Based on the findings of this evaluation, it is recommended that the remedy described in the ESD (EPA, 2006) be modified to expand MNA to include the western and central portions of the TCE plume. This change would be implemented through a new decision document. The P&T system would be placed in a standby mode to function as a contingent remedy until the second five-year review to be conducted in the year 2016 evaluates and confirms the protectiveness of MNA as the sole remedy for the site. While in the standby mode, the P&T system would be routinely maintained such that continuous or pulsed operations could readily resume if warranted.

Continued semiannual groundwater monitoring, as specified in the *Field Sampling Plan* (CH2M HILL, 2010), with semiannual and annual reporting of the monitoring results will provide a comprehensive data set to support the evaluations needed to confirm that MNA is effective while also providing important input for the second five-year review. If the second five-year review concludes that MNA alone is protective, the P&T system will be decommissioned prior to completion of the 10 year long-term remedial action (LTRA) period, which occurs on August 26, 2017, and transfer of the FAP site to NMED for the remaining operations and maintenance (O&M) period. A tentative schedule of activities planned for the 2013 through 2017 (5 year) period is presented in **Table ES-1**.

In the event, the second five-year review concludes that sitewide MNA is not protective of human health and the environment, then EPA will modify the remedy as necessary. The scope of any required remedy modifications would most likely be determined through a Focused Feasibility Study, Proposed Plan, and ROD amendment that will allow for review and comment by the public.

FIGURE ES-2

Snapshots of F&T Modeling Results – P&T System Remains On Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque NM

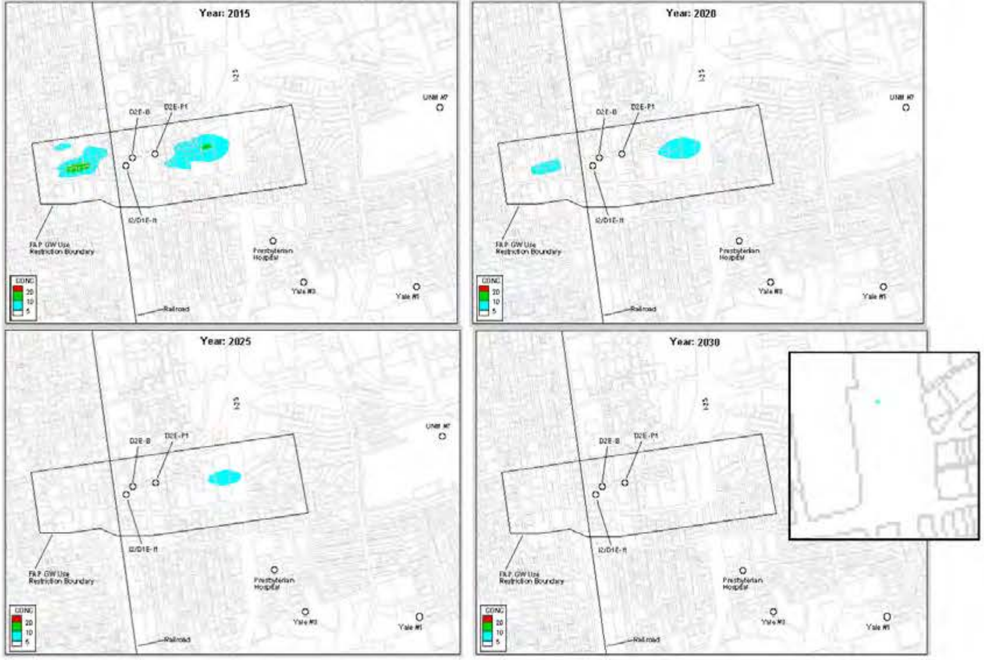

FIGURE ES-3

Snapshots of F&T Modeling Results – P&T System Turned Off Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque NM

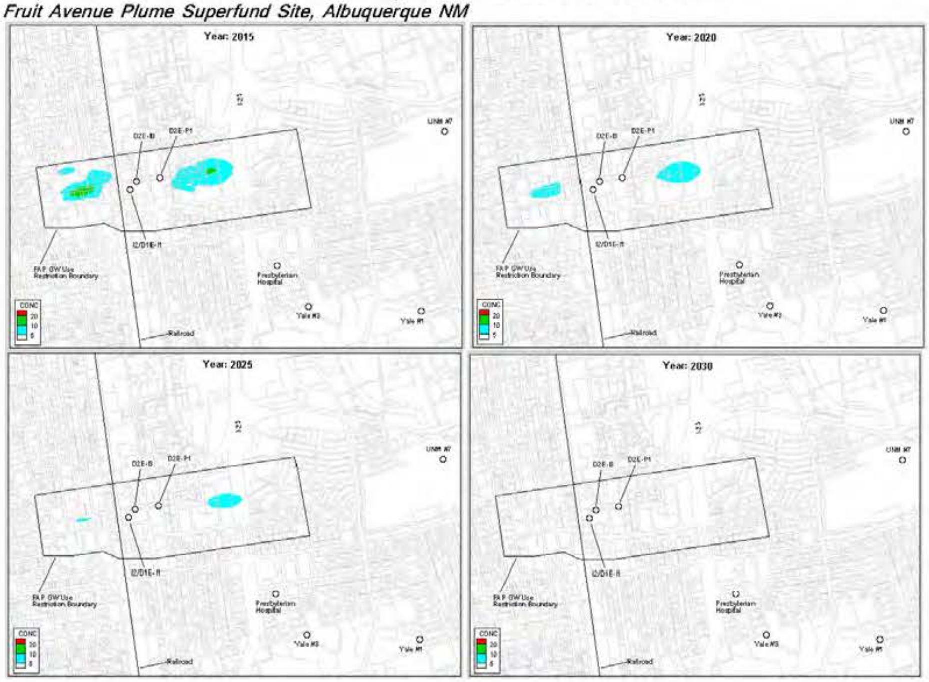

TABLE ES-1
Future Groundwater Monitoring and Reporting Activities Schedule
Fruit Avenue Plume Superfund Site, Albuquerque NM

Date	Activity
2013	February – First semiannual groundwater monitoring event conducted April – Draft Final Cleanup Status Report No. 39 issued May – Draft Final First Semiannual Groundwater Monitoring Report issued June – Draft Final Decision Document issued July – Draft Final CSR No. 40 issued August – Second semiannual groundwater monitoring event conducted September – Signed Decision Document issued, pump-and-treat system shutdown October – Draft Final CSR No. 41 issued November – Annual Long-term Monitoring Report issued
2014	February – First semiannual groundwater monitoring event conducted May – Draft Final First Semiannual Groundwater Monitoring Report issued August – Second semiannual groundwater monitoring event conducted November – Annual Long-term Monitoring Report issued
2015	February – First semiannual groundwater monitoring event conducted, includes testing for MNA parameters including those recommended in the 2013 MNA update report May – Draft Final First Semiannual Groundwater Monitoring Report issued August – Second semiannual groundwater monitoring event conducted August – Draft Final MNA Performance Evaluation Report issued November – Annual Long-term Monitoring Report issued
2016	February – First semiannual groundwater monitoring event conducted May – Draft Final First Semiannual Groundwater Monitoring Report issued August – Second semiannual groundwater monitoring event conducted November – Annual Long-term Monitoring Report issued December – Second Five Year Report issued
2017	January – Begin decommissioning of pump-and-treat system (if second five-year review confirms protectiveness) February – Annual groundwater monitoring event conducted May – Draft Final Annual Groundwater Monitoring Report issued August 26 - FAP site transferred to NMED

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Acronyms and Abbreviations

µg/L	micrograms per liter
5YR	five-year review
ASTP	air stripper treatment plant
bgs	below ground surface
BNSF	Burlington Northern Santa Fe
BTEX	benzene, toluene, ethylbenzene, and xylene
CERCLA	Comprehensive, Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
cis-1,2-DCE	cis-1,2-dichloroethene
CLP	Contract Laboratory Program
CoA	City of Albuquerque
COC	contaminant of concern
COV	coefficient of variation
CSIA	compound-specific stable isotope analysis
CSM	conceptual site model
CSR	Clean-Up Status Report
cVOC	chlorinated volatile organic compound
D1, D2, D3, and D4	deep aquifer zones
DE&S	Duke Engineering & Services
DO	dissolved oxygen
DQO	data quality objective
EPA	U.S. Environmental Protection Agency
ESD	*Explanation of Significant Differences*
FAP	Fruit Avenue Plume Superfund Site
FID	flame ionization detector
FS	Feasibility Study
GC	gas chromatography
gpm	gallons per minute
I1	intermediate 1 aquifer zone
I2	intermediate 2 aquifer zone
kg	kilogram
LTM	long-term monitoring
LTMO	long-term monitoring optimization
LTRA	long-term remedial action
m^3/kg	cubic meters per kilogram
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Contaminant Level

MCLG	Maximum Contaminant Level Goal
mg/L	milligrams per liter
MK	Mann-Kendall
MMS	mass-magnetic susceptibility
MNA	monitored natural attenuation
mV	millivolt
NA	natural attenuation
NAIP	natural attenuation indicator parameter
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NPL	National Priorities List
O&M	operations and maintenance
ORP	oxidation-reduction potential
OSE	New Mexico Office of the State Engineer
P&T	pump-and-treat
PCE	perchloroethene
PLFA	phospholipid fatty acid
RA	remedial action
RAO	remedial action objective
REDOX	oxidation-reduction
RI	Remedial Investigation
ROD	Record of Decision
RSE	Remedial System Evaluation Report
S	shallow aquifer zone
SARA	Superfund Amendments and Reauthorization Act of 1986
SJCDWP	San Juan Chama Drinking Water Project
SVE	soil-vapor extraction
TCE	trichloroethene
TEAP	terminal electron-accepting process
TPH	total petroleum hydrocarbons
trans-1,2-DCE	trans-1,2-dichloroethene
UNM	University of New Mexico
USGS	U.S. Geological Survey
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound
Water Authority	Albuquerque Bernalillo County Water Utility Authority

Glossary

abiotic degradation: A chemical transformation reaction that degrades contaminants without microbial facilitation. See *reactive mineral*.

absorption: The process of taking in – the contaminant penetrates the interior portions of a solid particle in response to a concentration gradient. Compare to *adsorption*.

adsorption: The attachment of a contaminant to a solid surface. Adsorption processes include electrostatic attraction, chemical reaction, or incorporation of the contaminant into the porous surface of the solid aquifer material. Adsorption results in the removal of contaminants from groundwater. Organic compounds (such as trichloroethene [TCE]) adsorb to organic carbon in the aquifer materials and to a lesser extent to mineral surfaces. Adsorption results in the retardation, or slowing down, of the plume movement. Compare to *absorption*.

aerobic: Requiring or containing oxygen. Groundwater with dissolved oxygen concentrations greater than 0.5 mg/L is considered aerobic although at dissolved oxygen concentrations between 0.5 mg/L and 2 mg/L it may be considered anoxic. Compare with *anaerobic*.

aerobic cometabolism: A naturally occurring biologically mediated process that is capable of degrading trichloroethene (TCE) and other chloroethenes under aerobic conditions. The term cometabolism indicates that transformation of the contaminants is a secondary reaction. (Cometabolism is a result of nonspecific enzyme activity towards organic compounds that do not serve as carbon or energy sources.) The microbes consume other forms of organic carbon for their energy needs, and in the process, produce enzymes that fortuitously degrade other compounds such as chloroethenes.

aerobic oxidation: The microbiological use of less-oxidized chlorinated solvents (e.g. DCE or VC) as a primary substrate under aerobic and potentially anoxic conditions. The microorganism receives energy (resulting from electron transfer) from the degraded chlorinated solvent.

alluvial aquifer: An aquifer comprising unconsolidated material deposited by flowing water, typically occurring within river channels, adjacent to rivers (overbank deposits), and in buried paleochannels (old or ancient river channels). Alluvial aquifers are generally composed of mixtures of clay, silt, sand, and gravel sized material. Alluvial aquifers can store and transmit groundwater and can, therefore, be developed as a water source. These aquifers typically occur at shallower depths and may be more vulnerable to contamination.

anaerobic: Requiring the absence of oxygen. Compare with *aerobic*. Groundwater with dissolved oxygen concentrations less than 0.5 mg/L is considered anaerobic.

anaerobic biodegradation: The degradation of compounds by microorganisms in the absence of oxygen.

anaerobic reductive dechlorination: A chlorinated ethene degradation process where anaerobic microbes trigger a step-wise sequence of reactions that transform perchloroethene (PCE) and trichloroethene (TCE) to the harmless substance ethane. Microbes replace chloride molecules in the chemical's structure with hydrogen molecules. Replacement of one chloride molecule transforms PCE to TCE. Replacement of another chloride molecule transforms TCE to cis-dichloroethylene (cis 1,2-DCE), then cis 1,2-DCE to vinyl chloride, vinyl chloride to ethene, and then finally to carbon dioxide, water and chloride.

analyte: A chemical substance that is the subject of chemical analysis.

aquifer: A geologic formation which has structures or textures that store water or transmit appreciable water through them. A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to store and transmit water; and to yield economical quantities of water to boreholes or springs.

arsenic drinking water standard: The U.S. Environmental Protection Agency (EPA) has set the arsenic standard for drinking water at 0.010 parts per million (10 parts per billion) to protect consumers served by public water systems from the effects of long-term, chronic exposure to arsenic. Water systems must comply with this standard by January 23, 2006, providing additional protection to an estimated 13 million Americans. Arsenic enters drinking water supplies from natural deposits in the earth or from agricultural and industrial practices.

attenuate: To reduce the toxicity, mobility or concentration of a chemical compound.

attenuation rate: The rate at which contaminant concentrations are reduced by physical, chemical, and/or biological processes without human intervention.

back-diffusion: The process whereby contaminants, driven by a concentration gradient and having previously diffused out of well-connected aquifer matrix and into the pore space between fine-grained materials (see *matrix diffusion)*, now diffuse back into the aquifer. The fine-grained materials thereby act as a limited-but-potentially significant source of groundwater contamination.

biodegradation: Decomposition or breakdown of a substance (such as the structure of chemicals introduced into the environment) through the action of microorganisms (such as bacteria or fungi).

biomass: The amount of living matter (as in a unit volume).

chlorinated solvent: One of a large family of chemical compounds that contain chlorine, for example, carbon tetrachloride (CTC), TCE or methylene chloride. Chlorinated solvents are used for a wide variety of commercial and industrial purposes, including degreasers, cleaning solutions, paint thinners, pesticides, resins, glues, and a host of other mixing and thinning solutions. Their chlorine-containing chemical structure helps them to efficiently dissolve organic materials like fats and greases, exhibit non-flammable properties, and to serve as raw materials or intermediates in the production of other chemicals.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA): CERCLA, also known as Superfund, is the federal law that addresses the removal or cleanup of hazardous substances in the environment at hazardous waste sites where contamination originated prior to 1976. The Agency for Toxic Substances and Disease Registry (ATSDR), which was created by CERCLA, is responsible for assessing health issues and supporting public health activities related to hazardous waste sites or other environmental releases of hazardous substances. This law was later amended by the Superfund Amendments and Reauthorization Act (SARA).

concentration: The amount of a substance present in a certain amount of soil, water, air, or any other media.

contaminant: A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.

daughter product: A chemical compound formed by the degradation of another chemical compound. Some daughter products are more harmful to humans and the environment than the parent contaminant. See *parent contaminant*.

decay rate: The amount of concentration change per unit time. A contaminant decay rate includes concentration changes caused by degradation and non-degradation processes.

degradation: The act or process of reducing the complexity of a chemical compound.

dehalogenate: To remove halogen (typically chlorine) atoms from a molecule.

dermal absorption: Means passing through the skin. For a person or an animal, dermal absorption is the process of a substance getting into the body through the skin.

desorption: The process of releasing (something) through pores or interstices from a solid to aqueous media.

detection limit: The lowest concentration of a chemical that can be reliably distinguished from a zero concentration.

diffusion: The process by which ions or molecules move from areas of high solute concentrations to areas of low solute concentration. Also see *matrix diffusion*.

dilution: The action of being diminished in strength.

dispersion: The action of being scattered from a source. Dispersion is a scale-dependent factor with a magnitude that increases with increasing distance from the source.

electron acceptor: Compounds that accept electrons in oxidation-reduction reactions allow simultaneous oxidation of an electron donor compound (typically and organic compound). The most energetically favorable (in decreasing order) electron acceptors used by microorganisms in natural environments are oxygen, nitrate, manganese, iron, sulfate, and carbon dioxide.

enriched: Possessing a higher concentration of a heavier isotope(s). With respect to ^{13}Carbon, the nominal value of $\delta^{13}C$ becomes more positive.

exposure: Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term (acute exposure), of intermediate duration, or long-term (chronic exposure).

exposure pathway: The route a substance takes from its source (where it began) to its end point (where it comes in contact with a human or ecological receptor), and how people or other living organisms (plants, animals, birds) can come into contact with (or get exposed to) it. An exposure pathway has five parts: a source of contamination (such as an abandoned business); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching), and a receptor population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a complete exposure pathway.

extraction well: A well for removing groundwater from the aquifer and delivering water into the treatment system. The Fruit Avenue Plume Superfund site pump and treatment system has one extraction well, screened in the D2 aquifer zone. See *injection well*.

fault zone: A zone of displacement in geologic formations resulting from forces of tension or compression in the earth’s crust. Faults in the unconsolidated deposits underlying the site may act as conduits for vertical groundwater movement and groundwater contamination and as barriers to lateral movement.

feasibility study: A process used by the U.S. Environmental Protection Agency (EPA) and potentially responsible parties to determine the best way to clean up environmental contamination. .

gamma log: A record of the amount (activity) of natural gamma radiation emitted by the material surrounding a borehole. The most significant naturally occurring sources of gamma radiation are potassium-40 and daughter products of the uranium- and thorium-decay series. Clay- and shale-bearing rocks commonly emit gamma radiation because they include weathering products of potassium feldspar and mica and tend to concentrate uranium and thorium by ion absorption and exchange. Subsurface materials with low gamma values are considered aquifer zones and high gamma values indicate low-permeability fine-grained materials.

geochemistry: A science that deals with the chemical composition of and chemical changes in the matter of the earth, including the related chemical and geological properties of aquifer materials and groundwater.

geophysical log: A record of the structure and composition of the earth (including rock formations) encountered when drilling a well or similar type of test hole or boring. Common geophysical logs include caliper, gamma, single-point resistance, spontaneous potential, normal resistivity, electromagnetic induction, fluid resistivity, temperature, flowmeter, television, and acoustic televiewer. Also see *gamma log*, *resistivity log*.

gradient: The rate of regular or graded ascent (upgradient) or descent (downgradient). Also see *hydraulic gradient*.

groundwater: Water beneath the earth's surface in the spaces between soil particles and between rock surfaces. Compare with *surface water*.

groundwater contaminant plume: A volume of contaminated groundwater that extends downward and outward from a specific source; the shape, movement and fate of the plume is affected by the physical and chemical properties of the local geology, the contaminant type, and the flow characteristics of the area groundwater.

groundwater monitoring: The routine sampling, analysis, and evaluation of one or more elements of the groundwater resource for a specific objective(s). Groundwater monitoring is a formal process of regularly collecting groundwater data (for example, water levels, water quality laboratory analysis, rainfall, pumping rates/volumes) and analyzing the data to observe trends until monitoring objectives are met.

groundwater plume: See *groundwater contaminant plume*.

half-life: The time required for half the amount (concentration) of a substance introduced into an ecosystem to be eliminated or disintegrated by natural processes. The half-life of a contaminant in an aquifer is described by the degradation rate.

halogenate: To treat or combine with a halogen (typically chlorine).

hydraulic barrier: A general term referring to existing conditions or modifications of a groundwater flow system which restrict or impede movement of contaminants.

hydraulic gradient: With regard to an aquifer, the rate of change of pressure head per unit distance (horizontal or vertical) at a given point and in a given direction. Hydraulic gradient provides an indication of the direction of groundwater flow. Also see *gradient*.

hydrogeology: The study of the properties, circulation, and occurrence of groundwater. Hydrogeology allows the understanding, quantification, and management of water resources.

injection well: A vertical pipe in the ground into which water, other liquids, or gases are pumped or allowed to flow. The Fruit Avenue Plume pump and treat system uses two injection wells to return treated water into the aquifer. See *extraction well*.

isotope: Atoms of the same element having the same number of protons (same atomic number) but with a different number of neutrons in the nucleus (different mass numbers). Environmental isotopes are important for investigating the origins of water in the subsurface, evaluating groundwater and surface water mixing, differentiating contaminant sources, and, quantifying contaminant degradation.

magnetic susceptibility: The magnetization of a material per unit applied field. It describes the magnetic response of a substance to an applied magnetic field.

matrix diffusion: The transfer of solutes from the main groundwater conduits to the surrounding aquifer matrix by means of diffusion. Also see *diffusion*.

microbiological analysis: The identification of microorganisms, either unicellular (single cell) , multicellular (cell colony), or acellular (lacking cells).

migration: Moving (contaminant) from one location to another.

mole: The base unit of the amount of pure substance in the International System of Units that contains the same number of elementary units (atoms, molecules) as there are atoms in 12 grams of carbon 12.

mole fraction: The ratio of the number of moles of a given component in a mixture to the total number of moles of all the components.

monitored natural attenuation (MNA): Reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active methods. The 'natural attenuation processes' that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. Typical natural attenuation processes include biodegradation; abiotic degradation; dispersion; dilution; sorption; volatilization; chemical or biological stabilization, transformation, or destruction of contaminants.

natural attenuation (NA): Reduction in mass or concentration of a compound in groundwater over time or distance from the source of constituents of concern due to naturally occurring physical, chemical, and biological processes, such as; biodegradation, abiotic degradation, dispersion, dilution, sorption, and volatilization. Natural attenuation processes affect the fate and transport of contaminants in groundwater.

nonparametric trend analysis: A method commonly used in statistics to model and analyze ordinal or nominal data with small sample sizes. Typically, this type of analysis is used when the data have an unknown statistical distribution, are non-normal, or have a sample size so small that the central limit theorem can't be applied to assume the distribution.

oxidation: The loss of at least one electron (or increase in oxidation state) when two or more substances interact. Those substances may or may not include oxygen.

oxidation-reduction potential (ORP): The standard potential of an atom or ion that undergoes oxidation at the anode or reduction at the cathode in an electrochemcial cell as compared to the potential of a standard hydrogen electrode when it is undergoing the same process. Oxidation-reduction is also referred to as redox.

oxidizing conditions: A chemical environment in which oxidation is favorable.

parent compound: See *parent contaminant*.

parent contaminant: The original chemical compound (contaminant) released from a contaminant source that is sequentially transformed into one or more other chemical compounds. See *daughter product*.

plume: See groundwater contaminant plume.

point decay rate: An estimate of the rate at which contaminant concentrations are changing over time at one sample location. Decay is caused by the physical, chemical and/or biological processes occurring in the environment without human intervention**.**

production well: A well used to retrieve water from an underground aquifer.

pump-and-treat (P&T) system: A system comprised of an array of extraction wells or trenches that pumps contaminated groundwater, treats it to reduce contaminant concentrations to levels below cleanup standards (maximum contaminant levels [MCLs]), and then discharges the treated water.

Rayleigh fractionation: Separation processes where the product is removed from the reactant. Rayleigh fractionation is an important, open system process that involves the progressive removal of a fractional increment of a trace substance from a larger reservoir. A consistent relationship, such as a distribution coefficient, equilibrium constant, or a fractionation factor, is maintained between the reservoir and each increment at the instant of its formation, but once formed, each increment is thereafter removed or otherwise isolated from the system. The Rayleigh fractionation model describes the concentrations and stable isotope signatures of contaminants undergoing sequential degradation processes.

reactive minerals: Any one or more of a variety of naturally occurring iron or sulfide bearing minerals, such as mackinawite, pyrite, magnetite, green rust, and iron-bearing clays (reactive minerals), which have been shown to facilitate degradation of chlorinated ethenes. Reactive minerals support complete transformation of TCE and cis-1,2-DCE through various reactions, which may avoid the creation of potentially harmful daughter products, such as vinyl chloride. In these reactions, the mineral surfaces act as electron donors and /or reaction mediators to increase the rate of transformation via one or more abiotic degradation pathways.

redox (oxidation-reduction): The chemical reaction whereby electrons are removed (oxidation) from atoms of the substance being oxidized and transferred to those being reduced (reduction).

reducing conditions: A chemical environment in which reduction is favorable. Reducing conditions can indicate the presence of iron sulfide or methane.

reduction: The addition of at least one electron (or decrease in oxidation state) when substances come into contact with each other.

reductive dechlorination: A term that is used to describe certain types of degradation of chlorinated organic compounds by chemical reduction with release of chloride ions. Stepwise reductive dechlorination can be biologically enhanced by bacteria that derive energy by facilitating the transfer of an electron between electron donors and electron acceptors.

remedial investigation: The CERCLA process of determining the type and extent of hazardous material contamination present at a site, and the risk posed by hazardous substances.

remediation: The action of remedying something, in particular of reversing or stopping environmental damage.

remediation goals: Media-specific cleanup goals for a selected remedial action. Remediation efforts are considered complete and no further action would be necessary upon attainment of the remediation goals.

resistivity log: A record of the electric resistivity of the geologic media and groundwater occurrences penetrated by a borehole. Changes in resistivity reflect differences in geologic materials and dissolved-solids concentration of water. Fluid-resistivity logs are useful for delineating water-bearing zones and identifying vertical flow in the borehole.

risk: The probability that something will cause injury or harm.

solvent: A liquid capable of dissolving or dispersing another substance (for example, acetone or mineral spirits).

source of contamination: The place where a hazardous substance comes from, such as a landfill, waste pond, incinerator, storage tank, or drum. A source of contamination is the first part of an exposure pathway.

stakeholder: A person, group, or community who has an interest in activities at a hazardous waste site.

Superfund Amendments and Reauthorization Act (SARA): In 1986, SARA amended the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and expanded the health-related responsibilities of the Agency for Toxic Substances and Disease Registry (ATSDR). CERCLA and SARA direct ATSDR to look into the health effects from substance exposures at hazardous waste sites and to perform activities including health education, health studies, surveillance, health consultations, and toxicological profiles.

Superfund site: A site where toxic wastes have been dumped or spilled, and the Environmental Protection Agency has designated them to be cleaned up.

surface water: Water on the surface of the earth, such as in lakes, rivers, streams, ponds, and springs. Compare with *groundwater*.

thermodynamic stability: The enthalpy or potential energy of a compound relative to a reference state.

thermodynamics: Physics that deals with the mechanical action or relations of heat.

vadose zone: A subsurface zone of soil or rock containing fluid under pressure that is less than that of the atmosphere. Pore spaces in the vadose zone are partly filled with water and partly filled with air. The vadose zone is limited by the land surface above and by the water table below.

volatile organic compound (VOC): Any compound of carbon with a high vapor pressure, typically with low water solubility, low molecular weight, and a tendency to persist in and migrate with groundwater. VOCs are numerous, varied, and ubiquitous. They include both human-made and naturally occurring chemical compounds. VOC contamination of drinking water supplies is a human-health concern because many are toxic and are known or suspected human carcinogens.

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SECTION 1

Introduction

This monitored natural attenuation (MNA) report has been prepared for the Fruit Avenue Plume (FAP) Superfund Site (Site). In 2006, the U.S. Environmental Protection Agency (EPA) issued an *Explanation of Significant Differences (ESD) for the Fruit Avenue Plume Superfund Site* (EPA, 2006). The ESD modified the response action selected in the *Record of Decision (ROD) Fruit Avenue Plume Site Albuquerque, New Mexico CERCLIS # NMD986668911* (EPA, 2001) to incorporate MNA as a component of the overall Site response action. The information used to select MNA in the ESD was presented in *Natural Attenuation Evaluation Version 1.1 Fruit Avenue Plume Superfund Site, Albuquerque, New Mexico* (EPA, 2006).

Natural attenuation (NA) processes (biodegradation, adsorption, diffusion, dispersion) affect the fate and transport of contaminants in groundwater. These processes can provide an important contribution to the overall remediation of a site, especially in the diffuse or low-concentration portions of a groundwater contaminant plume.

Monitored natural attenuation as applied to groundwater contamination at Superfund sites is typically used to complement active remediation of contaminant source zones or to address low-concentration areas. Under the Comprehensive, Environmental Response, Compensation, and Liability Act (CERCLA), when MNA is used as a response action, it is subject to periodic evaluation to confirm that NA processes are occurring in accordance with expectations and are capable of achieving cleanup levels in a reasonable timeframe.

1.1 Purpose

This document provides an updated evaluation of the NA processes occurring at the FAP Superfund site (the site). This evaluation is designed to assess whether MNA of the downgradient trichloroethene (TCE) plume, as implemented under the ESD (EPA, 2006), remains protective of human health and the environment in accordance with the remedial action objectives (RAOs) specified in the ROD (EPA, 2001). A secondary objective for this evaluation is to assess whether MNA can effectively address other portions of the TCE plume, specifically that portion that lies west (upgradient) of the existing pump-and-treat (P&T) system and any residual TCE that may remain within the area remediated by the P&T system.

If this updated evaluation concludes that MNA of the remaining portions of the site-related TCE plume is protective of human health and the environment and complies with applicable, relevant, and appropriate requirements within a reasonable timeframe, EPA will seek concurrence from the New Mexico Environment Department (NMED) to modify the selected P&T response action to include MNA for both the upgradient (west) and downgradient (east) portions of the FAP. This change will be implemented through a ROD Amendment, upon which the existing P&T system will be placed in a standby mode for the next 5 years (2013 to 2017) while continuing to monitor TCE concentration trends in accordance with the *Field Sampling Plan* (CH2M HILL, 2010). If this monitoring confirms during the next Five-Year Review that MNA remains protective of human health and the environment, EPA will decommission the P&T system prior to transferring operation and maintenance (O&M) responsibilities for the site to NMED in 2017.

1.2 Organization

The organization and content of this report is similar to that presented in *Natural Attenuation Evaluation Version 1.1 Fruit Avenue Plume Superfund Site, Albuquerque, New Mexico* (CH2M HILL, 2005a). This report is divided into the following sections:

- Section 1 - **Introduction** - describes the purpose of the report.
- Section 2 - **Site Description and Background Information**– provides background information including a description of the site and conceptual site model (CSM), current remedial action accomplishments preceding

the production of this report, a summary of the 2005 MNA evaluation report findings, and MNA objectives and decision points.

- **Section 3** - **Evaluation of Natural Attenuation Processes** – identifies the processes acting on the TCE contaminant plume at the site and simulates future transport of the Sites TCE contaminant plume.
- **Section 4** - **Natural Attenuation Effectiveness Compared to Pump-and-Treat** – provides a quantitative comparison of TCE removal by the P&T system versus NA.
- **Section 5** - **Conclusions** – summarizes the overall effectiveness of NA processes within the eastern (downgradient) and western (presumed source area) portions of the TCE plume, provides an updated estimate of time to achieve the remedial goals specified in the ROD, re-evaluates the CSM, and evaluates decision points.
- **Section 6 - Recommendations** – provides recommendations for future MNA sampling and data evaluation, and recommends response action modifications to achieve remedial goals in the most cost-effective manner and within a timeframe that is commensurate with the expected use of groundwater within the site boundary.
- **Section 7** - **Works Cited**– lists the references that supported the evaluations presented in this report.
- **Appendices A through L -** A majority of the information contained in this report was developed using the findings of other evaluations covering the many different facets of MNA, as follows:
  - **Appendix A** presents s tabular summary of the historical and Long-Term Monitoring Optimization (LTMO) Report groundwater monitoring programs, and hydrogeologic information on the different aquifer zones present at the FAP site.
  - **Appendix B** presents February 2012 groundwater elevation contour and flow maps, TCE distribution maps, and groundwater elevation hydrographs for each aquifer zone.
  - **Appendix C** presents a tabular summary of the water quality data used for this MNA evaluation.
  - **Appendix D** presents the results of a Mann-Kendall (MK) statistical evaluation of TCE and cis-1,2-DCE concentration data for a many of the long-term monitoring (LTM) well locations. The MK statistic provides an indication on whether contaminant concentrations are stable, increasing, or decreasing or whether no trend is evident. For MNA to be deemed effective, contaminant concentrations must generally be stable or decreasing at representative locations across a site.
  - **Appendix E** presents the results of compound-specific isotope analysis (CSIA). CSIA is a tool that can be used to differentiate degradation NA processes from non-degradation (dispersion, diffusion, and sorption) NA processes.
  - **Appendix F** presents the results from an evaluation of NA indicator parameters. Indirect evidence of NA processes provides an additional line of evidence that can help establish whether the geochemical conditions within an aquifer support or inhibit NA processes.
  - **Appendix G** summarizes the results from microbiological testing that was performed to identify the type and cell counts for the primary microorganisms associated with degradation processes.
  - **Appendix H** presents the results from an evaluation of abiotic NA processes at the FAP site.
  - **Appendix I** describes the approach used to calculate the TCE degradation rate for use in the contaminant fate and transport modeling described in **Appendix J**.
  - **Appendix J** describes the approach and results of groundwater flow and TCE fate and transport modeling that was conducted to estimate the time required to achieve the 5-micrograms-per-liter (µg/L) remedial goal with and without operation of the FAP P&T system.

- **Appendix K** summarizes the results from aquifer testing recently completed at the site. This testing was performed to develop hydraulic conductivity estimates for comparison to those determined by calibration of the groundwater flow model.
- **Appendix L** summarizes approach used to calculate the volume of contaminated groundwater and mass of TCE present in the aquifer at the FAP site.

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SECTION 2

Site Description and Background Information

The FAP Superfund site (Comprehensive Environmental Response, Compensation, and Liability Information System [CERCLIS] No. NMD986668911) is identified on the National Priorities List (NPL) as a chlorinated solvent groundwater plume located in the downtown area of Albuquerque, New Mexico. Remedial action at the site is led by EPA, with the NMED, Water Authority, and City of Albuquerque (CoA) representing other stakeholders.

The site consists of a groundwater contaminant plume, spanning multiple aquifer zones up to 544 feet deep, and is approximately 2/3 mile long and 550 feet to 1,300 feet wide. The geographic coordinates for the center of the site are Latitude 35°5’21” North, and Longitude 106°38’40” West in Township 10N, Range 3E. **Figure 2-1** depicts the overall area of the site and illustrates the location of the nearest Albuquerque Bernalillo County Water Utility Authority (Water Authority) and University of New Mexico (UNM) production wells.

The suspected sources of the groundwater contaminant plume are historic releases from several facilities (Sunshine Laundry, Elite Cleaners, and American Linen Corporation) that formerly operated laundry and/or dry cleaning operations near the corner of 3rd Street and Roma Avenue from 1924 to 1973. In 1973, the buildings were demolished and replaced by a paved parking area as part of an Urban Development Plan. The City of Albuquerque first discovered chlorinated solvent contamination in groundwater near the site in April 1989 during a routine inspection of the Coca-Cola Bottling Plant water supply well, located at 205 Marquette Avenue NE, which was plugged and abandoned in 1989 (DE&S, 2001b). In addition, two underground storage tanks (USTs)—a 300-gallon UST and a 1,500-gallon UST—were removed from the former Elite Cleaners/Sunshine Laundry property by the City of Albuquerque in November 1989.

Groundwater is an important source of drinking water for the City of Albuquerque. Currently, there is an array of water supply wells located east (downgradient) of the site that are operated by the Water Authority and the UNM. These wells are screened in the same alluvial aquifer that is being remediated under the FAP Superfund site ROD. Protection of water quality at the Water Authority and UNM well locations from impacts associated with the FAP Superfund site is consistent with the requirements established in the ROD.

A separate TCE plume is encroaching upon the site and comingling with the FAP TCE plume. This plume originates from an unknown source located west (upgradient) of the FAP site.

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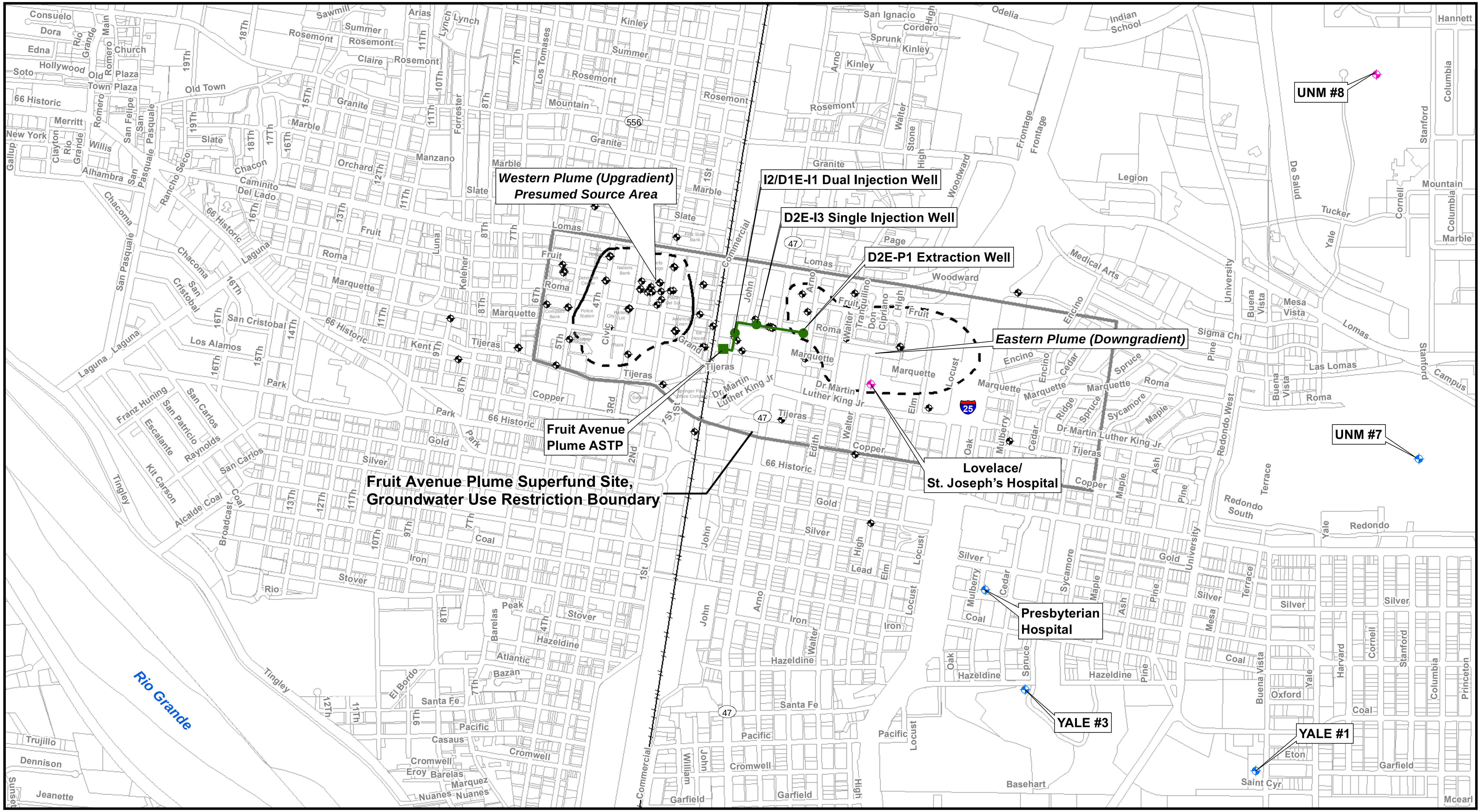

LEGEND

- ◆ Monitor Well
- ◇ Other Site Monitor Well
- ▭ Presumed Source Area
- ● Extraction Well
- ■ Air Stripper Treatment Plant
- ● Injection Well
- ◆ Existing and Potential Receptor Wells not used as a Drinking Water Supply
- ◆ Existing and Potential Receptors Wells used for a Drinking Water Supply
- ┼ Railroad
- ━ FAP TCE Composite Plume Boundary at 5 µg/L. An offsite TCE plume located west of the presumed source area is not shown. This plume is not part of FAP Site.

N

0 300 600 1,200 Feet

FIGURE 2-1
Site Map
Fruit Avenue Plume Superfund Site
Albuquerque, NM

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2.1 Reference Documents

A number of key reference documents cited in this report provide historical background and recent information on site activities. The following paragraphs provide a brief summary of these.

The City of Albuquerque and the NMED conducted several investigations between 1989 and 1999 to determine the source of the contamination. In 1999, EPA placed the site on the NPL. After conducting a Remedial Investigation (RI) and Feasibility Study (FS), EPA issued a ROD in 2001 (EPA, 2001).

Following the 2005 NA Evaluation (CH2M HILL, 2005a), the EPA issued the ESD (EPA, 2006), which modified the response action selected in the ROD. The ESD (EPA, 2006) eliminated certain elements of the sitewide response action and implemented MNA as a response action for portions of the TCE plume that are not included in the capture zone of the P&T system. The ESD requires periodic reviews to confirm that MNA remains effective.

The *Annual Groundwater Sampling Report* (e.g. CH2M HILL, 2012a) summarizes and evaluates the data collected during the two semiannual groundwater sampling events conducted each year. This report is the primary source of information used for evaluating the effectiveness of MNA at the site.

The LTMO (CH2M HILL, 2009a) used both qualitative and quantitative analyses to investigate sampling methods, analyte lists, and concentration and water-level trends at individual wells; the spatial distribution of monitoring locations across the site; and the temporal distribution of sampling events. The LTMO updated the CSM and recommended several changes to the LTM program (**Appendix A**).

The quarterly *Clean-Up Status Report* (CSR) (e.g., CH2M HILL, 2012c) present general information on the performance of the P&T remedy and describe remedial action accomplishments.

The *Remedial System Evaluation Report* (RSE) (CH2M HILL, 2009b) evaluated operation of the P&T system and its contribution toward achievement of the remedial action objectives (RAOs) specified in the ROD. The RSE concluded that full-time operation of the P&T system was no longer necessary to meet RAOs, and recommended that pulsed operation of the system be evaluated through a pilot test.

The NMED and EPA recently completed the first five-year review (5YR) for the FAP Superfund site (EPA, 2011). The 5YR is a technical evaluation that assesses the implementation and performance of a response action to determine if the response action is or will be protective of human health and the environment. Section 121 of CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), requires that remedial actions that result in any hazardous substances, pollutants, or contaminants remaining at a site be subject to a 5YR until such time that contaminant concentrations achieve a level of protection that allows for unlimited use and unrestricted exposure. The 5YR review concluded, "Current groundwater monitoring data indicate that the remedy is functioning as expected, is protective in the short-term, and is progressing toward achieving the remedial goals set out in the ROD."

2.2 Conceptual Site Model

Site-specific data have been collected at the site since 1989 to develop the CSM, which was last revised as part of the LTMO (CH2M HILL, 2009a). Subsurface soil properties and geophysical parameters have been logged during well construction (CH2M HILL, 2004, includes monitor well construction details). Additional data are available from periodic groundwater elevation measurements (CH2M HILL, 2009b), aquifer pumping tests, and groundwater flow modeling (CH2M HILL, 2005a). The regional aquifer, the Central Rio Grande Basin, is one of the most studied groundwater basins in the United States (U.S. Geological Survey [USGS], 2003, Reeder et al, 1967, and Bjorklund and Maxwell, 1961). These data were consolidated into a comprehensive CSM (CH2M HILL, 2009a), which is briefly summarized in the following subsections.

2.2.1 Changes to the CSM since Completion of the 2005 MNA Report

Three parts of the CSM have been updated since the previous NA Evaluation (CH2M HILL, 2005a).

1. More thorough understanding of the characteristics of the hydrogeology and contaminants in the presumed source area, and the effectiveness of MNA in the downgradient portion of the plume, resulted in the ESD (EPA, 2006), which eliminated portions of the response action proposed by the ROD (EPA, 2001).
2. The installation and sampling of additional downgradient groundwater monitor wells (MNW-13, MNW-15, and MNW-16) has permitted delineation of the downgradient eastern end of the plume, as defined by the 5-microgram per Liter (µg/L) isopleth.
3. The upgradient, offsite TCE plume is not part of the FAP Superfund site. The analytical sampling results from wells located on the western and southwestern portions of the FAP site have been allocated to differentiate the two plumes, although some commingling has already occurred.

Because the upgradient, offsite plume is not part of the FAP site, it is no longer referred to as the western portion of the plume. In the remainder of this report, the portion of the site near the presumed source area is referred to as the western plume, the portion of the site near the P&T system is called the central plume, and downgradient of the P&T system is the eastern plume.

2.2.2 Geology

The site is located in the central portion of the Albuquerque Basin, a geologic feature filled with unconsolidated to loosely consolidated gravel, sand, silt, and clay. The ground surface elevation near the site varies from 4,950 feet to 5,125 feet above mean sea level, and slopes from the east down toward the Rio Grande to the west. The Rio Grande is located just over one mile west-southwest of the site.

Of particular interest are the river deposits identified as the axial Rio Grande facies that underlie the site. These braided streambed deposits consist of well-sorted coarse sand to gravel separated by silty and clayey fine sands. Based on soil boring logs and geophysical parameters measured in the MNA wells, the correlatable geologic strata are generally horizontal on the western portion of the site but dip down to the east on the eastern portion of the site (**Figure 2-2**). These strata are divided into different aquifer zones for assessing groundwater flow and contaminant distribution at the site.

2.2.3 Hydrogeology

Seven aquifer zones, differentiated based on geologic and hydraulic characteristics, have been defined at the site (**Appendix A**). These zones are identified as the shallow (S) aquifer zone, the intermediate 1 (I1) and intermediate 2 (I2) aquifer zones, and deep aquifer zones D1, D2, D3, and D4. The hydraulic characteristics of the aquifer zones are summarized from previous reports (CH2M HILL, 2009a), which document estimated values from the literature, one aquifer pumping test at SFMW-47(I1/I2), and a calibrated groundwater flow model. An additional aquifer pumping test was conducted as part of this MNA Evaluation and is discussed later in this report.

The uppermost water-bearing zone (shallow aquifer zone) is present approximately 40 feet below ground surface (bgs) beneath the western portion of the site and up to 250 feet bgs at well MNW-15 at the site's eastern boundary due to the increasing ground surface elevation. The average groundwater velocity in each of the aquifer zones is estimated to range between 0.4 to 0.8 foot/day. Groundwater at the site generally flows eastward from the site toward the main regional groundwater pumping centers related to the Water Authority well fields (**Appendix B**).

The aquifer zones designated at the site are generally sandy or gravely zones separated by discontinuous silty and clayey sands and clay intervals. These zones are identifiable based on gamma and resistivity geophysical logs, and can be cross-correlated between boreholes across the site. The shallow, I1, I2, and D1 aquifer zones are contiguous and unconfined. Distinct and uniform low-resistivity and low-gamma intervals are identifiable in the D2, D3, and D4 aquifer zones. These intervals are separated by intervals of greater variability, presumably shorter intervals of fine-grained materials. The D2, D3, and D4 intervals are treated as leaky-confined aquifers to enable the groundwater flow model to be calibrated.

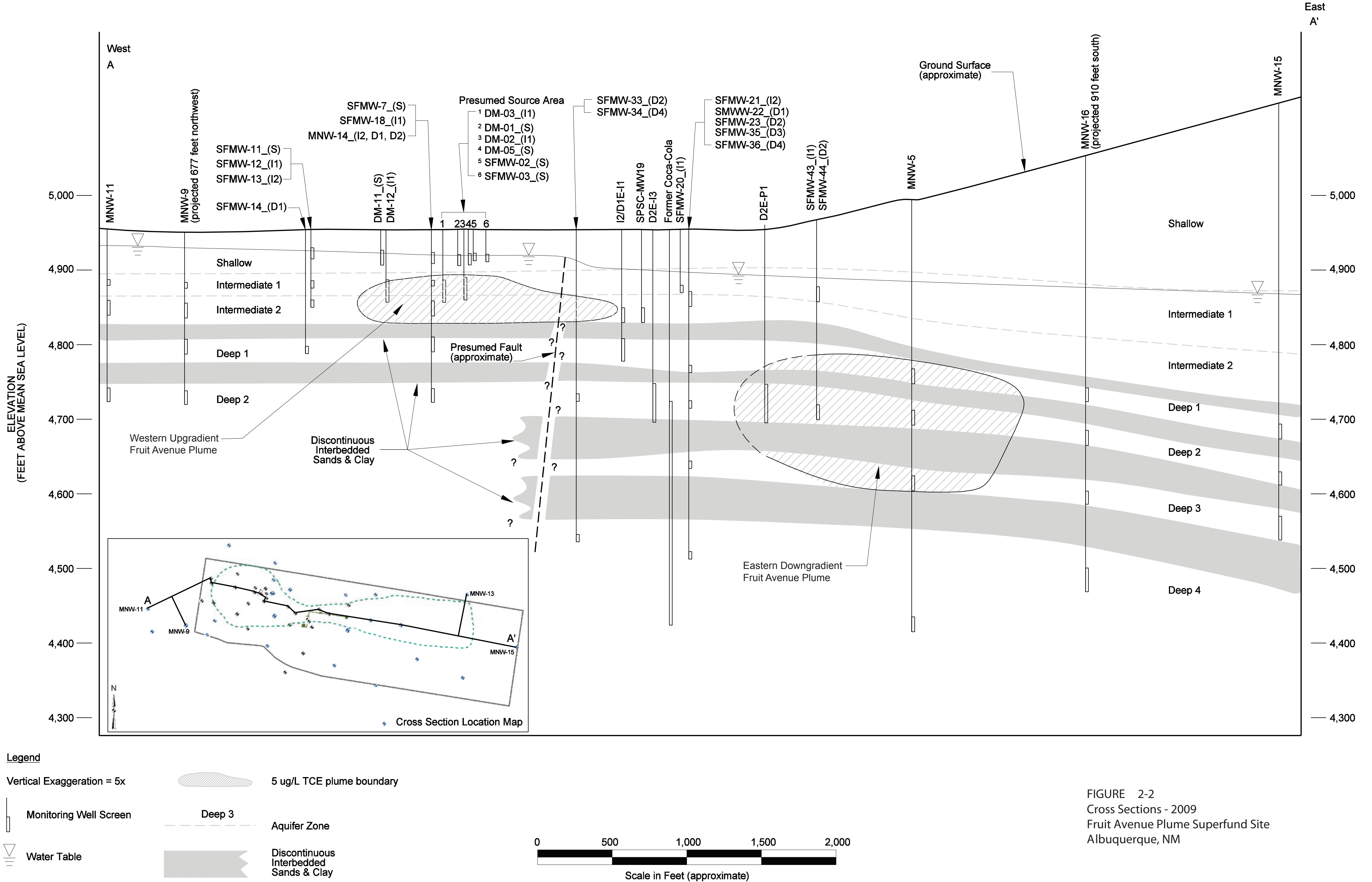

FIGURE 2-2
Cross Sections - 2009
Fruit Avenue Plume Superfund Site
Albuquerque, NM

CH2MHILL.

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Groundwater flow across the site (**Appendix B**) is influenced by an apparent fault zone, or other vertical geologic feature located between 2nd Street and the Burlington Northern Santa Fe (BNSF) railroad tracks, trending roughly parallel to 2nd Street. The potential effects of the apparent fault on the capture zone of the P&T system and the transport of contaminants have not been assessed.

The primary source of regional groundwater recharge is infiltration from the Rio Grande, located approximately 2½ miles east of the site. Local groundwater recharge is primarily lateral inflow from the aquifer adjacent to the site and possibly leaking sewers and water distribution lines (USGS, 2002).

Groundwater flow directions and levels are expected to change as pumping rates are modified at various local well fields in response to two changes. Groundwater levels at the site are expected to rise approximately 20 feet near the site's chlorinated solvent source area over the next 30 years as the Water Authority increasingly uses surface water as a public water supply source (USGS, 2002 and 2003). In addition, the Water Authority is changing its pumping scheme in response to the more-stringent arsenic drinking water standard. The long-term groundwater monitoring program implemented at the FAP Superfund site includes water level measurements at over 100 monitoring well locations across the site (**Figure 2-3**). This program will provide the information needed to assess what affect rising water levels and pumping rate changes have on groundwater flow patterns at the site.

Injection of treated water from the air stripper treatment plant (ASTP) influences groundwater flow patterns near the injection and extraction wells. In particular, injection of treated water creates a groundwater elevation mound near the injection wells that diverts a portion of the upgradient TCE plume present in the I1/I2 and D1 aquifer zones to the north toward the perimeter of the groundwater extraction well's hydraulic capture zone.

2.2.4 Contaminant Sources

A number of investigations have been conducted to identify the source of chlorinated solvent detected in groundwater at the FAP site. A chronology of these investigations and their key findings is summarized in **Table 2-1**. The Feasibility Study report (DE&S, 2001a) identified the Elite Cleaners/Sunshine Laundry, formerly located in the area of the Wells Fargo parking lot (2nd Street and Roma Avenue) (**Figure 2-1** and **Figure 2-2**), as the presumed source of chlorinated solvents detected in site groundwater. Chlorinated solvent contamination has been confirmed at this location through onsite observation of UST removals and soil sampling. Other potential chlorinated solvent sources such as former laundries, dry cleaners, machine shops, and auto repair shops were also identified within three blocks of the presumed source area in historical documents, and it is possible there are other minor contributing sources in the area.

The ROD lists perchloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), and trans-1,2-dichloroethene (trans-1,2-DCE) as contaminants of concern (COCs) for the site. The only COC that exceeds its remedial goal is TCE and there are less frequent detections of PCE, and the PCE and TCE daughter products cis-1,2-DCE and trans-1,2-DCE. Vinyl chloride (VC), another recognized potentially harmful daughter product, has not been consistently detected in groundwater samples collected at the site.

A primary source of TCE is no longer present at the site. A soil-vapor extraction (SVE) pilot test conducted at the presumed source area in 2002 (CH2M HILL, 2002) detected petroleum hydrocarbons (probably Stoddard solvent) and less than one percent chlorinated solvents in the soil gas generated during the test. Because of the unlikely presence of soil contaminated with chlorinated solvents or the presence of free-phase chlorinated solvents, the ESD removed SVE and hot-spot treatment from the response action selected in the ROD. If there is residual soil contamination that has not been detected and that could affect the groundwater, it is likely a small vadose zone source that may be discoverable when groundwater levels rise in response to the San Juan Chama Drinking Water Project (SJCDWP) diversion.

It is possible that matrix diffusion remains a potential low-level secondary source for the TCE plume at the site. TCE previously present in groundwater in the presumed source area may have been sequestered in or sorbed onto fine-grained aquifer materials. These aquifer materials act like a low-level source by slowly releasing TCE to the higher-conductivity adjacent aquifer materials. The magnitude of this back-diffusion and desorption has declined over time, as reflected in the groundwater sampling results. Additionally, conditions favorable for degradation of TCE are more likely to be present in the fine-grained materials.

TABLE 2-1
Summary of Previous Source Investigations
Fruit Avenue Plume Superfund Site, Albuquerque NM

Date	Activity Description	Summary of Results
April 1989	CoA conducts routine sampling of Coca-Cola Well located at 205 Marquette Avenue NE.	Analytical results detect chlorinated solvents PCE, TCE, and cis-1,2-DCE. TCE present at concentrations above the 5 µg/L MCL. The CoA recommends that Coca-Cola stop using its supply well because the MCL for TCE was exceeded. Coca-Cola switches to municipal water for potable and non-potable operations in 1989.
1989	City of Albuquerque identified public supply wells, industrial wells, and monitoring wells in the downtown Albuquerque area in an effort to determine the source(s) of contamination observed in the Coca-Cola well.	CoA discovered chlorinated solvent contamination in ground water underlying two facilities located within 2,500 feet of the Coca-Cola supply well; at a monitor well located at the Convention Center, and monitor/industrial wells located at the Lomas Center. The source(s) of this contamination was not determined.
1989	NMED completes a Preliminary Assessment (PA)	Five potential sources of the ground water contamination in the vicinity of the Coca-Cola well identified. They include: a. Excelsior Cleaners (currently American Linen) located between Roma and Marquette Avenues, and First and Second Streets; b. Former Albuquerque Bus Terminal located on the southeast corner of Marquette Avenue and Second Street (currently the site of the Convention Center). c. Wyandotte Chemicals formerly at Tijeras Avenue and First Street (currently the site of the Springer Plaza Office Complex); d. Former Elite Cleaners at 514 Third Street (currently a parking lot leased by Wells Fargo Bank); e. Lomas Center at the southeast corner of Lomas Boulevard and Broadway Avenue (former location of Sno-White (Rutledge) Linen and a gasoline station); currently a McDonald's restaurant.
Nov 1989	CoA removes the USTs (a300 gallon and 1,500 gallons) from the former Elite Cleaners/Sunshine Laundry property.	Soil sampling showed PCE and TCE contamination as high as 3 milligrams per kilogram (mg/kg) and 0.5 mg/kg, respectively from the surface to at least 24 feet below ground surface (bgs). Although the tanks appeared to be intact during removal, contaminated soils around the tanks and extensive soil staining indicated a release of contaminants was associated with the former Elite Cleaners/Sunshine Laundry property.
Oct 1990	NMED submits a Screening Site Inspection (SSI) report to the EPA. The SSI included installation of four monitor wells on the former Elite Cleaners/Sunshine Laundry property (SFMW-1 through SFMW-4).	Three of these wells found ground water contaminated with TCE at levels exceeding the MCL.
1993	NMED conducted an Expanded Site Inspection (ESI) for the Fruit Avenue Plume. The ESI included installation of two soil borings and three monitor wells (SFMW-5, 6, and 7) on or near the former Elite Cleaners/Sunshine Laundry property.	Soil and ground water analytical data gathered during the ESI indicated that waste sources at the former Elite Cleaners/Sunshine Laundry property contributed to observed contamination in the shallow zone, and that contamination was present in ground water collected from greater depths.
1993	Wells Fargo Bank, which leases the parking lot that used to be the former Elite Cleaners/Sunshine Laundry property, hires a contractor to conduct a Phase II Hydrogeologic Investigation. The investigation consisted of a historical site review, sampling of existing wells,	Soil sampling results showed the presence of Stoddard solvent, diesel and oil range hydrocarbons, and low levels of PCE, TCE, and 1,2-DCE in the vicinity of the two former USTs on site. The primary chlorinated solvent ground water contaminant was TCE, with the highest concentration (72 µg/L) detected in monitor well DM-12, located west,

TABLE 2-1
Summary of Previous Source Investigations
Fruit Avenue Plume Superfund Site, Albuquerque NM

Date	Activity Description	Summary of Results
	drilling of seven soil borings, and installation of 16 monitoring wells (DM-1 through DM-13(D2)).	and up-gradient of the former Elite Cleaners/Sunshine Laundry property.
1996	NMED completes a comprehensive ground water sampling event	The primary VOCs detected in ground water included TCE, PCE, and 1,2-DCE as in previous investigations. TCE was detected in 17 of the 23 wells sampled, with the highest concentration of 58 µg/L detected in intermediate zone well DM-13(I), located in the source area vicinity (former Elite Cleaners/ Sunshine Laundry property).
1997	Western Bank, located at the northeast corner of Marquette Avenue and Sixth Street (west of the former Elite Cleaners/Sunshine Laundry), hires a contractor to conduct a limited phase II investigation of its property	Ground water sample results showed no detectable VOCs in the shallow zone wells, and trace levels of TCE, 1,2-DCE, and toluene in the intermediate zone wells.
1997/1998	NMED conducted a two-phase field investigation (hereinafter referred to as the Background Investigation) to determine the lateral and vertical extent of ground water contamination, and to determine whether other source areas besides the former Elite Cleaners/Sunshine Laundry property existed. The NMED installs 30 monitoring wells ranging in depth from 50 to 440 feet (SFMW-8 through SFMW-37) and six Geoprobe borings.	TCE concentrations exceeding the MCL were detected in 22 of 65 wells sampled, with the highest concentration of TCE (86 µg/L) detected in monitoring well DM-13(I). PCE concentrations exceeded the MCL in two of the 65 wells sampled. VOC concentrations in the shallow and intermediate zones appeared to center on the former Elite Cleaners/Sunshine Laundry property.
1998	NMED investigates five potential source areas during the Background Investigation, and the Remedial Investigation.	Except for the former Elite Cleaners property, no soil, vapor, or ground water data linked any of the potential source areas to the Fruit Avenue Plume contamination. The NMED concludes that the property housing the former Elite Cleaners and Sunshine Laundry facilities is the primary source of soil and ground water contamination.
1999	NMED performed a Remedial Investigation which included the installation of six additional wells (SFMW-38 through SFMW-42, and the McDonald's Well), and one year of quarterly ground water sampling.	Ground water sampling data showed that the highest concentrations of TCE were still centered near the former Elite Cleaners/Sunshine Laundry property (monitoring wells SFMW-19 and DM-13(I) had 90 µg/L and 69 µg/L TCE, respectively). Ground water data also showed that TCE contamination above the MCL of 5 µg/L extended in the deep portion of the aquifer to a depth of at least 544 feet bgs, and had migrated east as far as Elm Street. The NMED oversees sealing of the Coca-Cola production well in September of 1999, and the plugging and abandonment of the Rutledge Linen production well in June 2000.
June 2002	Soil Vapor Extraction Pilot Test - Wells Fargo parking lot near former USTs	Petroleum hydrocarbon contamination associated with USTs makes up 99% of observed contamination.
Sep 2002	Site wide	"No free- or residual-phase DNAPLs have been observed…"
2003	Dual-tube sonic drilling and soil sampling - 32 soil samples and discrete-depth groundwater samples from HSM-I2-x Locations in Wells Fargo and Plaza del Sol parking lots.	One soil sample contained PCE (0.044 mg/kg) in excess of RAOs. The majority of other samples did not detect PCE or TCE.
2003	Direct push soil vapor sampling - Marquette to Lomas and 2nd to 4th.	Soil vapor TCE concentrations not indicative of significant soil contamination.

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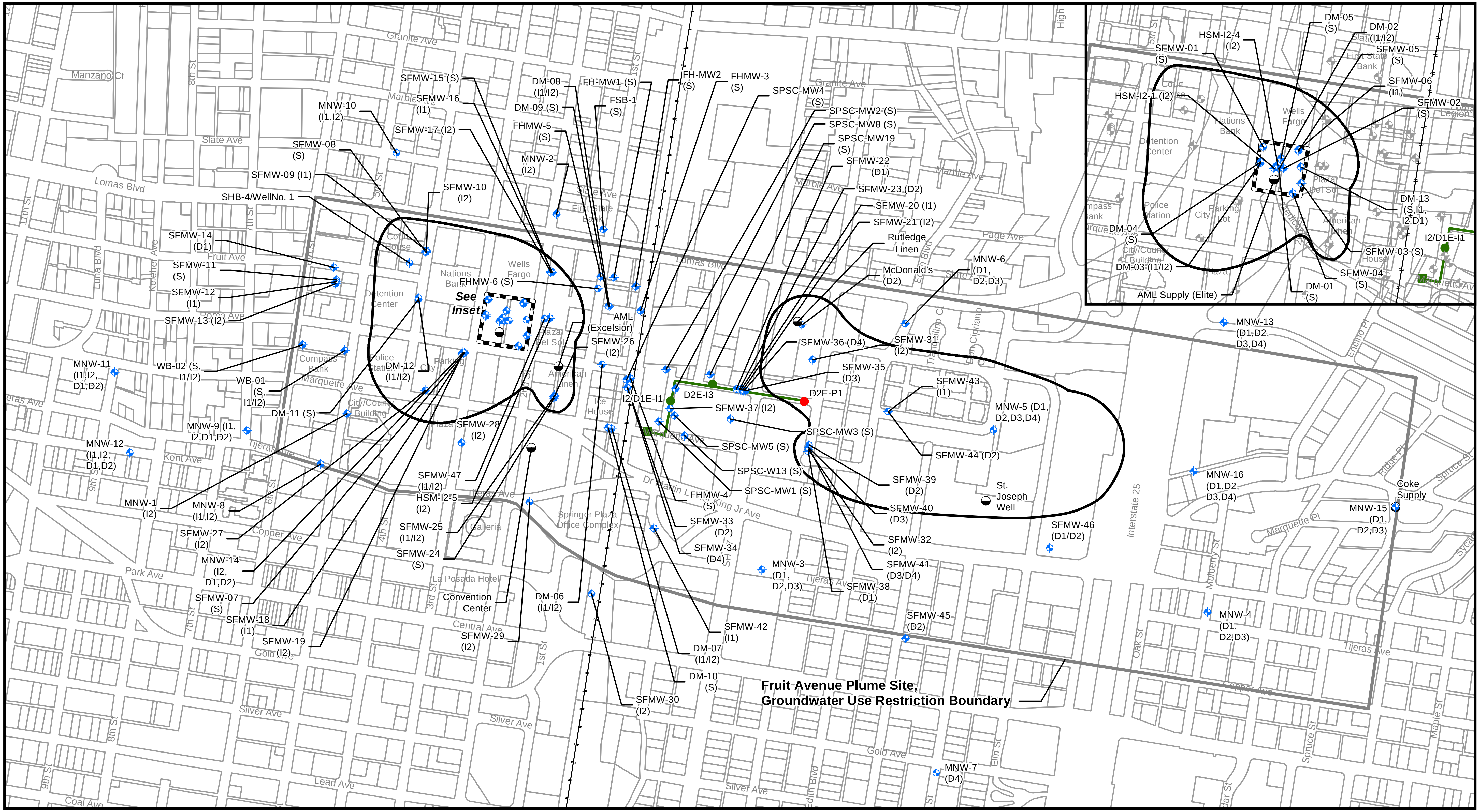

LEGEND

- ✦ Monitor Well
- ▨ Presumed Source Area
- ● Extraction Well
- ■ Air Stripper Treatment Plant
- ● Injection Well
- ┼ Railroad
- ━ FAP TCE Composite Plume Boundary at 5 µg/L. An offsite TCE plume located west of the presumed source area is not shown. This plume is not part of FAP Site.

N

0 150 300 600 Feet

Aquifer Zones:

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

FIGURE 2-3
LTM Program Monitor Wells
February 2012
Fruit Avenue Plume Superfund Site
Albuquerque, NM

J:\FRUITAVENUE_345406\MAPFILES\SITE_MAP_HISTORICAL.MXD FLONDON 10/29/2012 12:18:06 PM

CH2MHILL.

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2.2.5 Nature and Extent of Groundwater Contamination

The ROD (EPA, 2001) estimated that the site contained 320 million gallons of contaminated groundwater. The contaminated groundwater plume is described as having three portions:

- The primary, or western, portion of the plume lies west of the BNSF railroad tracks and upgradient of the P&T system with chlorinated solvent contamination generally occurring in the shallow (S) and intermediate (I1 and I2) aquifer zones.
- The central portion of the plume affected by the P&T system, contains chlorinated solvent in both the intermediate and deep aquifer zones. Currently, no TCE has been detected at concentrations above 5.0 µg/L in monitor well groundwater samples collected from this portion of the site.
- The eastern portion of the plume lies east (downgradient) of the P&T system with chlorinated solvent contamination generally occurring in the deeper (D1, D2, D3) aquifer zones.

Currently, TCE is the only COC that exceeds its remedial goal of 5 µg/L. Based on the most recent LTM results (CH2M HILL, 2012d), TCE is present at 42 of 56 locations at concentrations ranging from less than 0.5 µg/L to 39 µg/L with only 19 locations showing concentrations above the 5-µg/L remedial goal. PCE was detected at 7 locations at concentrations of less than 0.69 µg/L. Cis-1,2-DCE was detected at 34 locations at concentrations of less than 8.6 µg/L, and trans-1,2-DCE at 24 locations at concentrations of less than 8.7 µg/L. VC has been detected in seven samples collected from six different monitor wells between 1998 and 2011 at concentrations between 0.3 µg/L and 1.7 µg/L (**Appendix C**). Three of the detections have occurred since the 2005 MNA evaluation. Ethene, a product of the natural degradation of TCE, cis 1,2-DCE and VC, which does not have a remedial goal established in the ROD, has been detected in 63 of 80 samples at concentrations between 6.3 µg/L and 1800 µg/L. Because TCE is the only COC that routinely exceeds its remedial goal, much of the evaluation presented in this report focuses on TCE.

Of particular interest to the MNA evaluation is the concentration of cis-1,2-DCE and ethene found throughout the plume. In February 2012 (CH2M HILL, 2012d), cis-1,2 DCE was found in all aquifer zones (except the D4 aquifer zone) ranging in concentration from 0.22 µg/L to 8.6 µg/L. Both cis-1,2-DCE and ethene are biodegradation products of TCE. Since the RI (DE&S, 2001b) did not identify a cis-1,2-DCE source, the presence of cis-1,2-DCE is a positive indicator that NA processes are transforming TCE to cis-1,2-DCE, which has a remedial goal of 70 µg/L. The presence of ethene, an even later stage biodegradation product, further supports that contaminant degradation is occurring at the FAP site.

Although not identified as a COC for the FAP site, total petroleum hydrocarbons (TPH) have also been detected at several locations within the site boundary:

- TPH has been observed in soil and soil gas samples collected beneath the Wells Fargo parking lot (presumed TCE source area). This occurrence is most likely from a historic release of Stoddard solvent used in dry cleaning.
- The former Total Fuel Station located at the southeast corner of Lomas Boulevard and 2nd Street is about 500 feet downgradient and cross-gradient to the Wells Fargo parking lot in the central portion of the plume. This site had a leaking petroleum UST at one time.
- Only a block away from the former Total Fuel Station is the former Fur & Hide UST site. This site is located about 500 feet downgradient of the Wells Fargo parking lot. This site also had a former leaking petroleum UST. Monitor wells named FHMW-## were installed as part of the investigation at this site.
- The Southeastern Public Service Company/Maloof UST site is located about 1,000 feet downgradient of the Wells Fargo parking lot and at the transition between the central and eastern portions of the FAP – TCE plume. This site also had a former leaking petroleum UST. Monitor wells named SPSC-## were installed as part of the investigation at this site.

TPH is relevant to the MNA evaluation presented in this document because soluble TPH can enhance biodegradation of TCE to cis-1,2-DCE, VC, and ethene. Additional information on this process is presented in **Section 3** of this report.

2.2.6 Contaminant Transport

The eastward migration of the FAP – TCE plume is caused by the induced groundwater flow direction towards the Water Authority and UNM water supply wells.

The vertical migration of TCE from the shallow and intermediate aquifer zones to the deeper aquifer zones is attributed to two conditions:

- The downward vertical hydraulic gradient that resulted from historical pumping of the Coca-Cola well before it was taken out of service in 1989.
- The Coca-Cola well bore may have provided a preferential flow pathway for the downward migration of contaminants under the effect of natural or pumping induced vertical hydraulic gradients.

The Coca-Cola well was abandoned by NMED in September 1999 (DE&S, 2001b) and is no longer expected to act as a preferential flow pathway.

Vertical migration of contaminants in groundwater may have also been enhanced by a suspected fault zone located between 1st Street and 2nd Street. The vertical permeability of geologic materials within the fault zone may be greater, thereby enhancing vertical groundwater flow and TCE transport. Future groundwater monitoring within the I2 and D1 monitoring wells located downgradient of the fault zone may provide new information on vertical TCE migration in this area.

In 2005, CH2M HILL completed a MNA evaluation for the site (CH2M HILL, 2005a), which concluded TCE decay occurs through biological degradation and physical processes. However, biodegradation at the site is likely limited by the following conditions:

- Low contaminant concentrations that limit the population growth of niche microbes capable of reductive dechlorination.
- Inadequate amounts or limited distribution of organic carbon and other electron donors.
- High concentrations of alternate electron acceptor compounds (sulfate) that compete (e.g., are energetically more favorable) with the chlorinated solvent compounds during the reductive dechlorination reactions.

Because the TCE plume at the site has persisted at relatively similar concentrations for the 23 years since its discovery, biodegradation rates appear to be slow. While biodegradation is occurring, the slow rate translates to a longer remedial action timeframe.

As described further in **Appendix F** and **Appendix G**, various indicators support the determination that TCE biodegradation is occurring at the site. The microbial analysis indicates that while bioactivity in the aquifer is low, a population of suitable microbes is present. Low concentrations of organic carbon are present and petroleum hydrocarbons (benzene, toluene, ethylbenzene, and xylenes [BTEX]) are available as electron donors in some portions of the aquifer. The geochemical indicators suggest that oxidation-reduction (redox) conditions are favorable to support some biodegradation in portions of the aquifer. The widespread occurrence of cis-1,2-DCE and trans-1,2-DCE, without evidence of a primary release, provides additional evidence that partial biodegradation (TCE to cis-1,2-DCE and trans-1,2-DCE) is occurring. Although evidence of the cis-1,2-DCE to VC biodegradation pathway is limited, it is reasonable to conclude based on oxidation-reduction potential (ORP) measurements, that redox conditions within the aquifer are favorable for aerobic transformation of VC to ethene. The presence of ethene also indicates that natural processes are contributing to the complete dechlorination of chlorinated solvent and the destruction of contaminant mass in the plume. Biodegradation to some degree is observed in all portions of the site but is expected to be more predominant within the fine-grained aquifer zones.

An effort was made previously (CH2M HILL, 2005a) to estimate TCE decay rates for inclusion in a numerical contaminant transport model. The estimated decay coefficient yielded TCE half-lives ranging from 2.23 to 115 years. TCE half-lives estimated from laboratory microcosm and field studies have reported values ranging from 0.76 to 13.6 years (Aronson and Howard, 1997).

The estimated half-lives were tested in the 2005 MNA numerical contaminant transport model (MODFLOW-SURFACT) for the site and generally found to overestimate TCE degradation. Most estimated half-lives were too short and predicted that the TCE plume should completely degrade within a few years of the initial release. This is clearly not the case, as the site plume has persisted in some areas for many years. The wide range of estimated half-lives derived from the site data also illustrates that the degradation rate is difficult to define and that the estimating process is very sensitive to input parameters. As such, small changes in the field data result in large changes to the estimated degradation rate.

The uncertainties encountered in estimating the TCE half-life were attributed to differing assumptions between the tool (BIOCHLOR and NA Software computer-based contaminant fate and transport model [EPA, 2000]) used to estimate the half-life and the hydrogeologic and geochemical characteristics of the plume. The half-life estimates were also complicated by the lack of ideally placed monitoring wells necessary to optimize the computer model algorithms to interpolate and derive decay rates. Due to a lack of confidence in the estimated rates, decay was excluded from the 2005 contaminant fate and transport model simulations. Exclusion of decay from the model yields a more conservative (greater) estimate of contaminant transport distances and remediation timeframes. The 2005 NA evaluation concluded that although biodegradation processes were difficult to quantify, and there were uncertainties in the nature and extent of the plume, using a worst-case (no degradation) scenario suggested that NA alone may be sufficient to meet RAOs within about 40 years (by 2046). Additionally, operation of the existing P&T system was to contribute to meeting RAOs earlier (by mid-2042).

Since completing the 2005 NA evaluation, additional tools have been developed for estimating decay rates and estimating the fraction of decay that is attributable to degradation processes. The evaluation methods and results are presented in **Appendix H** and **Appendix I**.

2.2.7 Receptors

Two groundwater production wells have been taken out of service due to elevated TCE concentrations: the Coca-Cola production well where TCE was initially discovered at the site was plugged and abandoned in 1999. The Lovelace Hospital well has been without a pump and not in use since 1998. According to the NMOSE WATERS database, the Lovelace Hospital does not possess a water right. There are no other known production wells located within the groundwater use restriction boundary.

Beyond the groundwater use restriction boundary, potential receptors include the Presbyterian Hospital well, the Water Authority's Yale #3, Yale #1, and Yale #2 wells, and the UNM #7 and UNM #8 groundwater production wells (**Figure 2-1**). TCE and its breakdown products have been detected in samples collected from the Presbyterian Hospital well (0.58 µg/L TCE and 0.13 µg/L DCE; 2008 Personal communication from Bill Maier, Presbyterian Hospital Facilities Manager), and monitoring wells near UNM #7 (46 J µg/L TCE in MW-5;NMED, 2002). A connection between these detections and the FAP site has not been demonstrated. The Presbyterian Hospital well is currently being used for cooling water and UNM #8 is being used for irrigation. The 2012 Water Quality Report from the Water Authority (ABCWUA, 2013) indicates that TCE has not been detected in samples collected from entry points to the distribution system or from customer taps. Given the location and current and future projected pumping rates of the down gradient water supply wells, their operation is unlikely to affect NA processes within the groundwater use restriction area.

Ecological and human health risk assessments were conducted for the RI report (DE&S, 2001b). There are no complete ecological exposure pathways. The primary risks to human health are future ingestion and dermal absorption of contaminated groundwater.

2.2.8 Upgradient - Offsite Plume

As first described in the *Fruit Avenue Plume Superfund Site Second Quarter 2005 Groundwater Sampling Event* (CH2M HILL, 2005b), an unidentified source located west of the FAP site has formed a separate chlorinated solvent groundwater plume. This upgradient, offsite TCE plume is not part of the FAP Superfund site. The plume originates west of the site with TCE and cis-1,2-DCE detected in the I2, D1, and D2 aquifer zones. Within the I2 aquifer zone, TCE concentrations at MNW-1 (I1) declined from 10 µg/L in 2003 to less than 1 µg/L in 2007 but have since risen to 17 µg/L in August 2012. Within the D1 aquifer zone, TCE concentrations have risen steadily at MNW-11 (D1) from 14 µg/L in April 2005 to 46 µg/L in August 2012. Monitoring well MNW-11 is located approximately 2,500 feet (west) upgradient of the FAP site's presumed source area.

The full nature and extent of the offsite plume is unknown. The plume has begun to commingle with the FAP – TCE plume (**Figures 11, 12,** and **13** in **Appendix B**). Through the semiannual groundwater sampling events, EPA and NMED continue to monitor the migration of the offsite plume onto the site and its commingling with the FAP – TCE plume. The potential impact of the offsite TCE plume on cleanup of the FAP is not addressed in this report.

Per the ROD (EPA, 2001), and 40 CFR 300.425 (b) (1), a site may undergo remedial action financed by the Trust Fund (Superfund) only after it is placed on the NPL. Since the offsite plume is a separate release, and not part of the FAP site, and has not been listed on the NPL, resources designated for remedial action of the FAP site cannot be expended on the "offsite" plume. The NMED is conducting a preliminary assessment of the offsite plume that may eventually lead to a listing on the NPL and a future response action. The preliminary assessment is scheduled to be completed in 2015. Until the preliminary assessment is complete, the scope of future offsite plume activities is limited to tracking the offsite plume's migration onto the FAP site.

2.3 Remedial Action

The FAP remedial action (RA) began in October 2003. The ROD (EPA, 2001), as modified by the ESD, specified the following response action components:

- A groundwater P&T system with extraction, treatment, and reinjection components installed in the central portion of the plume.
- LTM to track the effectiveness of the P&T system and MNA portion of the response action.
- Groundwater use restrictions as defined under New Mexico Administrative Code (NMAC) 19.25.9.

2.3.1 Remedial Action Objectives

The ROD and ESD specified the following RAOs for the site:

- Prevent human ingestion of, inhalation of, or dermal contact with groundwater that contains concentrations of PCE above 5 µg/L, TCE above 5 µg/L, cis-1,2-DCE above 70 µg/L, trans-1,2-DCE above 100 µg/L (these concentrations are the Maximum Contaminant Level Goals (MCLGs) set by the Clean Water Act (CWA), or are Maximum Contaminant Levels where MCLGs are set at zero).
- Prevent human ingestion of, inhalation of, or dermal contact with concentrations of PCE and TCE in groundwater, the source of which is contaminated soil with concentrations of PCE and TCE that exceed 0.027 mg/kg and 0.024 mg/kg, respectively. That is, while the exposure route involves groundwater as the medium of concern, the source of the PCE and TCE contamination in question is contaminated soil, even though that soil poses no direct risk to human health.

The groundwater remediation goals for the FAP site's COC were set at the non-zero maximum contaminant level goals (MCLGs) or where the MCLGs are zero, at maximum contaminant levels (MCLs) established under the Safe Drinking Water Act.

Restoration of groundwater to remediation goals less than non-zero MCLGs or where MCLGs are zero at MCLs occurs only when a more conservative state standard exists. The NMED groundwater standard (NMAC 20.6.2.31013) for TCE is 100 µg/L which is not as stringent as the MCL. Therefore, EPA and NMED are remediating

TCE contaminated groundwater at the FAP site to the MCL of 5 µg/L that is 20-times lower than the State standard.

Sampling conducted during the 2003 remedial design investigation did not identify the presence of PCE or TCE contaminated soil that could act as a groundwater contaminant source. Consequently, the ESD eliminated soil vapor extraction and in situ chemical oxidation of TCE contaminated soil as components of the overall site response action.

Although a point of compliance is not specified in the ROD, the groundwater use restriction boundary (**Figure 2-1**) is currently used as an interim point of compliance. Once the cleanup levels specified in the ROD (EPA, 2001) are achieved throughout the site, the groundwater use restriction will be lifted, allowing for unlimited use.

The P&T remedy selected in the ROD indicated that TCE concentrations within the plume would be reduced to the 5 µg/L remedial goal within 15 years except for a portion of the intermediate aquifer zone near the presumed source area, where restoration could take 30 years or more. That is, the plume in the presumed source area was expected to persist beyond the year 2031, and TCE in the downgradient and peripheral portions of the plume was expected to decay below 5 µg/L by year 2016.

Because the design and construction of the existing P&T system differs from that described in the ROD, the actual remediation timeframe will be different. The ESD (EPA, 2006) did not identify a remediation timeframe for the as-built P&T system; nonetheless, it indicated that operation of the P&T would contribute to meeting RAOs by mid-2042. With respect to remediation timeframes, the National Contingency Plan (40 CFR 300.430 (a) (1) (iii)) indicates, "*EPA expects to return usable ground waters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site.*" With the Water Authority's increasing reliance on surface water to meet water supply requirements (Water Authority, 2007), an aggressive remediation timeframe for the FAP site no longer appears necessary if additional water supply wells are not planned within the groundwater use restriction area.

2.3.2 Groundwater P&T Remedy

The P&T system consists of one groundwater extraction well (D2E-P1), an ASTP, and two injection wells identified as I2/D1E-I1 and D2E-I3 (**Figure 2-2**). Since system startup in November 2005, the P&T system has removed approximately 10.2 kilograms (kg) of chlorinated solvent mass from the aquifer (CH2M HILL, 2012c). System operations include the following:

- Groundwater is pumped at about 85 gallons per minute (gpm) from a single extraction well (D2E-P1) screened in the D2 aquifer zone. Groundwater elevation measurements indicate that extraction well pumping influences groundwater flow patterns in the D1, D2, and D3 aquifer zones. This well is located near the intersection of Arno Street and Roma Avenue.
- Extracted groundwater is conveyed through an underground pipe to the centrally located ASTP where volatile organic compounds (VOC) are removed from the water.
- The treated water is returned to the aquifer via two reinjection wells (I2/D1E-I1 and D2E I3).

As reported in the 2012 Q1 Clean-Up Status Report (CH2M HILL, 2012c), the P&T system has extracted, treated, and returned to the aquifer 207.5 million gallons of contaminated groundwater. An estimated 10.2 kilograms of total VOCs (consisting of TCE, cis-1,2-DCE, and trans-1,2-DCE), have been removed from the aquifer since system startup.

The P&T system extraction and injection well layout do not contribute to hydraulic control of the presumed source area plume. Because this P&T system design was modified during construction, the groundwater mound created by the injection of treated water is not large enough to provide a hydraulic barrier to contaminant transport. Rather the centrally located groundwater mound likely diverts the TCE plume to the north away from the extraction well.

Pulsed operation of the P&T system was recommended by the *Remedial System Evaluation Report* (CH2M HILL, 2009b) to allow the TCE plume to reach the extraction well and be treated. The decision to start or stop the system during pulsed operations is based on evaluation of COC concentration rebound and plume mobility criteria. Influent TCE concentrations to the ASTP and the concentration of TCE in monitor wells affected by P&T operations are monitored to evaluate whether the P&T system should remain in the pulsed operation run mode or transition to the pulsed operation rest mode. The decision criteria are detailed in the RSE Report (CH2M HILL, 2009b). The first pulsed operations rest mode period started in July 2009. The ASTP was returned to pulsed operations run mode in November 2010 and has remained in the run mode since then. Because relatively high levels of TCE present in the presumed source area did not reach the extraction well prior to restarting the P&T system, the first rest phase may have been too short to achieve the goals of pulsed operation.

The downgradient portion of the plume extends approximately 2,000 feet east of the extraction well. Capture of the downgradient portion of the plume was not included in the original P&T system design basis.

2.3.3 MNA Response Action

The 2005 NA Evaluation (CH2M HILL, 2005a) indicated that natural attenuation of site contaminants takes place by both biological and physical processes. The geochemical and biological analytical results suggest that contaminant mass is being removed from the aquifer by reductive dechlorination and possibly other degradation processes. The dechlorination processes appeared to be more complete in the western portion of the plume near the presumed source area that lies near the Wells Fargo parking lot. The dechlorination processes may have been limited by geochemical conditions and a low level of bioactivity in the aquifer. Although biodegradation was difficult to quantify, any biodegradation of contaminants contributes to the reduction of contaminant concentrations.

The P&T system negatively impacts NA processes by returning treated water to the aquifer through two injection wells screened in the I2 and D1/D2 aquifer zones. The treated water contains elevated concentrations of dissolved oxygen and decreased carbon dioxide resulting from the air stripping treatment process, and elevated concentrations of sulfate arising from the use of sulfuric acid to control mineral scaling in the ASTP. These conditions impede further biodegradation within the central portion of the TCE plume.

The physical NA processes of diffusion, dispersion, and adsorption also contribute to the reduction of TCE and cis-1,2-DCE concentrations. Evaluation of these processes in the 2005 NA evaluation, using a worst-case (no degradation) scenario in a numerical contaminant transport model, determined that these physical processes alone prevent TCE concentrations above the remedial goal from reaching the downgradient receptor wells. At the time of the 2005 report, and based on the assumptions in the model, it appeared that NA alone may be sufficient to meet the RAOs by reducing the maximum TCE concentration of 98 µg/L to less than the 5 µg/L remediation goal throughout the aquifer within about 40 years (year 2046). Operation of the P&T system would reduce the time required to achieve the remedial goal by only 4 years (year 2042). These time frame estimates are tempered by considerable uncertainty in the upgradient extent of the offsite plume, the potential for a residual TCE source in the presumed source area (Wells Fargo parking lot), and the current downgradient extent of the plume.

During its operating lifetime, the P&T system was predicted to remove approximately 24 percent (8.3 kg) of the initial TCE mass present within the FAP plume. To date, the P&T system has removed 7.3 kg of TCE or about 90 percent of the 8.3 kg originally estimated.

Based on the 2005 MNA Evaluation (CH2M HILL, 2005a), the ESD (EPA, 2006) removed SVE, in-situ chemical oxidation, and restrictive covenants from the response action. The ESD further indicated, “MNA through semi-annual groundwater monitoring has been shown an effective response action for treatment of the plume perimeter that is not included in the capture zone of the ASTP system. Further monitoring of the shallow groundwater will continue at this time, since EPA’s studies show that currently the groundwater treatment and natural attenuation are reducing the concentrations of contaminants” and five year reviews are required “to ensure that the remedy is, or will be, protective of human health and the environment.”

2.3.4 Institutional Controls

The entire site is serviced by the municipal water supply system operated by the Water Authority. It is unlikely that private groundwater wells would be installed within the site boundary. At this time, there is a regulation developed by the New Mexico Office of the State Engineer (OSE) that prevents issuance of well-drilling permits within the 300-acre groundwater use restriction boundary (**Figure 2-1**). This restriction is promulgated under the New Mexico Administrative Code, Title 19, Chapter 25, Part 9.

The New Mexico OSE is responsible for enforcing the groundwater use restriction boundary. It is unknown at this time if any applications have been submitted, or permits issued, for the installation of groundwater production wells within the groundwater use restriction boundary.

2.4 MNA Objectives and Decision Points

The objective for this evaluation is to confirm that NA processes, can achieve the RAOs described in the ROD (EPA, 2001) and ESD (EPA, 2006) in an efficient and reasonable timeframe. A secondary objective for this evaluation is to assess whether MNA can effectively address other portions of the TCE plume, specifically that portion that lies west (upgradient) of the existing P&T system.

2.4.1 MNA Performance Criteria

The operational objective for the site is to partially contain and treat the TCE plume using the P&T system, thereby reducing the plume's toxicity and volume, such that MNA can address the remaining portions of the plume that lie outside the P&T system's zone of influence. Thus, the primary goal of the MNA response action is to ensure that portions of the plume not captured by the P&T system do not reach potential receptors at concentrations above the remediation goals described in **Section 2.2.7**.

EPA guidance (EPA 1998 and EPA 199b) provides criteria for evaluating the use of MNA as a remedy. As with any other remedial alternative, MNA should be selected only where it meets all relevant remedy selection criteria, and where it will meet site remediation objectives within a timeframe that is reasonable compared to that offered by other methods. The evaluation criteria are similar to those used to evaluate performance of other groundwater remedial technologies and generally require the selected remedy to:

- Prevent exposure to contaminated groundwater
- Minimize further plume migration
- Minimize further contaminant release from source materials, and
- Restore the aquifer to cleanup levels appropriate for the current and future anticipated beneficial uses to the extent practicable

As with other remediation methods, the progress of MNA toward the site's remedial objectives should be carefully monitored and compared with expectations, and contingency measures should be planned where appropriate.

2.4.2 Data Quality Objectives and Decision Criteria

To assess whether the stated objective can be achieved, the effects of current and future P&T system operation were considered through contaminant transport modeling in addition to evaluation of NA data obtained from testing of groundwater samples collected at the site. These evaluations are designed to help determine whether modifications to one or more of the existing groundwater response action components (e.g., P&T system, MNA, or groundwater use restriction boundary) are necessary.

To help with the overall assessment, the initial data quality objectives (DQOs) from the LTMO (CH2M HILL, 2009a) were reviewed using the seven-step DQO process. This review resulted in the following updated DQOs for this MNA evaluation.

2.4.2.1 State the Problem

Can MNA provide sufficient remedial action to address the portion of the plume not remediated by the P&T system, and if so, can MNA be expanded to address the western plume?

2.4.2.2 Identify the Goal of the Study

If MNA is effective, then develop implementation strategy to expand MNA to remaining portions of the plume or recommend that P&T and MNA continue as the primary remedial action.

If MNA is not effective, then identify modifications to existing remedy components or additional remedial measures to ensure RAOs are achieved in a reasonable timeframe.

2.4.2.3 Identify Information Inputs

The following inputs are required to evaluate the appropriateness of MNA as a primary response action (ITRC 2008, EPA, 1999b):

- Evaluation of whether COCs can be effectively remediated by NA processes.
- Demand for resources within the groundwater use restriction boundary.
- Evaluation of whether the plume is stable or shrinking.
- Evaluation of whether NA conditions are sustainable.
- Human health and environmental risks assessments.
- Whether degradation products (e.g. cis-1,2-DCE and VC for TCE) present a greater risk than parent contaminants.
- The impact of the P&T remedy on the MNA response action.
- The impact of nearby groundwater production wells on MNA response action.
- Estimate of remediation time frame that is commensurate with expected period when resource use will be required.
- Cost-benefit analysis.

The last two inputs are not evaluated in this report because: 1) although groundwater is currently being pumped from Water Authority wells located downgradient of the site, groundwater pumping rates from these wells are expected to decline in the future in response to increased reliance on surface water resources (Water Authority, 2007); and 2) this report is a technical evaluation designed to assess MNA effectiveness only, not cost-benefit performance.

2.4.2.4 Define the Boundaries of the Study

The boundaries of the study are defined by the current and future horizontal and vertical extent of the TCE plume at the site, and the location of existing and potential receptor wells, which represent the only complete exposure pathway for the contaminated groundwater at the site. The available data and the predictive quality of the groundwater flow modeling define the temporal extent of this study. Temporal boundaries of the study include the presumed remediation timeframes estimated from the ROD or alternate timeframe agreements between EPA, NMED, and the stakeholders.

2.4.2.5 Develop the Analytical Approach

Technical decision rules for assessing MNA effectiveness at the site include the following:

- If TCE concentrations in the downgradient groundwater plume are stable or decreasing, then MNA is effective.
- If the distribution of TCE in the groundwater plume, as defined by the 5 µg/L remedial goal is stable or decreasing, then MNA is effective.
- If the contaminated groundwater plume is not migrating beyond the groundwater use restriction boundary, then MNA is effective.

Additional decision rules that may need to be addressed include the following:

- If the leading edge of the TCE plume, as defined by the 5 µg/L remedial goal, migrates beyond the groundwater use restriction boundary, then additional monitor wells and/or monitoring at points of potential exposure (water supply wells) may be needed.
- If TCE concentrations in the groundwater plume are consistently increasing, then expansion of the P&T system, and/or implementation of an alternate response action may be needed.
- If rising groundwater levels in the presumed source area mobilize previously undiscovered COCs, then the effectiveness of MNA may need to be re-evaluated, or implementation of an alternate response action considered.
- If the upgradient offsite plume interferes with achieving site remediation goals, then action under a separate decision document may be required to address that plume.

If MNA is sufficient to address contaminated groundwater at the site, then the P&T system can be placed in a standby mode and eventually decommissioned.

2.4.2.6 Specify Performance or Acceptance Criteria

The proposed performance criteria for this evaluation include the following:

- If TCE concentrations at representative monitoring wells within the plume boundary show stable to declining concentrations, and TCE concentrations at the furthest downgradient FAP monitor wells (MNW-4 and MNW-15) consistently remain at concentrations less than 2.5 µg/L (one-half of the MCL), then MNA in conjunction with maintenance of groundwater use restrictions can serve as the sole response action components.
- If TCE concentrations at representative monitoring wells within the plume boundary consistently show stable to increasing trends, and TCE concentrations at MNW-4 and MNW-15 consistently remain at concentrations of less than 2.5 µg/L, then P&T in combination MNA will continue as the primary response action components.
- If TCE concentrations at representative monitoring wells within the plume boundary are increasing, and TCE concentrations at MNW-4 and MNW-15 increase and consistently remain above 2.5 µg/L, then modification of the existing P&T, MNA, or groundwater use restriction boundary is necessary.

2.4.2.7 Develop Plan for Obtaining the Data

The inputs to the decision define the MNA Evaluation. This evaluation shall be conducted to make specific recommendations for the use of, or need for enhancement of, MNA as a primary response action at the site.

2.4.3 Natural Attenuation Data Collection

The goals for this MNA evaluation are coincident with the purpose of the LTM program objectives as discussed in the LTMO (CH2M HILL, 2009a). The LTM objectives are to provide ongoing monitoring of defined chemical and hydraulic parameters in accordance with the RAOs described in the ROD (EPA, 2001). These parameters are periodically measured to monitor plume boundary changes, to ensure that COC concentrations at the groundwater use restriction boundary remain at levels below the ROD remediation goals, and to help evaluate the effectiveness of the P&T and MNA response actions. The LTM program and supplemental MNA sampling event are defined in the site's *Field Sampling Plan* (CH2M HILL, 2010).

2.4.3.1 Adequacy of Monitoring Network and Schedule

The LTM program sampling locations were selected primarily based on information provided in the LTMO (CH2M HILL, 2009a) to provide information throughout and at the boundaries of the plume in three dimensions. Groundwater samples are collected from the monitoring wells either semiannually, annually, or biennially, depending on concentration, rate of change, and location. The most recent description of LTM sampling results is provided in the 2011 Annual Groundwater Sampling Report (CH2M HILL, 2011).

Monitoring well locations (**Table 2-2**) for the supplemental MNA sampling event were selected to provide data representative of the western plume (near the presumed source area), central plume (near the P&T system), and the eastern plume. Sampling was also performed to obtain "background" water quality information from monitoring well locations unaffected by the TCE plume. Monitoring well locations also were selected to provide information from each of the seven aquifer zones. In addition, several samples were collected from upgradient of the FAP. Eight of the nine wells included in the prior 2004 and 2005 MNA sampling events were included in the 2010 event to confirm prior results.

TABLE 2-2
Sampling Locations for MNA Parameters
Fruit Avenue Plume Superfund Site, Albuquerque NM

Aquifer Zone	Plume Zone				
	Upgradient	**Presumed Source Area**	**Cross-gradient**	**Plume Core**	**Downgradient of Plume**
Intermediate-1 (I1)	SFMW-12(I1)	SFMW-16(I1), SFMW-25(I1)	None	SFMW-20(I1)	SFMW-43(I1)
Intermediate-2 (I2)	SFMW-13(I2)	HSM-I2-4, HSM-I2-5, MNW-14(I2)	MNW-02(I2)	None	SFMW-21(I2) SFMW-32(I2)
Deep-1 (D1)	SFMW-22(D1)	None	None	MNW-05(D1)	MNW-15(D1)
Deep-2 (D2)	SFMW-33(D2)	None	MNW-03(D2), MNW-06(D2)	SFMW-23(D2), SFMW-44(D2), MNW-5(D2)	MNW-15(D2)
Deep-3 (D3)	SFMW-35(D3)	None		SFMW-40(D3)	MNW-15(D3)
Deep-4 (D4)	None	None	None	None	None
Offsite Plume	None	None	None	MNW-08(I2) MNW-09(I2) MNW-09(D1)	None
Total Field samples (28)	5	5	3	9	6

MNA samples for this report were collected during the 2010 annual LTM sampling event (**Appendix C**). MNA sampling was performed on four previous occasions at the site (in 1997, 2002, 2004, and 2010; **Appendix C**). The next MNA sampling and data evaluation event will occur in 2015 to provide sufficient time to complete an updated MNA technical evaluation prior to commencing second 5-year review (due in 2016) activities.

2.4.3.2 Monitoring Parameters, Analytical Methods, and Field Methods

Groundwater samples collected as part of the LTM program are analyzed by a Contract Laboratory Program (CLP) laboratory for VOCs via SOM01.2. The list of analytes, analytical methods, and analytical laboratories for the groundwater samples collected for the 2010 MNA evaluation are provided in **Table 2-3**. Field test methods were used for parameters requiring immediate analysis.

TABLE 2-3
List of Analytes, Analytical Methods, and Laboratories for the 2010 MNA Sampling Event
Fruit Avenue Plume Superfund Site, Albuquerque NM

Analyte Group	Analytical Method	Analytes		Analytical Laboratory
General Chemistry	EPA 200.7	Calcium Iron	Magnesium Manganese	CLP or EPA Region 6-Houston
	EPA 160.1	Total Dissolved Solids		EPA Region 6-Houston
	EPA 300.0	Sulfate	Chloride	EPA Region 6-Houston
	EPA 310.1	Alkalinity, Bicarbonate	Alkalinity, Carbonate Alkalinity, Total	EPA Region 6-Houston
	EPA 415.1	Total Organic Carbon		EPA Region 6-Houston
	EPA 353.2	Nitrate, as N	Nitrite, as N	EPA Region 6-Houston
	EPA 376.1	Sulfide		EPA Region 6-Houston
General Chemistry	Field Instrument	Oxygen Reduction Potential	pH	Field analysis
	Micro-Chem Field Kit[c]	Total and Ferrous Iron, Sulfate and Sulfide	Dissolved Oxygen Nitrate and Nitrite	Field analysis
Dissolved Gasses	RSK-175 or equivalent (GC/FID)	Methane, Ethane, Ethene	Free Carbon Dioxide	Tier-4 Laboratory
Molecular Biology (b)	PLFA	Anaerobic Metal Reducers (BrMo Decreased Permeability Eukaryotes (Polyenoics) Srb/Actinomycetes (MidBrSats)	Firmicutes (TerBrSats) General (NSats) Proteobacteria (Monos) Slowed Growth	Tier-4 Laboratory
Compound Specific Stable Isotopes[a, b]	GC/C/IRMS	δ^{13}C on TCE & DCE		Tier-4 Laboratory

Notes:

(a) Analysis performed only on TCE and cis-1,2-DCE for samples containing sufficient concentrations needed to meet minimum analytical requirements. Samples may be submitted from wells HSM-I2-5 (I2), SFMW-44 (D2), MNW-5 (D1), and MNW-5 (D2).

(b) Tier – 4 Laboratories: Microseeps – Pittsburgh PA, Microbial Insights – Rockford, TN

Micro-chem field kits by CHEMetrics, Inc.®.

2.4.3.3 Changes to the MNA Evaluation since 2005

This MNA data evaluation is generally designed to replicate the work done during the 2005 MNA evaluation. Several sampling locations were added. Compound-specific isotope analysis (CSIA) was added to provide a better understanding of degradation versus non-degradation processes. CSIA was not a commercially viable technology at the time of the previous MNA evaluation. Groundwater sampling and borehole geophysics were conducted to support an evaluation of abiotic degradation.

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SECTION 3

Evaluation of Natural Attenuation Processes

NA processes include biodegradation, abiotic degradation, and non-degrading physical processes. For the purposes of this report, *degradation* processes break down an organic molecule, converting parent compounds to potentially harmful intermediate daughter products and finally to innocuous daughter products such as carbon-dioxide. *Decay* of contaminants refers to the decreasing concentration observed, which may be caused by both degradation and non-degrading physical processes such as diffusion, dispersion, and adsorption.

3.1 Degradation Principles

Biodegradation is defined as the process of breaking down an organic molecule by converting it to biomass, carbon dioxide, and water. Abiotic degradation is defined as the process of breaking down an organic molecule by reaction on a catalytic mineral surface, converting it to carbon dioxide and water. Although abiotic degradation is a less commonly investigated process, chloroethenes have been found to undergo abiotic degradation in the presence of a variety of iron-bearing minerals such as mackinawite and magnetite (EPA, 2009b) and to undergo biodegradation by naturally occurring microbes. During both of these processes intermediate compounds, or daughter products of the parent compound, may be formed. Depending on the characteristics of the degradation environment, the daughter products may or may not be stable, and may be more or less harmful than the parent compounds.

Biodegradation and abiotic degradation generally reduce the toxicity, mobility, and volume of contaminants within a groundwater contaminant plume by transforming contaminants into less toxic or non-toxic forms and reducing concentrations. In some instances, these two natural degradation processes alone may be sufficient to meet the RAOs for a site. This section reviews these two degradation processes, which are applicable for the COCs present at the site, and discusses the effects these processes have on the fate and transport of contaminants in site groundwater.

3.1.1 Biodegradation of Chloroethenes

Naturally occurring microbes can metabolize a wide variety of organic compounds such as sugars, starches, and amino acids. Microbes from aquifers that have been contaminated with synthetic organic compounds also have been found capable of degrading these compounds. The following elements are necessary for biodegradation of chlorinated solvents to be successful:

1. A population of “niche” bacteria that perform the biodegradation reactions
2. Sufficient nutrients such as nitrogen, phosphorus, potassium, and organic carbon (electron donors) to sustain the microbial population’s existence
3. Sufficient quantities of contaminants (electron acceptors) in a soluble form to promote the growth of niche bacteria
4. Tolerable variations in temperature, pH, and other geochemical parameters to minimize disruptions to the biodegradation processes

Deficiencies in these parameters may be sufficient to slow biodegradation rates, stop a sequential process, or prevent the initiation of the degradation reactions. For example, if contaminant concentrations are very low, the population of specialized niche bacteria may never flourish and be sufficiently robust to affect the plume. Specific biodegradation reactions play an important role in determining the fate of organic contaminants.

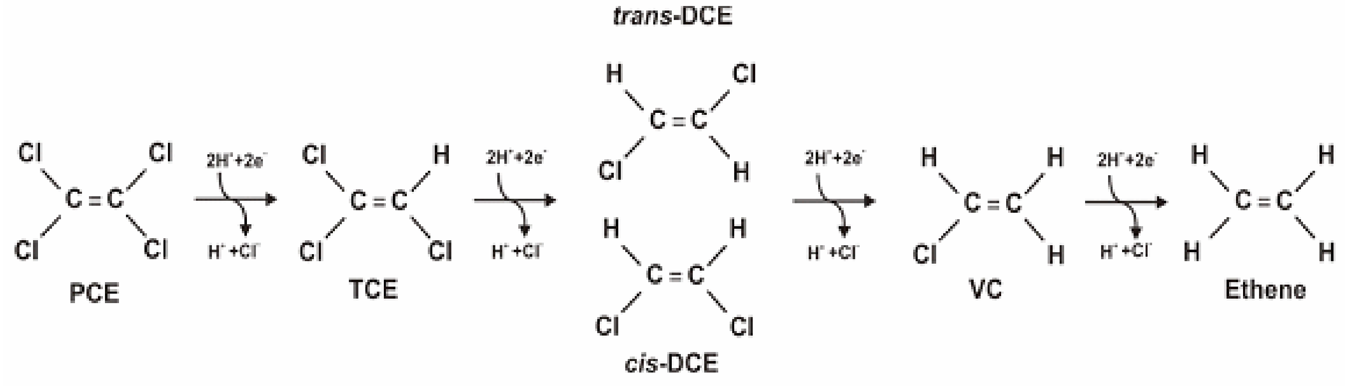
Chlorinated solvent plumes, and the biodegradation that occurs within them, generally can be described as one of three types (Wiedemeier et al., 1998):

- Type 1 where high concentrations of anthropogenic nutrients drive reductive dechlorination.

- Type 2 where moderate concentrations of natural nutrients result in slower biodegradation.
- Type 3 where low concentrations of natural nutrients and high dissolved oxygen concentrations result in low rates of biodegradation of the more-chlorinated ethenes. Attenuation occurs primarily through diffusion, dispersion, and sorption with limited biodegradation taking place in localized areas. Where present, VC can be rapidly oxidized. Overall, the FAP exhibits Type 3 plume behavior.

In Type 1 and Type 2 plumes, biodegradation processes transform chlorinated solvents through reductive (anaerobic) dechlorination. Reductive dechlorination is the replacement of a chlorine atom in a chloroethene molecule with a hydrogen atom, thereby releasing a chloride ion to the groundwater. **Figure 3-1** illustrates the stepwise reductive dechlorination process that transforms PCE and TCE to ethene:

FIGURE 3-1
Stepwise Reductive Dechlorination of Chlorinated Solvents
Fruit Avenue Plume Superfund Site, Albuquerque, NM

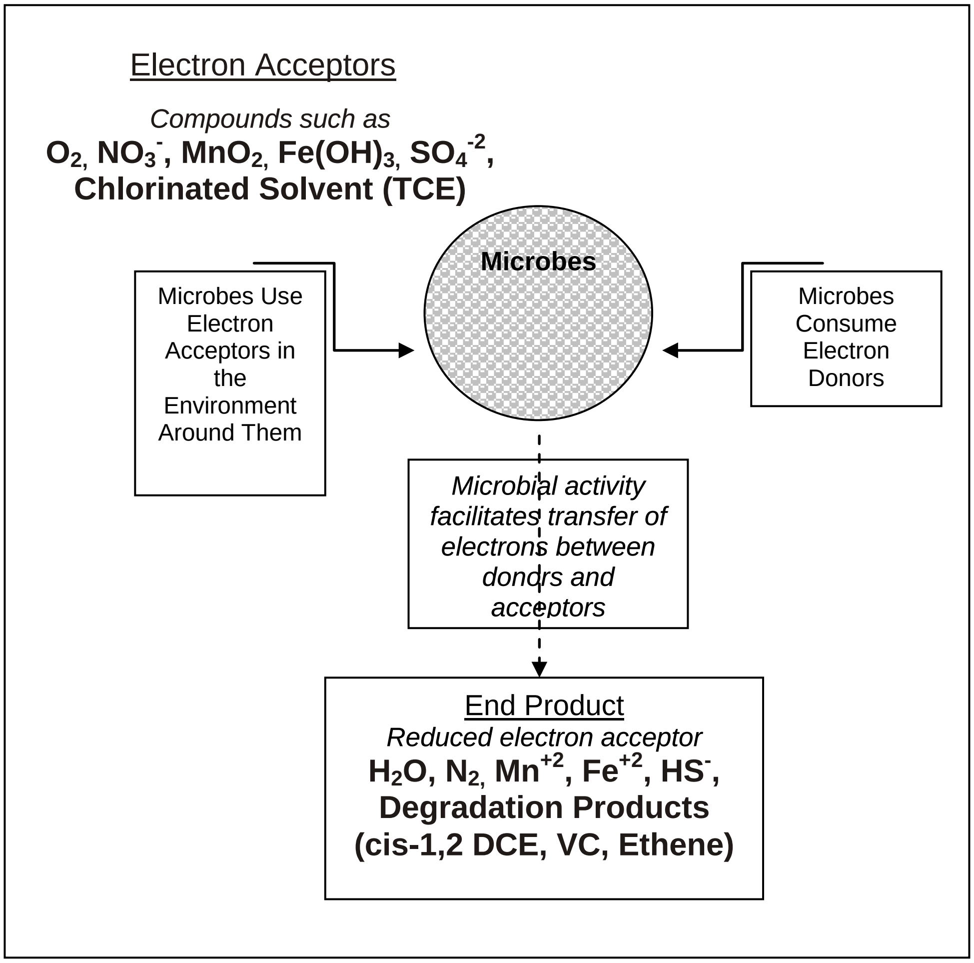


Through repetition of this stepwise process, TCE is transformed to cis-1,2-DCE and then VC. In Type 1 or Type 2 plumes, VC is further reduced to ethene and then to ethane by substituting two hydrogen atoms for the double bond in the ethene molecule. In deeply anaerobic conditions (methanogenic), the transformation of VC to ethene/ethane is slowed such that VC often accumulates. If VC is transported by natural groundwater flow into a portion of the aquifer where dissolved oxygen is present, an aerobic transformation reaction is favored as in Type 3 plumes, where VC is oxidized to carbon dioxide. Theoretically, the end products of the degradation reactions (ethane and ethene) should be amenable to further biodegradation to carbon dioxide and water.

Plumes may exhibit different behavior in a source area compared to the leading edge (Wiedemeier et al., 1998). The combination of Type 1 or Type 2 behavior (anaerobic reductive dechlorination of TCE) in the source area, followed by Type 3 behavior (aerobic microbial oxidation of DCE and VC) at the plume margins, provides a microbial pathway for complete degradation of chlorinated solvent in groundwater plumes, thus making MNA a viable component of, or an alternative to, an active remedy. Another case is where Type 1 or Type 2 behavior takes place in lenses or layers of fine-grained materials where groundwater movement is limited and Type 3 behavior occurs in the high-flow coarse-grained layers of the aquifer.

Stepwise reductive dechlorination can be biologically enhanced by bacteria that derive energy by facilitating the transfer of an electron between electron donors and electron acceptors (**Figure 3-2**). Microbial degradation of an electron donor, such as a naturally occurring carbon source, (the electron donor) also requires the microbe to use an available electron acceptor. After the more-preferred electron acceptors (such as oxygen and nitrate) have been used up, the aquifer microbial communities use less efficient or energetically favorable electron acceptors such as manganese, ferric iron, and sulfate. If an aquifer does not have a sufficient supply of electron acceptors, chloroethenes may be used. If all preferred electron acceptors are exhausted, methanogenic conditions may develop, and the less preferred electron acceptors (such as chloroethenes) can be rapidly dechlorinated. If the more preferred electron acceptors are not exhausted, development of conditions in which chloroethenes are reduced may be prevented (Chapelle, et al., 2003).

FIGURE 3-2
Schematic of Biologically Mediated Reductive Dechlorination
Fruit Avenue Plume Superfund Site, Albuquerque NM



It is possible that anaerobic conditions conducive to reductive dechlorination are not widespread at a site, and are only present in relatively small localized portions of the aquifer. At the FAP site, the discontinuous silty and clayey sands and clay intervals of the braided streambed deposits of the Rio Grande facies likely provide zones with higher nutrient concentrations, and low groundwater flow rates, which permit development of geochemical environments amenable to reductive dechlorination processes.

Several other microbial mechanisms for biodegradation of chloroethenes, including aerobic oxidation, anaerobic oxidation, and aerobic cometabolism, have been identified. A wide variety of chlorinated solvents (including TCE, cis-1,2-DCE, trans-1,2-DCE, and VC) can be cometabolically degraded. Cometabolism is a result of nonspecific enzyme activity towards organic compounds that do not serve as carbon or energy sources. Cometabolism of chloroethenes is mediated by the enzyme methane monooxygenase (MMO), which is produced by methanotrophic bacteria. Methantrophs are environmentally ubiquitous bacteria that oxidize methane as an energy source and carbon source (Brigmon, 2001). Unlike reductive dechlorination, the chlorinated compounds are completely mineralized to carbon dioxide and chloride with no toxic intermediates (Conrad, et al., 2010).

$$\text{TCE \& DCE} \rightarrow \text{Dichloroacetate, Glyoxylic acid, Formate} \rightarrow CO_2 + HCl$$

Oxidation of cis-1,2-DCE and trans-1,2-DCE to carbon dioxide, in the absence of an apparent alternative substrate, has also been demonstrated (Bradley and Chapelle, 2000).

$$O_2 + \text{DCE} \rightarrow Cl^- + CO_2$$

It has also been demonstrated that sulfate-reducing and iron-reducing microbial populations can dehalogenate and mineralize chloroethenes, and that the dehalogenating populations may be distinct under different redox conditions (e.g., sulfate-reducing, iron-reducing, or methanogenic [Chapelle, 2003]). Conditions that would be marginal for biodegradation of highly concentrated chloroethenes may be suitable for reductive dechlorination of lower-concentration contaminant plumes.

3.1.2 Evidence for Biodegradation

Biodegradation of chloroethenes in contaminated environments is complex and the exact mechanism occurring at a given location within a site can be difficult to identify and may change over time. To evaluate if biodegradation is taking place or is capable of occurring, the following lines of evidence are generally examined.

3.1.2.1 Direct Evidence of Biodegradation

Direct evidence of biodegradation is provided by changes in the composition and concentration of the suite of contaminants at the site, and by observation of isotopic changes that cannot be produced by a known process besides degradation.

Contaminant Concentrations

Chlorinated VOC (cVOC) concentrations are evaluated (**Appendix D**) to assess if degradation products are present and if there has been changes in the concentration of the contaminants over time. Although PCE and TCE are the primary or parent contaminants at most cVOC contaminated sites, DCE (cis-and trans isomers), VC, ethene, and ethane (the degradation products) are not. A reduction in the concentration of the parent contaminant(s), in conjunction with the appearance of the degradation products (including chloride), suggests that a biodegradation process is actively dechlorinating the parent contaminant(s).

CSIA

CSIA is an assessment tool that can provide data demonstrating degradation of contaminants at the site. A detailed explanation of CSIA and evaluation of site data is included in **Appendix E** and summarized in **Section 3.2.1.5**. In summary, concentration and isotopic composition are independent characteristics of a compound (e.g., color and mass of an apple). Physical reactions (evaporation, sorption, dispersion, and diffusion) *do not* significantly affect carbon isotopes. Degradation reactions (biological or chemical oxidation-reduction reactions, and hydrolysis) *do* affect carbon isotopes. The amount of change to the carbon isotopes depends on completeness of the degradation and the degradation pathway, and so the isotope analysis may point to a particular degradation process.

3.1.2.2 Indirect Evidence of Biodegradation

Demonstrating the potential for degradation provides an indirect line of evidence. This generally consists of demonstrating favorable conditions for degradation through the evaluation of the predominant terminal electron-accepting processes (TEAPs) and nutrient levels (**Appendix F**), and microbial ecology (**Appendix G**).

Predominant TEAPs

Geochemical conditions are evaluated to identify which TEAPs are acting on portions of the contaminant plume (the electron acceptors). At least some combination of basic geochemical conditions is considered necessary for biodegradation to proceed in an aquifer. Contiguous zones of the aquifer with similar predominant TEAPs (Redox Zones) are named for the TEAP (Wiedemeier et al., 1998). A more-detailed discussion is provided in **Appendix F** and results are summarized in **Section 3.2.2.1**.

Electron Donors

Geochemical conditions are evaluated to identify predominant electron donors, such as naturally occurring organic carbon or anthropogenic hydrocarbons. As a result of its critical role, the lack of organic carbon in aquifers is also typically the limiting nutrient preventing microbial degradation of contaminants. A more-detailed discussion is provided in **Appendix F** and results are summarized in **Section 3.2.2.2**.

Microbial Ecology

Microbial ecology is examined to determine if adequate populations of dechlorinating bacteria are present in the aquifer. Various protein and DNA analyses are available to identify the diversity, concentration, and vitality of the microbes present at the site. A more-detailed discussion is provided in **Appendix G** and results are summarized in **Section 3.2.2.3.**

3.1.3 Abiotic Degradation of Chlorinated Ethenes

A variety of iron-bearing soil minerals such as mackinawite, pyrite, magnetite, green rust, and iron-bearing clays have been shown to catalyze degradation of cVOCs (EPA, 2009b). Reactive iron minerals support complete transformation of TCE through dichloro-elimination reactions that may avoid the production of potentially harmful daughter products such as VC. In these reactions, the mineral surfaces act as electron donors and /or reaction mediators to increase the rate of reductive dechlorination. Thermodynamically stable minerals such as pyrite and magnetite support comparatively slower rates of TCE degradation than metastable phases such as mackinawite.

3.1.3.1 Direct Evidence of Abiotic Degradation

The absence of VC in anaerobic systems may provide evidence that abiotic degradation is operative because the daughter products of abiotic degradation may be glycolate, acetate, formate, and carbon dioxide (USEPA, 2009b). Because anaerobic biodegradation follows hydrogenolysis exclusively, and produces TCE, DCE, and VC sequentially, the presence of VC suggests that anaerobic biodegradation is operative.

Abiotic degradation fractionates stable carbon isotopes similarly to biodegradation. The Rayleigh fractionation model applies to abiotic degradation (Rayleigh, 1896). Different abiotic mechanisms produce characteristic patterns of fractionation, which may be identified in field data.

3.1.3.2 Indirect Evidence of Abiotic Degradation

The identification of reactive iron-bearing minerals in aquifer materials is suggestive that abiotic degradation may be an operative mechanism for degradation.

Collection and analysis of aquifer solids may allow identification of reactive minerals. Analysis of aquifer solids is difficult because such minerals may be unstable in the presence of atmospheric oxygen and may be present in only very low concentrations. At the FAP site, sampling of aquifer solids was not done because such sampling would have required drilling to depths of between 90 and 400 feet to collect representative samples.

In lieu of collecting aquifer solid samples, aqueous geochemical mineral speciation modeling was performed. This method can be used to assess if reactive minerals that support abiotic degradation may be present in the aquifer. Potentially reactive phases may be present in situations where solids cannot be collected and analyzed for mineral content.

Higher magnetite concentrations may support increased abiotic degradation rates, and the bulk concentration of magnetite can be estimated from the magnetic susceptibility of a soil sample.

3.2 Degradation of Contaminants at the Site

In this section, the evidence for degradation processes at the FAP site is summarized with detailed information provided in the cited appendices.

Three types of site-specific information or “evidence” are typically used to evaluate degradation processes at a site (EPA, 1999a):

1. Historical groundwater and/or soil chemistry data that demonstrate a clear and meaningful trend of decreasing contaminant mass and/or concentration over time at appropriate monitoring or sampling points. In the case of a groundwater plume, decreasing concentrations should not be solely the result of plume

migration. In the case of inorganic contaminants, the primary attenuating mechanism should also be understood (**Section 3.2.1** addresses these *Tier 1* criteria).

2. Hydrogeologic and geochemical data that can be used to demonstrate indirectly the type(s) of natural attenuation processes active at the site, and the rate at which such processes will reduce contaminant concentrations to required levels. For example, characterization data may be used to quantify or to demonstrate and quantify the rates of biological degradation processes occurring at the site (**Section 3.2.2**).
3. Data from field or microcosm studies (conducted in or with actual contaminated site media) that directly demonstrate the occurrence of a particular natural attenuation process at the site and its ability to degrade the contaminants of concern (typically used to demonstrate biological degradation processes only).

Unless EPA or the implementing state agency determines that historical data (number 1 above) are of sufficient quality and duration to support a decision to use MNA, EPA expects that data characterizing the nature and rates of natural attenuation processes at the site (number 2 above) should be provided. Where the latter are also inadequate or inconclusive, data from microcosm studies (number 3 above) may also be necessary. Tier 1 and Tier 2 criteria for the FAP site are described in the following subsections.

3.2.1 Direct Evidence for Dechlorination of Chlorinated Volatile Organic Compounds

The first tier of site-specific information used to evaluate degradation is historical data that demonstrate a clear and meaningful trend of decreasing contaminant mass and/or concentration over time (EPA, 1999a). This evaluation examines temporal changes in TCE concentrations in conjunction with CSIA data from the site, which together provide a direct line of evidence that TCE degradation is occurring at varying degrees across the site.

3.2.1.1 Sitewide Contaminant Concentration Trends

Temporal variations in TCE concentrations are illustrated and discussed in **Appendix D** and summarized below.

A comparison of the 20 highest observed historical (pre year 2010) TCE concentrations to the 20 highest observed recent (post year 2010) TCE concentrations indicates that sitewide TCE and cis-1,2-DCE concentrations have decreased. The 20 highest observed historical TCE concentrations ranged from 99 µg/L to 18 µg/L. More recently, the 20 highest observed TCE concentrations have ranged from 54 µg/L to 5.2 µg/L.

3.2.1.2 Mann-Kendall Evaluation

Nonparametric trend analyses (using the MK test) were conducted to assess the statistical significance of temporal trends in TCE and cis-1,2-DCE concentrations in groundwater at the FAP site. The MK test is a nonparametric statistical procedure designed for analyzing trends in environmental data over time (Gilbert, 1987). Because the MK evaluation is a nonparametric method, the test does not require any assumptions as to the statistical distribution of the data and can be used with data sets that include irregular sampling intervals and missing data. The test is based on the idea that a lack of trend should correspond to a time series plot fluctuating randomly about a constant mean level, with no visually apparent upward or downward pattern (EPA, 2009a). If an increasing trend exists, the sample taken first from any randomly selected pair of measurements should, on average, have a lower concentration than the measurement collected at a later point in time. Additional information on the MK test is provided in **Appendix D**.

For this evaluation, MK was used to test for a significant trend in TCE and cis-1,2-DCE concentrations at a confidence level greater than or equal to 95 percent (significance level of 0.05). Tests were performed using current and historical groundwater analytical data collected at individual monitoring wells. Statistical validity of the trend analysis requires constraints on the minimum data input. To ensure a meaningful comparison of TCE and cis-1,2-DCE concentrations over time, trend evaluations were only performed for wells with at least six independent sampling events and a TCE and/or cis-1,2-DCE detection frequency greater than 50 percent.

Where insufficient evidence for identifying a significant, non-zero trend at the 95 percent confidence level existed, concentrations were deemed stable if the coefficient of variation (COV) was less than 1.0. The COV is a statistical measure of how the individual data points vary about the mean value and is defined as the standard deviation divided by the sample mean. COV values less than or near 1.0 indicate that the data form a relatively close group about the mean value while COV values larger than 1.0 indicate that the data show a greater degree of scatter about the mean.

The temporal behavior of the TCE and cis-1,2-DCE data was also examined graphically in **Appendix D** to confirm the results of the MK evaluation. Scatterplots of TCE and cis-1,2-DCE concentrations as a function of time were generated for each monitoring well. Several monitoring wells clearly show a trend so a second chart and analysis was completed for the more recent data. These locations are identified by “Recent Only” in the monitoring well ID.

The results of the MK evaluation are summarized in **Table 3-1** and discussed further below. Across the FAP site, decreasing TCE concentrations are found in 33 of 62 wells while stable TCE concentrations occur at 12 of 62 well locations. Increasing TCE concentrations are found in 12 of 62 wells. Decreasing or stable TCE concentration trends at 46 of the 62 monitoring well locations evaluated are indicative of an attenuating plume.

TABLE 3-1
Summary of Mann Kendall Analysis of Data from Individual Monitor Wells
Fruit Avenue Plume Superfund Site, Albuquerque NM

		Number of Monitor Wells with						
Plume Area	**Analyte**	**Decreasing Trend**	**Increasing Trend**	**No Trend - Stable**	**No Trend – Not Stable**	**Greater than 50% Non-Detect**	**Fewer than Six Samples**	**Total Number of Wells Used for MK Trend Evaluation**
Presumed Source Area (Western Plume)	TCE	20	5	11	2	3	6	38
	DCE	11	5	14	1	6	10	31
Near the P&T System (Central Plume)	TCE	8	1	2	1	3	7	12
	DCE	9	1	2	1	3	4	13
Downgradient of the P&T System (Eastern Plume)	TCE	5	6	0	1	3	3	12
	DCE	3	4	2	0	1	0	9
Site wide Total	TCE	33 of 62	12 of 62	13 of 62	4 of 62	9 of 62	16 of 62	62 of 87
	DCE	23 of 53	10 of 53	18 of 53	2 of 53	10 of 53	14 of 53	53 of 77

Gray shaded cells indicate the number of monitoring wells where the available data do not meet the usability criteria.

Presumed Source Area (Western Plume). Decreasing TCE concentrations trends occur at 20 of 38 monitor wells. Stable concentrations are present at 11 of 38 monitor wells while increasing concentration trends occur at 5 locations. Decreasing cis-1,2-DCE concentration trends occur at 11 of 31 monitor well locations while stable concentrations are present at 14 of 31 monitor wells. Increasing concentration trends occur at 5 locations. The generally decreasing and low concentrations of TCE and cis-1,2-DCE present in and near the presumed source area (western portion of the plume) indicate that the plume is attenuating. In addition, decreasing TCE concentrations in groundwater near the presumed source area suggest that ongoing releases from potential vadose zone sources are insignificant. Increasing concentration trends were noted at the following locations:

- SFMW-16(I1) and SFMW-17(I2), which are located adjacent to the downgradient edge of the presumed source area, where both TCE and cis-1,2-DCE concentrations are increasing. Other evidence also suggests that the plume may be migrating eastward from the source area. This migration is most likely responsible for the increasing concentrations observed at these two locations.

- DM-13(I1), where TCE concentrations are stable and DCE concentrations are increasing. This condition suggests that some desorption and back-diffusion of TCE is occurring at a rate similar to the degradation rate while cis-1,2-DCE production exceeds its degradation rate.
- MNW-14(I2) where both TCE and DCE concentrations are increasing. This condition likely results from commingling of the upgradient offsite plume with the remnants of the presumed source area plume.

Data from monitor wells associated with the offsite plume were evaluated to predict possible effects upon the FAP. Increasing followed by decreasing TCE/cis-1,2-DCE concentrations in the I2 aquifer zone monitor wells MNW-9(I2) and MNW-11(I2) suggest that the offsite plume has migrated onto the FAP site. Increasing TCE concentrations in D1 aquifer zone monitor well MNW-11(D1) suggest that the upgradient end of the offsite plume has not been identified while the offsite plume’s leading edge continues to advance on to the FAP site. These interpretations are substantiated by data collected during the second semiannual 2012 LTM sampling event (CH2M HILL, 2012b).

Vicinity of P&T System (Central Plume). As expected, 8 of the 12 monitoring wells in the central plume area show a sudden decrease in TCE concentrations following startup of the P&T system in 2005. Reduction of TCE and cis-1,2-DCE concentrations at monitor wells in this area results from mass removal by the P&T system, dilution associated with injection of treated groundwater, and changes in the location and shape of the plume caused by pumping and injection.

Downgradient of P&T System (Eastern Plume). In the eastern portion of the TCE plume, in the deeper aquifer zones, decreasing TCE concentrations occur at 5 of 12 monitor well locations. Stable concentrations are present at none of the 12 locations evaluated. Increasing TCE concentrations are present at 6 of 12 locations. The increasing concentrations at MNW-4(D2), SFMW-44(D2), and MNW-5(D3) correlate with the natural migration of the TCE plume.

3.2.1.3 Mole Fraction

The degree to which TCE and cis-1,2-DCE are being degraded at the site can be illustrated by observing the molar fraction of each cVOC present in groundwater. The data and analysis of cVOC mole fractions is presented in **Appendix D** and the results are summarized as follows.

In the western portion of the site near the presumed source area, the relative percent (%) mole fraction evaluation indicates that approximately one-fifth to one-third of the total cVOC concentration is present in the form of cis-1,2-DCE. Because cis-1,2-DCE as a manufactured product was not released at the FAP site, the presence of this constituent indicates that conditions are amenable for TCE degradation to cis-1,2-DCE.

In the central portion of the plume near the P&T system, low concentrations of TCE and cis-1,2-DCE reflect the effect of the P&T system and thus do not provide evidence for or against the existence of ongoing NA processes.

In the eastern downgradient portion of the site, approximately one-third to one-half of the total cVOC concentration is present in the form of cis-1,2-DCE. The presence of cis-1,2-DCE suggests that conditions are amenable for TCE transformation. This portion of the plume has a higher mole fraction (0.33 versus 0.28) of cis-1,2-DCE than the western portion of the plume near the presumed source area, indicating that degradation processes are more active in the downgradient portion of the plume.

Across the site, the presence of cis-1,2-DCE and decreasing concentrations of TCE suggest that a degradation process is operative. The mole ratio evaluation shows that approximately one-fifth to one-half of the TCE currently present in groundwater has been transformed to cis-1,2-DCE. The near absence of VC suggests that some other process, besides the stepwise reductive dechlorination of cis-1,2-DCE to VC, is responsible for the decay of cis-1,2-DCE. Because VC has only been detected sporadically, and methane, ethane, and ethene are not routinely tested, the mass of cis-1,2-DCE that has been transformed to VC or directly oxidized to methane, ethane, or ethene cannot be estimated.

3.2.1.4 Site Wide Evaluation of Contaminant Concentrations – MAROS[3] 0th, 1st, 2nd Moments

The FAP site contains over 100 groundwater monitor wells that have been sampled at frequencies ranging from quarterly to biennially. To increase the effectiveness of the LTM program, a comprehensive evaluation was conducted in 2009 and the results presented in the LTMO report (CH2M HILL, 2009a). One of the evaluation tools employed as part of this effort was a spatial moment analysis performed using the *Monitoring and Remediation Optimization System* (Groundwater Services Inc., 2006). The MAROS evaluation performed statistical analysis of plume-wide TCE concentration trends using LTM results through 2009 to determine whether the plume was decreasing/increasing in total mass (0th moment), retreating or advancing away from the source area (1st moment), or changing in length and width (2nd moment).

The MAROS evaluation determined that in the western portion of the TCE plume, in the I2 aquifer zone, the TCE plume was decreasing in mass, retreating towards the presumed source area, and shrinking in length while increasing in width. This behavior is consistent with an attenuating plume.

In the eastern (downgradient) portion of the TCE plume, the MAROS evaluation determined that the TCE plume in the D2 and D3 aquifer zones was advancing away from the presumed source area, and increasing in width while decreasing in length. Overall, the TCE plume in the D1 and D2 aquifer zones was decreasing in mass while the TCE plume in the D3 aquifer zone was increasing in mass. This behavior is consistent with a plume that while relatively stable in size and mass, is being transported under the influence of the regional hydraulic gradient.

3.2.1.5 Compound Specific Isotope Analysis & Qualitative Evaluation

As described in **Section 3.1.2.1**, CSIA is an assessment tool that can provide data demonstrating TCE degradation.

CSIA measures the relative isotopic composition of a specific element in a contaminant molecule (e.g., PCE, TCE, and cis-1,2-DCE) present in a dissolved groundwater sample (a contaminant plume). In CSIA, the symbol $\delta^{13}C$ is a measurement of the ratio of stable carbon isotopes in the compound. A precise definition of $\delta^{13}C$, and the CSIA analysis results, are discussed in detail in **Appendix E.**

The $\delta^{13}C$ of TCE in the samples (-20.83‰ to -16.76‰) is 9‰ to 13‰ enriched compared to newly manufactured TCE product (approximately -30‰ per Hunkeler, et al, 2008). This enrichment is sufficient (greater than 2‰) to indicate that degradation is the primary cause of TCE fractionation at the site.

The $\delta^{13}C$ of cis-1,2-DCE in the samples (-37.94‰ to -31.73‰) is less than that of newly manufactured cis-1,2-DCE product (approximately -30‰ per Hunkeler, et al, 2008) indicating that cis-1,2-DCE has been produced by TCE degradation and was not part of the original release. Because the $\delta^{13}C$ of cis-1,2-DCE (a potentially harmful daughter product) is not enriched more than the TCE originally released, no conclusions can be made from the CSIA data regarding the further degradation of cis-1,2-DCE. However, as described in later sections of this report, cis-1,2-DCE is being degraded via other NA processes.

The $\delta^{13}C$ of TCE and cis-1,2-DCE near the presumed source area is less enriched compared to $\delta^{13}C$ of TCE and cis-1,2-DCE in the eastern portion of the plume, indicating that a smaller fraction of the contamination in the presumed source area has been degraded compared to downgradient locations. This is consistent with the mole fraction evaluation presented in **Section 3.2.1.3**.

The CSIA information, which is a direct line of evidence, indicates that TCE degradation is occurring at varying degrees across the site.

3.2.2 Indirect Evidence of Biodegradation

The second tier of site-specific information used to evaluate MNA is hydrogeologic, geochemical, and biological data that can be used to demonstrate indirectly the types of natural attenuation processes active at the site, and the rate at which sub processes will reduce contaminant concentrations (EPA, 1999a). The following subsections

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[3] Monitoring and Remediation Optimization System (MAROS) User's Guide, 2006

evaluate groundwater geochemistry and microbial ecology. Degradation rates are estimated from field data in **Section 3.3** of this report.

3.2.2.1 Evaluation of Predominant TEAPs

TEAPs, a natural attenuation indicator parameter (NAIP), are evaluated in **Appendix F.**

The TEAP evaluation indicates that, outside the area influenced by the injection of treated water from the ASTP (where conditions are generally aerobic), conflicting evidence makes it difficult to identify specific redox zones and processes as follows:

- Elevated sulfate and non-detect sulfide concentrations suggest aerobic conditions. Treated groundwater discharged to the two injection wells contains sulfate resulting from breakdown of the sulfuric acid used to control mineral scaling in the ASTP.
- Non-detect ferrous iron concentrations suggest aerobic conditions.
- DO concentrations ranging from less than 0.5 milligrams per liter (mg/L) to 2 mg/L in the intermediate aquifer zones indicate anaerobic to intermediate conditions while DO concentrations (typically 1 to 3 mg/L) in the deep aquifer zones suggest aerobic conditions. Treated groundwater discharged to the two injection wells contains elevated DO concentrations resulting from the ASTP.
- ORP measurements of less than 50 millivolts (mV) occur at some intermediate and deep aquifer zone monitoring well locations, suggesting that nominally anaerobic conditions conducive to reductive dechlorination processes are locally present.

In the intermediate aquifer zones, ORP, ferrous iron, DO, and sulfide concentrations indicate that mildly aerobic conditions are present. However, detectable sulfide in six samples suggests that anaerobic conditions exist in localized zones across the site. Such conflicting results may be attributed to the mixing of anaerobic groundwater from low-flow, fine-grained sediments with aerobic groundwater from high-flow, coarse-grained sediments during the well purging and sample collection process.

In the deep aquifer zones, near and upgradient of the ASTP, high DO, non-detect ferrous iron, and non-detect sulfide concentrations indicate that aerobic conditions are prevalent. Downgradient of the portion of the site influenced by injection of ASTP-treated water, detectable sulfide and ORP measurements less than 0 mV suggest that a mildly anaerobic zone may exist.

Compared to the previous TEAP evaluation (CH2M HILL, 2005a), this TEAP evaluation finds similar mildly anaerobic conditions across the site indicative of Type 3 plume behavior; however, the previous evaluation identified more distinct zones of anaerobic conditions. The loss of anaerobic conditions within the central and downgradient portions of the FAP plume observed between the 2005 and 2010 MNA sampling event is most likely attributed to injection of treated water from the ASTP, which contains elevated DO concentrations.

Analytical results from groundwater samples collected more recently have higher concentrations of methane, along with chloride concentrations that are two times background concentrations and carbon dioxide concentrations two to five times background concentrations. These results illustrate the cumulative effects of ongoing oxidation or cometabolic degradation processes.

The distribution of NAIPs suggests that adjacent portions of the aquifer have differing TEAPs. The interbedded fine-grained materials between the aquifer zones likely include have anaerobic conditions conducive to reductive dechlorination while the high-flow coarse-grained materials have aerobic conditions typical of Type 3 plumes.

Continued operation of the ASTP will impede biodegradation processes and potentially prolong the downgradient plume. The ASTP adds oxygen and sulfate, and removes carbon dioxide from the treated water that is reinjected into the aquifer. As the volume of treated water around the injection wells expands and mixes with native groundwater, the groundwater geochemistry becomes less favorable for TCE degradation via the reductive dechlorination pathway.

3.2.2.2 Evaluation of the Presence of Electron Donors: Nutrients and Carbon Sources

Total organic carbon analyses show that organic carbon is generally present at concentrations at or below 3 mg/L. Although these levels (<20 mg/L) are considered insufficient to support rapid biodegradation of high TCE concentrations, they may be sufficient to support enough microbial activity to degrade the low TCE concentrations present at the site (EPA, 1998).

There are locations within the site boundaries where petroleum hydrocarbons occur as part of unrelated UST releases. Slightly elevated methane and low DO concentrations at monitoring wells SFMW-20(I1), MNW-2(I2), and SFMW-21(I2) suggest that the additional carbon source provided by the petroleum hydrocarbons may promote reductive dechlorination, despite high sulfate concentrations. Chlorinated VOC concentration trends in this area are inconclusive, primarily due to the low density of monitoring well locations. Well MNW-2(I2) is adjacent to a former UST site and beyond the FAP site plume boundary. Wells SFMW-20(I1) and SFMW-21 (I2) are located on the downgradient end of the FAP within the I1/I2 aquifer zones and may be influenced by the P&T system.

3.2.2.3 Evaluation of Microbial Analyses

The phospholipid fatty acid (PLFA) evaluation in **Appendix G** indicates that there is a low level of biomass present, indicating that biodegradation is a slow TCE transformation pathway. The similarities between the microbial community structure within the plume at locations with decreasing TCE concentration trends suggests that the low concentrations of TCE present at the site are not enhancing the growth of reductive dechlorination bacteria within the plume.

3.2.3 Results of Abiotic Degradation Evaluation

Direct evidence that demonstrates the effects of abiotic degradation includes plume degradation patterns and CSIA. Indirect evidence includes data indicating that the site has conditions conducive to abiotic degradation, such as high concentrations of reactive minerals, which are evident though mineral equilibrium modeling and downhole magnetic susceptibility measurements. Evidence for abiotic degradation at the site, evaluated in **Appendix H**, is summarized in the following subsections.

3.2.3.1 Plume Degradation Patterns

As reported in **Appendix D**, TCE, cis-1,2,-DCE, and trans-1,2-DCE are commonly detected in groundwater samples from the site. Because DCE (cis-and trans isomers) is not associated with a historical release at the site, its presence suggests that biologically mediated reductive dechlorination of TCE occurs at the site. Cis-1,2-DCE concentrations are decreasing in both the presumed source area and downgradient of the P&T system (**Appendix D**). As concluded in **Appendix D**, the decreasing cis-1,2-DCE concentrations suggest that a degradation process is operative. VC has not been detected in groundwater samples collected from the site at concentrations above 1.7 µg/L, and 93 of the 100 detections were limited to three historical sample events conducted in 2004 and 2005. As concluded in **Appendix D**, the near absence of VC in the more recent samples suggests that stepwise reductive dechlorination (hydrogenolysis) is not likely to be the process primarily responsible for transformation of cis-1,2-DCE. The daughter products of abiotic degradation (for example, acetylene, glycolate, acetate, and formate [EPA, 2009b]), which are more easily degraded than the parent compounds (EPA, 1998), have not yet been investigated at this site.

3.2.3.2 Stable Isotope Evidence

Appendix E concluded that the CSIA data indicate TCE is being transformed to cis-1,2-DCE, and degradation contributes considerably to the observed decrease in TCE concentrations at the site. Because the observed TCE fractionation is less than would be expected based on the amount of decay, it is not currently possible to identify the specific process or bacteria that are responsible for TCE degradation at the site. Although abiotic degradation is not considered the sole cause of δ^{13}C enrichment, if it was assumed to be solely responsible, then, based on the calculations described in **Appendix E** and an enrichment factor for magnetite (Liang et al., 2007), the fraction of TCE mass remaining is estimated to range from 71 to 79 percent. The degradation rate, based on the calculations described in **Appendix I**, including an estimated release date, ranges from -0.006 to -0.009 per year.

3.2.3.3 Magnetic Susceptibility

The bulk concentration of the reactive mineral magnetite can be estimated from magnetic susceptibility (EPA, 2009b) measurements performed using a downhole instrument. The volume-magnetic susceptibility (VMS) measured in Système International d'Unites (SI) units is converted to mass-magnetic susceptibility (MMS) by dividing the measurement by the density of aquifer materials. Based on the evaluations reported by EPA (2009b), "a mass magnetic susceptibility in the range of 1×10^{-6} cubic meters per kilogram (m^3/kg) may indicate that degradation of PCE or TCE at rates near 0.3 to 2 per year is possible but should not be taken a proof that abiotic degradation will occur at those rates."

The MMS at the site ranged from 5.36×10^{-9} to 4.88×10^{-6} m^3/kg and averaged 1.45×10^{-6} m^3/kg. This is high enough to suggest that degradation TCE at rates near 0.3 to 2 per year is possible (EPA, 2009b). These rates exceed the TCE degradation rate estimated in **Appendix I**, which recommended that degradation rates of -0.022 per year and -0.030 per year be applied to the intermediate and deep aquifer zones, respectively, in the flow and transport model.

3.2.3.4 Mineral Equilibrium Modeling

The mineral equilibrium modeling was used to evaluate whether groundwater chemistry reflects the presence of reactive minerals. Because of the extremely low concentrations of sulfide and ferrous iron and the presence of detectable concentrations of DO in each of the three samples, none of the samples was in equilibrium with ferrous sulfide phases, such as mackinawite, amorphous FeS, or pyrite.

It is likely that the interbedded fine-grained aquifer materials have favorable conditions that are conducive for microbial reductive dechlorination processes. These same would have conditions that are also conducive to the formation of reactive minerals. The mineral equilibrium modeling was used to determine whether the concentrations of ferrous iron or sulfide in the anaerobic zones could be easily masked (diluted and oxidized) by mixing with very similar, but more aerobic, water during sampling.

The results presented in **Appendix H** indicate that the concentrations of ferrous iron and sulfide necessary for each of the three samples to reach saturation with amorphous FeS are less than 1.0 mg/L and 0.5 mg/L, respectively. The concentrations required to reach equilibrium with mackinawite and pyrite are much lower. These results indicate that while the groundwater chemistry does not conclusively show the presence of reactive minerals, the groundwater chemistry does permit their presence with very small changes to the observed ferrous iron and sulfide concentrations, as might be found in the interbedded silty and clayey sands that lie between the intermediate and deep aquifer zones.

3.2.4 Sustainability of Observed Degradation

Aquifer conditions conducive to NA processes active at the FAP site are generally sustainable, because they are not unnaturally modified or anthropogenic modifications to the aquifer. Thus, the processes and rates of reductive dechlorination, cometabolism, oxidation, and abiotic degradation of cVOCs present at the site are expected to be sustainable for the foreseeable future.

The NA processes active in the central and downgradient plume areas would be improved if the P&T system were shut down, because the injection of treated water containing high concentrations of DO and sulfate, which compete with TCE and cis-1,2-DCE in oxidation-reduction reactions, would stop.

3.2.5 Summary of Degradation

Multiple lines of evidence were analyzed to evaluate TCE degradation at the site as follows:

- The primary line of evidence, declining TCE concentrations, indicates that the plume near the presumed source area is decreasing in mass, retreating towards the source, and decreasing in length. The downgradient portion of the plume, outside the influence of the P&T system, is moving away from the presumed source in response to natural groundwater flow. (Tier 1)

- The CSIA and cVOC mole fraction evaluations indicate that TCE is degrading to cis-1,2-DCE. (Tier 1) The most likely mechanism for degradation of TCE to cis-1,2-DCE is reductive dechlorination.
- Based on the near absence of VC and low concentrations of ethene, there is limited evidence that cis-1,2-DCE is degraded by reductive dechlorination. Generally decreasing cis-1,2-DCE concentrations, non-detect or low concentrations of VC and ethene, and carbon dioxide concentrations that are two to five times background concentrations, indicate that aerobic oxidation, aerobic cometabolism, or abiotic degradation processes are active. (Tier 1)
- Secondary or indirect lines of evidence, such as TEAP evaluations, suggest that conditions are not optimal sitewide for biologically mediated reductive dechlorination of TCE. However, the more fine-grained layers between the aquifer zones, which are not individually and directly monitored, likely harbor conditions more conducive to reductive dechlorination. Conditions are more widely favorable for oxidation or cometabolic degradation of cis-1,2-DCE and VC. (Tier 2)
- Microbial analysis indicates that the bacterial populations and their level of activity in the aquifer are generally low and not consistent with significant levels of biodegradation activity. The microbial analyses available (PLFA) are not capable of identifying specific bacteria, enzymes, or microbial processes. (Tier 2)
- The plume degradation patterns and magnetic susceptibility evaluation provide sufficient evidence to indicate that abiotic transformation reactions contribute to the degradation of TCE and cis-1,2-DCE at the site. The mineral equilibrium modeling results suggest that very small changes to the observed ferrous iron and sulfide concentrations would confirm the presence of reactive minerals, and such changes could be supported by layers between the aquifer zones which are hypothesized to have anaerobic conditions.
- The geochemical conditions outside the influence of the P&T system are sustainable long-term. However, the characteristics of the treated water returned to the aquifer following ASTP treatment significantly impedes reductive dechlorination near the injection wells and in the area where treated water mixes with native groundwater. (Tier 2)

In summary, the multiple lines of evidence indicate that the FAP exhibits Type 3 plume behavior within the actively monitored zones. Although conditions are not robust for reductive dechlorination across the TCE plume footprint, evidence of reductive dechlorination and other degradation reactions has been observed indicating that the processes play a significant role in the transformation of TCE at the site. The CSIA evidence indicates that TCE is degrading to cis-1,2-DCE. Although the evidence indicates that physical processes are responsible for a majority of the TCE decay at the site, the rates of degradation observed are adequate given the low-levels of TCE and cis-1,2-DCE remaining. Decreasing cis-1,2-DCE concentrations are most likely caused by aerobic oxidation, aerobic cometabolism, or abiotic degradation, as indicated by the lack of VC.

3.3 Attenuation Rate Estimates

Attenuation rates describe the rate at which contaminant concentrations are reduced by physical, chemical, and/or biological processes without human intervention (Newell et. al, 2002). Two attenuation rates are used in this report for different purposes: *Point decay rates* are used to estimate how quickly TCE concentrations are changing over time. *Degradation rates* are used to characterize the rate of TCE transformation to less chlorinated compounds, and to provide a quantitative estimate of degradation for use in TCE fate and transport modeling. Site data are evaluated to estimate attenuation rates in **Appendix I** and summarized below.

Dilution and dispersion are strong components of the apparent decay at the site, as suggested by the 2005 NA Evaluation (CH2M HILL, 2005a). Because of this, decay rates estimated from TCE concentrations, which include contributions from physical, chemical, and biological processes, will be greater than that attributed to biodegradation alone. Because biological and physical attenuation are operable NA processes at this site, the decay rate constants estimated in this section reflect the contributions of both processes.

3.3.1 Estimation of Rate Constants Based on TCE Concentrations

Point decay rates at 20 individual monitor wells were estimated from measured TCE concentrations (**Appendix I**). Decay rate estimates were completed for monitoring well locations where (1) the MK analysis in **Appendix D** indicated that there was a decreasing trend, (2) historical TCE concentrations exceeded the 5 µg/L remedial goal, and (3) TCE concentrations were unlikely to have been affected by the P&T system. The units on the rate constants are 1/year where a negative constant indicates declining concentrations.

The mean point TCE decay rates calculated in **Appendix I** varied from -0.08/year to -0.32/year, averaging -0.17/year. The slowest point decay rates at a 95 percent confidence varied from +0.01/year to -0.24/year, averaging -0.12/year. A comparison of decay rates from the S, I1, and I2 aquifer zones with the decay rates from the D1 and D2 aquifer zones using an F-Test and T-test shows there is a 50 percent to 77 percent probability that there is no difference between the two sets of rates.

Applying the rate constants to monitor wells with TCE concentrations greater than the 5 µg/L remedial goal provides an estimate of the date the remedial goal is met at those locations (see **Table 2 in Appendix I**). Achievement of the remedial goal calculated using the mean rate constants ranges from the year 2012 (e.g. locations that have already achieved the remedial goal) to the year 2029 at DM-13(I1). The longest restoration timeframe at 95 percent confidence is at SFMW-27(I2) which is predicted to achieve the remedial goal by 2023, however at 95 percent confidence, the estimated remedial timeframe at DM-13(I1) is unknown.

As indicated in **Section 3.2.1.2** and **Appendix D**, several locations currently have increasing TCE concentrations. Increasing concentrations occur immediately downgradient of the presumed source area where the plume may be migrating eastward, near the downgradient – eastern portion of the plume where increasing concentrations reflect natural migration, and in the western portion of the plume where commingling with the upgradient-offsite plume is occurring. Although locations with increasing TCE concentrations cannot be included in a decay rate estimation, their presence is noted and tempers the conclusion of rate constant estimates.

The point decay rates and estimated time of remediation estimated in **Appendix I** were used for comparison to the fate and transport simulations presented in **Section 3.6** of this report.

3.3.2 Degradation Rates Based on CSIA and Magnetic Susceptibility Interpretations

Degradation rates (transformation of parent compounds to daughter compounds) were estimated from CSIA data (**Appendix E**) and magnetic susceptibility data (**Appendix H**). CSIA and magnetic susceptibility derived rates provide an estimate of degradation attributed to biological and abiotic processes whereas methods that use concentration (Hunkeler et. al, 2008) data alone include these two pathways plus physical process such as dispersion, diffusion, and sorption.

The evaluation of magnetic susceptibility data provided an upper limit on abiotic degradation rates of 0.3 to 2 per year. That limit is more than 10 times the biodegradation rates estimated in **Appendix I**. Abiotic degradation rates estimated from CSIA data range from -0.006 to -0.009 per year.

The biodegradation rates estimated from the CSIA data were used in the fate and transport model discussed in **Section 3.6**. It was recommended, based on evaluation of the CSIA data, that fate and transport model layers representative of the shallow, I1, and I2 aquifer zones use a value of -0.022/year, and model layers representative of the deep aquifer zones use a value of -0.029/year. These rates include contributions from all degradation processes.

The estimated timeframe (number of years) required for TCE concentrations to decrease to concentrations below the 5-µg/L remedial goal at monitor well locations where TCE concentrations currently exceed this level is provided in **Table 2** of **Appendix I**.

3.4 Evaluation of Potentially Toxic and/or Mobile Transformation Products

The ROD established PCE, TCE, cis-1,2-DCE, and trans-1,2-DCE as COCs at the site. Although not listed and infrequently detected, VC is a toxic and mobile TCE degradation product. At this time, groundwater quality is improving because more-toxic TCE is being transformed into less-toxic cis-1,2-DCE, which has a remedial goal of 70 µg/L. Because cis-1,2-DCE concentrations are generally higher than those of trans-1,2-DCE, and because the 70 µg/L remedial goal for cis-1,2-DCE is lower than the 100 µg/L remedial goal for trans-1,2-DCE, the potential for cis-1,2-DCE concentrations to exceed the 70 µg/L remedial goal is evaluated in this section. Cis-1,2 DCE and trans-1,2-DCE concentrations at monitor well locations across the site are illustrated in **Appendix D**.

Across the site, cis-1,2-DCE concentrations are generally decreasing, suggesting that degradation of cis-1,2-DCE occurs faster than its production from TCE. Several locations do have increasing cis-1,2-DCE concentrations:

- DM-13(I1), SFMW-10(I2), SFMW-16 (I1), SFMW-17(I2), and MNW-14(I2), in the presumed source area
- SFMW-44(D2) and MNW-5(D3) in the downgradient portion of the plume

The potential for cis-1,2-DCE concentrations to rise higher than currently observed levels was estimated (**Table 3-2**) at the locations where increasing cis-1,2-DCE concentrations occur. The estimate assumed that all TCE would be converted to cis-1,2-DCE and added to the existing concentration. The estimated maximum cis-1,2-DCE concentration would be less than the 70-µg/L remedial goal.

At this time, VC is infrequently detected at the site, suggesting that VC resulting from cis-1,2-DCE transformation is immediately oxidized, or cis-1,2-DCE is degraded by a process that does not produce VC. Based on this evaluation, DCE and VC concentrations are below, and are expected to remain below, their remedial goals.

TABLE 3-2
Maximum cis-1,2-DCE Concentration Estimate
Fruit Avenue Plume Superfund Site, Albuquerque NM

Well ID	cis-1,2-DCE Concentration		TCE Concentration		Sum	Sum as cis-1,2-DCE
	[µg/L]	[µMole/L]	[µg/L]	[µMole/L]	[µMole/L]	[µg/L]
Presumed Source Area						
DM-13(I1)	10	0.10	52	0.40	0.50	48
SFMW-10(I2)	4.3	0.044	13	0.10	0.14	14
SFMW-16(I1)	3.9	0.040	32	0.24	0.28	28
SFMW-17(I2)	6	0.062	6	0.046	0.11	10
MNW-14(I2)	8.5	0.088	39	0.30	0.38	37
Downgradient						
SFMW-44 (D2)	4.8	0.050	3.7	0.028	0.078	7.5
MNW-5 (D3)	7	0.072	15	0.11	0.19	18

Non-chlorinated daughter products of TCE abiotic degradation, such as acetylene, glycolate, acetate, and formate (EPA, 2009b), typically are not found in groundwater because they are more easily degraded than the parent compounds. Additionally, these compounds and other potential intermediate daughter products are not routinely analyzed at environmental restoration sites under typical groundwater monitoring programs. A search (October 2012) of the US National Library of Medicine's Toxicology Data Network (TOXNET, available at http://toxnet.nlm.nih.gov/index.html) for the daughter products listed above, and the potential intermediaries illustrated in **Appendix H**, found that:

- 5 of 15 were not included in the database
- No applicable environmental standards exists for 8 of 15
- Chloroacetic acid is regulated as a disinfection byproduct and the MCL of haloacetic acids (HAA5) is 60 µg/L
- Formic acid has a Florida drinking water guideline of 14,000 µg/L

3.5 Non-Degrading Physical Processes

This section describes the physical processes that reduce the contaminant concentrations: diffusion, dispersion, and sorption. The effects of non-degrading physical processes are presented in **Section 3.6.**

3.5.1 Diffusion and Dispersion

Diffusion is the movement of a contaminant (such as TCE) in water from a zone of higher concentration toward a zone of lower concentration. Diffusion occurs as long as a concentration gradient exists even if the water is not moving. This process alone will cause the extent of a contaminant plume to increase and the maximum concentrations to decrease. Given a limited contaminant source and an unlimited aquifer, a contaminant plume would eventually diffuse so the contaminant concentrations would be below the remedial goals and below eventually laboratory method detection limits. However, diffusion does not rapidly reduce contaminant concentrations.

Dispersion is the mechanical mixing of contaminated water with uncontaminated (or lower concentration) water and is caused by the tortuous flow of groundwater through aquifer materials. The result of dispersion is that the contaminant plume stretches out both along and across the flow path, causing the extent of a contaminant plume to increase and the maximum concentrations to decrease. Given a limited contaminant source and an unlimited aquifer, a contaminant plume would grow in length and width and eventually disperse so that the contaminant concentrations would be below the remedial goals and eventually the laboratory method detection limits. Dispersion is a relatively rapid process that reduces contaminant concentrations. Separating the relative effects of diffusion and dispersion is very difficult and so they are typically treated as a combined process called hydrodynamic dispersion.

Diffusion and dispersion appear to have influenced contaminant mobility in groundwater at the FAP site, given the extended length of the plume and comparatively low to moderate concentrations of cVOCs observed. TCE concentrations have been as high as 99 µg/L in the presumed source area and decrease to non-detect levels approximately 3,600 feet downgradient at monitoring well MNW-16. The elongated nature of the plume suggests significant longitudinal spreading through diffusion and dispersion.

3.5.2 Sorption

Sorption (adsorption and absorption) plays an important role in retarding plume migration. Adsorption is the attachment of a contaminant to a solid surface. Adsorption processes include electrostatic attraction, chemical reaction, or incorporation of the contaminant into the porous surface of the solid aquifer material. Adsorption results in the removal of contaminants from groundwater. Organic compounds (such as TCE) adsorb to organic carbon in the aquifer materials and to a lesser extent to mineral surfaces. Adsorption results in the retardation, or slowing down, of the plume movement. Absorption is similar except the contaminant penetrates the interior portions of a solid particle.

Potential uncertainties in the non-degrading processes are evaluated in the sensitivity analysis of the fate and transport model.

3.6 Flow and Transport Modeling

A site-specific numerical flow and transport model was created to examine changes in plume concentrations and location under two primary scenarios:

1. A base case scenario with the P&T system turned off in 2012
2. A base case scenario where the P&T system continues to operate through the year 2060

This modeling effort was conducted to assess the effectiveness of the P&T system in terms of its ability to accelerate cleanup at the FAP site and to assess the fate of the TCE plume in the event the P&T system is shut down to enhance MNA effectiveness and to allow MNA to complete the balance of the remedial action.

A sensitivity analysis was also performed by running several additional simulations to test the sensitivity of the base case results (P&T system off) to variation in key model input parameters. Neither base case included a contaminant source term or contribution from the upgradient offsite plume.

A significant change for this modeling effort from the 2005 MNA evaluation (CH2M HILL, 2005a) is inclusion of a non-zero degradation term as a model input parameter(**Table 3-3**). The previous effort did not include degradation because uncertainty in the degradation rate was too great, leading to overly optimistic predictions. The additional work described in **Section 3.3** and **Appendix I** provides sufficient confidence in the degradation rate estimates to allow their use in the TCE fate and transport model simulations.

TABLE 3-3
Contaminant Transport Parameters
Fruit Avenue Plume Superfund Site, Albuquerque NM

Parameters	Base Case Scenario		Sensitivity Analysis Scenario					
	P&T System Off – Year 2012	**P&T System On - 2060**	**Low Degra-dation**	**Low Disper-sivity**	**Low K_d**	**Low Porosity**	**High Porosity**	**No Degra-dation, Low Disper-sivity, Low K_d**
Dispersion Parameters								
Longitudinal Dispersivity (ft)	40	40	40	20	40	40	40	20
Transverse Dispersivity (ft)	4	4	4	2	4	4	4	2
Vertical Dispersivity (ft)	0.4	0.4	0.4	0.2	0.4	0.4	0.4	0.2
Aquifer Parameters								
Effective Porosity (dimensionless)	0.2	0.2	0.2	0.2	0.2	0.13	0.28	0.2
Bulk Density (µg/L)	$1.93x10^{9}$	$1.93x10^{9}$	$1.93x10^{9}$	$1.93x10^{9}$	$1.93x10^{9}$	$1.93x10^{9}$	$1.93x10^{9}$	$1.93x10^{9}$
Chemical-Specific Transport Parameters								
Soil/Water Partition Coefficient K_d (L/µg)	$3.44x10^{-11}$	$3.44x10^{-11}$	$3.44x10^{-11}$	$3.44x10^{-11}$	$1.04x10^{-11}$	$3.44x10^{-11}$	$3.44x10^{-11}$	$1.04x10^{-11}$
Degradation Rate for layers 1-3 ($years^{-1}$)(S, I1, I2)	0.0215	0.0215	0.011	0.0215	0.0215	0.0215	0.0215	0
Degradation Rate for layer 4 ($years^{-1}$) (I2, D1)	0.0255	0.0255	0.013	0.0255	0.0255	0.0255	0.0255	0
Degradation Rate for layers 5-9 ($years^{-1}$) (D1, D2, D3, D4)	0.0295	0.0295	0.015	0.0295	0.0295	0.0295	0.0295	0
Calculated Retardation Factor (dimensionless)	1.33	1.33	1.33	1.33	1.1	1.33	1.33	1.1
Calculated Decay Half Life for layers 1-3 (years)	32.2	32.2	63	32.2	32.2	32.2	32.2	NA
Calculated Decay Half Life for layer 4 (years)	27.2	27.2	53.3	27.2	27.2	27.2	27.2	NA
Calculated Decay Half Life for layers 5-9 (years)	23.5	23.5	46.2	23.5	23.5	23.5	23.5	NA

Notes:
ft is feet
K_d is soil water partition coefficient
NA is not applicable
L/µg is liters per microgram
µg/L is micrograms per liter
(Bulk Density/Effective Porosity)
Retardation Factor = 1 + K_d*
Decay Half Life = Ln(2)/Degradation Rate

A more detailed discussion of the modeling is provided in **Appendix J**. Part of the model review process included comparison of model parameters to the aquifer pumping test results, which are provided in **Appendix K**. A summary of the modeling results are as follows:

- TCE concentrations are predicted to decrease below 5 µg/L by the year 2030 and 2031 for both base case scenarios (P&T system turned off in 2012 and P&T system remains on, respectively) (**Table 3-4** and **Figures 3-3** and **3-4**). There are only slight differences in the simulations of the FAP plume migration between these two scenarios. This timeframe is comparable to the year 2025 estimate made using the point decay estimates presented in **Section 3.3.1.**
- For the sensitivity simulation, under conservative conditions of low degradation and low dispersion (and assuming there is no continuous source), the 5 µg/L TCE concentration is not predicted to extend beyond the current groundwater use restriction boundary.
- Only by selecting the most conservative values for the parameters tested (no degradation, low dispersivity, and low K_d), does the plume migrate beyond the groundwater use restriction boundary. This scenario is not considered realistic since, as discussed in **Sections 3.2** and **3.3**, degradation of TCE is occurring at the site.
- A comparison of the downgradient plume boundary predicted in the 2005 MNA Evaluation (CH2M HILL, 2005a) and that predicted by the current evaluation indicates that the plume is advancing slower and decaying faster than previously predicted (**Table 3-5**). This change is attributed to the inclusion of degradation in the model and a smaller plume shell. The smaller plume shell resulted from the absence of cVOCs in groundwater samples that were collected from newly installed monitor well MNW-16. This well was installed in 2012 and, therefore, was not present at the site during the 2005 MNA evaluation.

In summary, the fate and transport modeling results, in conjunction with the calculated degradation rates (see **Section 3.3**) generally support the other lines-of-evidence that the FAP – TCE plume is attenuating.

TABLE 3-4
Summary of Remediation Performance for 2012 Modeling Scenarios
Fruit Avenue Plume Superfund Site, Albuquerque NM

Simulation Type	Year that TCE Concentration Declines to				Year that 5 µg/L TCE Concentration Reaches GW Use Restriction Boundary
	< 10 µg/L in Presumed Source Area (Western Plume)	< 10 µg/L Down-gradient Plume	< 5 µg/L in Presumed Source Area (Western Plume)	< 5 µg/L Down-gradient Plume	
Base Case Scenarios					
P&T system on (Figure 3-3)	2019	2017	2026	2031	Does Not
MNA - P&T system off (Figure 3-4)	2019	2016	2026	2030	Does Not
Sensitivity Analysis Scenarios					
Low Dispersivity	2021	2017	2028	2032	Does Not
Low Degradation	2019	2018	2026	2037	Does Not
Low K_d	2017	2016	2024	2029	Does Not
Low Porosity	2017	2016	2022	2028	Does Not
High Porosity	2021	2017	2028	2032	Does Not
No Degradation, Low Dispersivity, Low K_d	2021	2023	2029	2054	2038

Notes:
K_d is soil water partition coefficient
µg/L is micrograms per liter

3.6.1 Other Flow and Transport Models for Middle Rio Grande Basin

While EPA was conducting the MNA evaluation for the FAP site, as documented in this report, the United States Geological Survey (USGS) was developing a separate groundwater flow and transport model to simulate the transport of anthropogenic and natural contaminants within the Middle Rio Grande Basin (MRGB). The USGS model development and simulation results are presented in *Simulations of Groundwater Flow, Transport, and Age in Albuquerque, New Mexico, for a Study of Transport of Anthropogenic and Natural Contaminants (TANC) to Public-Supply Wells* (Scientific Investigations Report 2012-5242, 2013).

In addition to simulating the transport of carbon-14, tritium, chlorofluorocarbons, and groundwater of various ages, the USGS also used the TANC model to simulate the transport of chlorinated solvent, presumably from the FAP source area. Although, the TANC model chlorinated solvent simulations were not a key focus for the USGS modeling effort, the simulation results are useful for comparison to those obtained using the FAP flow and transport model.

The TANC model simulations show transport of chlorinated solvent released from the FAP source area. Dissolved phase solvent (note: concentration was not specified) was released once per year for a 14 year period between 1975 and 1989 and solvent transport simulated using effective porosity values of 8 percent and 1.1 percent. For comparison, the FAP model used porosity values ranging from 13 to 28 percent. In the TANC model simulation, chlorinated solvent is transported east-southeast at the 8 percent porosity value and southeast at the 1.1 percent porosity value indicating that pumping from the local water supply wells exerts a greater influence on chlorinated solvent plume transport at the lower effective porosity value. There are no time-steps shown on the TANC model simulations, so the rate of transport cannot be determined. Conversely, the FAP model, which uses higher effective porosity values, shows TCE migration in a more easterly direction. It should also be noted, that the TANC model only shows transport pathways. The model does not include a decay factor nor are the data post-processed in a manner that estimates solvent concentrations and plume boundaries. Therefore, the only conclusion that can be drawn from the TANC model simulation is that, in the absence of decay, chlorinated solvent with an unknown concentration could be intercepted by pumping of a downgradient water supply well at very low effective porosity values.

It is expected that there are a number of key similarities and differences between the design and construction of the two models, and it is not possible to determine which model design more accurately simulates the features, events and processes occurring within the MRGB. The FAP model was designed, constructed and calibrated with a groundwater elevation and TCE concentration data set generated from measurements performed at approximately 100 monitor wells over a 10 to 15 year period, whereas the TANC model is supported by a much less robust model calibration dataset. Based on current information, the simulations generated by the FAP model are more technically defensible.

FIGURE 3-3
Snapshots of F&T Modeling Results – P&T System Remains On Base Case Scenario
Fruit Avenue Plume Superfund Site, Albuquerque NM

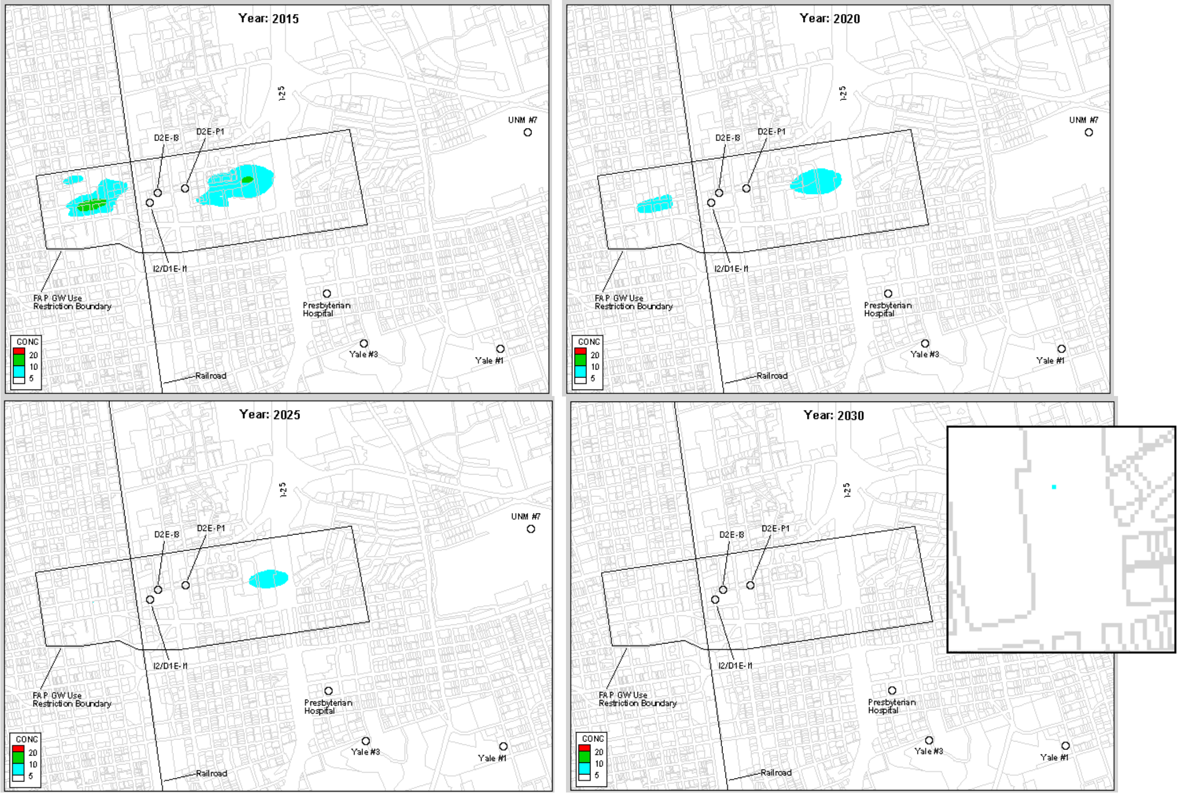

FIGURE 3-4
Snapshots of F&T Modeling Results – P&T System Turned Off Base Case Scenario
Fruit Avenue Plume Superfund Site, Albuquerque NM

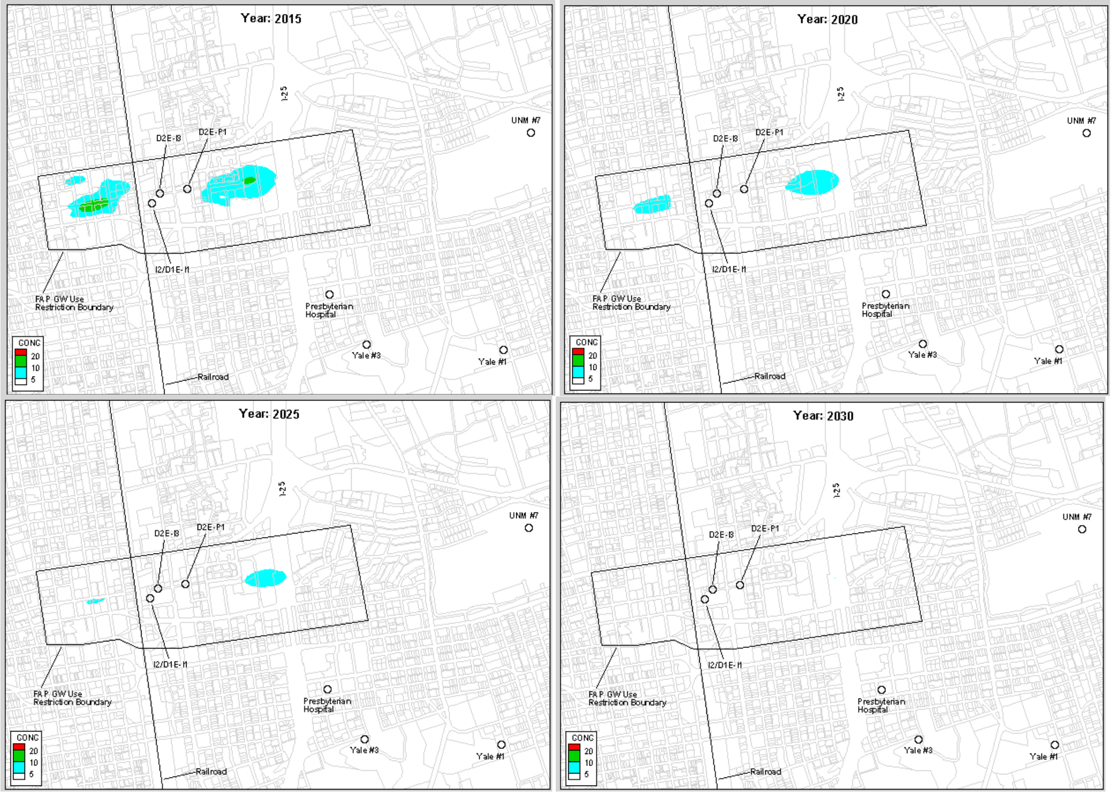

TABLE 3-5
Comparison of 2005 and 2010 Groundwater Flow and Transport Model Results
Fruit Avenue Plume Superfund Site, Albuquerque NM

Base Case Scenario	Year that TCE Concentrations Drop Below 5 µg/L	Location where TCE Concentrations Drop Below 5 µg/L
2005 Model “No Action” (CH2M HILL, 2005a)	2046	1,150 Feet West of University Boulevard
2012 Model “P&T System Turned Off” (this report)	2030	Eastern Edge of Interstate 25

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SECTION 4

Natural Attenuation Effectiveness Compared to Pump-and-Treat

The mass of TCE removed by MNA from the aquifer was estimated from the modeled groundwater plume shell and the mass removed by the ASTP (CH2M HILL, 2012c). A numerical model of the TCE plume was developed based on historical groundwater sampling results (CH2M HILL, 2012a). **Figures 4-1** and **4-2** are snapshots from the model, which are included as a DVD attachment to **Appendix L**. Sample results from wells in the upgradient offsite plume were excluded from the TCE plume shell construction. The total mass removed from the plume (M_0-M_T) was attributed to (1) mass removed by MNA (M_{MNA}), and (2) mass removed by P&T system operations (M_{ASTP}) so that the mass removed by the MNA response action (M_{MNA}) can be calculated from **Equation 1:**

$$\mathrm{M_{MNA}} = (\mathrm{M_0} - \mathrm{M_t}) - \mathrm{M_{ASTP}}$$

Cumulative estimates of these parameters are listed in **Table 4-1** and illustrated in **Figure 4-3**. The volume and mass of the calculated plume shell generally increased between discovery in 1986 through 1998 (**Appendix J**) because additional wells were added to delineate the extent of the plume. No plume volume or TCE mass calculations are provided for the 1986 through 1998 period. Between 1998 and 2005, an expected increase in the plume volume and mass resulting from installation and sampling of new monitoring wells is partially offset by decreasing TCE concentrations, resulting in an overall decline in TCE mass as the plume is more thoroughly characterized. The 1998 plume shell was selected as a starting point for this evaluation because it represented the highest observed volume and mass of TCE present within the plume shell.

Fluctuations in the mass of dissolved TCE present in the plume shell result from variations in the TCE concentration at monitor wells that represent larger volumes of the plume (e.g., MNW-5(D2)). The estimate of TCE mass removed by the ASTP is skewed high in this analysis because concentrations less than the 5 µg/L remedial goal are included, whereas the MNA response action is assumed to act on only the TCE plume where concentrations exceed the 5 µg/L remedial goal.

Based on this analysis, it is estimated that the MNA response action has removed 14.4 kg of TCE compared to 6.9 kg of TCE removed by the P&T system. Overall, MNA accounts for two-thirds of the total TCE mass removed from the plume since startup of the P&T remedy in 2005 and the February 2012 LTM sampling event.

FIGURE 4-1
June 2005 TCE Plume Shell (Greater than 5 µg/L) with Volume and Mass Estimate
Fruit Avenue Plume Superfund Site, Albuquerque NM

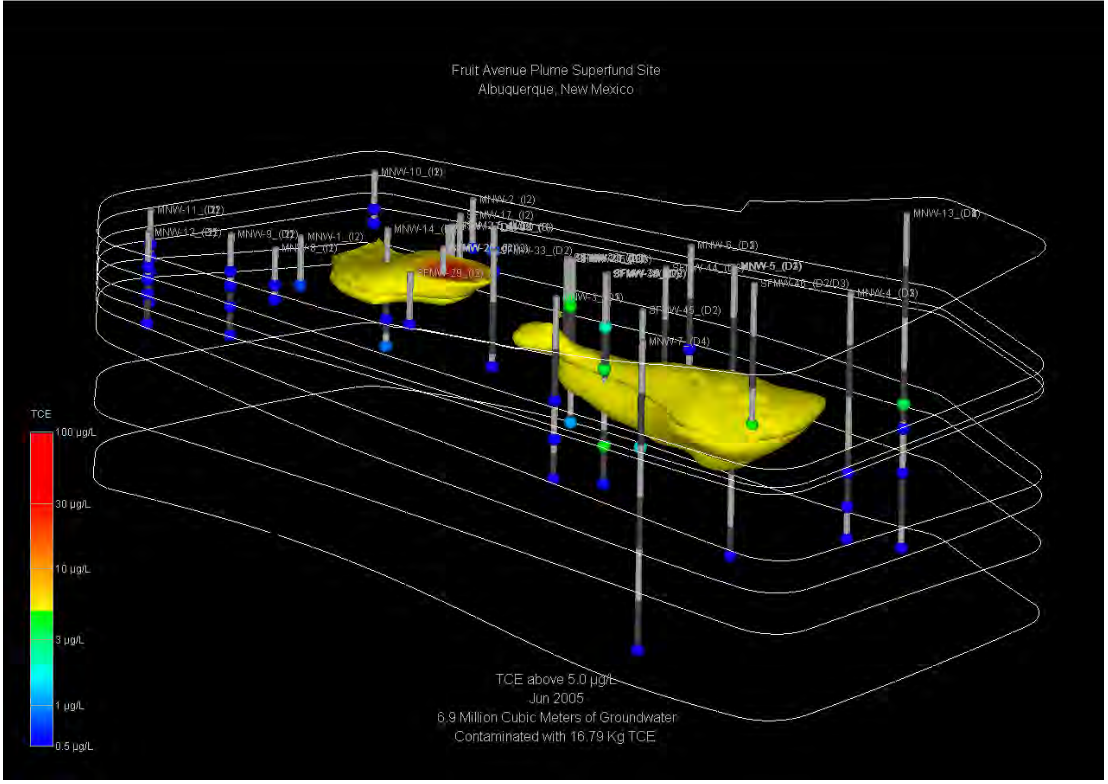


FIGURE 4-2
February 2012 TCE Plume Shell (Greater than 5 µg/L) with Volume and Mass Estimate
Fruit Avenue Plume Superfund Site, Albuquerque NM

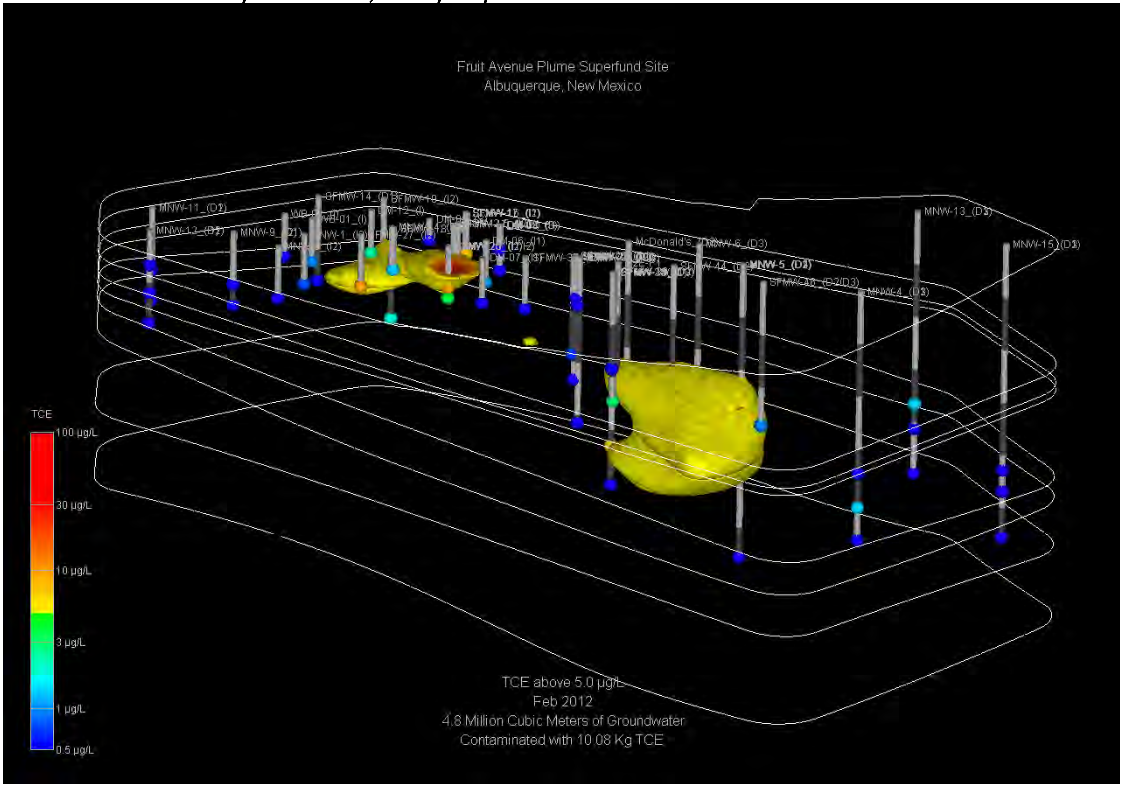


TABLE 4-1

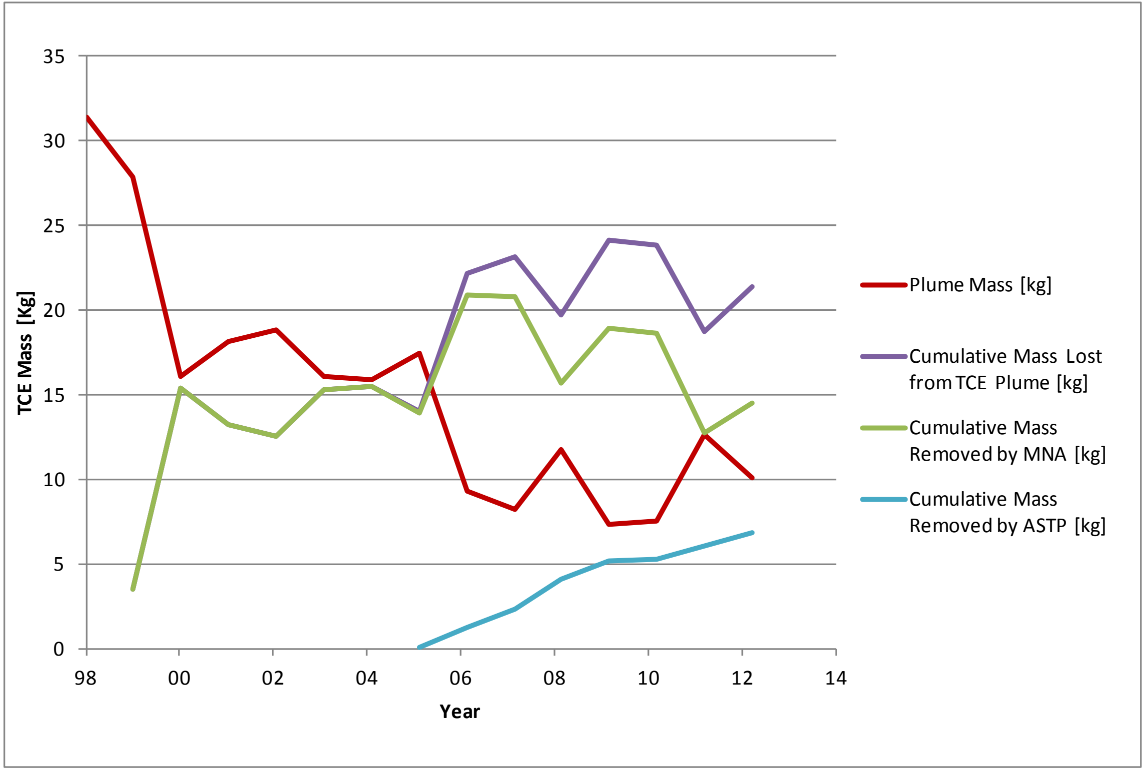
Cumulative TCE Mass Removed by MNA

Fruit Avenue Plume Superfund Site, Albuquerque NM

	Estimated TCE Plume Volume	Estimated TCE Plume Mass	Cumulative Mass Lost from TCE Plume	Cumulative TCE Mass Removed [kg]		Fraction of TCE Removed	
Date	**[10^6 M^3]**	**[kg]**	**[kg]**	**ASTP**	**MNA**	**ASTP**	**MNA**
Jun-98	8.6	31.42					
Jun-99	8.1	27.88	3.54	0	3.540	0%	100%
Jun-00	5.9	16.05	15.37	0	15.370	0%	100%
Jun-01	6.8	18.17	13.25	0	13.250	0%	100%
Jun-02	7.2	18.87	12.55	0	12.550	0%	100%
Jun-03	6.4	16.11	15.31	0	15.310	0%	100%
Jun-04	6.0	15.89	15.53	0	15.530	0%	100%
Jun-05	7.2	17.42	14.00	0.059	13.941	0%	100%
Jun-06	4.0	9.26	22.16	1.30	20.862	6%	94%
Jun-07	3.4	8.24	23.18	2.35	20.826	10%	90%
Jun-08	5.1	11.72	19.70	4.06	15.636	21%	79%
Jun-09	3.3	7.32	24.10	5.21	18.886	22%	78%
Jun-10	3.8	7.57	23.85	5.25	18.605	22%	78%
Jun-11	5.7	12.67	18.75	6.04	12.712	32%	68%
Jun-12	4.8	10.08	21.34	6.88	14.464	32%	68%

Note: The starting date for this table was selected because the maximum known plume mass and plume volumes were estimated to occur at that time. Additional monitor wells have been installed since then (e.g., MNW-5 and MNW-6), which did expand the footprint of the plume and, thus, in this exercise, underestimates the mass lost from the plume and underestimates the mass removed by MNA.

FIGURE 4-3
Cumulative Dissolved TCE Plume Shell (>5 µg/L) Mass Estimates
Fruit Avenue Plume Superfund Site, Albuquerque NM.



SECTION 5

Conclusions

This section consolidates the findings presented in **Sections 2**, **3,** and **4**, and explains how these findings support continued MNA of the downgradient TCE plume, as implemented under the ESD (EPA, 2006). In addition, this section explains how these findings support MNA as a response action for the other portions of the TCE plume, specifically that portion that lies west (upgradient) of the existing P&T system, and how remedial goals will be met by 2030, even with the P&T system turned off.

5.1 Revised Conceptual Site Model

This subsection summarizes the minor changes to the CSM based on this updated MNA evaluation.

As indicated in **Section 2**, it is assumed that fine-grained aquifer materials have the potential to release low-levels of TCE to groundwater through desorption and matrix diffusion. It is believed that high concentrations of TCE previously present in groundwater in the presumed source area have been sequestered in fine-grained aquifer materials. These fine-grained materials presently act as a low-level source by slowly releasing TCE to the higher-conductivity adjacent aquifer materials. It is also possible that undiscovered contaminated vadose zone soil may represent a future source as groundwater levels rise in response to reduced groundwater pumping and increased surface water usage. However, at this time, TCE concentrations in groundwater suggest that desorption and matrix diffusion are relatively insignificant processes and that groundwater is not in contact with contaminated soil.

As previously predicted (CH2M HILL, 2005a), TCE concentrations continue to decrease at most locations. Geochemistry parameters (TEAPs) measured during the second MNA sampling event in 2010 appear to be less definitive than the previous events. This may be caused by decreasing biodegradation associated with lower cVOC concentrations.

Two hydrogeologic changes are apparent. Groundwater levels are rising as expected and the previously easterly groundwater flow direction in the D1, D2, D3, and D4 aquifer zones may have shifted slightly to the southeast. The rising water levels were anticipated in the 2005 MNA evaluation, and are expected to continue. The change in the groundwater flow direction is likely caused by changes in groundwater pumping by the Water Authority well field located southeast of the site.

Estimates of TCE degradation rates presented in this report are supported by multiple lines of evidence and considered representative for inclusion in the CSM. Stable isotope data (i.e., CSIA data) confirm previous determinations that TCE is degrading to cis-1,2-DCE. Abiotic degradation has been added to the list of potential processes that contributing to TCE and DCE decay. Type 3 plume behavior, while not conducive to rapid degradation of TCE and cis-1,2-DCE, is conducive to an adequate level of degradation such that degradation can be recognized as an important NA process for this site.

A comparison of the plume geometry predicted in the 2005 NA Evaluation (CH2M HILL, 2005a), to the plume geometry predicted by the 2012 modeling effort, shows that the plume is advancing slower and degrading faster than predicted in 2005. Inclusion of a degradation factor in the 2012 modeling is expected to account for much of the difference between the 2005 and 2012 simulation results.

5.2 Summary of Findings

Multiple lines of evidence were analyzed to evaluate TCE degradation and decay at the site. This subsection summarizes the findings presented in **Sections 3** and **4**.

- The risk assessment conducted for the RI is still applicable. Exposure pathways that might pose a risk to ecological receptors or human health are currently incomplete.

- In the intermediate aquifer zone plume, TCE mass is decreasing, the center of mass is stable and the plume length is shrinking. In the D1 and D2 aquifer zones, TCE mass is currently decreasing, the center of mass is advancing and the plume length is decreasing. In the D3 aquifer zone plume, TCE mass is currently increasing due to transport from the overlying D1 and D2 aquifer zones, the plume length is decreasing while the center of mass is advancing under the influence of the regional groundwater flow gradient. TCE and cis-1,2-DCE concentrations are declining as TCE is transformed to cis-1,2-DCE and cis-1,2-DCE to carbon dioxide and water.
- Based on the results of the CSIA evaluation, degradation of TCE to cis-1,2-DCE is occurring at the site. Although site conditions are not amenable to biologically mediated reductive dechlorination throughout all of the aquifer zones, reductive dechlorination in combination with physical attenuation are the key processes responsible for TCE concentration reductions in groundwater. Degradation of cis-1,2-DCE may be caused by aerobic oxidation, aerobic cometabilization, or abiotic degradation.
- Although the plume is advancing at some locations, the flow and transport modeling indicates that it is decaying fast enough that it is not expected to move beyond the groundwater use restriction boundary.
- TCE concentrations are projected to drop below the 5-µg/L remedial goal before reaching the groundwater use restriction boundary and before adversely impacting potential receptor wells. TCE concentrations are expected to drop below the 5 µg/L remedial goal by the year 2030 with the P&T system turned off and 2031 with the P&T system left on. This is 15 years earlier than estimated in the 2005 NA Evaluation (CH2M HILL, 2005a) and is considered reasonable based on groundwater use projections for this site.
- It is estimated that the MNA response action has removed at least two-thirds of the TCE mass lost between startup of the P&T system and the February 2012 LTM sampling event.
- The geochemical characteristics of the water returned to the aquifer following ASTP treatment hinder reductive dechlorination near the injection wells and in the area where treated water mixes with native groundwater. Therefore, the efficiency of NA is expected to increase by turning off the P&T system, thereby enhancing conditions for reductive dechlorination, and increasing the likelihood of achieving the 5-ug/L remedial goal before the year 2030.
- The geochemical conditions outside the influence of the P&T system are sustainable long-term. Type 3 plume conditions, while not optimal for degradation, are sustainable, especially if injection of treated water is discontinued.

5.3 Uncertainties

Uncertainties remain concerning the processes that cause degradation of TCE and cis-1,2-DCE at the site . Although the magnetic susceptibility evaluation indicated that sufficient magnetite is present in the aquifer materials to support abiotic degradation, the CSIA evaluation was unable to discern between abiotic and biotic degradation processes. The microbial data (PLFA analyses) previously collected at the site are not capable of identifying specific bacteria, enzymes, or microbial processes. However, other microbiological analyses are now available to ascertain the specific bacteria, enzymes, and/or microbial processes responsible for degradation of site contaminants.

Although no contaminated soil was found in the presumed source area, rising water levels may reveal the presence of a contaminant source not discovered during previous investigations.

The MAROS evaluation of plume moments (mass, location, length and width) has not been updated with LTM data collected between 2010 and 2012. However, if the previous MAROS evaluation were updated to include this information, it is expected that the determinations would be similar.

5.4 Efficacy of MNA

The inputs required to evaluate the appropriateness of MNA as a primary response action (**Section 2.4.2.3**) (EPA, 1999b) have been evaluated in this report and are summarized below.

- COCs can be effectively remediated by NA processes at the site.
- There is no current demand for groundwater resources within the groundwater use restriction boundary.
- Although the plume in the eastern downgradient portion of the site is advancing away from the presumed source area, the plume in the presumed source area is shrinking.
- Type 3 plume conditions are sustainable.
- Human health and environmental risks assessments indicate that there are no complete exposure pathways.
- Degradation products cis-1,2-DCE and VC are not accumulating and are not projected to exceed their remediation goals. Thus, they do not present a greater risk than their TCE parent contaminant.
- The P&T remedy has a negative impact on the MNA response action, exacerbating the aquifer conditions needed for more effective reductive dechlorination.

At this time, and based on the assumptions in the groundwater flow and transport model, MNA alone is sufficient to meet the RAOs as required by the ESD.

- In compliance with the ESD (EPA, 2006), the portion of the TCE plume downgradient of the P&T system is expected to decay to less than 5 μg/L within the current groundwater use restriction boundary (an interim point of compliance).
- A reasonable remediation timeframe goal is expected to be met. That is, based on the flow and transport modeling and the point decay rates, the maximum TCE concentration is expected to decay to below the MCL within 30 years of promulgation of the ROD (by about 2031).
- In addition, operation of the P&T system to remove TCE from the plume at the presumed source area is not expected to contribute significantly to meeting the RAOs earlier.

5.5 Summary

In summary, the multiple lines of evidence indicate that the FAP exhibits Type 3 plume behavior. Although conditions are not robust for anaerobic reductive dechlorination across the TCE plume footprint, degradation plays a significant part in the decay of TCE at the site. The CSIA evidence indicates that TCE is degrading to cis-1,2-DCE. The CSIA evidence also indicates that dispersion, diffusion, and sorption cause the majority of the observed TCE decay. Decreasing cis-1,2-DCE concentrations are also likely caused by aerobic oxidation, aerobic cometabolism, or abiotic degradation, as indicated by the near absence of VC and elevated carbon dioxide concentrations and the magnetic susceptibility results.

Based on the findings of this evaluation, concentrations of TCE that are present downgradient of the ASTP, and not captured by the existing P&T system, are expected to attenuate to concentrations below the 5 μg/L remedial goal specified in the ROD before the plume reaches the current groundwater use restriction boundary. Furthermore, this report finds that TCE present upgradient of the P&T system is also expected to naturally attenuate below the 5 μg/L remedial goal *even if the P&T system is shutdown*. That is, MNA, acting as the sole response action at the site, is expected to maintain the concentration of TCE below the RAOs at the groundwater use restriction boundary and is expected to meet the RAOs within the 30-year remediation timeframe estimate identified in the ROD.

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SECTION 6

Recommendations

Based on this report's findings, it is recommended that the FAP P&T system be immediately placed in a standby mode. A decision document should be prepared to modify the selected response action to expand the use of MNA, in lieu of P&T, to complete remedial action of the central and western portions of the site-related TCE plume. MNA will continue to be used to address the eastern plume.

The decision document would maintain the P&T system in a standby mode, as a contingent remedy, until additional LTM and the second 5YR confirm that MNA as the sole response action is performing in accordance with expectations, is protective of human health and the environment, and is capable of achieving remedial goals. In the standby mode, the P&T system will be routinely maintained such that continuous or pulsed operations can readily resume. If the second 5YR confirms these requirements, then the P&T system would be decommissioned prior to completion of LTRA, which will occur on August 26, 2017, and the site would be transferred to NMED for the remaining O&M period.

In the event, the second five-year review concludes that sitewide MNA is not protective of human health and the environment, then EPA will modify the remedy as necessary. The scope of any required remedy modifications would most likely be determined through a Focused Feasibility Study, Proposed Plan, and ROD amendment that will allow for review and comment by the public.

6.1 Response Action Modifications

At this time, the only recommended modification is suspension of the P&T portion of the response action and expansion of MNA to include the central and western portion of the FAP – TCE plume.

6.2 Changes to LTM and MNA Monitoring

Continued monitoring of MNA parameters on a five-year cycle is required by the ESD. The CSIA sampling should be performed concurrently with MNA parameters to provide confirmation of the recent testing and to determine if degradation conditions have changed, especially if the P&T system is placed in a standby mode. Additional analyses that may prove useful include dissolved hydrogen, which requires special sampling equipment but provides strong evidence of specific redox processes (e.g. nitrate reduction, iron reduction, sulfate reduction and methanogenesis). Additional sampling for microbiological analyses should be conducted to ascertain the specific bacteria, enzymes, and/or microbial processes responsible for degradation of site contaminants. The recommended qPCR analyses will demonstrate the presence or absence of Dehalococcoides spp and other bacteria capable of reductive dechlorination of TCE. Analysis also will be done to identify bacteria responsible for aerobic oxidation and cometabolic transformation of TCE, cis 1,2-DCE, and VC. The next round of MNA sampling should be conducted in early 2015.

Future monitoring under the current LTM program includes a sampling location and schedule regime that will provide the information necessary to confirm the interpretations presented in this report. Since the current degradation process(es) are not fully understood, it is possible that current NA processes may be enhanced or new NA processes may result from shutdown of the P&T system.

The TCE plume and the presence of potentially harmful and innocuous daughter products should be evaluated as is currently done through the annual LTM reports. If conditions change and MNA becomes less effective at addressing site-related contaminants, resumption of P&T operations or evaluation of alternate technologies may be warranted. The ROD (EPA, 2001) and ESD (EPA, 2006) discussed the use of other technologies such as point-of-use treatment, in situ permeable reactive barrier, SVE, and hot-spot treatment. However, these technologies were rejected due to effectiveness, implementability or cost limitations. Expansion or modification of the P&T system, as suggested in the RSE (CH2M HILL, 2009), may also represent a viable approach. The exact nature of contingency actions, if deemed necessary in the second 5YR, would be determined based on evaluation of future groundwater quality monitoring results.

Both the Presbyterian and Lovelace (former Saint Joseph) hospital wells should be added to the LTM program. These are the nearest potential receptors and the Lovelace hospital well is within the groundwater use restriction boundary. It is expected that as the remedial goals are met the Lovelace hospital well may be returned to service and the Presbyterian hospital well will be returned to potable use.

SECTION 7

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Appendix A
Long-Term Monitoring Optimization Report Excerpts

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TABLE ES-1
Comparison of Existing LTM Program with Recommended Program
Fruit Avenue Plume Superfund Site

Parameter	LTM Program – 2009	Current LTM Program
Sampling Method	PDBs	PDBs
Analytical Method	Contract Laboratory Program Samples analyzed for VOCs by method SOM01.2.	Contract Laboratory Program Samples analyzed by method SOM01.2. Reduce analyte list to PCE, TCE, cis 1,2-DCE, Trans-DCE, VC, BTEX only One round of sampling and testing for MNA parameters before 2015
No. of Sampled Locations	60 locations	71 locations
Water-Level Monitoring	110 locations	94 locations, after well abandonments
Sampling Frequency	Two events per year	Two events per year, February and August
		1 well monthly (extraction well)
	37 wells 2 times per year	22 wells 2 times per year
	9 wells 1 time per year	24 additional wells 1 time per year
	14 wells every other year	24 additional wells every other year (71 total wells)
Abandoned Wells	- - -	36 wells
New Monitor Wells	- - -	If warranted by changing conditions
Well Maintenance	- - -	Well head rebuilds (~32)

Notes:
BTEX = benzene, toluene, ethylbenzene, and xylenes
cis 1,2-DCE = Cis 1,2-dichlorethene
MNA = monitored natural attenuation
PDB = passive diffusion bag sampler

PCE = tetrachlorethene
TCE = trichlorethene
Trans- 1,2-DCE = trans 1,2-dichlorethene
VOC = volatile organic compound

VC = vinyl chloride

TABLE 2-1
Aquifer Zones and Characteristic Parameters in the Area Affected by the P&T System
Fruit Avenue Plume Superfund Site

Aquifer Zone	Approximate Elevation Range[a] (ft amsl)	Transmissivity (gpd/ft)	Storage Coefficient	Porosity (%)	Aquifer Thickness (feet)
S	Above 4,912	NT	NT	NT	N/A
I1	4,864 to 4,912	*720**	*0.05**	*0.15**	36
I2	4,849 to 4,864	900	0.05	0.15	15
D1	4,765 to 4,849	9,000	0.0005	0.20	84
D2	4,698 to 4,765	10,000	0.0005	0.20	67
D3	4,620 to 4,698	*11,700**	*0.0005**	*0.20**	78
D4	Below 4,620	NT	NT	NT	Unknown

Notes:

ft amsl = feet above mean sea level

gpd/ft = gallons per day per foot

N/A = Not Applicable

NT = Not Tested

S = Shallow aquifer zone

I1 = Intermediate aquifer zone 1. I2 = Intermediate aquifer zone 2

D1 to D4 = Deep aquifer zones 1 to 4

[a] Aquifer zone elevation and thickness' for the area outside the zone influenced by the pump-and-treat system are different.

**I1 and D3* aquifer zone properties are assumed to be the same as the adjacent aquifer zones (I2 and D2) except for transmissivity which was adjusted to account for the measured aquifer zone thickness.

Aquifer zone elevations listed in this table are representative of the area near the P&T system. The depth to and thickness of each aquifer zone varies across the Site, most notably on the east side of the presumed fault. See **Figure 2-1**.

Appendix B
February 2012 Groundwater Elevation Contour and Flow Maps, TCE Distribution Maps, and Groundwater Elevation Hydrographs

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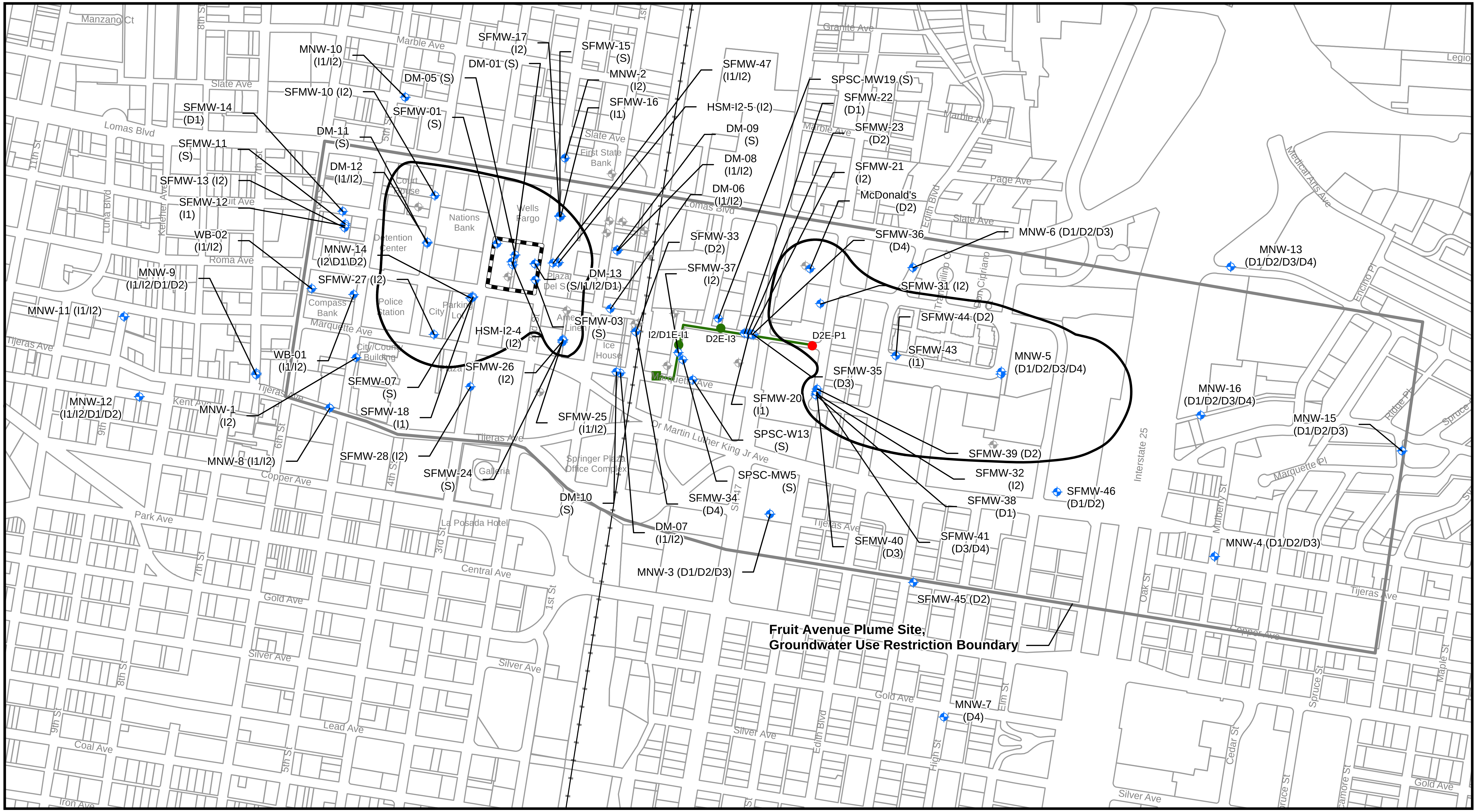

LEGEND

◆ D4 Zone Monitor Well
◇ Other Site Monitor Well
▭ Presumed Source Area
🔴 Extraction Well
🟩 Air Stripper Treatment Plant
🟢 Injection Well
—+— Railroad
— FAP TCE Composite Plume Boundary at 5 ug/L (dashed where inferred). The upgradient TCE plume located west of the Site is not shown. This plume is not part of FAP Site.

Aquifer Zones:
S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

FIGURE 1
Site Map
February 2012
Fruit Avenue Plume Superfund Site
Albuquerque, NM

CH2MHILL.

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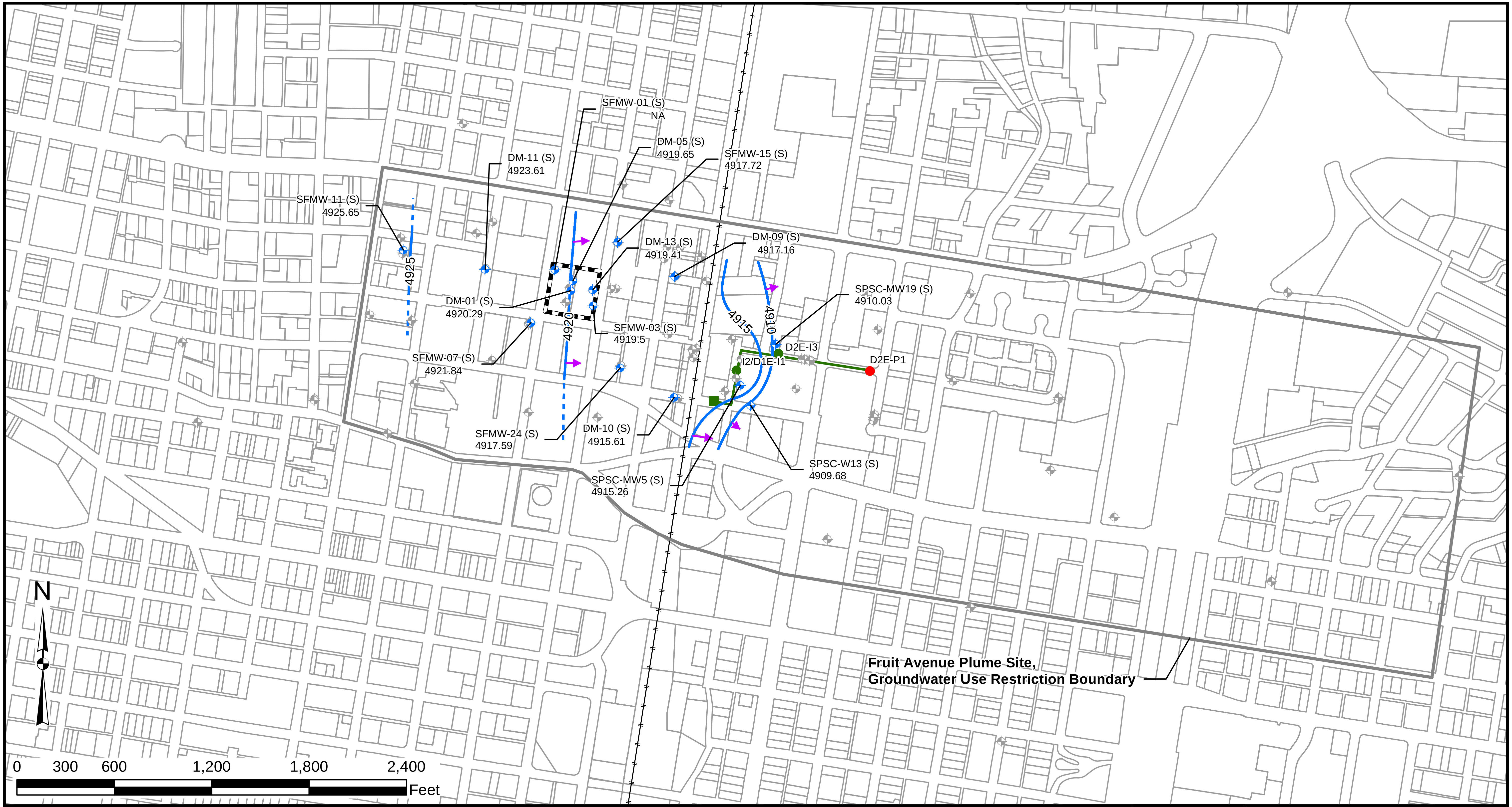

Legend

- ⌖ S Zone Monitor Well
- ⌖ Other Site Monitor Well
- ▨ Presumed Source Area
- 🔴 Extraction Well
- 🟩 Air Stripper Treatment Plant
- 🟢 Injection Well
- ┼ Railroad
- → Inferred Direction of Groundwater Flow
- ― Water Level Contour (dashed where inferred)

Aquifer Zones

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Notes

1. Water levels are in feet above Mean Sea Level (MSL).
2. Water level contour interval is 5 feet.
3. Water level data contoured by hand by triangulation with linear interpolation with consideration for known site hydrogeology. Horizontal flow is assumed based on homogeneous and isotropic conditions.
4. NA, Water level not collected.

Figure 2

Distribution of Water Levels in the Shallow Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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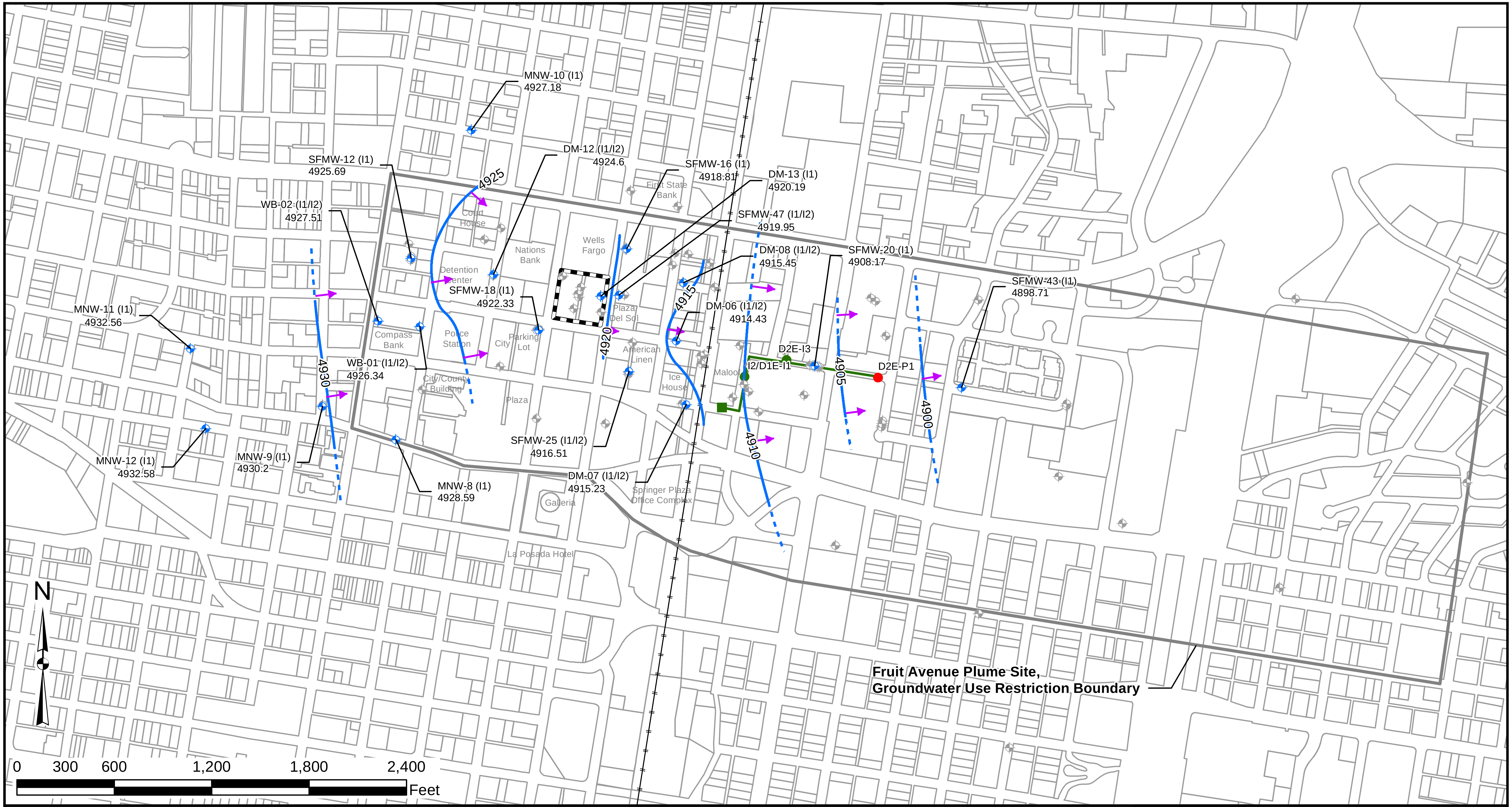

Legend

- ⊕ I1 Zone Monitor Well
- ⊕ Other Site Monitor Well
- ▨ Presumed Source Area
- 🔴 Extraction Well
- 🟩 Air Stripper Treatment Plant
- ● Injection Well
- ┼ Railroad
- → Inferred Direction of Groundwater Flow
- ― Water Level Contour (dashed where inferred)

Aquifer Zones

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Notes

1. Water levels are in feet above Mean Sea Level (MSL).
2. Water level contour interval is 5 feet.
3. Water level data contoured by hand by triangulation with linear interpolation with consideration for known site hydrogeology. Horizontal flow is assumed based on homogeneous and isotropic conditions.

Figure 3

Distribution of Water Levels in the I1 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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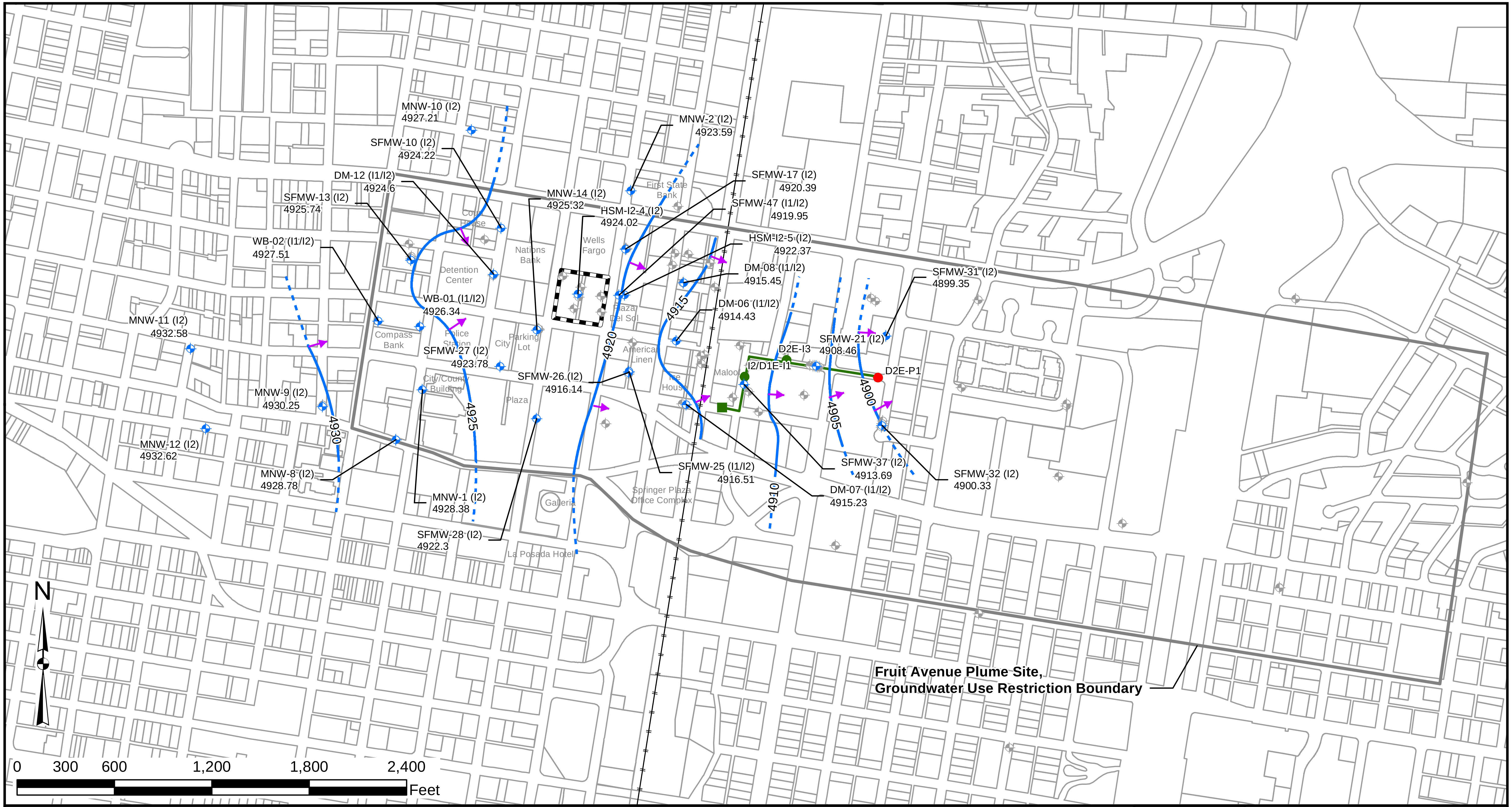

Legend

- 🔵 I2 Zone Monitor Well
- ⊕ Other Site Monitor Well
- ▨ Presumed Source Area
- 🔴 Extraction Well
- 🟩 Air Stripper Treatment Plant
- 🟢 Injection Well
- ┼ Railroad
- → Inferred Direction of Groundwater Flow
- ― Water Level Contour (dashed where inferred)

Aquifer Zones

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Notes

1. Water levels are in feet above Mean Sea Level (MSL).
2. Water level contour interval is 5 feet.
3. Water level data contoured by hand by triangulation with linear interpolation with consideration for known site hydrogeology. Horizontal flow is assumed based on homogeneous and isotropic conditions.

Figure 4

Distribution of Water Levels in the I2 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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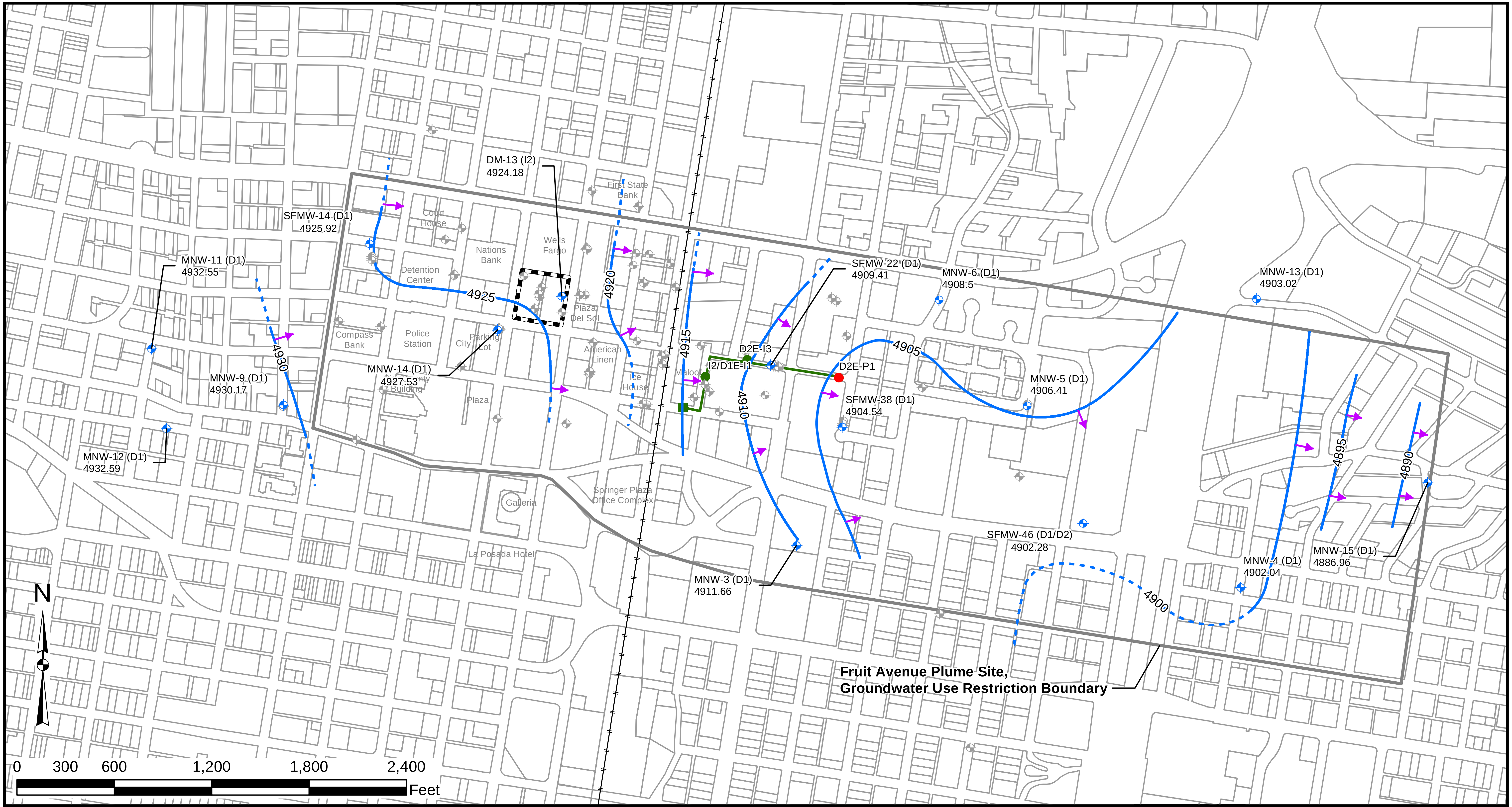

Legend

- ⌖ D1 Zone Monitor Well
- ⌖ Other Site Monitor Well
- ▨ Presumed Source Area
- 🔴 Extraction Well
- 🟩 Air Stripper Treatment Plant
- 🟢 Injection Well
- Railroad
- ➝ Inferred Direction of Groundwater Flow
- Water Level Contour (dashed where inferred)

Aquifer Zones

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Notes

1. Water levels are in feet above Mean Sea Level (MSL).
2. Water level contour interval is 5 feet.
3. Water level data contoured by hand by triangulation with linear interpolation with consideration for known site hydrogeology. Horizontal flow is assumed based on homogeneous and isotropic conditions.

Figure 5

Distribution of Water Levels in the D1 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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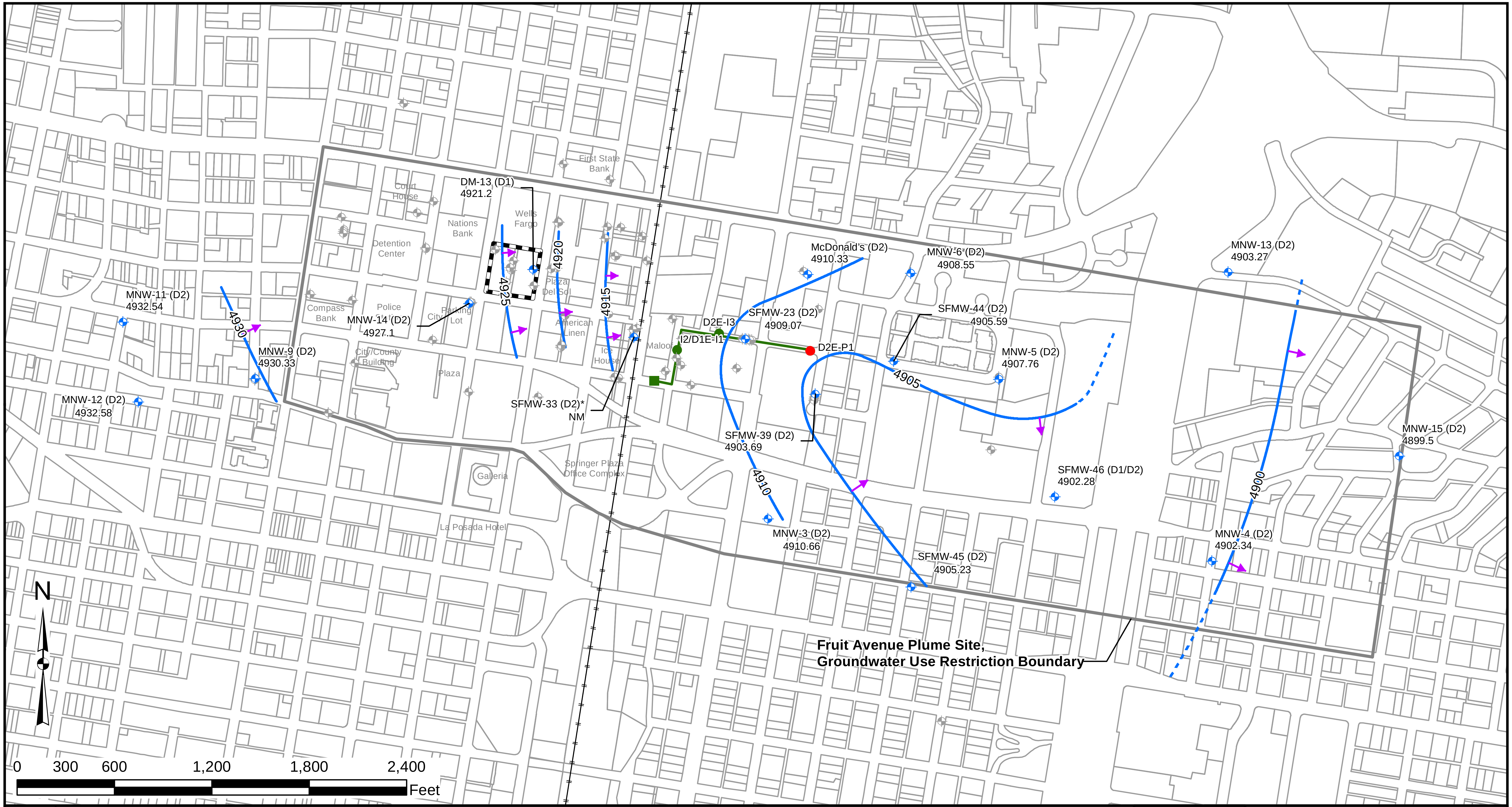

Legend

→ Inferred Direction of Groundwater Flow
⊕ D2 Zone Monitor Well
⊕ Other Site Monitor Well
▨ Presumed Source Area
● Extraction Well
■ Air Stripper Treatment Plant
● Injection Well
—+— Railroad
— Water Level Contour (dashed where inferred)

Aquifer Zones

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Notes

1. Water levels are in feet above Mean Sea Level (MSL).
2. Water level contour interval is 5 feet.
3. Water level data contoured by hand by triangulation with linear interpolation with consideration for known site hydrogeology. Horizontal flow is assumed based on homogeneous and isotropic conditions.
4. * - Unable to locate well.
5. NM - Water level not measured.

Figure 6

Distribution of Water Levels in the D2 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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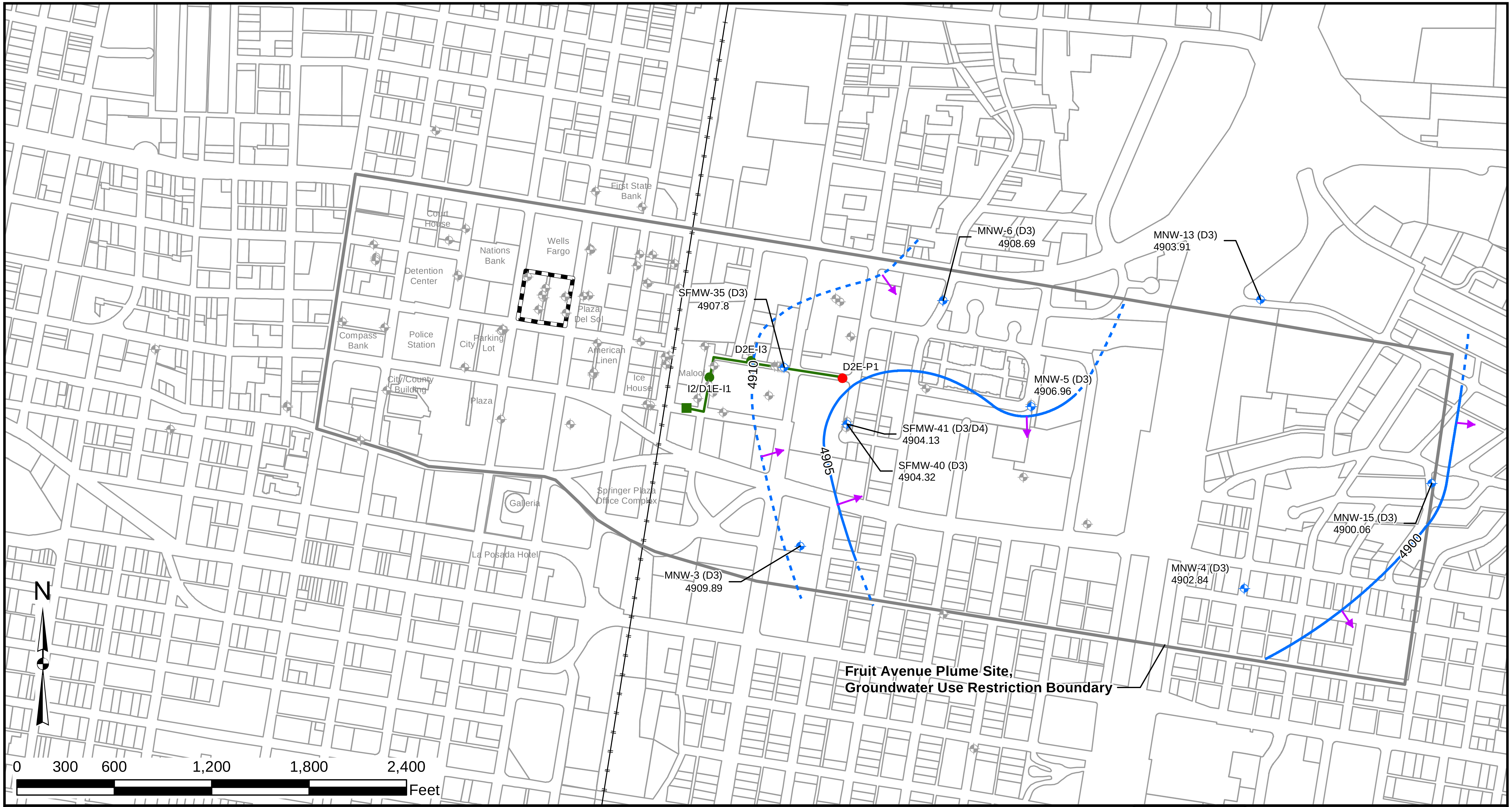

Legend

✦ D3 Zone Monitor Well
✧ Other Site Monitor Well
▨ Presumed Source Area
● Extraction Well
■ Air Stripper Treatment Plant
● Injection Well
+-+ Railroad
→ Inferred Direction of Groundwater Flow
— Water Level Contour (dashed where inferred)

Aquifer Zones

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Notes

1. Water levels are in feet above Mean Sea Level (MSL).
2. Water level contour interval is 5 feet.
3. Water level data contoured by hand by triangulation with linear interpolation with consideration for known site hydrogeology. Horizontal flow is assumed based on homogeneous and isotropic conditions.

Figure 7

Distribution of Water Levels in the D3 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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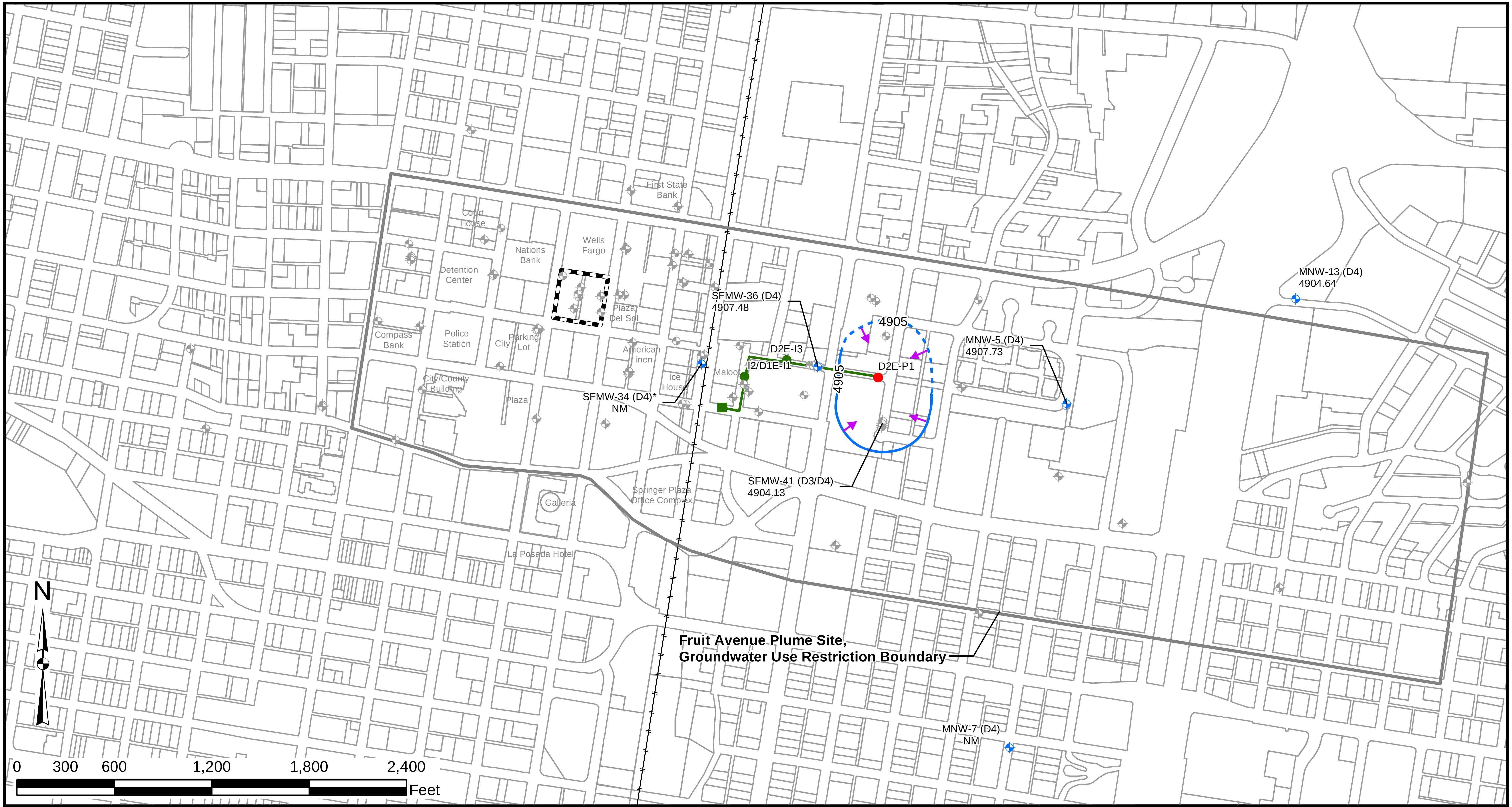

Legend

- ⌖ D4 Zone Monitor Well
- ⌖ Other Site Monitor Well
- ▨ Presumed Source Area
- ● Extraction Well
- ■ Air Stripper Treatment Plant
- ● Injection Well
- ┼ Railroad
- → Inferred Direction of Groundwater Flow
- — Water Level Contour (dashed where inferred)

Aquifer Zones

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Notes

1. Water levels are in feet above Mean Sea Level (MSL).
2. Water level contour interval is 5 feet.
3. Water level data contoured by hand by triangulation with linear interpolation with consideration for known site hydrogeology. Horizontal flow is assumed based on homogeneous and isotropic conditions.
4. * - Unable to locate well.
5. NM - Water level not measured.

Figure 8

Distribution of Water Levels in the D4 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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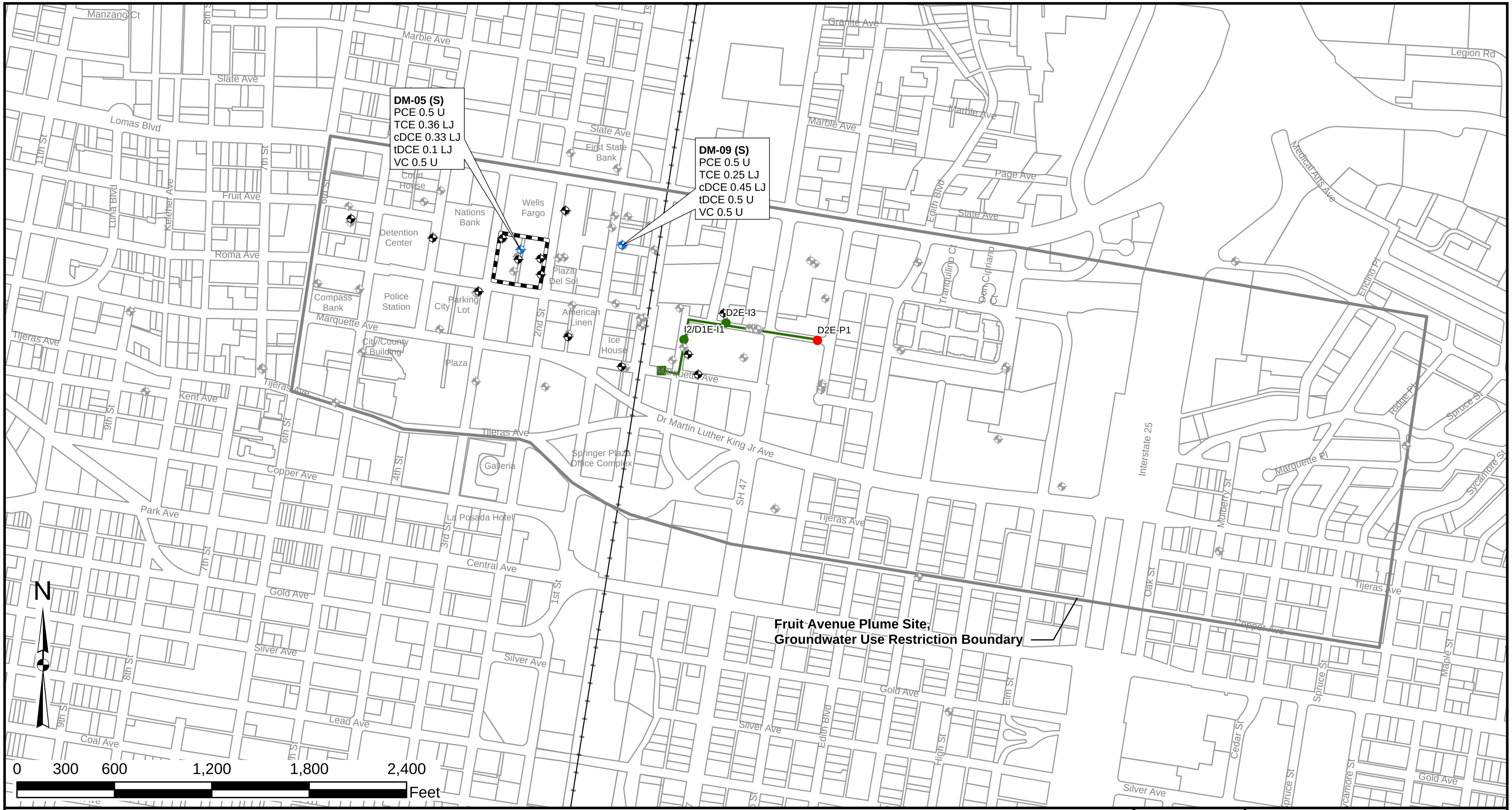

DM-05 (S)
PCE 0.5 U
TCE 0.36 LJ
cDCE 0.33 LJ
tDCE 0.1 LJ
VC 0.5 U

DM-09 (S)
PCE 0.5 U
TCE 0.25 LJ
cDCE 0.45 LJ
tDCE 0.5 U
VC 0.5 U

Fruit Avenue Plume Site, Groundwater Use Restriction Boundary

Legend

✦ S Zone Monitor Well	┼ Railroad
✦ S Zone Monitor Well- Not Sampled	▨ Presumed Source Area
✦ Other Site Monitor Well	
🔴 Extraction Well	
🟩 Air Stripper Treatment Plant	
🟢 Injection Well	

Aquifer Zones:
S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Volatile Organic Compounds:
Cis-1,2-dichloroethene (cDCE)
Trans-1,2-dichloroethene (tDCE)
Tetrachloroethene (PCE)
Trichloroethene (TCE)
Vinyl chloride (VC)

Units: micrograms per liter (µg/L)
Qualifiers: J - estimated
U - not detected
LJ - Estimated Concentration
= - detected concentration

Figure 9

Distribution of Chlorinated VOCs in the Shallow Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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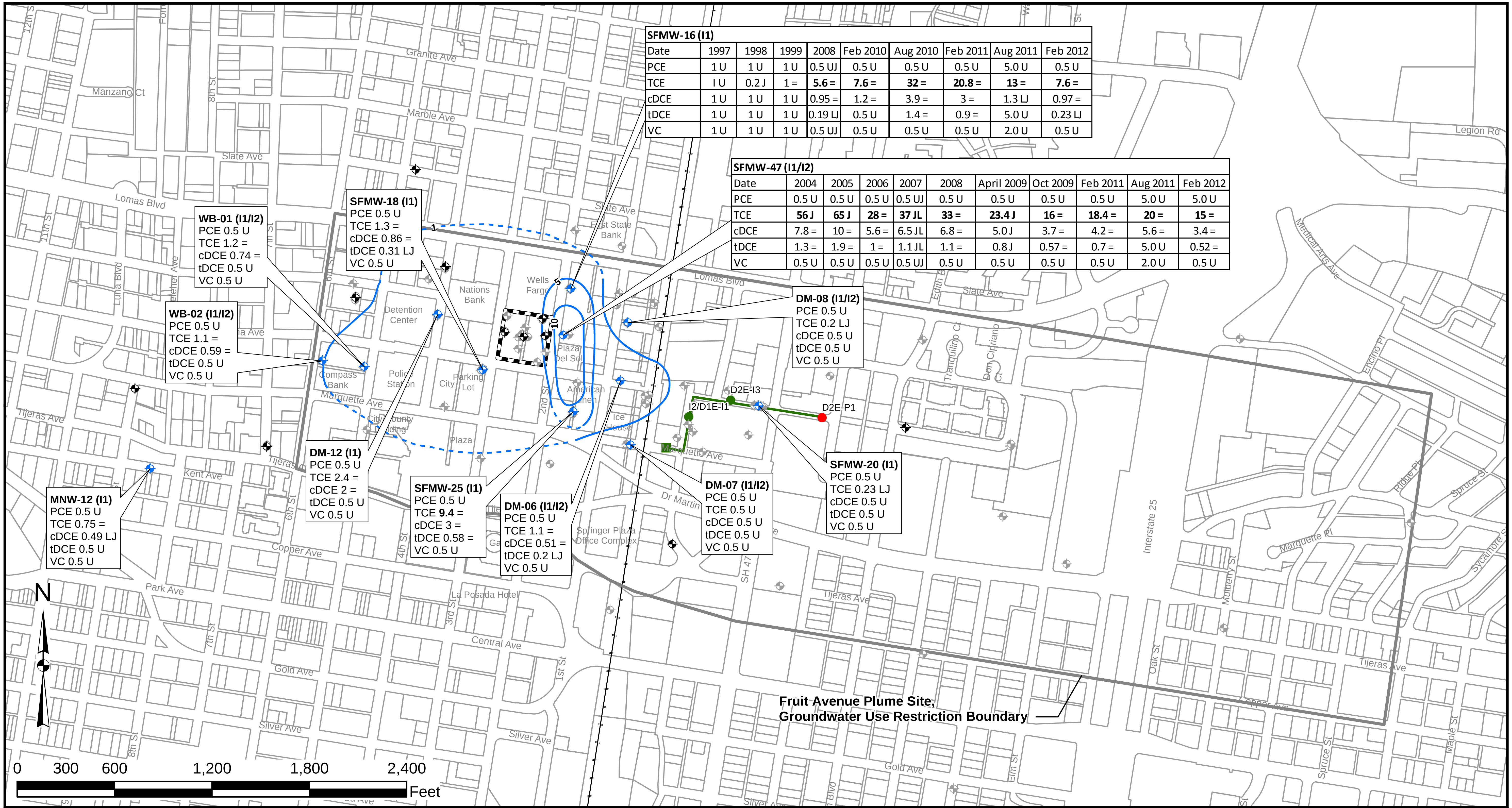

SFMW-16 (I1)

Date	1997	1998	1999	2008	Feb 2010	Aug 2010	Feb 2011	Aug 2011	Feb 2012
PCE	1 U	1 U	1 U	0.5 UJ	0.5 U	0.5 U	0.5 U	5.0 U	0.5 U
TCE	I U	0.2 J	1 =	**5.6 =**	**7.6 =**	**32 =**	**20.8 =**	**13 =**	**7.6 =**
cDCE	1 U	1 U	1 U	0.95 =	1.2 =	3.9 =	3 =	1.3 LJ	0.97 =
tDCE	1 U	1 U	1 U	0.19 LJ	0.5 U	1.4 =	0.9 =	5.0 U	0.23 LJ
VC	1 U	1 U	1 U	0.5 UJ	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

SFMW-47 (I1/I2)

Date	2004	2005	2006	2007	2008	April 2009	Oct 2009	Feb 2011	Aug 2011	Feb 2012
PCE	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U	0.5 U	5.0 U	5.0 U
TCE	**56 J**	**65 J**	**28 =**	**37 JL**	**33 =**	**23.4 J**	**16 =**	**18.4 =**	**20 =**	**15 =**
cDCE	7.8 =	10 =	5.6 =	6.5 JL	6.8 =	5.0 J	3.7 =	4.2 =	5.6 =	3.4 =
tDCE	1.3 =	1.9 =	1 =	1.1 JL	1.1 =	0.8 J	0.57 =	0.7 =	5.0 U	0.52 =
VC	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

SFMW-18 (I1)
PCE 0.5 U
TCE 1.3 =
cDCE 0.86 =
tDCE 0.31 LJ
VC 0.5 U

WB-01 (I1/I2)
PCE 0.5 U
TCE 1.2 =
cDCE 0.74 =
tDCE 0.5 U
VC 0.5 U

WB-02 (I1/I2)
PCE 0.5 U
TCE 1.1 =
cDCE 0.59 =
tDCE 0.5 U
VC 0.5 U

DM-08 (I1/I2)
PCE 0.5 U
TCE 0.2 LJ
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

DM-12 (I1)
PCE 0.5 U
TCE 2.4 =
cDCE 2 =
tDCE 0.5 U
VC 0.5 U

MNW-12 (I1)
PCE 0.5 U
TCE 0.75 =
cDCE 0.49 LJ
tDCE 0.5 U
VC 0.5 U

SFMW-25 (I1)
PCE 0.5 U
TCE **9.4 =**
cDCE 3 =
tDCE 0.58 =
VC 0.5 U

DM-06 (I1/I2)
PCE 0.5 U
TCE 1.1 =
cDCE 0.51 =
tDCE 0.2 LJ
VC 0.5 U

DM-07 (I1/I2)
PCE 0.5 U
TCE 0.5 U
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

SFMW-20 (I1)
PCE 0.5 U
TCE 0.23 LJ
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

Legend

⌖	I1 Zone Monitor Well
⌖	I1 Zone Monitor Well- Not Sampled
⌖	Other Site Monitor Well
●	Extraction Well
🟩	Air Stripper Treatment Plant
●	Injection Well
┼	Railroad
▨	Presumed Source Area
—	TCE concentration contour (dashed where inferred)

Aquifer Zones:
S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Volatile Organic Compounds:
Cis-1,2-dichloroethene (cDCE)
Trans-1,2-dichloroethene (tDCE)
Tetrachloroethene (PCE)
Trichloroethene (TCE)
Vinyl chloride (VC)

Units: micrograms per liter (µg/L)
Qualifiers: J - estimated
U - not detected
LJ - Estimated Concentration
= - detected concentration

Note
WB-01(I1/I2) concentrations biased low, data not used for contouring

Figure 10

Source: CH2MHILL

Distribution of Chlorinated VOCs in the I1 Aquifer Zone February 2012

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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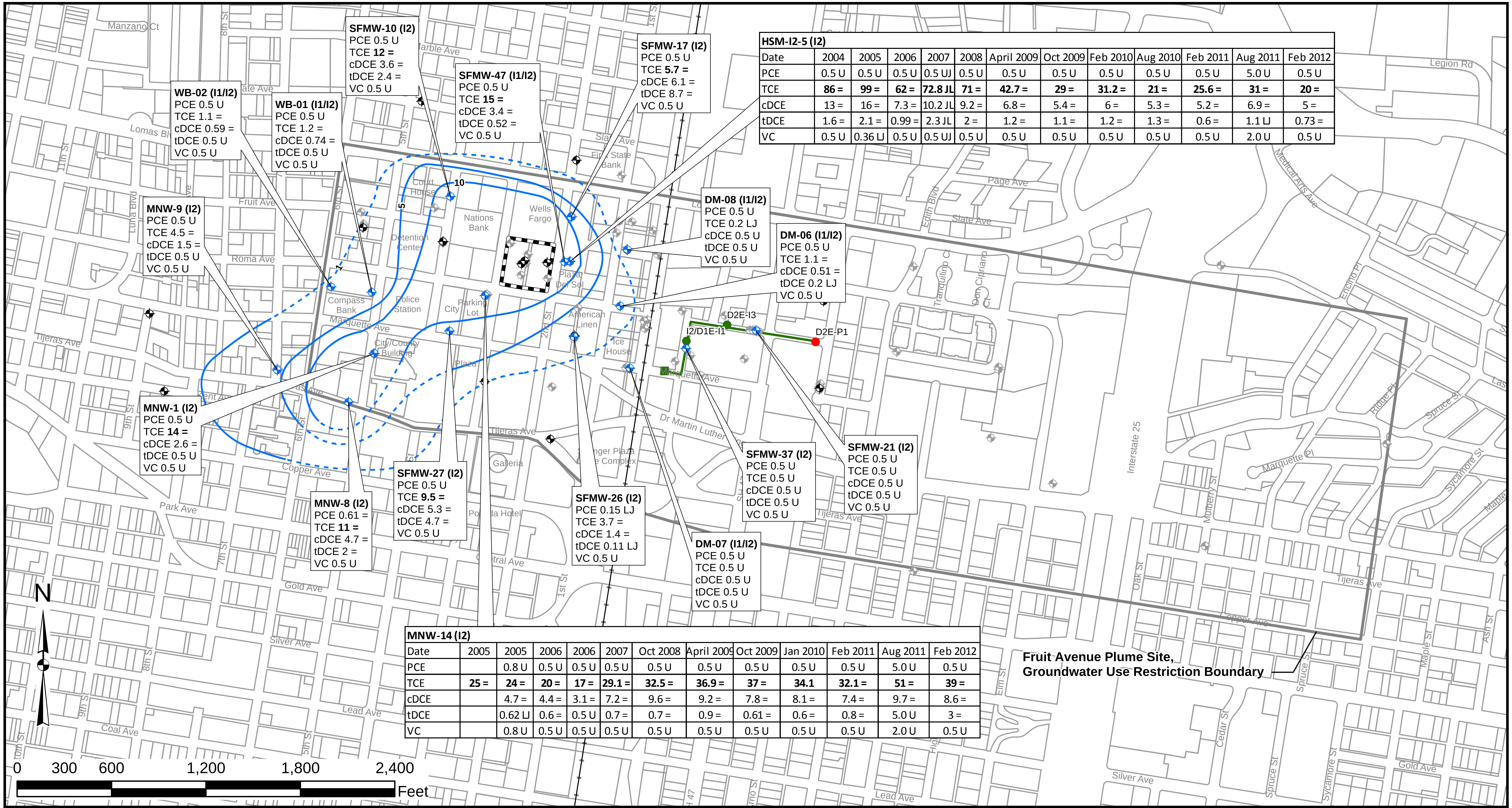

HSM-I2-5 (I2)												
Date	2004	2005	2006	2007	2008	April 2009	Oct 2009	Feb 2010	Aug 2010	Feb 2011	Aug 2011	Feb 2012
PCE	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	5.0 U	0.5 U
TCE	**86 =**	**99 =**	**62 =**	**72.8 JL**	**71 =**	**42.7 =**	**29 =**	**31.2 =**	**21 =**	**25.6 =**	**31 =**	**20 =**
cDCE	13 =	16 =	7.3 =	10.2 JL	9.2 =	6.8 =	5.4 =	6 =	5.3 =	5.2 =	6.9 =	5 =
tDCE	1.6 =	2.1 =	0.99 =	2.3 JL	2 =	1.2 =	1.1 =	1.2 =	1.3 =	0.6 =	1.1 LJ	0.73 =
VC	0.5 U	0.36 LJ	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

MNW-14 (I2)												
Date	2005	2005	2006	2006	2007	Oct 2008	April 2009	Oct 2009	Jan 2010	Feb 2011	Aug 2011	Feb 2012
PCE		0.8 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	5.0 U	0.5 U
TCE	**25 =**	**24 =**	**20 =**	**17 =**	**29.1 =**	**32.5 =**	**36.9 =**	**37 =**	**34.1**	**32.1 =**	**51 =**	**39 =**
cDCE		4.7 =	4.4 =	3.1 =	7.2 =	9.6 =	9.2 =	7.8 =	8.1 =	7.4 =	9.7 =	8.6 =
tDCE		0.62 LJ	0.6 =	0.5 U	0.7 =	0.7 =	0.9 =	0.61 =	0.6 =	0.8 =	5.0 U	3 =
VC		0.8 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

Legend

✦	I2 Zone Monitor Well
✦	I2 Zone Monitor Well- Not Sampled
✦	Other Site Monitor Well
●	Extraction Well
■	Air Stripper Treatment Plant
●	Injection Well
┼┼	Railroad
▨	Presumed Source Area
━	TCE concentration contour (dashed where inferred)

Aquifer Zones:
S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Volatile Organic Compounds:
Cis-1,2-dichloroethene (cDCE)
Trans-1,2-dichloroethene (tDCE)
Tetrachloroethene (PCE)
Trichloroethene (TCE)
Vinyl chloride (VC)

Units: micrograms per liter (µg/L)
Qualifers: J - estimated
U - not detected
LJ - Estimated Concentration
= - detected concentration

Note
WB-01(I1/I2) concentrations biased low, data not used for contouring

Figure 11

Distribution of Chlorinated VOCs in the I2 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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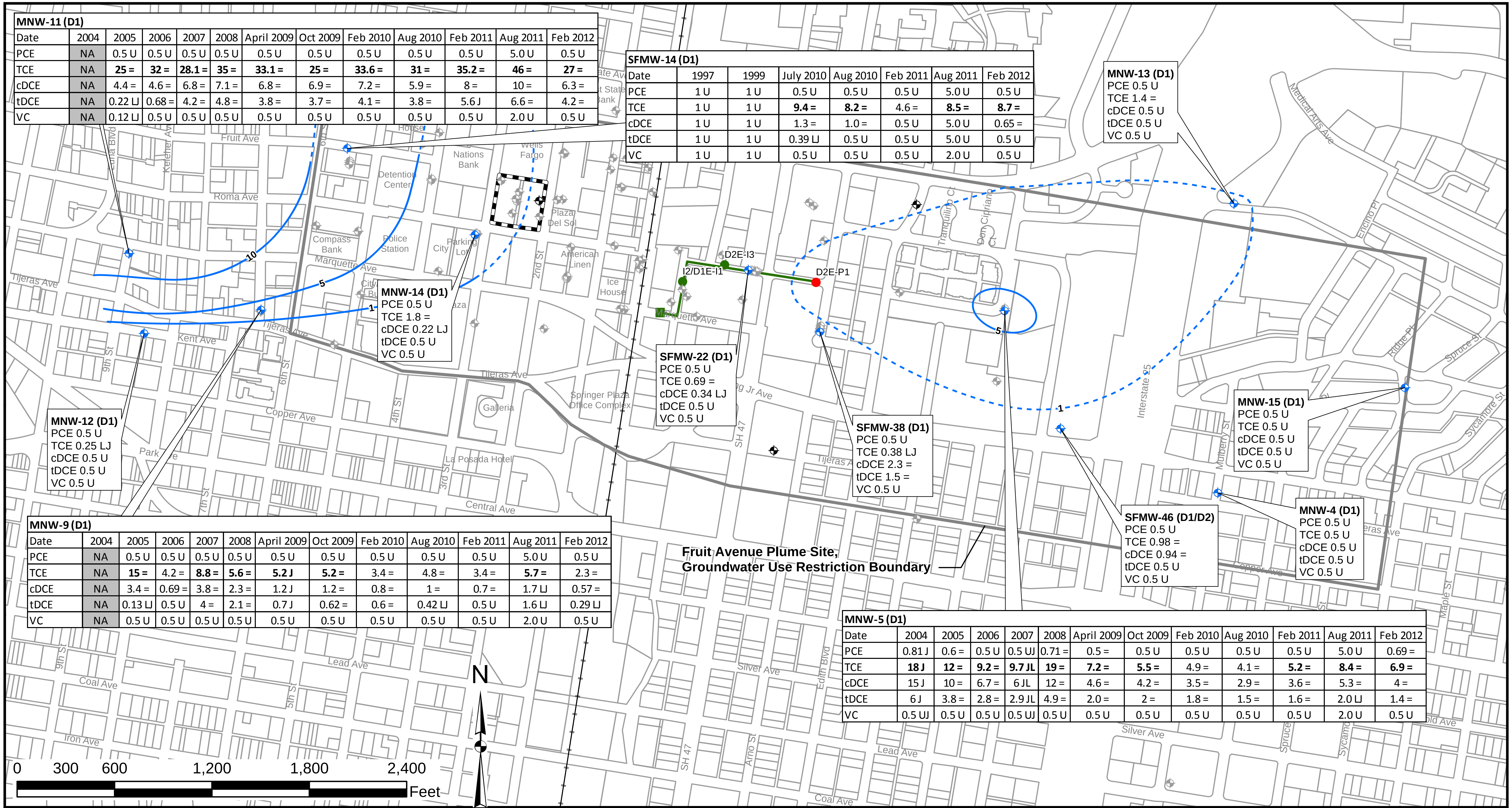

MNW-11 (D1)

Date	2004	2005	2006	2007	2008	April 2009	Oct 2009	Feb 2010	Aug 2010	Feb 2011	Aug 2011	Feb 2012
PCE	NA	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	5.0 U	0.5 U
TCE	NA	**25 =**	**32 =**	**28.1 =**	**35 =**	**33.1 =**	**25 =**	**33.6 =**	**31 =**	**35.2 =**	**46 =**	**27 =**
cDCE	NA	4.4 =	4.6 =	6.8 =	7.1 =	6.8 =	6.9 =	7.2 =	5.9 =	8 =	10 =	6.3 =
tDCE	NA	0.22 LJ	0.68 =	4.2 =	4.8 =	3.8 =	3.7 =	4.1 =	3.8 =	5.6 J	6.6 =	4.2 =
VC	NA	0.12 LJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

SFMW-14 (D1)

Date	1997	1999	July 2010	Aug 2010	Feb 2011	Aug 2011	Feb 2012
PCE	1 U	1 U	0.5 U	0.5 U	0.5 U	5.0 U	0.5 U
TCE	1 U	1 U	**9.4 =**	**8.2 =**	4.6 =	**8.5 =**	**8.7 =**
cDCE	1 U	1 U	1.3 =	1.0 =	0.5 U	5.0 U	0.65 =
tDCE	1 U	1 U	0.39 LJ	0.5 U	0.5 U	5.0 U	0.5 U
VC	1 U	1 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

MNW-13 (D1)
PCE 0.5 U
TCE 1.4 =
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

MNW-14 (D1)
PCE 0.5 U
TCE 1.8 =
cDCE 0.22 LJ
tDCE 0.5 U
VC 0.5 U

SFMW-22 (D1)
PCE 0.5 U
TCE 0.69 =
cDCE 0.34 LJ
tDCE 0.5 U
VC 0.5 U

SFMW-38 (D1)
PCE 0.5 U
TCE 0.38 LJ
cDCE 2.3 =
tDCE 1.5 =
VC 0.5 U

MNW-12 (D1)
PCE 0.5 U
TCE 0.25 LJ
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

MNW-15 (D1)
PCE 0.5 U
TCE 0.5 U
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

SFMW-46 (D1/D2)
PCE 0.5 U
TCE 0.98 =
cDCE 0.94 =
tDCE 0.5 U
VC 0.5 U

MNW-4 (D1)
PCE 0.5 U
TCE 0.5 U
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

MNW-9 (D1)

Date	2004	2005	2006	2007	2008	April 2009	Oct 2009	Feb 2010	Aug 2010	Feb 2011	Aug 2011	Feb 2012
PCE	NA	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	5.0 U	0.5 U
TCE	NA	**15 =**	4.2 =	**8.8 =**	**5.6 =**	**5.2 J**	**5.2 =**	3.4 =	4.8 =	3.4 =	**5.7 =**	2.3 =
cDCE	NA	3.4 =	0.69 =	3.8 =	2.3 =	1.2 J	1.2 =	0.8 =	1 =	0.7 =	1.7 LJ	0.57 =
tDCE	NA	0.13 LJ	0.5 U	4 =	2.1 =	0.7 J	0.62 =	0.6 =	0.42 LJ	0.5 U	1.6 LJ	0.29 LJ
VC	NA	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

Fruit Avenue Plume Site, Groundwater Use Restriction Boundary

MNW-5 (D1)

Date	2004	2005	2006	2007	2008	April 2009	Oct 2009	Feb 2010	Aug 2010	Feb 2011	Aug 2011	Feb 2012
PCE	0.81 J	0.6 =	0.5 U	0.5 UJ	0.71 =	0.5 =	0.5 U	0.5 U	0.5 U	0.5 U	5.0 U	0.69 =
TCE	**18 J**	**12 =**	**9.2 =**	**9.7 JL**	**19 =**	**7.2 =**	**5.5 =**	4.9 =	4.1 =	**5.2 =**	**8.4 =**	**6.9 =**
cDCE	15 J	10 =	6.7 =	6 JL	12 =	4.6 =	4.2 =	3.5 =	2.9 =	3.6 =	5.3 =	4 =
tDCE	6 J	3.8 =	2.8 =	2.9 JL	4.9 =	2.0 =	2 =	1.8 =	1.5 =	1.6 =	2.0 LJ	1.4 =
VC	0.5 UJ	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

Legend

🔴	Extraction Well	┼─┼	Railroad
⌖	D1 Zone Monitor Well	▨	Presumed Source Area
⌖	D1 Zone Monitor Well- Not Sampled	─	TCE concentration contour (dashed where inferred)
⌖	Other Site Monitor Well		
🟩	Air Stripper Treatment Plant		
●	Injection Well		

Aquifer Zones:
S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Volatile Organic Compounds:
Cis-1,2-dichloroethene (cDCE)
Trans-1,2-dichloroethene (tDCE)
Tetrachloroethene (PCE)
Trichloroethene (TCE)
Vinyl chloride (VC)

Units: micrograms per liter (µg/L)
Qualifers: J - estimated
U - not detected
LJ - Estimated Concentration
= - detected concentration

Figure 12

Distribution of Chlorinated VOCs in the D1 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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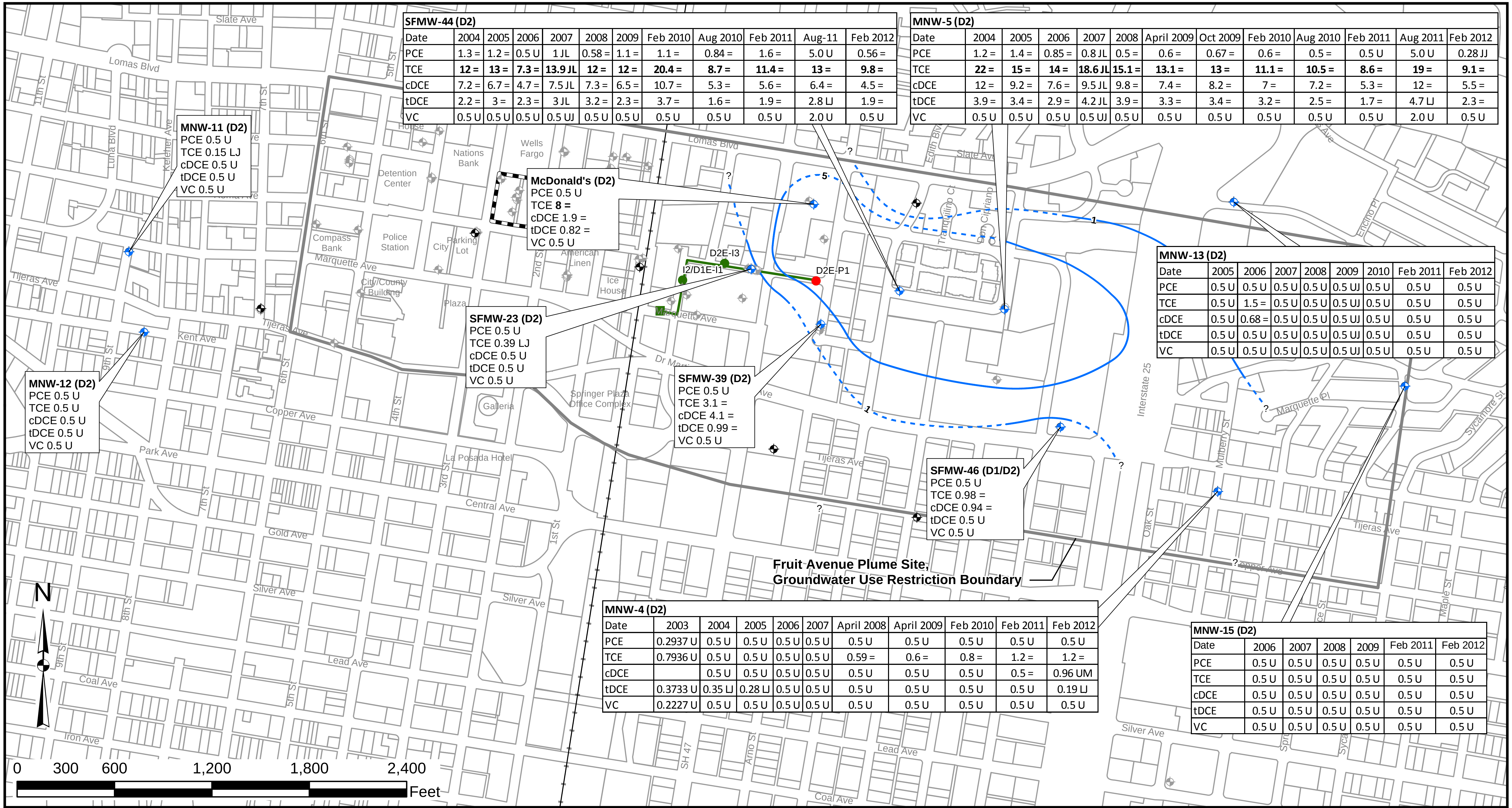

SFMW-44 (D2)

Date	2004	2005	2006	2007	2008	2009	Feb 2010	Aug 2010	Feb 2011	Aug-11	Feb 2012
PCE	1.3 =	1.2 =	0.5 U	1 JL	0.58 =	1.1 =	1.1 =	0.84 =	1.6 =	5.0 U	0.56 =
TCE	**12 =**	**13 =**	**7.3 =**	**13.9 JL**	**12 =**	**12 =**	**20.4 =**	**8.7 =**	**11.4 =**	**13 =**	**9.8 =**
cDCE	7.2 =	6.7 =	4.7 =	7.5 JL	7.3 =	6.5 =	10.7 =	5.3 =	5.6 =	6.4 =	4.5 =
tDCE	2.2 =	3 =	2.3 =	3 JL	3.2 =	2.3 =	3.7 =	1.6 =	1.9 =	2.8 LJ	1.9 =
VC	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

MNW-5 (D2)

Date	2004	2005	2006	2007	2008	April 2009	Oct 2009	Feb 2010	Aug 2010	Feb 2011	Aug 2011	Feb 2012
PCE	1.2 =	1.4 =	0.85 =	0.8 JL	0.5 =	0.6 =	0.67 =	0.6 =	0.5 =	0.5 U	5.0 U	0.28 JJ
TCE	**22 =**	**15 =**	**14 =**	**18.6 JL**	**15.1 =**	**13.1 =**	**13 =**	**11.1 =**	**10.5 =**	**8.6 =**	**19 =**	**9.1 =**
cDCE	12 =	9.2 =	7.6 =	9.5 JL	9.8 =	7.4 =	8.2 =	7 =	7.2 =	5.3 =	12 =	5.5 =
tDCE	3.9 =	3.4 =	2.9 =	4.2 JL	3.9 =	3.3 =	3.4 =	3.2 =	2.5 =	1.7 =	4.7 LJ	2.3 =
VC	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

MNW-11 (D2)
PCE 0.5 U
TCE 0.15 LJ
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

McDonald's (D2)
PCE 0.5 U
TCE **8 =**
cDCE 1.9 =
tDCE 0.82 =
VC 0.5 U

MNW-13 (D2)

Date	2005	2006	2007	2008	2009	2010	Feb 2011	Feb 2012
PCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U
TCE	0.5 U	1.5 =	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U
cDCE	0.5 U	0.68 =	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U
tDCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U
VC	0.5 U	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U

SFMW-23 (D2)
PCE 0.5 U
TCE 0.39 LJ
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

MNW-12 (D2)
PCE 0.5 U
TCE 0.5 U
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

SFMW-39 (D2)
PCE 0.5 U
TCE 3.1 =
cDCE 4.1 =
tDCE 0.99 =
VC 0.5 U

SFMW-46 (D1/D2)
PCE 0.5 U
TCE 0.98 =
cDCE 0.94 =
tDCE 0.5 U
VC 0.5 U

Fruit Avenue Plume Site,
Groundwater Use Restriction Boundary

MNW-4 (D2)

Date	2003	2004	2005	2006	2007	April 2008	April 2009	Feb 2010	Feb 2011	Feb 2012
PCE	0.2937 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
TCE	0.7936 U	0.5 U	0.5 U	0.5 U	0.5 U	0.59 =	0.6 =	0.8 =	1.2 =	1.2 =
cDCE		0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 =	0.96 UM
tDCE	0.3733 U	0.35 LJ	0.28 LJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.19 LJ
VC	0.2227 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U

MNW-15 (D2)

Date	2006	2007	2008	2009	Feb 2011	Feb 2012
PCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
TCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
cDCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
tDCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
VC	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U

Legend

⌖	D2 Zone Monitor Well	┼┼	Railroad
⌖	D2 Zone Monitor Well- Not Sampled	▨	Presumed Source Area
⌖	Other Site Monitor Well	—	TCE concentration contour (dashed where inferred)
🟩	Air Stripper Treatment Plant		
●	Injection Well		
🟥	Extraction Well		

Aquifer Zones:
S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Volatile Organic Compounds:
Cis-1,2-dichloroethene (cDCE)
Trans-1,2-dichloroethene (tDCE)
Tetrachloroethene (PCE)
Trichloroethene (TCE)
Vinyl chloride (VC)

Units: micrograms per liter (ug/L)
Qualifiers: J - estimated
U - not detected
LJ - Estimated Concentration
= - detected concentration

Figure 13

Distribution of Chlorinated VOCs in the D2 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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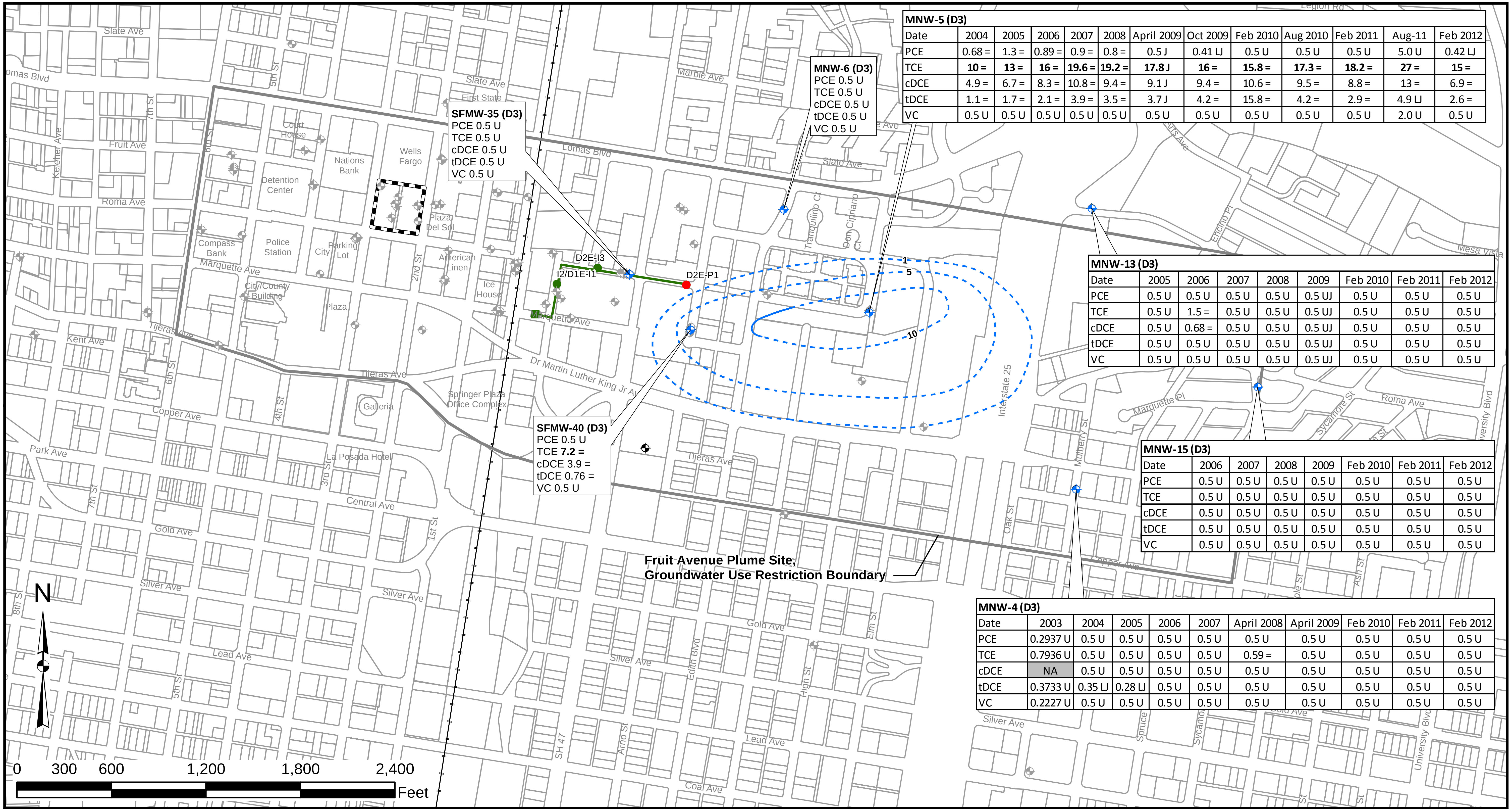

SFMW-35 (D3)
PCE 0.5 U
TCE 0.5 U
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

MNW-6 (D3)
PCE 0.5 U
TCE 0.5 U
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

SFMW-40 (D3)
PCE 0.5 U
TCE **7.2 =**
cDCE 3.9 =
tDCE 0.76 =
VC 0.5 U

MNW-5 (D3)

Date	2004	2005	2006	2007	2008	April 2009	Oct 2009	Feb 2010	Aug 2010	Feb 2011	Aug-11	Feb 2012
PCE	0.68 =	1.3 =	0.89 =	0.9 =	0.8 =	0.5 J	0.41 LJ	0.5 U	0.5 U	0.5 U	5.0 U	0.42 LJ
TCE	**10 =**	**13 =**	**16 =**	**19.6 =**	**19.2 =**	**17.8 J**	**16 =**	**15.8 =**	**17.3 =**	**18.2 =**	**27 =**	**15 =**
cDCE	4.9 =	6.7 =	8.3 =	10.8 =	9.4 =	9.1 J	9.4 =	10.6 =	9.5 =	8.8 =	13 =	6.9 =
tDCE	1.1 =	1.7 =	2.1 =	3.9 =	3.5 =	3.7 J	4.2 =	15.8 =	4.2 =	2.9 =	4.9 LJ	2.6 =
VC	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	2.0 U	0.5 U

MNW-13 (D3)

Date	2005	2006	2007	2008	2009	Feb 2010	Feb 2011	Feb 2012
PCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U
TCE	0.5 U	1.5 =	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U
cDCE	0.5 U	0.68 =	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U
tDCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U
VC	0.5 U	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U

MNW-15 (D3)

Date	2006	2007	2008	2009	Feb 2010	Feb 2011	Feb 2012
PCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
TCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
cDCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
tDCE	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
VC	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U

MNW-4 (D3)

Date	2003	2004	2005	2006	2007	April 2008	April 2009	Feb 2010	Feb 2011	Feb 2012
PCE	0.2937 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
TCE	0.7936 U	0.5 U	0.5 U	0.5 U	0.5 U	0.59 =	0.5 U	0.5 U	0.5 U	0.5 U
cDCE	NA	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
tDCE	0.3733 U	0.35 LJ	0.28 LJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
VC	0.2227 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U

Legend

⯁	D3 Zone Monitor Well
⯁	D3 Zone Monitor Well- Not Sampled
⯁	Other Site Monitor Well
🟩	Air Stripper Treatment Plant
●	Injection Well
●	Extraction Well
┼┼	Railroad
▨	Presumed Source Area
─	TCE concentration contour (dashed where inferred)

Aquifer Zones:
S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Volatile Organic Compounds:
Cis-1,2-dichloroethene (cDCE)
Trans-1,2-dichloroethene (tDCE)
Tetrachloroethene (PCE)
Trichloroethene (TCE)
Vinyl chloride (VC)

Units: micrograms per liter (µg/L)
Qualifiers: J - estimated
U - Not Detected
UJ - Not Detected, estimated concentration
LJ - Estimated Concentration
= - detected concentration

Figure 14

Distribution of Chlorinated VOCs in the D3 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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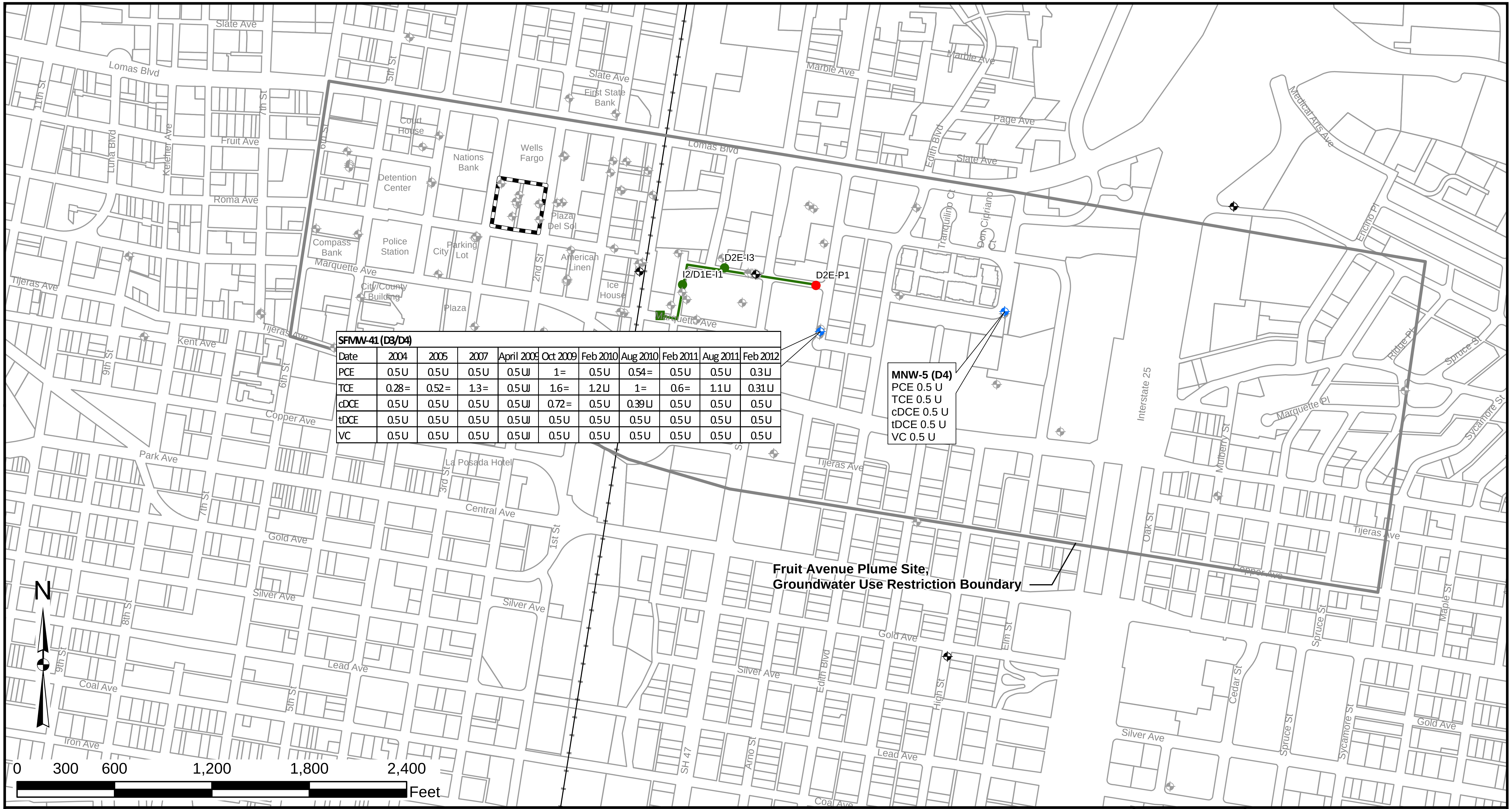

SFMW-41 (D3/D4)

Date	2004	2005	2007	April 2009	Oct 2009	Feb 2010	Aug 2010	Feb 2011	Aug 2011	Feb 2012
PCE	0.5 U	0.5 U	0.5 U	0.5 UJ	1 =	0.5 U	0.54 =	0.5 U	0.5 U	0.3 LJ
TCE	0.28 =	0.52 =	1.3 =	0.5 UJ	1.6 =	1.2 LJ	1 =	0.6 =	1.1 LJ	0.31 LJ
cDCE	0.5 U	0.5 U	0.5 U	0.5 UJ	0.72 =	0.5 U	0.39 LJ	0.5 U	0.5 U	0.5 U
tDCE	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U
VC	0.5 U	0.5 U	0.5 U	0.5 UJ	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U

MNW-5 (D4)
PCE 0.5 U
TCE 0.5 U
cDCE 0.5 U
tDCE 0.5 U
VC 0.5 U

Fruit Avenue Plume Site, Groundwater Use Restriction Boundary

Legend

- ⊕ D4 Zone Monitor Well
- ⊕ D4 Zone Monitor Well- Not Sampled
- ⊕ Other Site Monitor Well
- 🔴 Extraction Well
- 🟩 Air Stripper Treatment Plant
- ● Injection Well
- ┼┼ Railroad
- ▭ Presumed Source Area
- ― TCE concentration contour (dashed where inferred)

Aquifer Zones:
S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Volatile Organic Compounds:
Cis-1,2-dichloroethene (cDCE)
Trans-1,2-dichloroethene (tDCE)
Tetrachloroethene (PCE)
Trichloroethene (TCE)
Vinyl chloride (VC)

Units: micrograms per liter (µg/L)
Qualifiers: J - estimated
U - Not Detected
UJ - Not Detected, estimated concentration
LJ - Estimated Concentration
= - detected concentration

Figure 15

Distribution of Chlorinated VOCs in the D4 Aquifer Zone February 2012

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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Figure 3-8

Shallow Aquifer Zone-Groundwater Elevation Trends Over Time
February 2002 through August 2011
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

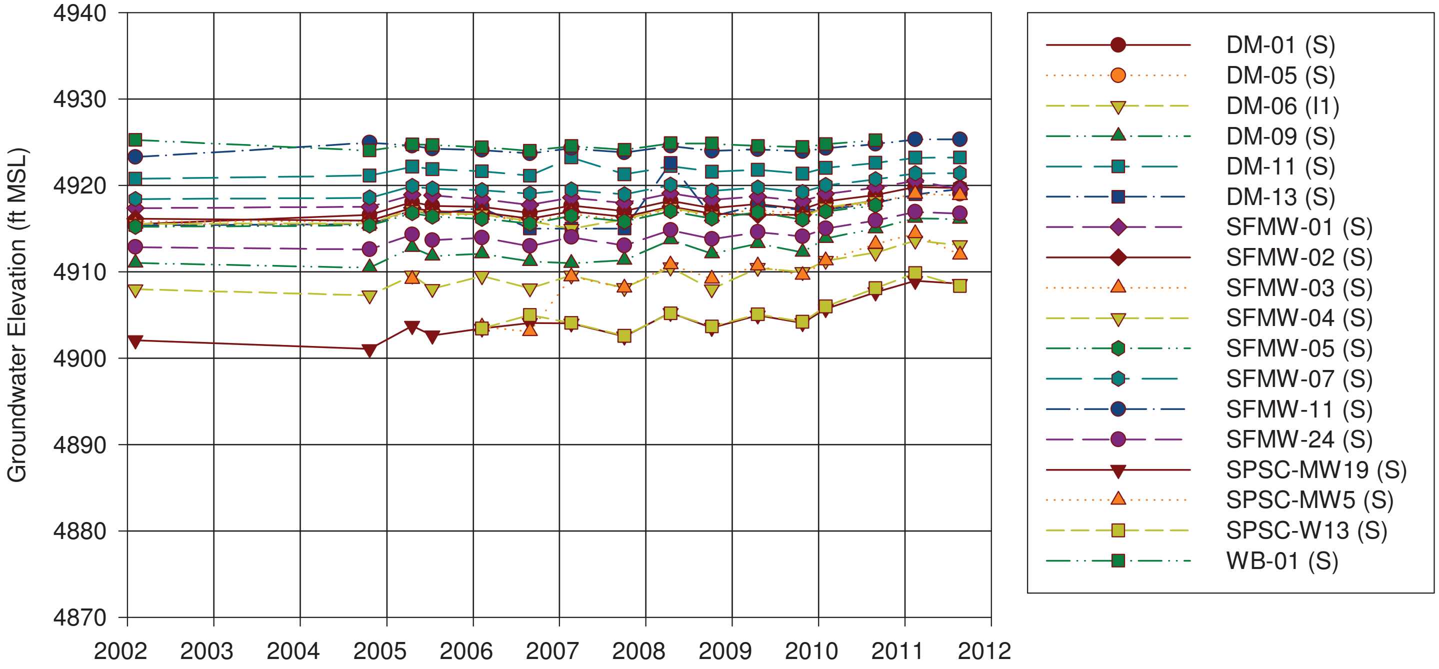


Figure 3-9

I1 Aquifer Zone-Groundwater Elevation Trends Over Time
February 2002 through August 2011
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

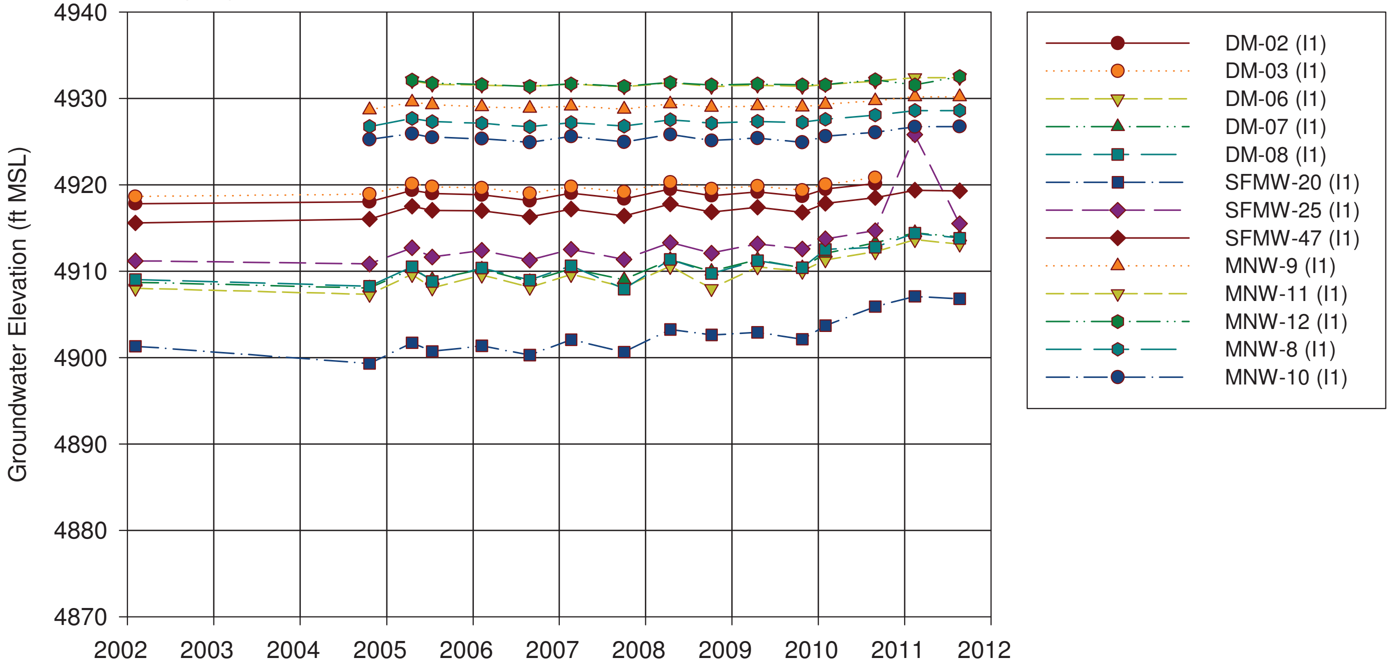


Figure 3-10

I2 Aquifer Zone-Groundwater Elevation Trends Over Time

February 2002 through August 2011

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

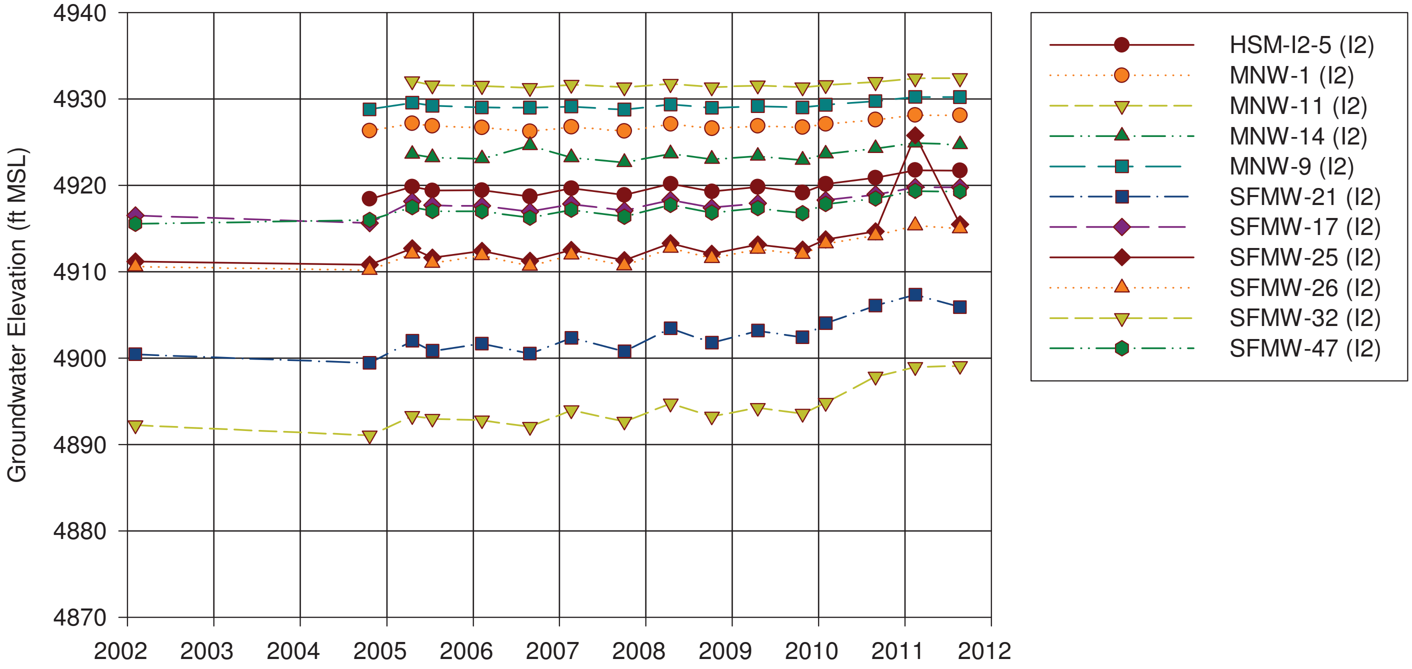


Figure 3-11

D1 Aquifer Zone-Groundwater Elevation Trends Over Time

February 2002 through August 2011

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

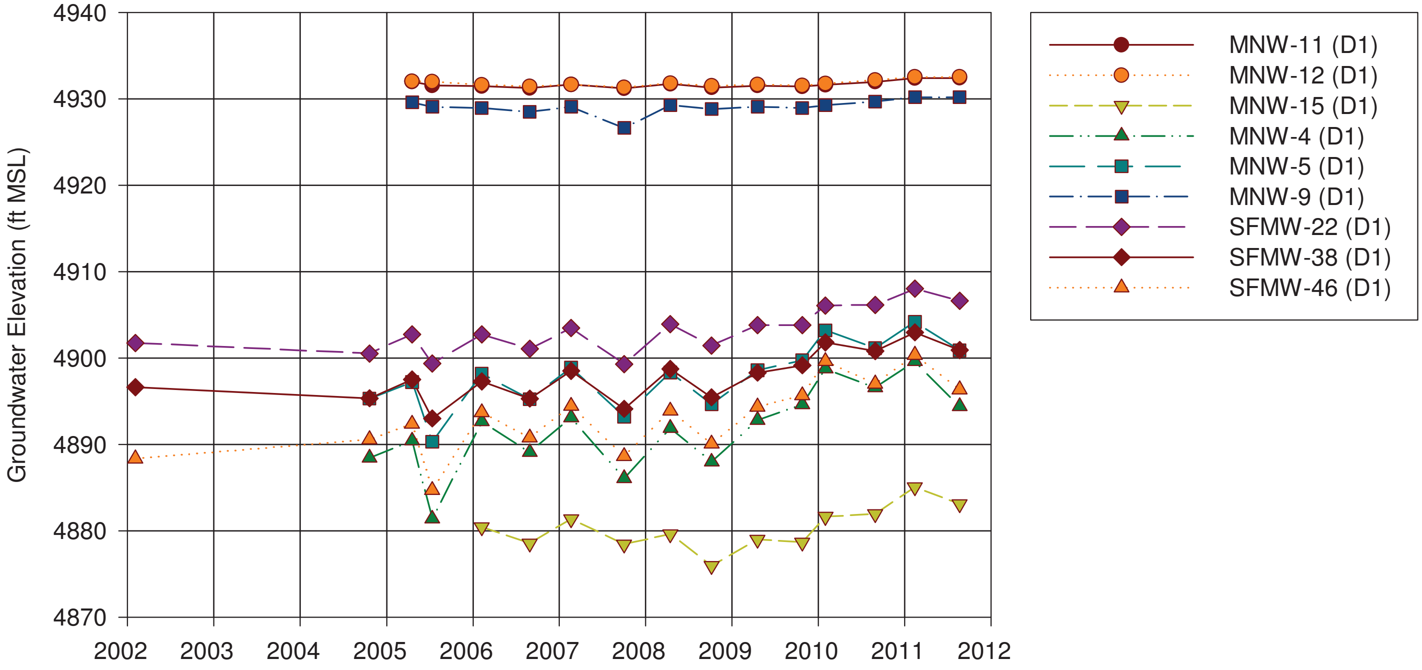


Figure 3-12

D2 Aquifer Zone-Groundwater Elevation Trends Over Time

February 2002 through August 2011

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

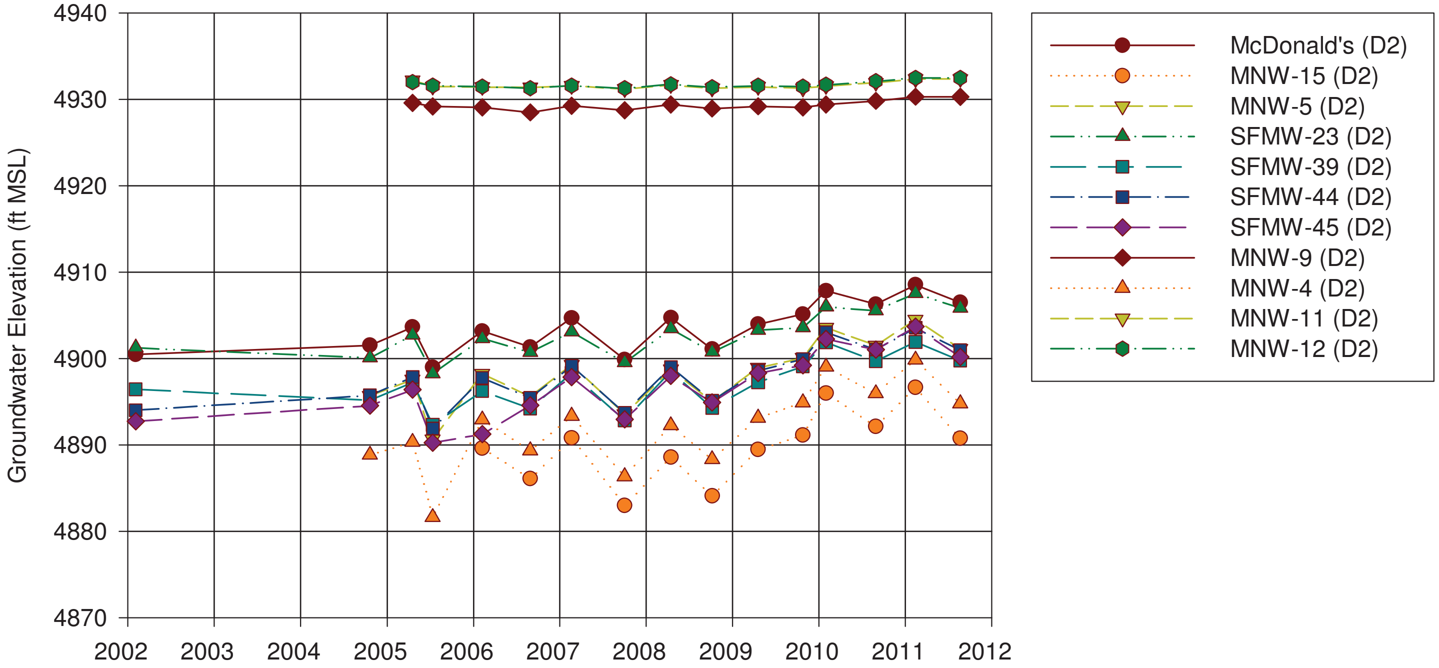


Figure 3-13

D3 Aquifer Zone-Groundwater Elevation Trends Over Time

February 2002 through August 2011

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

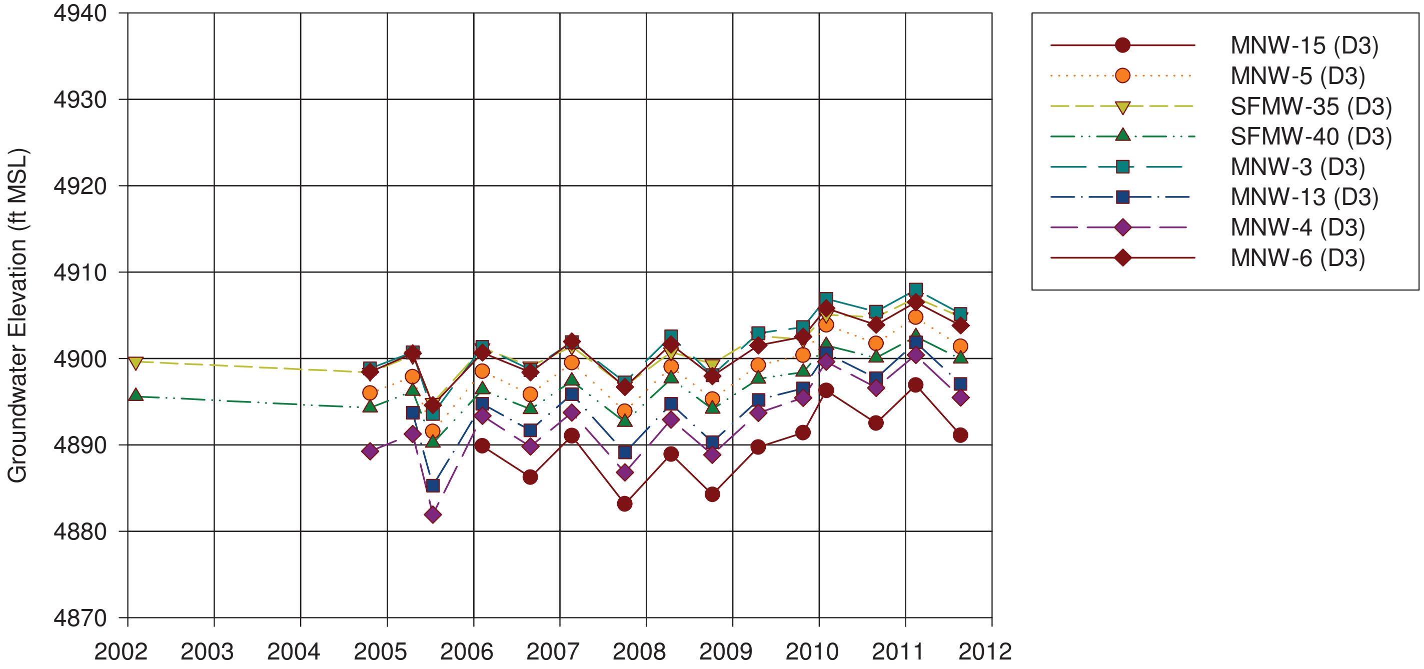


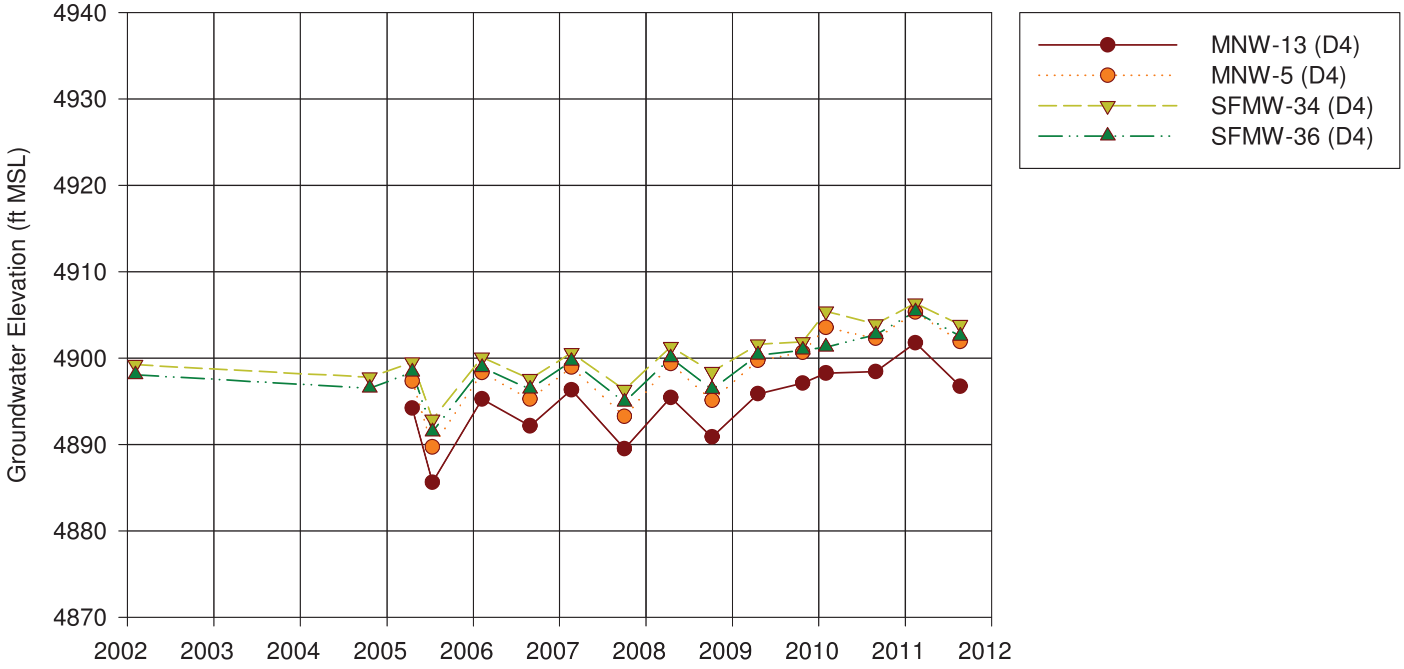
Figure 3-14

D4 Aquifer Zone-Groundwater Level Elevation Trends Over Time

February 2002 through August 2011

Fruit Avenue Plume Superfund Site

Albuquerqe, New Mexico



Appendix C
MNA Field and Laboratory Analysis Data

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Table 1

Summary of NA Parameters - 1997

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

		WELL ID:	DM-6(I)	DM-12(I)	DM-13(I)	SFMW-11 (S)	SFMW-12 (I1)	SFMW-13 (I2)
		SAMPLE DATE:	11/05/1997	11/13/1997	11/12/1997	11/13/1997	11/13/1997	11/13/1997
	ANALYTE	UNITS						
GASES	Ethane	µl/L	<2	<2	1	<2	<2	<2
GASES	Ethene	µl/L	<2	<2	1	<2	<2	<2
GASES	Methane	µl/L	27.6	7.1	8.7	3	4.2	4.5
GENCHEM	Alkalinity(CO3 & HCO3)	mg/L	313	317	265	270	302	311
GENCHEM	Bicarbonate	mg/L	382	387	323	329	369	379
GENCHEM	Carbonate	mg/L	0	0	0	0	0	0
GENCHEM	Hardness(Ca & Mg)	mG/L CaCO3	422	360	348	249	260	268
GENCHEM	Chloride	mg/L	54.1	49	51.6	36.5	35.8	39.5
GENCHEM	Sulfate	mg/L	372	316	282	219	211	236
GENCHEM	Total Phosphate	mg/L	0.6	0.05	<0.05	0.33	<0.05	0.09
GENCHEM	Ammonia	mg/L	<0.1	0.11	<0.1	0.12	0.12	<0.1
GENCHEM	Nitrate	mg/L	<0.06	<0.1	0.05	<0.1	<0.1	<0.1
GENCHEM	Nitrate + Nitrite	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
GENCHEM	Nitrite	mg/L	<0.04	NA	NA	NA	NA	NA
GENCHEM	TKN	mg/L	0.14	0.33	0.2	0.4	0.28	0.24
GENCHEM	TDS	mg/L	992	932	858	708	726	788
GENCHEM	TOC	mg/L	<5	11.1	2.5	<5	5.78	<5
Metals	Calcium	mg/L	127	106	94.7	75	78.1	69.1
Metals	Iron (Dissolved)	µg/L	NA	NA	NA	636	13.9 LUC	NA
Metals	Magnesium	mg/L	25.5	23.3	27	15.1	15.8	23.3
Metals	Potassium	mg/L	15.2	11.5	13.2	10.1	10.9	13.4
Metals	Sodium	mg/L	104	96.2	70.1	113	111	96.6
VOC	PCE	mg/L	<1	<1	<5	<1	<1	<1
VOC	TCE	mg/L	4	57	76	<1	2	7
VOC	cis-1,2 DCE	mg/L	2	16	10	0.8	2	3
VOC	trans-1,2 DCE	mg/L	2	7	<5	1	1	2
VOC	Vinyl Chloride	mg/L	<1	<1	<1	<1	<1	<1
FIELD	D.O.-field measurements	mg/L	3.07	0.66	1.27	NM	1.67	1.51
FIELD	pH	pH Units	8.09	8.3	7.96	8.16	8.19	8.13

NOTES:

NA- Not analyzed

L- Reported concentration is between the IDL and the CRDL

NM - Not measured

UC- Reported concentration should be used as a raised detection limit because of apparent blank contamination.

< - not detected above the CRDL

Table 1
Summary of NA Parameters - 1997
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

		WELL ID:	SFMW-14 (D1)	SFMW-15 (S)	SFMW-16 (I1)	SFMW-17 (I2)	SFMW-20 (I1)	SFMW-21 (I2)
		SAMPLE DATE:	11/13/1997	11/18/1997	11/18/1997	11/18/1997	11/04/1997	11/04/1997
	ANALYTE	UNITS						
GASES	Ethane	µl/L	<2	<2	<2	<2	<2	<2
GASES	Ethene	µl/L	<2	<2	<2	<2	<2	<2
GASES	Methane	µl/L	3	43.4	21	20.6	5	70.4
GENCHEM	Alkalinity(CO3 & HCO3)	mg/L	131	463	190	181	317	211
GENCHEM	Bicarbonate	mg/L	159	565	232	221	387	258
GENCHEM	Carbonate	mg/L	0.96	0	0	0	0	0
GENCHEM	Hardness(Ca & Mg)	mG/L CaCO3	133	313	295	235	388	423
GENCHEM	Chloride	mg/L	12.8	49.6	44.7	43.1	71.3	68
GENCHEM	Sulfate	mg/L	52.1	238	145	124	408	361
GENCHEM	Total Phosphate	mg/L	<0.05	0.22	<0.05	<0.05	0.07	0.05
GENCHEM	Ammonia	mg/L	<0.1	0.12	<0.1	<0.1	<0.1	<0.1
GENCHEM	Nitrate	mg/L	<0.1	<0.1	<0.1	<0.1	<0.248	<0.06
GENCHEM	Nitrate + Nitrite	mg/L	<0.1	<0.1	<0.1	<0.1	0.288	<0.1
GENCHEM	Nitrite	mg/L	NA	NA	NA	NA	<0.04	<0.04
GENCHEM	TKN	mg/L	<0.1	0.25	0.18	0.12	0.24	0.17
GENCHEM	TDS	mg/L	3.16	934	566	538	1080	978
GENCHEM	TOC	mg/L	<5	5.31	<5	<5	11.1	<5
Metals	Calcium	mg/L	37.7	81.6	85.8	67.9	112	118
Metals	Iron (Dissolved)	µg/L	20.4 LUC	834	10.9 LUC	4.7 LUC	72.4 LUC	52.7 LUC
Metals	Magnesium	mg/L	9.45	26.7	19.7	15.8	26.3	31.1
Metals	Potassium	mg/L	9.23	14.6	15.1	11.8	15.7	12
Metals	Sodium	mg/L	34.3	119	46.3	43.1	134	62.1
VOC	PCE	mg/L	<1	<1	<1	<1	<1	0.6
VOC	TCE	mg/L	<1	<1	<1	<1	4	9
VOC	cis-1,2 DCE	mg/L	<1	<1	<1	<1	2	6
VOC	trans-1,2 DCE	mg/L	<1	<1	<1	<1	0.8	3
VOC	Vinyl Chloride	mg/L	<1	<1	<1	<1	<1	<1
FIELD	D.O.-field measurements	mg/L	1.18	NM	0.90	0.86	NM	NM
FIELD	pH	pH Units	8.31	7.62	7.8	7.8	7.98	8.12

NOTES:
NA- Not analyzed
L- Reported concentration is between the IDL and the CRDL
NM - Not measured
UC- Reported concentration should be used as a raised detection limit because of apparent blank contamination.
< - not detected above the CRDL

Table 1
Summary of NA Parameters - 1997
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

		WELL ID:	SFMW-22 (D1)	SFMW-23 (D2)	SFMW-24 (S)	SFMW-25 (I1)	SFMW-26 (I2)
		SAMPLE DATE:	11/04/1997	11/04/1997	11/05/1997	11/05/1997	11/05/1997
	ANALYTE	UNITS					
GASES	Ethane	µl/L	<2	<2	<2	1	1
GASES	Ethene	µl/L	<2	<2	<2	1	1
GASES	Methane	µl/L	11.6	7.2	10.8	8.2	9.1
GENCHEM	Alkalinity(CO3 & HCO3)	mg/L	289	265	290	279	219
GENCHEM	Bicarbonate	mg/L	353	323	354	340	267
GENCHEM	Carbonate	mg/L	0	0	0	0	0
GENCHEM	Hardness(Ca & Mg)	mG/L CaCO3	439	398	222	312	309
GENCHEM	Chloride	mg/L	52	53.7	45.2	46.6	39.5
GENCHEM	Sulfate	mg/L	325		324	276	193
GENCHEM	Total Phosphate	mg/L	<0.05	<0.05	0.11	0.11	0.18
GENCHEM	Ammonia	mg/L	<0.1	<0.1	0.12	0.2	<0.1
GENCHEM	Nitrate	mg/L	<0.06	<0.06	<0.06	0.03	0.03
GENCHEM	Nitrate + Nitrite	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1
GENCHEM	Nitrite	mg/L	<0.04	<0.04	<0.04	<0.04	<0.04
GENCHEM	TKN	mg/L	0.26	0.16	0.3	0.2	<0.1
GENCHEM	TDS	mg/L	886	794	864	818	630
GENCHEM	TOC	mg/L	<5	<5	<5	2.5	2.5
Metals	Calcium	mg/L	126	108	60.9	86.2	90.3
Metals	Iron (Dissolved)	µg/L	32.2 LUC	<15	69.1 LUC	56.1 LUC	27.1 LUC
Metals	Magnesium	mg/L	30.1	31.1	17.1	23.6	20.4
Metals	Potassium	mg/L	14.7	15.8	11.5	12.9	11.9
Metals	Sodium	mg/L	78.5	7.8	103	74.1	54.6
VOC	PCE	mg/L	<1	<1	<1	<1	<1
VOC	TCE	mg/L	11	35	2	54	22
VOC	cis-1,2 DCE	mg/L	7	9	2	13	7
VOC	trans-1,2 DCE	mg/L	4	3	1	4	2
VOC	Vinyl Chloride	mg/L	<1	<1	<1	<1	<1
FIELD	D.O.-field measurements	mg/L	6.1	0.91	NM	0.66	0.64
FIELD	pH	pH Units	7.99	8.05	8.08	8.21	8.16

NOTES:
NA- Not analyzed
L- Reported concentration is between the IDL and the CRDL
NM - Not measured
UC- Reported concentration should be used as a raised
detection limit because of apparent blank contamination.
< - not detected above the CRDL

Table 2

Summary of NA Parameters - 2002

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

		WELL ID:	DM-06(I)	DM-08(I)	DM-09(S)	DM-12(I)	DM-13(D2)	DM-13(I)
		SAMPLE DATE:	3/4/2002	2/21/2002	2/21/2002	3/7/2002	2/20/2002	2/26/2002
Param Class	Analyte Description	Concentration Units						
GASES	ETHANE	ng/L	110 =	49 =	230 =	75 =		62 =
GASES	ETHENE	ng/L	17 =			34 =	7.9 =	14 =
GASES	METHANE	µg/L	9.7 =	18 =	190 =	3.2 =	0.079 =	4.4 =
GENCHEM	ALKALINITY, BICARBONATE (AS CACO3)	mg/L	311 =	302 =	308 =	322 =	129 =	283 =
GENCHEM	ALKALINITY, TOTAL (AS CACO3)	mg/L	311 =	302 =	308 =	322 =	129 =	283 =
GENCHEM	CHLORIDE (AS CL)	mg/L	58 =	47 =	44 =	49 =	44 =	49 =
GENCHEM	NITROGEN, AMMONIA (AS N)	mg/L						
GENCHEM	NITROGEN, KJELDAHL, TOTAL	mg/L	0.13 =	0.1 =	0.35 =	0.26 =	0.06 =	0.19 =
GENCHEM	PHOSPHORUS, TOTAL ORTHOPHOSPHATE (AS PO4)	mg/L						
GENCHEM	SULFATE (AS SO4)	mg/L	365 =	289 =	252 =	287 =	108 =	202 =
GENCHEM	TOTAL DISSOLVED SOLIDS (RESIDUE, FILTERABLE)	mg/L	1050 =	878 =	828 =	906 =	429 =	822 =
GENCHEM	TOTAL ORGANIC CARBON	mg/L	2 =	1 =	2 =	3 =		2 =
METAL	CALCIUM	mg/L	134 =	117 =	133 =	134 =	51.6 =	119 =
METAL	IRON	mg/L	0.23 =	0.1 =	1.38 =			
METAL	MAGNESIUM	mg/L	26.6 =	25 =	19.1 =	20.1 =	12 =	25.2 =
METAL	POTASSIUM	mg/L	15.6 =	15.7 =	11.8 =	10.9 =	10.3 =	12.8 =
METAL	SODIUM	mg/L	108 =	110 =	89.9 =	98.9 =	44.2 =	63.9 =
VOC	CIS-1,2-DICHLOROETHYLENE	µg/L	1.5 =			6.2 =		7.9 J
VOC	TETRACHLOROETHYLENE(PCE)	µg/L						
VOC	TRANS-1,2-DICHLOROETHENE	µg/L				2.8 =		2.8 J
VOC	TRICHLOROETHYLENE (TCE)	µg/L	4.5 =	1 =		27 =		52 J
VOC	VINYL CHLORIDE	µg/L						
Field	TEMPERATURE	°C	NA	NA	NA	NA	NA	19.16
Field	pH - field		NA	NA	NA	NA	NA	7.18
Field	DISSOLVED OXYGEN	mg/L	0.2 =	NA	NA	0.1 =	NA	NA
Field	ORP - field	milliVolts	NA	NA	NA	NA	NA	-4
Field	DO - field	mg/L	NA	NA	NA	NA	NA	0
Field	Nitrate - field	mg/L	NA	NA	NA	NA	NA	0
Field	Nitrite - field	mg/L	NA	NA	NA	NA	NA	0
Field	Ferrous Iron	mg/L	NA	NA	NA	NA	NA	0

NOTES:
- - - = not detected
NA = not analyzed

Table 2

Summary of NA Parameters - 2002

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

Param Class	Analyte Description	WELL ID: SAMPLE DATE: Concentration Units	DM-13(S) 2/21/2002	DM-06(I) 3/4/2002	SFMW-10(I2) 3/6/2002	SFMW-11(S) 2/28/2002	SFMW-13(I2) 2/28/2002
GASES	ETHANE	ng/L	30 =	69 =	24 =	6.8 =	18 =
GASES	ETHENE	ng/L		14 =	100 =	6.3 =	19 =
GASES	METHANE	µg/L	0.47 =	6.3 =	5.4 =	0.41 =	2.4 =
GENCHEM	ALKALINITY, BICARBONATE (AS CACO3)	mg/L	276 =	317 =	287 =	279 =	296 =
GENCHEM	ALKALINITY, TOTAL (AS CACO3)	mg/L	276 =	317 =	287 =	279 =	296 =
GENCHEM	CHLORIDE (AS CL)	mg/L	42 =	58 =	61 =	42 =	36 =
GENCHEM	NITROGEN, AMMONIA (AS N)	mg/L					
GENCHEM	NITROGEN, KJELDAHL, TOTAL	mg/L	0.18 =	0.12 =	0.18 =	0.18 =	0.15 =
GENCHEM	PHOSPHORUS, TOTAL ORTHOPHOSPHATE (AS PO4)	mg/L	0.19 =				
GENCHEM	SULFATE (AS SO4)	mg/L	607 =	366 =	310 =	258 =	194 =
GENCHEM	TOTAL DISSOLVED SOLIDS (RESIDUE, FILTERABLE)	mg/L	838 =	1090 =	990 =	764 =	684 =
GENCHEM	TOTAL ORGANIC CARBON	mg/L	2 =	2 =	3 =	2 =	2 =
METAL	CALCIUM	mg/L	115 =	137 =	145 =	104 =	92.1 =
METAL	IRON	mg/L	0.35 =	0.21 =		0.7 =	0.03 =
METAL	MAGNESIUM	mg/L	18.4 =	27.1 =	27.2 =	17.6 =	18.7 =
METAL	POTASSIUM	mg/L	11.6 =	15.9 =	11.7 =	10.1 =	11.8 =
METAL	SODIUM	mg/L	88.8 =	111 =	42.9 =	83.6 =	94.7 =
VOC	CIS-1,2-DICHLOROETHYLENE	µg/L	1.2 =		1.4 =		1.4 =
VOC	TETRACHLOROETHYLENE(PCE)	µg/L	1.1 =				
VOC	TRANS-1,2-DICHLOROETHENE	µg/L					
VOC	TRICHLOROETHYLENE (TCE)	µg/L	1.7 =		6.8 =		1.8 =
VOC	VINYL CHLORIDE	µg/L					
Field	TEMPERATURE	°C	18.5	NA	NA	19.6	NA
Field	pH - field		7.3	NA	NA	7.28	NA
Field	DISSOLVED OXYGEN	mg/L	NA	NA	0.1 =	0.8	0.3 =
Field	ORP - field	milliVolts	193	NA	NA	-110	NA
Field	DO - field	mg/L	1.97	NA	NA	0.54	NA
Field	Nitrate - field	mg/L	0	NA	NA	<0.1	NA
Field	Nitrite - field	mg/L	0	NA	NA	<0.2	NA
Field	Ferrous Iron	mg/L	0	NA	NA	<2	NA

NOTES:
- - - = not detected
NA = not analyzed

Table 2
Summary of NA Parameters - 2002
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

Param Class	Analyte Description	WELL ID: SAMPLE DATE: Concentration Units	SFMW-14(D1) 2/28/2002	SFMW-19(I2) 3/7/2002	SFMW-20(I1) 3/5/2002	SFMW-22(D1) 3/5/2002
GASES	ETHANE	ng/L	12 =	60 =	250 =	74 =
GASES	ETHENE	ng/L	9.3 =		40 =	150 =
GASES	METHANE	µg/L	0.77 =	4.4 =	15 =	11.6=
GENCHEM	ALKALINITY, BICARBONATE (AS CACO3)	mg/L	122 =	283 =	330 =	274 =
GENCHEM	ALKALINITY, TOTAL (AS CACO3)	mg/L	122 =	283 =	330 =	274 =
GENCHEM	CHLORIDE (AS CL)	mg/L	16 =	61 =	96 =	50 =
GENCHEM	NITROGEN, AMMONIA (AS N)	mg/L				
GENCHEM	NITROGEN, KJELDAHL, TOTAL	mg/L		0.23 =	0.12 =	0.09 =
GENCHEM	PHOSPHORUS, TOTAL ORTHOPHOSPHATE (AS PO4)	mg/L				
GENCHEM	SULFATE (AS SO4)	mg/L	60 =	297 =	441 =	296 =
GENCHEM	TOTAL DISSOLVED SOLIDS (RESIDUE, FILTERABLE)	mg/L	297 =	880 =	1240 =	922 =
GENCHEM	TOTAL ORGANIC CARBON	mg/L		3 =	2 =	2 =
METAL	CALCIUM	mg/L	32.7 =	144 =	159 =	120 =
METAL	IRON	mg/L				
METAL	MAGNESIUM	mg/L	8.6 =	29.6 =	27.3 =	25.9 =
METAL	POTASSIUM	mg/L	8.3 =	13.9 =	14.5 =	12.5 =
METAL	SODIUM	mg/L	22.4 =	62.2 =	127 =	70.6 =
VOC	CIS-1,2-DICHLOROETHYLENE	µg/L		7.2 =	1.2 =	5.1 =
VOC	TETRACHLOROETHYLENE(PCE)	µg/L				
VOC	TRANS-1,2-DICHLOROETHENE	µg/L		1.8 =		2.8 =
VOC	TRICHLOROETHYLENE (TCE)	µg/L		69 =	2.3 =	8.5 =
VOC	VINYL CHLORIDE	µg/L				
Field	TEMPERATURE	°C	19.6	19.97	NA	21.62
Field	pH - field		7.78	7.04	NA	7.13
Field	DISSOLVED OXYGEN	mg/L	0.9	0.07	0.1 =	0.4
Field	ORP - field	milliVolts	76	-115	NA	-111
Field	DO - field	mg/L	0	0.38	NA	0.09
Field	Nitrate - field	mg/L	<0.1	<0.1	NA	<0.1
Field	Nitrite - field	mg/L	<0.1	<0.1	NA	<0.1
Field	Ferrous Iron	mg/L	<2	<0.1	NA	<0.1

NOTES:
- - - = not detected
NA = not analyzed

Table 2

Summary of NA Parameters - 2002

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

Param Class	Analyte Description	WELL ID: SAMPLE DATE: Concentration Units	SFMW-23(D2) 3/7/2002	SFMW-24(S) 3/6/2002	SFMW-28(I2) 3/6/2002	SFMW-40(D3) 3/5/2002
GASES	ETHANE	ng/L	57 =	12 =	42 =	20 =
GASES	ETHENE	ng/L	16 =			
GASES	METHANE	µg/L	3.5 =	1.6 =	2.7 =	8.6 =
GENCHEM	ALKALINITY, BICARBONATE (AS CACO3)	mg/L	257 =	281 =	251 =	239 =
GENCHEM	ALKALINITY, TOTAL (AS CACO3)	mg/L	257 =	281 =	251 =	239 =
GENCHEM	CHLORIDE (AS CL)	mg/L	57 =	43 =	66 =	58 =
GENCHEM	NITROGEN, AMMONIA (AS N)	mg/L		0.06 =		
GENCHEM	NITROGEN, KJELDAHL, TOTAL	mg/L	0.11 =	0.19 =	0.14 =	0.07 =
GENCHEM	PHOSPHORUS, TOTAL ORTHOPHOSPHATE (AS PO4)	mg/L				
GENCHEM	SULFATE (AS SO4)	mg/L	270 =	278 =	207 =	205 =
GENCHEM	TOTAL DISSOLVED SOLIDS (RESIDUE, FILTERABLE)	mg/L	846 =	838 =	772 =	700 =
GENCHEM	TOTAL ORGANIC CARBON	mg/L	2 =	2 =	2 =	1 =
METAL	CALCIUM	mg/L	102 =	105 =	110 =	85.3 =
METAL	IRON	mg/L		0.17 =		
METAL	MAGNESIUM	mg/L	27.9 =	17.2 =	20.5 =	23.2 =
METAL	POTASSIUM	mg/L	14.1 =	11.4 =	10.8 =	12.6 =
METAL	SODIUM	mg/L	72.9 =	98.8 =	45.8 =	49 =
VOC	CIS-1,2-DICHLOROETHYLENE	µg/L	6.8 =	1.1 =	1.5 =	6 =
VOC	TETRACHLOROETHYLENE(PCE)	µg/L				
VOC	TRANS-1,2-DICHLOROETHENE	µg/L	2.9 =			1.7 =
VOC	TRICHLOROETHYLENE (TCE)	µg/L	27 =	1 =	2.2 =	5.5 =
VOC	VINYL CHLORIDE	µg/L				
Field	TEMPERATURE	^{o}C	21.24	19.18	NA	NA
Field	pH - field		7.05	7.07	NA	NA
Field	DISSOLVED OXYGEN	mg/L	0.3	0.5	0.2 =	0.2 =
Field	ORP - field	milliVolts	-27	10	NA	NA
Field	DO - field	mg/L	0.02	0.5	NA	NA
Field	Nitrate - field	mg/L	0.1	<0.1	NA	NA
Field	Nitrite - field	mg/L	<0.1	<0.1	NA	NA
Field	Ferrous Iron	mg/L	0.1	<0.1	NA	NA

NOTES:

- - - = not detected

NA = not analyzed

Table 2
Summary of NA Parameters - 2002
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

		WELL ID:	SFMW-41(D4)	SFMW-14(D1)	SFMW-41(D4)	WB-02(S)
		SAMPLE DATE:	3/4/2002	2/28/2002	3/4/2002	3/6/2002
Param Class	Analyte Description	Concentration Units				
GASES	ETHANE	ng/L	9.8 =	13 =	8.4 =	6 =
GASES	ETHENE	ng/L	24 =	9 =	14 =	26 =
GASES	METHANE	µg/L	0.33 =	0.78 =	0.27 =	1.3 =
GENCHEM	ALKALINITY, BICARBONATE (AS CACO3)	mg/L	119 =	124 =	119 =	300 =
GENCHEM	ALKALINITY, TOTAL (AS CACO3)	mg/L	119 =	124 =	119 =	300 =
GENCHEM	CHLORIDE (AS CL)	mg/L	16 =	16 =	16 =	46 =
GENCHEM	NITROGEN, AMMONIA (AS N)	mg/L				
GENCHEM	NITROGEN, KJELDAHL, TOTAL	mg/L				1.24 =
GENCHEM	PHOSPHORUS, TOTAL ORTHOPHOSPHATE (AS PO4)	mg/L				0.16 =
GENCHEM	SULFATE (AS SO4)	mg/L	53 =	59 =	53 =	287 =
GENCHEM	TOTAL DISSOLVED SOLIDS (RESIDUE, FILTERABLE)	mg/L	294 =	298 =	292 =	1170 =
GENCHEM	TOTAL ORGANIC CARBON	mg/L				3 =
METAL	CALCIUM	mg/L	24.7 =	33 =	26 =	126 =
METAL	IRON	mg/L				11.3 =
METAL	MAGNESIUM	mg/L	6.7 =	8.7 =	6.9 =	18.2 =
METAL	POTASSIUM	mg/L	8 =	8.3 =	8.5 =	12.1 =
METAL	SODIUM	mg/L	33.3 =	22.4 =	34.7 =	84.7 =
VOC	CIS-1,2-DICHLOROETHYLENE	µg/L				
VOC	TETRACHLOROETHYLENE(PCE)	µg/L				
VOC	TRANS-1,2-DICHLOROETHENE	µg/L				
VOC	TRICHLOROETHYLENE (TCE)	µg/L				
VOC	VINYL CHLORIDE	µg/L				
Field	TEMPERATURE	°C	NA	NA	NA	18.86
Field	pH - field		NA	NA	NA	7.26
Field	DISSOLVED OXYGEN	mg/L	71 =	NA	NA	0.8
Field	ORP - field	milliVolts	NA	NA	NA	-72
Field	DO - field	mg/L	NA	NA	NA	0.43
Field	Nitrate - field	mg/L	NA	NA	NA	<0.1
Field	Nitrite - field	mg/L	NA	NA	NA	<0.1
Field	Ferrous Iron	mg/L	NA	NA	NA	0.4

NOTES:
- - - = not detected
NA = not analyzed

Table 3

Summary of NA Parameters - 2004
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

		Location ID :	HSM-I2-5	MNW-10 (I2)	MNW-2(I2)	MNW-3 (D2)	MNW-4 (D2)	MNW-6 (D2)
		Date Collected :	11/15/04	11/16/04	11/17/04	11/8/04	11/16/04	11/9/04
Param Class	ANALYTE DESCRIPTION	Unit						
GAS	CARBON DIOXIDE FREE	mg/L	30 =	26 =	28 =	27 =	4.2 =	8.8 =
GAS	ETHANE	ng/L	45 =	140 =	550 =	12 =	93 =	24 =
GAS	ETHENE	ng/L	38 =	220 =	1700 =	460 =	1800 =	650 =
GAS	METHANE	µg/L	3.3 =	7.2 =	17 =	4.6 =	4.5 =	2.5 =
GENCHEM	ALKALINITY, BICARBONATE (AS CACO3)	mg/L	270 =	272 =	259 =	246 =	118 =	144 =
GENCHEM	ALKALINITY, TOTAL (AS CaCO3)	mg/L	270 =	272 =	259 =	246 =	118 =	144 =
GENCHEM	CHLORIDE (AS CL)	mg/L	56.2 =	38.1 =	53.3 =	43.8 =	23 =	42.5 =
GENCHEM	SULFATE (AS SO4)	mg/L	280 =	267 =	236 =	236 =	55.8 =	159 =
GENCHEM	SULFIDE	mg/L	0.02 =	- - -	0.05 =	0.03 =	0.05 =	0.04 =
METALS	CALCIUM	µg/L	123000 =	112000 =	100000 =	109000 =	37500 =	82700 =
METALS	IRON	µg/L	- - -	993 =	554 =	341 =	264 =	320 =
METALS	MAGNESIUM	µg/L	31400 =	23300 =	19700 =	29300 =	6750 =	15400 =
METALS	MANGANESE	µg/L	16.6 J^	1290 J^	505 J^	93.8 =	215 J^	263 =
METALS	POTASSIUM	µg/L	16100 =	14200 =	11800 =	17400 =	8070 =	11100 J^
METALS	SODIUM	µg/L	65700 =	89200 =	93100 =	77700 =	36200 =	45800 =
VOC	cis-1,2-DICHLOROETHYLENE	µg/L	9.6 =	- - -	- - -	- - -	- - -	- - -
VOC	PCE	µg/L	- - -	- - -	- - -	- - -	- - -	- - -
VOC	TCE	µg/L	54 =	- - -	- - -	- - -	0.35 LJ	0.2 LJ
VOC	trans-1,2-DICHLOROETHENE	µg/L	1.6 =	- - -	- - -	- - -	- - -	- - -
VOC	VINYL CHLORIDE	µg/L	- - -	- - -	- - -	- - -	- - -	- - -
Field	Ferrous Iron	mg/L	0.1	1	1	0.3	0.2	0.4
Field	Temperature	°C	15.3	16.5	14.5	NA	19.20	18.4
Field	pH	Unit	7.21	7.29	7.25	NA	7.70	7.38
Field	Conductivity	mS/cm	1.060	1.060	1.030	NA	0.463	0.838
Field	ORP	mV	-44	-142	-155	NA	-175	-180
Field	Turbidity	NTU	27.2	9.0	12.1	NA	0.0	14.8
Field	Dissolved Oxygen	mg/L	1.10	1.50	1.10	NA	1.00	1.60

NOTES:
- - - = not detected
NA = not analyzed

Table 3
Summary of NA Parameters - 2004
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

		Location ID :	MNW-8 (I2)	SFMW-21(I2)	SFMW-23(D2)	SFMW-32(I2)	SFMW-33(D2)	SFMW-44(D2)
		Date Collected :	11/16/04	11/9/04	11/8/04	11/15/04	11/15/04	11/9/04
Param Class	ANALYTE DESCRIPTION	Unit						
GAS	CARBON DIOXIDE FREE	mg/L	32 =	50 =	32 =	37 =	3 =	29 =
GAS	ETHANE	ng/L	87 =	120 =	47 =	61 =	- - -	34 =
GAS	ETHENE	ng/L	93 =	- - -	130 =	9.9 =	140 =	20 J
GAS	METHANE	µg/L	7 =	29 =	5 =	8.8 =	7.2 =	2.8 =
GENCHEM	ALKALINITY, BICARBONATE (AS CACO3)	mg/L	273 =	293 =	262 =	294 =	127 =	233 =
GENCHEM	ALKALINITY, TOTAL (AS CaCO3)	mg/L	273 =	293 =	262 =	294 =	127 =	233 =
GENCHEM	CHLORIDE (AS CL)	mg/L	39.8 =	46.6 =	68.3 =	60.1 =	- - -	63.1 =
GENCHEM	SULFATE (AS SO4)	mg/L	218 =	253 =	375 =	335 =	- - -	225 =
GENCHEM	SULFIDE	mg/L	0.01 =	0.01 =	- - -	- - -	0.02 =	- - -
METALS	CALCIUM	µg/L	99000 =	198000 =	111000 =	113000 =	25300 =	132000 =
METALS	IRON	µg/L	323 =	731 =	- - -	221 =	- - -	- - -
METALS	MAGNESIUM	µg/L	20800 =	31300 =	29400 =	19100 =	6240 =	24100 =
METALS	MANGANESE	µg/L	395 J^	9.9 LJ	3 LJ	58.4 J^	4.2 LJ	17.6 =
METALS	POTASSIUM	µg/L	14200 =	13000 =	17300 J^	14700 =	8340 =	12900 =
METALS	SODIUM	µg/L	81100 =	78500 =	93200 =	132000 =	36800 =	66200 =
VOC	cis-1,2-DICHLOROETHYLENE	µg/L	- - -	4.7 =	6 =	1.7 =	- - -	7.1 =
VOC	PCE	µg/L	- - -	- - -	- - -	- - -	- - -	1.5 =
VOC	TCE	µg/L	0.44 LJ	5 =	16 J	2.7 =	0.16 LJ	12 =
VOC	trans-1,2-DICHLOROETHENE	µg/L	- - -	2.2 =	2.2 =	0.32 LJ	- - -	2.3 =
VOC	VINYL CHLORIDE	µg/L	- - -	0.46 LJ	0.27 LJ	- - -	- - -	- - -
Field	Ferrous Iron	mg/L	0.3	<0.1	<0.1	0.2	<0.1	<0.1
Field	Temperature	°C	14.5	NA	NA	17.2	17.80	17.5
Field	pH	Unit	7.13	NA	NA	7.14	7.88	7.15
Field	Conductivity	mS/cm	0.950	NA	NA	1.280	0.399	0.960
Field	ORP	mV	-150	NA	NA	-49	114	-7
Field	Turbidity	NTU	20.0	NA	NA	14.6	27.2	8.5
Field	Dissolved Oxygen	mg/L	1.00	NA	NA	1.90	0.90	1.10

NOTES:
- - - = not detected
NA = not analyzed

Attachment 8a

Dissolved Ferrous Iron Concentrations at monitor wells sampled for MNA parameters
April 16 - 18, 2005
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

StationID :		HSM-I2-4	HSM-I2-5	MNW-5 (D1)	MNW-9 (D1)	MNW-9 (I2)	SFMW-23	SFMW-44
Location :		HSM-I2-4	HSM-I2-5	MNW-5-D1	MNW-9-D1	MNW-9-I2	SFMW-23-D2	SFMW-44-D2
SampleID :		MF1DA7	MF1DA5	MF1DB1	MF1DB5	MF1DB3	MF1DA6	MF1DA9
Date Collected :		4/19/05	4/19/05	4/18/05	4/20/05	4/20/05	4/21/05	4/19/05
Time Collected :		13:05	9:30	11:00	12:05	9:20	8:05	16:17
Matrix :		WG	WG	WG	WG	WG	WG	WG
Sample Type :		N	N	N	N	N	N	N
Analyte	Unit							
Dissolved Ferrous Iron (Fe II)	ppm	0.8	0.0	0.0	0.0	3.0	0.0	0.0

Notes:
ppm - parts per million
MNA - monitored natural attenuation

Attachement 8b

Dissolved Gasses Field Sample Analytical Results and Quality Control Sample results at monitor wells sampled for MNA parameters

April 16 - 18, 2005

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

StationID :		HSM-I2-4	HSM-I2-5	MNW-5 (D1)	MNW-9 (D1)	MNW-9 (I2)	SFMW-23	SFMW-44	SFMW-44
Location :		HSM-I2-4	HSM-I2-5	MNW-5-D1	MNW-9-D1	MNW-9-I2	SFMW-23-D2	SFMW-44-D2	SFMW-44-D2-FD
SampleID :		HSM-I2-4-Q205	HSM-I2-5-Q205	MNW-5-D1-Q205	MNW-9-D1-Q205	MNW-9-I2-Q205	SFMW-23-D2-Q205	SFMW-44-D2-Q205	SFMW-44-D2FD-Q205
Date Collected :		4/19/05	4/19/05	4/18/05	4/20/05	4/20/05	4/21/05	4/19/05	4/19/05
Time Collected :		13:05	9:30	11:00	12:05	9:20	8:05	16:17	16:25
Matrix :		WG	WG	WG	WG	WG	WG	WG	WG
Sample Type :		N	N	N	N	N	N	N	FD
Analyte	Unit								
CARBON DIOXIDE FREE	mg/L				0.6 UJ	0.6 UJ	0.6 UJ		
ETHANE	ng/L	180 =	83 =	51 =	69 =	140 =	55 =	53 =	50 =
ETHENE	ng/L	1100 =	44 =	220 =	550 =	360 =	240 =	120 =	140 =
METHANE	ug/L	7.8 =	6.4 =	16 =	6.5 =	6.7 =	5.3 =	4.3 =	4.2 =

Notes:

MNA - monitored natural attenuation
WG - Ground Water
WQ - Quality Control Sample
N - Normal Field Sample
EB - Equipment Blank
FD - Field Duplicate
mg/L - milligrams per liter
ug/L - micrograms per liter
ng/L - nanograms per liter
U - Not detected
= - Detected Concentration
J - Estimated Concentration
L - Reported concentration is below the Contract Required Quantitation Limit.

Attachement 8c

Dissolved Metals Field Sample Analytical Results and Quality Control Sample results at monitor wells sampled for MNA parameters
April 16 - 18, 2005
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

StationID :		FIELDQC	HSM-I2-4	HSM-I2-5	MNW-5 (D1)	MNW-9 (D1)	MNW-9 (I2)	MNW-9 (I2)	SFMW-23	SFMW-44	SFMW-44
Location :		EB01	HSM-I2-4	HSM-I2-5	MNW-5-D1	MNW-9-D1	MNW-9-I2	MNW-9-I2-FD	SFMW-23-D2	SFMW-44-D2	SFMW-44-D2-FD
SampleID :		MF1DA4	MF1D95	MF1D93	MF1D99	MF1DA3	MF1DA1	MF1DA2	MF1D94	MF1D97	MF1D98
Date Collected :		4/18/05	4/19/05	4/19/05	4/18/05	4/20/05	4/20/05	4/20/05	4/21/05	4/19/05	4/19/05
Time Collected :		13:35	13:05	9:30	11:00	12:05	9:20	9:20	8:05	16:17	16:25
Matrix :		WQ	WG	WG	WG	WG	WG	WG	WG	WG	WG
Sample Type :		EB	N	N	N	N	N	FD	N	N	FD
Analyte	Unit										
CALCIUM	UG/L	5000 U	132000 =	126000 =	110000 =	98200 =	110000 =	112000 =	104000 =	125000 =	126000 =
IRON	UG/L	100 U	517 =	113 =	113 =	829 =	1630 =	1580 =	100 U	100 U	100 U
MAGNESIUM	UG/L	5000 U	24700 =	32300 =	17100 =	26000 =	27100 =	27300 =	28000 =	22300 =	22600 =
MANGANESE	UG/L	15 U	260 =	21.5 =	26.9 =	645 =	702 =	711 =	15 U	15 U	15 U

Notes:
MNA - monitored natural attenuation
WG - Ground Water
WQ - Quality Control Sample
N - Normal Field Sample
EB - Equipment Blank
FD - Field Duplicate
mg/L - milligrams per liter
ug/L - micrograms per liter
ng/L - nanograms per liter
U - Not detected
= - Detected Concentration
J - Estimated Concentration
L - Reported concentration is below the Contract Required Quantitation Limit.

Attachement 8d
Total Metals Field Sample Analytical Results and Quality Control Sample results at monitor wells sampled for MNA parameters
April 16 - 18, 2005
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

StationID :		FIELDQC	HSM-I2-4	HSM-I2-5	MNW-5 (D1)	MNW-9 (D1)	MNW-9 (I2)	MNW-9 (I2)	SFMW-23	SFMW-44	SFMW-44
Location :		EB01	HSM-I2-4	HSM-I2-5	MNW-5-D1	MNW-9-D1	MNW-9-I2	MNW-9-I2-FD	SFMW-23-D2	SFMW-44-D2	SFMW-44-D2-FD
SampleID :		MF1DB6	MF1DA7	MF1DA5	MF1DB1	MF1DB5	MF1DB3	MF1DB4	MF1DA6	MF1DA9	MF1DB0
Date Collected :		4/18/05	4/19/05	4/19/05	4/18/05	4/20/05	4/20/05	4/20/05	4/21/05	4/19/05	4/19/05
Time Collected :		13:35	13:05	9:30	11:00	12:05	9:20	9:20	8:05	16:17	16:25
Matrix :		WQ	WG	WG	WG	WG	WG	WG	WG	WG	WG
Sample Type :		EB	N	N	N	N	N	FD	N	N	FD
Analyte	Unit										
CALCIUM	UG/L	22.1 LJv	107000 =	106000 =	104000 =	105000 =	119000 =	124000 =	115000 =	111000 =	131000 =
IRON	UG/L	61.4 LJ	571 =	431 =	94.5 LJ	1020 =	1820 =	1800 =	46.4 LJ	424 J	746 J
MAGNESIUM	UG/L	5000 U	20000 =	27200 =	16100 =	27400 =	29300 =	30600 =	30600 =	19400 =	22800 =
MANGANESE	UG/L	15 U	211 =	26.6 =	28.9 =	684 =	758 =	796 =	15 U	55.4 =	78.9 =

Notes:
MNA - monitored natural attenuation
WG - Ground Water
WQ - Quality Control Sample
N - Normal Field Sample
EB - Equipment Blank
FD - Field Duplicate
mg/L - milligrams per liter
ug/L - micrograms per liter
ng/L - nanograms per liter
U - Not detected
= - Detected Concentration
J - Estimated Concentration
L - Reported concentration is below the Contract Required Quantitation Limit.

Attachement 8e

Phospholipids Fatty Acid (PLFA) Field Sample Analytical Results and Quality Control Sample results at monitor wells sampled for MNA parameters

April 16 - 18, 2005

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

	StationID :	HSM-I2-4	HSM-I2-5	MNW-5 (D1)	MNW-9 (D1)	MNW-9 (I2)	SFMW-23	SFMW-44	SFMW-44
	Location :	HSM-I2-4	HSM-I2-5	MNW-5-D1	MNW-9-D1	MNW-9-I2	SFMW-23-D2	SFMW-44-D2	SFMW-44-D2-FD
	SampleID :	HSM-I2-4-Q205	HSM-I2-5-Q205	MNW-5-D1-Q205	MNW-9-D1-Q205	MNW-9-I2-Q205	SFMW-23-D2-Q205	SFMW-44-D2-Q205	SFMW-44-D2FD-Q205
	Date Collected :	4/19/05	4/19/05	4/18/05	4/20/05	4/20/05	4/21/05	4/19/05	4/19/05
	Time Collected :	13:05	9:30	11:00	12:05	9:20	8:05	16:17	16:25
	Matrix :	WG	WG	WG	WG	WG	WG	WG	WG
	Sample Type :	N	N	N	N	N	N	N	FD
Analyte	Units								
Anaerobic metal reducers (BrMonos)	Percent	0	0.58	0	1.19	1.27	0	1.32	8.82
Cells/mL		15700	89400	7780	89300	17900	2530	45100	23800
Decreased Permeability		0.074	0.277	0.000	0.071	0.376	0.000	0.000	0.000
Eukaryotes (polyenoics)	Percent	2.41	0.58	3.61	5.95	4.16	0	6.29	2.37
Firmicutes (TerBrSats)	Percent	5.24	3.2	12.79	6.81	4.52	0	5.3	7.84
General (Nsats)	Percent	35.91	6.11	31.38	28.64	27.49	61.66	45.29	22.07
Proteobacteria (Monos)	Percent	51.41	84.49	28.29	56.13	61.29	38.35	37.94	53.6
Slowed Growth		0.489	0.748	0.986	1.204	0.583	0.690	0.697	0.160
SRB/Actinomycetes (MidBrSats)	Percent	5.03	5.04	23.92	1.29	1.27	0	3.86	5.29

Notes:

MNA - monitored natural attenuation
WG - Ground Water
WQ - Quality Control Sample
N - Normal Field Sample
EB - Equipment Blank
FD - Field Duplicate
mg/L - milligrams per liter
ug/L - micrograms per liter
ng/L - nanograms per liter
U - Not detected
= - Detected Concentration
J - Estimated Concentration
L - Reported concentration is below the Contract Required Quantitation Limit.

Attachement 8f

General Chemistry Field Sample Analytical Results and Quality Control Sample results at monitor wells sampled for MNA parameters

April 16 - 18, 2005

Fruit Avenue Plume Superfund Site

Albuquerque, New Mexico

StationID :		FIELDQC	HSM-I2-4	HSM-I2-5	MNW-5 (D1)	MNW-5 (D1)	MNW-5 (D1)	MNW-5 (D1)
Location :		EB01	HSM-I2-4	HSM-I2-5	MNW-5-D1	MNW-5-D1	MNW-5-D1	MNW-5-D1
SampleID :		EB01-Q205	HSM-I2-4-Q205	HSM-I2-5-Q205	MNW-5-D1-Q205	MNW-5-D1-Q205MS	MNW-5-D1-Q205SD	WG187310-04DUP01
Date Collected :		4/18/05	4/19/05	4/19/05	4/18/05	4/18/05	4/18/05	4/18/05
Time Collected :		13:35	13:05	9:30	11:00	11:00	11:00	11:00
Matrix :		WQ	WG	WG	WG	WG	WG	WG
Sample Type :		EB	N	N	N	MS	SD	LR
Analyte	Unit							
ALKALINITY, BICARBONATE (AS CACO3)	mg/L		286 =	264 =	226 =			
ALKALINITY, CARBONATE (AS CACO3)	mg/L		0 U	0 U	0 U			
ALKALINITY, PHENOLPHTHALEIN	mg/L		0 U	0 U	0 U			
ALKALINITY, TOTAL (AS CaCO3)	mg/L		286 =	264 =	226 =			
CHLORIDE (AS CL)	mg/L	1 <	42 =	54 =	60 =			
NITROGEN, NITRATE (AS N)	mg/L	0.1 U	0.1 U	0.1 U	0.1 U	4.26 =	4.24 =	0.1 U
NITROGEN, NITRITE	mg/L	0.1 U	0.1 U	0.1 U	0.1 U	3.49 =	3.47 =	0.1 U
SULFATE (AS SO4)	mg/L	1 <	240 =	262 =	195 =			
SULFIDE	mg/L	0.01 <	0.03 =	0.01 =	0.01 <			
TOTAL DISSOLVED SOLIDS (RESIDUE, FILTERABLE)	mg/L		780 =	824 =	682 =			
TOTAL ORGANIC CARBON	mg/L		3 =	2 =	2 =			

Notes:

MNA - monitored natural attenuation

WG - Ground Water

WQ - Quality Control Sample

N - Normal Field Sample

EB - Equipment Blank

FD - Field Duplicate

mg/L - milligrams per liter

ug/L - micrograms per liter

ng/L - nanograms per liter

U - Not detected

= - Detected Concentration

J - Estimated Concentration

L - Reported concentration is below the Contract Required Quantitation Limit.

Attachement 8f

General Chemistry Field Sample Analytical Results and Quality Control Sample results at monitor wells sampled for MNA parameters
April 16 - 18, 2005
Fruit Avenue Plume Superfund Site
Albuquerque, New Mexico

	MNW-9 (D1)	MNW-9 (I2)	MNW-9 (I2)	SFMW-23	SFMW-23	SFMW-44	SFMW-44
	MNW-9-D1	MNW-9-I2	MNW-9-I2	SFMW-23-D2	SFMW-23-D2	SFMW-44-D2	SFMW-44-D2-FD
	MNW-9-D1-Q205	MNW-9-I2-Q205	WG187515-04DUP01	SFMW-23-D2-Q205	WG187623-04DUP01	SFMW-44-D2-Q205	SFMW-44-D2FD-Q205
	4/20/05	4/20/05	4/20/05	4/21/05	4/21/05	4/19/05	4/19/05
	12:05	9:20	9:20	8:05	8:05	16:17	16:25
	WG	WG	WG	WG	WG	WG	WG
	N	N	LR	N	LR	N	FD
Analyte							
ALKALINITY, BICARBONATE (AS CACO3)	248 =	274 =		270 =		240 =	242 =
ALKALINITY, CARBONATE (AS CACO3)	0 U	0 U		0 U		0 U	0 U
ALKALINITY, PHENOLPHTHALEIN	0 U	0 U		0 U		0 U	0 U
ALKALINITY, TOTAL (AS CaCO3)	248 =	274 =		270 =		240 =	242 =
CHLORIDE (AS CL)	62 =	43 =		45 =		59 =	59 =
NITROGEN, NITRATE (AS N)	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
NITROGEN, NITRITE	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
SULFATE (AS SO4)	135 =	187 =		262 =		230 =	232 =
SULFIDE	0.05 =	0.06 =		0.01 <		0.01 <	0.01 <
TOTAL DISSOLVED SOLIDS (RESIDUE, FILTERABLE)	652 =	696 =		832 =		764 =	760 =
TOTAL ORGANIC CARBON	6 =	2 =		2 =		1 =	1 =

Notes:
MNA - monitored natural attenuation
WG - Ground Water
WQ - Quality Control Sample
N - Normal Field Sample
EB - Equipment Blank
FD - Field Duplicate
mg/L - milligrams per liter
ug/L - micrograms per liter
ng/L - nanograms per liter
U - Not detected
= - Detected Concentration
J - Estimated Concentration
L - Reported concentration is below the Contract Required Quantitation Limit.

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	Station ID :		HSM-I2-4	HSM-I2-5	MNW-14 (I2)	MNW-15 (D1)	MNW-15 (D2)	MNW-15 (D3)	MNW-2 (I2)	MNW-3 (D2)
	Date Collected :		8/31/10 15:15	8/30/10 14:57	9/7/10 15:40	9/9/10 11:15	9/15/10 12:05	9/9/10 16:05	9/1/10 9:15	9/8/10 12:30
Class	**Parameter Name**	**Unit**								
CSIA	cis-1,2-Dichloroethene	ug/L	NA	**6 =**	**8 =**	NA	NA	NA	NA	NA
CSIA	cis-1,2-Dichloroethene-carbon	‰	NA	**-37.04 =**	**-37.94 =**	NA	NA	NA	NA	NA
CSIA	Trichloroethene (TCE)	ug/L	NA	**30 =**	**20 =**	NA	NA	NA	NA	NA
CSIA	Trichloroethene-carbon	‰	NA	**-20.62 =**	**-17.36 =**	NA	NA	NA	NA	NA
GAS	CARBON DIOXIDE FREE	mg/L	**21 J**	**36 J**	**24 J**	**9.8 J**	**4.7 J**	**4.6 J**	**26 J**	**24 J**
GAS	ETHANE	ug/L	**0.036 J**	**0.071 J**	**0.074 J**	0.025 UJ	0.025 UJ	0.025 UJ	**0.041 J**	**0.006 J**
GAS	ETHENE	ug/L	**0.03 J**	**0.056 J**	**0.15 J**	**0.017 J**	0.025 UJ	**0.024 J**	**0.016 J**	**0.091 J**
GASES	Methane	ug/L	**4.2 J**	**4.4 J**	**3.9 J**	**0.18 J**	**1.3 J**	**0.084 J**	**9.7 J**	**0.9 J**
GENCHEM	Alkalinity, bicarbonate (as caco3)	mg/L	**254 JH**	**270 JH**	**269 =**	**165 =**	**136 =**	**127 =**	**256 JH**	**232 =**
GENCHEM	Alkalinity, carbonate (as caco3)	mg/L	10 U	10 U	10 U	10 U	10 U	10 U	10 UJ	10 U
GENCHEM	Alkalinity, total (as CaCO3)	mg/L	**254 JH**	**270 JH**	**269 =**	**165 =**	**136 =**	**127 =**	**256 JH**	**232 =**
GENCHEM	CHLORIDE (AS CL)	mg/L	**31 JH**	**50 JH**	**45 =**	**106 =**	**26 =**	**6 =**	**45 JH**	**37 =**
GENCHEM	nitrogen, nitrate (as n)	mg/L	0.02 UJ	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 UJ	0.02 U
GENCHEM	Nitrogen, nitrate-nitrite	mg/L	0.04 UJ	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 UJ	0.04 U
GENCHEM	nitrogen, nitrite	mg/L	0.02 UJ	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 UJ	0.02 U
GENCHEM	nonpurgeable organic carbon	mg/L	**3 J**	**2 =**	**2 =**	1 U	1 U	1 U	**2 J**	1 U
GENCHEM	SULFATE (AS SO4)	mg/L	**190 JH**	**258 =**	**239 =**	**238 =**	**78 =**	**39 =**	**256 J**	**214 =**
GENCHEM	Sulfide	mg/L	0.01 UJ	0.01 U	0.01 UJ	0.01 UJ	0.01 U	0.01 UJ	**0.02 JH**	**0.01 J**
GENCHEM	total dissolved solids (residue, filterable)	mg/L	**645 JH**	**788 JH**	**746 =**	**370 =**	**383 =**	**281 =**	**780 JH**	**694 =**
Metals	Calcium	ug/L	**95200 JH**	**117000 JH**	**122000 =**	**54100 =**	**48000 =**	**38900 =**	**135000 JH**	**89100 =**
Metals	Iron	ug/L	**67.7 JH**	25 U	**57.8 =**	**26.8 =**	25 U	**75.5 =**	**351 =**	**88.6 =**
Metals	Magnesium	ug/L	**18700 JH**	**31600 =**	**25100 =**	**10500 =**	**7160 =**	**7920 =**	**26500 JH**	**24400 =**
Metals	Manganese	ug/L	**233 =**	5 U	**22.5 =**	**62.9 =**	**14.4 =**	**58.7 =**	**187 =**	**16.9 =**
PLFA	Cells	cells/mL	**398 =**	**5930 =**	**14900 =**	**4490 =**	**1240 =**	**3260 =**	**1540 =**	**1040 =**
PLFA	Decreased Permeability	ratio tran	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**
PLFA	Slowed Growth	ratio cy/c	**0 ND**	**0 ND**	**0.9461333 =**	**0.2886248 =**	**0 ND**	**0.2474645 =**	**0 ND**	**0 ND**
PLFA	ANAEROBIC METAL REDUCERS (BRMONOS)	PERCENT	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**
PLFA	EUKARYOTES (POLYENOICS)	PERCENT	**0 ND**	**0 ND**	**6.38 =**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**
PLFA	FIRMICUTES (TERBRSATS)	PERCENT	**0 ND**	**0 ND**	**15.64 =**	**3.4 =**	**0 ND**	**0 ND**	**0 ND**	**0 ND**
PLFA	GENERAL (NSATS)	PERCENT	**0 ND**	**5.24 =**	**33.18 =**	**23.42 =**	**49.14 =**	**24.67 =**	**39.98 =**	**48.11 =**
PLFA	PROTOBACTERIA (MONOS)	PERCENT	**100 =**	**89.38 =**	**26.81 =**	**54.12 =**	**50.86 =**	**75.32 =**	**60.03 =**	**37.38 =**
PLFA	SRB/Actinomycetes (MidBrSats)	PERCENT	**0 ND**	**5.38 =**	**17.97 =**	**19.07 =**	**0 ND**	**0 ND**	**0 ND**	**14.51 =**
Field	Temp	C	20.98	20.94	33.19	21.39	23.05	22	20.38	23.51
Field	pH	units	7.47	7.61	7.19	6.93	7.27	7.43	7.24	7.14
Field	Conductivity	mS/cm	0.545	0.672	0.678	0.371	0.317	0.249	0.633	0.635
Field	DO - instrument	mg/L	0	0	0	0	0	0	0	0
Field	ORP	mV	-9.7	-36	45	-74	-75	-173	-128	-128
Field	Iron - total		0	0	0	0	0	0	1	0.1
Field	Iron - Ferrous		0	0	0	0	0.1	0	1	0.1
Field	Sulfide		0	0	0	0	0	0	0	0
Field	Nitrate		0	0	0	0	0	0	0.25	0
Field	Nitrite		0	0	0	0	0	0	0	0
Field	DO - Chem		0.25	1	1	3	2	2	0.1	1

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		Station ID :	MNW-5 (D1)	MNW-5 (D2)	MNW-6 (D2)	MNW-8 (I2)	MNW-9 (D1)	MNW-9 (I2)	SFMW-12(I1)	SFMW-13(I2)
		Date Collected :	9/2/10 10:13	9/8/10 13:42	9/1/10 16:25	9/8/10 8:55	9/2/10 14:10	9/7/10 9:25	8/31/10 12:27	8/31/10 10:15
Class	**Parameter Name**	**Unit**								
CSIA	cis-1,2-Dichloroethene	ug/L	NA	**6 =**	NA	NA	NA	NA	NA	NA
CSIA	cis-1,2-Dichloroethene-carbon	‰	NA	**-32.86 =**	NA	NA	NA	NA	NA	NA
CSIA	Trichloroethene (TCE)	ug/L	NA	**6 =**	NA	NA	NA	NA	NA	NA
CSIA	Trichloroethene-carbon	‰	NA	**-17.01 =**	NA	NA	NA	NA	NA	NA
GAS	CARBON DIOXIDE FREE	mg/L	**27 J**	**21 J**	**9.9 J**	**19 J**	**23 J**	**24 J**	**9.6 J**	**12 J**
GAS	ETHANE	ug/L	**0.052 J**	**0.034 J**	**0.007 J**	0.025 UJ	**0.031 J**	**0.11 J**	**0.01 J**	**0.011 J**
GAS	ETHENE	ug/L	**0.063 J**	**0.083 J**	**0.027 J**	0.025 UJ	**0.062 J**	**0.02 J**	**0.061 J**	**0.042 J**
GASES	Methane	ug/L	**16 J**	**1.3 J**	**1.2 J**	**2.4 J**	**2.8 J**	**4.8 J**	**5.9 J**	**6.3 J**
GENCHEM	Alkalinity, bicarbonate (as caco3)	mg/L	**228 JH**	**247 =**	**154 JH**	**250 =**	**229 JH**	10 U	**229 JH**	**248 JH**
GENCHEM	Alkalinity, carbonate (as caco3)	mg/L	10 U	10 U	10 UJ	10 U	10 U	**1288 =**	10 U	10 U
GENCHEM	Alkalinity, total (as CaCO3)	mg/L	**228 JH**	**247 =**	**154 JH**	**250 =**	**229 JH**	**1836 =**	**229 JH**	**248 JH**
GENCHEM	CHLORIDE (AS CL)	mg/L	**58 JH**	**53 =**	**46 JH**	**31 =**	**50 JH**	**32 =**	**26 JH**	**25 JH**
GENCHEM	nitrogen, nitrate (as n)	mg/L	0.02 U	0.02 U	0.02 UJ	0.02 U	0.02 U	0.02 U	0.02 UJ	0.02 UJ
GENCHEM	Nitrogen, nitrate-nitrite	mg/L	0.04 U	0.04 U	0.04 UJ	0.04 U	0.04 U	0.04 U	0.04 UJ	0.04 UJ
GENCHEM	nitrogen, nitrite	mg/L	0.02 U	0.02 U	0.02 UJ	0.02 U	0.02 U	0.02 U	0.02 UJ	0.02 UJ
GENCHEM	nonpurgeable organic carbon	mg/L	1 U	**1 =**	**2 J**	**2 =**	**3 =**	**3 =**	**2 J**	**2 J**
GENCHEM	SULFATE (AS SO4)	mg/L	**215 JH**	**213 =**	**167 JH**	**198 =**	**148 JH**	**181 =**	**137 JH**	**152 JH**
GENCHEM	Sulfide	mg/L	**0.02 JH**	**0.01 J**	0.01 UJ	0.01 UJ	0.01 U	0.01 UJ	**0.01 JH**	0.01 UJ
GENCHEM	total dissolved solids (residue, filterable)	mg/L	**718 JH**	**736 =**	**541 JH**	**690 =**	**610 JH**	**2000 =**	**531 JH**	**579 JH**
Metals	Calcium	ug/L	**116000 JH**	**119000 =**	**84600 JH**	**94300 =**	**96200 JH**	**103000 =**	**66000 JH**	**68400 JH**
Metals	Iron	ug/L	**145 JH**	**111 =**	**162 =**	**118 =**	**175 =**	**690 =**	**122 JH**	**59.8 JH**
Metals	Magnesium	ug/L	**18400 JH**	**16600 =**	**16000 JH**	**20400 =**	**25700 JH**	**25500 =**	**11000 JH**	**14200 JH**
Metals	Manganese	ug/L	**10.1 =**	**12.1 =**	**71.8 =**	**161 =**	**51 =**	**207 =**	**1100 =**	**736 =**
PLFA	Cells	cells/mL	**3970 =**	**8350 =**	**476 =**	**4100 =**	**3140 =**	**6130 =**	**6660 =**	**1000 =**
PLFA	Decreased Permeability	ratio tran	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**
PLFA	Slowed Growth	ratio cy/c	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**
PLFA	ANAEROBIC METAL REDUCERS (BRMONOS)	PERCENT	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**0 ND**	**1.58 =**	**0 ND**
PLFA	EUKARYOTES (POLYENOICS)	PERCENT	**0 ND**	**0 ND**	**0 ND**	**2.34 =**	**0 ND**	**0 ND**	**10.98 =**	**0 ND**
PLFA	FIRMICUTES (TERBRSATS)	PERCENT	**3.83 =**	**18.47 =**	**0 ND**	**5.66 =**	**0 ND**	**22.77 =**	**4.45 =**	**0 ND**
PLFA	GENERAL (NSATS)	PERCENT	**32.26 =**	**31.4 =**	**37.07 =**	**27.91 =**	**87.53 =**	**32.76 =**	**38.56 =**	**33.84 =**
PLFA	PROTOBACTERIA (MONOS)	PERCENT	**33.08 =**	**18.89 =**	**62.93 =**	**60.08 =**	**12.46 =**	**44.48 =**	**40.55 =**	**66.16 =**
PLFA	SRB/Actinomycetes (MidBrSats)	PERCENT	**30.83 =**	**31.24 =**	**0 ND**	**4.01 =**	**0 ND**	**0 ND**	**3.89 =**	**0 ND**
Field	Temp	C	22.42	22.29	24.5	21.7	23.52	20.44	26.72	21.55
Field	pH	units	7.14	7.29	7.59	7.08	7.3	7.29	7.99	7.91
Field	Conductivity	mS/cm	0.719	0.586	0.522	0.62	0.62	0.542	0.456	0.496
Field	DO - instrument	mg/L	0	0	4.74	0	0	0	0.96	0
Field	ORP	mV	-52	-79	-164	-63	-76	-161	-86	-103
Field	Iron - total		0	0	1	0	0	0.2	0	0
Field	Iron - Ferrous		0	0	1	0.1	0	0.8	0	0
Field	Sulfide		0	0	0	0	0	0	0	0
Field	Nitrate		0	0	0	0	0	0	0	0
Field	Nitrite		0	0	0	0	0	0	0	0
Field	DO - Chem		1	1	1	2	2	0	0.35	1

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	Station ID :		SFMW-16(I1)	SFMW-20(I1)	SFMW-21(I2)	SFMW-22(D1)	SFMW-23 (D2)	SFMW-25(I1)	SFMW-32(I2)	SFMW-33(D2)
	Date Collected :		9/2/10 9:20	9/1/10 11:05	9/1/10 14:20	8/30/10 9:34	8/30/10 13:31	9/7/10 9:25	9/1/10 13:45	9/8/10 10:55
Class	**Parameter Name**	**Unit**								
CSIA	cis-1,2-Dichloroethene	ug/L	NA	NA	NA	NA	NA	NA	NA	NA
CSIA	cis-1,2-Dichloroethene-carbon	‰	NA	NA	NA	NA	NA	NA	NA	NA
CSIA	Trichloroethene (TCE)	ug/L	NA	NA	NA	NA	NA	NA	NA	NA
CSIA	Trichloroethene-carbon	‰	NA	NA	NA	NA	NA	NA	NA	NA
GAS	CARBON DIOXIDE FREE	mg/L	**24 J**	**55 J**	**41 J**	**4.2 J**	**2.1 J**	**22 J**	**43 J**	**2.7 J**
GAS	ETHANE	ug/L	**0.045 J**	**0.043 J**	**0.053 J**	**0.023 J**	**0.022 J**	**0.061 J**	**0.055 J**	0.025 UJ
GAS	ETHENE	ug/L	**0.01 J**	**0.011 J**	**0.01 J**	**0.038 J**	**0.032 J**	**0.043 J**	**0.027 J**	0.025 UJ
GASES	Methane	ug/L	**4.8 J**	**11 J**	**13 J**	**0.18 J**	**0.32 J**	**5.5 J**	**20 J**	**0.31 J**
GENCHEM	Alkalinity, bicarbonate (as caco3)	mg/L	**242 JH**	**324 JH**	**290 JH**	**84 JH**	**65 JH**	**264 =**	**316 JH**	**120 =**
GENCHEM	Alkalinity, carbonate (as caco3)	mg/L	10 U	10 UJ	10 UJ	10 U	10 U	10 U	10 UJ	10 U
GENCHEM	Alkalinity, total (as CaCO3)	mg/L	**242 JH**	**324 JH**	**290 JH**	**84 JH**	**65 JH**	**264 =**	**316 JH**	**120 =**
GENCHEM	CHLORIDE (AS CL)	mg/L	**44 JH**	**184 JH**	**40 JH**	**45 JH**	**42 JH**	**42 =**	**62 JH**	**15 =**
GENCHEM	nitrogen, nitrate (as n)	mg/L	0.02 U	0.02 UJ	0.02 UJ	0.02 U	0.02 U	0.02 U	0.02 UJ	0.02 U
GENCHEM	Nitrogen, nitrate-nitrite	mg/L	0.04 U	0.04 UJ	0.04 UJ	0.04 U	0.04 U	0.04 U	0.04 UJ	0.04 U
GENCHEM	nitrogen, nitrite	mg/L	0.02 U	0.02 UJ	0.02 UJ	0.02 U	0.02 U	0.02 U	0.02 UJ	0.02 U
GENCHEM	nonpurgeable organic carbon	mg/L	**2 =**	**1 J**	**1 J**	**1 =**	1 U	**2 =**	**1 J**	1 U
GENCHEM	SULFATE (AS SO4)	mg/L	**206 JH**	**456 J**	**303 J**	**529 =**	**370 =**	**217 =**	**338 J**	**58 =**
GENCHEM	Sulfide	mg/L	0.01 U	**0.01 JH**	**0.03 JH**	0.01 U	0.01 U	0.01 UJ	**0.05 JH**	0.01 UJ
GENCHEM	total dissolved solids (residue, filterable)	mg/L	**694 JH**	**1320 J**	**870 JH**	**954 JH**	**732 JH**	**712 =**	**992 JH**	**304 =**
Metals	Calcium	ug/L	**113000 JH**	**184000 JH**	**149000 JH**	**123000 JH**	**92600 JH**	**98400 =**	**113000 JH**	**30400 =**
Metals	Iron	ug/L	25 U	**67.2 JH**	**184 =**	25 U	25 U	**52.4 =**	**181 =**	**40 =**
Metals	Magnesium	ug/L	**22700 JH**	**30900 =**	**23400 JH**	**28800 =**	**25300 JH**	**21700 =**	**19900 JH**	**7530 =**
Metals	Manganese	ug/L	5 U	**8.2 =**	5 U	5 U	5 U	**129 =**	**30.4 =**	5 U
PLFA	Cells	cells/mL	**544 =**	**930 =**	**9050 =**	**3960 =**	**1680 =**	**2700 =**	**37000 =**	**6820 =**
PLFA	Decreased Permeability	ratio tran	**0 ND**	**0 ND**	**0.0868644 =**	**0 ND**	**0 ND**	**0 ND**	**0.1871041 =**	**0 ND**
PLFA	Slowed Growth	ratio cy/c	**0 ND**	**0 ND**	**0.732582 =**	**0 ND**	**1.263158 =**	**0.4623166 =**	**0.2762721 =**	**1.038648 =**
PLFA	ANAEROBIC METAL REDUCERS (BRMONOS)	PERCENT	**0 ND**	**0 ND**	**1.2 =**	**0 ND**	**0 ND**	**0 ND**	**2.45 =**	**2.11 =**
PLFA	EUKARYOTES (POLYENOICS)	PERCENT	**0 ND**	**0 ND**	**3.17 =**	**0 ND**	**0 ND**	**0 ND**	**5.75 =**	**1.64 =**
PLFA	FIRMICUTES (TERBRSATS)	PERCENT	**0 ND**	**0 ND**	**4.29 =**	**3.02 =**	**0 ND**	**0 ND**	**6.69 =**	**7.84 =**
PLFA	GENERAL (NSATS)	PERCENT	**48.76 =**	**49.57 =**	**32.47 =**	**12.29 =**	**22.23 =**	**36.74 =**	**19.31 =**	**39.13 =**
PLFA	PROTOBACTERIA (MONOS)	PERCENT	**51.24 =**	**41.12 =**	**51.36 =**	**69.49 =**	**60.32 =**	**57.78 =**	**62.18 =**	**46.39 =**
PLFA	SRB/Actinomycetes (MidBrSats)	PERCENT	**0 ND**	**9.32 =**	**7.5 =**	**15.19 =**	**17.44 =**	**5.48 =**	**3.62 =**	**2.89 =**
Field	Temp	C	20.5	22.68	22.35	21.69	21.99	22.75	24.48	22.21
Field	pH	units	7.32	7.05	7.13	7.25	7.5	7.1	7.13	8.08
Field	Conductivity	mS/cm	0.597	1..68	0.699	0.863	0.663	0.653	0.946	0.236
Field	DO - instrument	mg/L	0	0	0	13.87	4.32	0	4.59	0
Field	ORP	mV	20	34	1	129	116	-92	-100	-11
Field	Iron - total		0	0	0	0	0	0	0	0
Field	Iron - Ferrous		0	0	0	0	0	0	0	0
Field	Sulfide		0.05	0	0	0	0	0	0	0
Field	Nitrate		1	0	0	0	0	0	0	0
Field	Nitrite		1	0	0	0	0	0	0	0
Field	DO - Chem		0.25	0.2	0.05	5	4	1	1	0.2

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	Station ID :		SFMW-35(D3)	SFMW-40 (D3)	SFMW-43 (I1)	SFMW-44 (D2)
	Date Collected :		9/1/10 10:35	8/31/10 9:57	9/2/10 11:30	8/31/10 14:13
Class	**Parameter Name**	**Unit**				
CSIA	cis-1,2-Dichloroethene	ug/L	NA	5 J	NA	6 =
CSIA	cis-1,2-Dichloroethene-carbon	‰	NA	-31.73 =	NA	-33.53 =
CSIA	Trichloroethene (TCE)	ug/L	NA	7 =	NA	10 =
CSIA	Trichloroethene-carbon	‰	NA	-16.76 =	NA	-17.63 =
GAS	CARBON DIOXIDE FREE	mg/L	2.9 J	24 J	54 J	28 J
GAS	ETHANE	ug/L	0.017 J	0.046 J	0.015 J	0.057 J
GAS	ETHENE	ug/L	0.025 J	0.02 J	0.009 J	0.01 J
GASES	Methane	ug/L	0.12 J	3.5 J	0.8 J	2.2 J
GENCHEM	Alkalinity, bicarbonate (as caco3)	mg/L	71 JH	231 JH	316 JH	244 JH
GENCHEM	Alkalinity, carbonate (as caco3)	mg/L	10 UJ	10 U	10 U	10 U
GENCHEM	Alkalinity, total (as CaCO3)	mg/L	71 JH	231 JH	316 JH	244 JH
GENCHEM	CHLORIDE (AS CL)	mg/L	44 JH	39 JH	82 JH	50 JH
GENCHEM	nitrogen, nitrate (as n)	mg/L	0.02 UJ	0.02 UJ	0.02 U	0.02 UJ
GENCHEM	Nitrogen, nitrate-nitrite	mg/L	0.04 UJ	0.04 UJ	0.04 U	0.04 UJ
GENCHEM	nitrogen, nitrite	mg/L	0.02 UJ	0.02 UJ	0.02 U	0.02 UJ
GENCHEM	nonpurgeable organic carbon	mg/L	1 UJ	1 UJ	1 U	1 J
GENCHEM	SULFATE (AS SO4)	mg/L	486 J	184 JH	349 =	247 J
GENCHEM	Sulfide	mg/L	0.03 J	0.01 JH	0.01 U	0.01 UJ
GENCHEM	total dissolved solids (residue, filterable)	mg/L	909 JH	660 JH	1010 JH	747 JH
Metals	Calcium	ug/L	122000 JH	102000 =	158000 JH	134000 =
Metals	Iron	ug/L	53.9 JH	25.4 =	25 U	25 U
Metals	Magnesium	ug/L	32500 =	28000 =	25300 JH	23800 =
Metals	Manganese	ug/L	5 U	5 U	10.3 =	8 =
PLFA	Cells	cells/mL	4850 =	1680 =	1960 =	579 =
PLFA	Decreased Permeability	ratio tran	0 ND	0 ND	0 ND	0 ND
PLFA	Slowed Growth	ratio cy/c	0.4303797 =	0 ND	0 ND	0 ND
PLFA	ANAEROBIC METAL REDUCERS (BRMONOS)	PERCENT	0 ND	0 ND	0 ND	0 ND
PLFA	EUKARYOTES (POLYENOICS)	PERCENT	0 ND	0 ND	0 ND	0 ND
PLFA	FIRMICUTES (TERBRSATS)	PERCENT	3.32 =	0 ND	0 ND	0 ND
PLFA	GENERAL (NSATS)	PERCENT	42.9 =	9.47 =	42.36 =	17.45 =
PLFA	PROTOBACTERIA (MONOS)	PERCENT	49.04 =	90.53 =	57.64 =	82.55 =
PLFA	SRB/Actinomycetes (MidBrSats)	PERCENT	4.75 =	0 ND	0 ND	0 ND
Field	Temp	C	23.03	22.71	21.7	23.54
Field	pH	units	7.8	7.28	7.181	7.25
Field	Conductivity	mS/cm	0.799	6.16	1.19	0.719
Field	DO - instrument	mg/L	7.38	0	0	0
Field	ORP	mV	98	23	12	59
Field	Iron - total		0	0	0	0
Field	Iron - Ferrous		0	0	0	0
Field	Sulfide		0	0	0	0
Field	Nitrate		0	0	0	0
Field	Nitrite		0	0	0	0
Field	DO - Chem		5	2	0.05	1

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Appendix D
Mann-Kendall Statistical Evaluation of TCE and Cis-1,2-DCE Concentration Data

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Fruit Avenue Plume Superfund Site Long-Term Remedial Action Appendix D – Mann-Kendall Statistical Evaluation of TCE and Cis-1,2-DCE Concentration Data

PREPARED FOR:	Bartolomé Cañellas /EPA Region 6 Remedial Project Manager
PREPARED BY:	CH2M HILL
DATE:	October, 2012
PROJECT:	EPA Region 6 Remedial Action Contract W-EP-06-021 Task Order No. 0003-RALR-06DD CH2M HILL Project No. 345406.PJ.14
DCN:	0003-02091

Appendix D presents the results of a Mann-Kendall (MK) statistical evaluation of TCE and cis-1,2-DCE concentration data for a many of the long term monitoring (LTM) well locations. The MK statistic provides an indication on whether contaminant concentrations are stable, increasing, or decreasing or whether no trend is evident. For MNA to be deemed effective, contaminant concentrations must generally be stable or decreasing at representative locations across a site.

The first tier of site-specific information used to evaluate MNA is historical data that demonstrate a clear and meaningful trend of decreasing contaminant mass and/or concentration over time (EPA, 1999). Although tetrachloroethylene (PCE) and trichloroethylene (TCE) are the primary or parent contaminants initially present at chlorinated solvent sites, cis-1,2-dichloroethylene (cis-1,2-DCE), vinyl chloride (VC), ethene, and ethane (the degradation products) are generally not. A reduction in the concentration of the parent contaminants, in conjunction with the appearance of the degradation products, suggests that some process is transforming the parent contaminant(s) resulting in a decrease in mass and/or concentration over time.

At the Fruit Avenue Plume Superfund site (the site), TCE is the primary parent compound and cis-1,2-DCE the primary degradation product. This technical memorandum (TM) examines temporal changes in TCE and cis-1,2-DCE concentrations, and molar concentration ratios of parent contaminants to daughter products, to draw conclusion on whether there is evidence of decreasing TCE and cis-1,2-DCE concentrations at the site.

Site-Wide Temporal Variations in TCE and cis-1,2-DCE Concentrations

Figure 1 and **Figure 2** display the 20 highest historical (1998-2010) and 20 highest recent (2011-2012) TCE and cis-1,2-DCE concentrations found at the site. The 20 highest observed historical TCE concentrations ranged from 99 µg/L to 18 µg/L. More recently, the 20 highest observed TCE concentrations range from 54 µg/L to 5.2 µg/L. The 20 highest observed historical cis-1,2-DCE concentrations ranged from 30 µg/L to 9 µg/L. More recently, the 20 highest observed cis-1,2-DCE concentrations range from 13 µg/L to 1.4 µg/L. These figures illustrate that site-wide TCE and cis-1,2-DCE concentrations have decreased from the historical levels.

FIGURE 1
20 Highest Observed TCE Concentrations (in µg/L) Found at the Site in Historical and Recent Data
Fruit Avenue Plume Superfund Site, Albuquerque NM

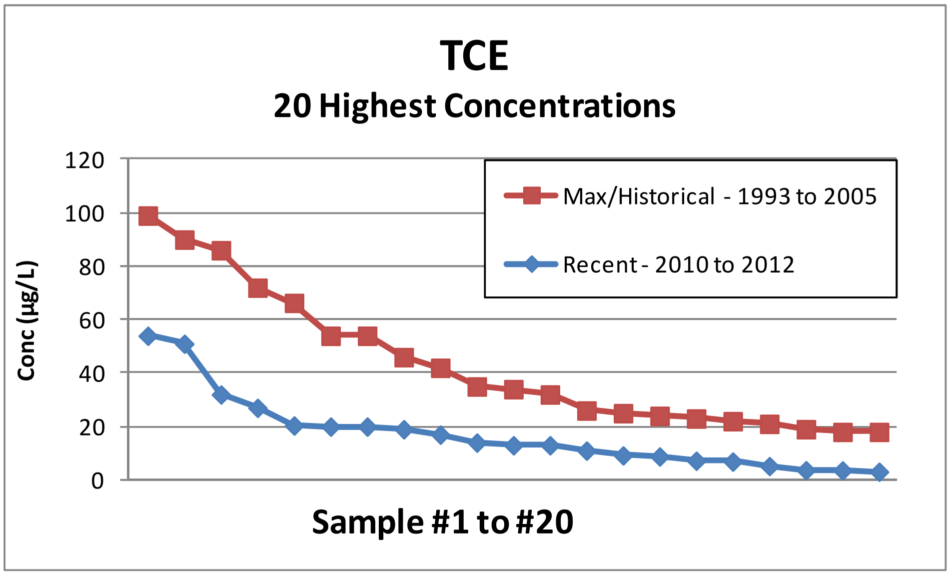
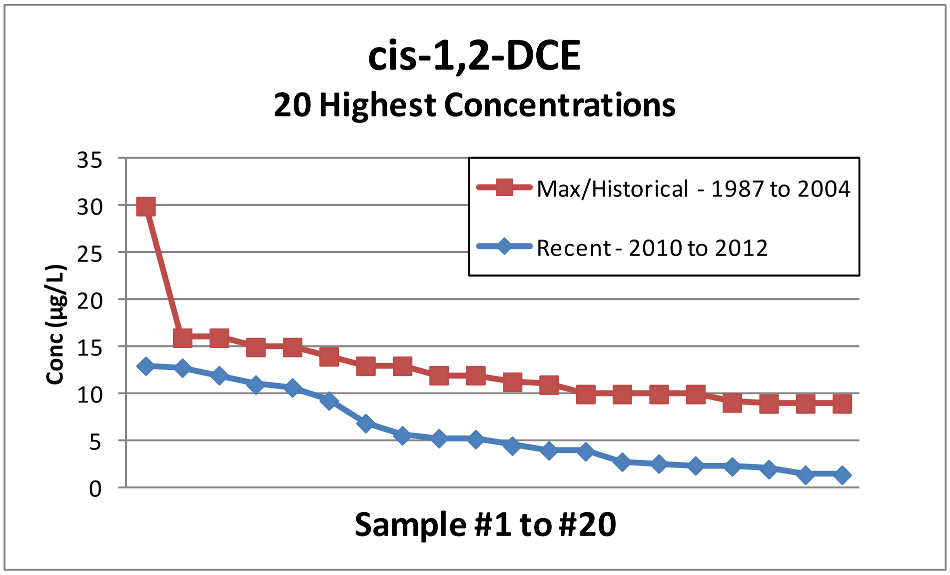


FIGURE 2
20 Highest Observed cis-1,2-DCE Concentrations (in µg/L) Found at the Site in Historical and Recent Data *Fruit Avenue Plume Superfund Site, Albuquerque NM*



Temporal Variations in TCE and cis-1,2-DCE Concentrations in Plume Regions

The concentration-versus-time data were analyzed using the MK non-parametric trend analysis, which indicates whether a temporal concentration trend is increasing, decreasing, stable, or whether there is no trend in the data set. The MK results and determination (increasing, decreasing, stable, or no trend) are presented in the tables accompanying **Attachments 1** to **4**. The MK result also provides an estimate of confidence in the trend. The charts and tables supporting the evaluation are organized by relative location (western, central and eastern) location within the plume. **Attachment 1** presents an analysis of data from monitor wells located in the western portion of the plume near the presumed source area. **Attachment 2** presents an analysis of data from monitor well located in the central portion of the plume near the pump-and-treat (P&T) system. **Attachment 3** presents an analysis of data from monitor wells located in the eastern portion of the plume downgradient of the P&T system. **Attachment 4** presents an analysis of data from monitor wells located in the upgradient offsite plume area. **Attachment 5** provides background information on the MK non-parametric trend analysis.

Because PCE and VC are rarely detected in groundwater samples at the site, they are excluded from the MK portion of the evaluation presented in this TM. Monitor wells are named for their location and the aquifer zone in which they are screened. Aquifer zone designations with a "/" (e.g., I1/I2) indicate that a well is screened across two aquifer zones. Maps illustrating the well locations may abbreviate the well IDs to indicate that up to four wells are present at a location by placing commas between the aquifer zone designations. For example, at MNW-5, there are four separated wells screened in four separate aquifer zones: MNW-5(D1, D2, D3, and D4).

Table 1 summarizes the MK analysis of monitor well data at the site.

Near the Presumed Source Area (Western Portion) of the Plume

The western portion of the TCE plume is characterized by monitor wells screened in the S, I1, I2, and D1 aquifer zones. Portions of the plume representative of the presumed source or western plume area are included in charts and tables in **Attachment 1**.

The maximum detected TCE concentration observed in this portion of the plume was 99 µg/L detected in a sample collected in 2005 from monitor well HSM-I2-5. Seven other locations also had concentrations above 50 µg/L. These wells included SFMW-19(I2), SFMW-25(I1/I2), SFMW-47(I2), MNW-14(I2), DM-2(I1/I2), DM-12(I1/I2), and DM-13(I1). In 2012, TCE concentrations at these locations range from 39 µg/L to 2.4 µg /L.

TABLE 1
Summary of Mann Kendall Analysis of Data from Individual Monitor Wells
Fruit Avenue Plume Superfund Site, Albuquerque NM

		Number of Monitor Wells with						
Plume Area	**Analyte**	**Decreasing Trend**	**Increasing Trend**	**No Trend - Stable**	**No Trend – Not Stable**	**Greater than 50% Non-Detect**	**Fewer than Six Samples**	**Total Number of Wells Used for MK Trend Evaluation [a]**
Presumed Source Area (Western Plume)	TCE	20	5	11	2	3	6	38
	DCE	11	5	14	1	6	10	31
Near the P&T System (Central Plume)	TCE	8	1	2	1	3	7	12
	DCE	9	1	2	1	3	4	13
Downgradient of the P&T System (Eastern Plume)	TCE	5	6	0	1	3	3	12
	DCE	3	4	2	0	1	0	9
Site wide Total	TCE	33 of 62	12 of 62	13 of 62	4 of 62	9 of 62	16 of 62	62 of 87
	DCE	23 of 53	10 of 53	18 of 53	2 of 53	10 of 53	14 of 53	53 of 77

Gray shaded cells indicate the number of monitoring wells where the available data do not meet the usability criteria.

[a] Total Number of Wells Used for MK Evaluation equals Total Number of Wells in Area minus Number of Wells with Greater Than 50% Non-Detect minus Number of Wells with Fewer than Six Samples.

In the presumed source area, 38 wells have sufficient TCE data to analyze. Decreasing TCE concentrations are found in 20 of 38 monitor wells and stable concentrations are found in 11 of 38 monitor wells. Increasing concentrations were found in 5 of 38 monitor wells.

The highest observed cis-1,2-DCE concentration detected in a groundwater from this area was 30 µg/L in a sample collected in 1987 from the now-abandoned Convention Center well. No locations had concentrations above the 70 µg/L remediation goal. **Table 1** indicates that in the presumed source area, 31 wells have sufficient cis-1,2-DCE data to analyze. Decreasing cis-1,2-DCE concentrations are found in 11 of 31 monitor wells and stable concentrations are found in 14 of 31 monitor wells. Increasing concentrations were found in 5 of 31 monitor wells.

The generally decreasing and low concentrations of TCE and cis-1,2-DCE observed indicate that the plume is attenuating in this area. In addition, the generally decreasing TCE concentrations in groundwater suggest no significant ongoing releases. Specific exceptions noted from the MK evaluation for this area include the following:

- SFMW-16(I1) and SFMW-17(I2) where both TCE and DCE concentrations are increasing; other evidence also suggests that the plume may be migrating eastward from the source area.
- DM-13(I1), where TCE concentrations are stable and DCE concentrations are increasing, suggesting that TCE transformation is stalling at DCE.
- MNW-14(I2) where both TCE and DCE concentrations are increasing; other evidence also suggests that the upgradient offsite plume may be migrating eastward onto the site.

Vicinity of Pump-and-Treat System

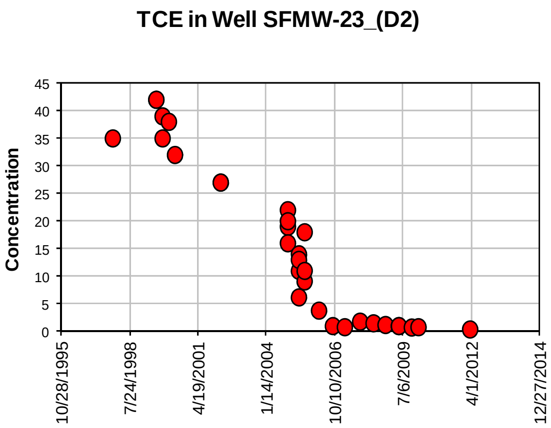
Portions of the plume that are affected by the P&T system are monitored by the following wells (**Attachment 2**):

- SPSC series wells in the shallow aquifer zone
- SFMW-20(I1), SFMW-21(I2), SFMW-22(D1), SFMW-23(D2), SFMW-35(D3), and SFMW-36(D4) located between the D2E-P1 extraction well and the D2E-I3 single injection well
- SFMW-37(I2) adjacent to the I2/D1E-I1 dual injection well
- McDonalds (D2) and SFMW-31(I2) north of the pumping well
- SFMW-32(I2), SFMW-38(D1), and SFMW-39(D2) to the south of the pumping well

The highest observed TCE concentration measured in groundwater near the P&T system was 42 µg/L detected in a field duplicate sample collected in 1999 from monitor well SFMW-23(D2). Two other locations had concentrations above 20 µg/L. They included: SPSC-MN4(S)(24 µg/L) and SPSC-MW6(S)(26 µg/L).

The MK evaluation for the central portion of the TCE plume summarized in **Table 1** indicates that 12 wells have sufficient TCE data to analyze. Decreasing TCE concentration trends are evident in 8 of 12 monitor wells and stable concentrations in 2 of 12 monitor wells. As expected, most of these wells exhibited a sharp decrease in TCE concentrations after the startup of the P&T system in 2005. For example, the TCE concentration at SFMW-23(D2) (**Figure 3**) decreased from 22 µg/L to 1 µg/L within 20 months of startup.

FIGURE 3
Example of the Sudden Decrease in TCE Concentration in Monitor Wells Near the Pump-and-Treat System
Fruit Avenue Plume Superfund Site, Albuquerque NM



Increasing TCE concentrations observed at the McDonalds well suggest that a portion of the plume represented by the TCE detections at SFMW-23(D2) may have been diverted to the north by injection of treated water at nearby injection well D3E-I3.

Eastern Portion of the Plume

The downgradient plume east of the P&T system is generally represented by monitor wells screened in the D1, D2, and D3 aquifer zones (**Attachment 3;** e.g., **Figure 4**). The MK evaluation was not performed for the D4 aquifer zone monitoring wells because all groundwater samples from this zone were non-detect (ND) for TCE and cis-1,2-DCE.

The highest observed TCE concentrations measured in groundwater samples collected from the respective aquifer zones located in this portion of the plume are: D1 = 19 µg/L at MNW-5(D1) in 2008, D2 = 42 µg/L at SFMW-23(D2) in 1999 (before startup of the P&T system), D3 = 27 µg/L at MNW-5(D3) in 2011. As of February 2012, TCE concentrations at all these locations have declined to less than 15 µg/L.

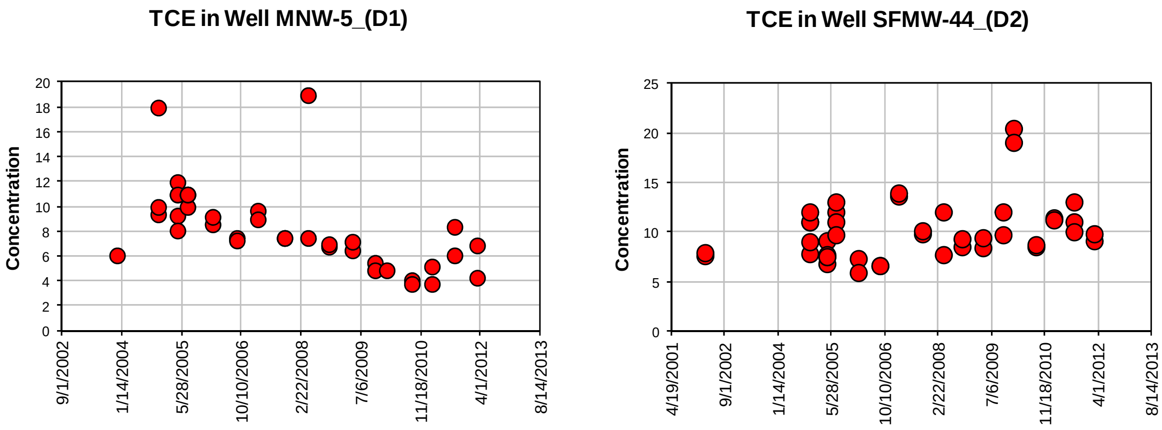
The summary of the MK analyses in **Table 1** indicates that 12 wells have sufficient TCE data to analyze. Decreasing TCE concentration trends occur at 5 locations while stable concentration trends were not identified at any location. Increasing TCE concentrations were identified at 6 monitor well locations.

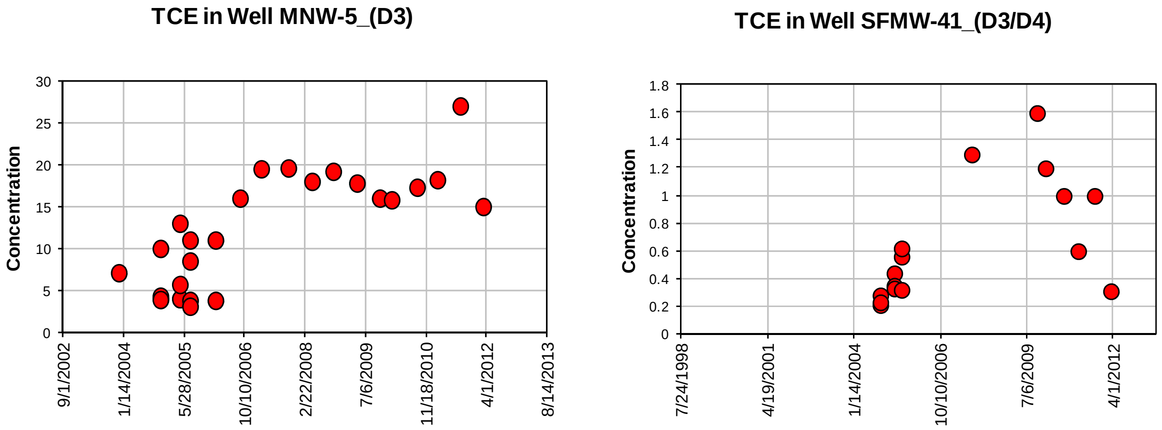
Four of five downgradient D1 wells are not affected by the P&T system. TCE concentrations at MNW-5(D1) (**Figure 4**) and SFMW-46(D1/D2) are decreasing (**Attachment 3**). TCE concentrations at MNW-4(D1) and MNW-6(D1) are neither decreasing nor increasing.

FIGURE 4

TCE Concentration (µg/L) Trends in D1, D2, D3 Aquifer Zone Monitor Wells Located in Eastern Portion of the Plume

Fruit Avenue Plume Superfund Site, Albuquerque NM





Six of eight downgradient D2 wells are not affected by the P&T system. Recent TCE concentration trends at MNW-5(D2) and SFMW-46(D1/D2) are decreasing (**Attachment 3**). TCE concentration trends at MNW-6(D2) and SFMW-45(D2) are neither decreasing nor increasing. TCE concentration trends at MNW-4(D2) and SFMW-44(D2) (**Figure 4**) are increasing.

Three downgradient D3 wells are not affected by the P&T system. TCE concentrations at MNW-5(D3) (**Figure 4**) increased from about 8 µg/L, when the well was installed in 2004, to 27 µg/L in 2011. Recent TCE concentrations at SFMW-40(D3) have increased from 3.6 µg/L to 7.2 µg/L. TCE is infrequently detected in MNW-4(D3).

Monitor well SFMW-41(D3/D4) (**Figure 4**) is screened *between* the D3 and D4 aquifer zones and has TCE concentrations below 2 µg/L, which have been decreasing since 2009. TCE has not been detected in the D4 aquifer zone.

In summary, 5 of 12 concentration trends in the eastern portion of the TCE plume in deeper aquifer zones (**Attachment 3**) are decreasing or stable. The increasing concentrations at MNW-4(D2), MNW-5(D3), and SFMW-44(D2) suggest that the plume is advancing from the D1 aquifer zone into the D2 and D3 aquifer zones under the influence of the regional groundwater flow gradient.

Offsite Plume – Located West of the FAP Site

Data from monitor wells associated with the offsite plume are plotted and analyzed separately from onsite data. The offsite plume was originally identified when TCE concentrations at monitoring wells MNW-9 and MNW-11 were deemed too high at locations too far upgradient and too deep to have been caused by a release from the

FAP's presumed source area. Concentrations of TCE in groundwater upgradient of the site are monitored and evaluated to assess the effects of offsite plume migration onto the FAP site.

TCE concentrations in the D1 aquifer zone (**Attachment 4**) indicate the presence of the offsite plume. As of February 2012, the TCE concentrations at MNW-11(D1) are higher than those recently observed within the FAP groundwater monitoring well network. The data presented in **Attachment 4** suggest that the portion of the offsite plume in the I2 aquifer zone has already migrated onto the FAP site. Analysis of data from monitor wells located southwest of the presumed source area (**Figure 5**) indicates that a portion of the TCE present at MNW-14, SFMW-11, SFMW-12, SFMW-13, SFMW-14, SFMW-27, SFMW-28, WB-01, and WB-02 is from the offsite plume. The TCE concentrations in this portion of the FAP site were allocated between the FAP-TCE plume and the offsite TCE plume. The allocated concentrations were used to create two plume shells, one for the FAP site (**Figure 5**) and a second plume shell for the offsite plume (**Figure 6**). User-interactive animations of the plume shells are included in **Attachment 6**. The full extent of the offsite plume is unknown; however, TCE concentration trends indicate that the plume continues to move toward and onto the FAP site.

FIGURE 5
West End of the FAP TCE Plume Shell used in the Flow and Transport Model (Appendix J).
Posted Analytical Sample Data are from February 2012.
Plume Shells Illustrated at 1 (blue), 5 (green), 10 (orange), and 20 (red) µg/L
View from the Southwest, MNW-11 And MNW-12 are the Nearest Monitor Wells in the Figure
Fruit Avenue Plume Superfund Site, Albuquerque NM

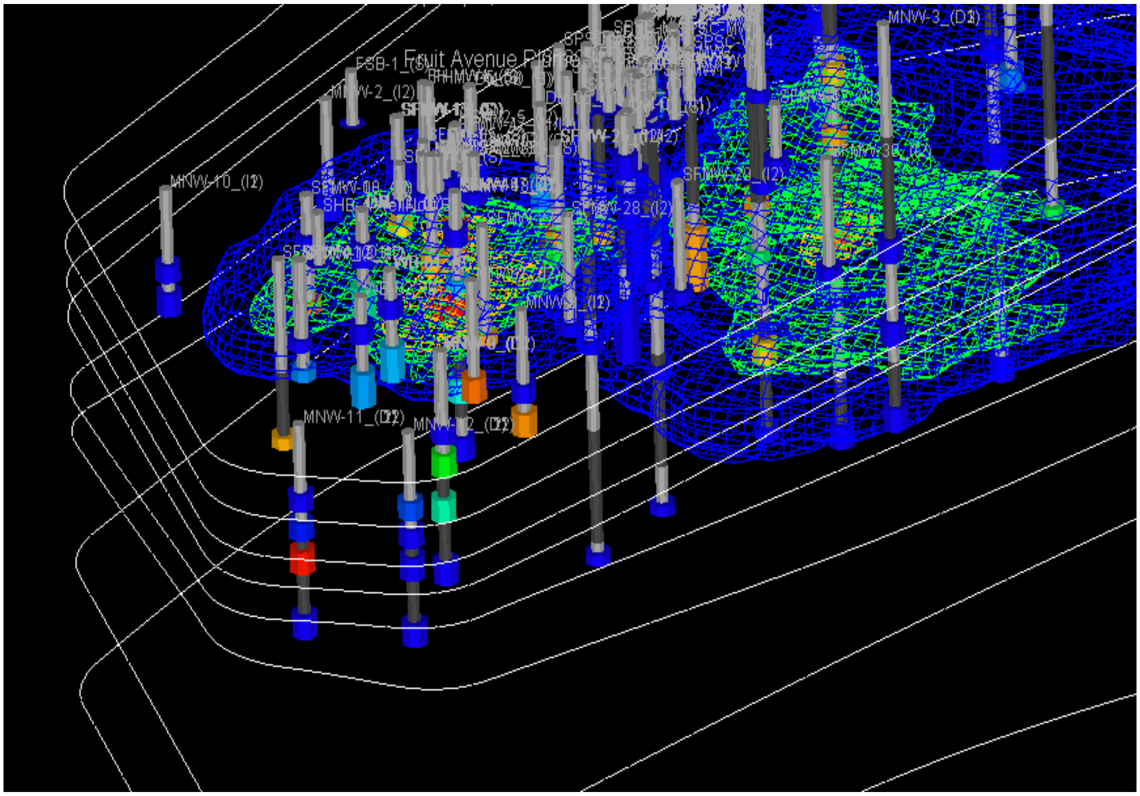
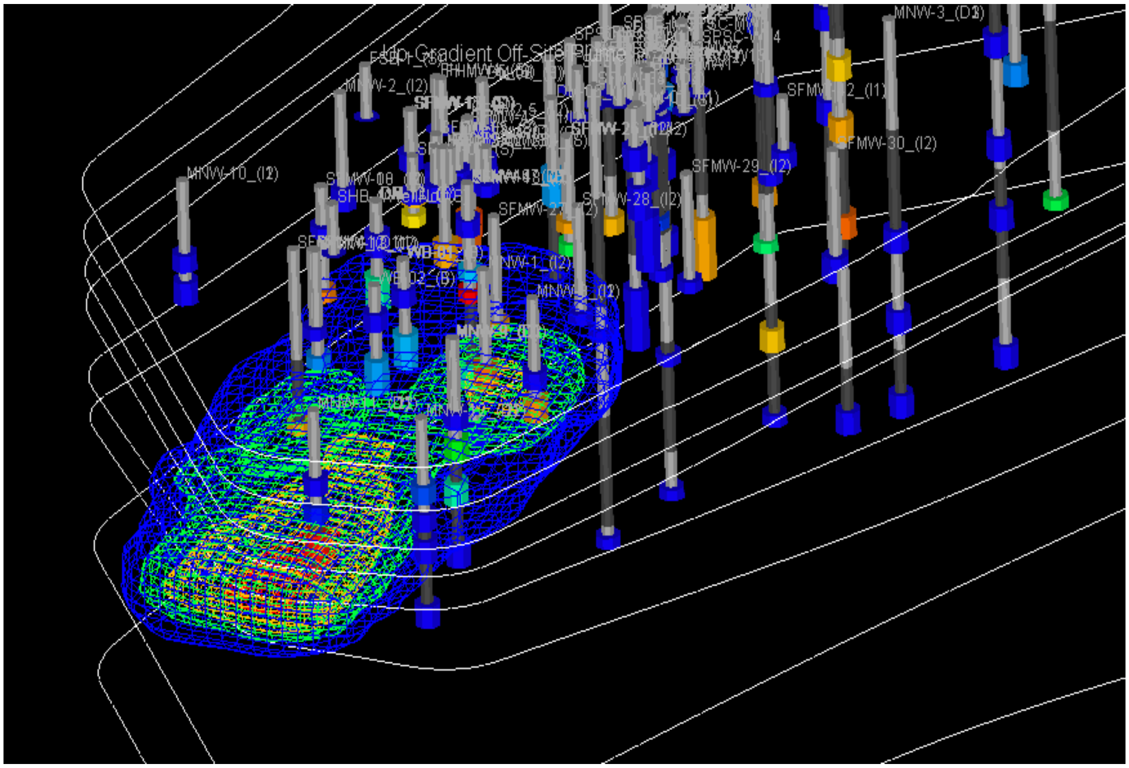


FIGURE 6
Offsite TCE Plume Shell Excluded from the Flow and Transport Model (Appendix J).
Posted Analytical Sample Data are from February 2012.
Plume Shells Illustrated at 1 (blue), 5 (green), 10 (orange), and 20 (red) µg/L
View from the Southwest, MNW-11 and MNW-12 are the Nearest Monitor Wells in the Figure
Fruit Avenue Plume Superfund Site, Albuquerque NM



Mole Fraction

The degree to which chlorinated volatile organic compounds (cVOCs) are being degraded can be illustrated by comparing the mole fraction of each cVOC present. By normalizing the contaminant of concern (COC) mass concentrations as mole fraction of the total cVOC mole concentration, contaminants can be quantified or "tracked" through a degradation pathway. The conversion to mole fraction of total cVOCs was conducted only for samples that were analyzed for dissolved gasses so the fraction of all cVOCs in the degradation pathway could be evaluated. The following equations illustrate how the mole fraction of TCE was calculated:

$$\#Moles_{TCE} = Concentration_{TCE} \div MoleMass_{TCE} \qquad \text{Equation 1}$$

$$Total\ Moles = \sum \#Moles_{(PCE,TCE,cDCE,tDCE,VC,Ethene)} \qquad \text{Equation 2}$$

$$MoleFraction\%_{TCE} = \frac{\#Moles_{TCE}}{TotalMoles} \qquad \text{Equation 3}$$

Table 2 presents the calculated mole fractions for PCE, TCE and their degradation products at selected monitoring well locations**.** Box plots illustrating the range of mole fractions observed are presented in **Figures 7, 8,** and **9**. In these figures, the box bounds the 25- to 75-percentile values for each cVOC. The median value is illustrated by a horizontal line within the box. In these figures, the mole fractions of PCE, TCE, DCE (cis-1,2-DCE plus trans 1,2-DCE), VC, and ethene are illustrated in the box plots. The wells and number of samples are listed in the legend.

TABLE 2

Calculated Mole Fractions of PCE, TCE and Their Degradation Products for Selected Wells

Fruit Avenue Plume Superfund Site, Albuquerque NM

	Mole Fraction				
Station ID	**PCE**	**TCE**	**cis + trans 1,2-DCE**	**VC**	**Ethene**
			Western Portion of Site Near Presumed Source Area		
SFMW-16(I1)	0.00	0.82	0.18	0.0	0.005
SFMW-25(I1)	0.00	0.65	0.34	0.0	0.014
HSM-I2-4	0.00	0.65	0.34	0.0	0.010
HSM-I2-5	0.00	0.71	0.28	0.0	0.009
MNW-14(I2)	0.00	0.70	0.28	0.0	0.013
Average	**0.00**	**0.71**	**0.28**	**0.0**	**0.01**
			Central – Near P&T System		
SFMW-20(I1)	0.00	0.82	0.00	0.0	0.18
SFMW-22(D1)	0.00	0.52	0.35	0.0	0.13
SFMW-23(D2)	0.00	0.72	0.00	0.0	0.28
SFMW-21(I2)	0.00	0.00	0.00	0.0	1.0
SFMW-32(I2)	0.00	0.00	0.00	0.0	1.0
Average	**0.00**	**0.41**	**0.07**	**0.0**	**0.52**
			Eastern - Down Gradient		
MNW-5(D1)	0.04	0.46	0.49	0.0	0.020
MNW-5(D2)	0.01	0.45	0.52	0.0	0.019
SFMW-44(D2)	0.02	0.52	0.46	0.0	0.002
SFMW-40(D3)	0.00	0.53	0.46	0.0	0.007
SFMW-43(I1)	0.00	0.57	0.39	0.0	0.042
Average	**0.01**	**0.51**	**0.46**	**0.0**	**0.02**

FIGURE 7

Mole Fraction of PCE, TCE and Their Degradation Products at Monitor Wells Located in Presumed Source Area

Fruit Avenue Plume Superfund Site, Albuquerque NM

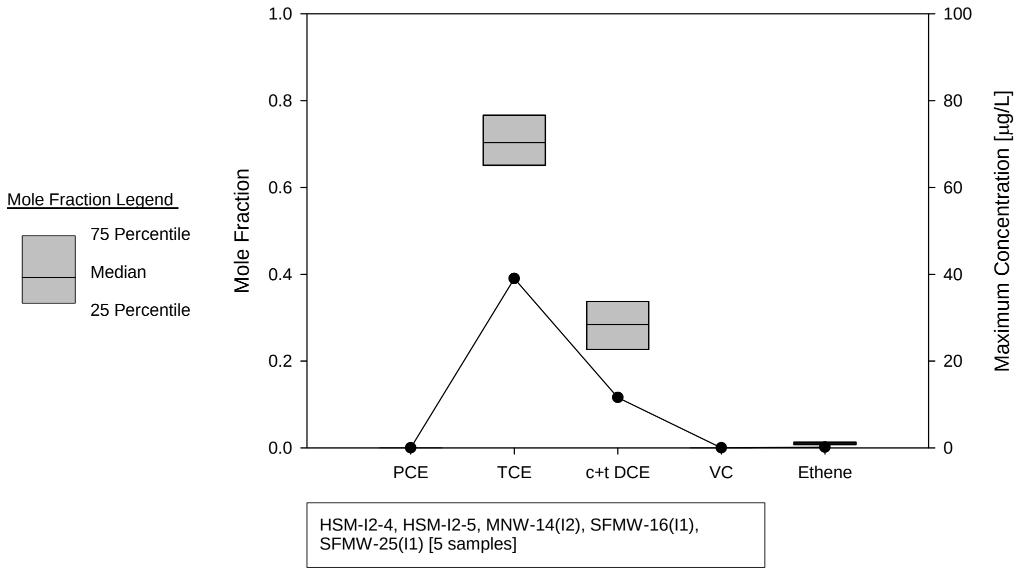


FIGURE 8

Mole Fraction of PCE, TCE and Their Degradation Products at Monitor Wells Located Near the P&T System

Fruit Avenue Plume Superfund Site, Albuquerque NM

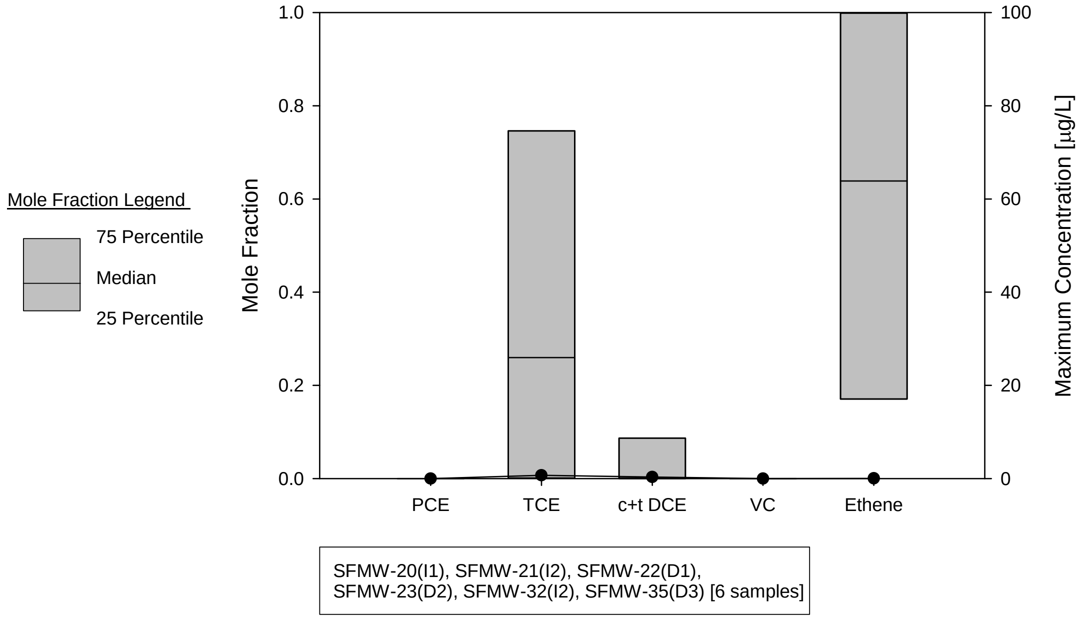
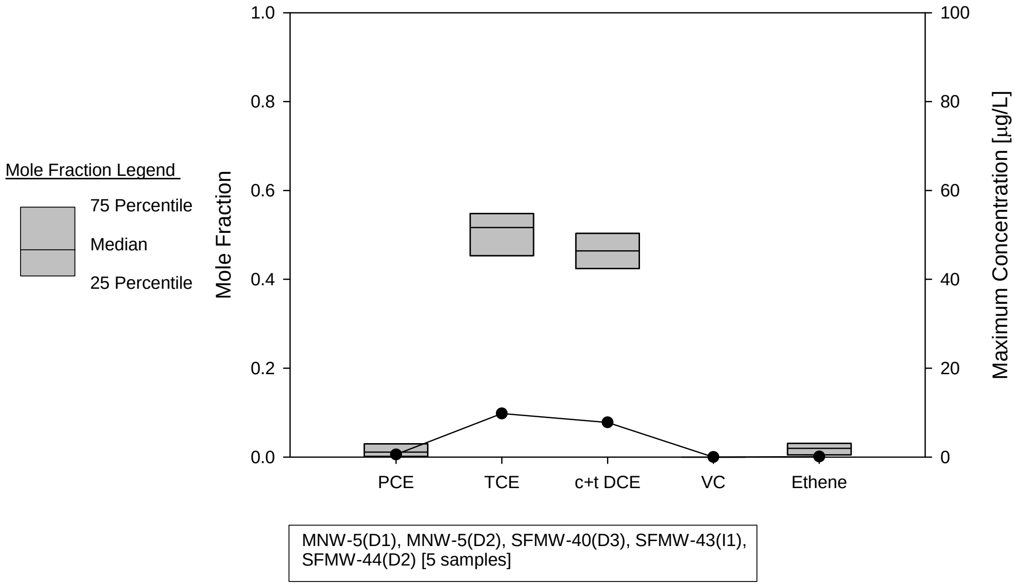


FIGURE 9

Mole Fraction of PCE, TCE and Their Degradation Products at Monitor Wells Located in the Eastern Portion of the Plume

Fruit Avenue Plume Superfund Site, Albuquerque NM



Western Portion of the Site near the Presumed Source Area

In the intermediate and shallow aquifer zones in the western portion of the plume [5 sample locations, **Table 1** and **Figure 7**]:

- 65 to 82 percent (0.65 to 0.82 of the mole-fraction) of the cVOC mass is TCE
- 18 to 34 percent of the cVOC mass is cis-1,2-DCE
- 0.5 to 1.3 percent of the cVOC mass is ethene

These mole fractions/relative percentages indicate that in this portion of the site, one-fifth to one-third of the total cVOC concentration is currently present in the form of DCE. The fraction of DCE present suggests that conditions are amenable to degradation of TCE to cis-1,2-DCE. The smaller mole fraction of DCE in this area compared to the eastern downgradient portion of the site, where cis-1,2-DCE accounts for 33 percent of the mole fraction, may suggest that a weak TCE source (e.g., matrix diffusion) remains in the presumed source area or geochemical conditions are less favorable for TCE to cis-1,2-DCE transformation.

Central Portion of the Site near the P&T System

In the central portion of the site near the P&T system (5 sample locations, **Table 1** and **Figure 6**), TCE concentrations are very low, ranging from ND to 0.69 µg/L. Where TCE is present:

- 52 to 82 percent of the cVOC mass is TCE
- 0 or 35 percent of the cVOC mass is cis-1,2-DCE
- 13 to 28 percent of the cVOC mass is ethene

At the locations where TCE is not-detected, and the aquifer restored by the P&T remedy, 100 percent of the cVOC mass is ethene.

Eastern Downgradient Portion of the Site

In the eastern downgradient portion of the plume, [5 sample locations, **Table 1** and **Figure 9**]:

- 45 to 57 percent of the cVOC mass is TCE
- 39 to 52 percent of the cVOC mass is cis 1,2-DCE
- 0.2 to 4.2 percent of the cVOC mass is ethene

These relative percentages/mole fractions indicate that in this portion of the site, one-third to one-half of the total cVOC concentration is currently present in the form of cis 1,2-DCE. The presence of cis 1,2-DCE suggests that conditions are more amenable for TCE degradation of TCE because this portion of the plume has a higher mole-fraction of cis 1,2-DCE than the western portion of the plume near the presumed source area.

The high fraction of ethene in SFMW-20(I2), SFMW-22(D1), and SFMW-23(D2) is likely the result of relatively low concentrations of TCE and cis 1,2-DCE in the treated water that is reinjected on the upgradient side of this portion of the site.

Summary

Across the site, TCE concentrations are generally declining with stable or decreasing concentrations observed at 53 percent of the monitoring well locations. The following locations exhibited increasing concentrations:

Immediately downgradient of the presumed historical source area in the vicinity of monitoring well SFMW-16(I1).

In the eastern plume D2/D3 aquifer zones where increasing concentrations at MNW-4(D2), SFMW-44(D2), and MNW-5(D3) suggest that the plume is advancing into the D3 aquifer zone under the influence of the regional groundwater flow gradient.

The mole ratio evaluation shows that approximately one-fifth to one-half of the TCE present in groundwater has been transformed to cis 1,2-DCE. Degradation of TCE is observed at varying degrees across the site.

The elevated mole-fraction of ethene and decreasing DCE concentrations suggest that a degradation process is operative. The absence of VC suggests that stepwise reductive dechlorination is not likely the process responsible for transformation of cis 1,2-DCE.

Works Cited

U.S. Environmental Protection Agency (EPA). 1999. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*. OSWER Directive 9200.4-17P. April 1999.

Attachment 1
Mann-Kendall Analysis – Presumed Source Area

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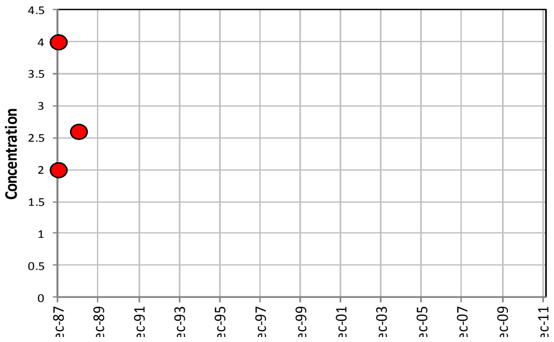
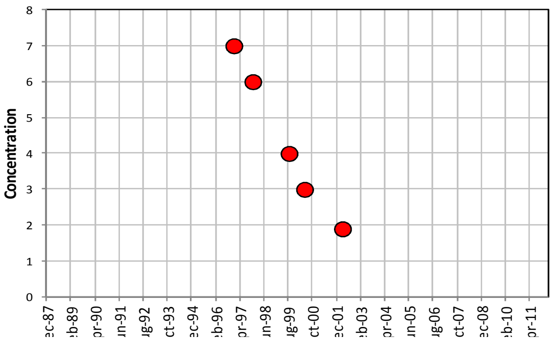
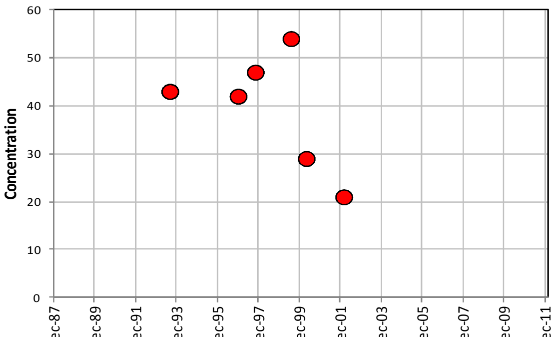


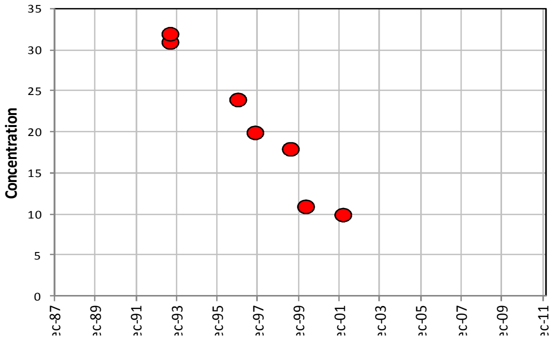
TCE in Conv_Center



TCE in DM-01_(S)



TCE in DM-02_(I1/I2)



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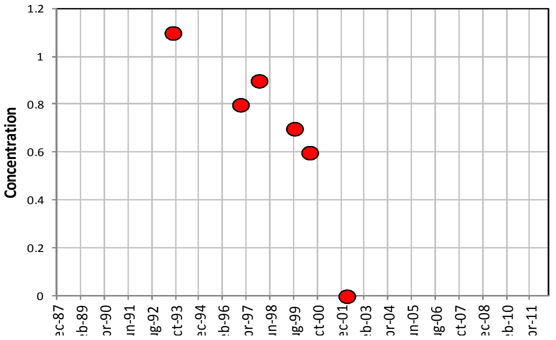

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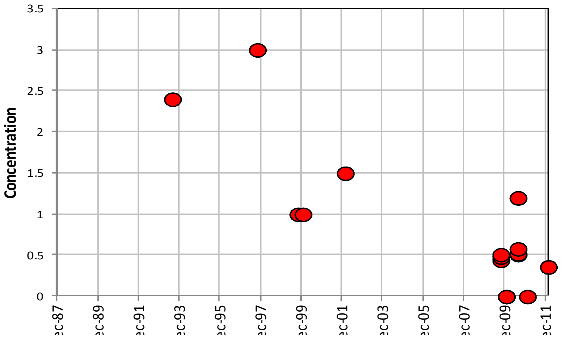

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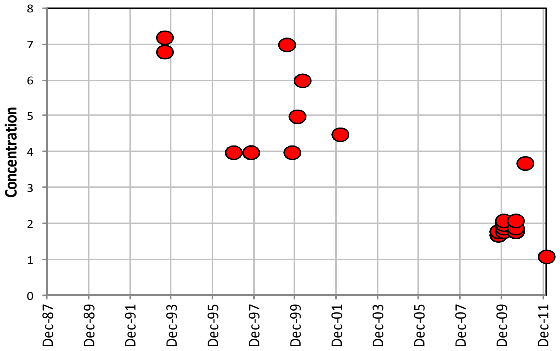

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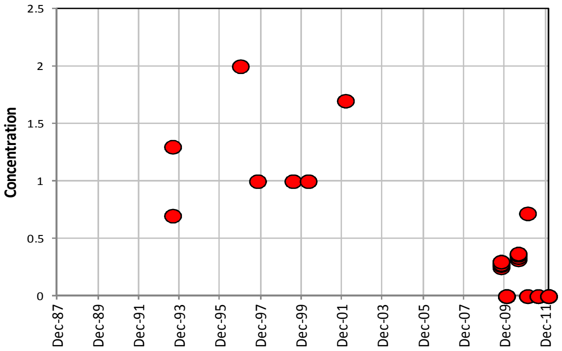
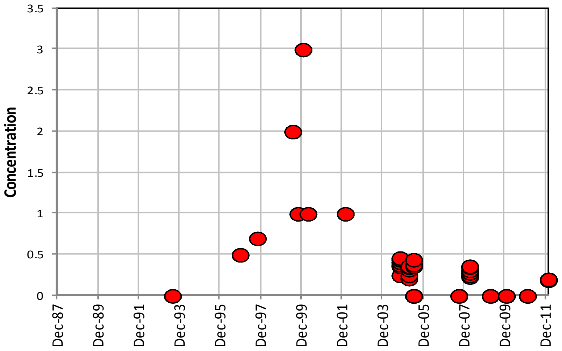
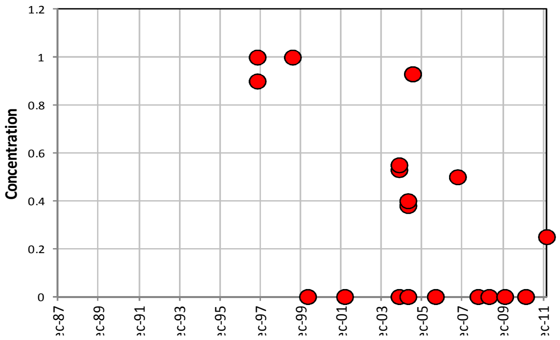


TCE in DM-07_(I1/I2)



TCE in DM-08_(I1/I2)

TCE in DM-09_(S)



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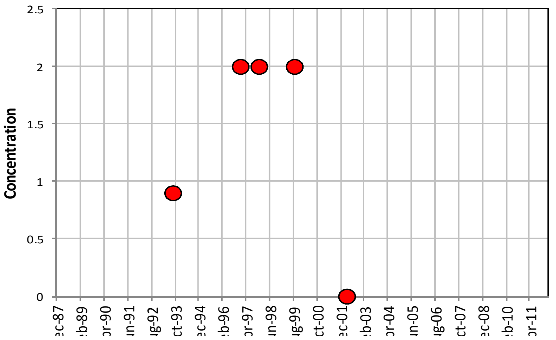

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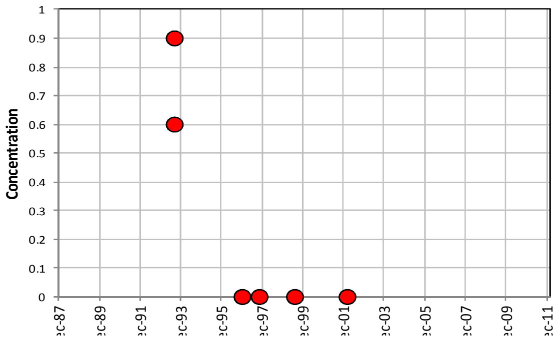

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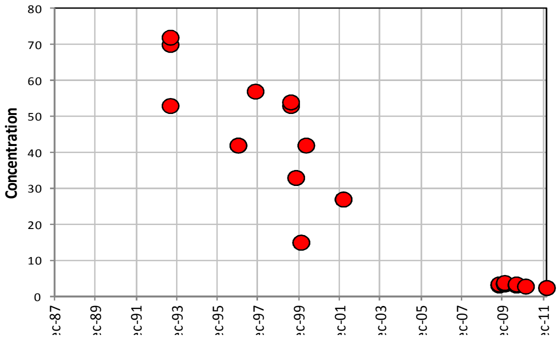

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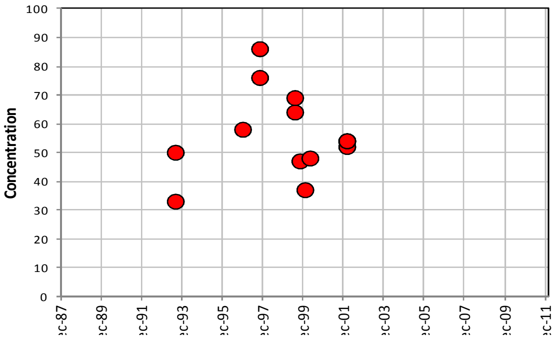

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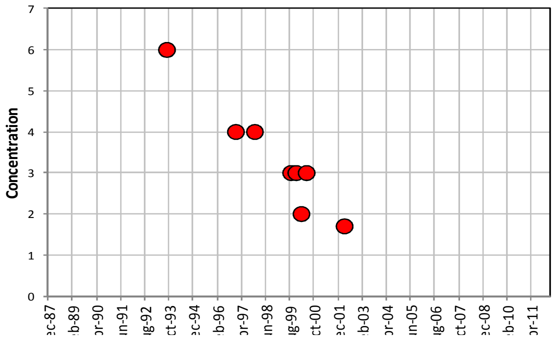
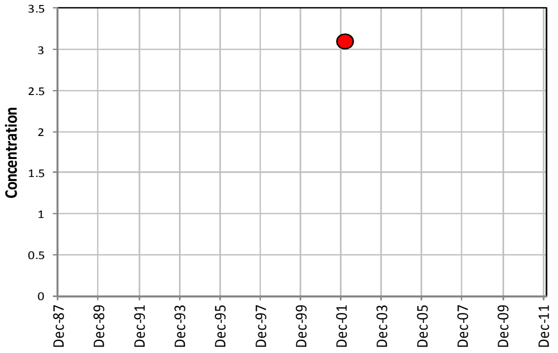


TCE in FH-MW3_(S)



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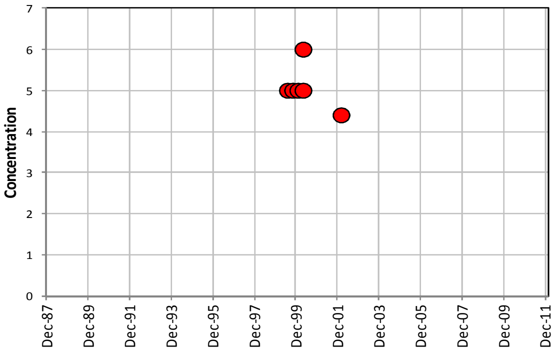
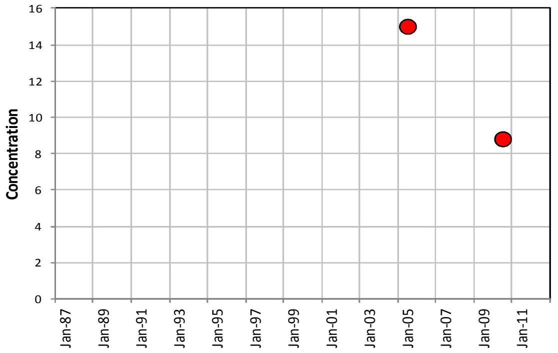
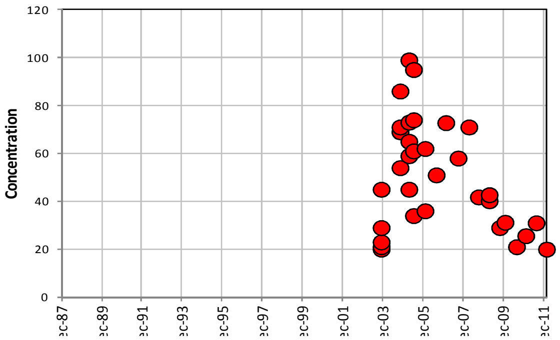


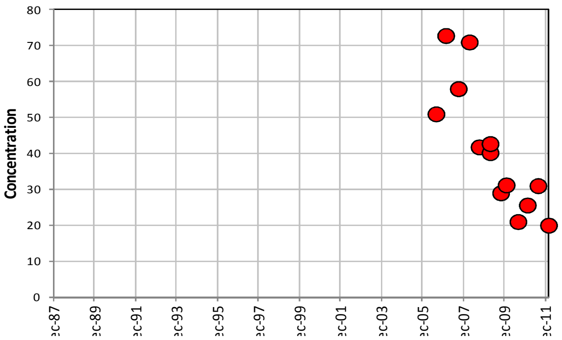
TCE in HSM-I2-4_(I2)



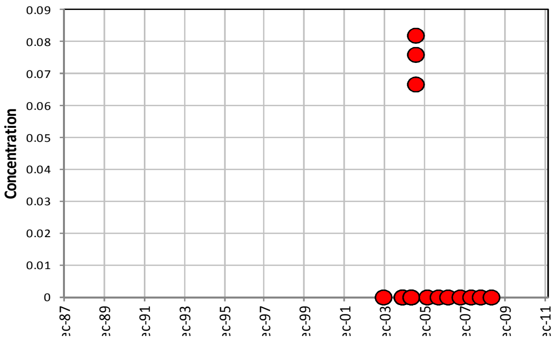
TCE in HSM-I2-5_(I2)



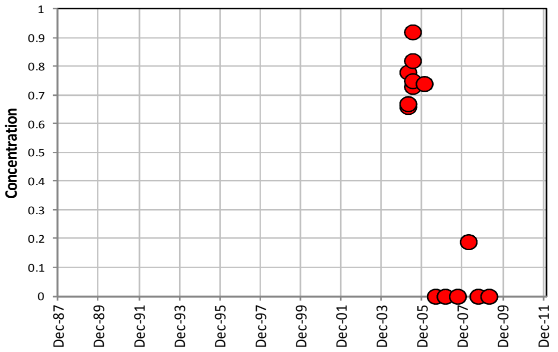
TCE in HSM-I2-5_(I2) (Recent Only)



TCE in MNW-10_(I1)



TCE in MNW-14_(D2)



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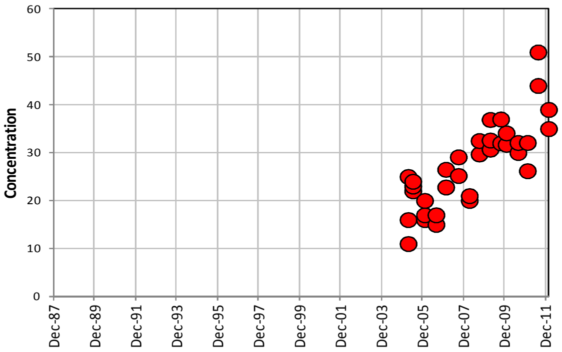
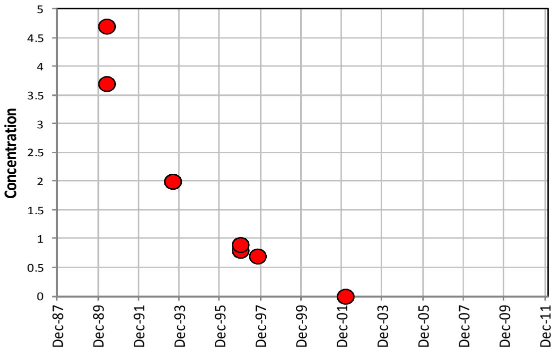
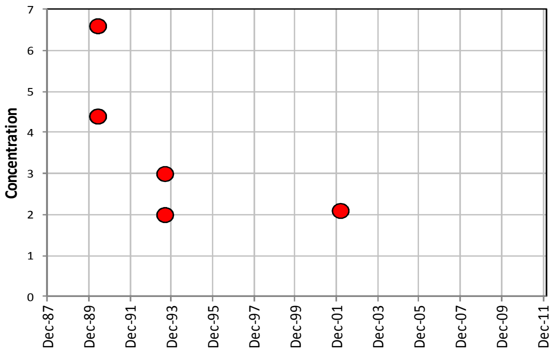


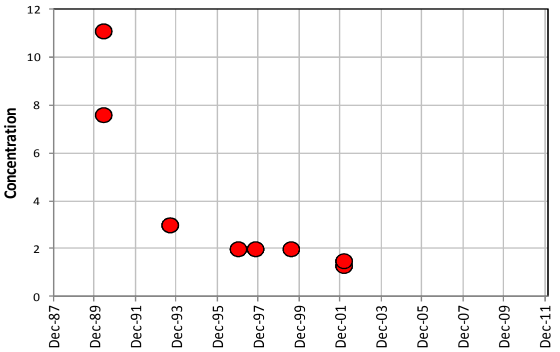
TCE in SFMW-01_(S)



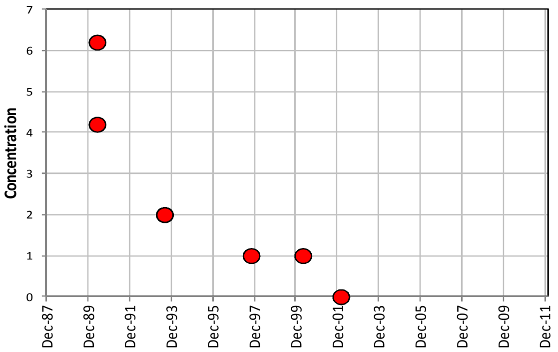
TCE in SFMW-02_(S)



TCE in SFMW-03_(S)



TCE in SFMW-04_(S)



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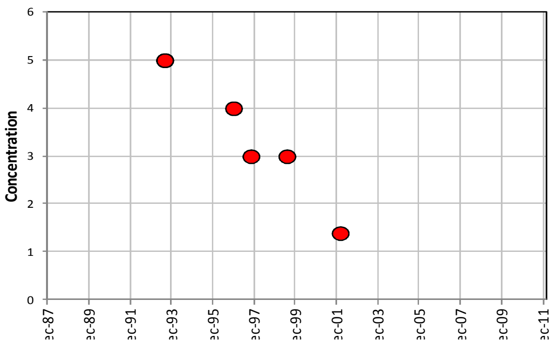

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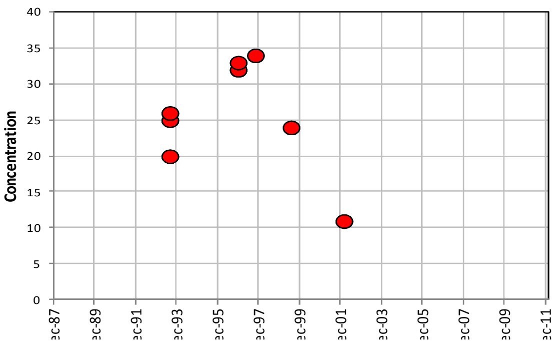

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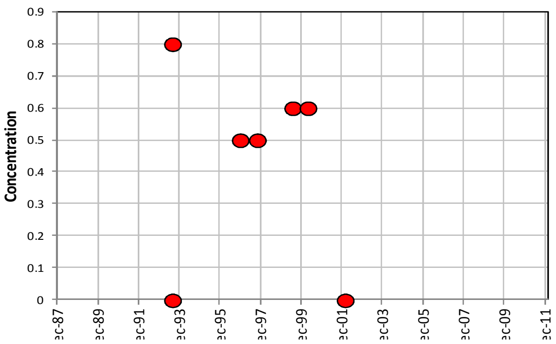

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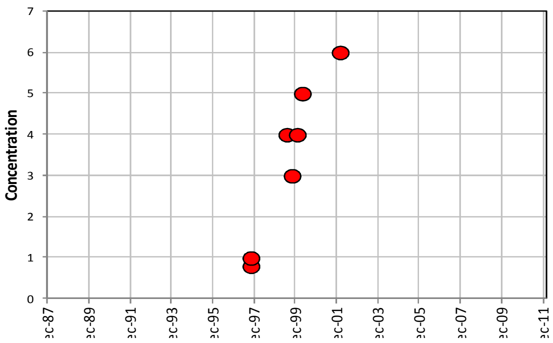

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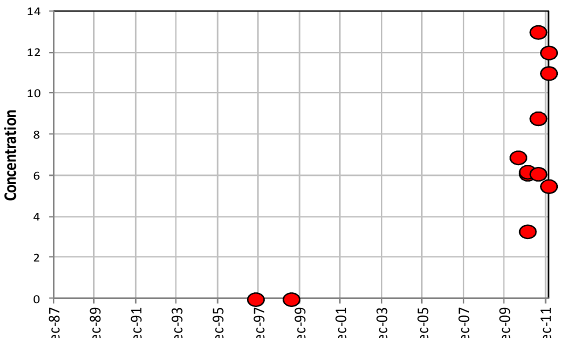
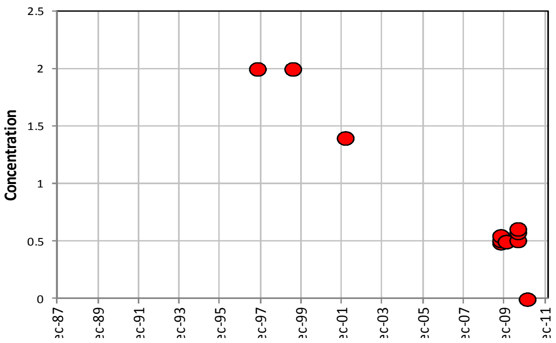


TCE in SFMW-12_(I1)



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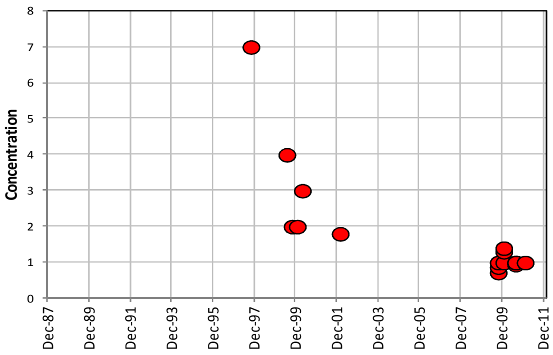

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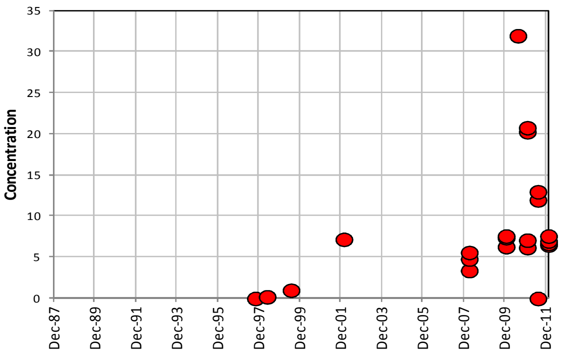
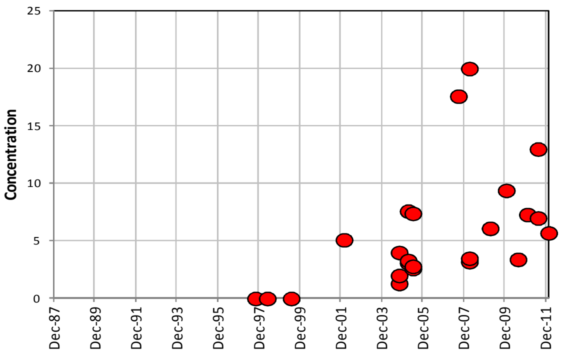
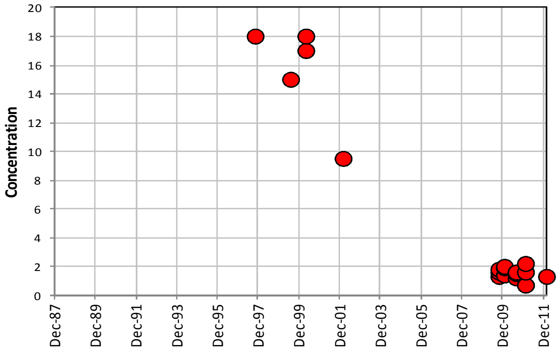


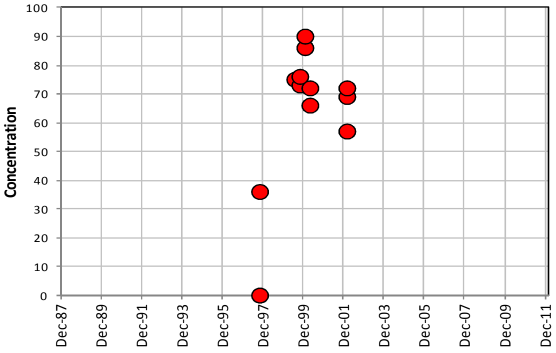
TCE in SFMW-17_(I2)



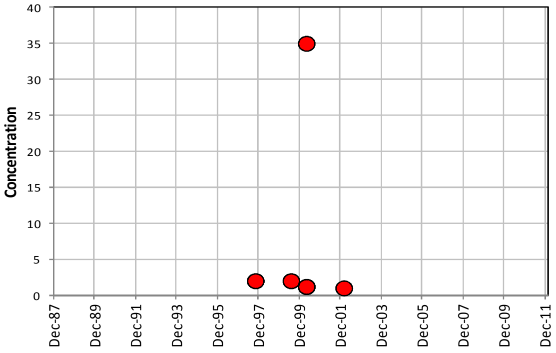
TCE in SFMW-18_(I1)



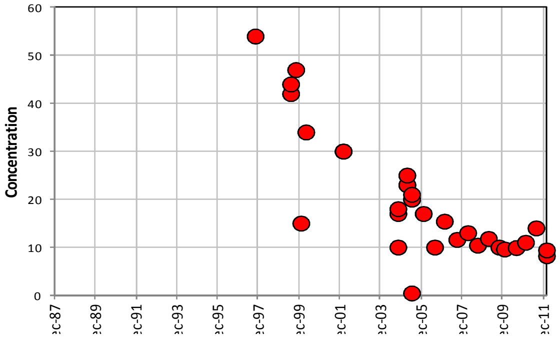
TCE in SFMW-19_(I2)



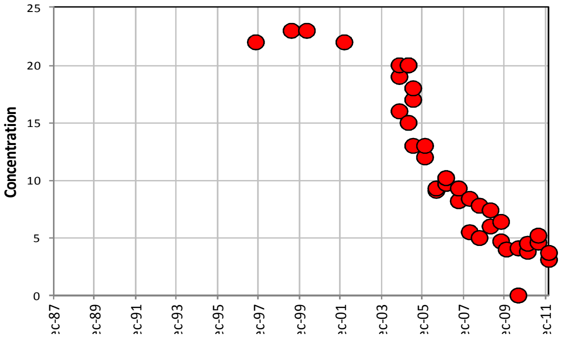
TCE in SFMW-24_(S)



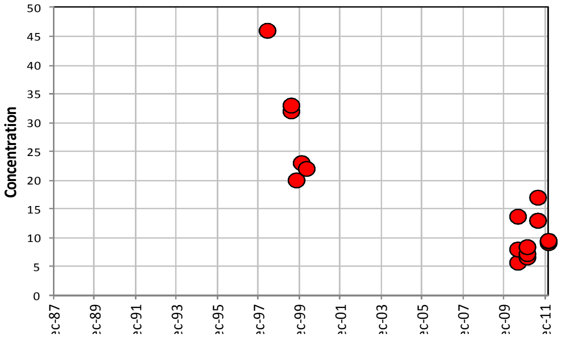
TCE in SFMW-25_(I1/I2)



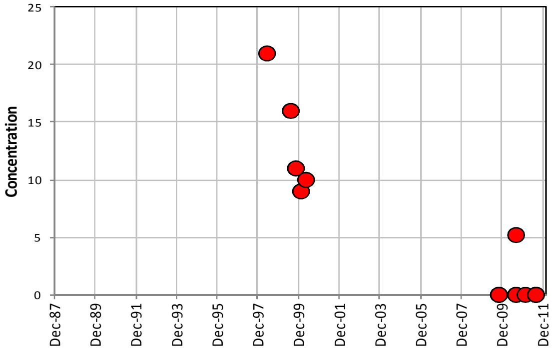
TCE in SFMW-26_(I2)



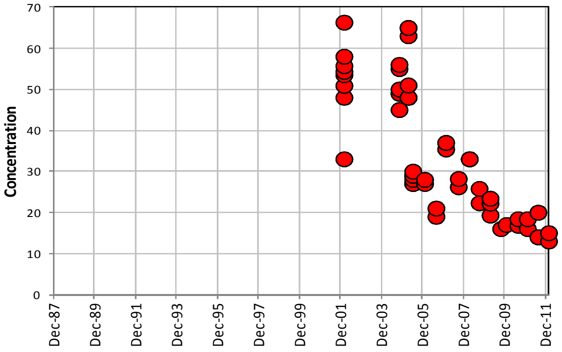
TCE in SFMW-27_(I2)



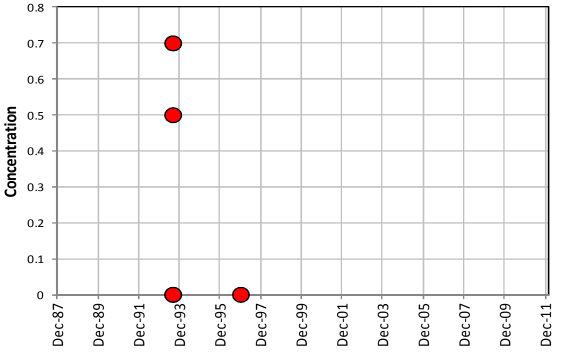
TCE in SFMW-28_(I2)

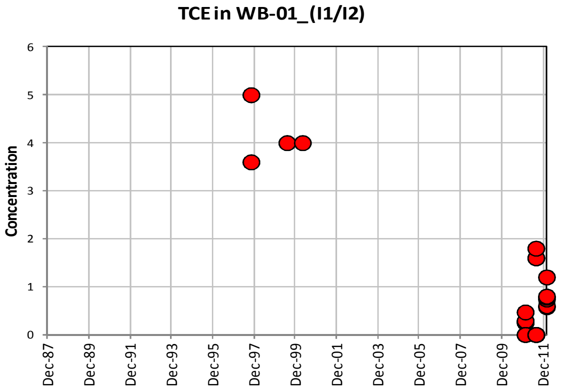


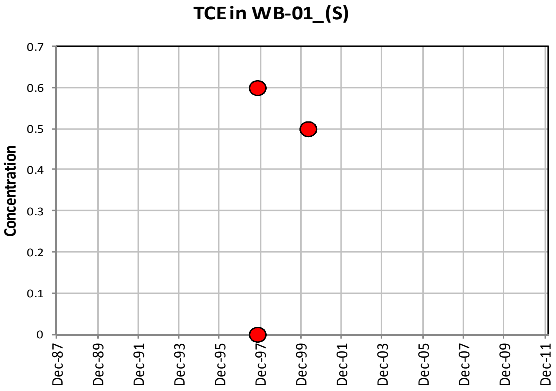
TCE in SFMW-47_(I1/I2)

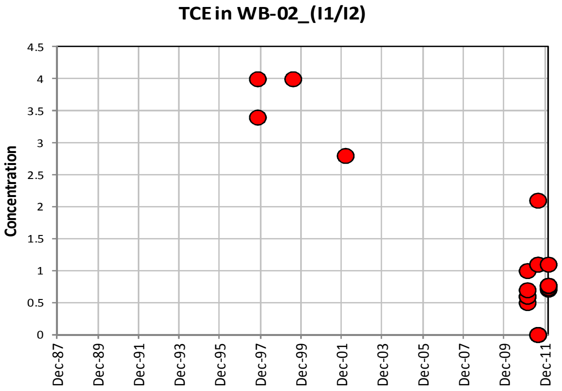


TCE in SHB-4/WellNo1(S)




TCE in WB-01_(I1/I2)
Concentration
6
5
4
3
2
1
0
Dec-87
Dec-89
Dec-91
Dec-93
Dec-95
Dec-97
Dec-99
Dec-01
Dec-03
Dec-05
Dec-07
Dec-09
Dec-11


TCE in WB-01_(S)
Concentration
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Dec-87
Dec-89
Dec-91
Dec-93
Dec-95
Dec-97
Dec-99
Dec-01
Dec-03
Dec-05
Dec-07
Dec-09
Dec-11


TCE in WB-02_(I1/I2)
Concentration
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Dec-87
Dec-89
Dec-91
Dec-93
Dec-95
Dec-97
Dec-99
Dec-01
Dec-03
Dec-05
Dec-07
Dec-09
Dec-11

Nonparametric Trend Analysis for TCE

Well	Detect	Nondetect	Total Samples	Detection Frequency	Min	Max	Mean	Median	MK Result	Trend	Stability
Conv_Center	6	0	6	100	2.00	4.00	2.87	2.60	70.3% (+)	**No Trend**	**Stable**
DM-01_(S)	5	0	5	100	1.90	7.00	4.38	4.00	NA	IS	NA
DM-02_(I1/I2)	7	0	7	100	21.0	54.0	39.9	43.0	76.4% (-)	**No Trend**	**Stable**
DM-03_(I1/I2)	7	0	7	100	10.0	32.0	20.9	20.0	99.9% (sig -)	**Decreasing Trend**	NA
DM-04_(S)	5	1	6	83	0.000	1.10	0.683	0.750	99.2% (sig -)	**Decreasing Trend**	NA
DM-05_(S)	13	3	16	81	0.000	3.00	0.844	0.515	97.1% (sig -)	**Decreasing Trend**	NA
DM-06_(I1/I2)	32	0	32	100	1.10	7.20	2.96	2.00	99.3% (sig -)	**Decreasing Trend**	NA
DM-07_(I1/I2)	20	18	38	53	0.000	2.00	0.348	0.260	100.0% (sig -)	**Decreasing Trend**	NA
DM-08_(I1/I2)	31	12	43	72	0.000	3.00	0.393	0.310	100.0% (sig -)	**Decreasing Trend**	NA
DM-09_(S)	11	9	20	55	0.000	1.00	0.369	0.315	96.3% (sig -)	**Decreasing Trend**	NA
DM-10_(S)	4	1	5	80	0.000	2.00	1.38	2.00	NA	IS	NA
DM-11_(S)	2	4	6	33	0.000	0.900	0.250	0.000	NA	>50% ND	NA
DM-12_(I1/I2)	36	0	36	100	2.40	72.0	18.7	3.45	100.0% (sig -)	**Decreasing Trend**	NA
DM-13_(I1)	14	0	14	100	33.0	86.0	55.9	54.0	52.1% (+)	**No Trend**	**Stable**
DM-13_(S)	8	0	8	100	1.70	6.00	3.34	3.00	99.7% (sig -)	**Decreasing Trend**	NA
FH-MW3_(S)	1	0	1	100	3.10	3.10	NA	NA	NA	IS	NA
FH-MW4_(S)	6	0	6	100	4.40	6.00	5.07	5.00	50.0% (-)	**No Trend**	**Stable**
HSM-I2-4_(I2)	2	0	2	100	8.80	15.0	11.9	11.9	NA	IS	NA
HSM-I2-5_(I2)	34	0	34	100	20.0	99.0	50.7	48.0	85.4% (-)	**No Trend**	**Stable**
HSM-I2-5_(I2) (Recent Only)	13	0	13	100	20.0	72.8	41.2	40.2	100.0% (sig -)	**Decreasing Trend**	NA
MNW-10_(I1)	3	14	17	18	0.000	0.082	0.013	0.000	NA	>50% ND	NA
MNW-14_(D2)	12	10	22	55	0.000	0.920	0.357	0.190	99.5% (sig -)	**Decreasing Trend**	NA
MNW-14_(I2)	34	0	34	100	11.0	51.0	27.6	27.8	100.0% (sig +)	**Increasing Trend**	NA
SFMW-01_(S)	7	1	8	88	0.000	4.70	1.85	1.45	99.5% (sig -)	**Decreasing Trend**	NA
SFMW-02_(S)	6	0	6	100	2.00	6.60	3.75	3.70	81.5% (-)	**No Trend**	**Stable**
SFMW-03_(S)	9	0	9	100	1.30	11.1	3.72	2.00	99.9% (sig -)	**Decreasing Trend**	NA
SFMW-04_(S)	6	1	7	86	0.000	6.20	2.34	2.00	99.5% (sig -)	**Decreasing Trend**	NA
SFMW-05_(S)	7	0	7	100	1.40	5.00	3.77	4.00	99.5% (sig -)	**Decreasing Trend**	NA
SFMW-06_(I1)	8	0	8	100	11.0	34.0	25.6	25.5	64.0% (+)	**No Trend**	**Stable**
SFMW-07_(S)	5	2	7	71	0.000	0.800	0.429	0.500	55.7% (-)	**No Trend**	**Stable**
SFMW-09_(I1)	7	0	7	100	0.800	6.00	3.40	4.00	99.7% (sig +)	**Increasing Trend**	NA
SFMW-10_(I2)	10	2	12	83	0.000	13.0	6.58	6.15	99.6% (sig +)	**Increasing Trend**	NA
SFMW-12_(I1)	12	1	13	92	0.000	2.00	0.781	0.510	88.6% (-)	**No Trend**	**Stable**
SFMW-13_(I2)	17	0	17	100	0.720	7.00	1.83	1.00	99.2% (sig -)	**Decreasing Trend**	NA

Nonparametric Trend Analysis for TCE

Well	Detect	Nondetect	Total Samples	Detection Frequency	Min	Max	Mean	Median	MK Result	Trend	Stability
SFMW-16_(I1)	20	2	22	91	0.000	32.0	8.30	6.85	99.4% (sig +)	**Increasing Trend**	NA
SFMW-17_(I2)	21	3	24	88	0.000	20.0	5.64	3.75	100.0% (sig +)	**Increasing Trend**	NA
SFMW-18_(I1)	20	0	20	100	0.700	18.0	5.00	1.60	99.6% (sig -)	**Decreasing Trend**	NA
SFMW-19_(I2)	11	1	12	92	0.000	90.0	64.3	72.0	55.3% (+)	**No Trend**	**Stable**
SFMW-24_(S)	6	0	6	100	1.00	35.0	7.07	1.60	76.5% (-)	**No Trend**	**Not Stable**
SFMW-25_(I1/I2)	32	0	32	100	0.430	54.0	19.8	16.2	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-26_(I2)	37	1	38	97	0.000	23.0	10.9	9.20	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-27_(I2)	18	0	18	100	5.70	46.0	16.5	13.0	97.8% (sig -)	**Decreasing Trend**	NA
SFMW-28_(I2)	6	10	16	38	0.000	21.0	4.51	0.000	NA	>50% ND	NA
SFMW-47_(I1/I2)	51	0	51	100	13.0	66.3	35.3	29.0	100.0% (sig -)	**Decreasing Trend**	NA
SHB-4/WellNo1(S)	2	3	5	40	0.000	0.700	0.240	0.000	NA	IS	NA
WB-01_(I1/I2)	18	6	24	75	0.000	5.00	1.16	0.590	72.4% (-)	**No Trend**	**Not Stable**
WB-01_(S)	2	1	3	67	0.000	0.600	0.367	0.500	NA	IS	NA
WB-02_(I1/I2)	20	3	23	87	0.000	4.00	1.22	0.770	71.0% (-)	**No Trend**	**Stable**

Notes:

IS = insufficient data (less than 6 sample results).

>50% ND = greater than 50 percent nondetects.

Trend analysis performed using Mann Kendall single-tailed test at 0.05 significance level.

For monitoring points exhibiting no trend at the 95% confidence level, concentrations are deemed stable if the coefficient of variation (COV) is equal to or less than one.

Attachment 2
Mann-Kendall Analysis – Pump & Treat Area

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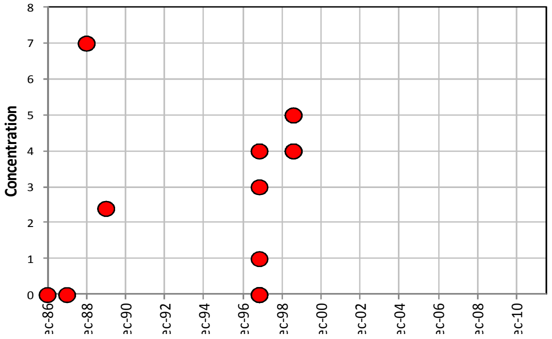
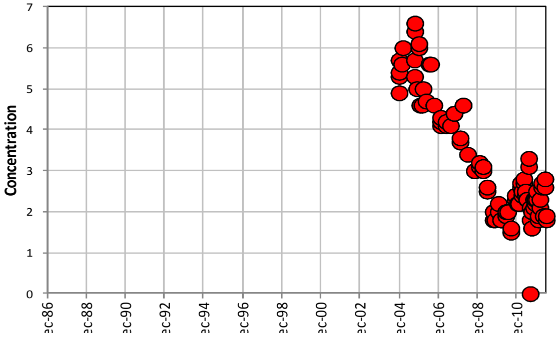
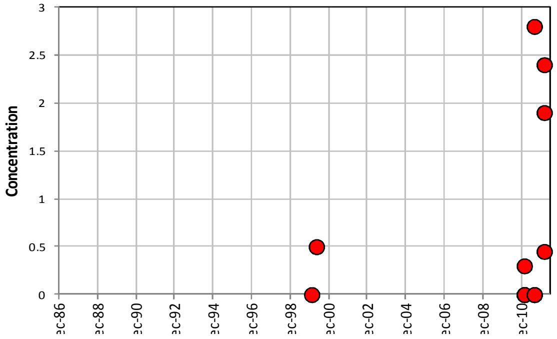
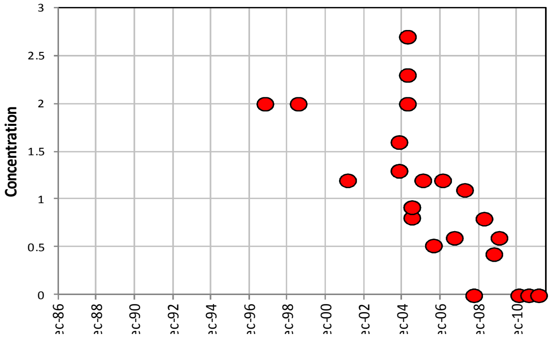
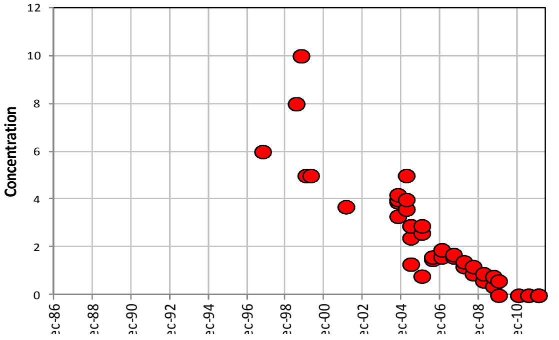
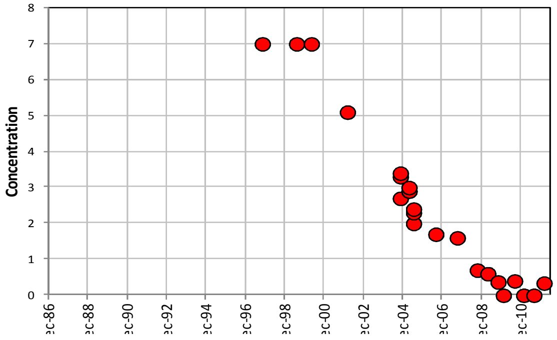

DCE in COKE_Supply

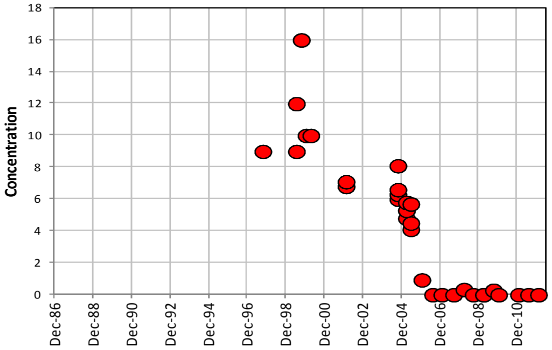

DCE in D2E-P1 (D2)

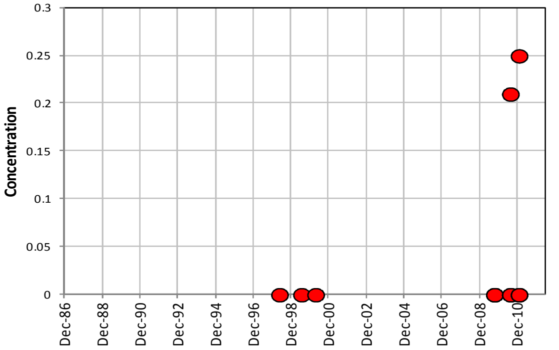

DCE in McDonalds_(D2)

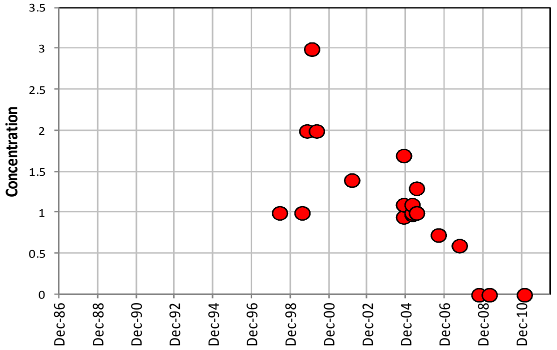

DCE in SFMW-20_(I1)


DCE in SFMW-21_(I2)

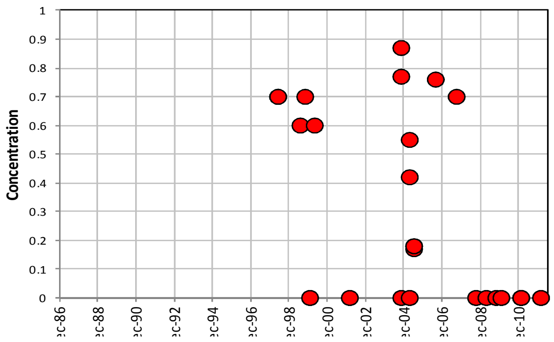

DCE in SFMW-22_(D1)


DCE in SFMW-23_(D2)

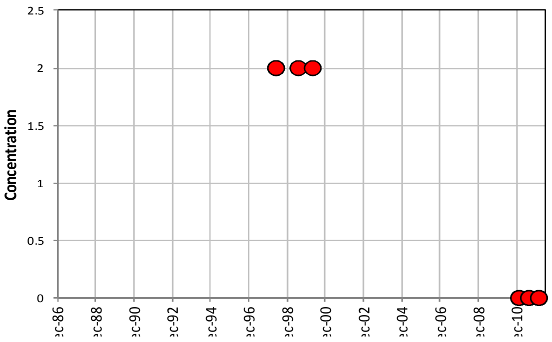

DCE in SFMW-31_(I2)


DCE in SFMW-32_(I2)

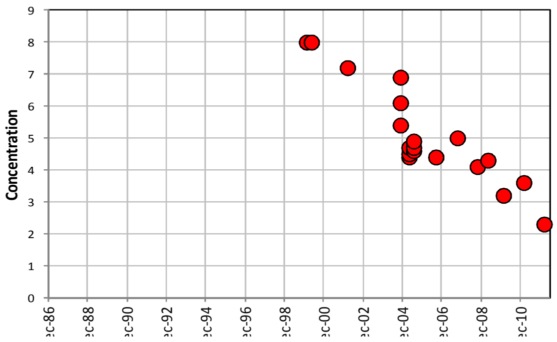
DCE in SFMW-35_(D3)



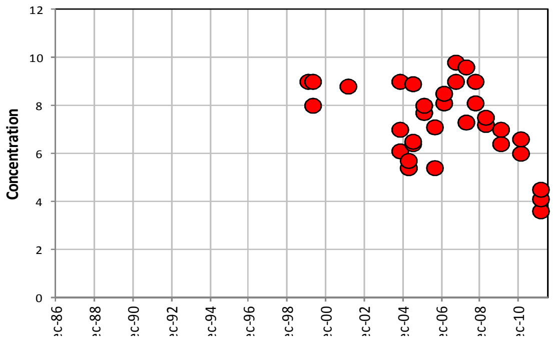
DCE in SFMW-37_(I2)



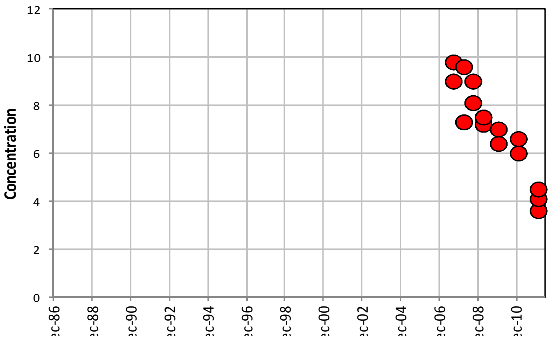
DCE in SFMW-38_(D1)



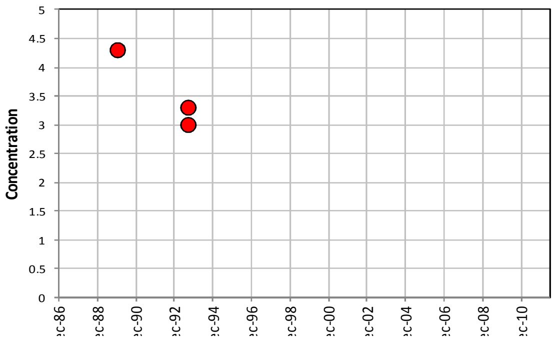
DCE in SFMW-39_(D2)



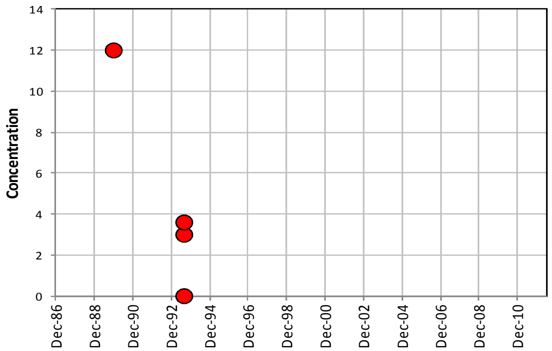
DCE in SFMW-39_(D2) (Recent)



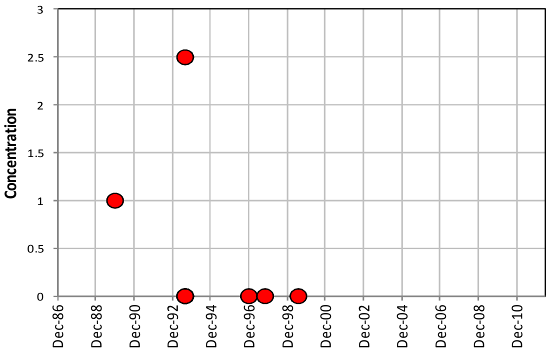
DCE in SPSC-MW1



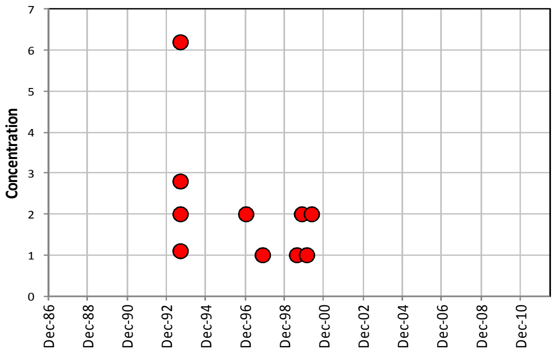
DCE in SPSC-MW2

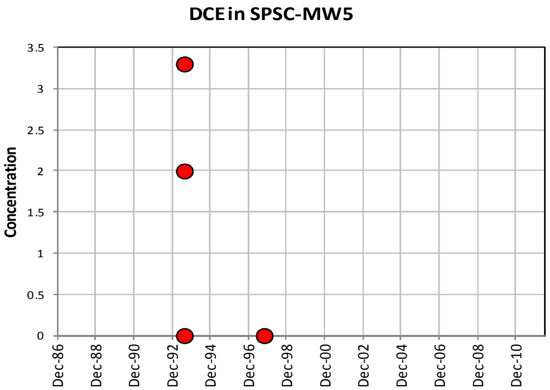


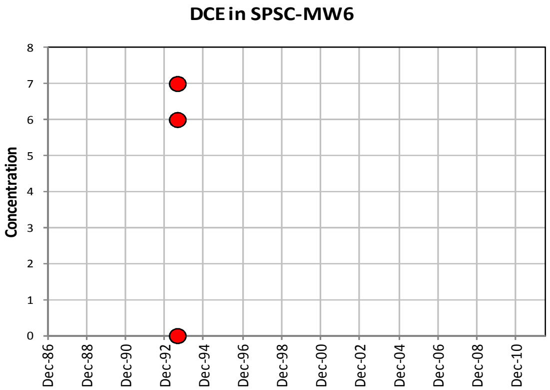
DCE in SPSC-MW3



DCE in SPSC-MW4




DCE in SPSC-MW5
Concentration
3.5
3
2.5
2
1.5
1
0.5
0
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Dec-00
Dec-02
Dec-04
Dec-06
Dec-08
Dec-10


DCE in SPSC-MW6
Concentration
8
7
6
5
4
3
2
1
0
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Dec-00
Dec-02
Dec-04
Dec-06
Dec-08
Dec-10

Nonparametric Trend Analysis for DCE

Well	Detect	Nondetect	Total Samples	Detection Frequency	Min	Max	Mean	Median	MK Result	Trend	Stability
COKE_Supply	15	5	20	75	0.000	7.00	3.09	4.00	96.3% (sig +)	**Increasing Trend**	NA
D2E-P1 (D2)	98	1	99	99	0.000	6.60	3.18	2.60	100.0% (sig -)	**Decreasing Trend**	NA
McDonalds_(D2)	6	6	12	50	0.000	2.80	0.696	0.150	82.7% (+)	**No Trend**	**Not Stable**
SFMW-20_(I1)	20	4	24	83	0.000	2.70	1.06	1.01	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-21_(I2)	37	8	45	82	0.000	10.0	2.38	1.60	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-22_(D1)	20	3	23	87	0.000	7.00	2.47	2.30	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-23_(D2)	23	10	33	70	0.000	16.0	4.85	5.30	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-31_(I2)	2	10	12	17	0.000	0.250	0.038	0.000	NA	>50% ND	NA
SFMW-32_(I2)	18	3	21	86	0.000	3.00	1.09	1.00	99.9% (sig -)	**Decreasing Trend**	NA
SFMW-35_(D3)	14	11	25	56	0.000	0.870	0.316	0.180	99.5% (sig -)	**Decreasing Trend**	NA
SFMW-37_(I2)	4	9	13	31	0.000	2.00	0.615	0.000	NA	>50% ND	NA
SFMW-38_(D1)	19	0	19	100	2.30	8.00	5.07	4.70	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-39_(D2)	34	0	34	100	3.60	9.80	7.23	7.25	93.5% (-)	**No Trend**	**Stable**
SFMW-39_(D2) (Recent)	15	0	15	100	3.60	9.80	7.05	7.20	100.0% (sig -)	**Decreasing Trend**	NA
SPSC-MW1	3	0	3	100	3.00	4.30	3.53	3.30	NA	IS	NA
SPSC-MW2	3	1	4	75	0.000	12.0	4.65	3.30	NA	IS	NA
SPSC-MW3	2	7	9	22	0.000	2.50	0.389	0.000	NA	>50% ND	NA
SPSC-MW4	10	0	10	100	1.00	6.20	2.11	2.00	72.9% (-)	**No Trend**	**Stable**
SPSC-MW5	2	2	4	50	0.000	3.30	1.33	1.00	NA	IS	NA
SPSC-MW6	2	1	3	67	0.000	7.00	4.33	6.00	NA	IS	NA

Notes:

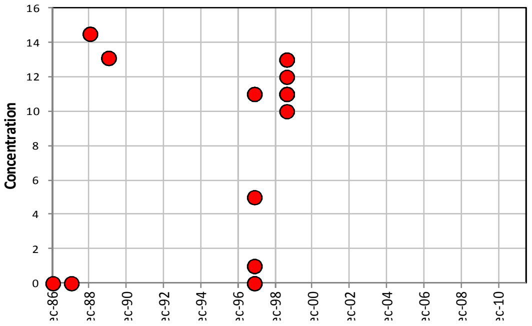
IS = insufficient data (less than 6 sample results).

>50% ND = greater than 50 percent nondetects.

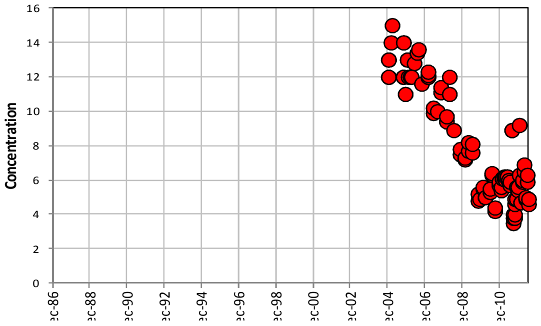
Trend analysis performed using Mann Kendall single-tailed test at 0.05 significance level.

For monitoring points exhibiting no trend at the 95% confidence level, concentrations are deemed stable if the coefficient of variation (COV) is equal to or less than one.

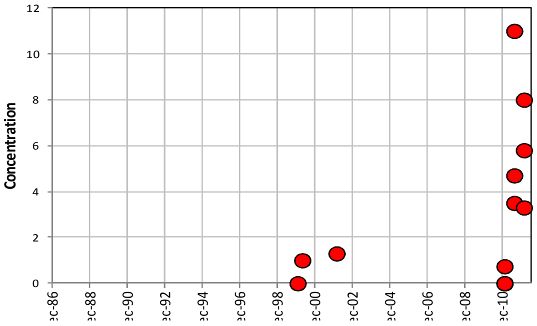
TCE in COKE_Supply



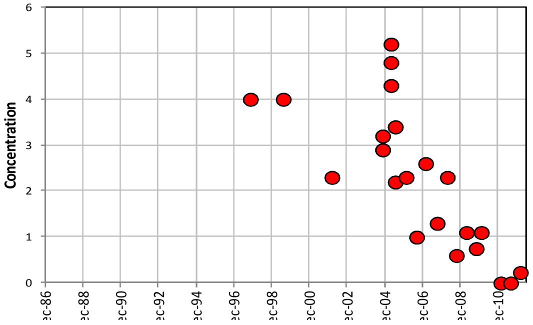
TCE in D2E-P1 (D2)



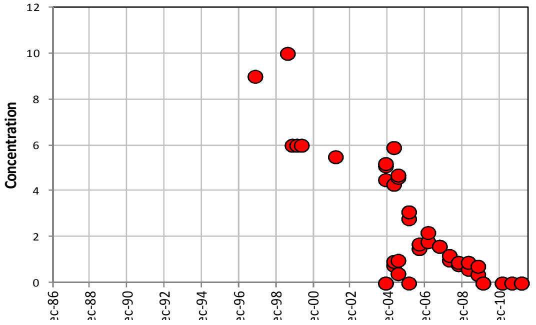
TCE in McDonalds_(D2)



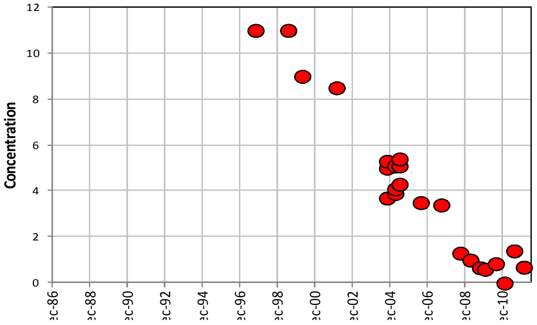
TCE in SFMW-20_(I1)



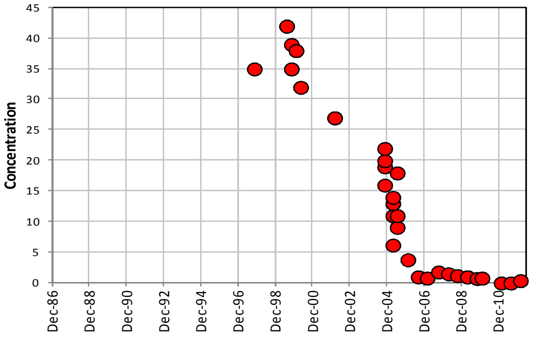
TCE in SFMW-21_(I2)



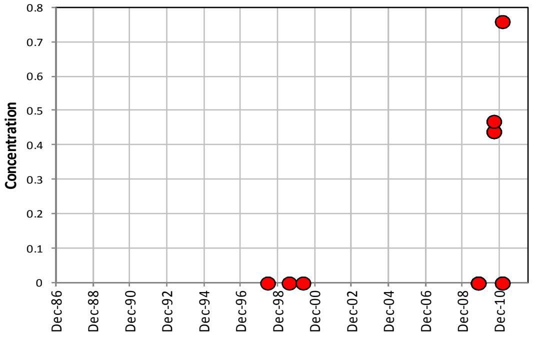
TCE in SFMW-22_(D1)



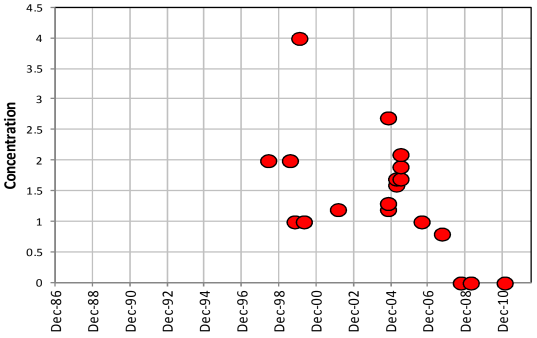
TCE in SFMW-23_(D2)

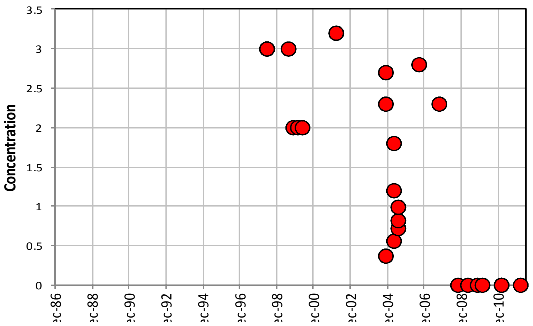


TCE in SFMW-31_(I2)

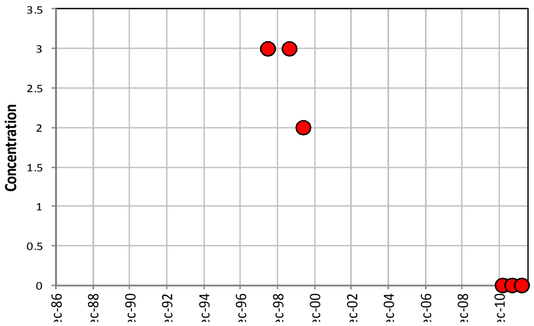


TCE in SFMW-32_(I2)

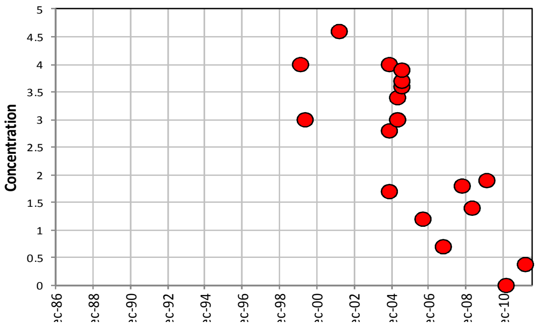




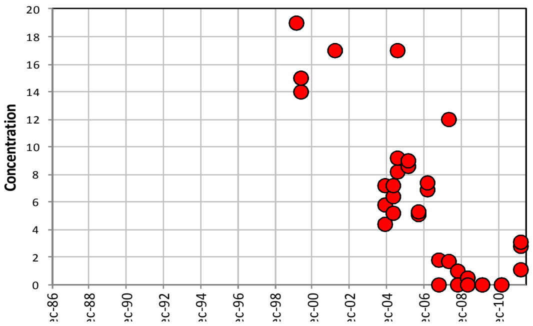
TCE in SFMW-35_(D3)



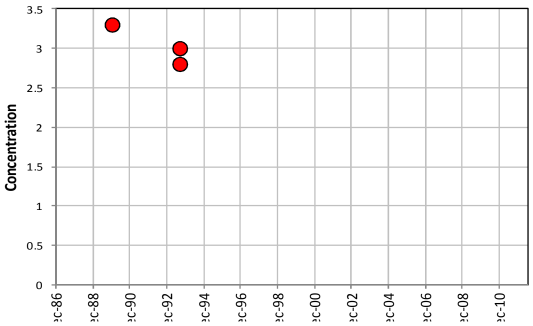
TCE in SFMW-37_(I2)



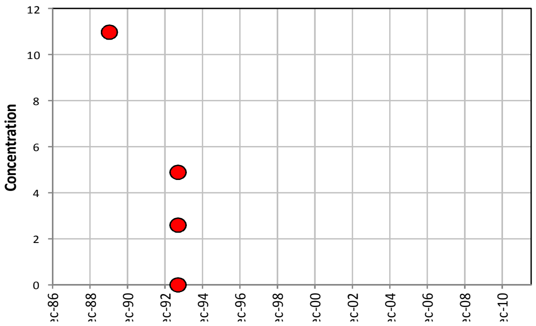
TCE in SFMW-38_(D1)



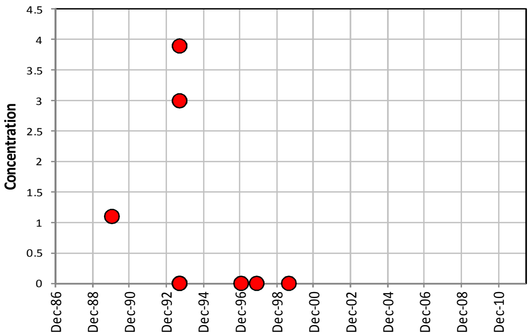
TCE in SFMW-39_(D2)



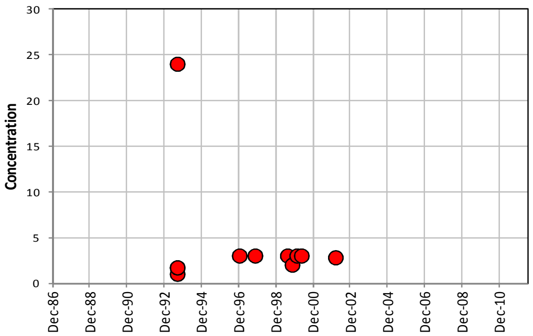
TCE in SPSC-MW1



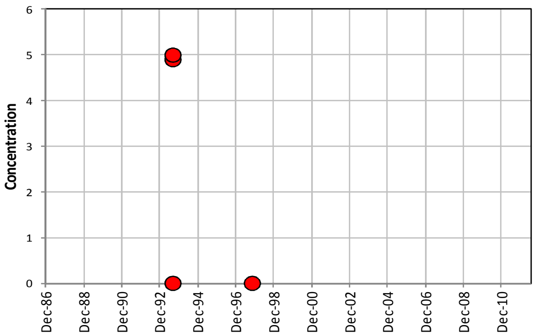
TCE in SPSC-MW2



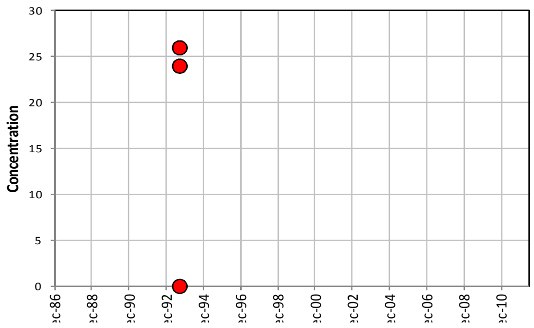
TCE in SPSC-MW3



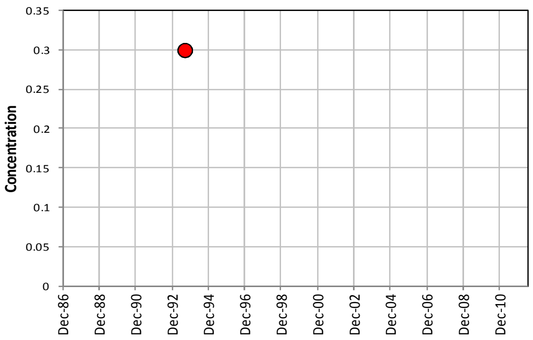
TCE in SPSC-MW4



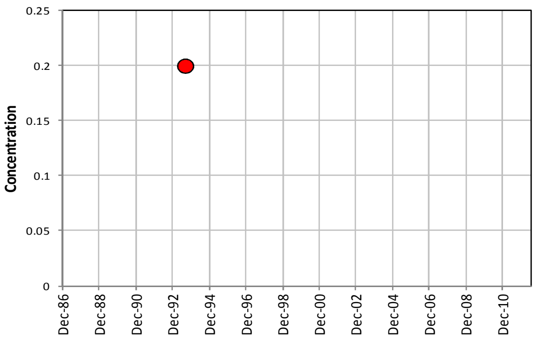
TCE in SPSC-MW5



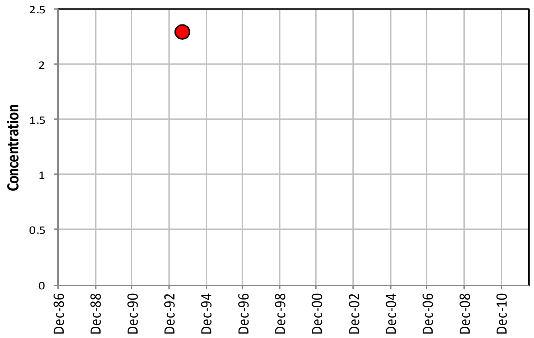
TCE in SPSC-MW6



TCE in SPSC-MWD



TCE in SPSC-W13



TCE in SPSC-W18

Nonparametric Trend Analysis for TCE

Well	Detect	Nondetect	Total Samples	Detection Frequency	Min	Max	Mean	Median	MK Result	Trend	Stability
COKE_Supply	16	4	20	80	0.000	14.5	8.26	11.0	79.1% (+)	**No Trend**	**Stable**
D2E-P1 (D2)	99	0	99	100	3.50	15.0	8.02	6.30	100.0% (sig -)	**Decreasing Trend**	NA
McDonalds_(D2)	9	4	13	69	0.000	11.0	3.03	1.30	99.3% (sig +)	**Increasing Trend**	NA
SFMW-20_(I1)	22	2	24	92	0.000	5.20	2.33	2.30	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-21_(I2)	33	12	45	73	0.000	10.0	2.28	1.00	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-22_(D1)	22	1	23	96	0.000	11.0	4.12	3.90	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-23_(D2)	31	2	33	94	0.000	42.0	14.9	11.0	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-31_(I2)	4	8	12	33	0.000	0.760	0.176	0.000	NA	>50% ND	NA
SFMW-32_(I2)	18	3	21	86	0.000	4.00	1.44	1.30	93.8% (-)	**No Trend**	**Stable**
SFMW-35_(D3)	18	7	25	72	0.000	3.20	1.39	1.20	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-37_(I2)	4	9	13	31	0.000	3.00	0.846	0.000	NA	>50% ND	NA
SFMW-38_(D1)	18	1	19	95	0.000	4.60	2.53	3.00	99.4% (sig -)	**Decreasing Trend**	NA
SFMW-39_(D2)	27	7	34	79	0.000	19.0	5.94	5.25	100.0% (sig -)	**Decreasing Trend**	NA
SPSC-MW1	3	0	3	100	2.80	3.30	3.03	3.00	NA	IS	NA
SPSC-MW2	3	1	4	75	0.000	11.0	4.63	3.75	NA	IS	NA
SPSC-MW3	3	6	9	33	0.000	3.90	0.889	0.000	NA	>50% ND	NA
SPSC-MW4	11	0	11	100	1.00	24.0	4.38	3.00	84.0% (+)	**No Trend**	**Not Stable**
SPSC-MW5	2	2	4	50	0.000	5.00	2.48	2.45	NA	IS	NA
SPSC-MW6	2	1	3	67	0.000	26.0	16.7	24.0	NA	IS	NA
SPSC-MWD	1	0	1	100	0.300	0.300	NA	NA	NA	IS	NA
SPSC-W13	1	0	1	100	0.200	0.200	NA	NA	NA	IS	NA
SPSC-W18	1	0	1	100	2.30	2.30	NA	NA	NA	IS	NA

Notes:

IS = insufficient data (less than 6 sample results).

>50% ND = greater than 50 percent nondetects.

Trend analysis performed using Mann Kendall single-tailed test at 0.05 significance level.

For monitoring points exhibiting no trend at the 95% confidence level, concentrations are deemed stable if the coefficient of variation (COV) is equal to or less than one.

Attachment 3

Mann-Kendall Analysis – Downgradient Area

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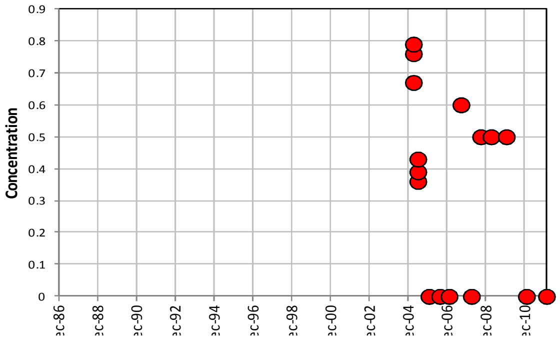
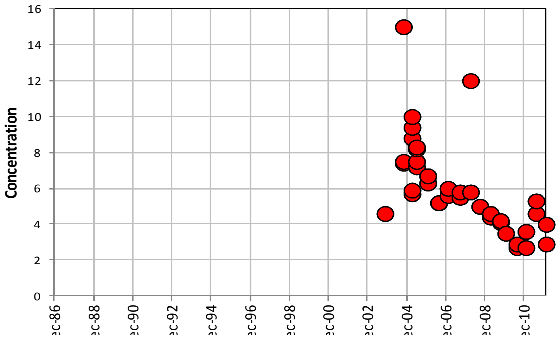
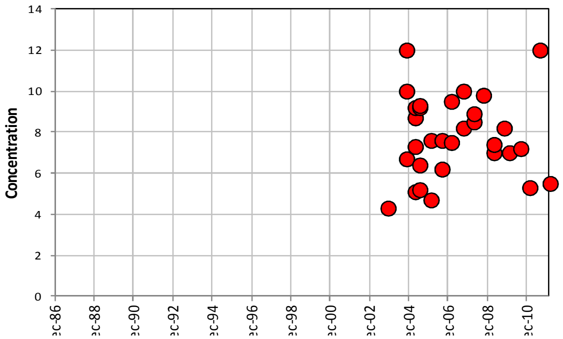
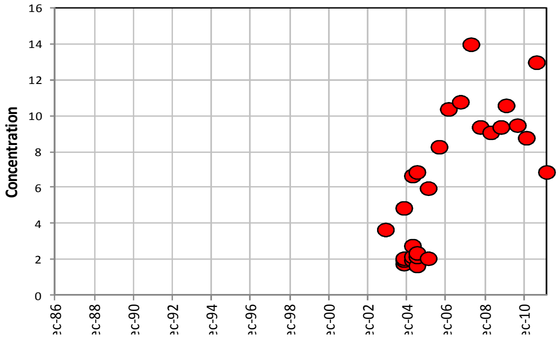
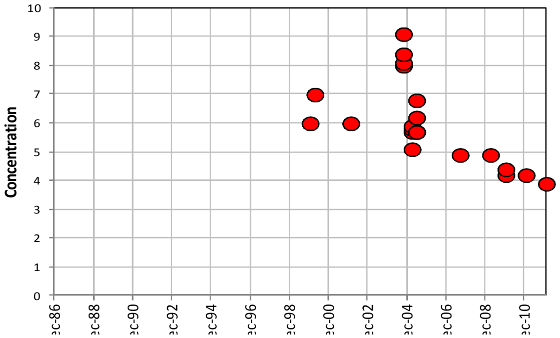
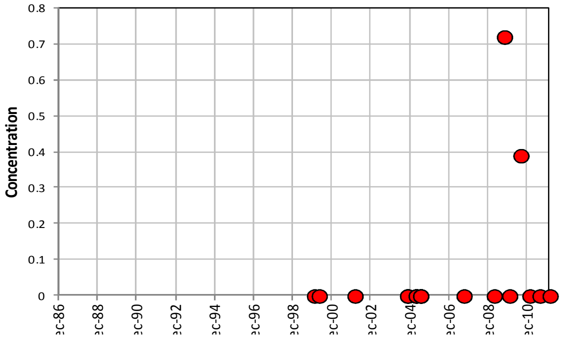

DCE in MNW-13_(D1)

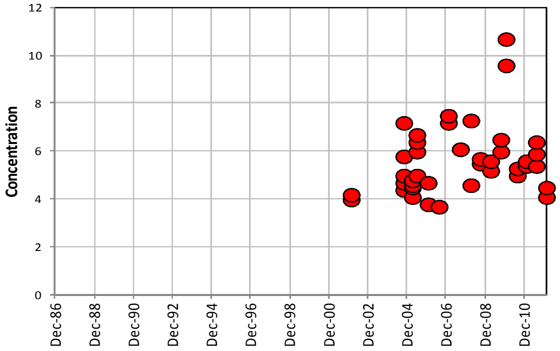

DCE in MNW-5_(D1)

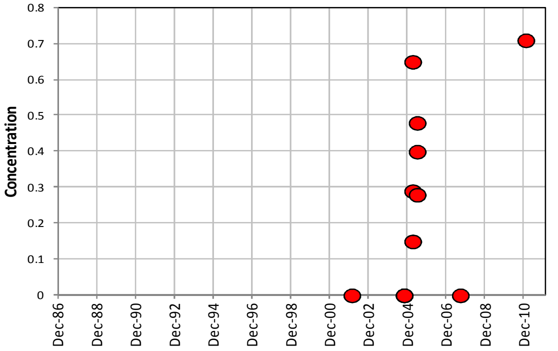

DCE in MNW-5_(D2)

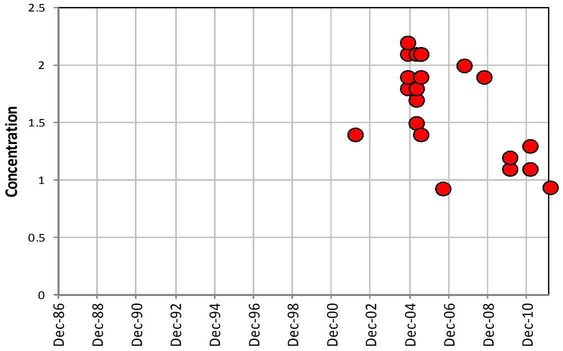

DCE in MNW-5_(D3)

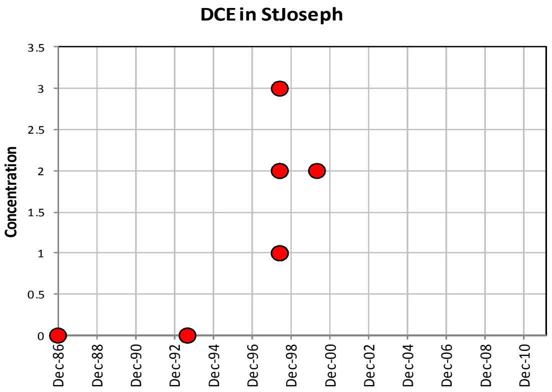

DCE in SFMW-40_(D3)


DCE in SFMW-41_(D3/D4)


DCE in SFMW-44_(D2)


DCE in SFMW-45_(D2)


DCE in SFMW-46_(D1/D2)


DCE in StJoseph
Concentration
3.5
3
2.5
2
1.5
1
0.5
0
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Dec-00
Dec-02
Dec-04
Dec-06
Dec-08
Dec-10

Nonparametric Trend Analysis for DCE

Well	Detect	Nondetect	Total Samples	Detection Frequency	Min	Max	Mean	Median	MK Result	Trend	Stability
MNW-13_(D1)	10	6	16	63	0.000	0.790	0.344	0.410	94.2% (-)	**No Trend**	**Stable**
MNW-5_(D1)	38	0	38	100	2.70	15.0	6.03	5.55	100.0% (sig -)	**Decreasing Trend**	NA
MNW-5_(D2)	31	0	31	100	4.30	12.0	7.79	7.60	61.4% (+)	**No Trend**	**Stable**
MNW-5_(D3)	27	0	27	100	1.70	14.0	6.29	6.70	100.0% (sig +)	**Increasing Trend**	NA
SFMW-40_(D3)	21	0	21	100	3.90	9.10	6.00	5.80	100.0% (sig -)	**Decreasing Trend**	NA
SFMW-41_(D3/D4)	2	18	20	10	0.000	0.720	0.056	0.000	NA	>50% ND	NA
SFMW-44_(D2)	43	0	43	100	3.70	10.7	5.57	5.40	98.3% (sig +)	**Increasing Trend**	NA
SFMW-45_(D2)	7	5	12	58	0.000	0.710	0.247	0.215	99.3% (sig +)	**Increasing Trend**	NA
SFMW-46_(D1/D2)	21	0	21	100	0.930	2.20	1.64	1.80	96.3% (sig -)	**Decreasing Trend**	NA
StJoseph	8	3	11	73	0.000	3.00	1.18	1.00	100.0% (sig +)	**Increasing Trend**	NA

Notes:

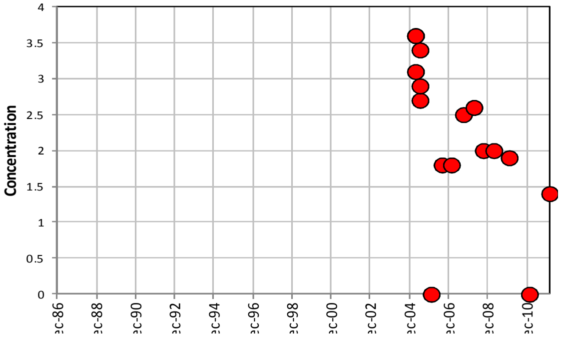
IS = insufficient data (less than 6 sample results).

>50% ND = greater than 50 percent nondetects.

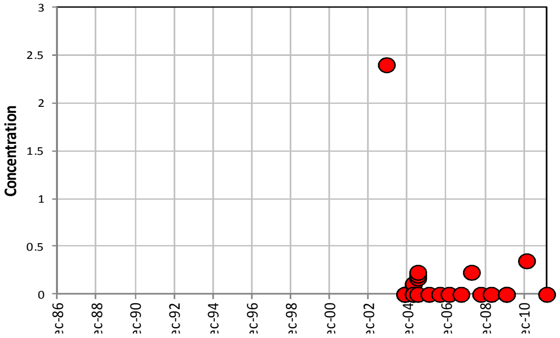
Trend analysis performed using Mann Kendall single-tailed test at 0.05 significance level.

For monitoring points exhibiting no trend at the 95% confidence level, concentrations are deemed stable if the coefficient of variation (COV) is equal to or less than one.

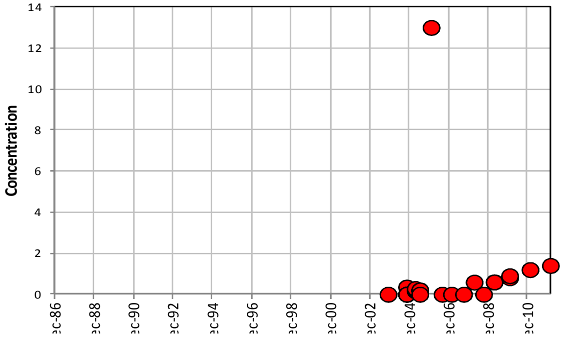
TCE in MNW-13_(D1)



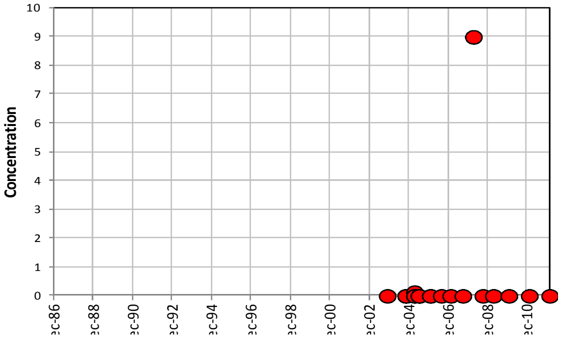
TCE in MNW-4_(D1)



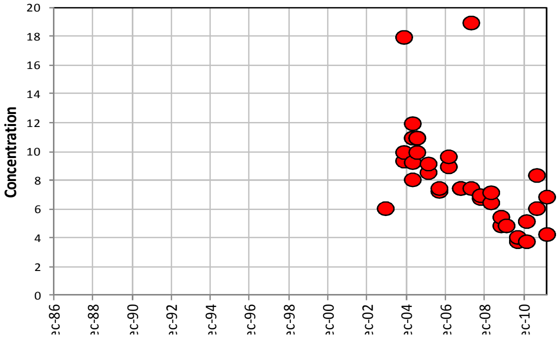
TCE in MNW-4_(D2)



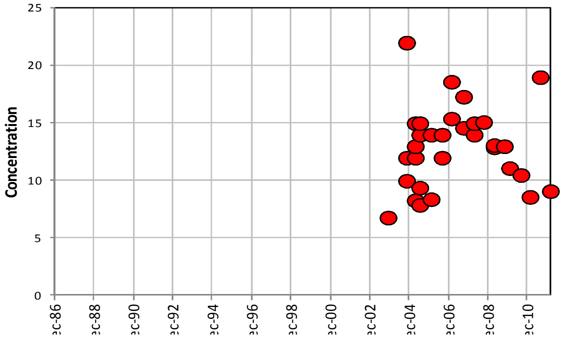
TCE in MNW-4_(D3)



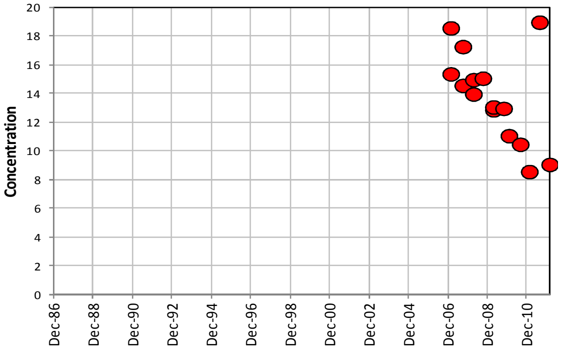
TCE in MNW-5_(D1)



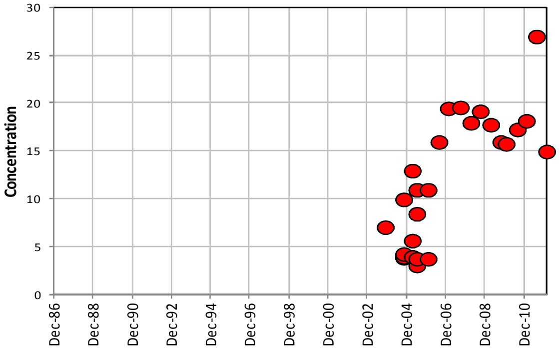
TCE in MNW-5_(D2)



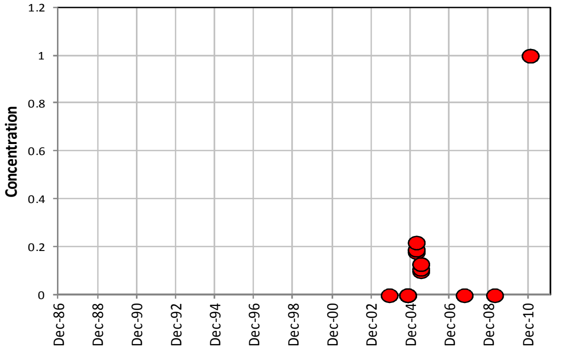
TCE in MNW-5_(D2) (Recent Only)



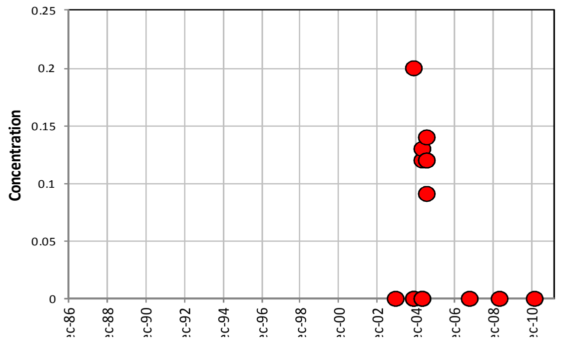
TCE in MNW-5_(D3)



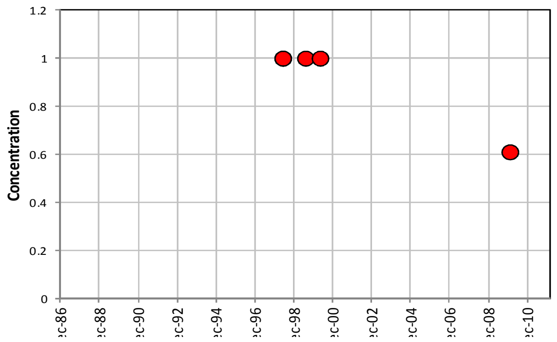
TCE in MNW-6_(D1)



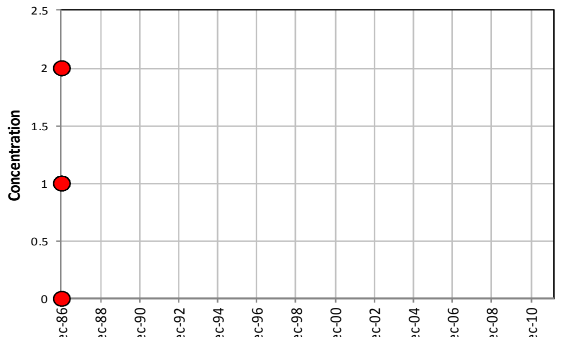
TCE in MNW-6_(D2)



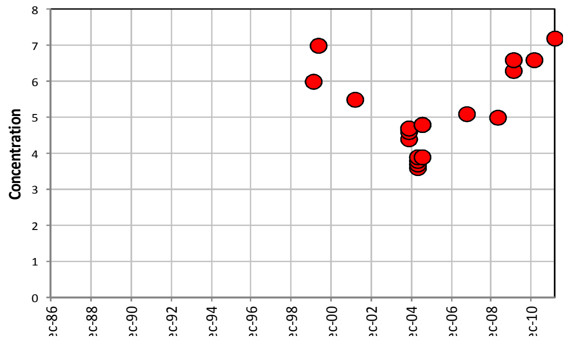
TCE in Presbyterian



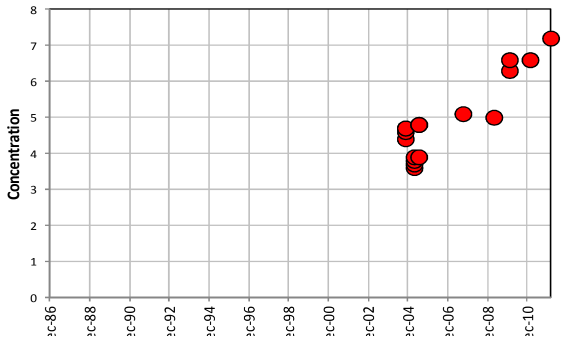
TCE in Rutledge



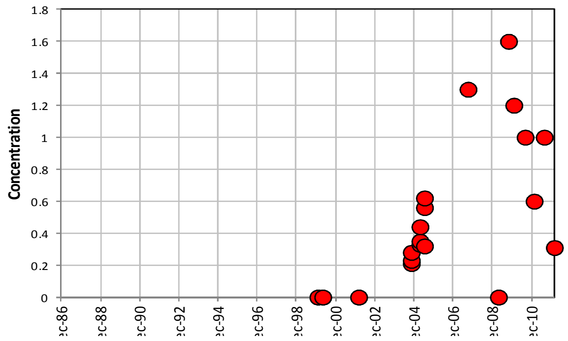
TCE in SFMW-40_(D3)



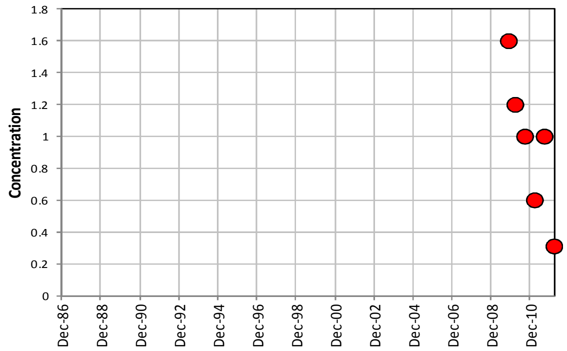
TCE in SFMW-40_(D3) (Recent Only)



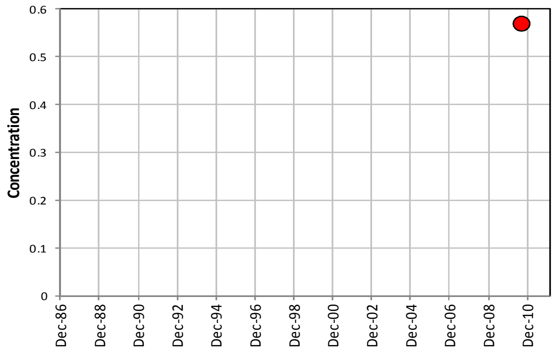
TCE in SFMW-41_(D3/D4)



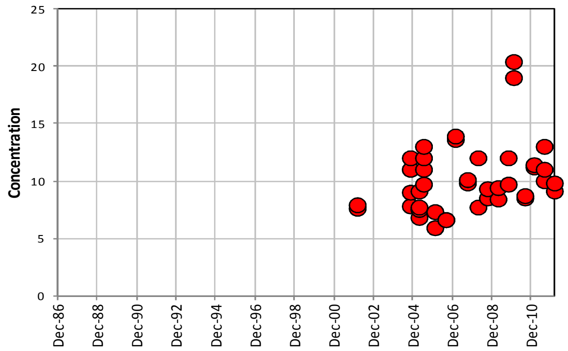
TCE in SFMW-41_(D3/D4) (Recent Only)



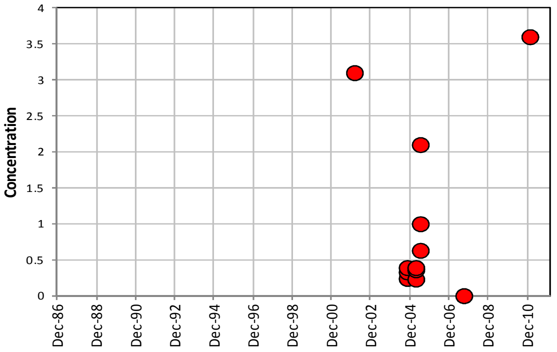
TCE in SFMW-43_(I1)



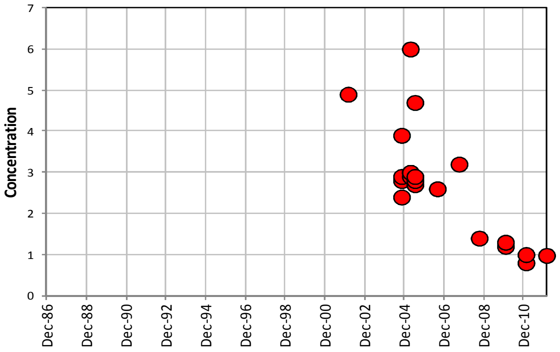
TCE in SFMW-44_(D2)



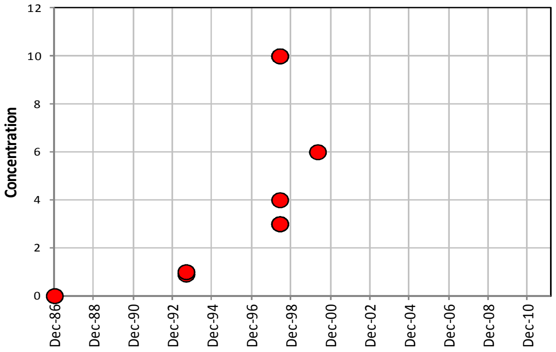
TCE in SFMW-45_(D2)



TCE in SFMW-46_(D1/D2)



TCE in StJoseph



Nonparametric Trend Analysis for TCE

Well	Detect	Nondetect	Total Samples	Detection Frequency	Min	Max	Mean	Median	MK Result	Trend	Stability
MNW-13_(D1)	14	2	16	88	0.000	3.60	2.21	2.25	99.8% (sig -)	**Decreasing Trend**	NA
MNW-4_(D1)	8	16	24	33	0.000	2.40	0.158	0.000	NA	>50% ND	NA
MNW-4_(D2)	16	10	26	62	0.000	13.0	0.805	0.205	99.9% (sig +)	**Increasing Trend**	NA
MNW-4_(D3)	2	22	24	8	0.000	9.00	0.380	0.000	NA	>50% ND	NA
MNW-5_(D1)	38	0	38	100	3.80	19.0	8.32	7.50	100.0% (sig -)	**Decreasing Trend**	NA
MNW-5_(D2)	31	0	31	100	6.80	22.0	12.9	13.0	82.1% (+)	**No Trend**	**Stable**
MNW-5_(D2) (Recent Only)	15	0	15	100	8.60	19.0	13.8	14.0	99.8% (sig -)	**Decreasing Trend**	NA
MNW-5_(D3)	27	0	27	100	3.10	27.0	11.7	11.0	100.0% (sig +)	**Increasing Trend**	NA
MNW-6_(D1)	10	7	17	59	0.000	1.00	0.191	0.110	97.4% (sig +)	**Increasing Trend**	NA
MNW-6_(D2)	7	9	16	44	0.000	0.200	0.058	0.000	NA	>50% ND	NA
Presbyterian	5	0	5	100	0.610	1.00	0.922	1.00	NA	IS	NA
Rutledge	4	1	5	80	0.000	2.00	1.20	1.00	NA	IS	NA
SFMW-40_(D3)	21	0	21	100	3.60	7.20	5.10	4.80	97.8% (sig +)	**Increasing Trend**	NA
SFMW-40_(D3) (Recent Only)	18	0	18	100	3.60	7.20	4.92	4.75	100.0% (sig +)	**Increasing Trend**	NA
SFMW-41_(D3/D4)	16	4	20	80	0.000	1.60	0.518	0.340	100.0% (sig +)	**Increasing Trend**	NA
SFMW-41_(D3/D4) (Recent Only)	6	0	6	100	0.310	1.60	0.952	1.00	98.2% (sig -)	**Decreasing Trend**	NA
SFMW-43_(I1)	1	0	1	100	0.570	0.570	NA	NA	NA	IS	NA
SFMW-44_(D2)	43	0	43	100	5.90	20.4	10.1	9.70	99.0% (sig +)	**Increasing Trend**	NA
SFMW-45_(D2)	11	1	12	92	0.000	3.60	1.03	0.390	86.0% (+)	**No Trend**	**Not Stable**
SFMW-46_(D1/D2)	21	0	21	100	0.800	6.00	2.73	2.80	99.8% (sig -)	**Decreasing Trend**	NA
StJoseph	10	1	11	91	0.000	10.0	4.63	3.00	100.0% (sig +)	**Increasing Trend**	NA

Notes:

IS = insufficient data (less than 6 sample results).

>50% ND = greater than 50 percent nondetects.

Trend analysis performed using Mann Kendall single-tailed test at 0.05 significance level.

For monitoring points exhibiting no trend at the 95% confidence level, concentrations are deemed stable if the coefficient of variation (COV) is equal to or less than one.

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Attachment 4
Mann-Kendall Analysis – Upgradient Offsite Plume

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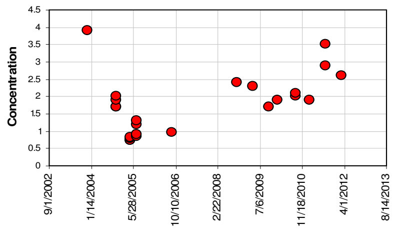
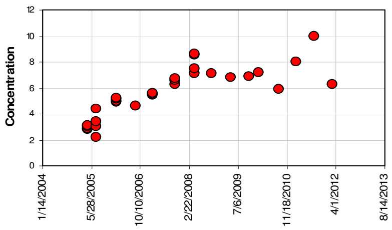
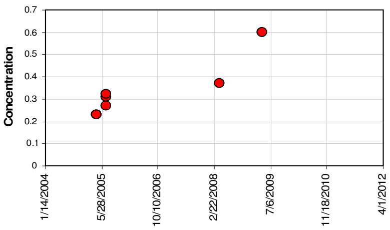
DCE in Well MNW-1_(I2)



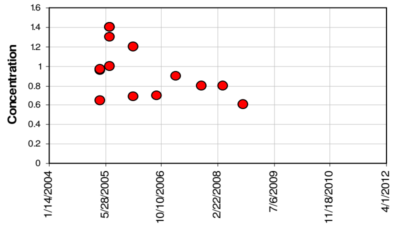
DCE in Well MNW-11_(D1)



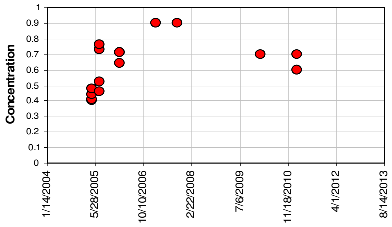
DCE in Well MNW-11_(I1)



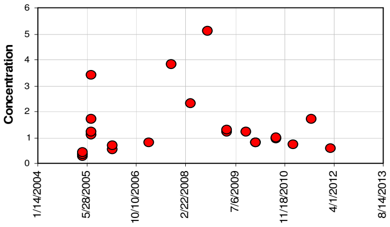
DCE in Well MNW-11_(I2)



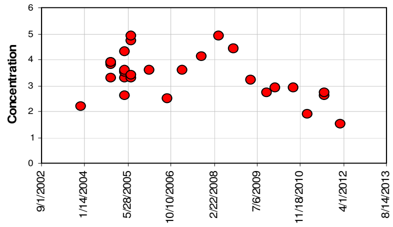
DCE in Well MNW-12_(D1)



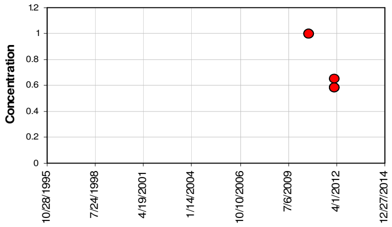
DCE in Well MNW-9_(D1)



DCE in Well MNW-9_(I2)



DCE in Well SFMW-14_(D1)



Nonparametric Trend Analysis for DCE

Well	Detect	Nondetect	Total Samples	Detection Frequency	Min	Max	Mean	Median	MK Result	Trend	Stability
MNW-1_(I2)	24	0	24	100	0.740	3.90	1.78	1.80	99.6% (sig +)	**Increasing Trend**	NA
MNW-11_(D1)	32	1	33	97	2.20	10.0	5.66	5.55	100.0% (sig +)	**Increasing Trend**	NA
MNW-11_(I1)	7	7	14	50	0.230	0.600	0.333	0.310	99.9% (sig +)	**Increasing Trend**	NA
MNW-11_(I2)	14	3	17	82	0.600	1.40	0.952	0.930	79.0% (-)	**No Trend**	**Stable**
MNW-12_(D1)	16	4	20	80	0.400	0.900	0.629	0.670	99.7% (sig +)	**Increasing Trend**	NA
MNW-9_(D1)	24	4	28	86	0.280	5.10	1.34	0.980	91.0% (+)	**No Trend**	**Stable**
MNW-9_(I2)	28	0	28	100	1.50	4.90	3.36	3.35	92.3% (-)	**No Trend**	**Stable**
SFMW-14_(D1)	5	9	14	36	0.580	1.00	0.762	0.650	NA	>50% ND	NA

Notes:

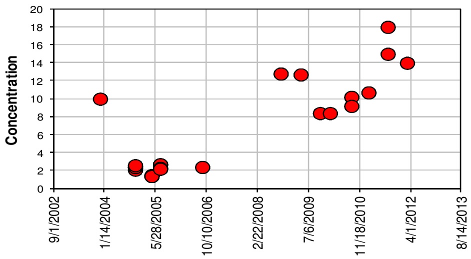
IS = insufficient data (less than 4 sample results).

>50% ND = greater than 50 percent nondetects.

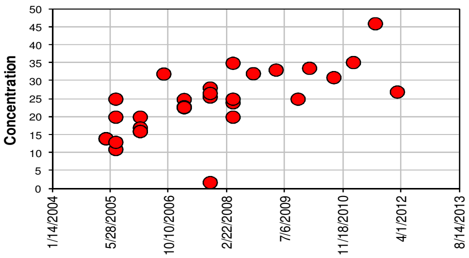
Trend analysis performed using Mann Kendall single-tailed test at 0.05 significance level.

For monitoring points exhibiting no trend at the 95% confidence level, concentrations are deemed stable if the coefficient of variation (COV) is equal to or less than one.

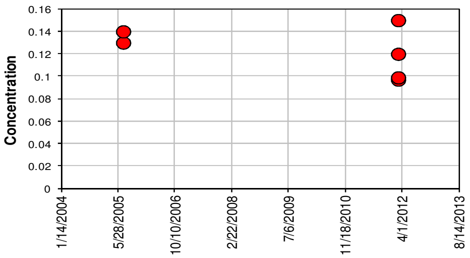
TCE in Well MNW-1_(I2)



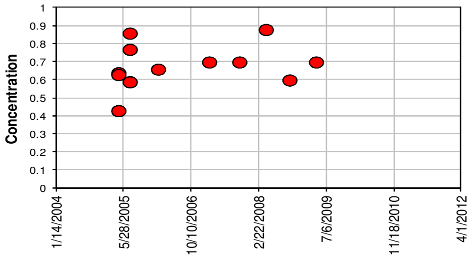
TCE in Well MNW-11_(D1)



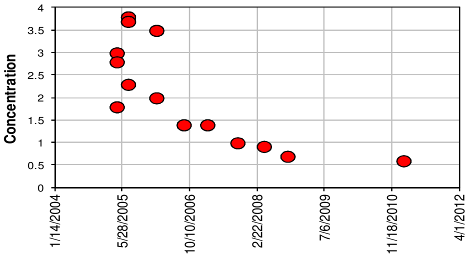
TCE in Well MNW-11_(D2)



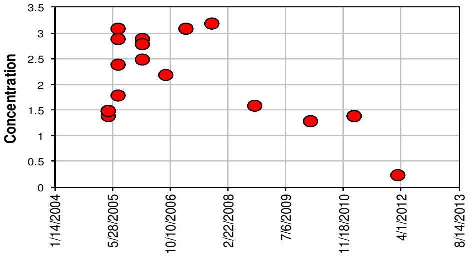
TCE in Well MNW-11_(I1)



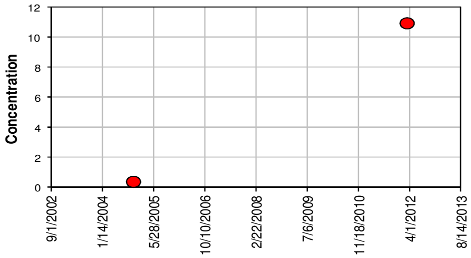
TCE in Well MNW-11_(I2)



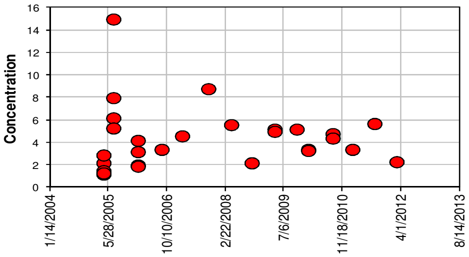
TCE in Well MNW-12_(D1)



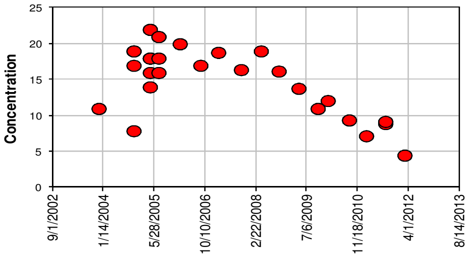
TCE in Well MNW-8_(I2)



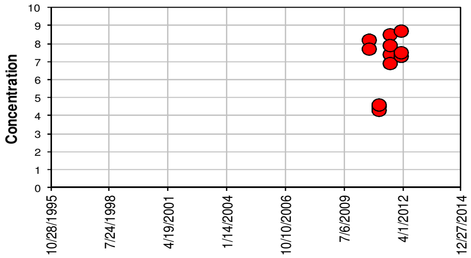
TCE in Well MNW-9_(D1)



TCE in Well MNW-9_(I2)



TCE in Well SFMW-14_(D1)



Nonparametric Trend Analysis for TCE

Well	Detect	Nondetect	Total Samples	Detection Frequency	Min	Max	Mean	Median	MK Result	Trend	Stability
MNW-1_(I2)	24	0	24	100	1.40	18.0	6.54	2.70	100.0% (sig +)	**Increasing Trend**	NA
MNW-11_(D1)	33	0	33	100	1.80	46.0	23.3	24.0	100.0% (sig +)	**Increasing Trend**	NA
MNW-11_(D2)	6	14	20	30	0.097	0.150	0.123	0.125	NA	>50% ND	NA
MNW-11_(I1)	12	2	14	86	0.430	0.880	0.680	0.680	79.0% (+)	**No Trend**	**Stable**
MNW-11_(I2)	15	2	17	88	0.600	3.80	2.17	2.00	99.9% (sig -)	**Decreasing Trend**	NA
MNW-12_(D1)	19	1	20	95	0.250	3.20	2.04	1.80	55.6% (-)	**No Trend**	**Stable**
MNW-8_(I2)	2	20	22	9	0.440	11.0	5.72	5.72	NA	>50% ND	NA
MNW-9_(D1)	28	0	28	100	1.20	15.0	4.36	3.80	83.8% (+)	**No Trend**	**Stable**
MNW-9_(I2)	28	0	28	100	4.50	22.0	15.1	16.3	99.5% (sig -)	**Decreasing Trend**	NA
SFMW-14_(D1	12	2	14	86	4.30	8.70	6.96	7.45	84.5% (+)	**No Trend**	**Stable**

Notes:

IS = insufficient data (less than 4 sample results).

>50% ND = greater than 50 percent nondetects.

Trend analysis performed using Mann Kendall single-tailed test at 0.05 significance level.

For monitoring points exhibiting no trend at the 95% confidence level, concentrations are deemed stable if the coefficient of variation (COV) is equal to or less than one.

Attachment 5
Description of the Non-Parametric MK Trend Analysis

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ATTACHMENT 5

Non-Parametric Trend Analysis

Non-parametric trend analyses (using the Mann-Kendall test) were conducted to assess the statistical significance of temporal trends in the concentrations of VOCs in groundwater and soil vapor at the site. The Mann-Kendall test is a nonparametric statistical procedure that is well suited for analyzing trends in environmental data over time (Gilbert, 1987). The Mann-Kendall test can be viewed as a nonparametric test for zero slope of the first-order regression of time-ordered concentration data versus time at an a priori specified significance level (e.g., 0.05). Because the Mann-Kendall trend test is a nonparametric method, the test does not require any assumptions as to the statistical distribution of the data and can be used with data sets that include irregular sampling intervals and missing data. The test is based on the idea that a lack of trend should correspond to a time series plot fluctuating randomly about a constant mean level, with no visually apparent upward or downward pattern (EPA, 2009). If an increasing trend exists, the sample taken first from any randomly selected pair of measurements should, on average, have a lower concentration than the measurement collected at a later point.

The method proceeds by calculating the slope of the change in a measurement per change in time, and determining the mean slope for a series of measurements. Only the relative magnitudes of the concentration values are needed to compute the Mann-Kendall statistic (S), not the actual concentrations themselves. Data reported less than the reporting or detection limit (non-detects) can be used in the Mann-Kendall test by assigning them a common value that is smaller than the smallest measured value in the data set (Gilbert, 1987). Any pair of tied values or any pair of non-detects is simply given a score of 0 in the calculation of the statistic. Positive values of the Mann-Kendall statistic (S) indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall statistic (i.e., the larger the absolute value of S, the stronger the evidence for a real increasing or decreasing trend).

For this analysis, the Mann-Kendall procedure was used to test for a significant trend in TCE and DCE concentrations at a confidence level greater than or equal to 95 percent (significance level of 0.05). Tests were performed using current and historical groundwater analytical data collected at the individual monitoring wells. Statistical validity of the trend analysis requires constraints on the minimum data input. To ensure a meaningful comparison of TCE and DCE concentrations over time, evaluation of trends were only performed for wells with at least six independent sampling events and a detection frequency greater than 50 percent. TCE and DCE concentrations were based on the results of the EPA SW846 Method 8260B analysis. For groundwater samples exhibiting concentrations of total VOCs below detectable levels, values were imputed to 0.0 µg/L.

Where there was insufficient evidence for identifying a significant, non-zero trend at the 95 percent confidence level, concentrations were deemed stable if the coefficient of variation (COV) was less than 1.0. The COV is a statistical measure of how the individual data points vary about the mean value and is defined as the standard deviation divided by the sample mean. Values less than or near 1.0 indicate that the data form a relatively close group about the mean value. Values larger than 1.0 indicate that the data show a greater degree of scatter about the mean.

The temporal behavior of the TCE and DCE data was examined graphically to confirm the results of the nonparametric statistical trend analysis. A scatterplot of TCE and DCE concentrations as a function of time was generated for each monitoring well. Several monitoring wells clearly demonstrated a changing trend so a second chart and analysis was completed for the more recent data. These locations are identified by “Recent Only” in the monitoring well ID.

Gilbert, R.O. (1987) *Statistical Methods for Environmental Pollution Monitoring*, Wiley, NY.

EPA (2009) *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities - Unified Guidance.* EPA 530/R-09-007

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Attachment 6
3-D User-Interactive Plume Shell (2012) Animation (Provided on CD)

User-interactive animations of the plume shells are included in Attachment 6, which is provided the on CD submitted with this report.

Appendix E
Compound Specific Isotope Analysis Data Evaluation

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Fruit Avenue Plume Superfund Site Long-Term Remedial Action Appendix E – Compound-Specific Isotope Analysis Data Evaluation

PREPARED FOR:	Bartolomé Cañellas /EPA Region 6 Remedial Project Manager
PREPARED BY:	CH2M HILL
DATE:	October 2012
PROJECT:	EPA Region 6 Remedial Action Contract W-EP-06-021 Task Order No. 0003-RALR-06DD CH2M HILL Project No. 345406.PJ.14
DCN:	0003-02091

Introduction

Compound specific stable isotope[1] analysis (CSIA) is an assessment tool that can provide data demonstrating contaminant degradation. Concentration and isotopic composition are independent characteristics of a compound (e.g., color and mass of an apple). Different isotopes of a compound all have the same number of protons and electrons, and the same atomic structure, but a different number of neutrons. Because the chemical behavior of an atom is largely determined by its atomic structure, different isotopes exhibit nearly identical chemical behavior even though they have different atomic mass. The main exception to this is the "kinetic isotope effect": due to their larger atomic mass, heavier isotopes tend to react more slowly than lighter isotopes of the same element. The mass difference results in partial separation of the lighter isotopes from the heavy isotopes during chemical reactions (e.g., degradation). This change in isotope composition is called "isotope fractionation." Important attributes of isotope behavior include the following:

- Physical reactions (evaporation, sorption, dispersion, diffusion) *do not* significantly fractionate carbon isotopes.
- Degradation reactions (biological, chemical oxidation-reduction reactions or hydrolysis) *do* fractionate carbon isotopes (**Figure 1**).

CSIA measures the relative isotopic composition of specific contaminant compounds (e.g., perchloroethylene [PCE], trichloroethylene [TCE], and dichloroethylene [DCE]) in a dissolved groundwater sample (a contaminant plume). In CSIA, the symbol $\delta^{13}C$ corresponds to the isotopic characteristic of the contaminant molecule (analysis) and ‰ (per mil) represents the units.

The $\delta^{13}C$ of a newly manufactured chlorinated solvent is about -30 +/-5 ‰ (Hunkeler et. al., 2008 and Shouakar-Stash et al, 2003). Lab variability in $\delta^{13}C$ is about 0.5 ‰; field variability is likely to be more.

Fractionation in a sample should be at least 2‰ (e.g., detection limit) to be considered positive identification of degradation (Hunkeler et. al., 2008). At least 20 percent by mass of initial source material may need to be degraded before the 2‰ change is evident in an environment sample (the fraction of original mass remaining (*f*) =0.8) (Hunkeler et. al., 2008).

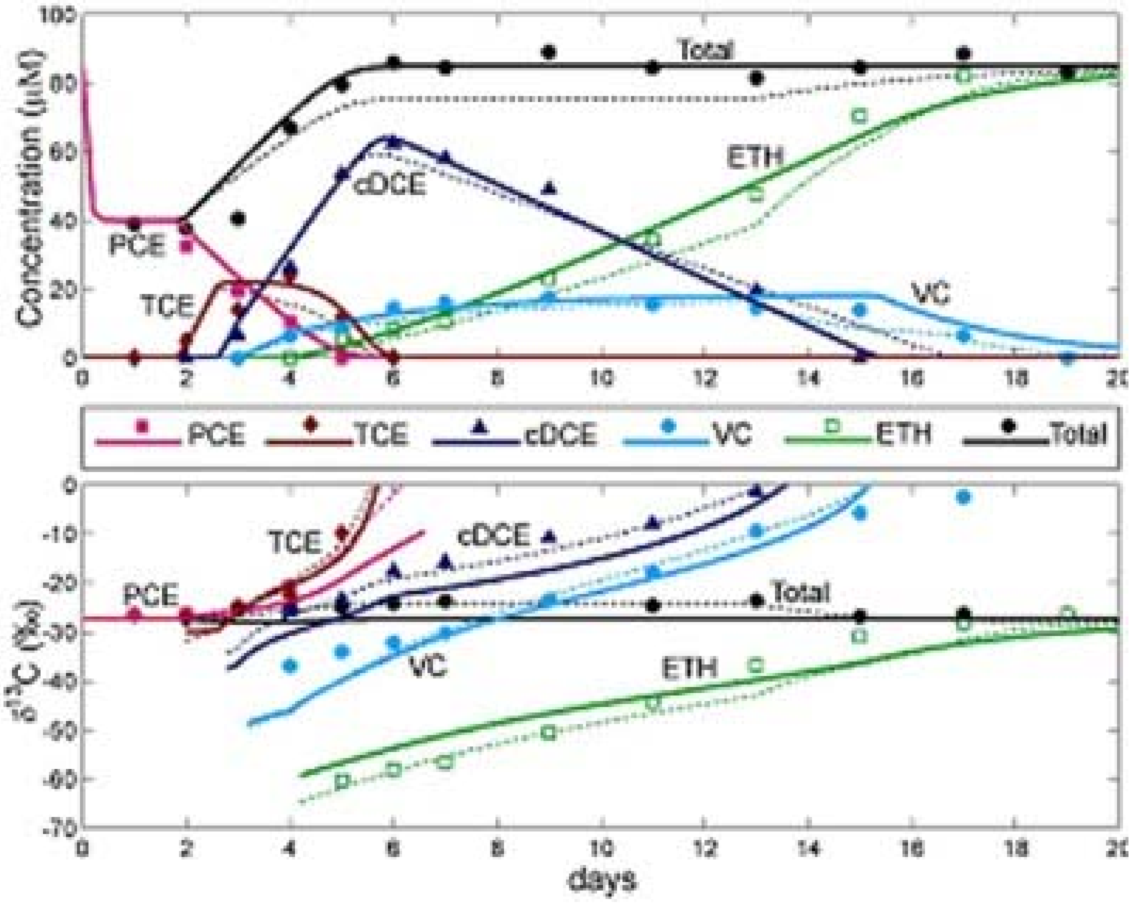
The amount of fractionation depends on the completeness of the degradation and the degradation pathway. Some site-specific conditions, such as microbiological species and availability of co-substrates, may affect the amount of observable fractionation (VanStone et al, 2004; Butler et al, 2005; Osenbruck et al, 2002).

---

[1] Isotope = two or more forms of the same compound having the same number of protons but with a different number of neutrons in the nucleus.

FIGURE 1

Example of fractionation of cVOCs over time during degradation (van Breukelen et al, 2005)



> *Note: The chart in the upper portion of Figure 1 shows the **concentration** of the parent cVOC (PCE in this example) decreasing as the concentration of the degradation products (TCE, cDCE and VC) initially rise then fall along the groundwater flowpath. In this example, ethene is not degraded, and therefore, accumulates as indicated by its rising concentration.*
>
> *The chart in the lower portion of Figure 1 shows the **isotope fractionation** that occurs under the conditions portrayed in the upper chart.*

Specific degradation pathways have unique fractionation factors ("**α**" Hunkeler et. al., 2008), and absent definitive evidence of the active pathway, a range of fractionation factors is used to address the uncertainty in quantitative estimates of degradation.

Stable isotope signatures can be used to quantify the relative extent of parent compound degradation (Sherwood-Lollar, 2001) if the following site conditions occur:

- There is no residual free-product present in the source area that acts as an infinite source of undegraded product.
- Contaminants present in the downgradient portion of the plume are derived from a single source.
- The contaminant in question is not derived by two different processes, (e.g., anthropogenic formation and natural biodegradation of DCE (typically the cis isomer), a daughter produce of TCE degradation).
- The isotopic difference between the parent contaminant in the source area and downgradient plume samples is due solely to degradation and not co-mingling with another source.

If these conditions are satisfied, then the mass fraction of the parent compound (e.g., TCE) remaining (***f***) at a sample location within the plume can be estimated from the Rayleigh equations expressed in δ‰ notation (**Equation 1**):

$$(\alpha - 1)\ln f = \ln\left(\frac{\frac{\delta^{13}C_S}{1000}+1}{\frac{\delta^{13}C_\emptyset}{1000}+1}\right) \qquad \text{Equation 1}$$

Where

- f = mass-fraction remaining
- α = fractionation factor
- $\delta^{13}C_S$ is the isotopic composition of the sample
- $\delta^{13}C_\emptyset$ is the isotopic composition of the source material

The fraction of mass remaining at a location can be combined with monitor well location and groundwater flow data to estimate degradation rates.

Sampling and Analysis

At the Fruit Avenue Plume (FAP) site, groundwater samples were collected from two monitor wells (HSM-I2-5 and MNW-14(I2)) located near the presumed source area and three wells (MNW-5(D2), SFMW-40(D3), and SFMW-44(D2) located in the eastern downgradient portion of the TCE plume. Field duplicate samples were collected from HSM-I2-5 and SFMW-44(D2). Sampling locations were limited to those wells with TCE and cis 1,2-DCE concentrations high enough to be analyzed for δ^{13}C. PCE and VC concentrations across the Site are too low in all samples for CSIA analysis. Samples were analyzed for δ^{13}C in TCE and cis-DCE by gas-chromatograph combustion isotope-ratio mass-spectrometry (GC/C/IRMS) by MicroSeeps™. The CSIA analysis results are summarized in **Table 1** and illustrated in **Figures 2** and **3.** Analytical laboratory reports are included in **Attachment 1**.

TABLE 1

Estimate of the Amount of TCE Degradation Based on CSIA Data

Fruit Avenue Plume Superfund Site, Albuquerque NM

Isotopic Signature of TCE Source (Sherwood Lollar et. al, 2001)	δ^{13}C =	-30	‰			
Fractionation Factor TCE → DCE (Hunkeler, et. al., 2008)				**Minimum Degradation**	**Average**	**Maximum Degradation**
	α =			0.9771	0.9884	0.9989
Well ID	**Sample Date**	**δ^{13}C-TCE**	**δ^{13}C-DCE**	**f = Fraction of original TCE mass remaining**		
Presumed Source Area						
HSM-I2-5	9/14/2010	-20.63	-37.04	66%	44%	0.016%
HSM-I2-5 (duplicate)	9/14/2010	-20.83	-37.70	66%	44%	0.019%
MNW-14 (I2)	9/7/2010	-17.36	-37.94	57%	33%	0.001%
Downgradient Plume						
SFMW-40 (D3)	8/31/2010	-16.76	-31.73	55%	31%	0.000%
SFMW-44 (D2)	8/31/2010	-17.63	-33.53	58%	34%	0.001%
SFMW-44 (D2) (duplicate)	8/31/2010	-17.95	-32.76	58%	34%	0.001%
MNW-5 (D2)	9/8/2010	-17.01	-32.86	56%	32%	0.001%

Notes: The enrichment is the difference between the δ^{13}C measured in the sample and the δ^{13}C present in the source material, which was conservatively assumed to be -24 ‰ representing the upper end of the range.

Evidence for Degradation of TCE

The $\delta^{13}C$ of TCE (**Table 1** and **Figure 2**) in the samples (-21‰ to -17‰) is 3‰ to 7‰ enriched compared to newly manufactured product (approximately -24‰ (Hunkeler et. al., 2008)). This enrichment is sufficient (greater than 2‰) to indicate that natural degradation may be considered the primary cause of TCE fractionation because physical reactions (evaporation, sorption, dispersion, diffusion) do not significantly fractionate carbon isotopes.

The $\delta^{13}C$ of DCE (**Table 1** and **Figure 2**) in the samples is less than that of newly manufactured product (approximately -30‰ [Hunkeler et. al., 2008]), indicating that DCE has been produced by degradation of TCE and was not part of the original release.

Because the $\delta^{13}C$ of DCE (daughter product) is not enriched more than the TCE originally released, CSIA does not provide evidence that cis-DCE is degrading. If the concentrations do not decrease and the $\delta^{13}C$ of DCE never exceeds -30‰, it may be concluded that DCE is not degrading. This condition is commonly referred to as “cis-DCE stall.” Furthermore, degradation caused by abiotic (reactive mineral mediated) reactions may not be identifiable because these reactions do not fractionate cis-DCE enough to produce a recognizable change in $\delta^{13}C$ (He, et. al, 2009).

FIGURE 2
Compound Specific Stable Isotope Mass Ratios.
Fruit Avenue Plume Superfund Site, Albuquerque NM

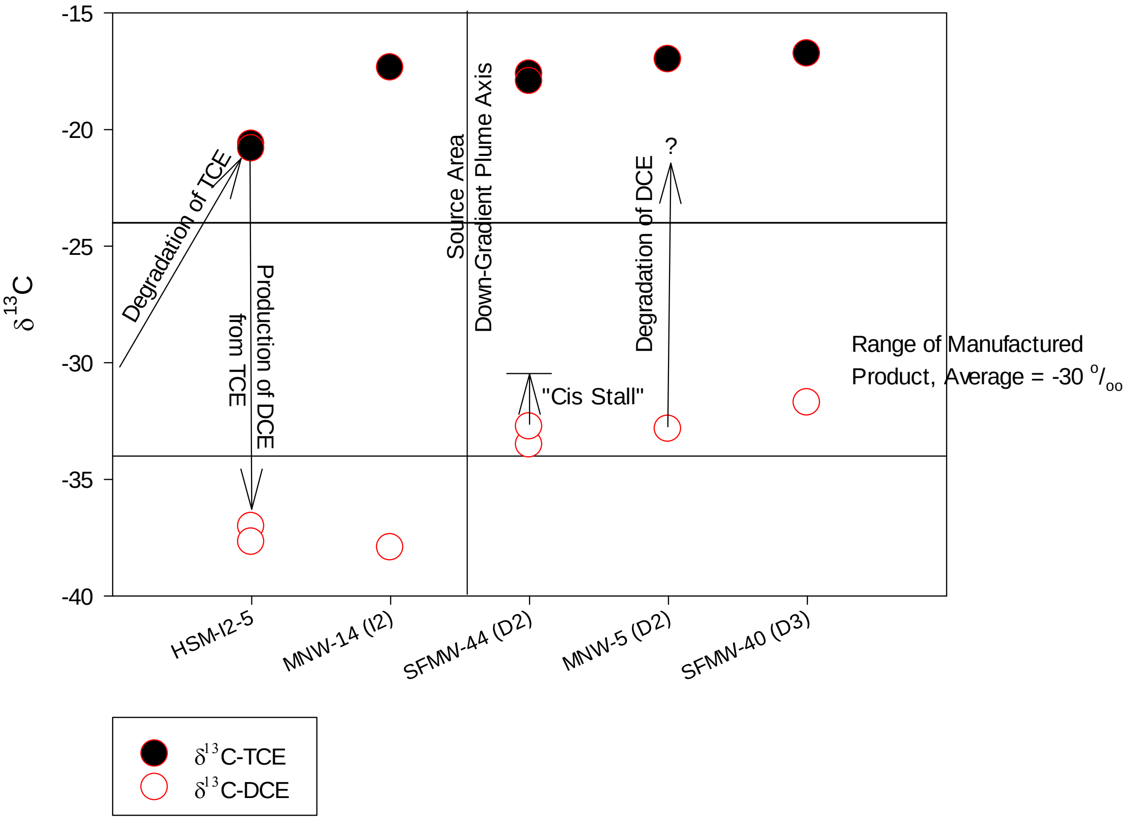
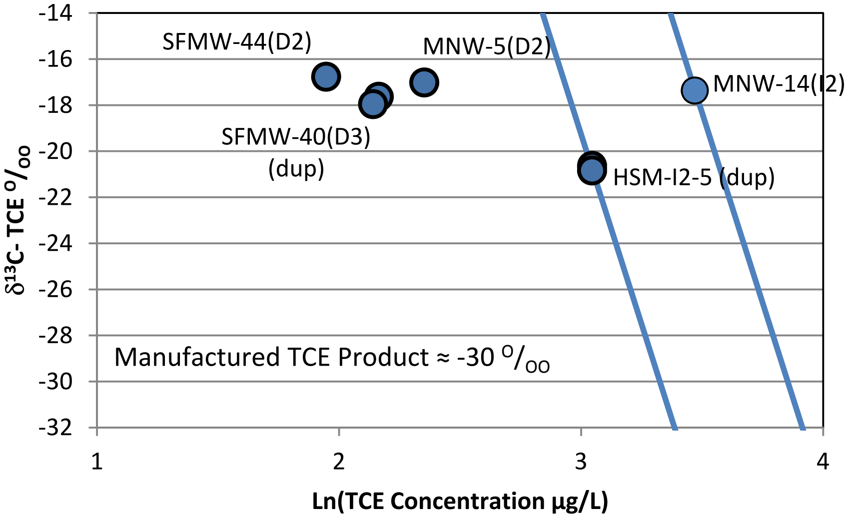


FIGURE 3

Testing CSIA Field Data for Compliance with Rayleigh Assumptions.

Fruit Avenue Plume Superfund Site, Albuquerque NM



The δ^{13}C of DCE in samples collected from the two wells near the source area is less enriched compared to δ^{13}C of DCE present in the three samples collected from the eastern, downgradient portion of the plume (**Figure 2**), indicating that a smaller fraction of the contamination in the source area has been degraded compared to the downgradient locations.

Usability of the Data for Quantitative Evaluations

The quantification of the relative extent of TCE degradation at the site requires that the previously-outlined assumptions be met.

- TCE concentrations in presumed source area groundwater are below 100 µg/L and a soil vapor extraction (SVE) pilot test did not indicate the presence of TCE-contaminated soil, suggesting that dense nonaqueous phase liquid (DNAPL) (effectively an infinite source of TCE product) is not present.
- Downgradient samples from SFMW-40(D3), SFMW-44(D2), and MNW-5(D2) are far enough downgradient to be well mixed and unaffected by the pump-and-treat (P&T) portion of the remedy.
- TCE is not likely to be affected by degradation of PCE because PCE is rarely observed at the site, and thus was likely a very small portion of the original release. The isotopic signature of DCE suggests that it is being produced by degradation of TCE and there is no evidence of a primary release of DCE at the site.
- The Rayleigh model (**Equation 1**) predicts that contaminant concentrations and δ^{13}C affected by a single degradation process should plot on a straight line. Deviations from the line indicate that additional processes are affecting the concentration and δ^{13}C. Deviations to the left of the line are caused by dilution, dispersion, sorption, and volatilization. Deviations to the right of the line are caused by mixing with another contaminant source (Hunkeler, 2008). **Figure 3** (based on Figure 4-2 in Hunkeler, 2008) illustrates plots of the Rayleigh equation through data from presumed source area wells MNW-14(I2) and HSM-I2-5, using $\delta^{13}C_{\emptyset}$ = -30‰ and a slope based on an unreasonably high fractionation factor (**α**) of 0.9989 (lines based on more-likely fractionation factors are more vertical). The information presented in **Figure 3** shows the following:

- The two samples from near the presumed source area HSM-I2-5 and MNW-14(I2) do not satisfy the same Rayleigh equation, suggesting that TCE at those locations may be from separate or mixed sources. It is unlikely that the samples from HSM-I2-5 are affected by mixing from MNW-14(I2) because HSM-I2-5 is too far cross-gradient. Plausible secondary sources have been investigated on the city block where MNW-14(I2) is located and an upgradient offsite plume is known to be migrating onto the FAP site. It is apparent that no sample pairs plot along the Rayleigh lines, indicating that changes in concentration are affected by more than one process. The downgradient samples (SFMW-40(D3), SFMW-44(D2), and MNW-5(D2)) deviate to the left of the lines, confirming the 2005 Natural Attenuation Evaluation (CH2M HILL, 2005) conclusions that dilution, dispersion, and/or sorption affect TCE concentrations.

The lowest δ^{13}C-TCE value at the site was collected from HSM-I2-5, which is immediately downgradient of the presumed source area but is still enriched by 10‰ over the reported source values. This enrichment and the TCE concentrations at that location (<100 µg/L) suggest that the sample is not representative of the initial release. The stable isotope signature of the source was thus assumed to be -30‰ +/-5‰ (Sherwood-Lollar, 2001) for this quantitative evaluation. This assumption permits evaluation of the fraction of mass remaining at locations near the samples collected from the presumed source area and in the eastern downgradient portion of the TCE plume.

Estimation of the Fraction of TCE Mass Remaining in the Groundwater Plume

Stable isotope signatures were used to quantify the relative extent of degradation of TCE at the site. The amount of degradation that has taken place at the site, independent of dilution and dispersion, is estimated in **Table 1**. The minimum, maximum, and average of a range of 15 fractionation factors (α, Hunkeler et. al., 2008) has been used to illustrate the uncertainty in the estimate. Rearrangement of **Equation 1** to solve for ***f*** yields (**Equation 2**) (from Hunkeler, 2008, equation 7.17):

$$f = e^{\frac{\ln\left(\frac{\frac{\delta^{13}C_S}{1000}+1}{\frac{\delta^{13}C_\emptyset}{1000}+1}\right)}{(\alpha-1)}} \qquad \text{Equation 2}$$

Where

f = mass-fraction of TCE remaining after degradation
α = fractionation factor (a range of values from Hunkeler, et. al., 2008)
$\delta^{13}C_S$ is the isotopic composition of TCE (7 field sample results from the Site)
$\delta^{13}C_\emptyset$ is the isotopic composition of the TCE source material (assumed to be -30‰)

The fraction of mass remaining in the portion of the plume near the presumed source area (**Table 1**), as estimated from the best estimate of fractionation factor (the average of fractionation factors reported in Hunkeler et. al 2008), is 44 percent to 33 percent of the original TCE mass. In the downgradient locations, approximately one-third of the TCE mass remains. The fraction remaining estimate based on the maximum degradation fractionation factor (0.9989, *f*=0.02 percent) seems unreasonable based on the other evaluations completed for this report. The fraction remaining estimate based on the minimum degradation fractionation factor (0.9771, 57 percent < *f* < 68 percent) appears reasonable.

Conclusions

The CSIA data indicate that TCE is degrading to DCE at the site. At this time, there is no stable isotope evidence that DCE is degrading to VC. In the Attenuation Rates Technical Memorandum (**Appendix I**), a companion appendix to this appendix, the fraction remaining estimates are used to estimate degradation rates.

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Attachment 1

Analytical Laboratory Report

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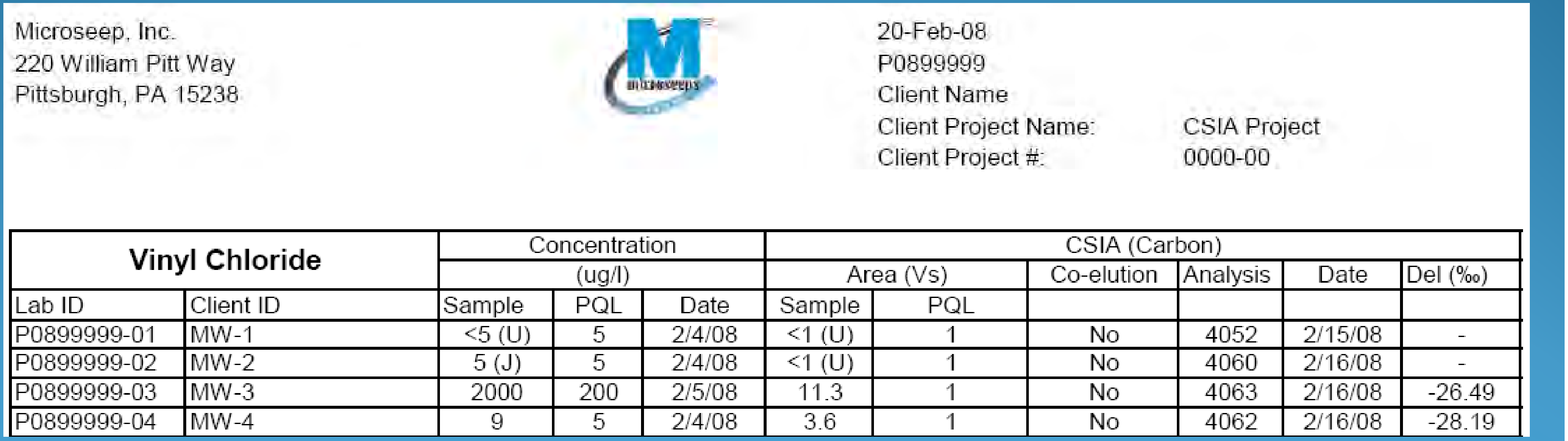
Interpreting Your CSIA Report

Mike O'Seeps, Ph.D.



Microseep, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

20-Feb-08
P0899999
Client Name
Client Project Name: CSIA Project
Client Project #: 0000-00

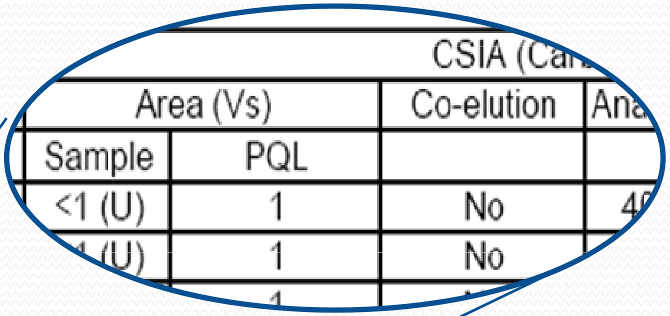
Vinyl Chloride		Concentration			CSIA (Carbon)					
		(ug/l)			Area (Vs)		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P0899999-01	MW-1	<5 (U)	5	2/4/08	<1 (U)	1	No	4052	2/15/08	-
P0899999-02	MW-2	5 (J)	5	2/4/08	<1 (U)	1	No	4060	2/16/08	-
P0899999-03	MW-3	2000	200	2/5/08	11.3	1	No	4063	2/16/08	-26.49
P0899999-04	MW-4	9	5	2/4/08	3.6	1	No	4062	2/16/08	-28.19

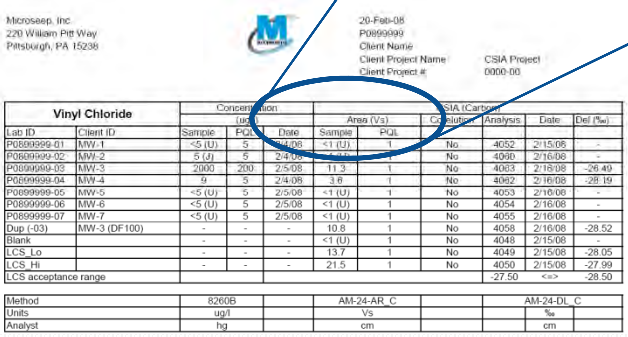
For many of you this is the first CSIA report you have received from Microseeps. Because this analysis is different than the concentration analyses that are typically obtained from a laboratory, this report is a bit unusual. This is an attempt to help you understand the report and how to use it. This document will focus on the report itself and how its content relates to your samples. It does not attempt to interpret the results in terms of site remediation. There are some excellent references that can help with that and they will be discussed at the end of this document.

Area

The CSIA instrument is operated to provide sensitive and accurate isotopic ratio measurements, not concentration measurements.

The CSIA section of the report specifies area, not concentrations. The instrument used in CSIA can provide very sensitive and accurate measurements of concentration, that is not its purpose. The CSIA instrument is operated to provide sensitive and accurate isotopic ratio measurements, not concentration measurements. SW846-8260B and EPA-624 are excellent methods for measuring concentration.





Microseep, Inc.
220 William Pitt Way
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20-Feb-08
P0899999
Client Name
Client Project Name CSIA Project
Client Project # 0000-00

Vinyl Chloride		Concentration (ug/l)			CSIA (Carbon)					
					Area (Vs)		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P0899999-01	MW-1	<5 (U)	5	2/4/08	<1 (U)	1	No	4052	2/15/08	-
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P0899999-04	MW-4	9	5	2/4/08	3.6	1	No	4062	2/16/08	-28.19
P0899999-05	MW-5	<5 (U)	5	2/5/08	<1 (U)	1	No	4053	2/16/08	-
P0899999-06	MW-6	<5 (U)	5	2/5/08	<1 (U)	1	No	4054	2/16/08	-
P0899999-07	MW-7	<5 (U)	5	2/5/08	<1 (U)	1	No	4055	2/16/08	-
Dup (-03)	MW-3 (DF100)	-	-	-	10.8	1	No	4058	2/16/08	-28.52
Blank		-	-	-	<1 (U)	1	No	4048	2/15/08	-
LCS_Lo		-	-	-	13.7	1	No	4049	2/15/08	-28.05
LCS_Hi		-	-	-	21.5	1	No	4050	2/15/08	-27.99
LCS acceptance range								-27.50	<=>	-28.50

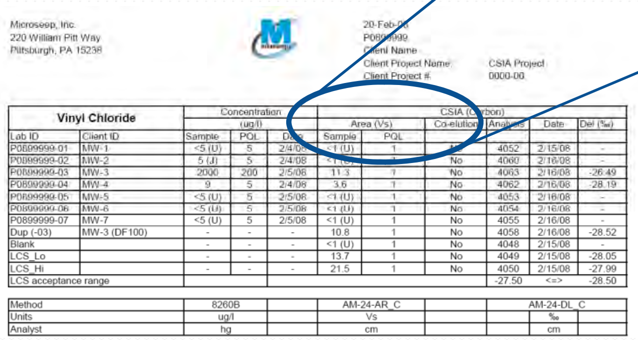
Method	8260B		AM-24-AR_C		AM-24-DL_C
Units	ug/l		Vs		‰
Analyst	hg		cm		cm

Microseeps' CSIA quality control (QC) program has been modeled after those methods because they use a very good and widely recognized QC program, but for measuring concentration CSIA is not an alternative to those methods. As such, the CSIA section of Microseeps' laboratory report does not specify concentrations, but area. We report area in Vs, or volt·seconds. Area is generally proportional to concentration and area values are provided in your CSIA report so that two points can be assessed.

PQL

Minimum signal strength – the reason behind the flags.

As with any instrument, there is some minimum threshold of signal required for a reliable isotopic ratio to be accurately measured. The PQL (Practical Quantitation Limit) is a systematically determined “reporting limit” that gives the minimum area necessary to produce an isotopic ratio measurement accurate to within ±0.5 per mil. The CSIA Standard Operating Procedure (SOP-AM24) gives the detailed procedure used for PQL determination. The measurement is somewhat less accurate, but still reliable, when the area is below the PQL.



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220 William Pitt Way
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20-Feb-08
P0899999
Client Name
Client Project Name: CSIA Project
Client Project #: 0000-00

Vinyl Chloride		Concentration (ug/l)			CSIA (Carbon)					
					Area (Vs)		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
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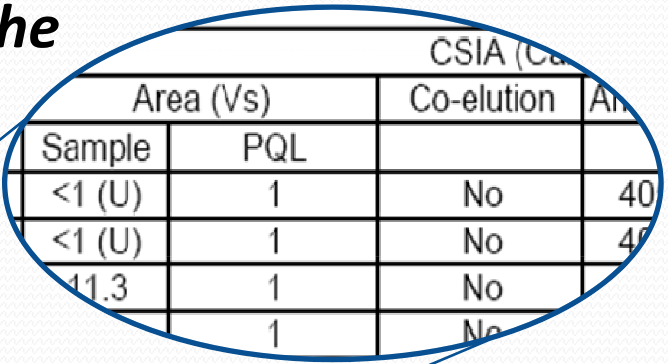
P0899999-02	MW-2	5 (J)	5	2/4/08	<1 (U)	1	No	4060	2/16/08	-
P0899999-03	MW-3	2000	200	2/5/08	11.3	1	No	4063	2/16/08	-26.49
P0899999-04	MW-4	9	5	2/4/08	3.6	1	No	4062	2/16/08	-28.19
P0899999-05	MW-5	<5 (U)	5	2/5/08	<1 (U)	1	No	4053	2/16/08	-
P0899999-06	MW-6	<5 (U)	5	2/5/08	<1 (U)	1	No	4054	2/16/08	-
P0899999-07	MW-7	<5 (U)	5	2/5/08	<1 (U)	1	No	4055	2/16/08	-
Dup (-03)	MW-3 (DF100)	-	-	-	10.8	1	No	4058	2/16/08	-28.52
Blank		-	-	-	<1 (U)	1	No	4048	2/15/08	-
LCS_Lo		-	-	-	13.7	1	No	4049	2/15/08	-28.05
LCS_Hi		-	-	-	21.5	1	No	4050	2/15/08	-27.99
LCS acceptance range								-27.50	<=>	-28.50

Method	8260B		AM-24-AR_C		AM-24-DL_C		
Units	ug/l		Vs			‰	
Analyst	hg		cm			cm	



		CSIA (Ca	
Area (Vs)		Co-elution	An
Sample	PQL		
<1 (U)	1	No	40
<1 (U)	1	No	4
11.3	1	No	
	1	No	

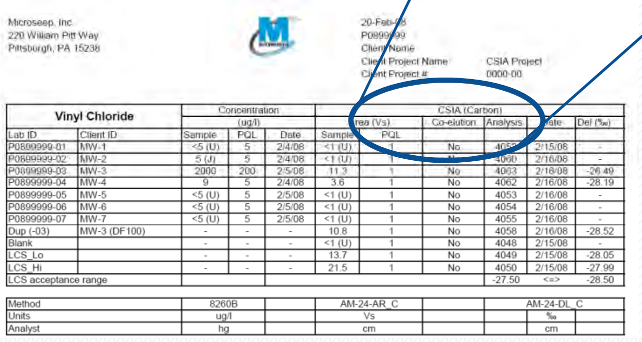
The range of this accuracy is very matrix dependant, but through experience we have found that duplicates still match to within two or three per mil when the signal is at least 80% of the PQL, so it can be considered that the method detection limit (MDL) is 80% of the PQL. Any areas which lie between the MDL and PQL are flagged with a J. Areas that are less than the MDL are treated as “non-detects” and the area is reported as being less than the PQL and flagged with a “U”. The measured area is reported to the user so that they can see if the signal strength was sufficient and/or what flags should be put upon the data.

PQL – the details

- U – indicates either that there was no peak corresponding to the target analyte or that if there was such a peak, it had an area less than the MDL and did not produce a reliable CSIA result.
- J – indicates that the target analyte was found but the area of the peak it produced is less than the PQL but greater than the MDL (the MDL is 80% of the PQL). The result is considered usable to ± 1-2 ‰, but not the standard ± 0.5 ‰.

Co-elution

If a co-contaminant elutes from the chromatographic column with a target analyte, the CSIA measurement of that target analyte may not be entirely of a single compound, but may be corrupted by the presence of the co-eluting compound. According to AM-24 there are specific ways to evaluate the CSIA results for this and they produce a simple Yes/No answer, and they are spelled out on the following page. A positive co-elution result indicates the data may be suspect.

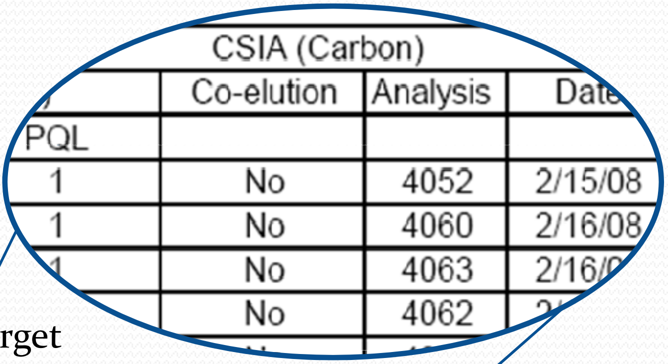


Microseep, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

20-Feb-08
P0899999
Client Name
Client Project Name CSIA Project
Client Project # 0000-00

Vinyl Chloride		Concentration			CSIA (Carbon)					
		(ug/l)			rea (Vs)		Co-elution	Analysis	ate	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P0899999-01	MW-1	<5 (U)	5	2/4/08	<1 (U)	1	No	4052	2/15/08	-
P0899999-02	MW-2	5 (J)	5	2/4/08	<1 (U)	1	No	4060	2/16/08	-
P0899999-03	MW-3	2000	200	2/5/08	11.3	1	No	4063	2/16/08	-26.49
P0899999-04	MW-4	9	5	2/4/08	3.6	1	No	4062	2/16/08	-28.19
P0899999-05	MW-5	<5 (U)	5	2/5/08	<1 (U)	1	No	4053	2/16/08	-
P0899999-06	MW-6	<5 (U)	5	2/5/08	<1 (U)	1	No	4054	2/16/08	-
P0899999-07	MW-7	<5 (U)	5	2/5/08	<1 (U)	1	No	4055	2/16/08	-
Dup (-03)	MW-3 (DF100)	-	-	-	10.8	1	No	4058	2/16/08	-28.52
Blank		-	-	-	<1 (U)	1	No	4048	2/15/08	-
LCS_Lo		-	-	-	13.7	1	No	4049	2/15/08	-28.05
LCS_Hi		-	-	-	21.5	1	No	4050	2/15/08	-27.99
LCS acceptance range								-27.50	<=>	-28.50

Method	8260B		AM-24-AR_C		AM-24-DL_C		
Units	ug/l		Vs			‰	
Analyst	hg		cm			cm	



	CSIA (Carbon)		
	Co-elution	Analysis	Date
PQL			
1	No	4052	2/15/08
1	No	4060	2/16/08
	No	4063	2/16/
	No	4062	

A positive co-elution result indicates the data may be suspect.

Why?

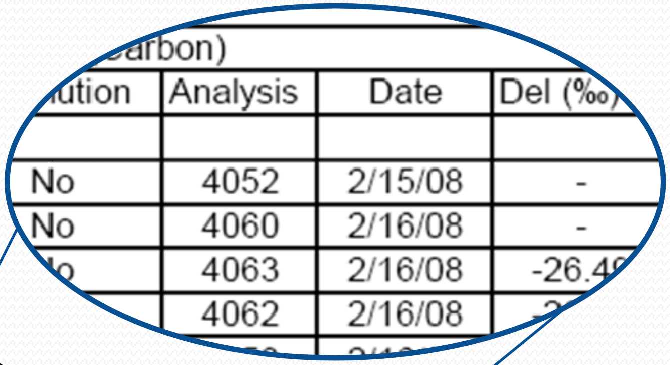
In CSIA, compounds are only separated as well as the gas chromatograph separates them. A concentration measurement such as an SW846-8260 then further distinguishes by mass. However, in CSIA all analytes are first combusted to carbon dioxide before the analytes enter the mass spectrometer. As such, an isotope ratio mass spectrometer, such as that used for CSIA, does not contribute to the identification of analytes.

Co-elution – the details

Two ways to detect co-elution

- Peak Shape Assessment
  - Available directly from IRMS
  - Requires examination of detailed results
- Comparison with a standard GCMS concentration
  - Microseeps performs this comparison
  - Allows detection of “perfect” co-elutions that don’t affect peak shape

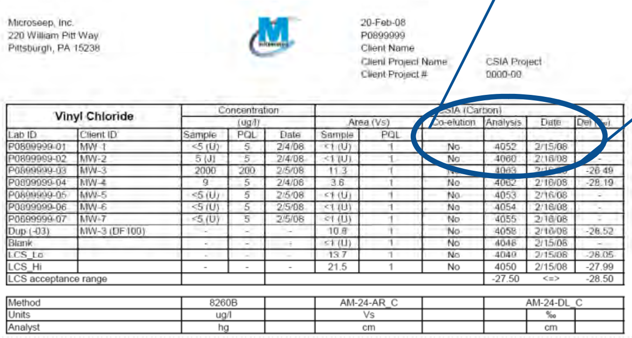
Analysis



arbon)			
ution	Analysis	Date	Del (‰)
No	4052	2/15/08	-
No	4060	2/16/08	-
lo	4063	2/16/08	-26.4
	4062	2/16/08	-2

A unique, sequential analysis number is automatically assigned to every analysis. The analysis number provided with each result identifies the analysis that measured the reported result. The data-user can use it as the cross-reference to the surrogate table.

Through this unique identifier, each result is cross-referenced to the surrogate table.



Microseep, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

20-Feb-08
P0899999
Client Name
Client Project Name CSIA Project
Client Project # 0000-00

Vinyl Chloride		Concentration					CSIA (Carbon)			
		(ug/l)			Area (Vs)		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P0899999-01	MW-1	<5 (U)	5	2/4/08	<1 (U)	1	No	4052	2/15/08	-
P0899999-02	MW-2	5 (J)	5	2/4/08	<1 (U)	1	No	4060	2/16/08	-
P0899999-03	MW-3	2000	200	2/5/08	11.3	1	No	4063	2/16/08	-26.49
P0899999-04	MW-4	9	5	2/4/08	3.6	1	No	4062	2/16/08	-28.19
P0899999-05	MW-5	<5 (U)	5	2/5/08	<1 (U)	1	No	4053	2/16/08	-
P0899999-06	MW-6	<5 (U)	5	2/5/08	<1 (U)	1	No	4054	2/16/08	-
P0899999-07	MW-7	<5 (U)	5	2/5/08	<1 (U)	1	No	4055	2/16/08	-
Dup (-03)	MW-3 (DF100)	-	-	-	10.8	1	No	4058	2/16/08	-28.52
Blank		-	-	-	<1 (U)	1	No	4048	2/15/08	-
LCS_Lo		-	-	-	13.7	1	No	4049	2/15/08	-28.05
LCS_Hi		-	-	-	21.5	1	No	4050	2/15/08	-27.99
LCS acceptance range								-27.50	<=>	-28.50

Method		8260B			AM-24-AR_C			AM-24-DL_C		
Units		ug/l			Vs				‰	
Analyst		hg			cm				cm	

From that the data user can see what the area response of the surrogate was in that sample, what dilution was analyzed to get the reported result and what del was measured for the surrogate in that sample.

Del

This is the documented, validated and final CSIA result.

This is the documented, validated and final CSIA result. It is linearly related to the isotopic ratio, but expressed in more convenient units. This is the result the data user most needs. How it relates to the measured values is discussed in SOP-AM24, but other than for a one time data validation, that information is not required.

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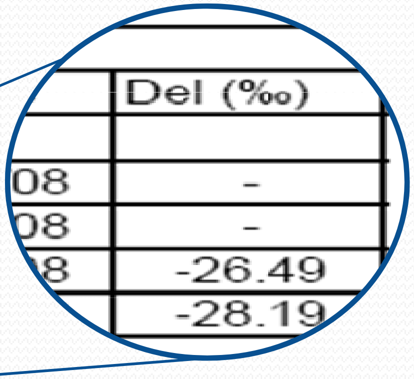
Client Name
Client Project Name: CSIA Project
Client Project #: 0000-00

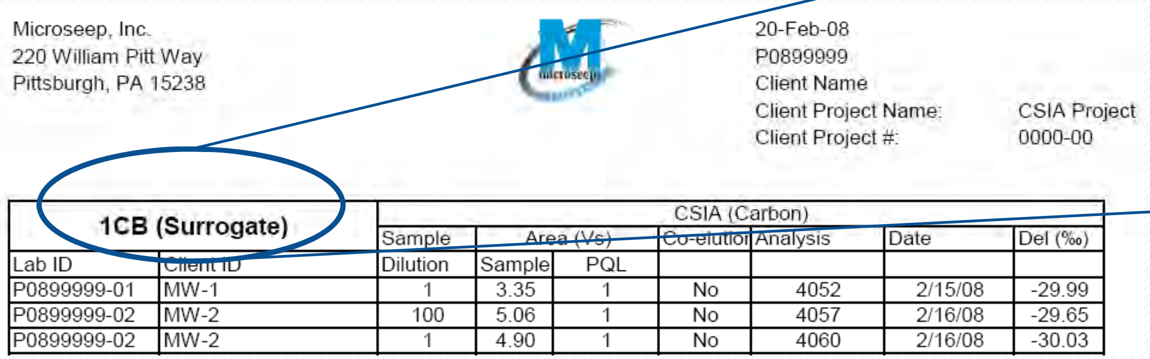
Vinyl Chloride		Concentration			CSIA (Carbon)					
		(ug/l)			Area (Vs)		Co-elution	Analysis	Da	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P0899999-01	MW-1	<5 (U)	5	2/4/08	<1 (U)	1	No	4052	2/15/0	-
P0899999-02	MW-2	5 (J)	5	2/4/08	<1 (U)	1	No	4060	2/16/08	-
P0899999-03	MW-3	2000	200	2/5/08	11.3	1	No	4063	2/16/08	-26.49
P0899999-04	MW-4	9	5	2/4/08	3.6	1	No	4062	2/16/08	-28.19
P0899999-05	MW-5	<5 (U)	5	2/5/08	<1 (U)	1	No	4053	2/16/08	-
P0899999-06	MW-6	<5 (U)	5	2/5/08	<1 (U)	1	No	4054	2/16/08	-
P0899999-07	MW-7	<5 (U)	5	2/5/08	<1 (U)	1	No	4055	2/16/08	-
Dup (-03)	MW-3 (DF100)	-	-	-	10.8	1	No	4058	2/16/08	-28.52
Blank		-	-	-	<1 (U)	1	No	4048	2/15/08	-
LCS_Lo		-	-	-	13.7	1	No	4049	2/15/08	-28.05
LCS_Hi		-	-	-	21.5	1	No	4050	2/15/08	-27.99
LCS acceptance range								-27.50	<=>	-28.50

Method	8260B		AM-24-AR_C		AM-24-DL_C	
Units	ug/l		Vs		‰	
Analyst	hg		cm		cm	



If the area was insufficient, i.e. marked with a "U" flag, the del result will appear as a "-" (in some formats it comes out as an "NR").

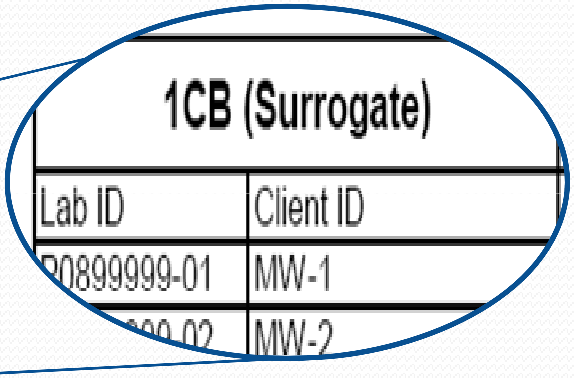
Surrogate



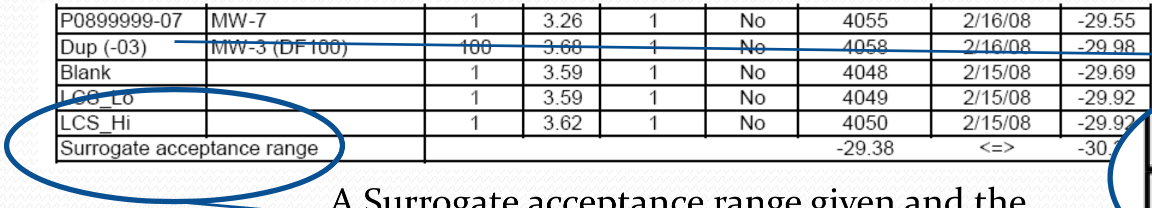
Microseep, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

20-Feb-08
P0899999
Client Name
Client Project Name: CSIA Project
Client Project #: 0000-00

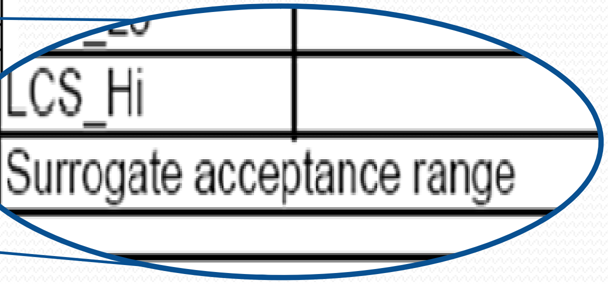
1CB (Surrogate)		CSIA (Carbon)						
		Sample	Area (Vs)		Co-elutio	Analysis	Date	Del (‰)
Lab ID	Client ID	Dilution	Sample	PQL				
P0899999-01	MW-1	1	3.35	1	No	4052	2/15/08	-29.99
P0899999-02	MW-2	100	5.06	1	No	4057	2/16/08	-29.65
P0899999-02	MW-2	1	4.90	1	No	4060	2/16/08	-30.03



A surrogate is injected into every field sample and every QC sample during analysis. The surrogate results are summarized in the surrogate table provided at the back of each CSIA report.
The surrogate allows for a check of the ability of the CSIA system to measure the del of that surrogate accurately from the same sample and dilution as was used for any of the target analyte measurements. The surrogate is chosen to be something that would not be present in a field sample, but there is still the potential for corruption of the surrogate peak by interferents present in the sample.

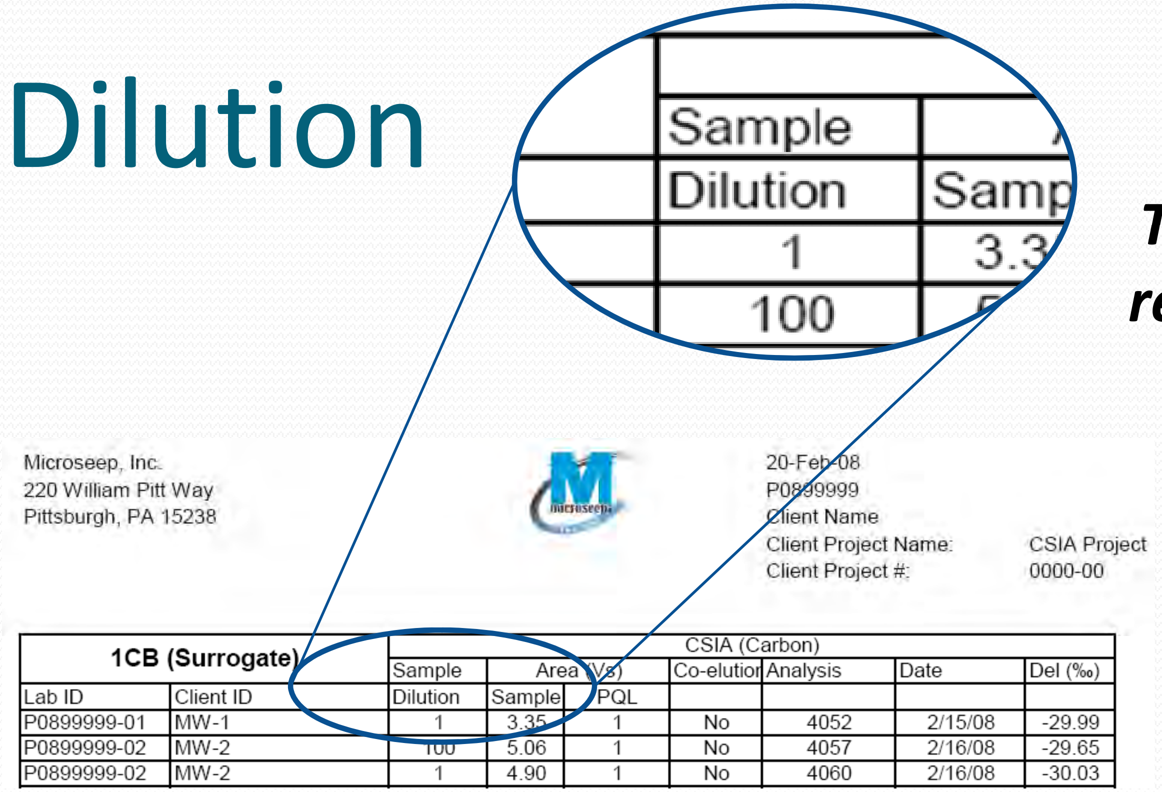


P0899999-07	MW-7	1	3.26	1	No	4055	2/16/08	-29.55
Dup (-03)	MW-3 (DF100)	100	3.68	1	No	4058	2/16/08	-29.98
Blank		1	3.59	1	No	4048	2/15/08	-29.69
LCS_Lo		1	3.59	1	No	4049	2/15/08	-29.92
LCS_Hi		1	3.62	1	No	4050	2/15/08	-29.92
Surrogate acceptance range						-29.38	<=>	-30.



A Surrogate acceptance range given and the measured del should be within those limits, unless a co-elution is reported.

Dilution



Microseep, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

20-Feb-08
P0899999
Client Name
Client Project Name: CSIA Project
Client Project #: 0000-00

1CB (Surrogate)		CSIA (Carbon)						
		Sample	Area (Vs)		Co-elutior	Analysis	Date	Del (‰)
Lab ID	Client ID	Dilution	Sample	PQL				
P0899999-01	MW-1	1	3.35	1	No	4052	2/15/08	-29.99
P0899999-02	MW-2	100	5.06	1	No	4057	2/16/08	-29.65
P0899999-02	MW-2	1	4.90	1	No	4060	2/16/08	-30.03

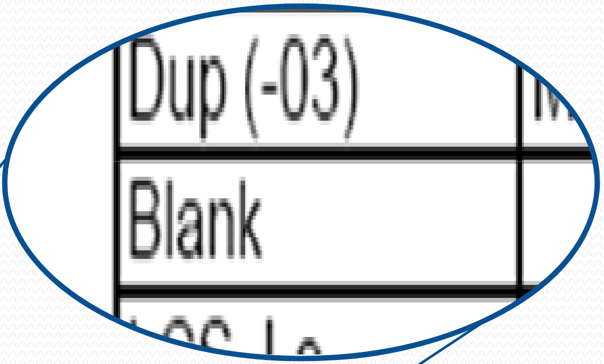
The most robust way to reduce signal strength is simple dilution, and that is the technique used at Microseeps.

To be able to accurately measure the del of the individual components, it is necessary to reduce the signal strength of the more concentrated species. The most robust way to reduce signal strength is simple dilution, and that is the technique used at Microseeps. To measure the species in that same sample that are present at low concentrations, a less diluted or undiluted run may be required. As such it is not uncommon for a single field sample to be analyzed two or three times. By using the analysis number given with each result, the surrogate table can be used to see what dilution was analyzed to obtain each result.

Batch Quality Control

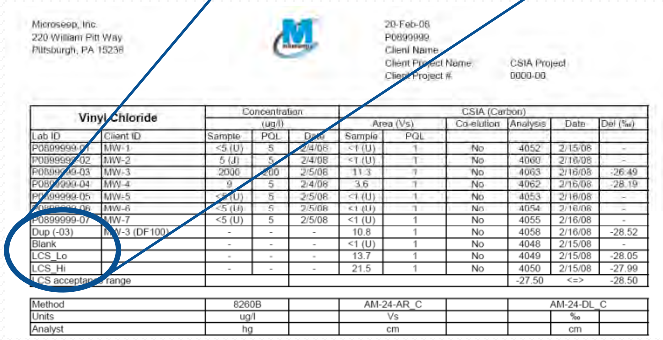
- Duplicate
- Blank
- Laboratory Control Samples
    - LCS_Lo
    - LCS_Hi
- Matrix Spikes
    - Matrix Spike Duplicates

Blank



The blank serves the typical role of proving that there is no contamination left from the previous run. While we are not measuring concentration, carry-over can pose a problem in CSIA because the del values of a particular analyte differs from sample to sample. If there is carry-over the measured del will reflect a mixture of the current sample and the previous one.

…carry-over can cause a problem in CSIA.



Microseep, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

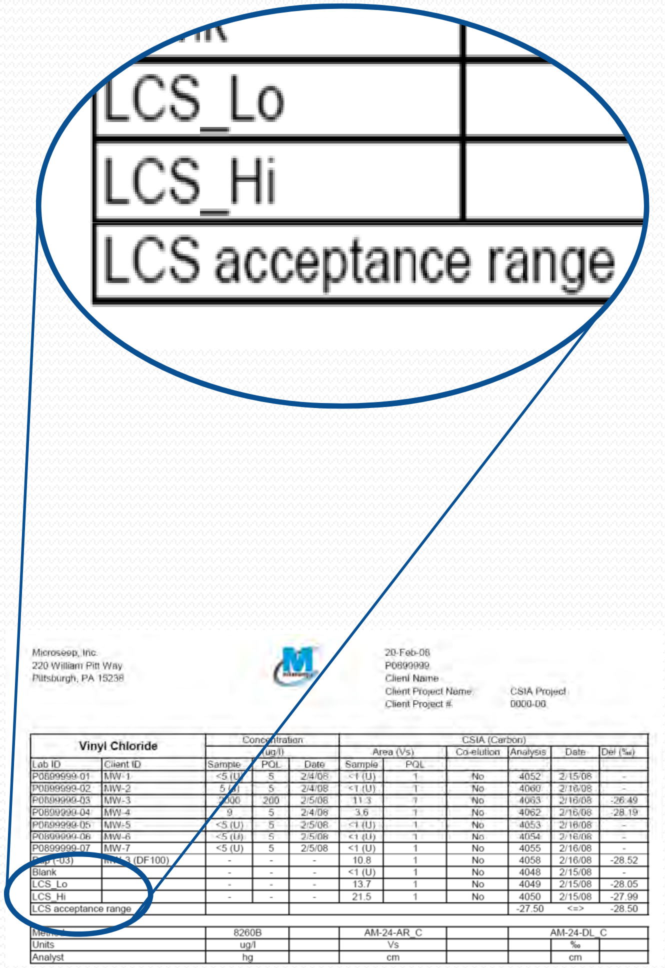
20-Feb-08
P0899999
Client Name
Client Project Name CSIA Project
Client Project # 0000-00

Vinyl Chloride		Concentration			CSIA (Carbon)					
		(ug/l)			Area (Vs)		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P0899999-01	MW-1	<5 (U)	5	2/4/08	<1 (U)	1	No	4052	2/15/08	-
P0899999-02	MW-2	5 (J)	5	2/4/08	<1 (U)	1	No	4060	2/16/08	-
P0899999-03	MW-3	2000	200	2/5/08	11.3	1	No	4063	2/16/08	-26.49
P0899999-04	MW-4	9	5	2/4/08	3.6	1	No	4062	2/16/08	-28.19
P0899999-05	MW-5	<5 (U)	5	2/5/08	<1 (U)	1	No	4053	2/16/08	-
P0899999-06	MW-6	<5 (U)	5	2/5/08	<1 (U)	1	No	4054	2/16/08	-
P0899999-07	MW-7	<5 (U)	5	2/5/08	<1 (U)	1	No	4055	2/16/08	-
Dup (-03)	MW-3 (DF100)	-	-	-	10.8	1	No	4058	2/16/08	-28.52
Blank		-	-	-	<1 (U)	1	No	4048	2/15/08	-
LCS_Lo		-	-	-	13.7	1	No	4049	2/15/08	-28.05
LCS_Hi		-	-	-	21.5	1	No	4050	2/15/08	-27.99
LCS acceptance range								-27.50	<=>	-28.50

Method	8260B		AM-24-AR_C		AM-24-DL_C	
Units	ug/l		Vs		‰	
Analyst	hg		cm		cm	

Ideally for each target analyte in the blank there is a U, but for the surrogate in the blank there is a strong signal and the expected del is measured for that surrogate. (The absence of target analytes is proven by the U's, and the surrogate response proves that if the target analytes were present, they would have been seen, so the U's are valid.)

Laboratory Control Samples



Microseep, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

20-Feb-08
P0899999
Client Name
Client Project Name: CSIA Project
Client Project #: 0000-00

Vinyl Chloride		Concentration (ug/l)			CSIA (Carbon)					
					Area (Vs)		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P0899999-01	MW-1	<5 (U)	5	2/4/08	<1 (U)	1	No	4052	2/15/08	-
P0899999-02	MW-2	5 (J)	5	2/4/08	<1 (U)	1	No	4060	2/16/08	-
P0899999-03	MW-3	2000	200	2/5/08	11.3	1	No	4063	2/16/08	-26.49
P0899999-04	MW-4	9	5	2/4/08	3.6	1	No	4062	2/16/08	-28.19
P0899999-05	MW-5	<5 (U)	5	2/5/08	<1 (U)	1	No	4053	2/16/08	-
P0899999-06	MW-6	<5 (U)	5	2/5/08	<1 (U)	1	No	4054	2/16/08	-
P0899999-07	MW-7	<5 (U)	5	2/5/08	<1 (U)	1	No	4055	2/16/08	-
Dup (-03)	MW-3 (DF100)	-	-	-	10.8	1	No	4058	2/16/08	-28.52
Blank		-	-	-	<1 (U)	1	No	4048	2/15/08	-
LCS_Lo		-	-	-	13.7	1	No	4049	2/15/08	-28.05
LCS_Hi		-	-	-	21.5	1	No	4050	2/15/08	-27.99
LCS acceptance range								-27.50	<=>	-28.50

Method		8260B			AM-24-AR_C			AM-24-DL_C		
Units		ug/l			Vs				‰	
Analyst		hg			cm				cm	

To ensure quality, Laboratory Control Samples (LCS's) are constructed from laboratory grade DI water spiked with all of the analytes. The del values measured from these samples can be checked against the "LCS accepted value" and the results should lie within that range. These values were arrived at by repeated analysis of these constituents in laboratory derived samples, and details of that procedure are available in Microseeps' SOP AM24.

It is important to note that an LCS acceptance range is given for the del of each compound. These ranges are measured through replicate analyses of the standard at various concentrations in water. The details are provided in the SOP AM-24. These ranges are very important and play a vital role in each of the three purposes of the LCS detailed on the following page..

LCS purposes

1. Measure the del of each target analyte in a isotopically known sample.

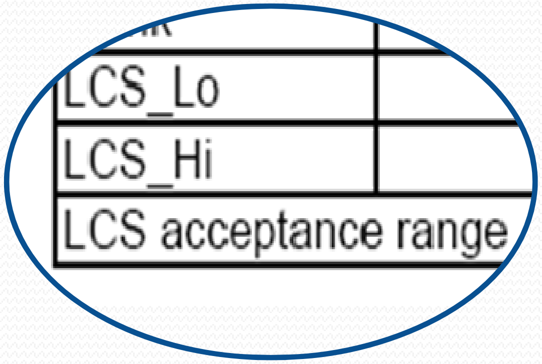
   This ensures that the measurements are accurate at the concentration in the LCS.

2. Measure the del in two samples that are isotopically identical but differ in concentration.

   This ensures there is no significant concentration dependence to the del measurements.

3. Calculate the calibration factor for later use in diagnosing co-elution.

   The contents of the LCS's are completely known, and there should be no co-elution in them. While this method is not intended to measure concentration, the area response, corrected for dilution, should be proportional to the concentration. That proportionality is used to insure that the peak area of a sample could all be attributed to the target analyte. If the peak area in a sample peak is larger than would be expected given the measured concentration, there is probably a co-elution. Co-elutions have been discussed in more detail previously.



LCS_Lo	
LCS_Hi	
LCS acceptance range	

Matrix Spikes

Matrix spikes and matrix spike duplicates are useful tools for validating concentration results. Unfortunately, they are not meaningful in CSIA. Several things have been done to make up for this. Duplicate samples are analyzed more frequently. Additionally, rather than just a single LCS, two LCS's are used.

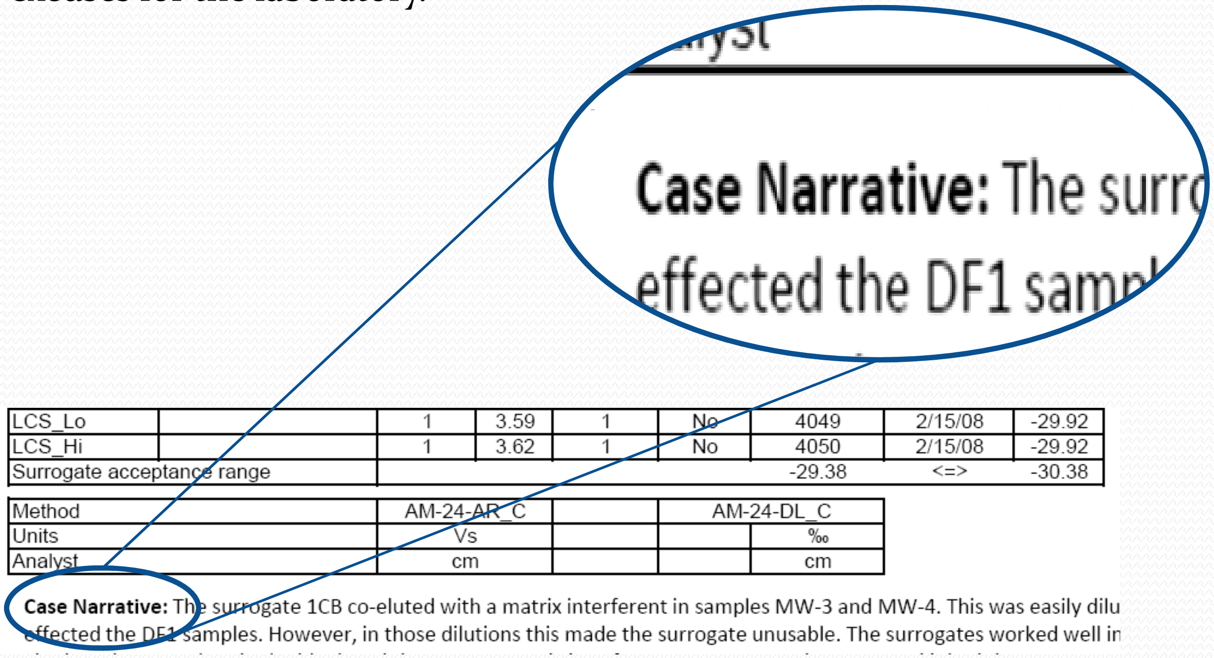
- For accuracy, use the LCS_Hi
- For precision, use the LCS_Lo and the LCS_Hi
- For matrix effects, use the surrogate

Case Narrative

In the Case Narrative any exceptions are discussed, as is their potential effect upon the reported data. Microseeps makes every effort to issue the most valid reports possible, and to flag any suspect data that is reported. In no way is the case narrative intended to alarm the data user nor is it intended to be a list of excuses for the laboratory.

The Case Narrative explains any exceptions.

Rather, the case narrative is intended to be a succinct description of the analytical project where the data validity is assessed and any potential detractions from that validity are explained in terms of their cause and their effect upon the reported data. This is presented to empower the data user to be more confident about their data.



LCS_Lo		1	3.59	1	No	4049	2/15/08	-29.92
LCS_Hi		1	3.62	1	No	4050	2/15/08	-29.92
Surrogate acceptance range						-29.38	<=>	-30.38

Method	AM-24-AR_C		AM-24-DL_C	
Units	Vs			‰
Analyst	cm			cm

Case Narrative: The surrogate 1CB co-eluted with a matrix interferent in samples MW-3 and MW-4. This was easily dilu

effected the DF1 samples. However, in those dilutions this made the surrogate unusable. The surrogates worked well in

Other References

This concludes the discussion of the report you have received from Microseeps. Interpretation of what the del values mean for your site is another very important issue. While that is beyond the scope of this document, there are several excellent sources of information we would like to point out:

- "Monitored Natural Attenuation of MTBE as a Risk Management Option at Leaking Underground Storage Tank Sites." 2005. USEPA, EPA/600/R-04/1790

It is focused upon MTBE, but it covers a lot of vital fundamentals that are applicable to CSIA in general.

- "Compound Specific Isotope Analysis: The Science, Technology and Selected Examples from the Literature with Application to Fuel Oxygenates and Chlorinated Solvents." 2007. Available at http://www.microseeps.com/pdf/csia.pdf

This paper is a review of much of the available literature, starting from the fundamental basics and covering MTBE remediation, chlorinated solvent remediation, biodegradation and such other topics as CSIA and ISCO or CSIA and modeling.

- The USEPA, in cooperation with the IAEA of the UN, is preparing "A Consensus Guide for Assessing Biodegradation and Source Identification with Compound Specific Isotope Analysis (CSIA)." That document is planned for release in October of 2008. It was prepared by a team of renowned experts and covers a multitude of issues in great depth.

We are confident that you will find the report you have received to be a very useful tool, and that CSIA can be a powerful part of your remediation work. Please feel free to contact us not only about work that has been done or is ongoing, but also work that is planned. We would love to discuss your project goals and potential ways we can fill them.

microseeps
insight

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Microseeps, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

CSIA Report

29-Sep-10
P1009025
CH2M Hill
Client Project Name: Fruit Ave Plume
Client Project #: 941455

cis-Dichloroethene		Concentration			CSIA (Carbon)					
		(ug/l)			Area		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P1009025-01	HSM-I2-Q310	6	5	9/14/10	3.67	1	No	11228	9/4/10	-37.04
Duplicate	HSM-I2-Q310	-	-	-	3.16	1	No	11229	9/4/10	-37.70
Blank	-	0	-	-	<1 (U)	1	No	11214	9/3/10	-
LCS_Lo	-	10	-	-	1.74	1	No	11216	9/3/10	-19.80
LCS_Hi	-	50	-	-	8.79	1	No	11217	9/3/10	-20.15
LCS acceptance range								-21.33	<=>	-22.33

Method	GCMS_CSIA	AM-24-AR_C	AM-24-DL_C
Units	ug/l	Vs	‰
Analyst	HG	HG	HG

Microseeps, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

CSIA Report

29-Sep-10
P1009025
CH2M Hill
Client Project Name: Fruit Ave Plume
Client Project #: 941455

Trichloroethene		Concentration			CSIA (Carbon)					
		(ug/l)			Area		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P1009025-01	HSM-I2-Q310	30	5	9/14/10	12.8	1	No	11228	9/4/10	-20.62
Duplicate	HSM-I2-Q310	-	-	-	10.8	1	No	11229	9/4/10	-20.83
Blank	-	0	-	-	<1 (U)	1	No	11214	9/3/10	-
LCS_Lo	-	10	-	-	1.76	1	No	11216	9/3/10	-29.76
LCS_Hi	-	50	-	-	8.08	1	No	11217	9/3/10	-30.53
LCS acceptance range								-30.06	<=>	-31.06

Method	GCMS_CSIA	AM-24-AR_C	AM-24-DL_C
Units	ug/l	Vs	‰
Analyst	HG	HG	HG

Microseeps, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

CSIA Report

29-Sep-10
P1009025
CH2M Hill

Client Project Name:	Fruit Ave Plume
Client Project #:	941455

1CP (Surrogate)		Sample Collection	CSIA (Carbon)						
Lab ID	Client ID		Area	Dilution	PQL	Co-elution	Analysis	Date	Del (‰)
P1009025-01	HSM-I2-Q310	08/30/10	2.24	1	1	No	11228	09/04/10	-36.62
Duplicate	HSM-I2-Q310	08/30/10	1.92	1	1	No	11229	09/04/10	-37.42
Blank	-	-	6.69	1	1	No	11214	09/03/10	-37.40
LCS_Lo	-	-	5.97	1	1	No	11216	09/03/10	-36.85
LCS_Hi	-	-	5.67	1	1	No	11217	09/03/10	-37.02
Surrogate acceptance range							-37.00	<=>	-38.00

Method		AM-24-AR_C	AM-24-DL_C
Units		Vs	‰
Analyst		HG	HG

Case Narrative: The blank, LCS's, duplicate and surrogates were all close to or within the acceptance range and the data is reported as valid and representative of the samples as received.

Microseeps, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

CSIA Report

29-Sep-10
P1009028
CH2M Hill
Client Project Name: Fruit Ave Plume
Client Project #: 941455

cis-Dichloroethene		Concentration (ug/l)			CSIA (Carbon)					
					Area		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P1009028-01	SFMW-40-D3-Q310	5 (J)	5	9/14/10	2.44	1	No	11242	9/7/10	-31.73
P1009028-02	SFMW-44-D2-Q310	6	5	9/14/10	2.98	1	No	11243	9/7/10	-33.53
Duplicate	SFMW-44-D2-Q310	-	-	-	3.09	1	No	11245	9/7/10	-32.76
Blank	-	0	-	-	<1 (U)	1	No	11230	9/4/10	-
LCS_Lo	-	10	-	-	2.08	1	No	11231	9/4/10	-19.52
LCS_Hi	-	50	-	-	10.2	1	No	11232	9/4/10	-20.09
LCS acceptance range								-21.33	<=>	-22.33

Method	GCMS_CSIA	AM-24-AR_C	AM-24-DL_C
Units	ug/l	Vs	‰
Analyst	HG	HG	HG

Microseeps, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

CSIA Report

29-Sep-10
P1009028
CH2M Hill
Client Project Name: Fruit Ave Plume
Client Project #: 941455

Trichloroethene		Concentration (ug/l)			CSIA (Carbon)					
					Area		Co-elution	Analysis	Date	Del (‰)
Lab ID	Client ID	Sample	PQL	Date	Sample	PQL				
P1009028-01	SFMW-40-D3-Q310	7	5	9/14/10	2.64	1	No	11242	9/7/10	-16.76
P1009028-02	SFMW-44-D2-Q310	10	5	9/14/10	3.73	1	No	11243	9/7/10	-17.63
Duplicate	SFMW-44-D2-Q310	-	-	-	3.70	1	No	11245	9/7/10	-17.95
Blank	-	0	-	-	<1 (U)	1	No	11230	9/4/10	-
LCS_Lo	-	10	-	-	1.92	1	No	11231	9/4/10	-28.71
LCS_Hi	-	50	-	-	9.26	1	No	11232	9/4/10	-30.74
LCS acceptance range								-30.06	<=>	-31.06

Method	GCMS_CSIA	AM-24-AR_C	AM-24-DL_C
Units	ug/l	Vs	‰
Analyst	HG	HG	HG

Microseeps, Inc.
220 William Pitt Way
Pittsburgh, PA 15238

CSIA Report

29-Sep-10
P1009028
CH2M Hill
Client Project Name: Fruit Ave Plume
Client Project #: 941455

1CP (Surrogate)		Sample Collection	CSIA (Carbon)						
Lab ID	Client ID		Area	Dilution	PQL	Co-elution	Analysis	Date	Del (‰)
P1009028-01	SFMW-40-D3-Q310	08/31/10	7.35	1	1	No	11242	09/07/10	-37.06
P1009028-02	SFMW-44-D2-Q310	08/31/10	6.69	1	1	No	11243	09/07/10	-37.44
Duplicate	SFMW-44-D2-Q310	08/31/10	5.60	1	1	No	11245	09/07/10	-37.61
Blank	-	-	2.04	1	1	No	11230	09/04/10	-37.32
LCS_Lo	-	-	1.93	1	1	No	11231	09/04/10	-37.08
LCS_Hi	-	-	1.84	1	1	No	11232	09/04/10	-36.52
Surrogate acceptance range							-37.00	<=>	-38.00

Method		AM-24-AR_C	AM-24-DL_C
Units		Vs	‰
Analyst		HG	HG

Case Narrative: The blank, LCS's, duplicate and surrogates were all close to or within the acceptance range and the data is reported as valid and representative of the samples as received.

microseeps
from insight comes solutions

Client Name:	CH2M Hill	Page:	Page 1 of 8
Contact:	John Ynfante	Lab Proj #:	P1009103
Address:	14701 St. Marys Lane Suite 300 Houston, TX 77079-2923	Report Date:	09/30/10
		Client Proj Name:	Fruit Ave Plume
		Client Proj #:	941455

Laboratory Results

Total pages in data package: 10

Lab Sample #	Client Sample ID
P1009103-01	MNW-14-I2-Q310

Microseeps test results meet all the requirements of the NELAC standards or provide reasons and/or justification if they do not.

Approved By: Debbie Hallo ***Date:*** 10-1-10

Project Manager: Debbie Hallo

The analytical results reported here are reliable and usable to the precision expressed in this report. As required by some regulating authorities, a full discussion of the uncertainty in our analytical results can be obtained at our web site or through customer service. Unless otherwise specified, all results are reported on a wet weight basis.

As a valued client we would appreciate your comments on our service.
Please call customer service at (412)826-5245 or email customerservice@microseeps.com.

Client Name:	CH2M Hill	Page:	Page 2 of 8
Contact:	John Ynfante	Lab Proj #:	P1009103
Address:	14701 St. Marys Lane Suite 300 Houston, TX 77079-2923	Report Date:	09/30/10
		Client Proj Name:	Fruit Ave Plume
		Client Proj #:	941455

Case Narrative: The blank, LCS's, duplicate and surrogates were all close to or within the acceptance range and the data are reported as valid and representative of the samples as received.

PA02-00538

Data Qualifiers: J - estimated value, U - Non detect, R - Poor surrogate recovery, M - Recovery/RPD poor for MS/MSD, SAMP/DUP, B - detected in blank, S - field sample as received did not meet NELAC sample acceptance criteria, L - Subcontracted Lab used, N - NELAC certified analysis

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Page: Page 3 of 8
Lab Proj #: P1009103
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Sample Description	Matrix	Lab Sample #	Sampled Date/Time	Received
MNW-14-I2-Q310	Water	P1009103-01	07 Sep. 10 15:40	08 Sep. 10 12:20

Analyte(s)	Flag	Result	PQL	Units	Method #	Analysis Date	By
CSIA							
cis-1,2-Dichloroethene		8.0	5.0	ug/L	Screen	9/16/10	hg
cis-1,2-Dichloroethene-area		4.59	1.0	Vs	AM24-AR_C	9/22/10	hg
cis-1,2-Dichloroethene-carbon		-37.94	-500.0	‰	AM24-DL_C	9/22/10	hg
cis-1,2-Dichloroethene-Co-elution		No	0.0	NA	8260B	9/22/10	hg
Surrogate-area		2.95	1.0	Vs	AM24-AR_C	9/22/10	hg
Surrogate-carbon		-37.17	-500.0	‰	AM24-DL_C	9/22/10	hg
Surrogate-Co-elution		No	0.0	NA	8260B	9/22/10	hg
Trichloroethene		20.0	5.0	ug/L	Screen	9/16/10	hg
Trichloroethene-area		8.28	1.0	Vs	AM24-AR_C	9/22/10	hg
Trichloroethene-carbon		-17.36	-500.0	‰	AM24-DL_C	9/22/10	hg
Trichloroethene-Co-elution		No	0.0	NA	8260B	9/22/10	hg

SURROGATE:

1-Chloropropane	120.00 %

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Lab Proj #: P1009103
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Prep Method: Purge and trap for aqueous samples

Analysis Method: CSIA Volatiles-Chlorinated

M100917013-MB

	Result		TrueSpikeConc.	RDL	%Recovery	Ctl Limits
Trichloroethene	< 5.0	ug/L		5.0		- NA
cis-1,2-Dichloroethene	< 5.0	ug/L		5.0		- NA

M100917013-LCS

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
Trichloroethene	40.0	ug/L	50.00	80.00	66 - 118
cis-1,2-Dichloroethene	50.0	ug/L	50.00	100.00	70 - 130

☐ Outlined Results indicate results outside of Control limits

Data Qualifiers: J - estimated value, U - Non detect, R - Poor surrogate recovery, M - Recovery/RPD poor for MS/MSD, SAMP/DUP, B - detected in blank, S - field sample as received did not meet NELAC sample acceptance criteria, L - Subcontracted Lab used, N - NELAC certified analysis

PA02-00538

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Page: Page 5 of 8
Lab Proj #: P1009103
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

P1009103-01A

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
1-Chloropropane	60.0	ug/L	50.00	120.00	70 - 130

M100917013-MB

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
1-Chloropropane	40.0	ug/L	50.00	80.00	70 - 130

M100917013-LCS

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
1-Chloropropane	60.0	ug/L	50.00	120.00	70 - 130

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Page: Page 6 of 8
Lab Proj #: P1009103
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Prep Method: 8260m-CoCr_Chlorinated

Analysis Method: 8260m-CoCr_Chlorinated

M100930038-MB

	Result		TrueSpikeConc.	RDL	%Recovery	Ctl Limits
Trichloroethene-Co-elution	No	NA		0.0		- NA
cis-1,2-Dichloroethene-Co-elution	No	NA		0.0		- NA
Surrogate-Co-elution	No	NA		0.0		- NA

P1009103-01A-DUP

	Result		TrueSpikeConc.	%Recovery	Ctl Limits	RPD	RPD Ctl Limits
Trichloroethene-Co-elution	No	NA			- NA	0	0 - 0
cis-1,2-Dichloroethene-Co-elution	No	NA			- NA	0	0 - 0
Surrogate-Co-elution	No	NA			- NA	0	0 - 0

☐ Outlined Results indicate results outside of Control limits

Data Qualifiers: J - estimated value, U - Non detect, R - Poor surrogate recovery, M - Recovery/RPD poor for MS/MSD, SAMP/DUP, B - detected in blank, S - field sample as received did not meet NELAC sample acceptance criteria, L - Subcontracted Lab used, N - NELAC certified analysis

PA02-00538

Client Name:	CH2M Hill	Page:	Page 7 of 8
Contact:	John Ynfante	Lab Proj #:	P1009103
Address:	14701 St. Marys Lane Suite 300 Houston, TX 77079-2923	Report Date:	09/30/10
		Client Proj Name:	Fruit Ave Plume
		Client Proj #:	941455

Prep Method: AM24-AR_C

Analysis Method: AM24-AR_C

M100930039-MB

	Result		TrueSpikeConc.	RDL	%Recovery	Ctl Limits
Trichloroethene-area	< 1.0	Vs		1.0		- NA
cis-1,2-Dichloroethene-area	< 1.0	Vs		1.0		- NA
Surrogate-area	7.27	Vs		1.0		- NA

P1009103-01A-DUP

	Result		TrueSpikeConc.	%Recovery	Ctl Limits	RPD	RPD Ctl Limits
Trichloroethene-area	8.66	Vs			- NA	4.49	0 - 20
cis-1,2-Dichloroethene-area	4.47	Vs			- NA	2.65	0 - 20
Surrogate-area	2.52	Vs			- NA	15.72	0 - 20

☐ Outlined Results indicate results outside of Control limits

Data Qualifiers: J - estimated value, U - Non detect, R - Poor surrogate recovery, M - Recovery/RPD poor for MS/MSD, SAMP/DUP, B - detected in blank, S - field sample as received did not meet NELAC sample acceptance criteria, L - Subcontracted Lab used, N - NELAC certified analysis

PA02-00538

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Lab Proj #: P1009103
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Prep Method: AM24-DL_C

Analysis Method: AM24-DL_C

M100930040-MB

	Result		TrueSpikeConc.	RDL	%Recovery	Ctl Limits
Trichloroethene-carbon	NR	‰		-500.0		- NA
cis-1,2-Dichloroethene-carbon	NR	‰		-500.0		- NA
Surrogate-carbon	-36.96	‰		-500.0		- NA

M100930040-LCS

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
Trichloroethene-carbon	-29.87	‰	-30.56	0.00	-31 - -30
cis-1,2-Dichloroethene-carbon	-20.19	‰	-21.83	0.00	-22 - -21
Surrogate-carbon	-37.44	‰	-37.50	0.00	-38 - -37

P1009103-01A-DUP

	Result		TrueSpikeConc.	%Recovery	Ctl Limits	RPD	RPD Ctl Limits
Trichloroethene-carbon	-17.62	‰			- NA	0	0 - 20
cis-1,2-Dichloroethene-carbon	-38.70	‰			- NA	0	0 - 20
Surrogate-carbon	-36.82	‰			- NA	0	0 - 20

☐ Outlined Results indicate results outside of Control limits

Data Qualifiers: J - estimated value, U - Non detect, R - Poor surrogate recovery, M - Recovery/RPD poor for MS/MSD, SAMP/DUP, B - detected in blank, S - field sample as received did not meet NELAC sample acceptance criteria, L - Subcontracted Lab used, N - NELAC certified analysis

PA02-00538

FED EX # 8717 3016 1078

Microseeps Lab. Proj. # P1009103

CHAIN - OF - CUSTODY RECORD

Microseeps COC cont. # 101

Phone: (412) 826-5245 Microseeps, Inc. - 220 William Pitt Way - Pittsburgh, PA 15238 Fax No. : (412) 826-3433

Company : CH2M HILL
Co. Address : 4041 Jefferson Plaza Suite 200 ABQ, NM 87109
Phone # : 505-884-5600 **Fax # :** N/A
Proj. Manager : Peter Van Noort
Proj. Name/Number : Fruit Ave Plume Superfund Site
Sampler's signature :
Cooler Temp. 3°C 9/8

Results to : John.ynfante@ch2m.com
Invoice to : per contract

Parameters Requested

Sample ID	Sample Description	Sample Type			Date	Time	# bottles	Dissolved Gases	CSIA	Remarks :
		Water	Vapor	Solid						
MNW-9-I2-0310	GW	X			9/7/10	0925	2	X		unpreserved
SFMW-25-I1-0310	GW	X			9/7/10	0925	2	X		unpreserved
MNW-14-I2-0310	GW	X			9/7/10	1540	2	X		unpreserved
MNW-14-I2-0310	GW	X			9/7/10	1540	9		X	

Relinquished by :	Company :	Date :	Time :	Received by :	Company :	Date :	Time :
	CH2M HILL	9/7/10	1830			9/8/10	[illegible]
Relinquished by :	Company :	Date :	Time :	Received by :	Company :	Date :	Time :
Relinquished by :	Company :	Date :	Time :	Received by :	Company :	Date :	Time :

WHITE COPY : Accompany Samples YELLOW COPY : Laboratory File PINK COPY : Submitter

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Cooler Receipt Form

Client: CH2M Hill **Client Code:** CH2-A **LabProject #:** P1009103

Project: Fruit Ave Plume

Cooler ID: 1

A. Preliminary Examination Phase: **Date cooler opened:** 9/8/2010

Cooler opened by: dp

1. **Was airbill Attached?** N/A **Airbill #:** **Carrier Name:** FedEx
2. **Custody Seals?** N/A **How many?** 0 **Location:** **Seal Name:**
3. **Seals intact?** Yes
4. **Screened for radiation?** N/A
5. **COC Attached?** Yes **Properly Completed?** Yes **Signed by employee?** Yes
6. **Project Identification from custody paper:** Fruit Ave Plume
7. **Preservative:** Yes **Temperature:** 3

Comments:

B. Log-In Phase: Samples Log-in Date: 9/8/2010 **Log-in By:** dp

1. **Packing Type:** Other
2. **Were samples in separate bags?** N/A
3. **Were containers intact?** Yes **Labels agree with COC?** Yes
4. **Number of bottles received:** 9 **Number of samples received:** 1
5. **Correct containers used?** Yes **Correct preservatives added?** N/A
6. **Sufficient sample volume?** Yes
7. **Bubbles in VOA samples?** N/A
8. **Was Project manager called and status discussed?** N/A

Comments:

Have designate person initial here to acknowledge receipt of cooler: **Date:** 9/8/10

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Page: Page 1 of 8
Lab Proj #: P1009199
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Laboratory Results

Total pages in data package: 10

Lab Sample #	Client Sample ID
P1009199-01	MNW-5-D2-Q310

Microseeps test results meet all the requirements of the NELAC standards or provide reasons and/or justification if they do not.

Approved By: Debbie Hallo ***Date:*** 10-1-10

Project Manager: Debbie Hallo

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Page: Page 2 of 8
Lab Proj #: P1009199
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Case Narrative: The blank, LCS's, duplicate and surrogates were all close to or within the acceptance range and the data are reported as valid and representative of the samples as received.

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Lab Proj #: P1009199
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Sample Description	Matrix	Lab Sample #	Sampled Date/Time	Received
MNW-5-D2-Q310	Water	P1009199-01	08 Sep. 10 13:42	15 Sep. 10 11:27

Analyte(s)	Flag	Result	PQL	Units	Method #	Analysis Date	By
CSIA							
cis-1,2-Dichloroethene		6.0	5.0	ug/L	Screen	9/16/10	hg
cis-1,2-Dichloroethene-area		3.21	1.0	Vs	AM24-AR_C	9/22/10	hg
cis-1,2-Dichloroethene-carbon		-32.86	-500.0	‰	AM24-DL_C	9/22/10	hg
cis-1,2-Dichloroethene-Co-elution		No	0.0	NA	8260B	9/22/10	hg
Surrogate-area		1.62	1.0	Vs	AM24-AR_C	9/22/10	hg
Surrogate-carbon		-37.86	-500.0	‰	AM24-DL_C	9/22/10	hg
Surrogate-Co-elution		No	0.0	NA	8260B	9/22/10	hg
Trichloroethene		6.0	5.0	ug/L	Screen	9/16/10	hg
Trichloroethene-area		2.68	1.0	Vs	AM24-AR_C	9/22/10	hg
Trichloroethene-carbon		-17.01	-500.0	‰	AM24-DL_C	9/22/10	hg
Trichloroethene-Co-elution		No	0.0	NA	8260B	9/22/10	hg

SURROGATE:
1-Chloropropane 140.00 %

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Lab Proj #: P1009199
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Prep Method: Purge and trap for aqueous samples

Analysis Method: CSIA Volatiles-Chlorinated

M100917013-MB

	Result		TrueSpikeConc.	RDL	%Recovery	Ctl Limits
Trichloroethene	< 5.0	ug/L		5.0		- NA
cis-1,2-Dichloroethene	< 5.0	ug/L		5.0		- NA

M100917013-LCS

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
Trichloroethene	40.0	ug/L	50.00	80.00	66 - 118
cis-1,2-Dichloroethene	50.0	ug/L	50.00	100.00	70 - 130

☐ Outlined Results indicate results outside of Control limits

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Page: Page 5 of 8
Lab Proj #: P1009199
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

P1009199-01A

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
1-Chloropropane	70.0	ug/L	50.00	140.00	70 - 130

M100917013-MB

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
1-Chloropropane	40.0	ug/L	50.00	80.00	70 - 130

M100917013-LCS

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
1-Chloropropane	60.0	ug/L	50.00	120.00	70 - 130

☐ Outlined Results indicate results outside of Control limits

Data Qualifiers: J - estimated value, U - Non detect, R - Poor surrogate recovery, M - Recovery/RPD poor for MS/MSD, SAMP/DUP, B - detected in blank, S - field sample as received did not meet NELAC sample acceptance criteria, L - Subcontracted Lab used, N - NELAC certified analysis

PA02-00538

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Page: Page 6 of 8
Lab Proj #: P1009199
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Prep Method: 8260m-CoCr_Chlorinated

Analysis Method: 8260m-CoCr_Chlorinated

M100930041-MB

	Result		TrueSpikeConc.	RDL	%Recovery	Ctl Limits
Trichloroethene-Co-elution	No	NA		0.0		- NA
cis-1,2-Dichloroethene-Co-elution	No	NA		0.0		- NA
Surrogate-Co-elution	No	NA		0.0		- NA

P1009199-01A-DUP

	Result		TrueSpikeConc.	%Recovery	Ctl Limits	RPD	RPD Ctl Limits
Trichloroethene-Co-elution	No	NA			- NA	0	0 - 0
cis-1,2-Dichloroethene-Co-elution	No	NA			- NA	0	0 - 0
Surrogate-Co-elution	No	NA			- NA	0	0 - 0

☐ Outlined Results indicate results outside of Control limits

Data Qualifiers: J - estimated value, U - Non detect, R - Poor surrogate recovery, M - Recovery/RPD poor for MS/MSD, SAMP/DUP, B - detected in blank, S - field sample as received did not meet NELAC sample acceptance criteria, L - Subcontracted Lab used, N - NELAC certified analysis

PA02-00538

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Page: Page 7 of 8
Lab Proj #: P1009199
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Prep Method: AM24-AR_C

Analysis Method: AM24-AR_C

M100930042-MB

	Result		TrueSpikeConc.	RDL	%Recovery	Ctl Limits
Trichloroethene-area	< 1.0	Vs		1.0		- NA
cis-1,2-Dichloroethene-area	< 1.0	Vs		1.0		- NA
Surrogate-area	2.30	Vs		1.0		- NA

P1009199-01A-DUP

	Result		TrueSpikeConc.	%Recovery	Ctl Limits	RPD	RPD Ctl Limits
Trichloroethene-area	3.92	Vs			- NA	$\boxed{37.58}$	0 - 20
cis-1,2-Dichloroethene-area	3.46	Vs			- NA	7.50	0 - 20
Surrogate-area	2.41	Vs			- NA	$\boxed{39.21}$	0 - 20

☐ Outlined Results indicate results outside of Control limits

Data Qualifiers: J - estimated value, U - Non detect, R - Poor surrogate recovery, M - Recovery/RPD poor for MS/MSD, SAMP/DUP, B - detected in blank, S - field sample as received did not meet NELAC sample acceptance criteria, L - Subcontracted Lab used, N - NELAC certified analysis

PA02-00538

Client Name: CH2M Hill
Contact: John Ynfante
Address: 14701 St. Marys Lane
Suite 300
Houston, TX 77079-2923

Page: Page 8 of 8
Lab Proj #: P1009199
Report Date: 09/30/10
Client Proj Name: Fruit Ave Plume
Client Proj #: 941455

Prep Method: AM24-DL_C
Analysis Method: AM24-DL_C

M100930043-MB

	Result		TrueSpikeConc.	RDL	%Recovery	Ctl Limits
Trichloroethene-carbon	NR	‰		-500.0		- NA
cis-1,2-Dichloroethene-carbon	NR	‰		-500.0		- NA
Surrogate-carbon	-37.49	‰		-500.0		- NA

M100930043-LCS

	Result		TrueSpikeConc.	%Recovery	Ctl Limits
Trichloroethene-carbon	-29.13	‰	-30.56	0.00	-31 - -30
cis-1,2-Dichloroethene-carbon	-19.82	‰	-21.83	0.00	-22 - -21
Surrogate-carbon	-36.91	‰	-37.50	0.00	-38 - -37

P1009199-01A-DUP

	Result		TrueSpikeConc.	%Recovery	Ctl Limits	RPD	RPD Ctl Limits
Trichloroethene-carbon	-17.61	‰			- NA	0	0 - 20
cis-1,2-Dichloroethene-carbon	-33.19	‰			- NA	0	0 - 20
Surrogate-carbon	-36.71	‰			- NA	0	0 - 20

☐ Outlined Results indicate results outside of Control limits

PA02-00538

Data Qualifiers: J - estimated value, U - Non detect, R - Poor surrogate recovery, M - Recovery/RPD poor for MS/MSD, SAMP/DUP, B - detected in blank, S - field sample as received did not meet NELAC sample acceptance criteria, L - Subcontracted Lab used, N - NELAC certified analysis

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Fed Ex # 8717 3015 9160

Microseeps Lab. Proj. # P1009199

CHAIN - OF - CUSTODY RECORD

Microseeps COC cont. # 602

Phone: (412) 826-5245 Microseeps, Inc. - 220 William Pitt Way - Pittsburgh, PA 15238 Fax No. : (412) 826-3433

Company : CH2M HILL
Co. Address : 4041 Jefferson Plaza NE Ste 200 ABQ NM 87109
Phone # : 505-884-5600 **Fax # :**
Proj. Manager : Peter van Noort
Proj. Name/Number : Fruit Ave Plume Superfund Site
Sampler's signature :
Cooler Temp. 4°C

Results to : john.ynfante@ch2m.com
Invoice to : per contract

Sample ID	Sample Description	Sample Type			Date	Time	# bottles	Parameters Requested											Remarks :
		Water	Vapor	Solid				Dissolved Gases	CSIA										
MNW-5-D2-Q310	gw	X			9/8/10	1342	2	X											unpreserved
MNW-5-D2-Q310	gw	X			9/8/10	1342	9		X										
SFMW-33-D2-Q310	gw	X			9/8/10	1055	2	X											unpreserved
MNW-8-I2-Q310	gw	X			9/8/10	855	2	X											unpreserved
MNW-3-D2-Q310	gw	X			9/8/10	1230	2	X											unpreserved

Relinquished by :	Company :	Date :	Time :	Received by :	Company :	Date :	Time :
	CH2M HILL	9/8/10	1830			9/18	1200

WHITE COPY : Accompany Samples YELLOW COPY : Laboratory File PINK COPY : Submitter

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Cooler Receipt Form

Client:CH2M Hill **Client Code:**CH2-A **LabProject #:** P1009199

Project: Fruit Ave Plume

Cooler ID: 1

A. Preliminary Examination Phase: **Date cooler opened:** 9/15/2010

Cooler opened by: dp

1. **Was airbill Attached?** N/A **Airbill #:** **Carrier Name:** FedEx
2. **Custody Seals?** N/A **How many?** 0 **Location:** **Seal Name:**
3. **Seals intact?** Yes
4. **Screened for radiation?** N/A
5. **COC Attached?** Yes **Properly Completed?** Yes **Signed by employee?** Yes
6. **Project Identification from custody paper:** Fruit Ave Plume
7. **Preservative:** Yes **Temperature:** 4

Comments:

B. Log-In Phase: Samples Log-in Date: 9/15/2010 **Log-in By:** dp

1. **Packing Type:** Other
2. **Were samples in separate bags?** N/A
3. **Were containers intact?** Yes **Labels agree with COC?** Yes
4. **Number of bottles received:** 9 **Number of samples received:** 1
5. **Correct containers used?** Yes **Correct preservatives added?** N/A
6. **Sufficient sample volume?** Yes
7. **Bubbles in VOA samples?** N/A
8. **Was Project manager called and status discussed?** N/A

Comments:

Have designate person initial here to acknowledge receipt of cooler: **Date:** 9/15/10

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Appendix F
Natural Attenuation Indicator Parameter Evaluation Results

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Fruit Avenue Plume Superfund Site Long-Term Remedial Action

Appendix F – Natural Attenuation Indicator Parameter Evaluation Results

PREPARED FOR:	Bartolomé Cañellas /EPA Region 6 Remedial Project Manager
PREPARED BY:	CH2M HILL
DATE:	October 2012
PROJECT:	EPA Region 6 Remedial Action Contract W-EP-06-021 Task Order No. 0003-RALR-06DD CH2M HILL Project No. 345406.PJ.14
DCN:	0003-02091

Biodegradation of chlorinated volatile organic compounds (cVOCs) such as trichloroethene (TCE) in the subsurface environment is complex and the exact mechanism occurring at any given location within a site can be difficult to determine and can change over time. To determine if biodegradation is occurring, both direct and indirect lines of evidence are typically examined. Direct evidence of degradation is provided by changes in the composition and concentration of the contaminants at the site. Indirect evidence such as redox conditions, microbial ecology, and nutrient levels, may show that the site has conditions favorable to degradation (EPA, 1999). This technical memorandum examines two lines of indirect evidence to evaluate the potential for trichloroethene (TCE) biodegradation at the Fruit Avenue Plume (FAP) site. These lines of evidence include natural attenuation indicator parameters (NAIPs) associated with recognized terminal electron-accepting processes (TEAPs), and nutrient levels.

In the far western portion of the site, TEAPs are expected to reflect natural conditions. In the western part of the plume near the presumed source area, in the central part of the plume near the pump-and-treat (P&T) system, and in the eastern, downgradient portion of the TCE plume, TEAPs may be affected by natural TCE biodegradation processes. In the vicinity of the P&T system's injection wells, TEAPs are expected to be strongly affected because the injection wells return treated water to the aquifer that contains high concentrations of dissolved oxygen (DO) and sulfate, and low concentrations of carbon dioxide (CO_2) at pH levels of 5.0-5.5.

Terminal Electron-Accepting Processes

Geochemical conditions were evaluated to identify which TEAPs are acting on portions of the TCE plume (the electron acceptors) in accordance with the following:

"During aerobic respiration, DO concentrations decrease. After depletion of DO, anaerobic microbes will use nitrate as an [alternate] electron acceptor, followed by [manganese], iron (III), then sulfate, and finally carbon dioxide (methanogenesis). Each sequential reaction drives the [oxidation-reduction potential (ORP)] of the groundwater downward into the [negative] range of within which reductive dechlorination can occur. Reductive dechlorination is most effective in the ORP range corresponding to sulfate reduction and methanogenesis, but dechlorination of TCE may also occur in the ORP range of denitrification or iron (III) reduction. Dehalogenation of DCE and VC generally are restricted to sulfate reducing and methanogenic conditions." (EPA, 1998)

Contiguous zones of the aquifer with similar predominant TEAPs (redox zones) are named for the TEAP, as explained below (EPA, 1998):

- If DO concentrations are generally greater than 0.5 mg/L (Oxic Zone) aerobic processes dominate and reductive dechlorination is unlikely. DO concentrations up to 0.5 mg/L are tolerated by anaerobic microorganisms.

- The presence of ammonia and nitrite (and consequently the absence of nitrate) indicates nitrate reducing conditions. If nitrate concentrations exceed 1 mg/L, DO concentrations are also likely to be high, and reductive dechlorination inhibited.
- If ferrous iron (Fe^{+2}) concentrations exceed about 1 mg/L (iron-reducing conditions), a reductive pathway is possible. Vinyl chloride (VC) may be oxidized to carbon dioxide. DO generally has a low concentration as well because it is depleted.
- If sulfate concentrations are low (generally less than 20 mg/L) and sulfide concentrations are high (generally greater than 1 mg/L), sulfate-reducing conditions are present and a reductive pathway is possible. DO generally has a low concentration as well because it is depleted.
- Carbon dioxide is the ultimate daughter product of DCE oxidation and of cometabolic degradation (Brigmon, 2001). Carbon dioxide concentrations greater than two times background indicate these processes are active.
- Methane concentrations greater than 0.5 mg/L (500 µg/L) suggest methanogenesis conditions (Methanogenic Zone) where the more halogenated cVOCs are readily biodegraded, however, VC may accumulate in methanogenic zones. In addition, DO and sulfate concentrations are generally low because they are typically depleted. Methane concentrations below 0.5 mg/L permit oxidation of VC.

Although the above redox zones are marked by steadily declining ORP, the boundaries between the different zones are expected to overlap such that one or more processes may be operating within the different portions of a PCE or TCE plume.

Other parameters such as total alkalinity, chloride, and oxidation-reduction potential (ORP) provide further indirect evidence of favorable reductive dechlorination conditions. Total alkalinity concentrations greater than 2 times background result from the reaction of microbial-produced carbon dioxide and aquifer materials. Chloride is a byproduct of cVOC degradation and concentrations greater than 2 times background may indicate cVOC degradation. The ORP of groundwater is a measure of the propensity of electron transfer in a solution. ORP is thus a function of and affects biodegradation reactions. A reductive dechlorination pathway is possible at ORP measurements less than +50 mV and more likely when ORP measured values are less than -100 mV.

The field and water quality parameters at the FAP site were evaluated to identify the predominant TEAPs and delineate redox zones within the site boundary (**Figures 1, 2, 3, and 4**). Some sampling results from upgradient wells are affected by the presence of an offsite TCE plume, that is unrelated to the FAP site, and are not discussed.

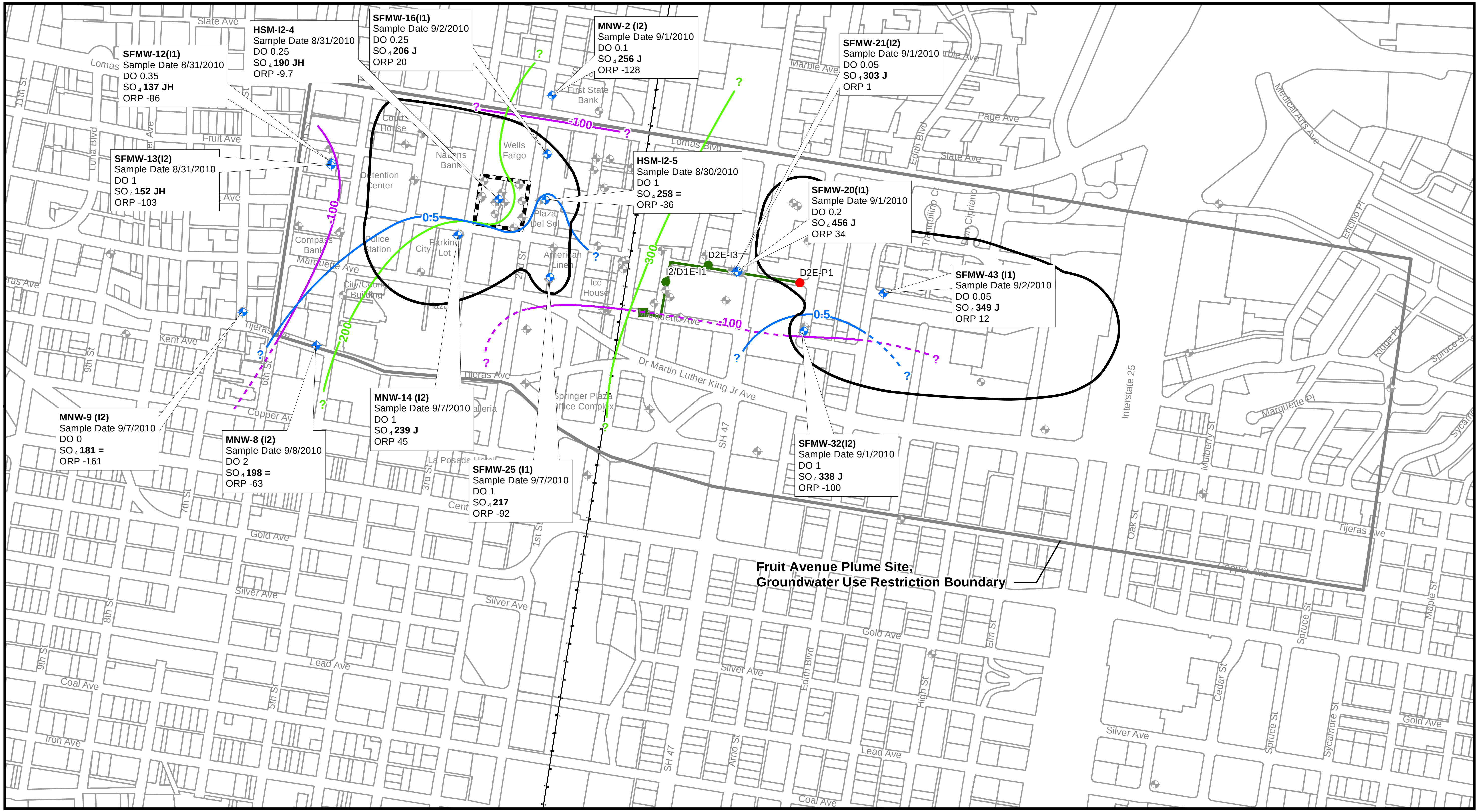
Dissolved Oxygen

In the intermediate aquifer zones (**Figure 1**), anaerobic conditions (DO < 0.5 mg/L) are present at 8 of the 14 locations where measurements were performed and anoxic (0.5 mg/L < DO < 2 mg/L) at the remaining 6 locations. In general, anaerobic conditions occur in the northern half of the site including the presumed source area. DO concentrations between 0.5 mg/L and 2 mg/L are found in the southern half of the site.

In the deep aquifer zones, aerobic conditions are found in the vicinity of the P&T system (**Figure 3**). The air-stripping treatment process used to remove TCE from groundwater aerates the water, thus increasing the DO concentration in the water that is injected at wells I2/D1E-I1 and D2E-I3. The remaining portions of the site, outside the influence of the injection wells, have DO concentrations between 1 mg/L and 3 mg/L. The distribution of DO suggests that, exclusive of the area around the P&T system, mildly aerobic conditions are present.

Ferrous iron

In the intermediate aquifer zones, ferrous iron concentrations are greater than 1 mg/L only at MNW-2(I2); at MNW-9(I2) the ferrous iron concentration was 0.8 mg/L (**Figure 2**). In the deep aquifer zones, ferrous iron concentrations are below detection limits (**Figure 4**). This suggests that there are no significant areas of iron-reducing conditions within the footprint of the plume.



LEGEND

⌖ TEAP Evaluation Monitor Well

⌖ Non-Redox Zone Evaluation LTM Monitor Well

┼─┼ Railroad

▨ Presumed Source Area

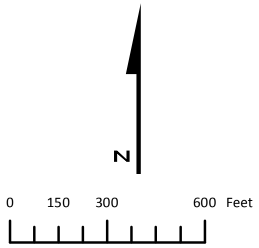
━ TCE Composite Plume within FAP Site Boundary

━ DO mg/L

━ SO_4 mg/L

━ ORP mV

(dashed where inferred)



Note

The exact sample date is indicated in the map callouts.

Concentration data contoured by hand.

Units: milligrams per liter (mg/L) for DO, Sulfate, Total Alkalinity, Chloride, Sulfide, and Iron.
millivolts (mV) for ORP
micrograms per liter (µg/L) for Methane
Qualifiers: J- estimated
U- not detected
L- concentration below the Reporting Limit
v - biased low
= - detected concentration
NA = Not Analyzed

FIGURE 1

Terminal Electron-Accepting Processes - Intermediate Aquifer Zones

September 2012

Fruit Avenue Plume Superfund Site

Albuquerque, NM

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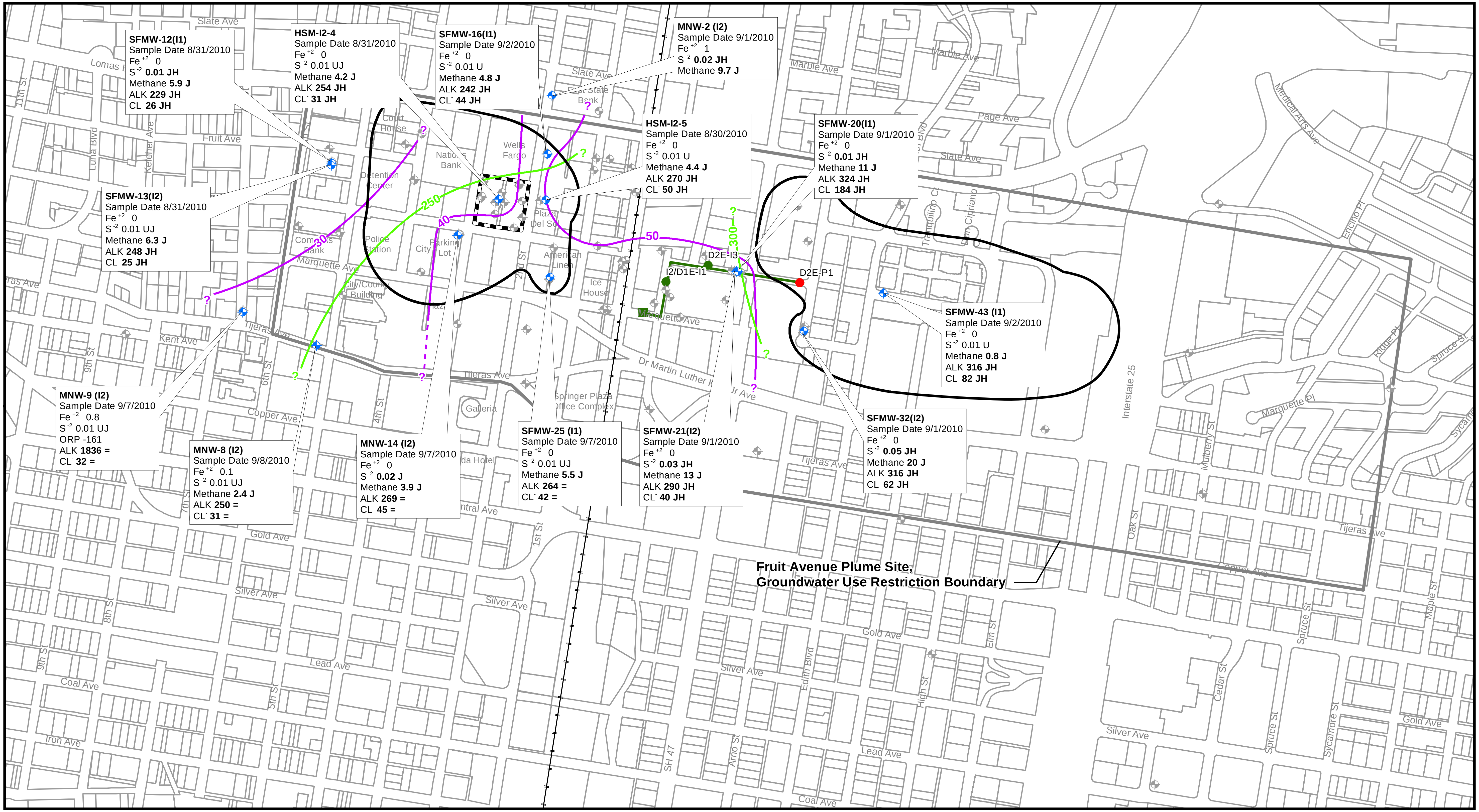

LEGEND

- ◆ TEAP Evaluation Monitor Well
- ◆ Non-Redox Zone Evaluation LTM Monitor Well
- ┼─┼ Railroad
- ▨ Presumed Source Area
- ─ TCE Composite Plume within FAP Site Boundary
- ─ ALK mg/L
- ─ CL^{-} mg/L

N

0 150 300 600 Feet

Note

The exact sample date is indicated in the map callouts.
Concentration data contoured by hand.

Units: milligrams per liter (mg/L) for DO, Sulfate, Total Alkalinity, Chloride, Sulfide, and Iron.
millivolts (mV) for ORP
micrograms per liter (μg/L) for Methane
Qualifiers: J- estimated
U- not detected
L- concentration below the Reporting Limit
v - biased low
= - detected concentration
NA = Not Analyzed

FIGURE 2
Terminal Electron-Accepting Processes - Intermediate Aquifer Zones
September 2012
Fruit Avenue Plume Superfund Site
Albuquerque, NM

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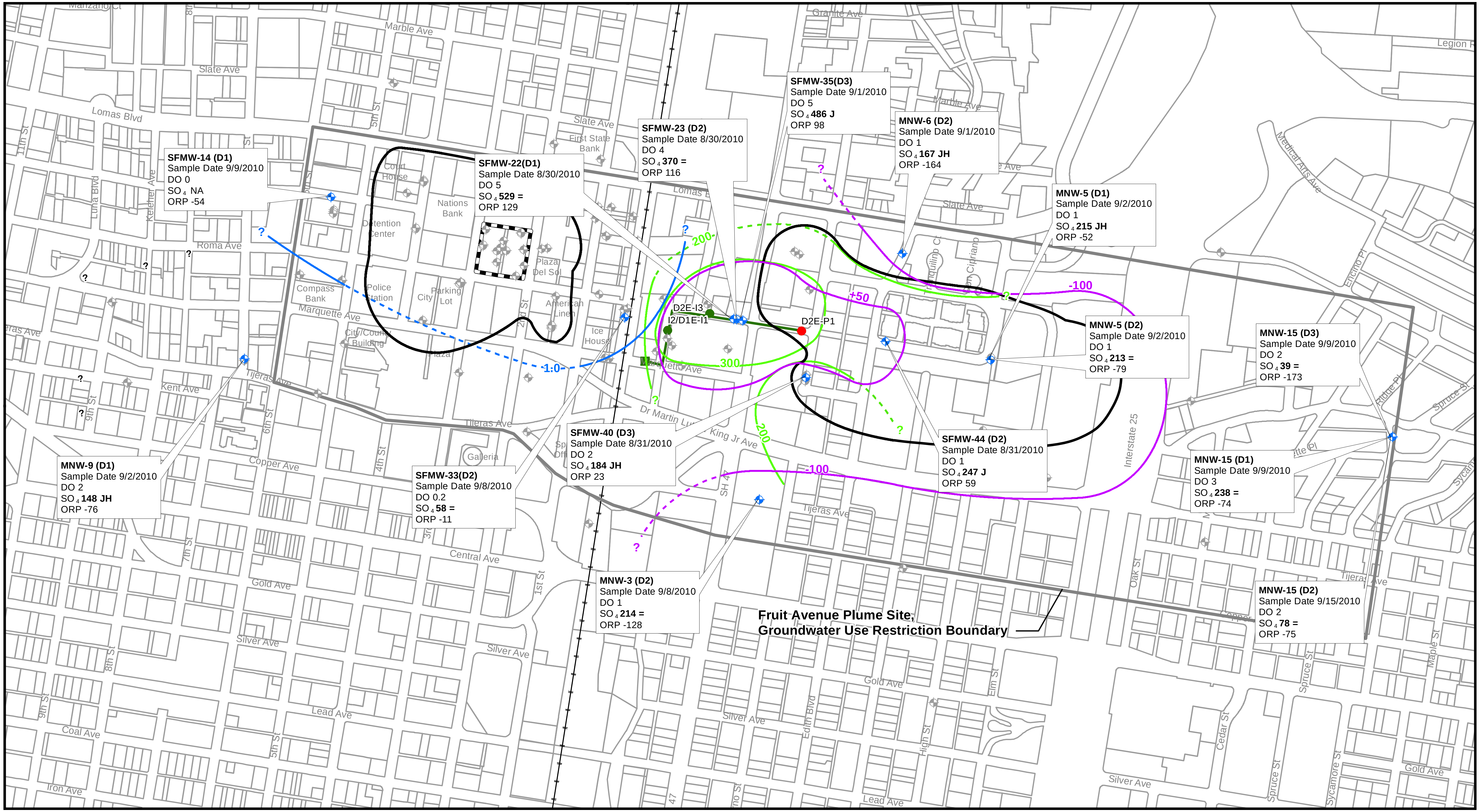

SFMW-14 (D1)
Sample Date 9/9/2010
DO 0
SO_4 NA
ORP -54

SFMW-22(D1)
Sample Date 8/30/2010
DO 5
SO_4 **529 =**
ORP 129

SFMW-23 (D2)
Sample Date 8/30/2010
DO 4
SO_4 **370 =**
ORP 116

SFMW-35(D3)
Sample Date 9/1/2010
DO 5
SO_4 **486 J**
ORP 98

MNW-6 (D2)
Sample Date 9/1/2010
DO 1
SO_4 **167 JH**
ORP -164

MNW-5 (D1)
Sample Date 9/2/2010
DO 1
SO_4 **215 JH**
ORP -52

MNW-5 (D2)
Sample Date 9/2/2010
DO 1
SO_4 **213 =**
ORP -79

MNW-15 (D3)
Sample Date 9/9/2010
DO 2
SO_4 **39 =**
ORP -173

MNW-15 (D1)
Sample Date 9/9/2010
DO 3
SO_4 **238 =**
ORP -74

MNW-15 (D2)
Sample Date 9/15/2010
DO 2
SO_4 **78 =**
ORP -75

SFMW-44 (D2)
Sample Date 8/31/2010
DO 1
SO_4 **247 J**
ORP 59

SFMW-40 (D3)
Sample Date 8/31/2010
DO 2
SO_4 **184 JH**
ORP 23

SFMW-33(D2)
Sample Date 9/8/2010
DO 0.2
SO_4 **58 =**
ORP -11

MNW-9 (D1)
Sample Date 9/2/2010
DO 2
SO_4 **148 JH**
ORP -76

MNW-3 (D2)
Sample Date 9/8/2010
DO 1
SO_4 **214 =**
ORP -128

LEGEND

- TEAP Evaluation Monitor Well
- Non-Redox Zone Evaluation LTM Monitor Well
- Railroad
- Presumed Source Area
- TCE Composite Plume within FAP Site Boundary
- DO mg/L
- SO_4 mg/L
- ORP mV

(dashed where inferred)

N

0 150 300 600 Feet

Note

The exact sample date is indicated in the map callouts.
Concentration data contoured by hand.

Units: milligrams per liter (mg/L) for DO, Sulfate, Total Alkalinity, Chloride, Sulfide, and Iron.
millivolts (mV) for ORP
micrograms per liter (µg/L) for Methane
Qualifiers: J- estimated
U- not detected
L- concentration below the Reporting Limit
v - biased low
= - detected concentration
NA = Not Analyzed

FIGURE 3
Terminal Electron-Accepting Processes -
Deep Aquifer Zones
September 2012
Fruit Avenue Plume Superfund Site
Albuquerque, NM

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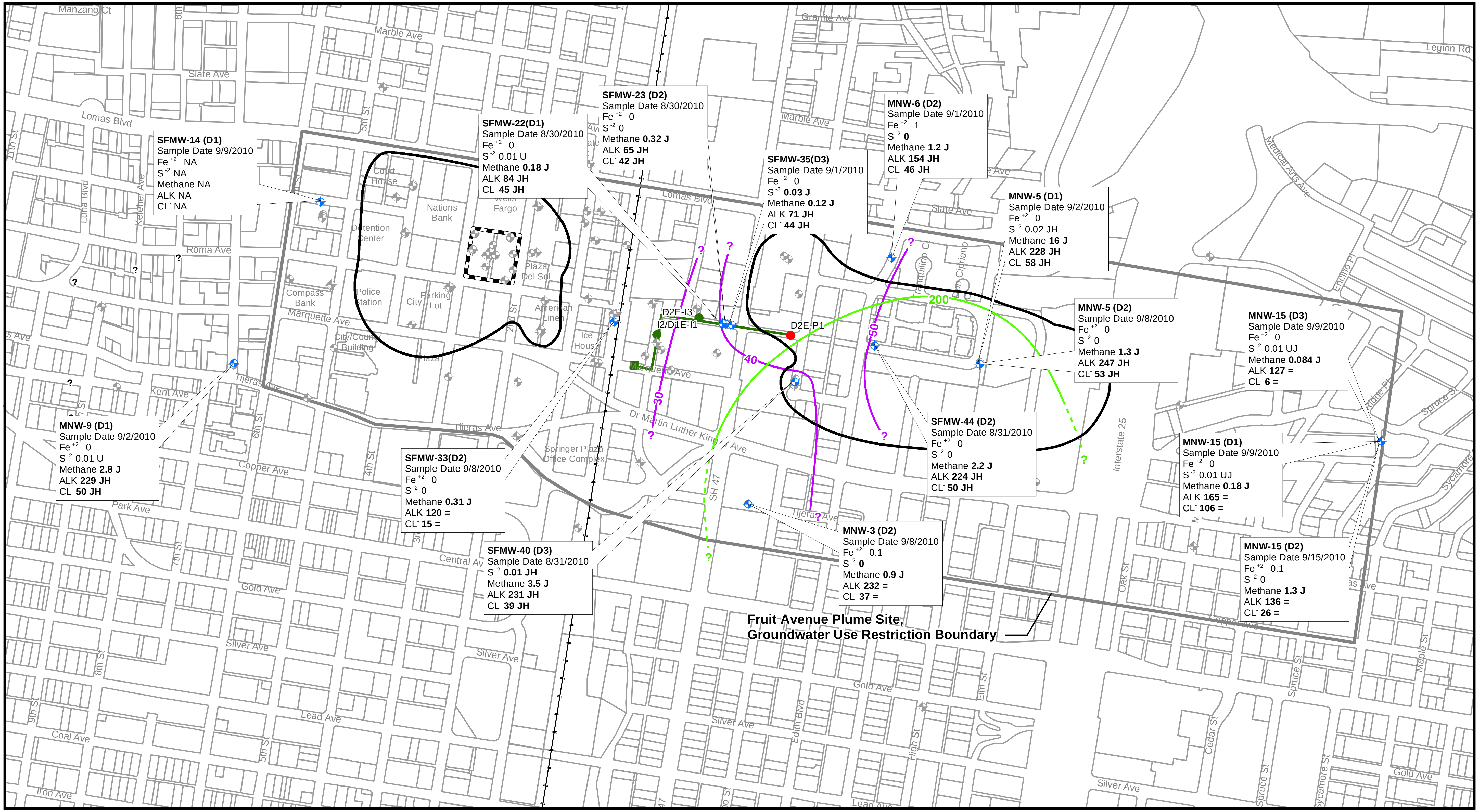

SFMW-14 (D1)
Sample Date 9/9/2010
Fe^{+2} NA
S^{-2} NA
Methane NA
ALK NA
CL^{-} NA

SFMW-22(D1)
Sample Date 8/30/2010
Fe^{+2} 0
S^{-2} 0.01 U
Methane **0.18 J**
ALK **84 JH**
CL^{-} **45 JH**

SFMW-23 (D2)
Sample Date 8/30/2010
Fe^{+2} 0
S^{-2} 0
Methane **0.32 J**
ALK **65 JH**
CL^{-} **42 JH**

SFMW-35(D3)
Sample Date 9/1/2010
Fe^{+2} 0
S^{-2} **0.03 J**
Methane **0.12 J**
ALK **71 JH**
CL^{-} **44 JH**

MNW-6 (D2)
Sample Date 9/1/2010
Fe^{+2} 1
S^{-2} **0**
Methane **1.2 J**
ALK **154 JH**
CL^{-} **46 JH**

MNW-5 (D1)
Sample Date 9/2/2010
Fe^{+2} 0
S^{-2} 0.02 JH
Methane **16 J**
ALK **228 JH**
CL^{-} **58 JH**

MNW-5 (D2)
Sample Date 9/8/2010
Fe^{+2} 0
S^{-2} 0
Methane **1.3 J**
ALK **247 JH**
CL^{-} **53 JH**

MNW-15 (D3)
Sample Date 9/9/2010
Fe^{+2} 0
S^{-2} 0.01 UJ
Methane **0.084 J**
ALK **127 =**
CL^{-} **6 =**

MNW-9 (D1)
Sample Date 9/2/2010
Fe^{+2} 0
S^{-2} 0.01 U
Methane **2.8 J**
ALK **229 JH**
CL^{-} **50 JH**

SFMW-33(D2)
Sample Date 9/8/2010
Fe^{+2} 0
S^{-2} 0
Methane **0.31 J**
ALK **120 =**
CL^{-} **15 =**

SFMW-44 (D2)
Sample Date 8/31/2010
Fe^{+2} 0
S^{-2} 0
Methane **2.2 J**
ALK **224 JH**
CL^{-} **50 JH**

MNW-15 (D1)
Sample Date 9/9/2010
Fe^{+2} 0
S^{-2} 0.01 UJ
Methane **0.18 J**
ALK **165 =**
CL^{-} **106 =**

SFMW-40 (D3)
Sample Date 8/31/2010
S^{-2} **0.01 JH**
Methane **3.5 J**
ALK **231 JH**
CL^{-} **39 JH**

MNW-3 (D2)
Sample Date 9/8/2010
Fe^{+2} 0.1
S^{-2} **0**
Methane **0.9 J**
ALK **232 =**
CL^{-} **37 =**

MNW-15 (D2)
Sample Date 9/15/2010
Fe^{+2} 0.1
S^{-2} 0
Methane **1.3 J**
ALK **136 =**
CL^{-} **26 =**

Fruit Avenue Plume Site,
Groundwater Use Restriction Boundary

LEGEND

- TEAP Evaluation Monitor Well
- Non-Redox Zone Evaluation LTM Monitor Well
- Railroad
- Presumed Source Area
- TCE Composite Plume within FAP Site Boundary
- ALK mg/L
- CL^{-} mg/L

(dashed where inferred)

N

0 150 300 600 Feet

Note
The exact sample date is indicated in the map callouts.
Concentration data contoured by hand.

Units: milligrams per liter (mg/L) for DO, Sulfate,
Total Alkalinity, Chloride, Sulfide, and Iron.
millivolts (mV) for ORP
micrograms per liter (µg/L) for Methane
Qualifiers: J- estimated
U- not detected
L- concentration below the Reporting Limit
v - biased low
= - detected concentration
NA = Not Analyzed

FIGURE 4
Terminal Electron-Accepting Processes -
Deep Aquifer Zones
September 2012
Fruit Avenue Plume Superfund Site
Albuquerque, NM

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Sulfate and Sulfide

Across the site, sulfate concentrations exceed the 20 mg/L while sulfide is present at low or non-detect levels indicating the absence of sulfate reducing conditions. Intermediate aquifer zone sulfate concentrations generally range from 150 to 200 mg/L (**Figure 1**). In the deep aquifer zones, sulfate concentrations generally range from 148 to 238 mg/L (**Figure 3**) with a maximum observed concentration of 529 mg/L detected at SFMW-22(D2). Sulfate concentrations generally increase downgradient in both the intermediate and deep aquifer zones except at downgradient well MNW-15(D3) where the lowest sulfate concentrations are found (39 mg/L). In both the intermediate and deep aquifer zones, sulfide concentrations do not exceed 0.05 mg/L (**Figure 2** and **Figure 4**). Sulfate and sulfide concentrations across the site suggest there are no areas within the monitored portions of the site with active sulfate reducing conditions.

The elevated sulfate concentrations in the central part of the plume near the P&T system injection wells are readily evident in **Figure 1** and **Figure 3**. This condition results from injection of treated water by the P&T system, which uses sulfuric acid to prevent scaling. Thus, the P&T system may be hampering reductive dechlorination processes through the addition of oxygenated water and excess sulfate.

Carbon Dioxide

In the intermediate aquifer zones, carbon dioxide concentrations increase downgradient from 9.6 mg/L at SFMW-12(I1) to 54 mg/L at SFMW-43(I1).

In the deep aquifer zones, carbon dioxide is lowest coincident with the volume of injected treated water at SFMW-23(D2) (2.1 mg/L), as expected, and highest coincident with the TCE plume at SFMW-44(D2)(28 mg/L).

Carbon dioxide concentrations are up to five times background concentrations indicating that oxidation or cometabolic degradation processes are active.

Methane

Methane concentrations across the site are too low to indicate that methanogenesis is a significant TEAP. In the intermediate aquifer zones, methane concentrations are generally less than 20 µg/L (**Figure 2**). In the deep aquifer zones, the highest observed methane concentrations occur at MNW-5(D1) (16 µg/L) and SFMW-40(D3) (3.5 µg/L) (**Figure 4**). The methane analysis results (all less than 500 µg/L) indicate that methanogenic conditions are not present within the monitored portions of the site.

The highest concentrations in the intermediate and deep aquifer zones are downgradient of the TCE plume in the respective aquifer zones. This suggests that some process associated with the site is producing the methane.

ORP

In the intermediate aquifer zones, ORP measurements are less than 50 mV (**Figure 1**) suggesting that a reductive pathway is possible. ORP measurements are lower (-100 to -128 mV) cross gradient of the plume in the intermediate zones. As expected, ORP measurements indicative of oxidizing conditions (ORP > +50mV) in the vicinity of the P&T system (**Figure 3**). Downgradient and cross gradient of the P&T system in the deep zones (e.g., at MNW-5(D1) and beyond), mildly reducing conditions are observed such that a reductive pathway is possible (ORP < 50 mV) or probable (OPR <-100 mV). The ORP measurements suggest that reducing conditions sufficient for reductive dechlorination exist outside the area influenced by the P&T system injection wells.

Alkalinity

Total alkalinity measured at MNW-15 (127 to 165 mg/L) is assumed to be representative of background conditions in the deep aquifer zones, because monitor wells on the other end of the plume appear to be affected by the upgradient offsite plume. In the deep aquifer zones, elevated alkalinity (228 to 247 mg/L) is found downgradient of the P&T system in SFMW-40(D3), SFMW-44(D2), MNW-3(D2), and MNW-5(D1 and D2) (**Figure 4**). There is no evidence of localized alkalinity effects associated with the P&T system injection wells, which contain residual sulfate and slightly acidic pH from use of sulfuric acid to control scaling in the ASTP. In the intermediate aquifer zones, total alkalinity is more uniform, ranging from 229 mg/L to 324 mg/L (**Figure 2**). The highest observed alkalinity concentrations occur at SFMW-20(I1), SFMW-32(I2), and SFMW-43(I1). The alkalinity concentrations generally increase along the flow path of the plume and approach the 2 times the background threshold that may be caused by reaction of biologically produced CO_2 with aquifer materials.

Chloride

A chloride plume often exists as a "shadow" of a chlorinated solvent plume. The chloride plume experiences dilution and dispersion and is not subject to retardation, therefore it's arrival typically precedes a chlorinated solvent plume. MNW-15(D2), MNW-15(D3), and SFMW-33(D2) have the lowest chloride concentrations (6, 26, and 15 mg/L) in the deep aquifers (**Figure 4**) suggesting that the chloride plume has not yet reached these locations, and they are appropriate to represent background concentrations. In the intermediate aquifer zones, elevated chloride concentrations (62 to 184 mg/L) are found in SFMW-20(I1), SFMW-32(I2), and SFMW-43(I1) (**Figure 2**), the same downgradient wells that had high alkalinity concentrations. In the deep aquifer zones, elevated chloride concentrations (37 to 58 mg/L) are found downgradient of the P&T system (**Figure 4**). The highest chloride concentration in the deep zones is found downgradient at MNW-15(D1)(106 mg/L), suggesting that the chloride plume has reached that location. Chloride concentrations generally increase along the plume's transport pathway and exceed the 2 times the background threshold that may be caused by release of chloride during TCE and DCE degradation.

Identification of Redox Zones

Outside the area influenced by the injected treated water, where conditions are generally oxidizing, conflicting results make identification of redox zones difficult:

- High sulfate and non-detect sulfide concentrations suggest the presence of oxidizing conditions.
- Non-detected ferrous iron concentrations suggest the presence of oxidizing conditions.
- Low-DO concentrations suggest oxidizing conditions.
- ORP measurements suggest mildly reducing conditions within the range where reductive dechlorination processes are known to occur.

In the intermediate aquifer zones, ORP, ferrous iron, DO, and sulfate concentrations indicate that mildly oxidizing conditions are present. Detectable sulfide in six samples suggests that localized zones of mildly reducing conditions are present in some portions of the site.

In the deep aquifer zones, near and upgradient of the ASTP, high DO, non-detect ferrous iron, and elevated sulfate concentrations indicate that oxidizing conditions are prevalent. Downgradient of the area influenced by injection of ASTP-treated water, detectable sulfide and ORP measurements less than zero suggest that a mildly reducing zone may exist. It should be noted, that monitoring results described in this technical memorandum represent only a portion of the total TCE plume footprint, and are likely biased by samples collected from monitor wells screened in the more permeable portions of the aquifer where contaminant transport occurs.

Compared to the previous TEAP evaluation (CH2M HILL, 2005 and **Attachment 1**), this TEAP evaluation finds similar mildly reducing conditions across the site; however, the previous evaluation identified more-distinct zones of reducing conditions. Methane concentrations are higher in the more-recent data.

Elevated carbon dioxide and chloride concentrations indicate the oxidation or cometabolic degradation of chloroethenes is occurring.

Injection of treated water from the ASTP (which contains elevated DO from the air-stripping process, elevated sulfate from sulfuric acid needed to inhibit scaling, and low carbon dioxide concentrations from the air stripping process) is impeding natural degradation processes in the eastern downgradient portion of the plume.

Evaluation of the Presence of Electron Donors: Nutrients and Carbon Sources

Geochemical conditions were also evaluated to identify the predominant electron donors.

Organic carbon is generally required for microbial degradation of cVOCs to support cell metabolism and growth. The organic carbon source functions as the electron donor in the oxidation-reduction reaction. Organic carbon in the aquifer can originate from a wide variety of natural organic compounds. In addition to natural organic matter, dissolved petroleum hydrocarbons are good sources of organic carbon where commingled cVOC and BTEX plumes occur. As a result of its key role in oxidation-reduction reactions, the lack of organic carbon in many aquifers is the limiting condition for microbial degradation of cVOCs.

Organic carbon analyses reported as TOC or non-purgeable organic carbon (NPOC) (**Appendix C**) are used to determine if adequate carbon is present. Concentrations greater than 20 mg/L are considered adequate to support biodegradation.

Natural Organic Carbon

Total organic carbon analyses show that NPOC is generally present at concentrations at or below 3 mg/L. Although these low levels (<20 mg/L) are considered insufficient to support rapid biodegradation of high cVOC concentrations, they may be sufficient to support enough microbial activity to degrade the low cVOC concentrations present at the FAP site (EPA, 1998).

Synthetic Organic Carbon: Petroleum Hydrocarbon Plumes Co-Located with the Site

Petroleum hydrocarbons may provide a carbon source to support reductive dechlorination where natural carbon sources are limited. There are locations within the Site boundaries where petroleum hydrocarbons and related VOCs occur relative to non-site-related underground storage tank releases. These sites, the former Total Fuel Station and the Fur & Hide site, are adjacent to each other and the presumed cVOC source area that now lies below the Wells Fargo parking lot. Most FAP site monitoring wells in this area are screened below the water table and would not be expected to detect petroleum hydrocarbons. Historic groundwater monitoring in this area has shown:

- The former Total Fuel Station, located at the southeast corner of Lomas Boulevard and 2nd Street, is about 500 feet downgradient and cross-gradient from the presumed source area located beneath the Wells Fargo parking lot. Low concentrations of BTEX compounds (7 µg/L total) were detected during the 1997 sampling event in SFMW-15(S).
- The former Fur & Hide site is located about 500 feet (one block) downgradient of the Wells Fargo parking lot. A 2002 sample from DM-09(S) in this area contained more than 400 µg/L BTEX.
- The Southeastern Public Service Company/Maloof UST site is located about 1,000 feet downgradient of the Wells Fargo parking lot and at the transition between the central and eastern portions of the plume. Site monitoring well SFMW-21(I2) has had limited occurrences of dichlorobenzene (0.64 J µg/L).
- Total petroleum hydrocarbons (TPH) have also been observed in soil and soil gas samples collected beneath the Wells Fargo parking lot. This TPH is believed to be associated with use of Stoddard solvent in dry cleaning.

Slightly elevated methane and low DO concentrations in SFMW-20(I1), MNW-2(I2), and SFMW-21(I2) near these sites suggest that the additional nutrients provided by the petroleum hydrocarbons promote methanogenesis, despite high sulfate concentrations.

Works Cited

CH2M HILL. 2005. *Natural Attenuation Evaluation,* v 1.1. Fruit Avenue Plume Superfund Site, Albuquerque NM. DCN 05-8326. December 2005.

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U.S. Environmental Protection Agency (EPA). 1999. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites.* OSWER Directive 9200.4-17P. April 1999.

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Attachment 1
Redox Zones November 2004 and April 2005 (CH2M HILL, 2005a)

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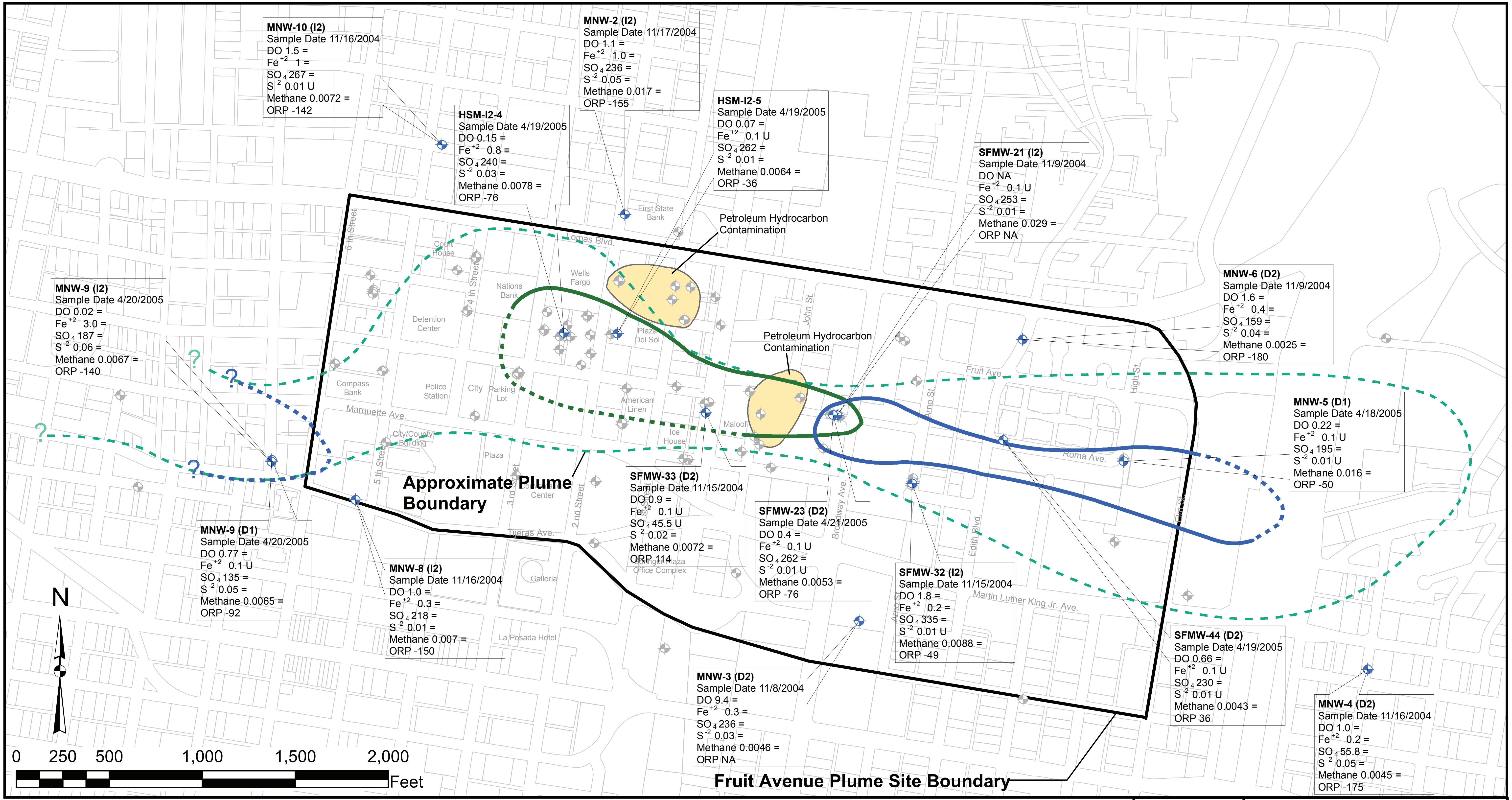

MNW-10 (I2)
Sample Date 11/16/2004
DO 1.5 =
Fe^{+2} 1 =
SO_4 267 =
S^{-2} 0.01 U
Methane 0.0072 =
ORP -142

MNW-2 (I2)
Sample Date 11/17/2004
DO 1.1 =
Fe^{+2} 1.0 =
SO_4 236 =
S^{-2} 0.05 =
Methane 0.017 =
ORP -155

HSM-I2-4
Sample Date 4/19/2005
DO 0.15 =
Fe^{+2} 0.8 =
SO_4 240 =
S^{-2} 0.03 =
Methane 0.0078 =
ORP -76

HSM-I2-5
Sample Date 4/19/2005
DO 0.07 =
Fe^{+2} 0.1 U
SO_4 262 =
S^{-2} 0.01 =
Methane 0.0064 =
ORP -36

SFMW-21 (I2)
Sample Date 11/9/2004
DO NA
Fe^{+2} 0.1 U
SO_4 253 =
S^{-2} 0.01 =
Methane 0.029 =
ORP NA

MNW-9 (I2)
Sample Date 4/20/2005
DO 0.02 =
Fe^{+2} 3.0 =
SO_4 187 =
S^{-2} 0.06 =
Methane 0.0067 =
ORP -140

MNW-6 (D2)
Sample Date 11/9/2004
DO 1.6 =
Fe^{+2} 0.4 =
SO_4 159 =
S^{-2} 0.04 =
Methane 0.0025 =
ORP -180

MNW-5 (D1)
Sample Date 4/18/2005
DO 0.22 =
Fe^{+2} 0.1 U
SO_4 195 =
S^{-2} 0.01 U
Methane 0.016 =
ORP -50

SFMW-33 (D2)
Sample Date 11/15/2004
DO 0.9 =
Fe^{+2} 0.1 U
SO_4 45.5 U
S^{-2} 0.02 =
Methane 0.0072 =
ORP 114

MNW-9 (D1)
Sample Date 4/20/2005
DO 0.77 =
Fe^{+2} 0.1 U
SO_4 135 =
S^{-2} 0.05 =
Methane 0.0065 =
ORP -92

MNW-8 (I2)
Sample Date 11/16/2004
DO 1.0 =
Fe^{+2} 0.3 =
SO_4 218 =
S^{-2} 0.01 =
Methane 0.007 =
ORP -150

SFMW-23 (D2)
Sample Date 4/21/2005
DO 0.4 =
Fe^{+2} 0.1 U
SO_4 262 =
S^{-2} 0.01 U
Methane 0.0053 =
ORP -76

SFMW-32 (I2)
Sample Date 11/15/2004
DO 1.8 =
Fe^{+2} 0.2 =
SO_4 335 =
S^{-2} 0.01 U
Methane 0.0088 =
ORP -49

SFMW-44 (D2)
Sample Date 4/19/2005
DO 0.66 =
Fe^{+2} 0.1 U
SO_4 230 =
S^{-2} 0.01 U
Methane 0.0043 =
ORP 36

MNW-3 (D2)
Sample Date 11/8/2004
DO 9.4 =
Fe^{+2} 0.3 =
SO_4 236 =
S^{-2} 0.03 =
Methane 0.0046 =
ORP NA

MNW-4 (D2)
Sample Date 11/16/2004
DO 1.0 =
Fe^{+2} 0.2 =
SO_4 55.8 =
S^{-2} 0.05 =
Methane 0.0045 =
ORP -175

Legend

⊕ Redox Zone Evaluation LTM Monitor Well
⊕ Non-Redox Zone Evaluation LTM Monitor Well
— Sulfate Reducing Zone - Intermediate Aquifer Zone (Dashed Where Inferred)
— Sulfate Reducing Zone - Deep Aquifer Zone (Dashed where inferred)
▨ Petroleum Hydrocarbon Contamination Area

009857

Aquifer Zones

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

Note

Data displayed on the map was compiled from ground water sampling events in November 2004 and April 2005. The exact sample date is indicated in the map callouts.

Concentration data contoured by hand.

Units: milligrams per liter (mg/L)
Units for ORP are millivolts (mV)
Qualifiers: J- estimated
U- not detected
L- concentration below the Reporting Limit
v - biased low
= - detected concentration
NA = Not Analyzed

Figure 4

Redox Zones
November 2004 and April 2005

Source: CH2MHILL

Fruit Avenue Plume Superfund Site
Albuquerque, NM

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Appendix G
Microbiological Test Results

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Fruit Avenue Plume Superfund Site Long-Term Remedial Action Appendix G - Microbiological Test Results

PREPARED FOR:	Bartolomé Cañellas /EPA Region 6 Remedial Project Manager
PREPARED BY:	CH2M HILL
DATE:	October 2012
PROJECT:	EPA Region 6 Remedial Action Contract W-EP-06-021 Task Order No. 0003-RALR-06DD CH2M HILL Project No. 345406.PJ.14
DCN:	0003-02091

Biodegradation of chlorinated volatile organic compounds (cVOCs) in the subsurface environment is complex and the exact mechanism occurring at any given location within a site can be difficult to determine and vary by location and time. To determine if biodegradation is taking place, both direct and indirect lines of evidence are examined. Direct evidence of cVOC degradation is provided by changes in the composition and concentration at the site. Indirect evidence, such as redox conditions, microbial ecology, and nutrient levels, can provide indirect evidence that the site has favorable degradation conditions (EPA, 1999). This technical memorandum examines microbial information to assess the potential for biodegradation at the Fruit Avenue Plume (FAP) Superfund site located in Albuquerque, NM.

Microbial Ecology

Microbial ecology is examined to determine if adequate populations of dechlorinating bacteria are present in the aquifer. Various protein and DNA analyses are available to identify the diversity, concentration, and vitality of the microbes present at a site.

Phospholipids are the primary lipids composing cellular membranes. They can be esterified[1] to many types of fatty acids. Once the phospholipids of an unknown sample are esterified, the composition of the resulting phospholipid–fatty acids (PLFA) can be compared to the PLFA of known organisms to determine the identity of the organisms present in a groundwater sample. PLFA are widely used in microbial ecology as chemotaxonomic markers of bacteria and other organisms. The chemical composition of the PLFA biomarkers differs depending on the type of organisms and, therefore, can be used to generate a "fingerprint" of the microbial community composition. However, unlike molecular methods, PLFA provides an approximate identification of the microbial community structure, and is unable to characterize the microbes to genus or species level. Quantitative polymerase chain reaction (qPCR) (such as CENSUS) can identify specific organisms or genes encoding specific biological functions, which in turn can be correlated with specific reductive dechlorination processes.

PLFA analysis identifies six categories of microbes: Anaerobic metal reducers (BrMonos), Eukaryotes (polyenoics), *Firmicutes* (TerBrSats), General (Nsats), *Proteobacteria* (Monos), and SRB/*Actinomycetes* (MidBrSats)]. The following four categories are associated with cVOC biodegradation, especially the first three:

- Sulfate-reducing bacteria (SRB)/*Actinomycetes*
- *Proteobacteria* (Monos)
- *Firmicutes* (TerBrSats)
- Anaerobic metal reducers (e.g., iron-reducing bacteria)

---

[1] A process by which fatty acids extracted from cell membranes are converted to fatty acid methyl esters, which are then analyzed using gas chromatography–mass spectrometry; the resulting profile constitutes a 'fingerprint' of the microorganisms in the sample, since it contains some microbial biomarkers.

Biodegradation of cVOCs may occur under sulfate-reducing conditions (*Pavlostathis and Zhuang, 1993*). *Proteobacteria* spp. have been reported as either capable of mediating cVOC reductive dechlorination (Scholzmuramatsu et al., 1995, Sung et al., 2003) or as a major component in consortia showing dechlorinating activities (Davis et al., 2002, Freeborn et al., 2005). Therefore, an increase/enrichment of *Proteobacteria* (Monos), *Firmicutes* (TerBrSats), and SRB/*Actinomycetes* in the microbial community structure within a plume relative to a background or offsite location provides indirect evidence that biodegradation is occurring at a site.

Sufficient biomass is also needed if biodegradation can be a major mechanism for contaminant removal. The overall abundance of microbes in a given sample may also be used as an indicator of the potential for biodegradation to occur. A biomass concentration between 10^5 and 10^6 cells/mL is regarded as moderate, while 10^7 to 10^8 cells/mL is regarded as high. A biomass of less than 10^5 indicates less potential for biodegradation.

Current and historical PLFA analytical results are tabulated in **Appendix C**, Natural Attenuation Data, of the main report. Laboratory results from the recent sampling are included as **Attachment 1**. The most recent data are illustrated in **Figure 1** and **Figure 2**.

Biomass

The biomass observed at monitoring well locations sampled at the FAP site in August 2010 was about 10^3 cells/mL with only two locations (MNW-14 (I2) and SFMW-32 (I2)) with biomass at 10^4 cells/mL levels. Biomass at these levels is not indicative of robust microbial community populations.

Comparison of PLFA to cVOC Data

The division of total biomass by the fraction of each microbial category for locations that have a decreasing trichloroethylene (TCE) concentration trend[2] is listed in **Table 1** and illustrated in **Figure 3**. Locations that have no TCE concentration trend are shown in **Figure 4**. Locations where the TCE concentration has generally been below 5 µg/L are show in **Figure 5**. These figures illustrate that *Proteobacteria* (Monos) are the most common category at the FAP site. Locations with decreasing TCE concentrations tend to have higher biomass. There is no discernible indication that locations with decreasing TCE have higher fractions of the three key categories of bacteria. Additionally, a relatively high portion of the relevant bacteria does not necessarily indicate decreased TCE concentrations. In general, the microbial community structure within the plume at locations with decreasing TCE concentrations does not appear to differ from that at other locations.

Comparison with Previous Evaluation

A comparison of PLFA results from sampling conducted at the same wells in 2005 and 2010 shows that biomass in samples from 2005 are uniformly greater than in samples from 2010. A comparison of PLFA percents (**Figure 6**) shows that since 2005, the sum fraction of PLFA from the three key categories has generally remained unchanged near the source area (HSM-I2-5) and may be increasing at downgradient locations (MNW-5(D1), SFMW-23(D2), and SFMW-44(D2)).

This evaluation corroborates the 2005 evaluation (CH2M HILL, 2005), which indicated that the PLFA analyses were consistent with most of the other geochemical data and indicated that the bacterial populations and their level of bioactivity in the aquifer were relatively low.

Summary

The PLFA evaluation indicates that biomass is low at the FAP site, resulting in less potential for biodegradation to be a major mechanism for contaminant removal. The similarities between the microbial community structure within the plume at locations with decreasing TCE concentration trends, and that of other locations, suggests that cVOCs at the FAP site are not enhancing the growth of degrading bacteria within the plume. Therefore, biological degradation processes most likely account for only a small portion of the naturally occurring TCE removal processes active at this site.

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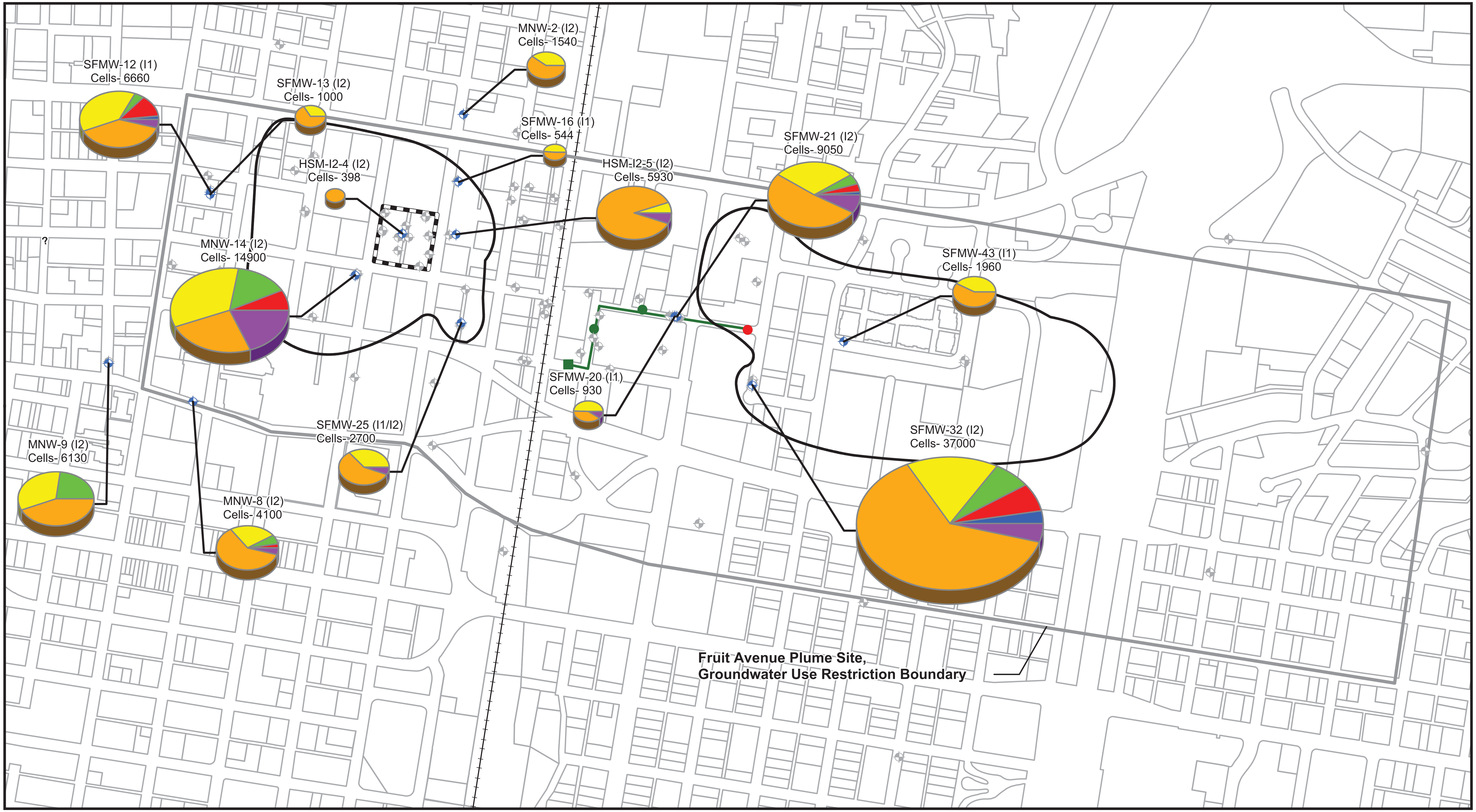
[2] "a decreasing TCE concentration trend" was evaluated using Mann-Kendall analysis and is reported in Appendix 4.



LEGEND

🟦 ANAEROBIC METAL REDUCERS (BRMONOS)
🟥 EUKARYOTES (POLYENOICS)
🟩 FIRMICUTES (TERBRSATS)
🟨 GENERAL (NSATS)
🟧 PROTOBACTERIA (MONOS)
🟪 SRB/Actinomycetes (MidBrSats)

⌖ Other Site Monitor Well
■ Air Stripper Treatment Plant
● Injection Well
● Extraction Well
┼ Railroad
▨ Presumed Source Area

⌖ Intermediate Zone Wells
— TCE Composite Plume within FAP Site Boundary (dashed where inferred)
● Size of Chart is Determined by Number of Cells

N

0 150 300 600 Feet

FIGURE 1
Microbiological (PLFA) Results
Intermediate
Fruit Avenue Plume Superfund Site
Albuquerque, NM

CH2MHILL.

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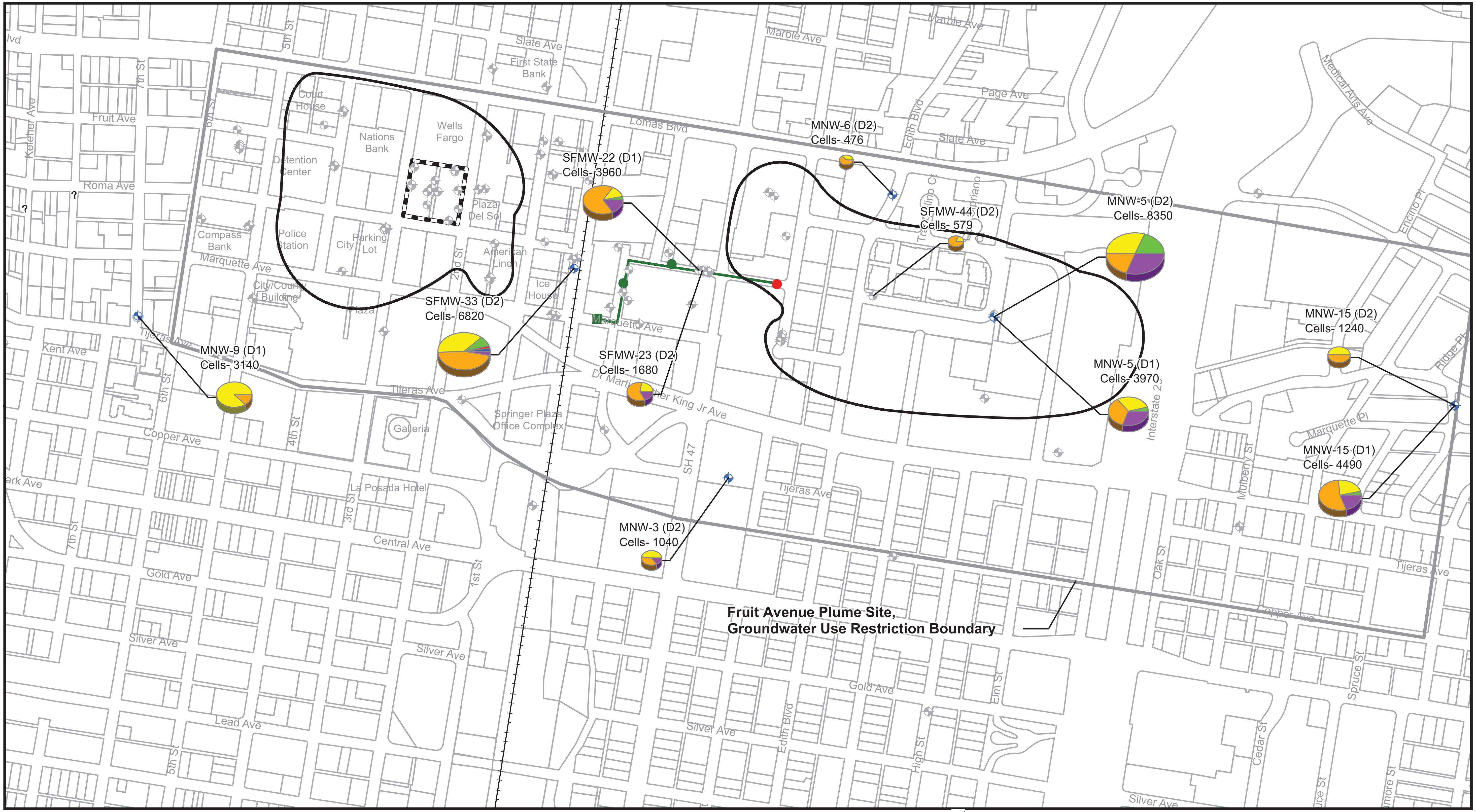

LEGEND

🟦 ANAEROBIC METAL REDUCERS (BRMONOS)
🟥 EUKARYOTES (POLYENOICS)
🟩 FIRMICUTES (TERBRSATS)
🟨 GENERAL (NSATS)
🟧 PROTOBACTERIA (MONOS)
🟪 SRB/Actinomycetes (MidBrSats)

◈ Other Site Monitor Well
■ Air Stripper Treatment Plant
● Injection Well
● Extraction Well
┼┼┼ Railroad
▨ Presumed Source Area

◈ Deep Zone Wells
— TCE Composite Plume within FAP Site Boundary (dashed where inferred)
● Size of Chart is Determined by Number of Cells

N

0 150 300 600 Feet

FIGURE 2
Microbiological (PLFA) Results
Deep
Fruit Avenue Plume Superfund Site
Albuquerque, NM

CH2MHILL.

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FIGURE 3

Microbe Categories [percentage x biomass] at Locations with a Decreasing TCE Concentration Trend

Fruit Avenue Plume Superfund Site, Albuquerque NM

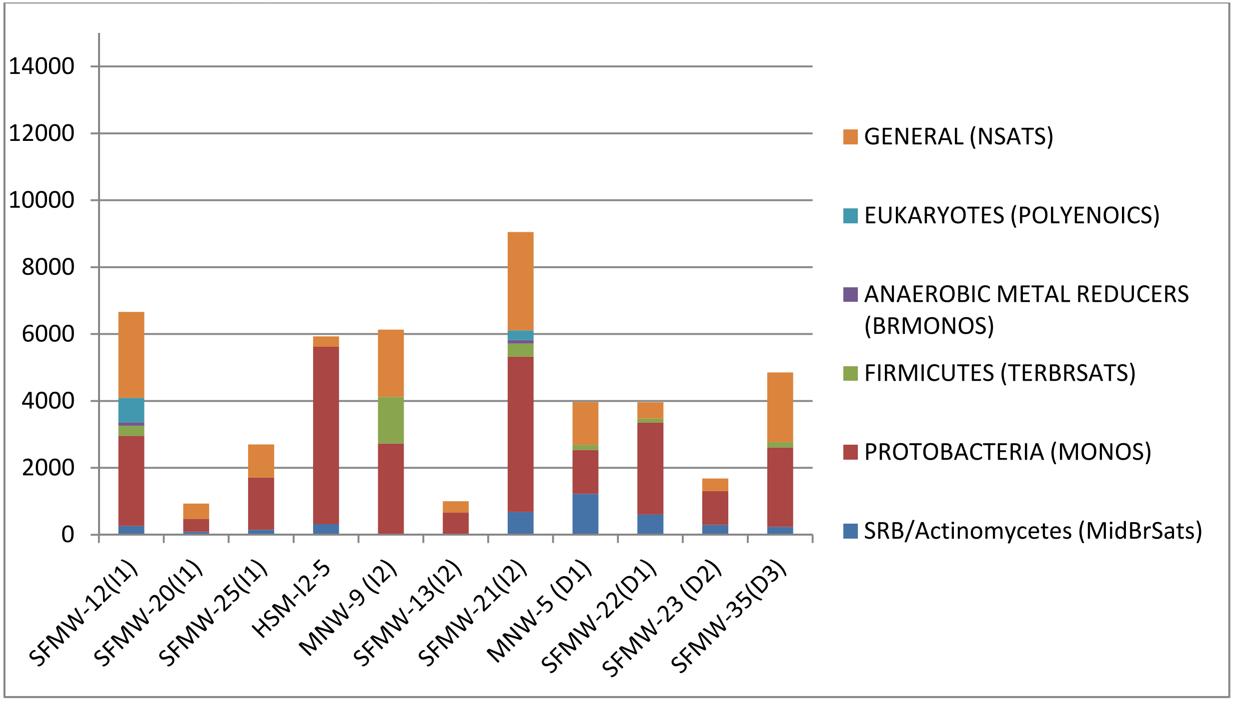


FIGURE 4 (LEFT)

Microbe Categories [percentage x biomass] at Locations with No Trend in TCE Concentrations

Fruit Avenue Plume Superfund Site, Albuquerque NM

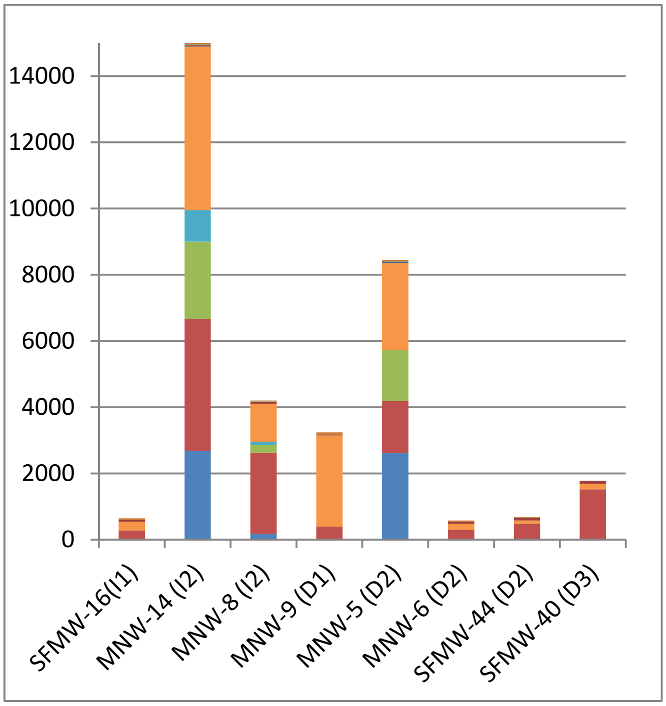


FIGURE 5 (RIGHT)

Microbe Categories [percentage x biomass] at Locations with TCE Concentrations <5 µg/L

Fruit Avenue Plume Superfund Site, Albuquerque NM

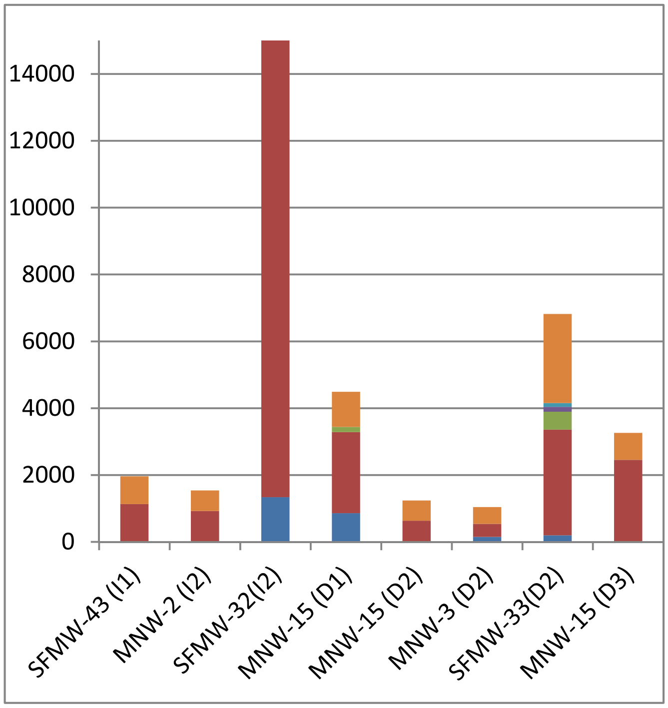


TABLE 1

PLFA Data At Locations with a Decreasing TCE Concentration Trend

Fruit Avenue Plume Superfund Site, Albuquerque NM

Wells where significant TCE decrease observed	PLFA results	
	Total biomass (cells/mL)[A]	Sum of the Fraction of the 3 Key Categories of Bacteria (%)[B]
SFMW-12(I1)	6,660	49%
SFMW-20(I1)	930	50%
SFMW-25(I1)	2,700	63%
HSM-I2-5	5,930	95%
MNW-9 (I2)	6,130	67%
SFMW-13(I2)	1,000	66%
SFMW-21(I2)	9,050	63%
MNW-5 (D1)	3,970	68%
SFMW-22(D1)	3,960	88%
SFMW-23 (D2)	1,680	78%
SFMW-35(D3)	4,850	57%

Note:

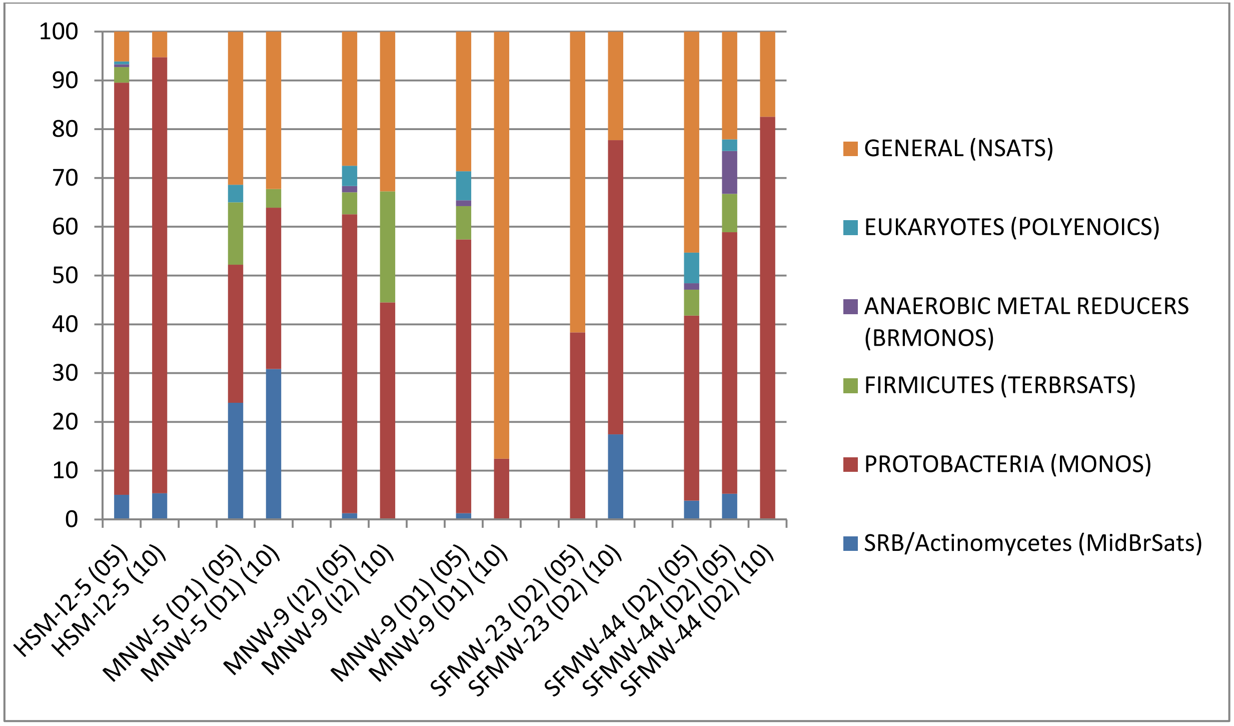
[A] biomass concentration between 10^5 and 10^6 cells/mL is regarded as moderate, while 10^7 to 10^8 cells/mL is regarded as high. A biomass of less than 10^5 indicates less potential for biodegradation.

[B] SRB (sulfate-reducing bacteria)/*Actinomycetes, Proteobacteria* (Monos), and *Firmicutes* (TerBrSats)

FIGURE 6

A Comparison of PLFA Results from 2005 and 2010 at Locations Sampled Both Years

Fruit Avenue Plume Superfund Site, Albuquerque NM



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Attachment 1
Analytical Laboratory Report

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microbialinsights

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Rockford TN 37853-3044
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Fax: (865) 573-8133
Email: info@microbe.com

Client: John Ynfante
CH2M HILL
14701 St. Mary’s Lane
Suite 300
Houston, TX 77079

Phone: 281.721.8546

Fax:

Identifier: 007HI **Date Rec:** 09/01/2010 **Report Date:** 10/06/2010

Client Project #: 345406.PJ.08 **Client Project Name:** Fruit Avenue Plume TO-003

Purchase Order #: 941422

Analysis Requested: PLFA

Reviewed By:

PLFA

Client:	**CH2M HILL**	**MI Project Number:**	**007HI**
Project:	Fruit Avenue Plume TO-003	Date Received:	09/01/2010

Sample Information

Sample Name:	**HSM-I2-5-Q310**	**SMFW-22-D1-Q310**	**SMFW-22-D2-Q310**	**SFMW-13-I2-Q310**	**SFMW-12-I1-Q310**
Sample Date:	08/30/2010	08/30/2010	08/30/2010	08/31/2010	08/31/2010
Sample Matrix:	Water	Water	Water	Water	Water
Analyst:	bj	bj	bj	bj	bj
Biomass					
Total Biomass (cells/mL)	**5.93E+03**	**3.96E+03**	**1.68E+03**	**1.00E+03**	**6.66E+03**
Community Structure (% total PLFA)					
Firmicutes (TerBrSats)	**0.00**	**3.02**	**0.00**	**0.00**	**4.45**
Proteobacteria (Monos)	**89.38**	**69.49**	**60.32**	**66.16**	**40.55**
Anaerobic metal reducers (BrMonos)	**0.00**	**0.00**	**0.00**	**0.00**	**1.58**
SRB/Actinomycetes (MidBrSats)	**5.38**	**15.19**	**17.44**	**0.00**	**3.89**
General (Nsats)	**5.24**	**12.29**	**22.23**	**33.84**	**38.56**
Eukaryotes (polyenoics)	**0.00**	**0.00**	**0.00**	**0.00**	**10.98**
Physiological Status (Proteobacteria only)					
Slowed Growth	**0.00**	**0.00**	**1.26**	**0.00**	**0.00**
Decreased Permeability	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Legend:
NA = Not Analyzed NS = Not Sampled

Client: **CH2M HILL**
Project: Fruit Avenue Plume TO-003

MI Project Number: **007HI**
Date Received: 09/01/2010

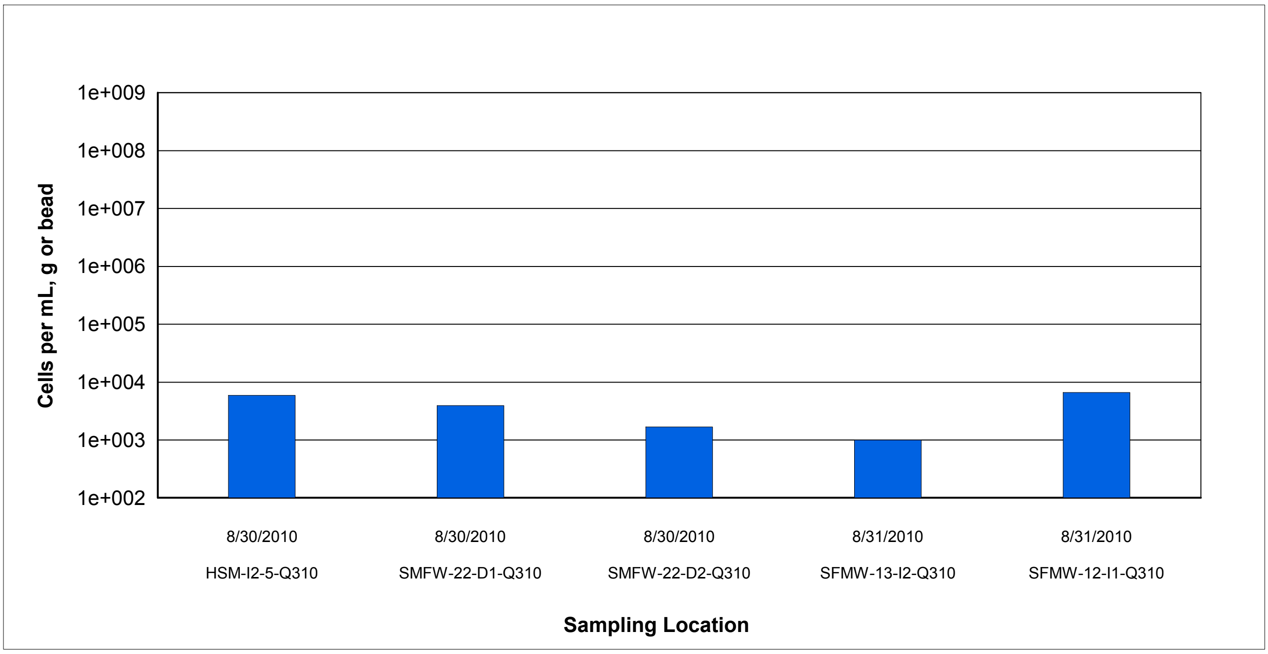

Figure 1. Biomass content is presented as a cell equivalent based on the total amount of phospholipid fatty acids (PLFA) extracted from a given sample. Total biomass is calculated based upon PLFA attributed to bacterial and eukaryotic biomass

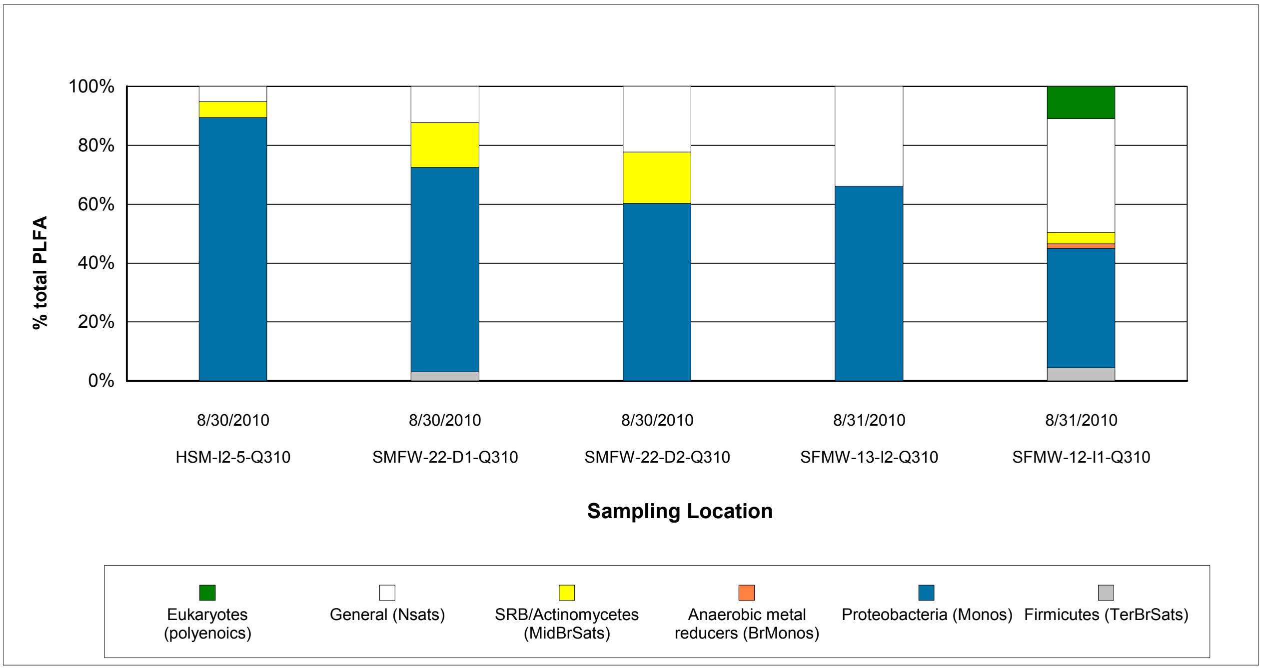

Figure 2. Relative percentages of total PLFA structural groups in the samples analyzed. Structural groups are assigned according to PLFA chemical structure, which is related to fatty acid biosynthesis.

PLFA

Client:	**CH2M HILL**	**MI Project Number:**	**007HI**
Project:	Fruit Avenue Plume TO-003	Date Received:	09/01/2010

Sample Information

Sample Name:	**HSM-I2-4-Q310**	**SFMW-44-D2-Q310**	**SFMW-40-D3-Q310**	**SFMW-32-I2-Q310**	**MNW-6-D2-Q310**
Sample Date:	08/31/2010	08/31/2010	08/31/2010	09/01/2010	09/01/2010
Sample Matrix:	Water	Water	Water	Water	Water
Analyst:	bj	bj	bj	bj	bj

Biomass

Total Biomass (cells/mL)	**3.98E+02**	**5.79E+02**	**1.68E+03**	**3.70E+04**	**4.76E+02**

Community Structure (% total PLFA)

Firmicutes (TerBrSats)	**0.00**	**0.00**	**0.00**	**6.69**	**0.00**
Proteobacteria (Monos)	**100.00**	**82.55**	**90.53**	**62.18**	**62.93**
Anaerobic metal reducers (BrMonos)	**0.00**	**0.00**	**0.00**	**2.45**	**0.00**
SRB/Actinomycetes (MidBrSats)	**0.00**	**0.00**	**0.00**	**3.62**	**0.00**
General (Nsats)	**0.00**	**17.45**	**9.47**	**19.31**	**37.07**
Eukaryotes (polyenoics)	**0.00**	**0.00**	**0.00**	**5.75**	**0.00**

Physiological Status (Proteobacteria only)

Slowed Growth	**0.00**	**0.00**	**0.00**	**0.28**	**0.00**
Decreased Permeability	**0.00**	**0.00**	**0.00**	**0.19**	**0.00**

Legend:
NA = Not Analyzed NS = Not Sampled

PLFA

Client:	**CH2M HILL**	**MI Project Number:**	**007HI**
Project:	Fruit Avenue Plume TO-003	Date Received:	09/01/2010

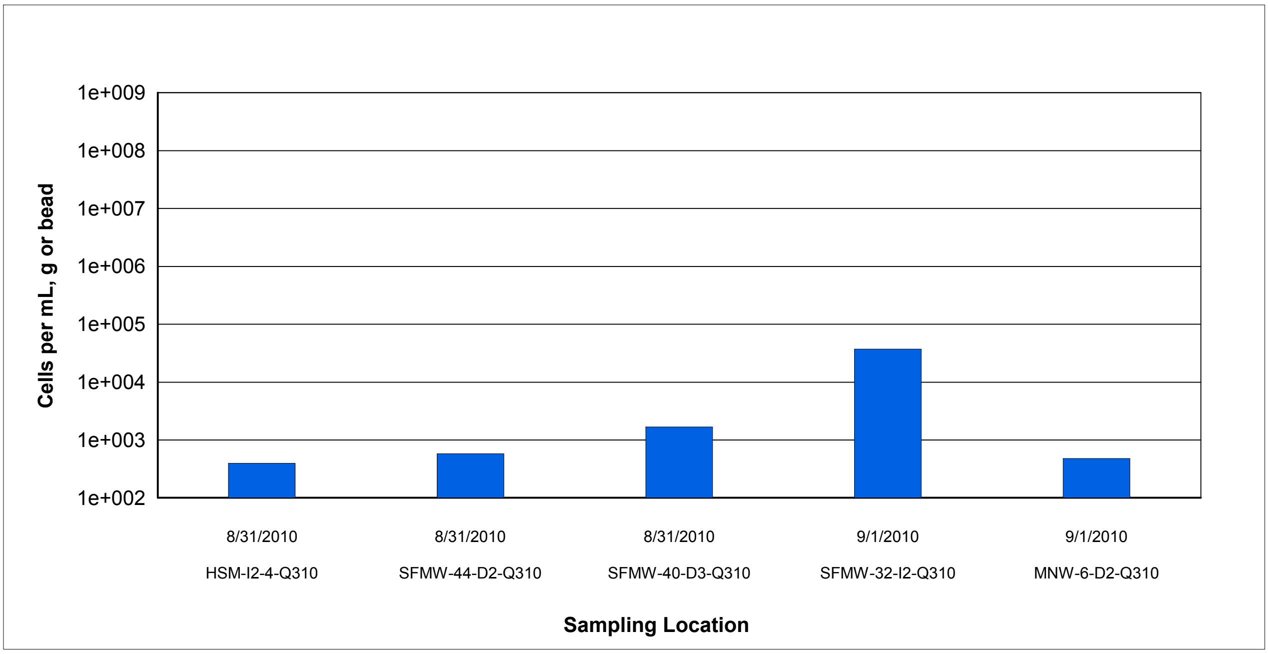

Figure 1. Biomass content is presented as a cell equivalent based on the total amount of phospholipid fatty acids (PLFA) extracted from a given sample. Total biomass is calculated based upon PLFA attributed to bacterial and eukaryotic biomass

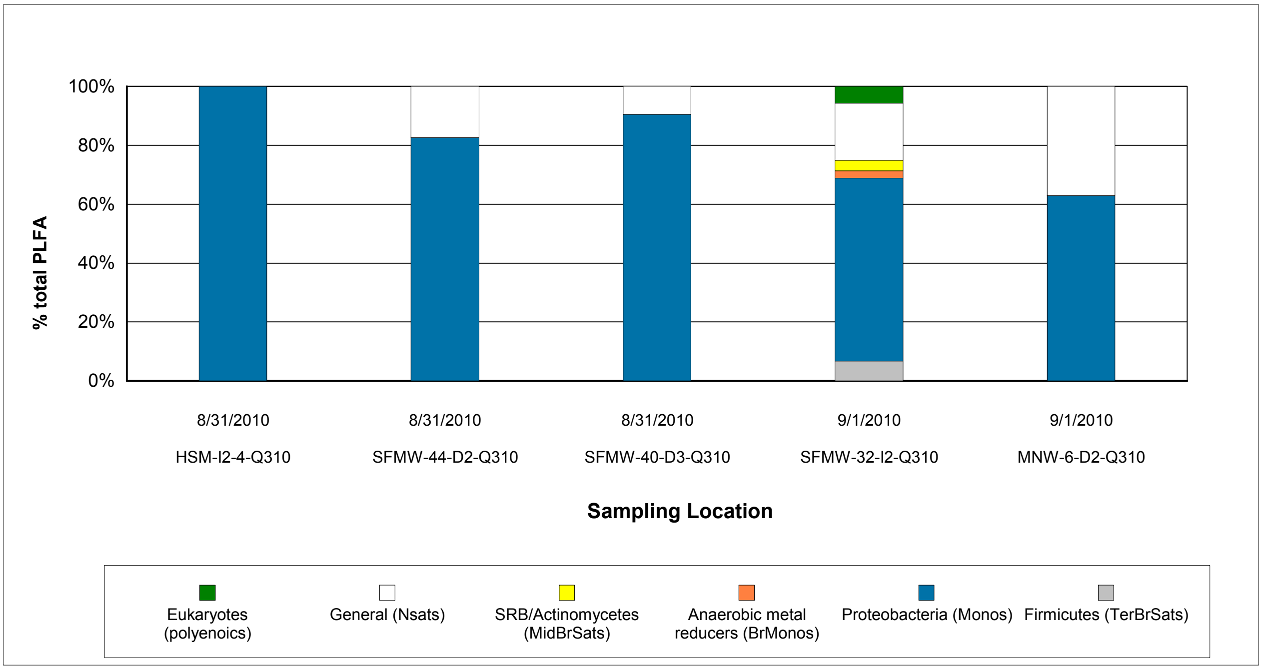

Figure 2. Relative percentages of total PLFA structural groups in the samples analyzed. Structural groups are assigned according to PLFA chemical structure, which is related to fatty acid biosynthesis.

Client: **CH2M HILL**
Project: Fruit Avenue Plume TO-003

MI Project Number: **007HI**
Date Received: 09/01/2010

Sample Information

Sample Name:	**SFMW-21-I2-Q310**	**SFMW-35-D3-Q310**	**SFMW-20-I1-Q310**	**MNW-2-I2-Q310**	**SFMW-16-I1-Q310**
Sample Date:	09/01/2010	09/01/2010	09/01/2010	09/01/2010	09/02/2010
Sample Matrix:	Water	Water	Water	Water	Water
Analyst:	bj	bj	bj	bj	bj

Biomass

Total Biomass (cells/mL)	**9.05E+03**	**4.85E+03**	**9.30E+02**	**1.54E+03**	**5.44E+02**

Community Structure (% total PLFA)

Firmicutes (TerBrSats)	**4.29**	**3.32**	**0.00**	**0.00**	**0.00**
Proteobacteria (Monos)	**51.36**	**49.04**	**41.12**	**60.03**	**51.24**
Anaerobic metal reducers (BrMonos)	**1.20**	**0.00**	**0.00**	**0.00**	**0.00**
SRB/Actinomycetes (MidBrSats)	**7.50**	**4.75**	**9.32**	**0.00**	**0.00**
General (Nsats)	**32.47**	**42.90**	**49.57**	**39.98**	**48.76**
Eukaryotes (polyenoics)	**3.17**	**0.00**	**0.00**	**0.00**	**0.00**

Physiological Status (Proteobacteria only)

Slowed Growth	**0.73**	**0.43**	**0.00**	**0.00**	**0.00**
Decreased Permeability	**0.09**	**0.00**	**0.00**	**0.00**	**0.00**

Legend:
NA = Not Analyzed NS = Not Sampled

Client: **CH2M HILL**
Project: Fruit Avenue Plume TO-003

MI Project Number: **007HI**
Date Received: 09/01/2010

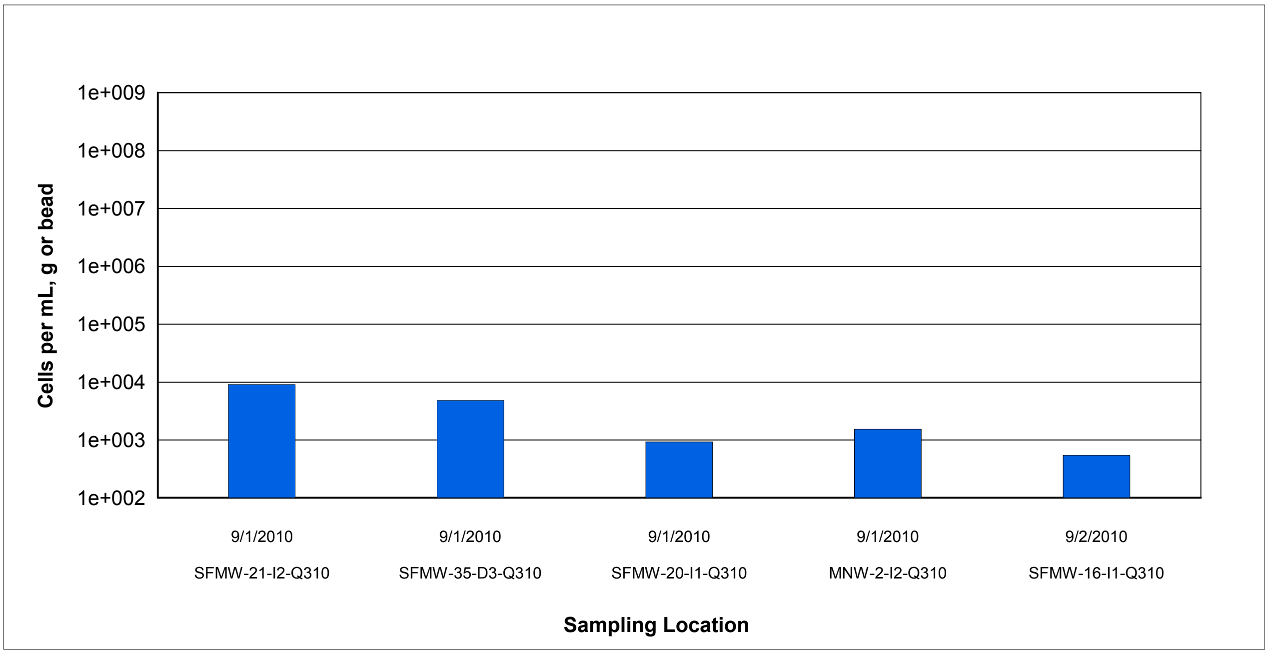

Figure 1. Biomass content is presented as a cell equivalent based on the total amount of phospholipid fatty acids (PLFA) extracted from a given sample. Total biomass is calculated based upon PLFA attributed to bacterial and eukaryotic biomass

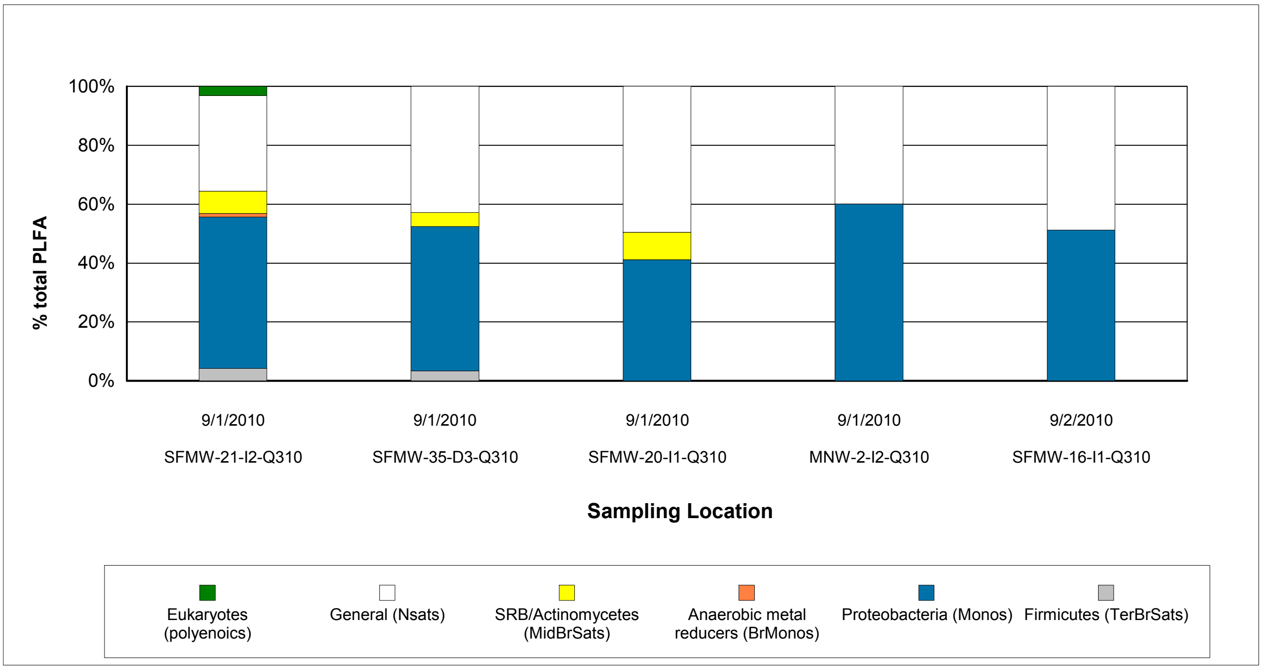

Figure 2. Relative percentages of total PLFA structural groups in the samples analyzed. Structural groups are assigned according to PLFA chemical structure, which is related to fatty acid biosynthesis.

PLFA

Client:	**CH2M HILL**	**MI Project Number:**	**007HI**
Project:	Fruit Avenue Plume TO-003	Date Received:	09/01/2010

Sample Information

Sample Name:	**SFMW-43-D3-Q310**	**MNW-5-D1-Q310**	**MNW-9-D1-Q310**	**MNW-9-I2-Q310**	**MNW-14-I2-Q310**
Sample Date:	09/02/2010	09/02/2010	09/02/2010	09/07/2010	09/07/2010
Sample Matrix:	Water	Water	Water	Water	Water
Analyst:	bj	bj	bb	bj	bj

Biomass

Total Biomass (cells/mL)	**1.96E+03**	**3.97E+03**	**3.14E+03**	**6.13E+03**	**1.49E+04**

Community Structure (% total PLFA)

Firmicutes (TerBrSats)	**0.00**	**3.83**	**0.00**	**22.77**	**15.64**
Proteobacteria (Monos)	**57.64**	**33.08**	**12.46**	**44.48**	**26.81**
Anaerobic metal reducers (BrMonos)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
SRB/Actinomycetes (MidBrSats)	**0.00**	**30.83**	**0.00**	**0.00**	**17.97**
General (Nsats)	**42.36**	**32.26**	**87.53**	**32.76**	**33.18**
Eukaryotes (polyenoics)	**0.00**	**0.00**	**0.00**	**0.00**	**6.38**

Physiological Status (Proteobacteria only)

Slowed Growth	**0.00**	**0.00**	**0.00**	**0.00**	**0.95**
Decreased Permeability	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Legend:
NA = Not Analyzed NS = Not Sampled

Client:	**CH2M HILL**	**MI Project Number:**	**007HI**
Project:	Fruit Avenue Plume TO-003	Date Received:	09/01/2010

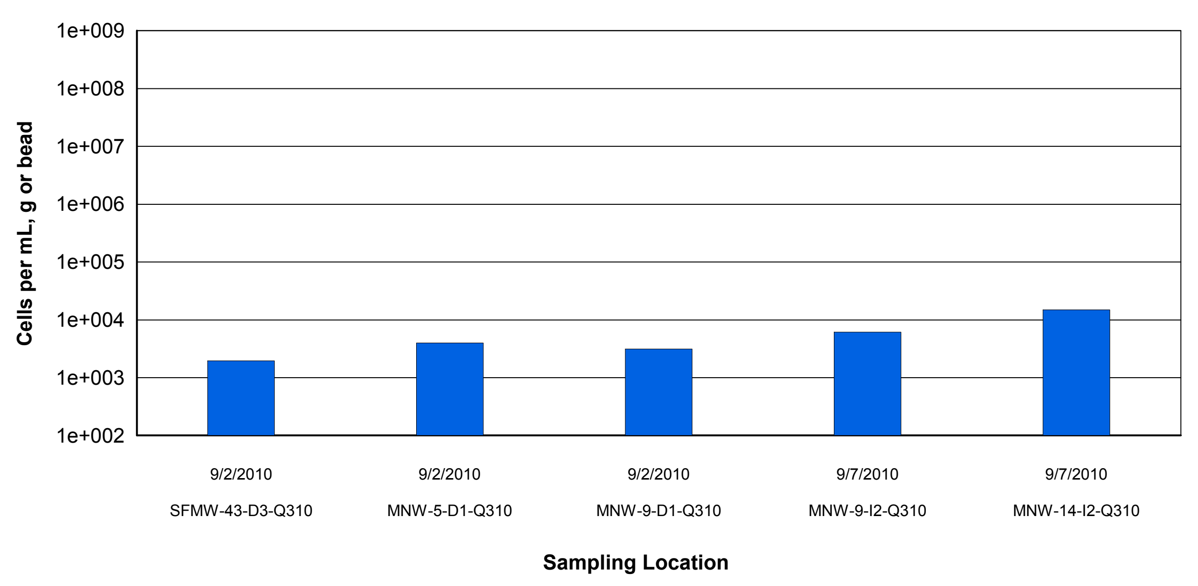

Figure 1. Biomass content is presented as a cell equivalent based on the total amount of phospholipid fatty acids (PLFA) extracted from a given sample. Total biomass is calculated based upon PLFA attributed to bacterial and eukaryotic biomass

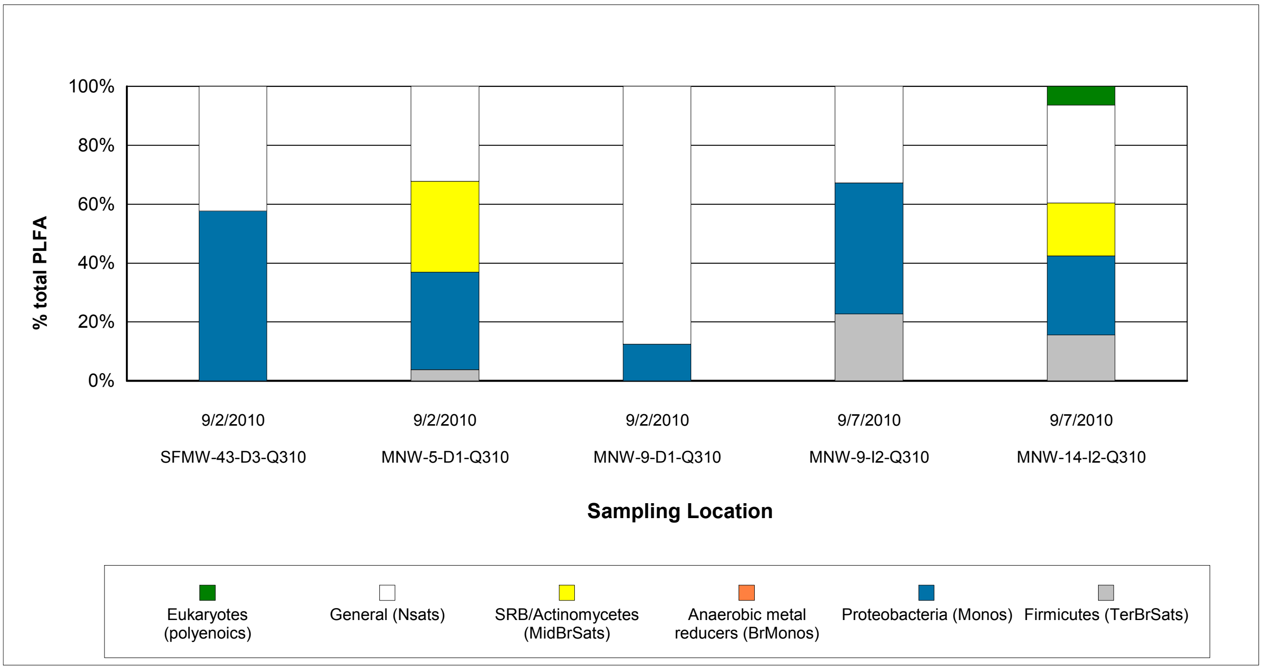

Figure 2. Relative percentages of total PLFA structural groups in the samples analyzed. Structural groups are assigned according to PLFA chemical structure, which is related to fatty acid biosynthesis.

PLFA

Client: **CH2M HILL**
Project: Fruit Avenue Plume TO-003

MI Project Number: **007HI**
Date Received: 09/01/2010

Sample Information

Sample Name:	**SFMW-25-I1-Q310**	**SFMW-33-D2-Q310**	**MNW-5-D2-Q310**	**MNW-8-I2-Q310**	**MNW-3-D2-Q310**
Sample Date:	09/07/2010	09/08/2010	09/08/2010	09/08/2010	09/08/2010
Sample Matrix:	Water	Water	Water	Water	Water
Analyst:	bj	bj	bj	bb	bj

Biomass

Total Biomass (cells/mL)	**2.70E+03**	**6.82E+03**	**8.35E+03**	**4.10E+03**	**1.04E+03**

Community Structure (% total PLFA)

Firmicutes (TerBrSats)	**0.00**	**7.84**	**18.47**	**5.66**	**0.00**
Proteobacteria (Monos)	**57.78**	**46.39**	**18.89**	**60.08**	**37.38**
Anaerobic metal reducers (BrMonos)	**0.00**	**2.11**	**0.00**	**0.00**	**0.00**
SRB/Actinomycetes (MidBrSats)	**5.48**	**2.89**	**31.24**	**4.01**	**14.51**
General (Nsats)	**36.74**	**39.13**	**31.40**	**27.91**	**48.11**
Eukaryotes (polyenoics)	**0.00**	**1.64**	**0.00**	**2.34**	**0.00**

Physiological Status (Proteobacteria only)

Slowed Growth	**0.46**	**1.04**	**0.00**	**0.00**	**0.00**
Decreased Permeability	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Legend:
NA = Not Analyzed NS = Not Sampled

Client: **CH2M HILL**
Project: Fruit Avenue Plume TO-003

MI Project Number: **007HI**
Date Received: 09/01/2010

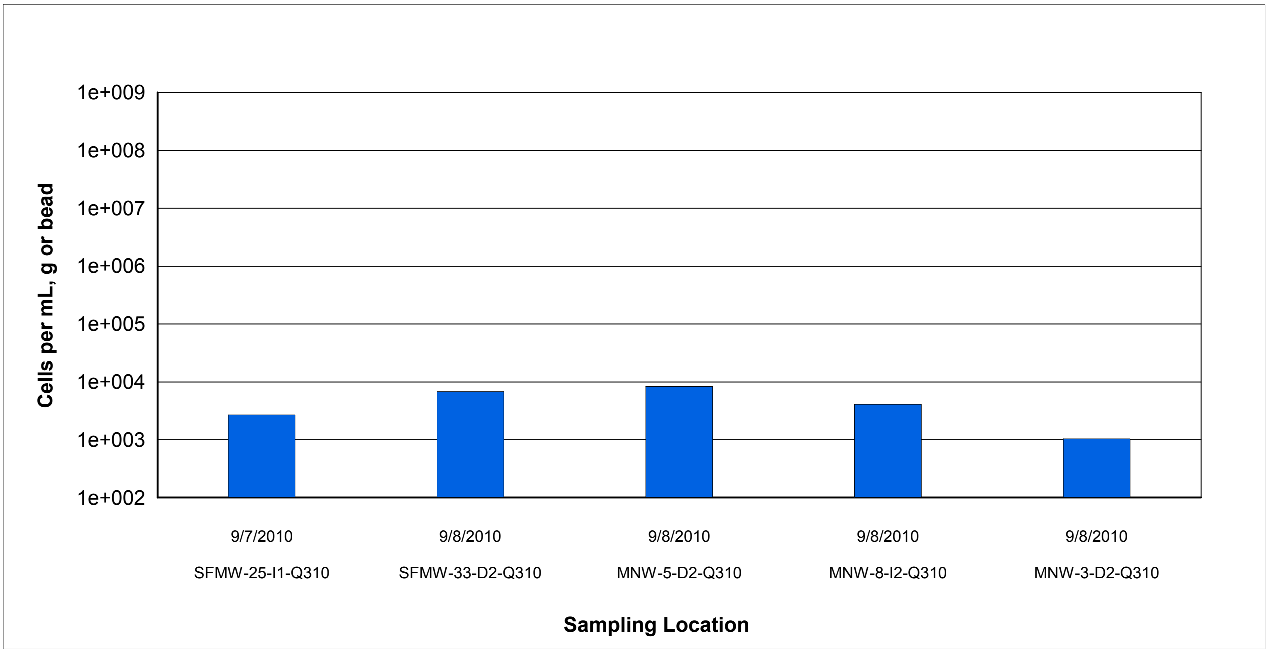

Figure 1. Biomass content is presented as a cell equivalent based on the total amount of phospholipid fatty acids (PLFA) extracted from a given sample. Total biomass is calculated based upon PLFA attributed to bacterial and eukaryotic biomass

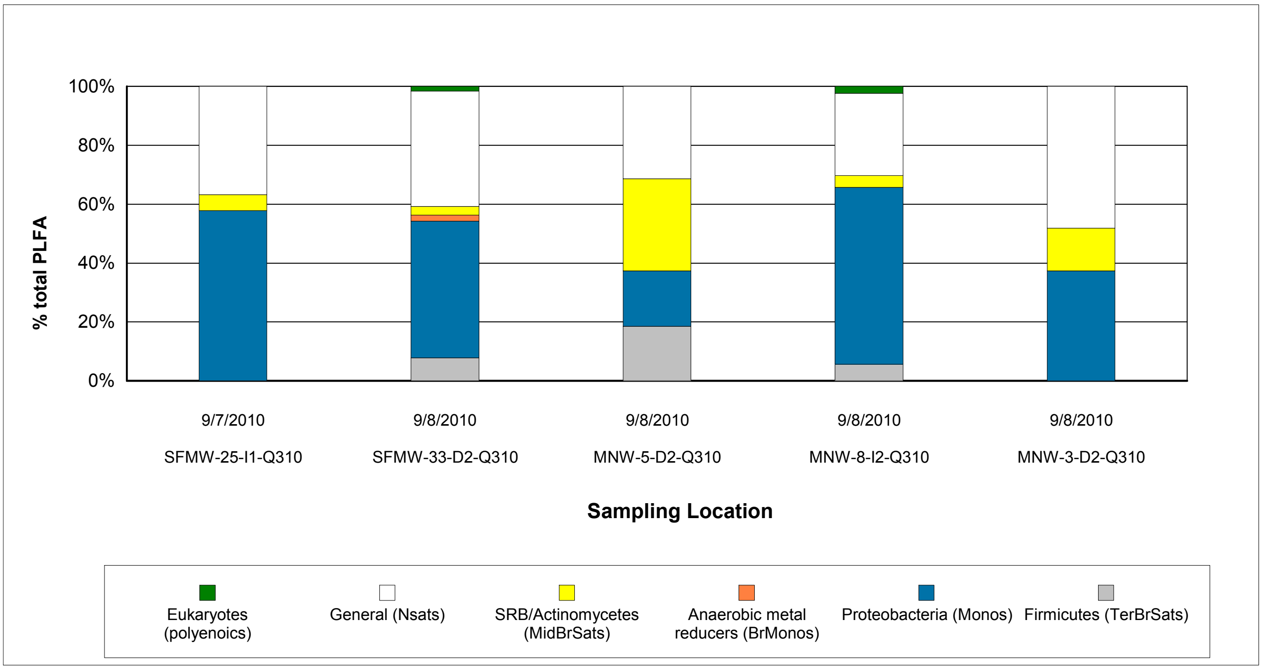

Figure 2. Relative percentages of total PLFA structural groups in the samples analyzed. Structural groups are assigned according to PLFA chemical structure, which is related to fatty acid biosynthesis.

PLFA

Client:	**CH2M HILL**	**MI Project Number:**	**007HI**
Project:	Fruit Avenue Plume TO-003	Date Received:	09/01/2010

Sample Information

Sample Name:	**MNW-15-D1-Q310**	**MNW-15-D3-Q310**	**MNW-15-D2-Q310**
Sample Date:	09/09/2010	09/09/2010	09/15/2010
Sample Matrix:	Water	Water	Water
Analyst:	bj	bj	bj

Biomass

Total Biomass (cells/mL)	**4.49E+03**	**3.26E+03**	**1.24E+03**

Community Structure (% total PLFA)

Firmicutes (TerBrSats)	**3.40**	**0.00**	**0.00**
Proteobacteria (Monos)	**54.12**	**75.32**	**50.86**
Anaerobic metal reducers (BrMonos)	**0.00**	**0.00**	**0.00**
SRB/Actinomycetes (MidBrSats)	**19.07**	**0.00**	**0.00**
General (Nsats)	**23.42**	**24.67**	**49.14**
Eukaryotes (polyenoics)	**0.00**	**0.00**	**0.00**

Physiological Status (Proteobacteria only)

Slowed Growth	**0.29**	**0.25**	**0.00**
Decreased Permeability	**0.00**	**0.00**	**0.00**

Legend:
NA = Not Analyzed NS = Not Sampled

Client: **CH2M HILL**
Project: Fruit Avenue Plume TO-003

MI Project Number: **007HI**
Date Received: 09/01/2010

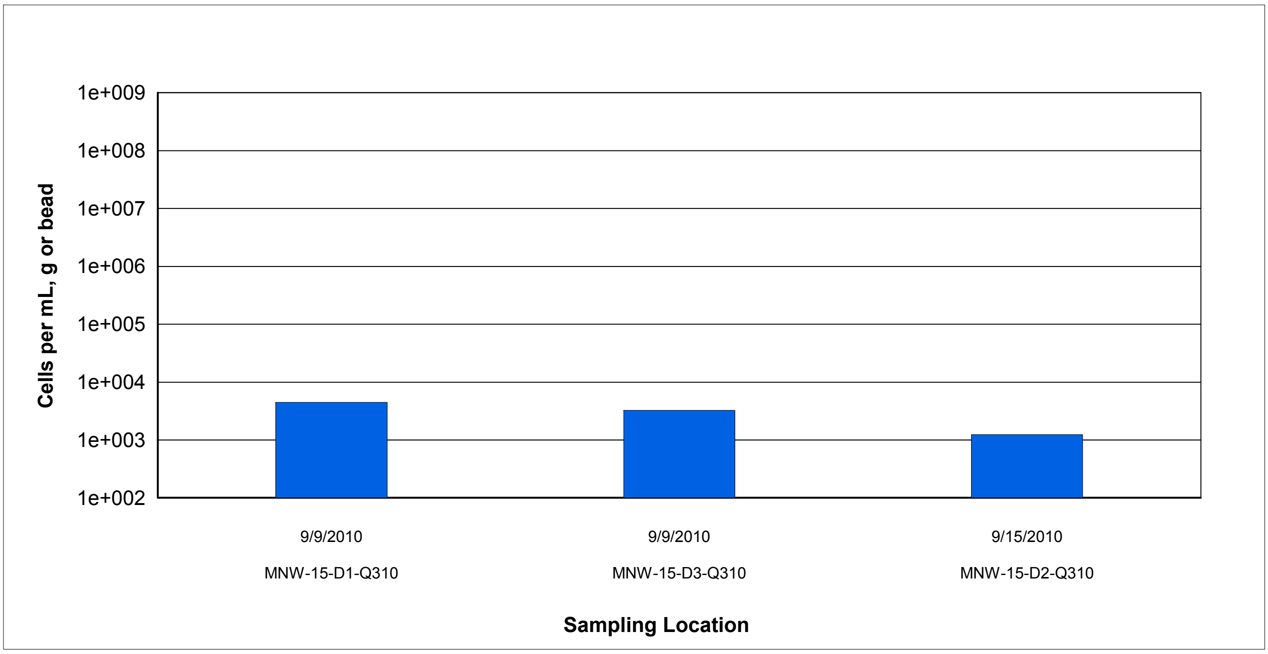

Figure 1. Biomass content is presented as a cell equivalent based on the total amount of phospholipid fatty acids (PLFA) extracted from a given sample. Total biomass is calculated based upon PLFA attributed to bacterial and eukaryotic biomass

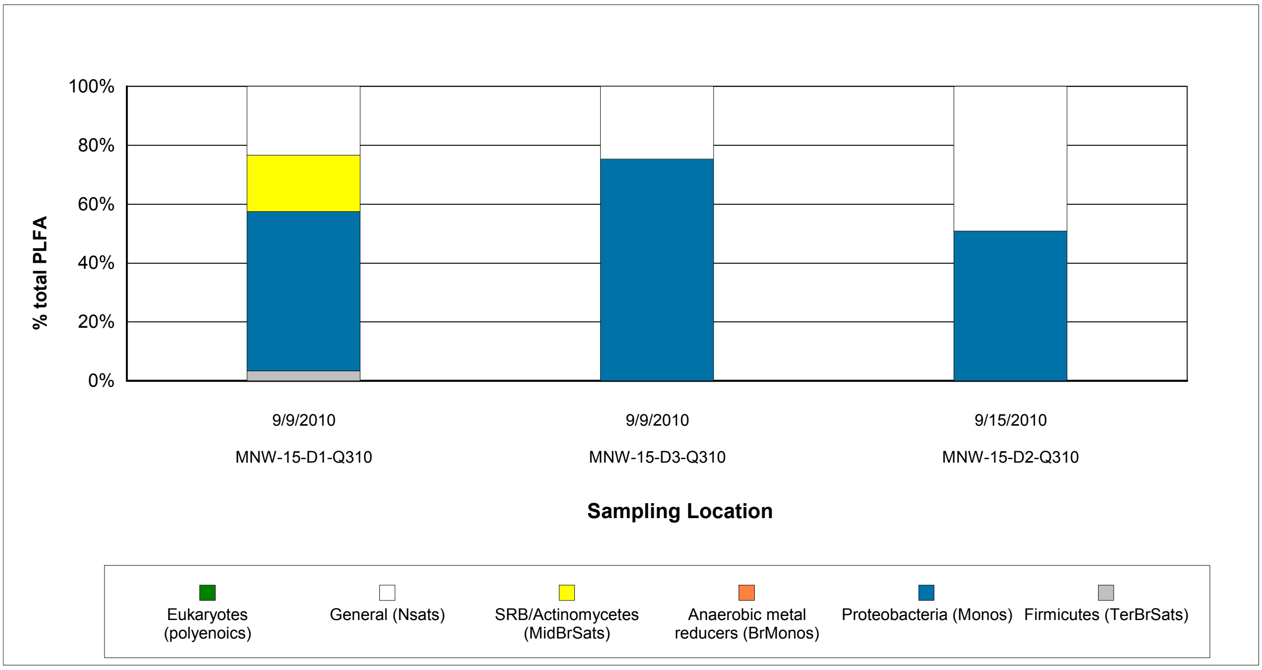

Figure 2. Relative percentages of total PLFA structural groups in the samples analyzed. Structural groups are assigned according to PLFA chemical structure, which is related to fatty acid biosynthesis.

Identifier: 007HI **Date Rec:** 09/01/2010 **Report Date:** 10/06/2010

Client Project #: 345406.PJ.08 **Client Project Name:** Fruit Avenue Plume TO-003

Purchase Order #: 941422

Comments: The following samples had total PLFA biomass below our PQL but above our LQL: SMFW-22-D1-Q310, SMFW-22-D2-Q310, SFMW-40-D3-Q310, MNW-2-I2-Q310, SFMW-43-D3-Q310, MNW-5-D1-Q310, MNW-9-D1-Q310, SFMW-25-I1-Q310, MNW-8-I2-Q310, MNW-15-D1-Q310 and MNW-15-D3-Q310.

The following samples have total PLFA biomass levels below our LQL: SFMW-13-I2-Q310, HSM-I2-4-Q310, SFMW-44-D2-Q310, MNW-6-D2-Q310, SFMW-20-I1-Q310, SFMW-16-I1-Q310, MNW-3-D2-Q310 and MNW-15-D2-Q310

Therefore, interpretation of the PLFA profiles from the above samples should be done with caution.

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Phospholipid Fatty Acid Analysis

Interpretation Guidelines

Phospholipids fatty acids (PLFA) are a main component of the membrane (essentially the "skin") of microbes and provide a powerful tool for assessing microbial responses to changes in their environment. This type of analysis provides direct information for assessing and monitoring sites where bioremediation processes, including natural attenuation, are of interest. Analysis of the types and amount of PLFA provides a broad based understanding of the entire microbial community with information obtained in three key areas viable biomass, community structure and metabolic activity.

What is the detection limit for PLFA?

Our limit of detection for PLFA analysis is ~150 picomoles of total PLFA and our limit of quantification is ~500 picomoles of total PLFA. Samples which contain PLFA amounts at or below 150 pmol cannot be used to determine biomass, likewise samples with PLFA content below ~500 pmol are generally considered to contain too few fatty acids to discuss community composition.

How should I interpret the PLFA results?

Interpreting the results obtained from PLFA analysis can be somewhat difficult, so this document was designed to provide a technical guideline. For convenience, this guideline has been divided into the three key areas.

Viable Biomass

PLFA analysis is one of the most reliable and accurate methods available for the determination of viable microbial biomass. Phospholipids break down rapidly upon cell death (21, 23), so biomass calculations based on PLFA content do not contain 'fossil' lipids of dead cells.

How is biomass measured?

Viable biomass is determined from the total amount of PLFA detected in a given sample. Since, phospholipids are an essential part of intact cell membranes they provide an accurate measure of viable cells.

How is biomass calculated?

Biomass levels are reported as cells per gram, mL or bead, and are calculated using a conversion factor of 20,000 cells/pmole of PLFA. This conversation factor is based upon cells grown in laboratory media, and varies somewhat with the type of organism and environmental conditions.

What does the concentration of biomass mean?

The overall abundance of microbes within a given sample is often used as an indicator of the potential for bioremediation to occur, but understanding the levels of biomass within each sample can be cumbersome. The following are benchmarks that can be used to understand whether the biomass levels are low, moderate or high.

Low	Moderate	High
10^3 to 10^4 cells	10^5 to 10^6 cells	10^7 to 10^8 cells

How do I know if a change in biomass is significant?

One of the primary functions of using PLFA analysis at contaminated sites is to evaluate how a community responds following a given treatment, but how does one know if the changes observed between two events are significant? As a general rule, biomass levels which increase or decrease by at least an order of magnitude are considered to be significant. However, changes in biomass levels of less than an order of magnitude may still show a trend. It is important to remember that many factors can affect microbial growth, so factors other than the treatment could be influencing the changes observed between sampling events. Some of the factors to consider are: temperature, moisture, pH, etc. The following illustration depicts three types of changes that occurred over time and the conclusions that could be drawn.

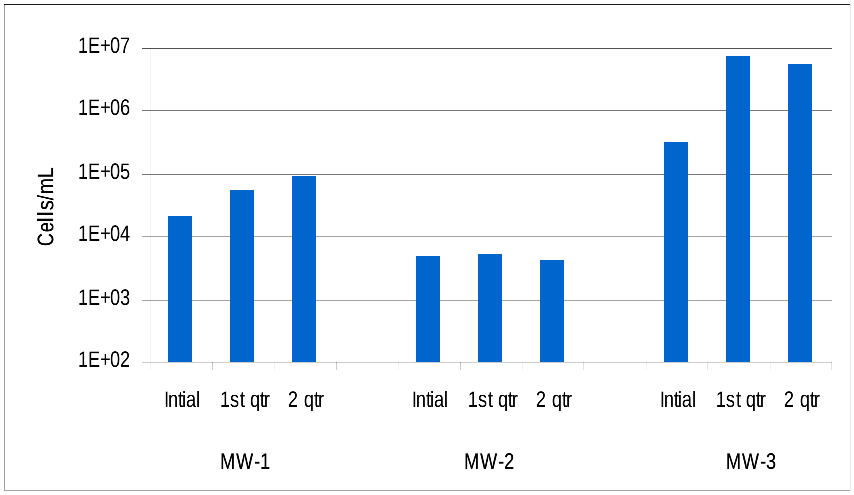

Figure 1. Biomass content is presented as a cell equivalent based on the total amount of phospholipid fatty acids (PLFA) extracted from a given sample. Total biomass is calculated based upon PLFA attributed to bacterial and eukaryotic biomass (associated with higher organisms).

Conclusions from graph above:

- MW-1 showed a trend of biomass levels increasing steadily over time, although cell concentrations were ~10^4 cells/mL at each sampling event.
- MW-2 showed no notable trends or significant changes in biomass concentrations.
- MW-3 showed a significant increase in biomass levels between the initial and 1st quarter sampling events (from ~10^5 to ~10^6 cells/mL).

Community Structure:

The PLFA in a sample can be separated into particular types, and the resulting PLFA “profile” reflects the proportions of the categories of organisms present in the sample. Because groups of bacteria differ in their metabolic capabilities, determining which bacterial groups are present and their relative distributions within the community can provide information on what metabolic processes are occurring at that location. This in turn can also provide information on the subsurface conditions (i.e oxidation/reduction status, etc.). Table 1 describes the six major structural groups used and their potential relevance to site specific projects.

Table 1. Description of PLFA structural groups.

PLFA Structural Group	General classification	Potential Relevance to Bioremediation Studies
Monoenoic (Monos)	Abundant in Proteobacteria (Gram negative bacteria), typically fast growing, utilize many carbon sources, and adapt quickly to a variety of environments.	Proteobacteria is one of the largest groups of bacteria and represents a wide variety of both aerobes and anaerobes. The majority of Hydrocarbon utilizing bacteria fall within the Proteobacteria
Terminally Branched Saturated (TerBrSats)	Characteristic of Firmicutes (Low G+C Gram-positive bacteria), and also found in Bacteriodes, and some Gram-negative bacteria (especially anaerobes).	Firmicutes are indicative of presence of anaerobic fermenting bacteria (mainly *Clostridia/Bacteriodes*-like), which produce the H_2 necessary for reductive dechlorination
Branched Monoenoic (BrMonos)	Found in the cell membranes of micro-aerophiles and anaerobes, such as sulfate- or iron-reducing bacteria	In contaminated environments high proportions are often associated with anaerobic sulfate and iron reducing bacteria
Mid-Chain Branched Saturated (MidBrSats)	Common in sulfate reducing bacteria and also Actinobacteria (High G+C Gram-positive bacteria).	In contaminated environments high proportions are often associated with anaerobic sulfate and iron reducing bacteria
Normal Saturated (Nsats)	Found in all organisms.	High proportions often indicate less diverse populations.
Polyenoic	Found in eukaryotes such as fungi, protozoa, algae, higher plants, and animals.	Eukaryotic scavengers will often rise up and prey on contaminant utilizing bacteria

Following are answers to some of the common questions about community composition and some detailed descriptions of some typical shifts which can be observed between sampling events.

How is the community structure data presented?

Community structure data is presented as percentage (%) of the total amount of PLFA. In order to relate the complex mixture of PLFA to the organisms present, the ratio of a specific PLFA group is determined (detailed in Table 1 above), and this corresponds to the proportion of the related bacterial classification within the overall community structure. Because normal saturated PLFA are found in both prokaryotes (bacteria) and eukaryotes (fungi, protozoa, diatoms etc), their distribution provides little insight into the types of microbes that are present at a sampling location. However, high proportions of normal saturates are often associated with less diverse microbial populations.

How can community structure data be used to manage my site?

It is important to understand that microbial communities are often a mixture of different types of bacteria (e.g. aerobes, sulfate reducers, methanogens, etc) with the abundance of each group behaving like a seesaw, i.e. as the population of one group increases, another is likely decreasing, mostly due to competition for available resources. The PLFA profile of a sample provides a “fingerprint” of the microbial community, showing relative proportions of the specific bacterial types at the time of sampling. This is a great tool for detecting shifts within the community over time and also to evaluate similarities/differences between sampling locations. It is important to note that PLFA analysis of community structure is analyzing the microbes directly, not just secondary breakdown products. So this provides evidence of how the entire microbial community is responding to the treatment.

How do I recognize community shifts and what they mean?

Shifts in the community structure are indications of changing conditions and their effect on the microbial community, and, by extension on the metabolic processes occurring at the sampling location. Some of the more commonly seen shifts within the community are illustrated and discussed below:

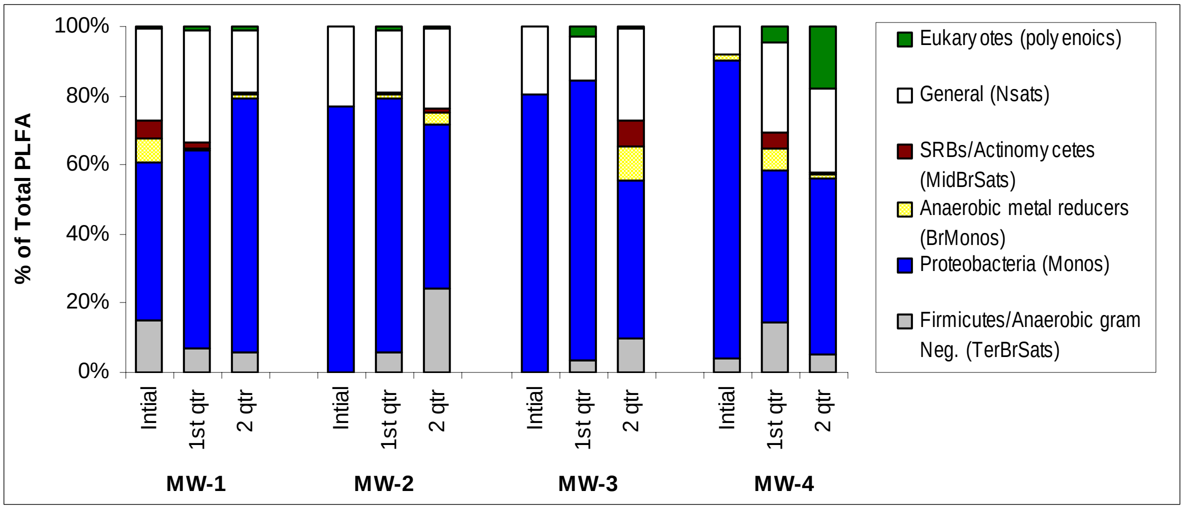

Figure 2. Relative percentages of total PLFA structural groups in the samples analyzed. Structural groups are assigned according to PLFA chemical structure, which is related to fatty acid biosynthesis. See Table 1 for detailed descriptions of structural groups.

- **Increased Proteobacteria**

Proportions of Proteobacteria are of interest because it is one of the largest groups of bacteria and represents a wide variety of both aerobe and anaerobes. The majority of hydrocarbons (including benzene and naphthalene) are metabolized by some member of Proteobacteria, mainly due to their ability to grow opportunistically, quickly taking advantage of available food (i.e. hydrocarbons), and adapting quickly to changes in the environment. The detection of increased proportions of Proteobacteria coupled with increased biomass suggests that the Proteobacteria are consuming something. In situations where it is important to determine the extent to which the Proteobacteria are utilizing anaerobic or aerobic pathways, it is possible to measure relative proportions of specific biomarkers that are associated with anaerobic or aerobic pathways thus separating the Proteobacteria into different groups, based on pathways used. Sample MW-1 from Figure 2 depicts a shift in community structure where the proportion of Proteobacteria has increased over time.

- **Increased Firmicutes/Anaerobic Gram negative bacteria**

Increased proportions of Firmicutes/Anaerobic Gram negative bacteria generally indicate that conditions are becoming more reductive (i.e. more anaerobic). Proportions of Firmicutes are of particular interest in sites contaminated with chlorinated hydrocarbons because Firmicutes include anaerobic fermenting bacteria (mainly *Clostridia/Bacteriodes*-like), which produce the H_2 necessary for reductive dechlorination.

Enhanced bioremediation of chlorinated solvents often employs the injection of fermentable substrates which, when utilized by fermenting bacteria, results in the release of H_2. Engineered shifts in the microbial community can be shown by observing increased proportions Firmicutes following an injection of fermentable substrate. Through long-term monitoring of the community structure it is possible to know when re-injection may be necessary or desirable. Sample MW-2 from Figure 2 depicts a shift in community structure where the proportion of Firmicutes has increased over time.

- **Increased anaerobic metal reducing bacteria (BrMonos) and SRB/Actinomycetes (MidBrSats)**

An increase in the proportions of metal and sulfate reducing bacterial groups, especially when combined with shifts in the other bacterial groups, can provide information helpful to monitoring bioremediation. Generally, an increase in metal and sulfate reducers points to more reduced (anaerobic) conditions at the sampled location. This is especially true if there is an increase in Firmicutes at the same time. Large increases in either metal and sulfate reducers, particularly if accompanied by a decrease in Firmicutes, may suggest that conditions are becoming increasingly reduced. In this situation the metal and sulfate reducers may be out-competing dechlorinators for available $H_{2,}$ thereby limiting the potential for reductive dechlorination at that location. Sample MW-3 from Figure 2 depicts a shift in community structure where the proportion of metal reducing bacteria has increased over time.

- **Increased Eukaryotes**

Eukaryotes include organisms such as fungi, protozoa, and diatoms. At a contaminated location, an increase in eukaryotes, particularly if seen with a decrease in the contaminant utilizing bacteria, suggests that eukaryotic scavengers are preying upon what had been an abundance of bacteria which were consuming the contaminant. Sample MW-4 from Figure 2 depicts a shift in community structure where the proportion of eukaryotes has increased over time.

Physiological status of Proteobacteria

The membrane of a microbe adapts to the changing conditions of its environment, and these changes are reflected in the PLFA. Toxic compounds or environmental conditions may disrupt the membrane and some bacteria respond by making *trans* fatty acids instead of the usual *cis* fatty acids (7) in order to strengthen the cell membrane, making it less permeable. Many Proteobacteria respond to lack of available substrate or to highly toxic conditions by making cyclopropyl (7) or mid-chain branched fatty acids (20) which point to less energy expenditure and a slowed growth rate. The physiological status ratios for Decreased Permeability (trans/cis ratio) and for Slowed Growth (cy/cis ratio) are based on dividing the amount of the fatty acid induced by environmental conditions by the amount of its biosynthetic precursor.

What does slowed growth or decreased permeability mean?

Ratios for slowed growth and for decreased permeability of the cell membrane provide information on the “health” of the Gram negative community, that is, how this population is responding to the conditions present in the environment. It should be noted that one must be cautious when interpreting these measures from only one sampling event. The most effective way to use the physiological status indicators is in long term monitoring and comparing how these ratios increase/decrease over time.

A marked increase in either of these ratios suggests a change in environment which is less favorable to the Gram negative Proteobacteria population. The ratio for slowed growth is a relative measure, and does not directly correspond to log or stationary phases of growth, but is useful as a comparison of growth rates among sampling locations and also over time. An increase in this ratio (i.e. slower growth rate) suggests a change in conditions which is not as supportive of rapid, “healthy” growth of the Gram negative population, often due to reduced available substrate (food). A larger ratio for decreased permeability suggests that the environment has become more toxic to the Gram negative population, requiring energy expenditure to produce *trans* fatty acids in order to make the membrane more rigid.

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Appendix H
Abiotic Natural Attenuation Evaluation Results

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Fruit Avenue Plume Superfund Site Long-Term Remedial Action Appendix H – Abiotic Natural Attenuation Evaluation Results

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DATE:	October 2012
PROJECT:	EPA Region 6 Remedial Action Contract W-EP-06-021 Task Order No. 0003-RALR-06DD CH2M HILL Project No. 345406.PJ.14
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This appendix (Appendix H) describes abiotic degradation processes for the Fruit Avenue Plume Superfund Site (the site). Abiotic degradation processes are chemical transformation reactions that degrade contaminants without microbial facilitation (EPA, 1998). Such reactions can reduce the toxicity, mobility, and volume of a trichloroethene (TCE) plume by transforming it into the less toxic cis 1,2-dichloroethene (cis 1,2-DCE) and/or non-toxic forms while reducing TCE concentrations in groundwater. This appendix summarizes chlorinated ethene abiotic degradation principles, the lines of evidence used to identify the presence of abiotic degradation pathways, and the field data collected from several monitor well locations (**Figure 1**) to obtain evidence of abiotic transformation at the site.

Principals of Abiotic Chlorinated Ethene Transformation

Much research has been done to identify and quantify chlorinated ethene transformation reactions that occur in engineered remedial systems, such as those that take place in: 1) permeable reactive barriers constructed of zero-valent iron (Van Stone et al., 2004, and Elsner et al., 2008); and 2) direct injection reactions driven by potassium permanganate or Fenton's reagent. Until recently, less research has been done to identify and quantify the naturally occurring reactions that abiotically transform tetrachloroethene (PCE) and TCE (U.S. Environmental Protection Agency [EPA], 2009 and Tobiszewski and Namiesnik, 2011).

A variety of naturally occurring iron-bearing soil minerals, such as mackinawite, pyrite, magnetite, green rust, and iron-bearing clays (reactive minerals), have been shown to facilitate degradation of chlorinated ethenes (EPA, 2009). Reactive minerals support complete transformation of TCE and cis-1,2-DCE through various reactions (**Figure 2**), which may avoid the creation of daughter products, such as vinyl chloride. In these reactions, the mineral surfaces act as electron donors and /or reaction mediators to increase the rate of transformation via one or more abiotic degradation pathways.

Abiotic degradation of TCE and cis-1,2-DCE on iron sulfide (FeS) minerals (such as mackinawite and pyrite) was demonstrated by several researchers (EPA, 2009). TCE is degraded by dihalo-elimination to chloroacetylene, which subsequently degrades to acetylene (the major reaction). TCE is also degraded by hydrogenolysis to cis-1,2-DCE (the minor reaction). Dihalo-elimination of cis-1,2-DCE on pyrite was demonstrated to produce acetylene and ethene, without producing vinyl chloride. This pyrite reaction rate increases with dissolved oxygen concentrations, resulting in several short-lived degradation products (EPA, 2009).

Degradation of TCE and cis-1,2-DCE on magnetite was demonstrated by Ferrey et al. (2004, in EPA, 2009). The mass of magnetic material in soil can be estimated from magnetic susceptibility; so, magnetic susceptibility measurements can provide an indication of a degradation pathway.

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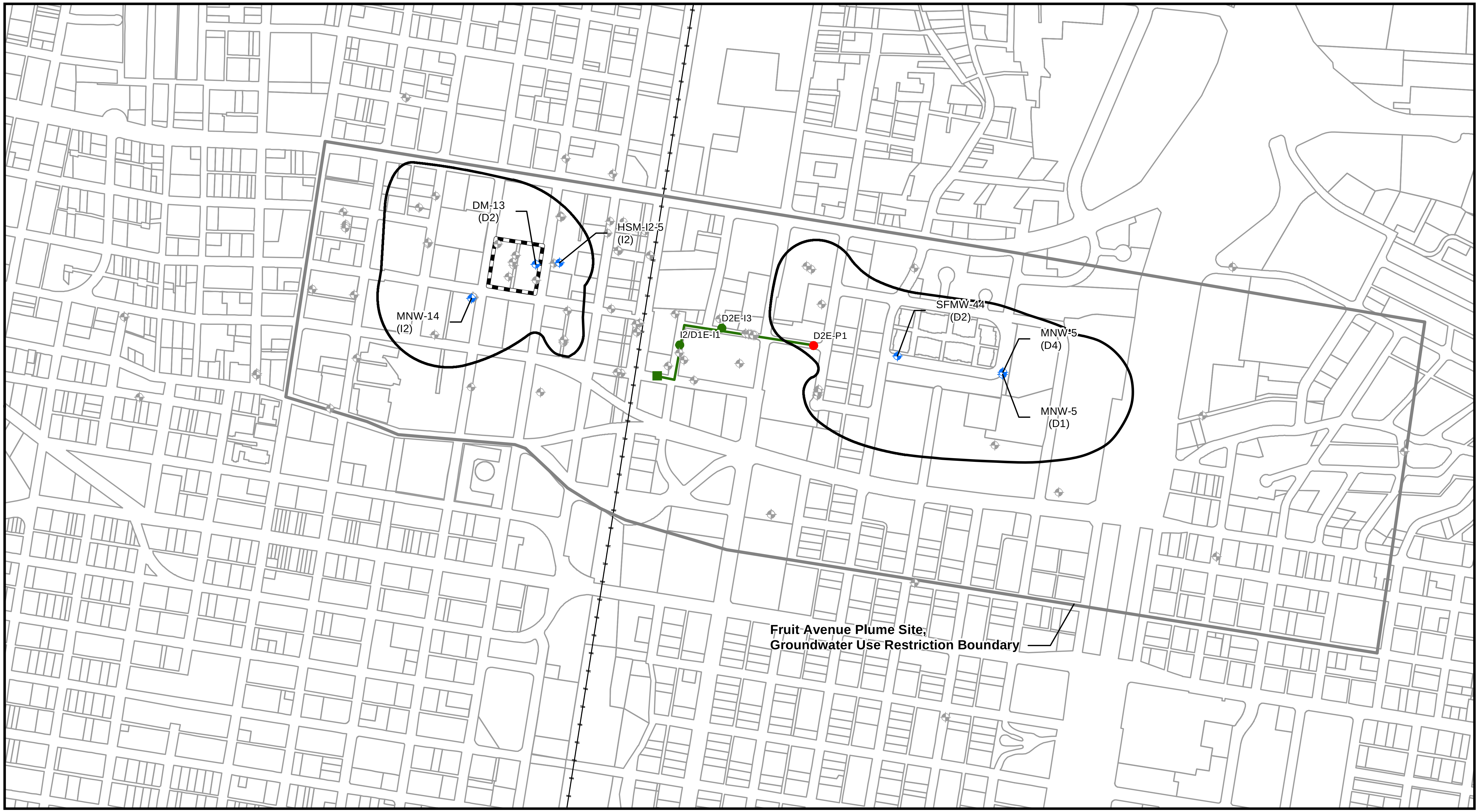

LEGEND

- ◈ Abiotic Degradation Sampling Locations
- ◈ Other Site Monitor Well
- ▨ Presumed Source Area
- ● Extraction Well
- ■ Air Stripper Treatment Plant
- ● Injection Well
- ┼─┼ Railroad
- ─ FAP TCE Composite Plume Boundary at 5 ug/L (dashed where inferred). The upgradient TCE plume located west of the Site is not shown. This plume is not part of FAP Site.

Aquifer Zones:
S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

FIGURE 1
Abiotic Degradation Sampling Locations
August 2012
Fruit Avenue Plume Superfund Site
Albuquerque, NM

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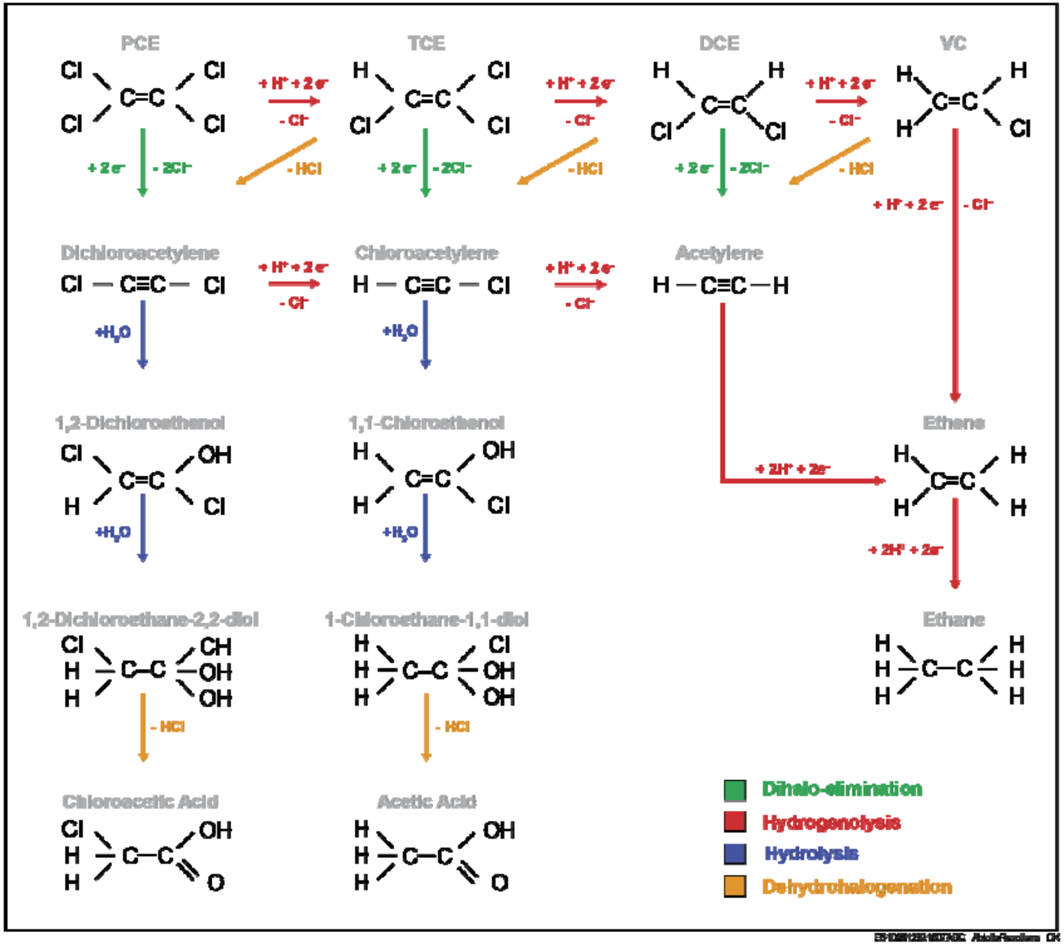
Natural abiotic degradation reactions are slower than biodegradation reactions; however, abiotic degradation may be a crucial process at sites where dechlorinating bacteria activity is low (EPA, 1998). Thermodynamically stable minerals, such as pyrite and magnetite, support comparatively slower TCE degradation rates than do metastable mineral phases, such as mackinawite (EPA, 2009). The rate of FeS-mediated abiotic degradation is a function of pH, with increasing pH resulting in an increased degradation rate (EPA, 2009). Although acetylene is a major reaction product for TCE transformation, it is quickly degraded to ethene and then carbon dioxide (CO_2) and water (EPA, 1998 and Wilson, 2012, personal communication).

FIGURE 2

Potential Chloroethene Abiotic Degradation Pathways (Brown et al., 2007).

Fruit Avenue Plume Superfund Site, Albuquerque, NM



Evidence for Abiotic Transformation

As with other transformation processes, both direct and indirect lines-of-evidence are used to identify abiotic degradation processes at a site. Direct evidence that demonstrates the effects of abiotic degradation includes plume degradation patterns and stable isotope analysis. Indirect evidence includes data indicating that the site has conditions conducive to abiotic degradation, such as high concentrations of reactive minerals, which are evident though mineral equilibrium modeling and down-hole magnetic susceptibility measurements.

Plume Degradation Patterns

Non-chlorinated daughter products of TCE abiotic degradation, such as acetylene, glycolate, acetate, and formate (EPA, 2009), typically are not found in groundwater because they are more easily degraded than the parent compounds. Additionally, these compounds are not routinely analyzed at environmental restoration sites under typical groundwater monitoring programs.

The loss of TCE without the appearance of the cis 1,2-DCE and vinyl chloride (VC) daughter products provides direct evidence for abiotic degradation. Because anaerobic biodegradation of TCE follows a hydrogenolysis pathway that produces cis-1,2-DCE and VC sequentially, the presence of VC suggests that anaerobic biodegradation is operative. Conversely, the absence of VC in an anaerobic system may provide evidence that abiotic degradation is operative. This can be ascertained by calculating the molar concentration of parent and daughter compounds relative to the distance from the source or relative to time.

Concentration trends for TCE and cis-1,2-DCE, which are evaluated in **Appendix D**, showed clear and meaningful trends of decreasing mass and concentration over time. An analysis of that data is also conducted in this technical memorandum (TM) to elucidate evidence for abiotic degradation.

Stable Isotope Evidence

Abiotic degradation fractionates stable carbon isotopes similarly to biodegradation. The Rayleigh fractionation model applies to abiotic degradation. Different abiotic degradation mechanisms produce characteristic patterns of fractionation. Using a fractionation factor appropriate for biodegradation to describe abiotic degradation may overestimate the actual extent of degradation (EPA, 2008). Inversely, identification of site-specific bulk enrichment factors (ε_{bulk})[1] cannot be used to distinguish between abiotic and biotic degradation of either TCE, because the reactions result in different degradation products, or cis-1,2-DCE, because the bulk enrichment factor is essentially zero (EPA, 2009).

Compound specific isotope analysis (CSIA) results for the site are reported in **Appendix E** and analyzed in **Appendix E** and **Appendix I**. As discussed in **Appendix E**, TCE concentrations at the site are affected by more than one process; in particular, dispersion and/or sorption affect TCE concentrations, in addition to transformation reactions. If all degradation is assumed to be caused by abiotic degradation, then previously determined bulk enrichment factors (shown in **Table 1**) can be used to estimate the fraction of TCE decay (decreasing concentration) caused by degradation (transformation reactions). An analysis of that data is reported in this Appendix to elucidate evidence for abiotic degradation.

TABLE 1
Bulk Enrichment Factors ($\varepsilon_{bulk)}$ for the Degradation of TCE[a] and cis-1,2-DCE
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Abiotic	Biotic[b]
-33.4 ±1.5 ‰ on Fe(II)S @pH 8	-4.07 ±0.48 ‰ @BB1
-27.9±1.3 ‰ on Fe(II)S @pH 9	-12.8 ±1.6 ‰ @Sm
-23.00±1.8 ‰ on chloride green rust	-15.27 ±0.79 ‰ @BBI
-21.7 ±1.0 ‰ on pyrite @pH 8	
-39±12 ‰ on magnetite	
-0.60 ‰ cis-1,2-DCE on magnetite (=zero at 90% confidence)	

[a] Bulk enrichment factors from Liang et al., (2007) reported in EPA, 2009.
[b] Biotic bulk enrichment factors produced by:

Notes:
‰: per mil
BB1: *Desulfuromonas michiganesis* strain BB1
BBI: bacterial consortium BioDechlor Inoculum
Sm: *Sulfurospirillum multivorans*

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[1] The bulk enrichment factor is the isotopic difference between two compounds, expressed in per mil (‰) notation. The bulk enrichment factor is often characteristic of particular reactions.

Methods for Assessing Abiotic Transformation

Mineralogical Characterization of Aquifer Materials

Collection and analysis of aquifer solids may allow identification of reactive minerals. Analysis of aquifer solids is difficult because the reactive minerals may be unstable in the presence of atmospheric oxygen and may be present at very low concentrations. At this site, sampling of aquifer solids was not performed because such sampling would have required drilling at depths between 90 and 400 feet to collect representative samples.

Magnetic Susceptibility

The bulk concentration of the reactive mineral magnetite can be estimated from magnetic susceptibility (EPA, 2009) measured using a down-hole instrument. The volume-magnetic susceptibility (VMS) measured in SI units is first converted to mass-magnetic susceptibility (MMS) by dividing the measurement by the density of aquifer materials (assumed to be 2/3 silica sand and 1/3 porosity) as follows:

$$5.0 \times 10^{-3}\, VMS[SI\ units]\ \times \frac{m^3}{1600\ kg} = 3.1 \times 10^{-6} \frac{m^3}{kg} MMS[SI\ units]$$

Based on the evaluations reported by EPA (2009), “a mass magnetic susceptibility in the range of 1x10^{-6} m^3/kg may indicate that degradation of PCE or TCE at rates near 0.3 to 2 per year is possible but should not be taken a proof that abiotic degradation will occur those rates.”

The MMS of a sample is then converted to the mass of magnetic material (MMM) (in milligrams per kilogram [mg/kg]) based on the following empirical formula (EPA, 2009):

$$MMM \frac{mg}{kg} = 10^{(1.0803 \times Log(MMS) + 9.7038)}$$

At this site, magnetic susceptibility of aquifer materials was measured using a 2HMA-100 combination magnetic susceptibility-induction downhole probe built by Mt. Sopris Instrument Company of Denver, Colorado, and based on the HMI 453 sensor from W-R Instruments of Brno, Czech Republic. The instrument returned a measurement of VMS which was converted to MMM based upon the equation described above (**Attachment A**). The instrument was calibrated between 0.50x10^{-3} and 5.0x10^{-3} SI units of VMS, according to the operator’s manual, using a vendor supplied calibration plate and “pucks.”

Downhole VMS was measured at four locations (**Table 2**) that were selected because they have: 1) previously shown relatively high TCE concentrations that have decayed over time; 2) included locations both near the presumed source area and the downgradient portion of the plume; and 3) known well construction. The four locations (**Table 2**) included: DM-13(D1), HSM-I2-5, MNW-5(D4), and SFMW-44(D2). During the onsite field measurement event, the probe was unable to pass a depth of 183 feet below the top of casing (btoc) in monitor well MNW-5(D4) because of an apparent bend in the well casing.

Mineral Equilibrium Modeling

The presence or absence of reactive minerals in aquifer solids may be predicted through geochemical mineral equilibrium modeling. Potentially reactive phases are present in situations where solids cannot be collected and analyzed for mineral content.

At this site, three groundwater samples were collected and analyzed for cations and anions (listed in **Attachment B**). Sample locations were selected because: (1) they have previously held relatively high TCE concentrations that have decayed over time; and (2) they included locations both near the presumed source area and the downgradient portion of the plume. Some effort was taken to select locations that could also have magnetic susceptibility measured; however, only HSM-I2-5 has both mineral speciation modeling results and magnetic susceptibility measurements. The sampling results were evaluated (**Attachment B**) with the equilibrium-based geochemical modeling program PHREEQC (Parkhurst and Appelo, 1999) to identify the saturation state of common aquifer minerals, including ferrous iron and sulfide phases.

TABLE 2
Summary of Magnetic Susceptibility Field Activities
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Well ID	Well Construction	Location	Depth and Aquifer Zones
DM-13(D1)	4"-diameter SCH 40 PVC. Mixed intervals of native backfill, 10-20 Colorado silica and bentonite gel slurry. 10 ¾ inch borehole.	Presumed Source Area	0 to 188 feet btoc S, I1, I2, D1
HSM-I2-5	3"-diameter SCH 80 PVC. Hydrated bentonite chip seal above gravel pack of 10-20 Colorado silica. 10 ¾ inch borehole.	Presumed Source Area	0 to 108 feet btoc S, I1, I2
MNW-5(D4)	2"-diameter SCH 80 PVC. Hydrated bentonite chip seal above gravel pack of 10-20 Colorado silica. 10 ¾ inch borehole.	Downgradient of P&T System	0 to 183 feet btoc S, I1, I2
SFMW-44(D2)	2"-diameter SCH 40 PVC. SFMW-43(I1) is constructed in the same borehole.	Downgradient of P&T System	0 to 266 feet btoc S, I1, I2, D1, D2

Note:

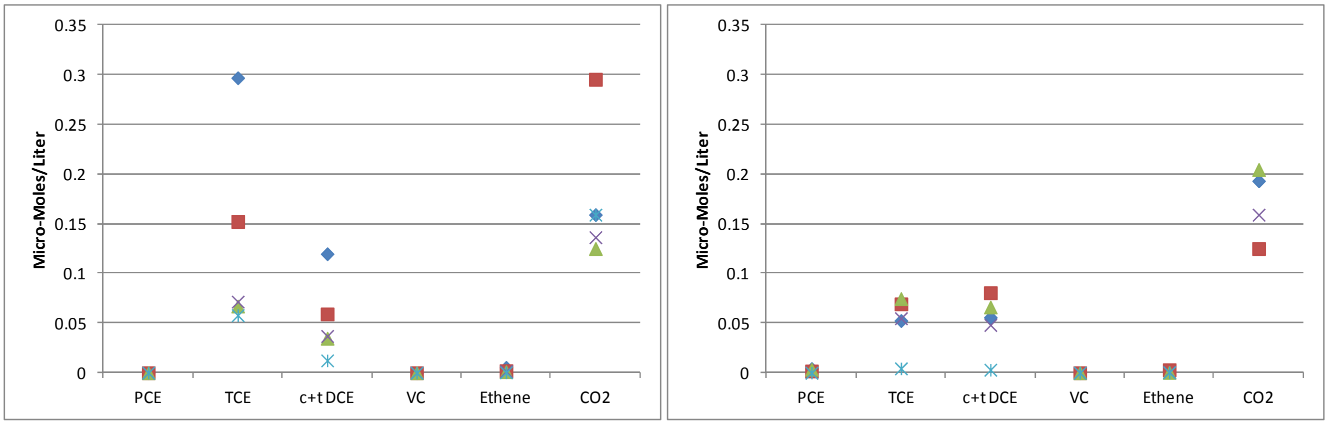
S, I1, I2, D1, D2 – Aquifer zone designations indicating Shallow, Intermediate-1, Intermediate-2, Deep-1, and Deep-2 aquifer zones.

Site-Specific Results and Interpretation

Plume Degradation Patterns

As reported in **Appendix D**, TCE, cis-1,2,-DCE and trans-1,2-DCE are commonly detected in groundwater samples from the site. Because DCE (cis and trans isomers) is not associated with an historic release at the site, its presence suggests that biologically mediated reductive dechlorination of TCE occurs at the site. **Figure 3** illustrates that in the presumed source area, among samples analyzed for ethene, TCE concentrations are as high as 0.3 micromolar. Downgradient, beyond the effects of the pump-and-treat (P&T) system at MNW-5(D1), MNW-5(D2), SFMW-44(D2), SFMW-40(D3), and SFMW-43(I1), TCE concentrations are less than 0.1 micromolar. This decrease is not accompanied by a similar increase in DCE concentrations, suggesting that abiotic TCE degradation reactions (such as dihalo-elimination and dehydrohalogenation, which produce dichloroacetylene and chloroacetylene instead of DCE) may contribute to the loss of TCE along the groundwater flow path.

FIGURE 3
Mole Concentration (Micromoles per Liter) of Chloroethenes and Transformation Products
Presumed Source Area (Left) and Downgradient of the P&T System (Right)
Fruit Avenue Plume Superfund Site, Albuquerque, NM



Although not shown in **Figure 3**, cis-1,2-DCE concentrations are decreasing in both the presumed source area and downgradient of the P&T system (see **Appendix D**). As concluded in **Appendix D**, the decreasing cis-1,2-DCE concentrations suggest that a degradation process is operative. VC has not been detected in groundwater samples collected from the site at concentrations above 1.1 micrograms per liter (µg/L) and 93 of the 100 detections were limited to three historical sample events conducted in 2004 and 2005. As concluded in **Appendix D**, the absence of VC in the more recent samples suggests that stepwise reductive dechlorination (hydrogenolysis) is not likely the process responsible for transformation of cis-1,2-DCE.

The daughter products of abiotic degradation (for example, acetylene, glycolate, acetate, and formate [EPA, 2009]), which are more easily degraded than the parent compounds (EPA, 1998), have not yet been investigated at this site.

Stable Isotope Evidence

The CSIA results reported in **Appendix E** are summarized in **Table 3** and illustrated in Kuder plots on **Figure 4**. **Appendix E** concluded that the CSIA data indicate that TCE is being transformed into cis-1,2-DCE and degradation contributes considerably to the observed decrease in TCE concentrations at the site. The Kuder plots on **Figure 4** confirm that the decay observed (the concentration change, x-axis of the plots) is more than would be expected if degradation (abiotic or biotic) were the only process responsible for the decay. Because the observed TCE fractionation is less than would be expected based on the amount of decay, it is not currently possible to identify the specific process or bacteria that are responsible for TCE degradation at the site.

TABLE 3
Summary of CSIA Results
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Well ID	TCE Concentrations[a]				C/Co [µM/µM]	TCE δ^{13}C ‰	cis-1,2-DCE δ^{13}C ‰	*f* Fraction of original TCE Mass Remaining	Degradation Rate in Time Based on Estimated Release Date, λ_t [1/year]
	C		Co						
	[µg/L]	[µM]	[µg/L]	[µM]					
Field Samples - Source Area									
HSM-I2-5	30	0.23	99	0.75	0.30	-20.63	-37.04	78%	-0.006
HSM-I2-5	30	0.23			0.30	-20.83	-37.70	79%	-0.006
MNW-14 (I2)	20	0.15			0.20	-17.36	-37.94	72%	-0.009
Field Samples - Downgradient									
SFMW-40 (D3)	7	0.05	99	0.75	0.07	-16.76	-31.73	71%	-0.009
SFMW-44 (D2)	10	0.08			0.10	-17.63	-33.53	72%	-0.009
SFMW-44 (D2)	10	0.08			0.10	-17.95	-32.76	73%	-0.008
MNW-5 (D2)	6	0.05			0.06	-17.01	-32.86	71%	-0.009

[a] Current TCE concentrations “C” are those measured during δ^{13}C analysis, samples collected 8/30/2010.
Max TCE concentration “Co” is 99 µg/L = 0.75 micro-molar (µM), sample collected from HSM-I2-5 on 4/19/2005

Notes:

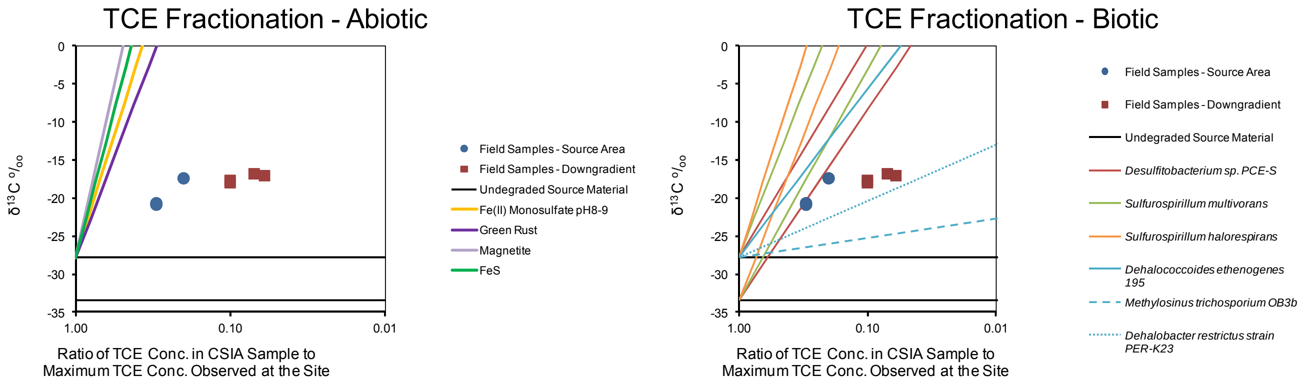
µM: micro-molar = micromoles per liter
δ^{13}C ‰: Stable carbon isotope ratio in TCE or cis-1,2-DCE in the sample.

If abiotic degradation is assumed to be solely responsible for the change in $\delta^{13}C$ observed in TCE, then, based on the calculations described in **Appendix E** and the enrichment factor for magnetite reported in **Table 1**, the fraction of TCE mass remaining is estimated to range from 71 to 79 percent (**Table 3**). The degradation rate, based on the calculations described in **Appendix I**, including an estimated release date, ranges from -0.006 to -0.009 per year.

FIGURE 4

Kuder Plots Illustrating the Expected and Measured Isotopic Enrichment of TCE Following Abiotic and Biotic Degradation

Fruit Avenue Plume Superfund Site, Albuquerque, NM



Magnetic Susceptibility

The VMS logs, calibration data, and well construction diagrams are included in **Attachment A**. Summary results, based on calculations described above, are listed in **Table 4**. VMS data were collected every 0.2 feet.

Data Quality Evaluation

Several steps were taken to evaluate and ensure the repeatability and representativeness of the VMS data. Data were recorded while advancing the probe down the well and while retrieving the probe back up the well; and the two data sets were compared to confirm the repeatability of the measurement. None of the data demonstrated repeatability poor enough to exclude it from the data evaluation.

VMS data in each log were also inspected to discern obvious effects of well construction, such as borehole diameter, annular fill material, centralizers, and potential ferrous debris.

Monitor well DM-13(D1) has several intervals where the annular fill material is either cement, bentonite clay slurry, 10-20 Colorado silica, native backfill, and 10-20 Colorado silica mixed with native backfill. The intervals with engineered materials appear have lower VMS than does the native backfill. This conclusion is tempered by the considerable variability in VMS in each interval. Inclusion of VMS data from intervals with engineered annular fill therefore provides a conservative estimate of the concentration of magnetite in the aquifer materials.

Several intervals in DM-13(D1) and SFMW-44(D2) clearly exhibited the effects of metallic well centralizers. One very short interval in SFMW-44(D2) had VMS that was 14 x 10^{-3}, which is suspected to not represent natural conditions. This interval and those intervals affected by well centralizers were excluded from the data evaluation.

The remaining digital VMS data for each well were converted by the equations above to MMS and MMM. The averages and standard deviation for each calculation are presented in **Table 4**.

TABLE 4
Summary of Magnetic Susceptibility Results
Fruit Avenue Plume Superfund Site, Albuquerque, NM

	VMS [SI Units] x10^{-3}		**MMS m^3/kg**		**MMM mg/kg**	
Well ID #Data Points	**Minimum & Maximum**	**Average ± Standard Deviation**	**Minimum & Maximum**	**Average ± Standard Deviation**	**Minimum & Maximum**	**Average ± Standard Deviation**
DM-13(D1) 928	1.36×10^{-4} 7.69×10^{-3}	$2.91 \pm 1.85 \times 10^{-3}$	8.49×10^{-8} 4.81×10^{-6}	$1.82 \pm 1.16 \times 10^{-6}$	116 9096	3232 ±2193
HSM-I2-5 524	2.91×10^{-4} 6.41×10^{-3}	$1.93 \pm 0.91 \times 10^{-3}$	1.82×10^{-7} 4.01×10^{-6}	$1.21 \pm 0.57 \times 10^{-6}$	265 7467	2063 ±1045
MNW-5(D4) 876	8.58×10^{-6} 6.23×10^{-3}	$2.24 \pm 1.40 \times 10^{-3}$	5.36×10^{-9} 3.90×10^{-6}	$1.40 \pm 0.88 \times 10^{-6}$	5.9 7246	2444 ±1631
SFMW-44(D2) 1196	4.83×10^{-5} 7.80×10^{-3}	$2.17 \pm 1.11 \times 10^{-3}$	3.02×10^{-8} 4.88×10^{-6}	$1.36 \pm 0.70 \times 10^{-6}$	38 9233	2349 ±1294

Notes:

m^3/kg: cubic meter per kilogram
"±7.2" one standard deviation
S, I1, I2, D1, D2 – Aquifer zone designations indicating Shallow, Intermediate-1, Intermediate-2, Deep-1, and Deep-2 aquifer zones.

Results

At DM-13, where VMS data were collected from the S, I1, I2, and D1 aquifer zones, the VMS ranged from 1.36×10^{-4} to7.69×10^{-3}, the MMS ranged from 8.49×10^{-8} to 4.81×10^{-6} m^3/kg, and the MMM ranged from 116 to 9,096 mg/kg, averaging 3,232 mg/kg. The VMS data from DM-13 appear to have three distinct intervals aligned with aquifer zones. The lowest VMS signal ($0.5x10^{-3}$ to $2x10^{-3}$) is found in the shallow aquifer zone. The I1 and I2 aquifer zones have a moderate ($1x10^{-3}$ to $5x10^{-3}$) VMS signal, with more variability over shorter depth intervals. The D1 aquifer zone has higher VMS ($4x10^{-3}$ to $8x10^{-3}$), with less variability over short depth intervals.

At HSM-I2-5, where VMS data were collected from the S, I1, and I2 aquifer zones, the VMS ranged from 2.91×10^{-4} to 6.41×10^{-3}, the MMS ranged from 1.82×10^{-7} to 4.01×10^{-6} m^3/kg, and the MMM ranged from 265 to 7,467 mg/kg, averaging 2,063 mg/kg. The VMS measured at HSM-I2-5 confirms the trends associated with aquifer zones, as observed in DM-13(D1). The VMS measured in the shallow aquifer zone is lower and more consistent. The VMS measured in the I1 and I2 aquifer zones is higher and has more variability over short depth intervals.

At MNW-5(D4), where VMS data were collected from the S, I1, and I2 aquifer zones, the VMS ranged from 8.58×10^{-6} to 6.23×10^{-3}, the MMS ranged from 5.36×10^{-9} to 3.90×10^{-6} m^3/kg, and the MMM ranged from 5.9 to 7,246 mg/kg, averaging 2,444 mg/kg. The VMS measured at MNW-5(D4) confirms the trends associated with aquifer zones as observed in DM-13(D1) and HSM-I2-5. The VMS measured in the shallow aquifer zone is lower and more consistent. The VMS measured in the I1 and I2 aquifer zones is higher and has more variability over short depth intervals.

At SFMW-44(D2), where VMS data were collected from the S, I1, I2, D1, and D2 aquifer zones, the VMS ranged from 4.83×10^{-5} to 7.80×10^{-3}, the MMS ranged from 3.02×10^{-8} to 4.88×10^{-6} m^3/kg, and the MMM ranged from 38 to 9,233 mg/kg, averaging 2,349 mg/kg. The VMS measured at SFMW-44(D2) generally confirms the trends associated with aquifer zones, as observed at the other locations. The VMS measured in the shallow aquifer zone is lower and more consistent. The VMS measured in the I1 and I2 aquifer zones is higher and has more variability over short depth intervals. A distinct change is noted at the top of the D1 aquifer zone, but the VMS does not increase substantially in the D1 or D2 zones, staying generally less than $6x10^{-3}$.

The MMS at the site averages (Table 4) $1.45x10^{-6}$ m^3/kg, which is high enough to suggest that degradation TCE at rates near 0.3 to 2 per year is possible (EPA, 2009). These rates exceed the TCE degradation rate estimated in

Appendix I, which recommended that degradation rates of -0.022 per year and -0.030 per year be applied to the intermediate and deep aquifer zones, respectively, in the flow and transport model.

Mineral Equilibrium Modeling

The mineral equilibrium modeling was used to evaluate whether groundwater chemistry reflects the presence of reactive minerals. Because of the extremely low concentrations of sulfide and ferrous iron and the presence of detectable concentrations of dissolved oxygen (DO) in each of the three samples, none of the samples was in equilibrium with ferrous sulfide phases, such as mackinawite, amorphous FeS, or pyrite.

It is hypothesized that relatively small volumes (micro-environments) exist at the Fruit Avenue Plume which have favorable conditions that are conducive for microbial reductive dechlorination processes. These same micro-environments would have conditions that are also conducive to formation of reactive minerals. Groundwater samples collected for use in the mineral equilibrium modeling possibly represented a mixture of waters collected from anoxic aquifer zones containing ferrous sulfide phases and from aerobic zones containing DO. Depending on the relative concentrations of DO to ferrous iron and sulfide in the two water types, mixing of the different waters would result in the oxidization of some or all of the ferrous iron and sulfide in the combined water, potentially masking the evidence for iron sulfide phases in the anoxic aquifer zones.

The mineral equilibrium modeling was used to determine whether the concentrations of ferrous iron or sulfide in the proposed reducing zones could be easily masked (diluted and oxidized) by mixing with very similar, but more oxidizing, water during sampling. The results presented in **Attachment B** indicate that the concentrations of ferrous iron and sulfide necessary for each of the three samples to reach saturation with amorphous FeS are less than 1.0 mg/L and 0.5 mg/L, respectively. The concentrations of ferrous iron and sulfide that must be present for these samples to reach equilibrium with mackinawite are less than half the values for amorphous FeS. The concentrations of ferrous iron and sulfide that must be present for these samples to reach equilibrium with pyrite are much lower. These results indicate that while the groundwater chemistry does not conclusively show the presence of reactive minerals, the groundwater chemistry does permit their presence with very small changes to the observed ferrous iron and sulfide concentrations, as might be found in previously hypothesized micro-environments.

Summary

The plume degradation patterns and magnetic susceptibility evaluation provide sufficient evidence to indicate that abiotic transformation reactions contribute to the degradation of TCE and cis-1,2-DCE at the site. The mineral equilibrium modeling results suggest that very small changes to the observed ferrous iron and sulfide concentrations would confirm the presence of reactive minerals, and such changes could be supported by micro-environments with reducing conditions. The CSIA evaluation, which is unable to differentiate between biotic and abiotic processes at this site, confirms that dispersion and/or sorption cause more TCE concentration decay than does abiotic degradation. The magnetic susceptibility evaluation suggests that degradation rates of 0.3 to 2 per year are possible, which is more than ten times the degradation rates estimated in **Appendix I**.

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Attachment A
Magnetic Susceptibility

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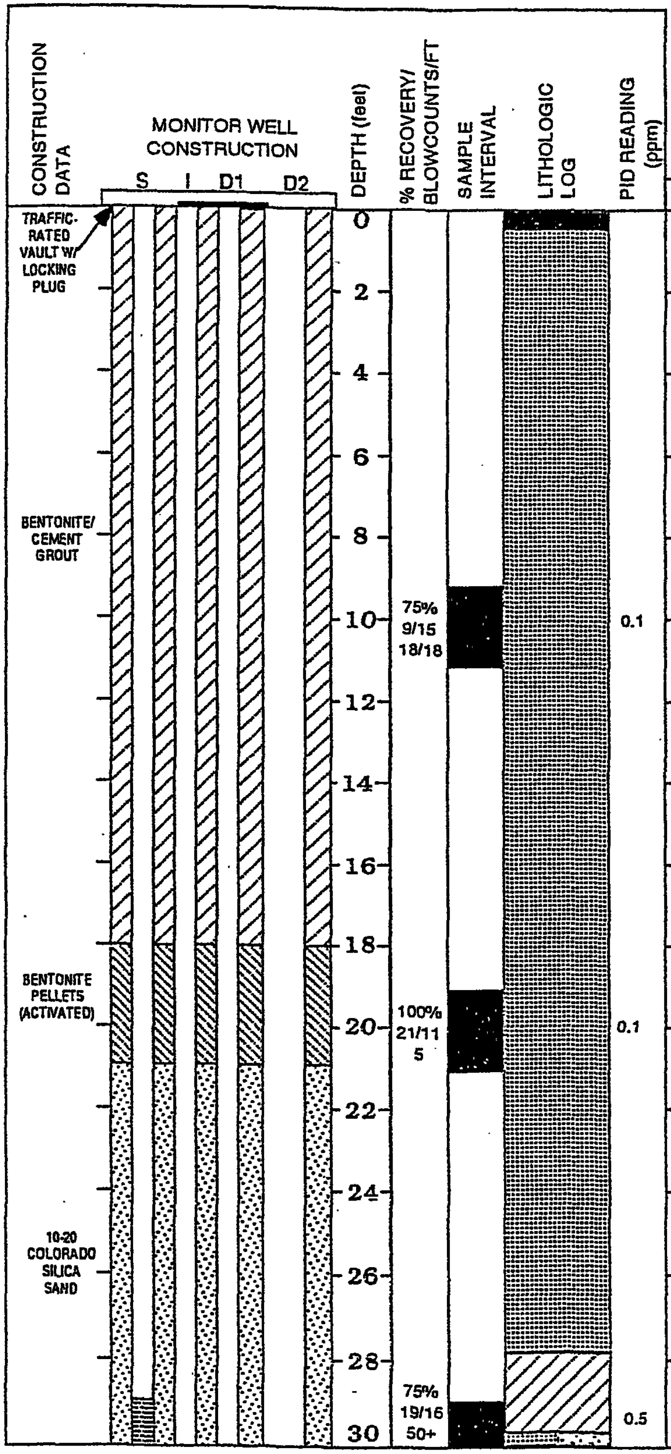
MONITOR WELL DM-13 (S, I, D1, D2)
A.I.C. PHASE II

DAMES & MOORE PAGE 1 OF 8

Job No: 27334-001-034 Client: Norwest
Date of Drilling: 10-13-93 Top of casing:
Type of Drilling: Percussion Hammer Drilling Co: Layne
Driller: G. Rodriguez Sampling Method: Split-spoon/cuttings
Total Depth: 230' Borehole Diameter: 10 3/4"
Blank Casing: Sched. 40/2" & 4" diameter Length: Variable
Screen: Sched. 40/2" & 4" diameter/0.01" slot size
Length: Variable' Depth to water: ~36'



LITHOLOGIC DESCRIPTION

0.0'-0.3' Asphalt

0.0'-5.0' (SP) Tan; fine to medium grained sand; minor coarse-grained clasts; unconsolidated; slightly moist; no apparent hydrocarbon odor. (Cuttings).

9.0'-11.0' 1.5' of sample in split spoon. (SP) Tan-brown; fine to medium-grained sand; well-sorted; unconsolidated; slightly moist; no apparent hydrocarbon odor.

~15.0'-18.0' (SP) Tan-brown; fine to medium-grained sand; well-sorted; unconsolidated; slightly moist; no apparent hydrocarbon odor. (Cuttings).

19.0'-21.0' 2.0' of sample in split spoon. (SP) Tan-brown; fine-grained sand; well sorted; unconsolidated; slightly moist; no apparent hydrocarbon odor.

~25.0'-28.0' (SP) Tan-brown; medium to fine-grained sand; localized trace gravel clasts; slightly moist; no apparent hydrocarbon odor. (Cuttings).

29.0'-30.5' 1.2' of sample in split spoon. 0.0'-0.6' (CL) Brown; silty clay; clay is plastic; slightly moist with minor silt component; no apparent hydrocarbon odor.
0.6'-0.8' (SP/GP) Tan-brown; medium-grained sand; surrounding one 1.5" rounded gravel clast. 0.8'-1.1' (SP) Tan-brown; medium-grained sand; unconsolidated; slightly moist; no apparent hydrocarbon odor.
1.1'-1.2' (SP/GP) Tan-brown; medium-grained sand; surrounding one 1.5" rounded gravel clast.

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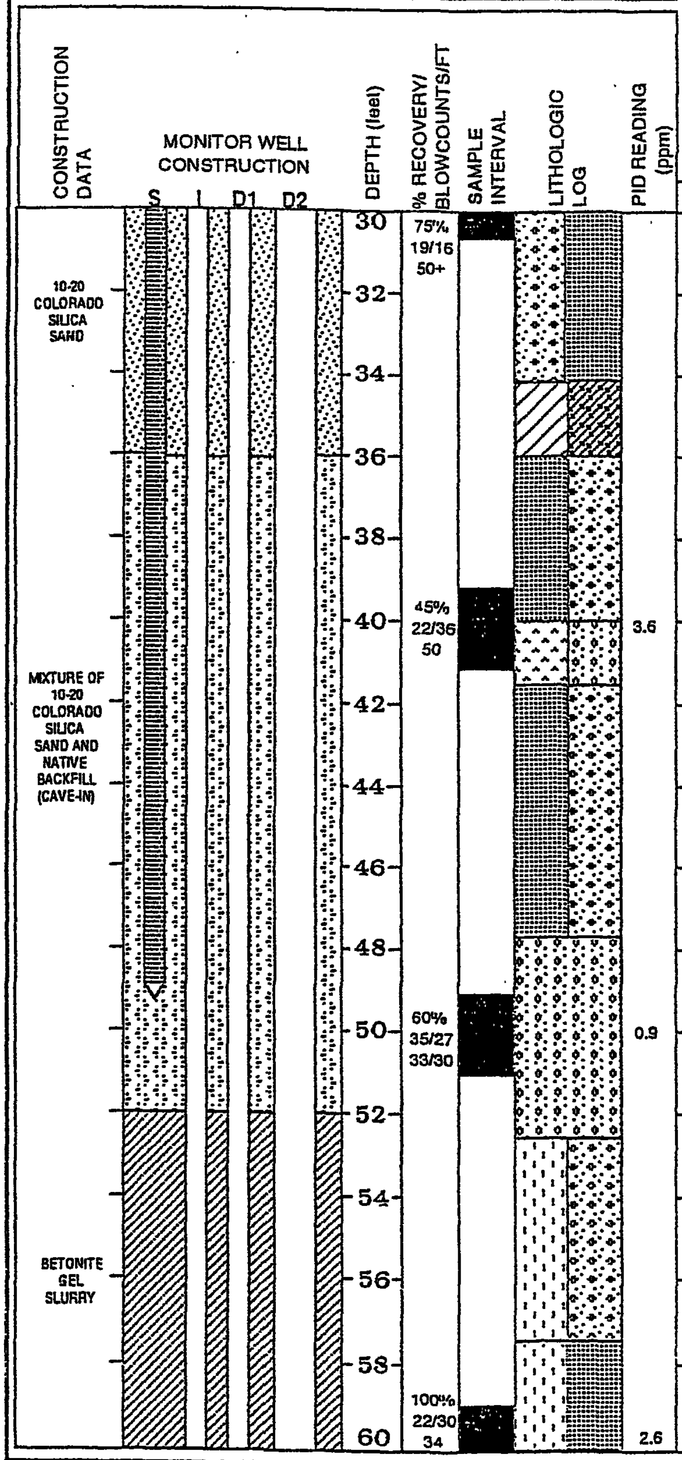
Drafted by: SDB
Checked by: WJB
January 1994

MONITOR WELL DM-13 (S, I, D1, D2)
A.I.C. PHASE II

DAMES & MOORE | **PAGE 2 OF 8**

Job No: 27334-001-034 Client: Norwest
Date of Drilling: 10-13-93 Top of casing: Variable
Type of Drilling: Percussion Hammer Drilling Co: Layne
Driller: G. Rodriguez Sampling Method: Split-spoon/cuttings
Total Depth: 230' Borehole Diameter: 10 3/4"
Blank Casing: Sched. 40/2" & 4" diameter Length: Variable
Screen: Sched. 40/2" & 4" diameter/0.01" slot size
Length: Variable' Depth to water: ~36'



LITHOLOGIC DESCRIPTION

~32.0'-34.0' (SP/GP) Brown-tan; medium-grained sand matrix with rounded gravel/cobbles ~3" in diameter; consolidated; sliightly moist; no apparent hydrocarbon odor. (Cuttings).

~34.0'-36.0' (CL/GC) Brown to brown-gray; clayey gravel; clay is plastic; gravel is up to 1" in diameter; rounded; moist; no apparent hydrocarbon odor. (Cuttings).

39.0'-40.5' 0.7' of sample in split spoon. 0.0'-0.4' (SP/GP) Brown; sandy gravel; medium to coarse-grained; moderately sorted; unconsolidated; gravel clast is ~2.5" in diameter; rounded; H2O saturated; no apparent hydrocarbon odor. 0.4'-0.7' (SW/GW) Brown; silty gravelly sand; fine to coarse-grained sand with silt; gravel is ~20% of segment and less than 1" in diameter; sand is poorly sorted; unconsolidated; H2O saturated; no apparent hydrocarbon odor.

~42.0'-43.0' (SP/GP) Coarse-grained sand; pebble gravel; moderately sorted; unconsolidated. (Cuttings).

~45.0'-48.0' (SP/GP) Brown; silty sandy gravel; medium to fine-grained sand with some silt; gravel is well sorted; rounded; ~1-2" in diameter; H2O saturated. (Cuttings).

49.0'-51.0' 1.2' of sample in split spoon. 0.0'-0.3' (Cave-in?) (SP) Brown; fine to medium sand; unconsolidated; H2O saturated; no apparent hydrocarbon odor. 0.3'-1.2' (GW) Brown; sandy gravel; gravel is rounded-subangular; ~50% of interval poorly sorted; fine to coarse-grained sand; poorly sorted sand; unconsolidated; H2O saturated; no apparent hydrocarbon odor.

55.0'-57.0' (SM/GP) Sandy gravel; gravel clasts well sorted; sub-rounded up to 2" in diameter; sand is very fine-grained moderate silt component; H2O saturated; no apparent hydrocarbon odor. (Cuttings).

59.0'-60.5' 2.0' of sample in split spoon. 0.0'-0.6' (Cave-in/slough?) (SP/SM) Very fine-grained sand and silt; unconsolidated. 0.6'-2.0' (SM/SP) Brown; very fine-grained sand with minor silt component; moderately sorted; trace medium sand clasts; unconsolidated; H2O saturated; no apparent hydrocarbon odor.

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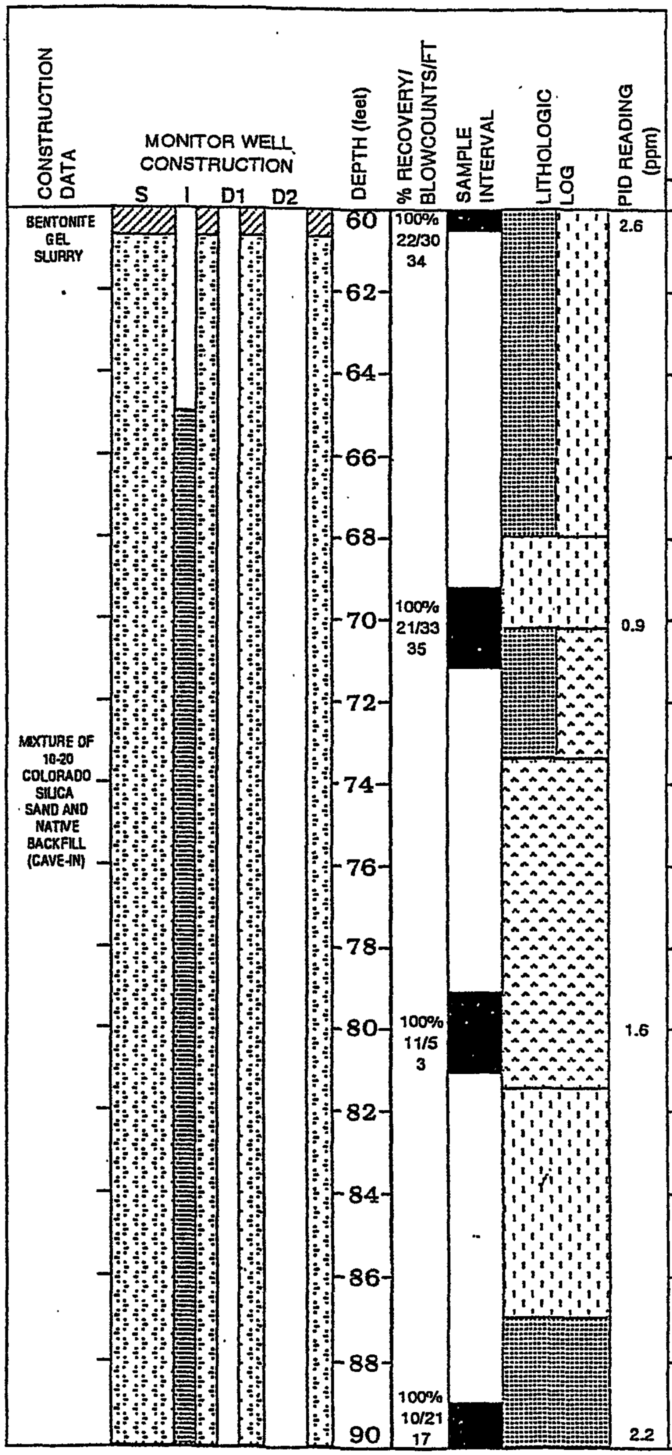
Checked by: WJB
January 1994

MONITOR WELL DM-13 (S, I, D1, D2)
A.I.C. PHASE II

DAMES & MOORE PAGE 3 OF 8

Job No: 27334-001-034 Client: Norwest
Date of Drilling: 10-13-93 Top of casing: Variable
Type of Drilling: Percussion Hammer Drilling Co: Layne
Driller: G. Rodriguez Sampling Method: Split-spoon/cuttings
Total Depth: 230' Borehole Diameter: 10 3/4"
Blank Casing: Sched. 40/2" & 4" diameter Length: Variable
Screen: Sched. 40/2" & 4" diameter/0.01" slot size
Length: Variable' Depth to water: ~36'



LITHOLOGIC DESCRIPTION

59.0'-60.5' 2.0' of sample in split spoon. 0.0'-0.6' (Cave-in/ slough ?) (SP/SM) Very fine-grained sand and silt; unconsolidated. 0.6'-2.0' (SM/SP) Brown; very fine-grained sand with minor silt component; moderately sorted; trace medium sand clasts; unconsolidated; H2O saturated; no apparent hydrocarbon odor.

~65.0' (SP/SM) Mixture of local coarse-grained sand and silty very fine-grained sand (difficult to determine original location in drive.) (Cuttings).

69.0'-70.5' 2.0' of sample in split spoon. 0.0'-0.8' (Heave) (SP/SM) 0.8'-1.4' (SM) Brown to brown-red; silty; very fine-grained sand; moderately well sorted; "soupy"; unconsolidated to locally cemented (CaCO3?) nodules; no visible cement; H2O saturated; no apparent hydrocarbon odor. 1.4'-2.0' (SP/SW) Brown to brown-red; silty sand; fine to medium-grained sand with minor coarse and very fine-grained fraction; silt is present in minor amounts; unconsolidated; H2O saturated; no apparent hydrocarbon odor.

~75.0' (SW) Brown; medium to coarse-grained sand with minor gravel clasts; clasts are up to 1/2" subangular; sub-rounded; < 5% of interval.

79.0'-80.5' 1.8' of sample in split spoon. 0.0'-0.5' (Cave-in slough) (SP) Medium to fine-grained sand. 0.5'-1.8' (SW) Brown; fine to coarse-grained sand; minor pebble clasts; poorly sorted; unconsolidated; H2O saturated; no apparent hydrocarbon odor.

~85.0' (SM) Brown; silty sand; very fine to fine-grained sand; unconsolidated; H2O saturated; no apparent hydrocarbon odor. (Cuttings).

89.0-90.5' 2.0' of sample in split spoon. 0.0'-0.7' (Cave-in/ Slough?) (SM/SP) Brown; silty; very fine-grained sand. 0.7'-2.0' (SP) Brown; very fine-grained sand; well sorted; unconsolidated; H2O saturated; no apparent hydrocarbon odor.

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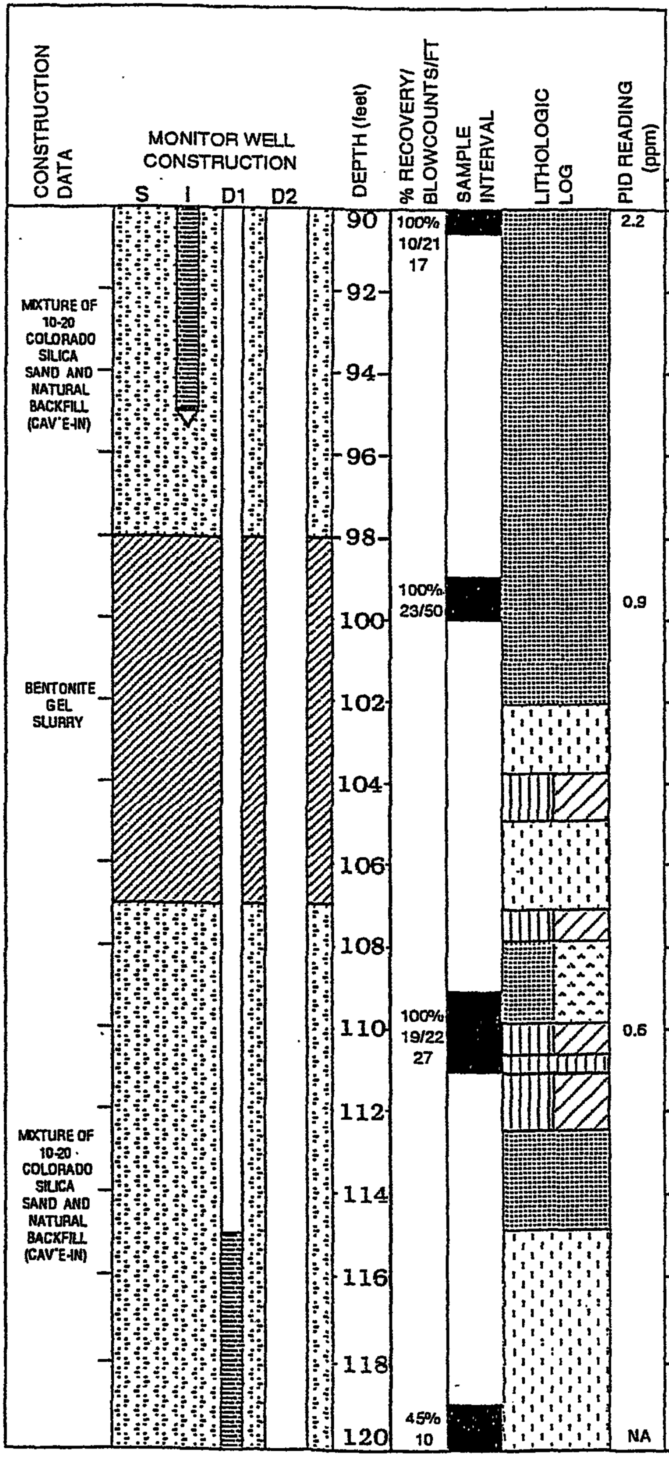
January 1994

MONITOR WELL DM-13 (S, I, D1, D2)
A.I.C. PHASE II

DAMES & MOORE

PAGE 4 OF 8

Job No: 27334-001-034 Client: Norwest
Date of Drilling: 10-13-93 Top of casing: Variable
Type of Drilling: Percussion Hammer Drilling Co: Layne
Driller: G. Rodriguez Sampling Method: Split-spoon/cuttings
Total Depth: 230' Borehole Diameter: 10 3/4"
Blank Casing: Sched. 40/2" & 4" diameter Length: Variable
Screen: Sched. 40/2" & 4" diameter/0.01" slot size
Length: Variable' Depth to water: ~36'



LITHOLOGIC DESCRIPTION

89.0-90.5' 2.0' of sample in split spoon. 0.0'-0.7' (Cave-in/ Slough?) (SM/SP) Brown; silty; very fine-grained sand. 0.7'-2.0' (SP) Brown; very fine-grained sand; well sorted; unconsolidated; H2O saturated; no apparent hydrocarbon odor.

99.0'-100.0' 2.0' of sample in split spoon. 0.0'-1.1' (Cave-in) (SP) Brown-tan; fine to medium-grained sand with trace silt; well sorted; unconsolidated. 1.1'-1.6' (SP) Brown; fine to medium-grained sand with localized pebble clasts; unconsolidated; H2O saturated; no apparent hydrocarbon odor. 1.6'-2.0' (SP) Brown to red-brown; very fine to fine-grained sand; trace silt; well sorted; unconsolidated; H2O saturated; no apparent hydrocarbon odor. (Indurated sandstone nodules ~1" in diameter at ~1.5' depth; gray (SP); fine-grained sand; moist.)

105' (SM) Brown; mixture of silty sand; consolidated; H2O saturated; and locally (MIL/CL) red-brown silt-clay; very slightly plastic; medium dense; appears in cuttings as 2"-3" nodules; moist; no apparent hydrocarbon odor. (Lab sample collected from clay cuttings.)

109.0'-110.5' 2.0' of sample in split spoon. 0.0'-1.2' (SP/SW) Brown; very fine to medium-grained sand; poor to moderate sorting with trace silt; unconsolidated; H2O saturated; trace coarse-grained sand and pebble clasts. 1.2'-1.8' (ML/CL) Brown-red; silty clay with localized (SM) pockets; dense; slighty plastic; laminated; localized CaCO3 nodules; moist; no apparent hydrocarbon odor. 1.8'-2.0' (ML) Red-brown; sandy silt; unconsolidated; H2O saturated; no apparent hydrocarbon odor.

~112.0' (SP) Coarse-grained sand; well sorted with minor pebbles; unconsolidated; no apparent hydrocarbon odor. (Cuttings).

~115.0' (SM) Silty; very fine-grained sand; unconsolidated; H2O saturated. (Cuttings)

119.0'-121.0' 2.0' of sample in split spoon. (SW) Brown; fine to coarse-grained sand; well graded; unconsolidated; wet; no apparent hydrocarbon odor. (May be cave-in from base of hole.)

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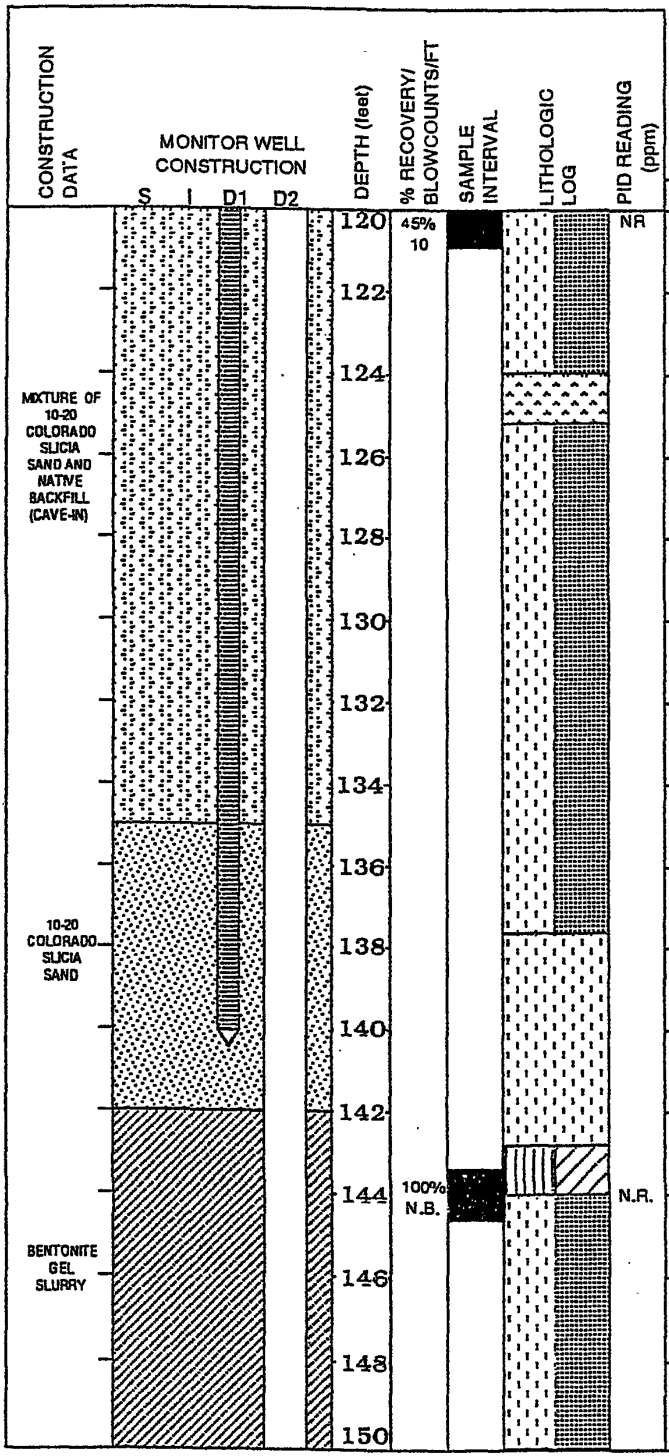
January 1994

MONITOR WELL DM-13 (S, I, D1, D2)
A.I.C. PHASE II

DAMES & MOORE PAGE 5 OF 8

Job No: 27334-001-034 Client: Norwest
Date of Drilling: 10-14-93 Top of casing: Variable
Type of Drilling: Percussion Hammer Drilling Co: Layne
Driller: G. Rodriguez Sampling Method: Split-spoon/cuttings
Total Depth: 230' Borehole Diameter: 10 3/4"
Blank Casing: Sched. 40/2" & 4" diameter Length: Variable
Screen: Sched. 40/2" & 4" diameter/0.01" slot size
Length: Variable' Depth to water: ~36'



LITHOLOGIC DESCRIPTION

119.0'-121.0' 2.0' of sample in split spoon. (SW) Brown; fine to coarse-grained sand; well graded; unconsolidated; wet; no apparent hydrocarbon odor. (May be cave-in from base of hole.)

~125.0' (SM/SP) and (SW) Brown; silty sand; mixed with zones of coarser-grained; medium to coarse-grained sand; silty sand; unconsolidated; no apparent hydrocarbon odor. (Cuttings).

~130.0' (SM/SP) Brown; silty sand; very fine to fine-grained; unconsolidated; H2O saturated; no apparent hydrocarbon odor. (Cuttings).

~135.0' (SM/SP) Brown; silty sand; very fine to fine-grained; unconsolidated; H2O saturated; no apparent hydrocarbon odor. (Cuttings).

~140.0' (SM) Brown; silty sand; very fine-grained sand; abundant silt; unconsolidated; moderately well sorted; H2O saturated; no apparent hydrocarbon odor. (Cuttings).

143.0'-144.5' 2.0' of sample in split spoon. 0.0'-0.9' (ML/CL) Red-brown; silty clay; non-plastic; silt % is high (20-30%?); slightly indurated; H2O saturated; no apparent hydrocarbon odor. 0.9'-2.0' (SM/SP) Red-brown; silty; very fine-grained sand; well sorted; unconsolidated; no apparent hydrocarbon odor.

~150.0' (SM/SP) Red-brown; silty; very fine-grained sand; well sorted; unconsolidated; no apparent hydrocarbon odor. (Cuttings).

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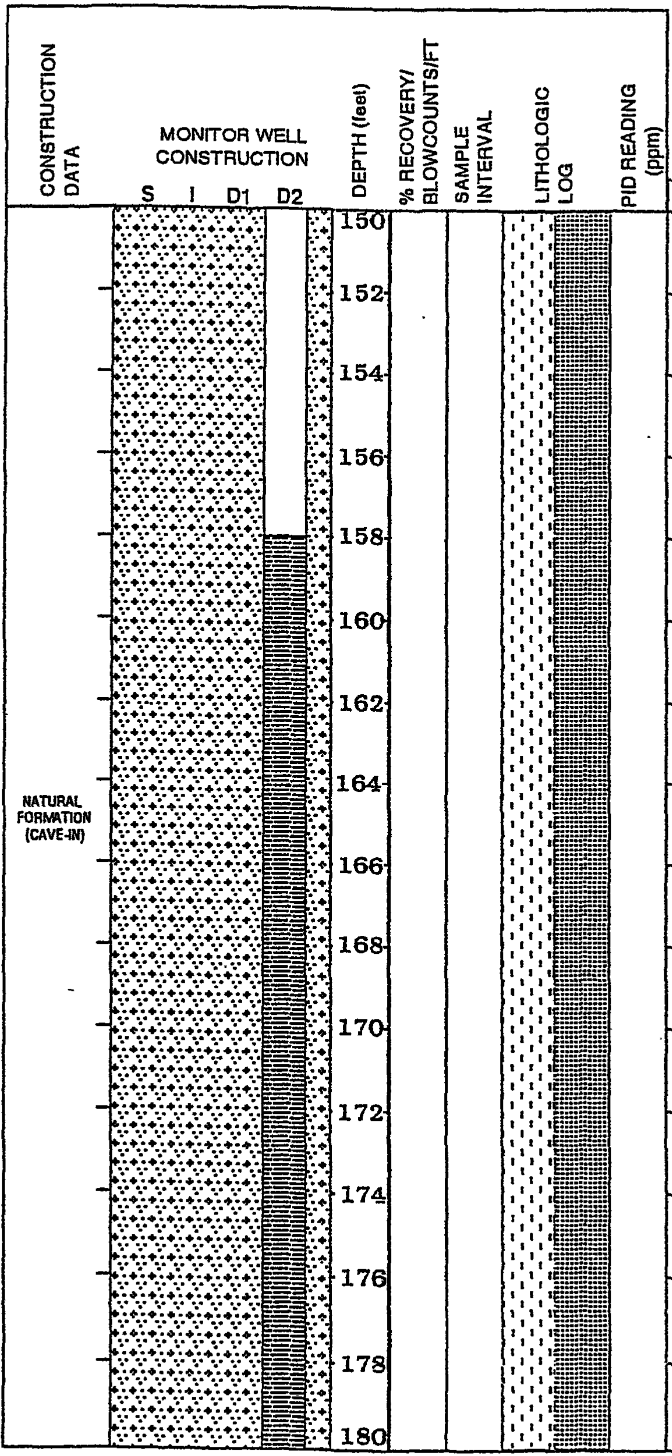
January 1994

MONITOR WELL DM-13 (S, I, D1, D2)
A.I.C. PHASE II

DAMES & MOORE PAGE 6 OF 8

Job No: 27334-001-034 Client: Norwest
Date of Drilling: 10-15-93 Top of casing: Variable
Type of Drilling: Percussion Hammer Drilling Co: Layne
Driller: G. Rodriguez Sampling Method: Split-spoon/cuttings
Total Depth: 230' Borehole Diameter: 10 3/4"
Blank Casing: Sched. 40/2" & 4" diameter Length: Variable
Screen: Sched. 40/2" & 4" diameter/0.01" slot size
Length: Variable Depth to water: ~36'



LITHOLOGIC DESCRIPTION

150.0' (SM/SP) Red-brown; silty; very fine-grained sand; well sorted; unconsolidated; no apparent hydrocarbon odor. (Cuttings).

155.0' (SM/SP) Red-brown; silty; very fine-grained sand; well sorted; unconsolidated; no apparent hydrocarbon odor. (Cuttings).

160.0' (SM/SP) Red-brown; silty; very fine-grained sand; very soft; well sorted; unconsolidated; no apparent hydrocarbon odor. (Cuttings). (Problems with heave in casing).

160.0'-180.0' (SM/SP) Brown; silty; fine to very fine-grained sand; very soft; unconsolidated; H2O saturated; no apparent hydrocarbon odor. (Cuttings). (Casing wants to slide into hole. Problems with heaving sand.)

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Drafted by: SDB
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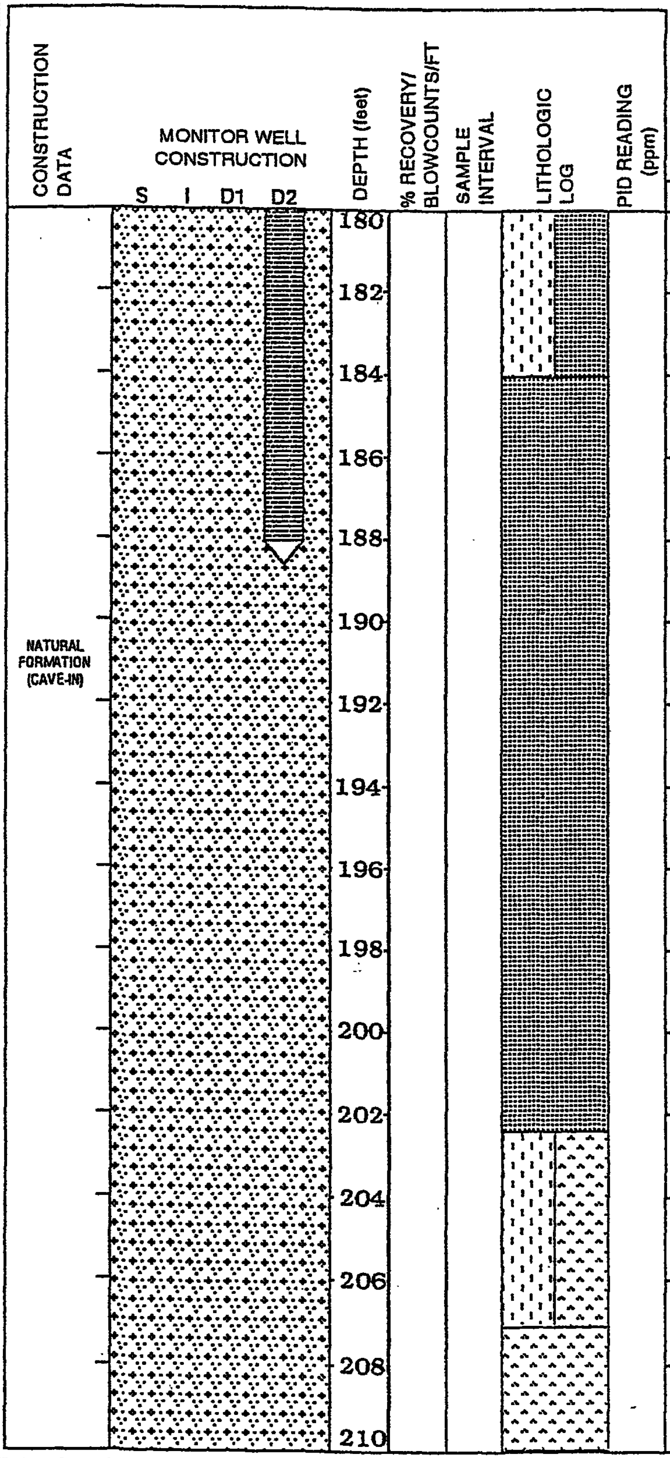
January 1994

MONITOR WELL DM-13 (S, I, D1, D2)
A.I.C. PHASE II

DAMES & MOORE PAGE 7 OF 8

Job No: 27334-001-034 Client: Norwest
Date of Drilling: 10-15-93 Top of casing: Variable
Type of Drilling: Percussion Hammer Drilling Co: Layne
Driller: G. Rodriguez Sampling Method: Split-spoon/cuttings
Total Depth: 230' Borehole Diameter: 10 3/4"
Blank Casing: Sched. 40/2" & 4" diameter Length: Variable
Screen: Sched. 40/2" & 4" diameter/0.01" slot size
Length: Variable' Depth to water: -36'



LITHOLOGIC DESCRIPTION

180.0' (SM/SP) Brown; silty; fine to very fine-grained sand; very soft; unconsolidated; H2O saturated; no apparent hydrocarbon odor. (Cuttings). (Casing wants to slide into hole. Problems with heaving sand.)

185.0' (SP) Brown; fine to medium-grained sand with minor silt component but less than above; moderately well sorted; H2O saturated; no apparent hydrocarbon odor. (Cuttings).

190.0' (SP) Brown; fine to medium-grained sand with minor silt component but less than above; moderately well sorted; H2O saturated; no apparent hydrocarbon odor. (Cuttings).

195.0' (SP) Brown; fine to medium-grained sand with minor silt component but less than above; moderately well sorted; H2O saturated; no apparent hydrocarbon odor. (Cuttings).

200.0' (SP) Brown; fine to medium-grained sand with minor silt component but less than above; moderately well sorted; H2O saturated; no apparent hydrocarbon odor. (Cuttings).

205.0' (SM/SW) Brown; silty sand; very fine to medium-grained sand with some coarse-grained clasts; minor silt content; unconsolidated; H2O saturated. (Cuttings).

210.0' (SW) Brown; fine to coarse-grained sand with minor silt; predominantly medium-grained sand; overall poorly sorted; unconsolidated; H2O saturated. (Cuttings).

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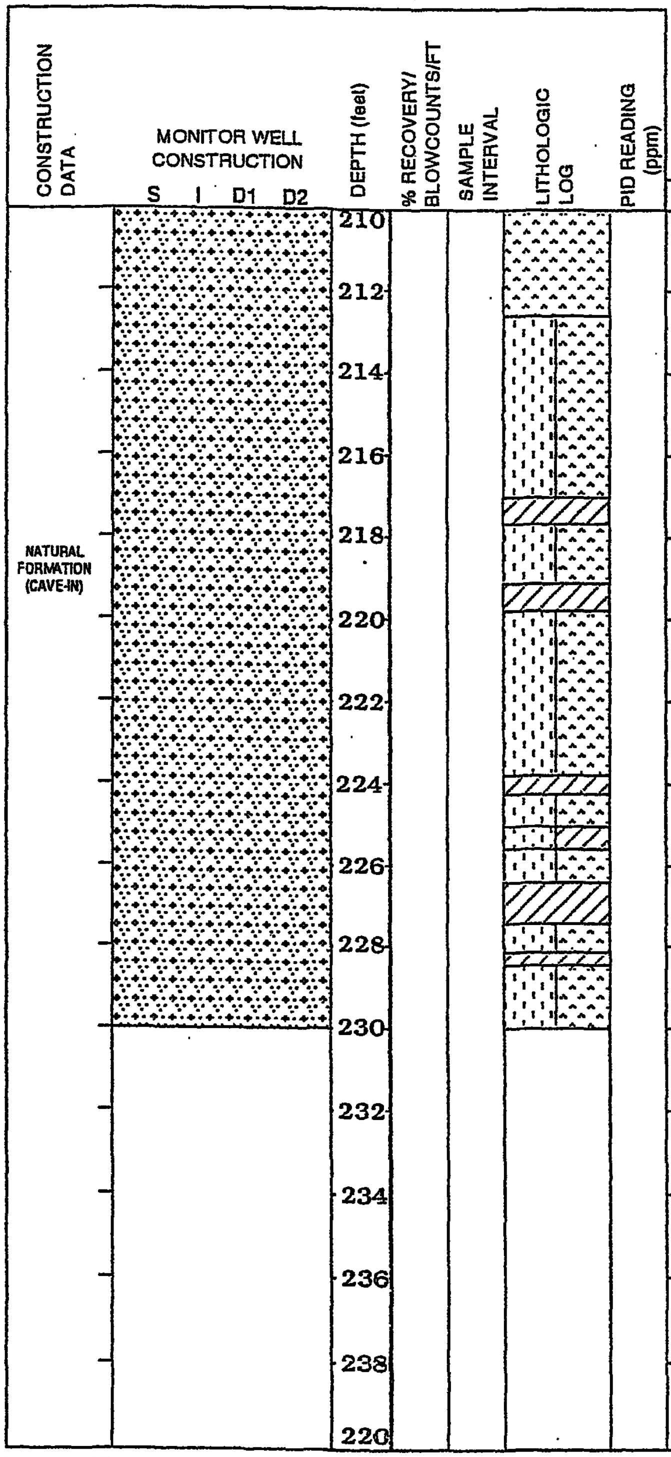
January 1994

MONITOR WELL DM-13 (S, I, D1, D2)
A.I.C. PHASE II

DAMES & MOORE PAGE 8 OF 8

Job No: 27334-001-034 Client: Norwest
Date of Drilling: 10-16-93 Top of casing: Variable
Type of Drilling: Percussion Hammer Drilling Co: Layne
Driller: G. Rodriguez Sampling Method: Split-spoon/cuttings
Total Depth: 230' Borehole Diameter: 10 3/4"
Blank Casing: Sched. 40/2" & 4" diameter Length: Variable
Screen: Sched. 40/2" & 4" diameter/0.01" slot size
Length: Variable' Depth to water: ~36'



LITHOLOGIC DESCRIPTION

210.0' (SW) Brown; fine to coarse-grained sand with minor silt; predominantly medium-grained sand; overall poorly sorted; unconsolidated; H2O saturated. (Cuttings).

215.0' (SM/SW) Silty sand; very fine to medium-grained sand; poorly sorted; unconsolidated; H2O saturated. (Cuttings).

217.0' (SM/SW) Red-brown; silty sand; very fine to medium-grained sand with (CL) chunks; poorly sorted; dense; slightly plastic; unconsolidated; moist. (Cuttings).

222.0'-230.0' (SM/SW) Red; silty sand with chunks of indurated (CL); brown-red; very dense; non-plastic; moist and chunks of laminated (SM/CL) silty sandy clay; weakly indurated; H20 saturated; no apparent hydrocarbon odor. (Individual zones may only be several inches to one foot in thickness.)

Total depth = 230 feet

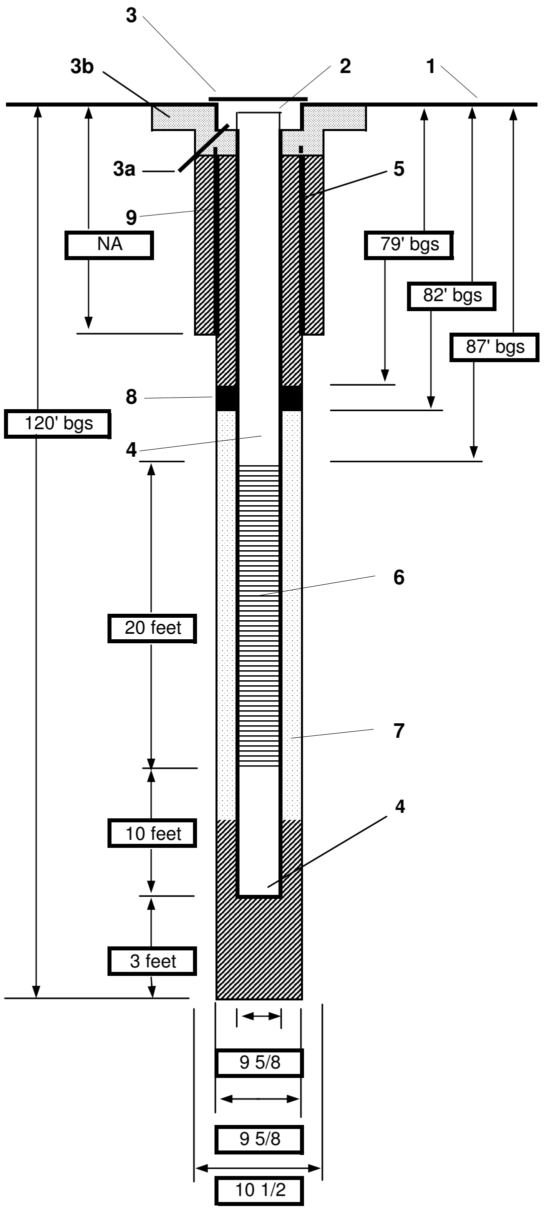
Dames & Moore, Inc.
Drafted by: SDB
Checked by: WJB
January 1994

CH2MHILL

PROJECT NUMBER **184740.RI.SI**	**WELL NUMBER** FINAL **HSM-I2-5** SHEET 1 OF 1

Fruit Avenue WELL COMPLETION DIAGRAM

PROJECT : Fruit Avenue Plume Superfund Site LOCATION : Plaza del Sol parking lot, 600 2nd St. NW
DRILLING CONTRACTOR : Water Development Corporation
DRILLING METHOD AND EQUIPMENT USED : 15K Sonic - Greg Gallio
WATER LEVELS : START : END : LOGGER : D.Boss-Walker



1- Ground elevation at well	Approximately 4956 ft msl
2- Top of casing elevation	Approximately 4955.5 ft msl
3- Wellhead protection cover type	12 inch flush mount, locking caps
a) drain tube?	No
b) concrete pad dimensions	3' x 3' saw-cut flush with existing pavement
4- Dia./type of well casing	4 inch Schedule 40 PVC well casing
Sump	10 feet of 4-in Schd 40 PVC
5- Dia./type surface casing	None
6- Type/slot/size of screen	87 Depth to top of screen [feet bgs] 20 feet of 4-inch diameter 0.010-inch cut slot sched. 40 PVC well screen
7- Type screen filter	 5 feet above screen.
8- Transition	5 feet of 16-30 sand 5 feet of Bentonite chips 1/2 bag
9- Grout	
a) Grout mix used	Bentonite chips
b) Method of placement	Tremmie
c) Vol.of surface casing grout	TBD
d) Vol. of well casing grout	TBD
Surface Seal	30 feet neat cement grout
Development method	Air lift, swabbing, bailing, over-pumping
Development time	TBD
Estimated purge volume	TBD
Geophysics	Yes
Disinfection	No
Pumping Test	No
Comments	

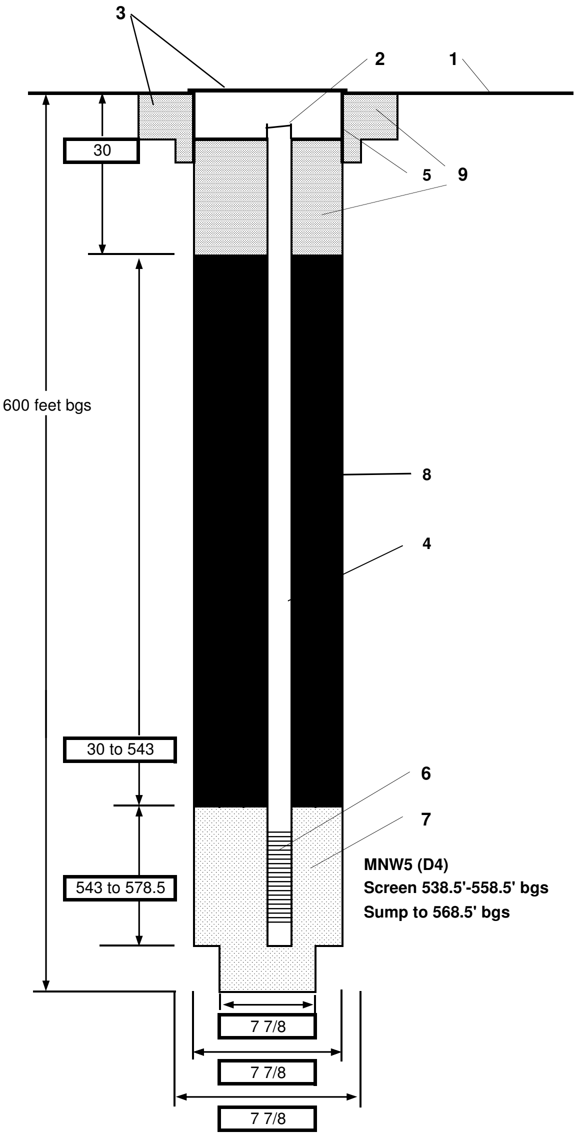
Illustration not to scale.

CH2MHILL

PROJECT NUMBER	WELL NUMBER	
184740	MNW5	SHEET 1 OF 1

Fruit Avenue Plume
FINAL WELL COMPLETION DIAGRAM

PROJECT : Fruit Avenue Plume Superfund Site
LOCATION : Roma & High St.
ELEVATION:
DRILLING CONTRACTOR : WDC
DRILLING METHOD AND EQUIPMENT USED: Mud rotary, GEFCO 30 K
WATER LEVELS : approx. 30 feet bgs
START : 3/15/2005
END : 3/18/2025
LOGGER : B Thomas

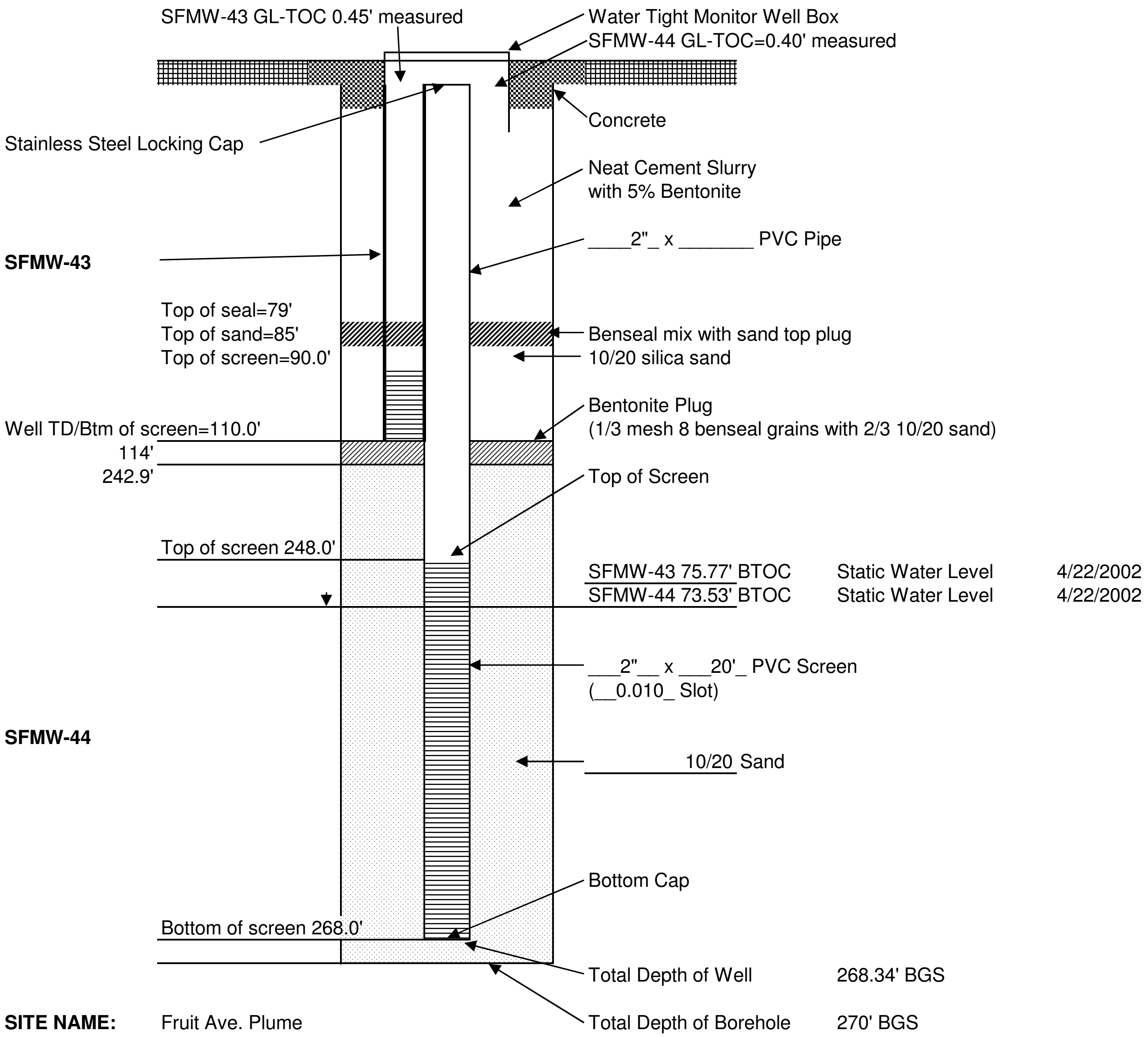


MNW5 (D4)
Screen 538.5'-558.5' bgs
Sump to 568.5' bgs

1- Ground elevation at well	Survey	4993.03 ft msl
2- Top of casing elevation	Survey	4992.51 ft msl
3- Wellhead protection cover type	12 inch flush mount, locking caps	
concrete pad dimensions	3' x 3' flush with existing ground	
4- Dia./type of well casing	2 inch Schd 40 PVC	
Sump	10 feet of 2 inch Schd 40 PVC	
5- Dia./type surface casing	None	
6- Type/slot/size of screen	0.010 inch cut slot well screen	
	539 Depth to top of D4 screen [feet bgs]	
	20 feet of 2 inch Schd 40 PVC well screen	
7- Type screen filter	Oglebay-Norton 10-20 Colorado Silica	
8- Grout		
a) Grout mix used	Bentonite chips with 10-20 sand	
b) Method of placement	Tremmie pipe	
c) Vol. of well casing grout		
9- Surface Seal	30 feet neat cement grout	
Development method	Air lift, swabbing, bailing, over-pumping	
Geophysics	Yes	
Disinfection	No	
Pumping Test	No	
Comments		

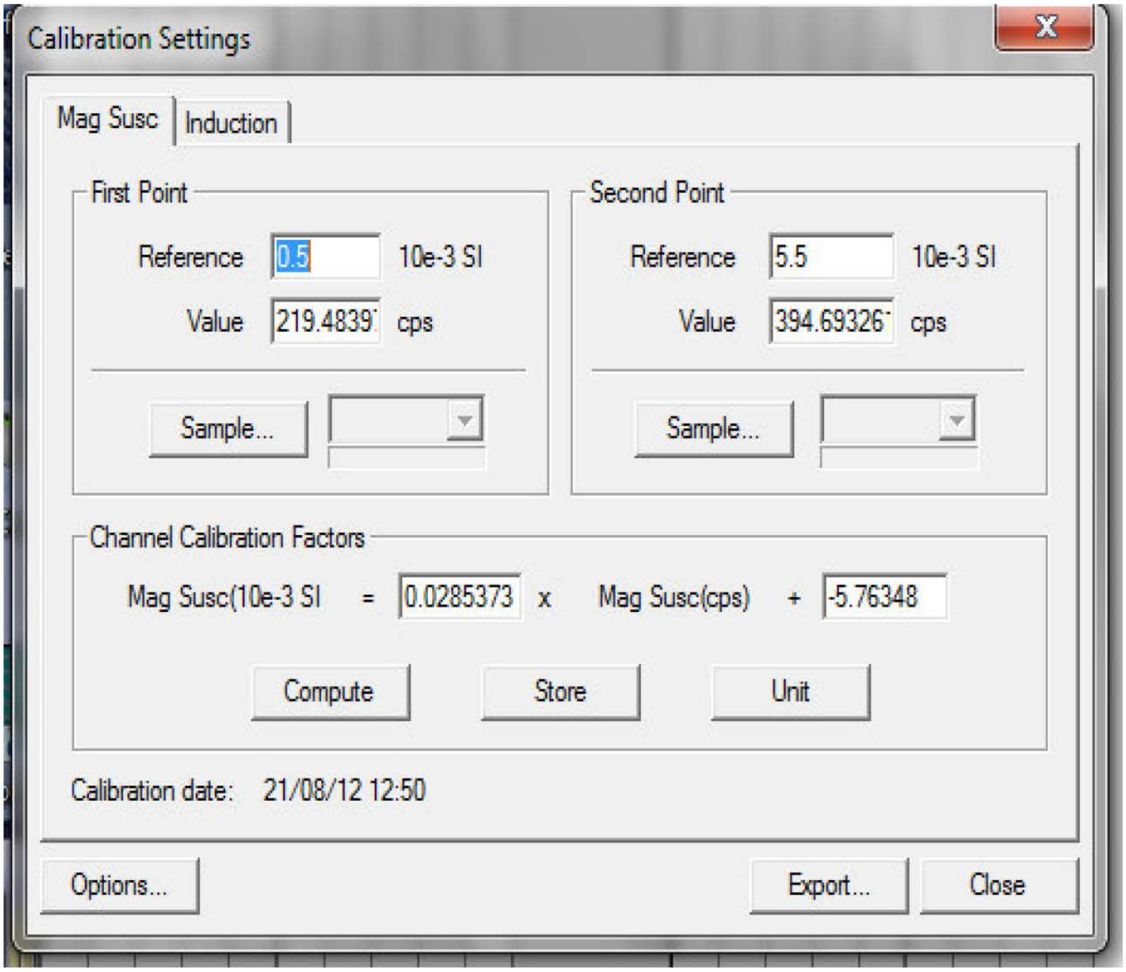
Illustration not to scale.

SFMW-43/44
TYPICAL SUBGRADE COMPLETION DIAGRAM



SITE NAME:	Fruit Ave. Plume
WELL ID:	SFMW-43/44
LOCATION:	NE corner of Roma and Edith, Albuquerque, NM Installed 3/21/2002

NAD83/NGVD29
Northing: 1487529.265
Easting: 1523444.122
GL elev: 4968.00
SFMW-43 TOC elev.: 4967.52
SFMW-44 TOC elev.: 4967.57



Calibration Settings

Mag Susc | Induction

First Point

Reference 0.5 10e-3 SI

Value 219.4839 cps

Second Point

Reference 5.5 10e-3 SI

Value 394.69326 cps

Channel Calibration Factors

Mag Susc(10e-3 SI = 0.0285373 x Mag Susc(cps) + -5.76348

Calibration date: 21/08/12 12:50

JET WEST
GEOPHYSICAL SERVICES, LLC.

COMPANY	CH2MHILL - Albuquerque
WELL ID	DM-13(D2)
FIELD	Fruit Avenue Plume Superfund Site
COUNTY	Bernalillo
STATE	NM

Northing:
Easting:

TYPE OF LOG: Magnentic Suseptability
Induction Conductivity
Derived Induction Resistivity

OTHER SERVICES
None

LOCATION Albuquerque, NM

SEC TWP RGE

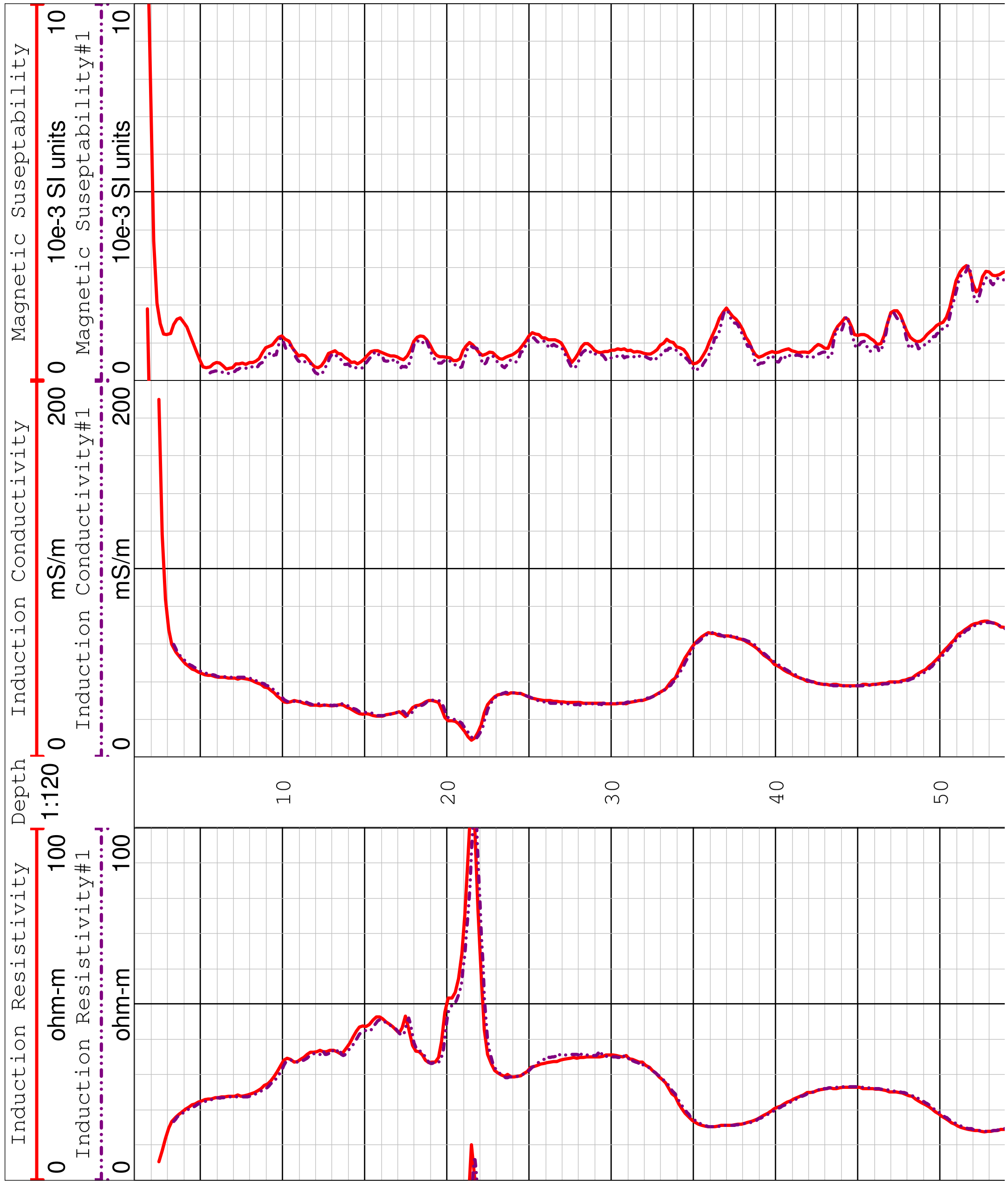
API No.

PERMANENT DATUM	Ground Level	ELEVATION		K.B.
LOG MEAS. FROM	Ground Level	ABOVE PERM. DATUM		T.O.C
DRILLING MEAS. FROM	Ground Level			G.L.

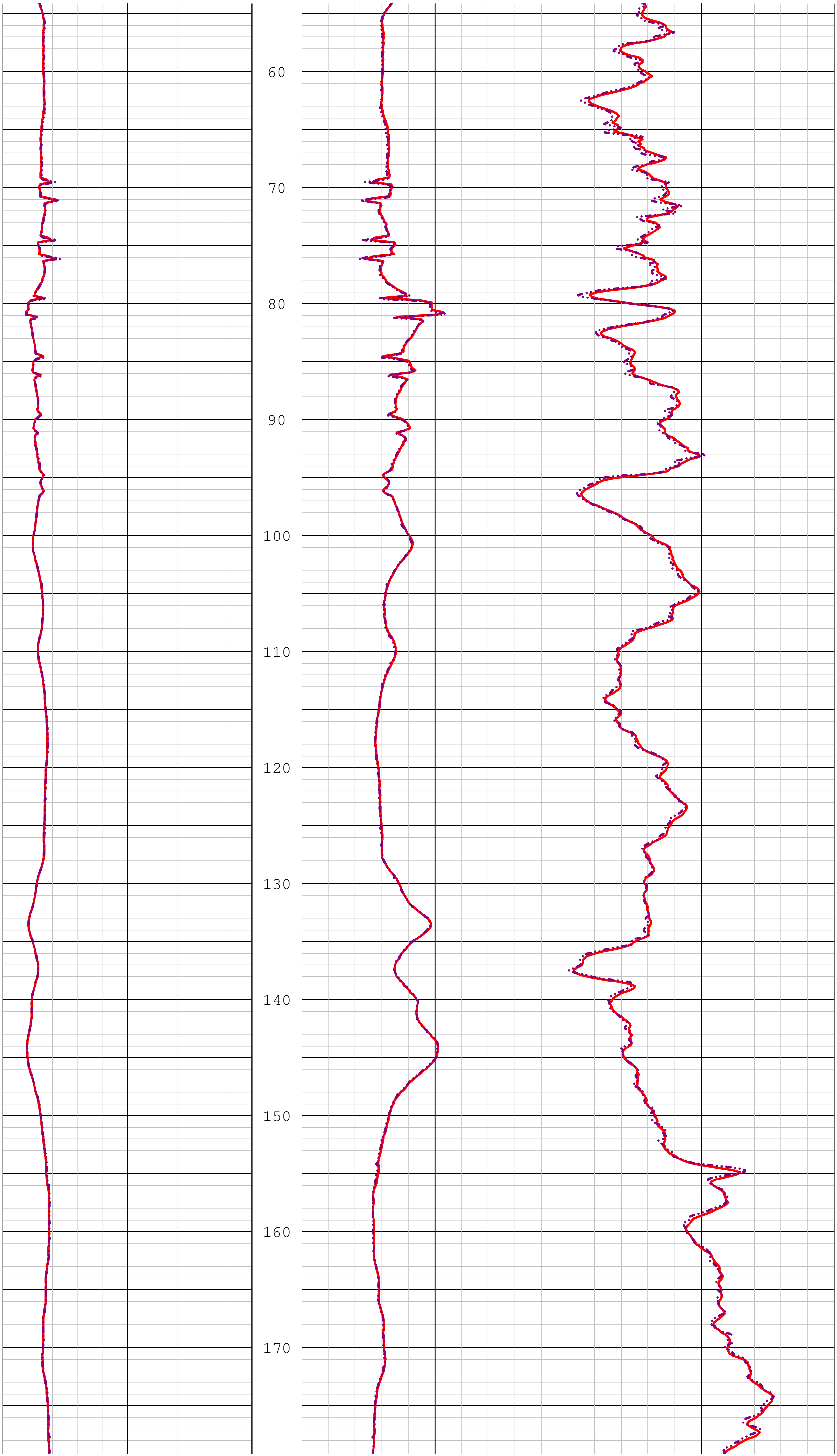
DATE	8-22-12	TYPE FLUID IN HOLE	Ground Water
RUN No.	one	SALINITY	
TYPE LOG	MSI - 2HMA-1000	DENSITY	
DEPTH-DRILLER		LEVEL	
DEPTH-LOGGER	108 ft.	MAX. REG. TEMP	
BTM LOGGED INTERVAL	107.6 ft.	DIGITIZE INTERVAL	
TOP LOGGED INTERVAL			
OPERATING RIG TIME			
RECORDED BY	T.Staatz		
WITNESSED BY	B. Lefevre - CH2MHILL		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE		FROM	TO
1				3" I.D.	PVC	Surface	
2							
3							

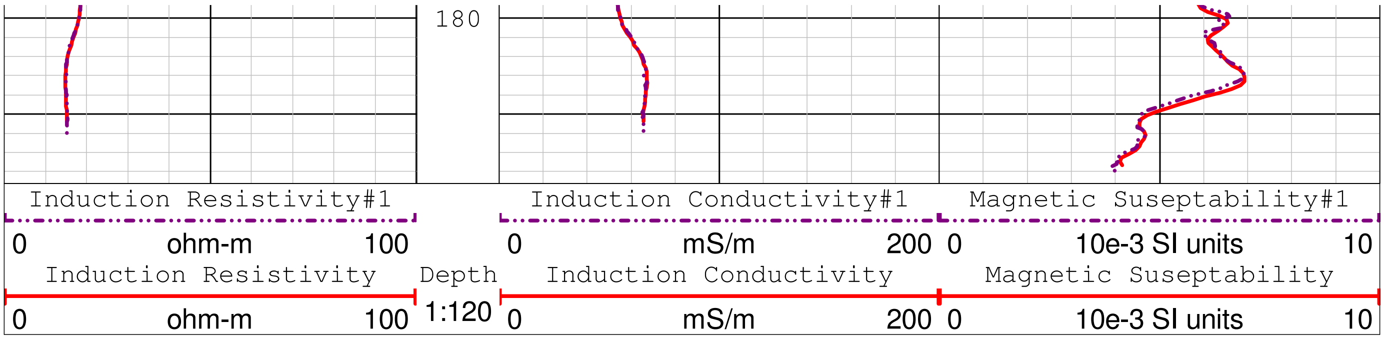
REMARKS:



009923



009924


180
Induction Resistivity#1
0 ohm-m 100
Induction Resistivity
0 ohm-m 100
Depth
1:120
Induction Conductivity#1
0 mS/m 200
Induction Conductivity
0 mS/m 200
Magnetic Suseptability#1
0 10e-3 SI units 10
Magnetic Suseptability
0 10e-3 SI units 10

JET WEST
GEOPHYSICAL SERVICES, LLC.

Northing:	COMPANY	CH2MHILL - Albuquerque	
Easting:	WELL ID	HSM-I2-5	
	FIELD	Fruit Avenue Plume Superfund Site	
	COUNTY	Bernalillo	STATE NM

TYPE OF LOG: Magnentic Suseptability
Induction Conductivity
Derived Induction Resistivity

OTHER SERVICES
None

LOCATION Albuquerque, NM

SEC TWP RGE

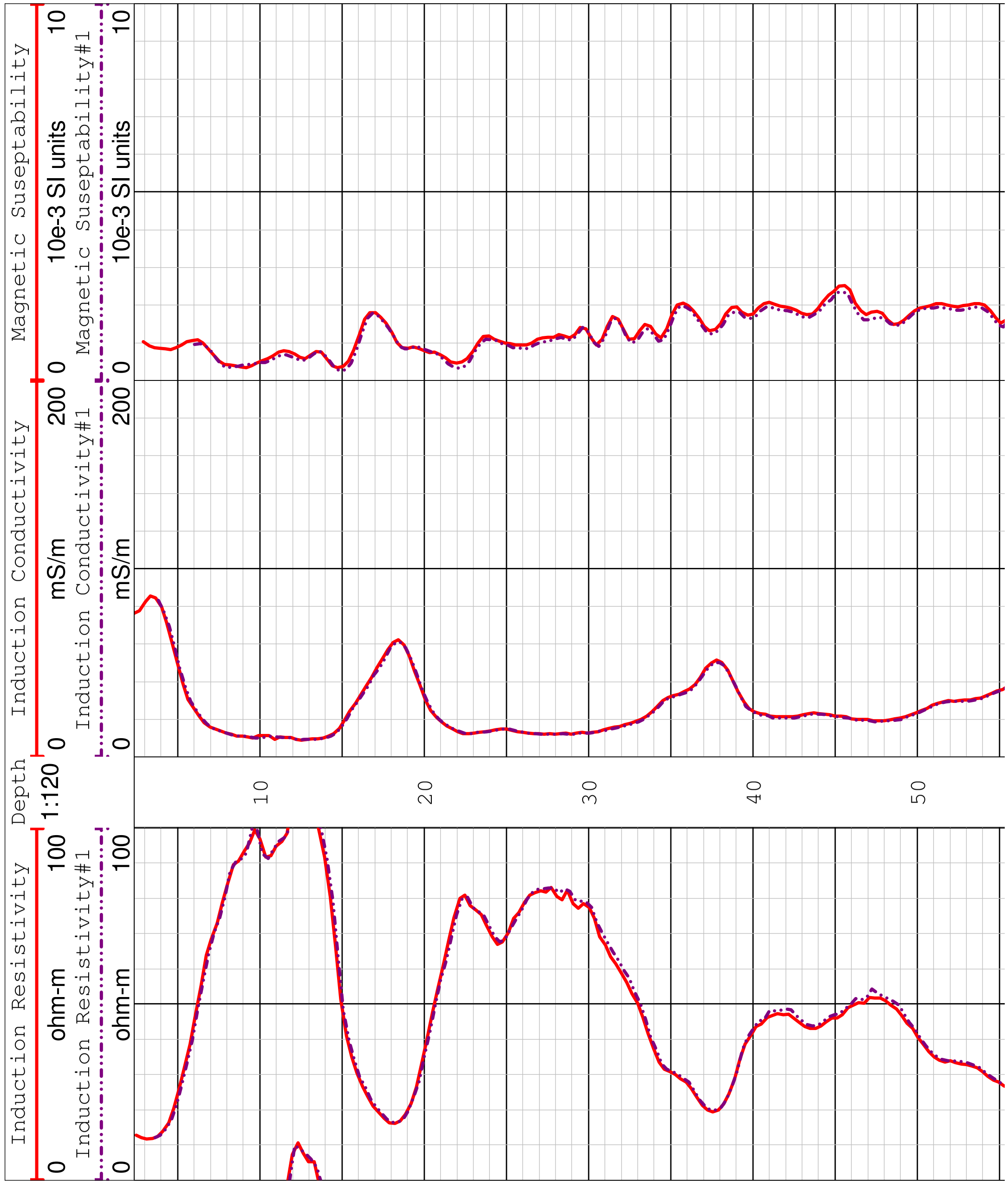
API No.

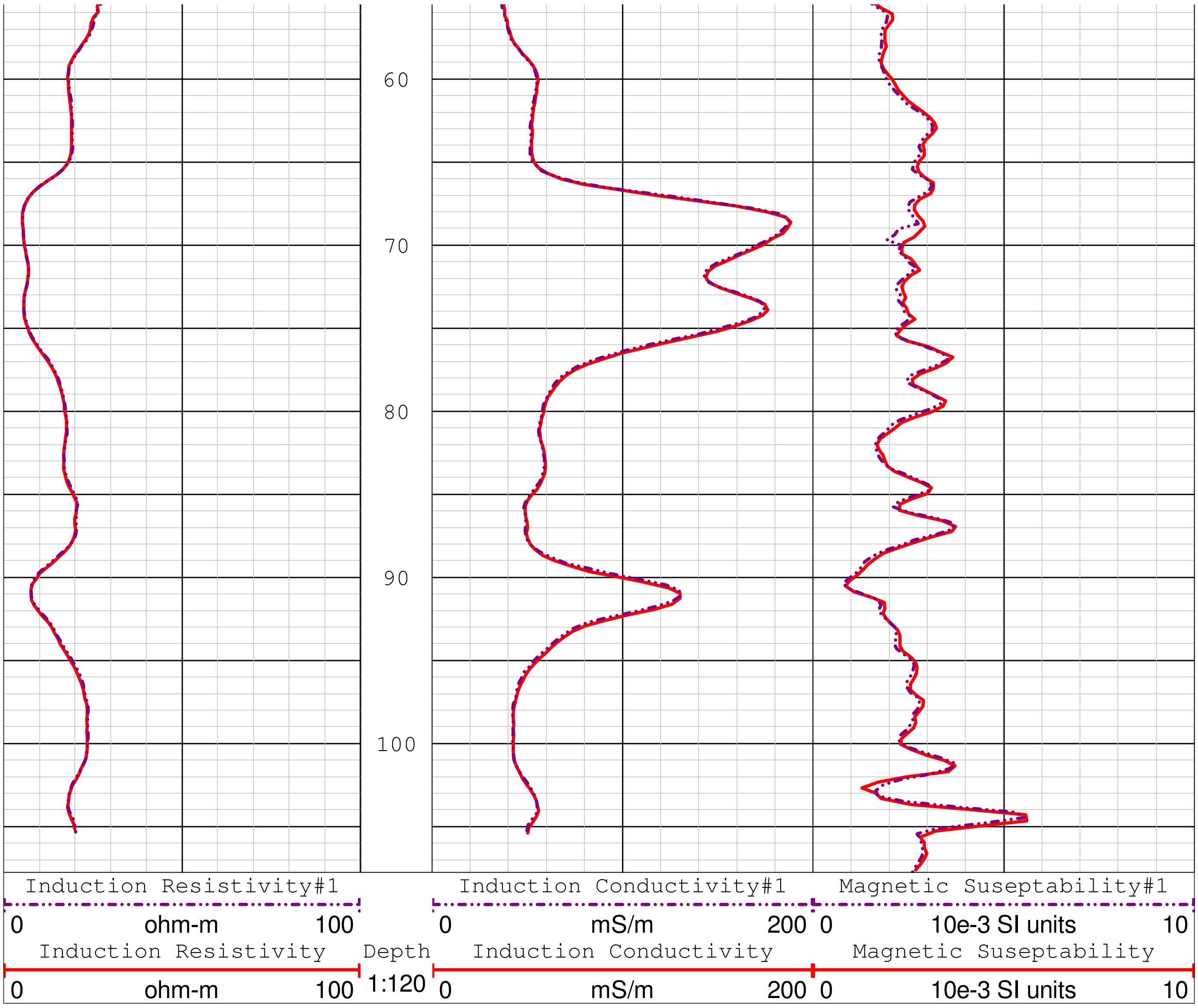
PERMANENT DATUM	Ground Level	ELEVATION	K.B.
LOG MEAS. FROM	Ground Level	ABOVE PERM. DATUM	T.O.C
DRILLING MEAS. FROM	Ground Level		G.L.

DATE	8-22-12	TYPE FLUID IN HOLE	Ground Water
RUN No.	one	SALINITY	
TYPE LOG	MSI - 2HMA-1000	DENSITY	
DEPTH-DRILLER		LEVEL	
DEPTH-LOGGER	108 ft.	MAX. REG. TEMP	
BTM LOGGED INTERVAL	107.6 ft.	DIGITIZE INTERVAL	
TOP LOGGED INTERVAL			
OPERATING RIG TIME			
RECORDED BY	T.Staatz		
WITNESSED BY	B. Lefevre - CH2MHILL		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE		FROM	TO
1				3" I.D.	PVC	Surface	
2							
3							

REMARKS:




60
70
80
90
100
Induction Resistivity#1
0 ohm-m 100
Induction Resistivity
0 ohm-m 100
Depth
1:120
Induction Conductivity#1
0 mS/m 200
Induction Conductivity
0 mS/m 200
Magnetic Suseptability#1
0 10e-3 SI units 10
Magnetic Suseptability
0 10e-3 SI units 10

JET WEST
GEOPHYSICAL SERVICES, LLC.

Northing:
Easting:

COMPANY CH2MHILL - Albuquerque
WELL ID MNW-5(D4)
FIELD Fruit Avenue Plume Superfund Site
COUNTY Bernalillo STATE NM

TYPE OF LOG: Magnentic Suseptability
Induction Conductivity
Derived Induction Resistivity

OTHER SERVICES
None

LOCATION Albuquerque, NM

SEC TWP RGE

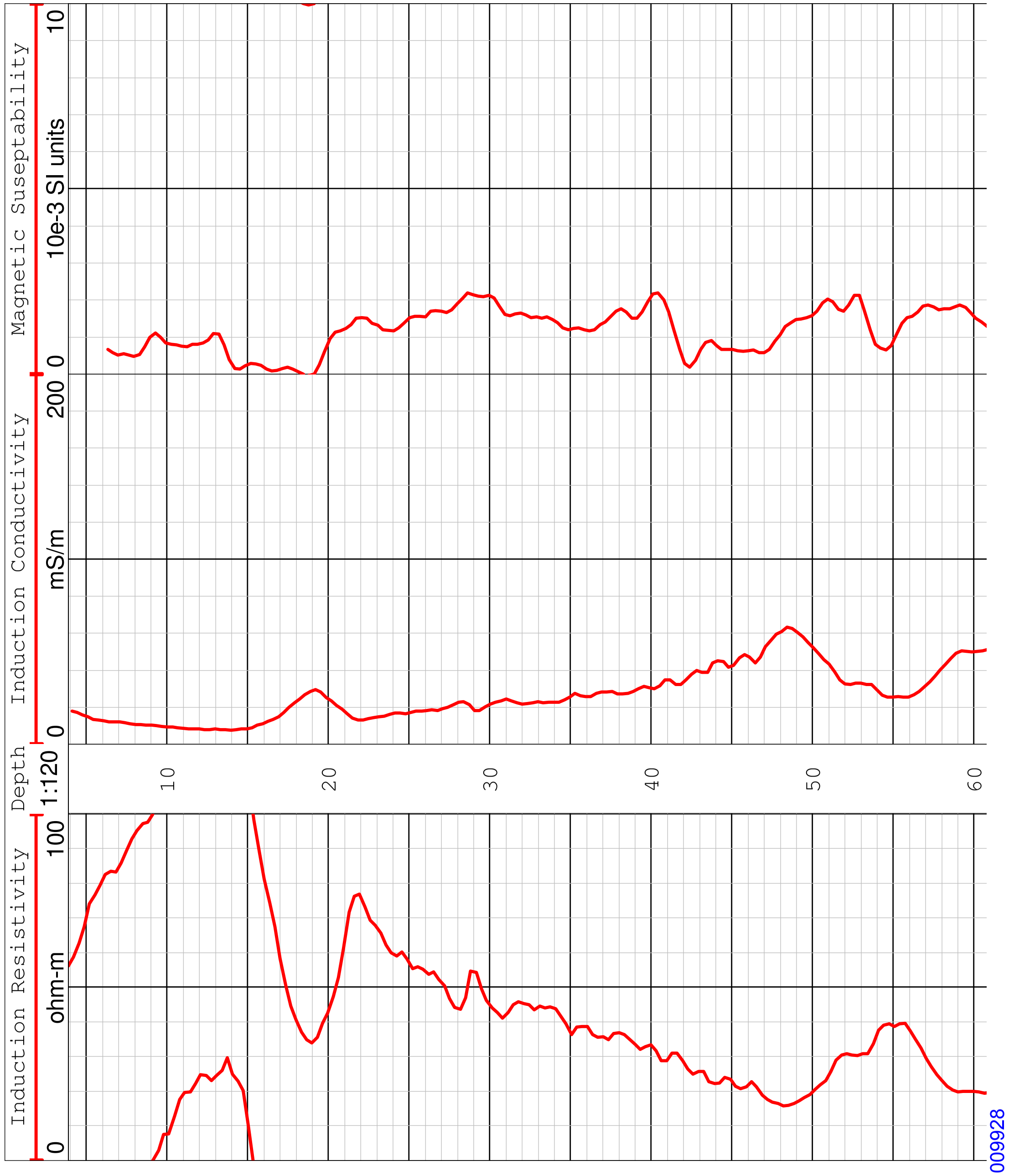
API No.

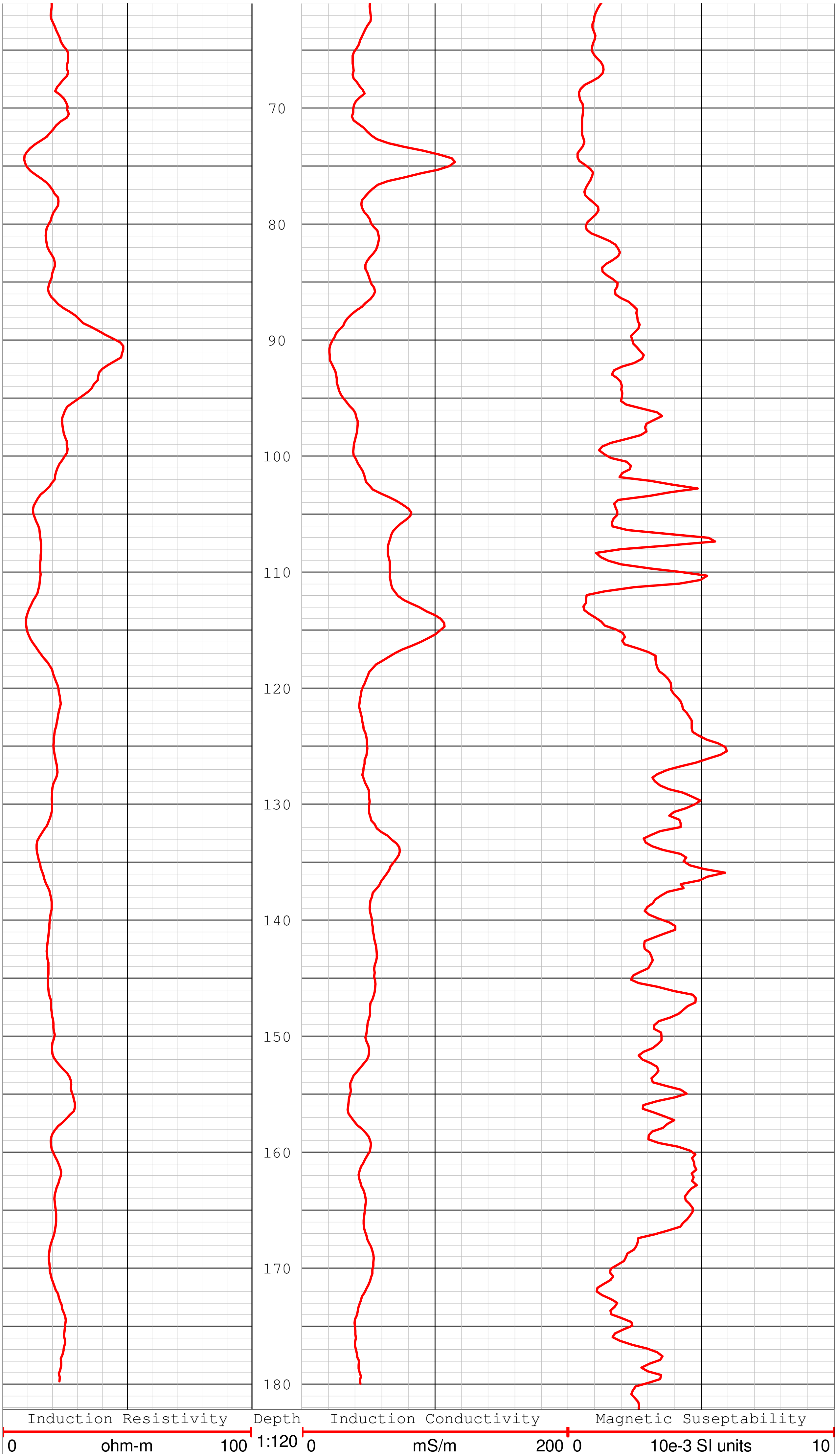
PERMANENT DATUM	Ground Level	ELEVATION	K.B.
LOG MEAS. FROM	Ground Level	ABOVE PERM. DATUM	T.O.C
DRILLING MEAS. FROM	Ground Level		G.L.

DATE	8-22-12	TYPE FLUID IN HOLE	Ground Water
RUN No.	one	SALINITY	
TYPE LOG	MSI - 2HMA-1000	DENSITY	
DEPTH-DRILLER		LEVEL	
DEPTH-LOGGER	183 ft.	MAX. REG. TEMP	
BTM LOGGED INTERVAL	182.2 ft.	DIGITIZE INTERVAL	
TOP LOGGED INTERVAL			
OPERATING RIG TIME			
RECORDED BY	T.Staatz		
WITNESSED BY	B. Lefevre - CH2MHILL		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE		FROM	TO
1				2" I.D.	PVC Schedule 80	Surface	
2							
3							

REMARKS: Unable to get to bottom of well, (578 feet)




70
80
90
100
110
120
130
140
150
160
170
180
Induction Resistivity
Depth
Induction Conductivity
Magnetic Suseptability
0
ohm-m
100
1:120
0
mS/m
200
0
10e-3 SI units
10

009929

JET WEST
GEOPHYSICAL SERVICES, LLC.

Northing:	COMPANY	CH2MHILL - Albuquerque	
Easting:	WELL ID	SFMW-44(D2)	
	FIELD	Fruit Avenue Plume Superfund Site	
	COUNTY	Bernalillo	STATE NM

TYPE OF LOG: Magnentic Suseptability
Induction Conductivity
Derived Induction Resistivity

OTHER SERVICES
None

LOCATION Albuquerque, NM

SEC TWP RGE

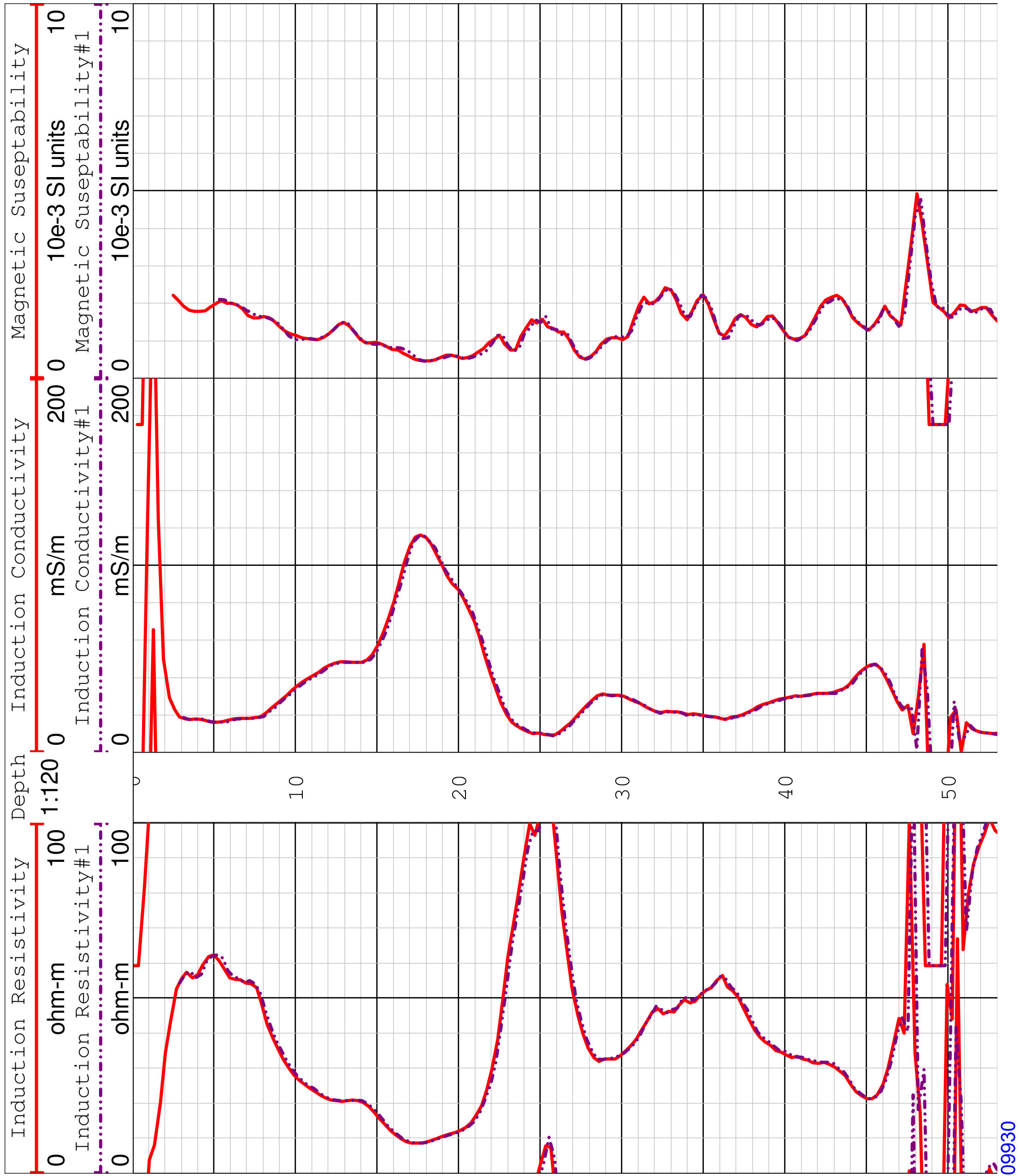
API No.

PERMANENT DATUM	Ground Level	ELEVATION	K.B.
LOG MEAS. FROM	Ground Level	ABOVE PERM. DATUM	T.O.C
DRILLING MEAS. FROM	Ground Level		G.L.

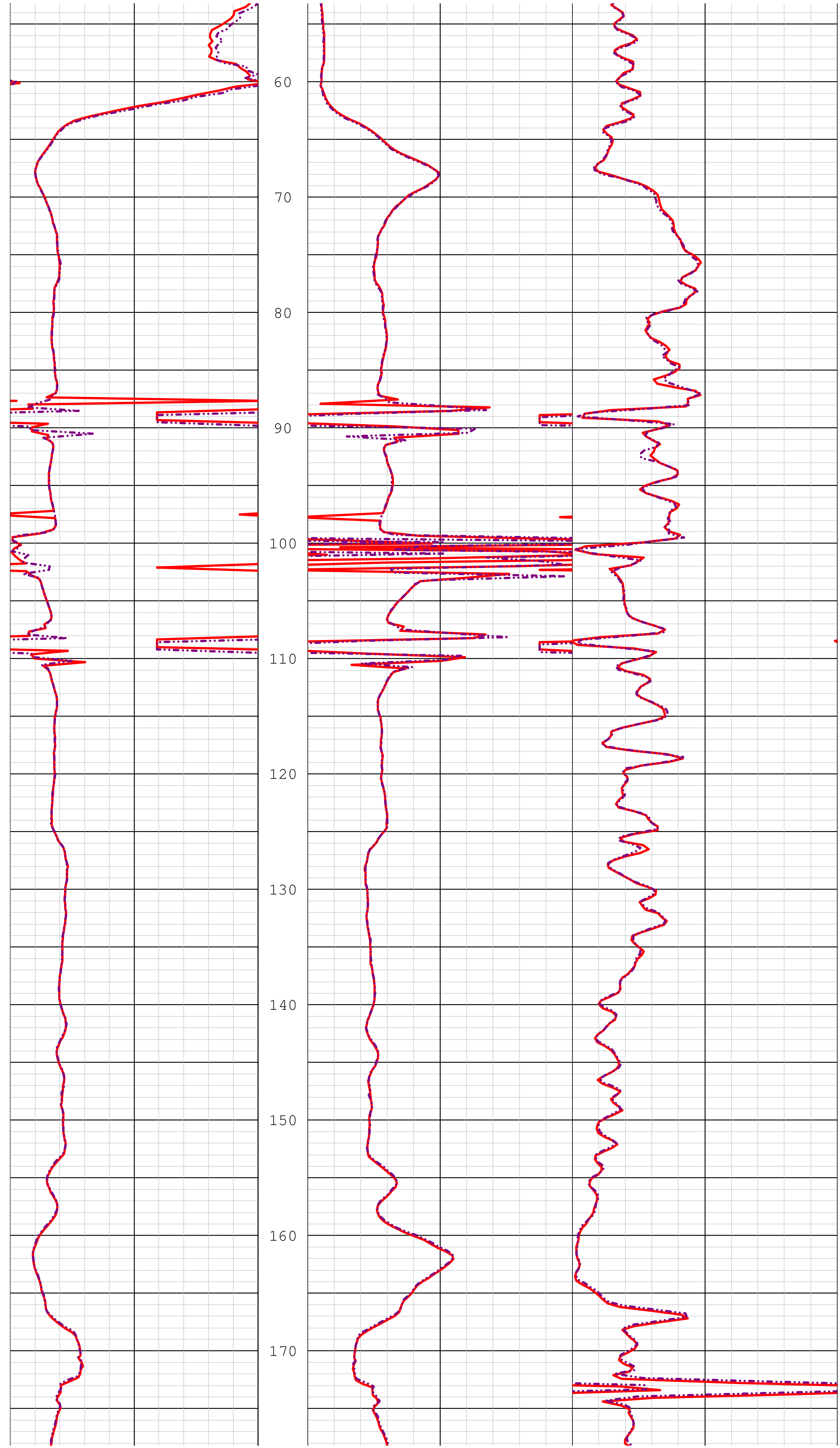
DATE	8-22-12	TYPE FLUID IN HOLE	Ground Water
RUN No.	one	SALINITY	
TYPE LOG	MSI - 2HMA-1000	DENSITY	
DEPTH-DRILLER		LEVEL	
DEPTH-LOGGER	266 ft.	MAX. REG. TEMP	
BTM LOGGED INTERVAL	265.6 ft.	DIGITIZE INTERVAL	
TOP LOGGED INTERVAL			
OPERATING RIG TIME			
RECORDED BY	T.Staatz		
WITNESSED BY	B. Lefevre - CH2MHILL		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE		FROM	TO
1				2" I.D.	PVC Schedule 40	Surface	
2							
3							

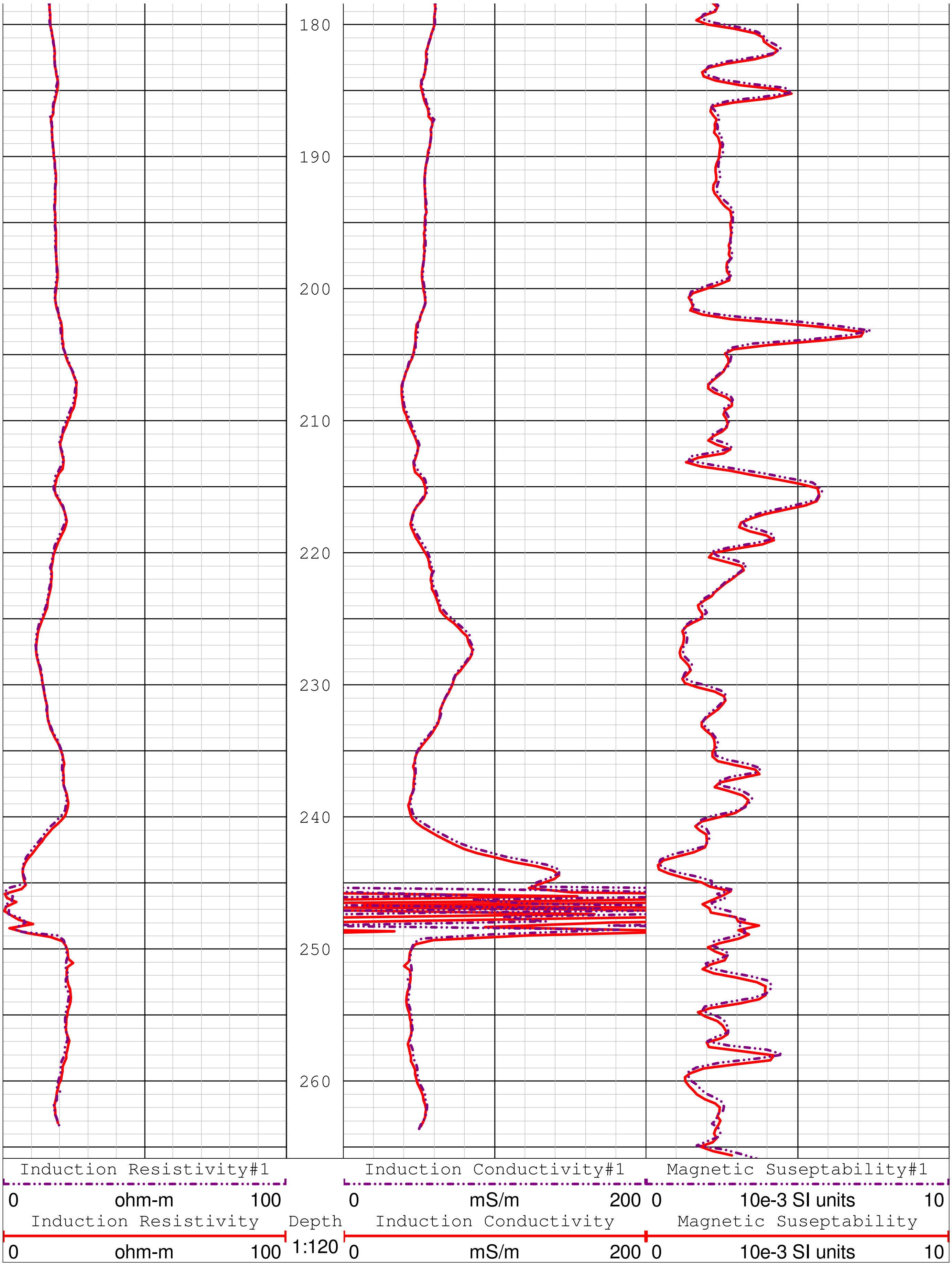
REMARKS:



009930



60
70
80
90
100
110
120
130
140
150
160
170


180
190
200
210
220
230
240
250
260
Induction Resistivity#1
0 ohm-m 100
Induction Resistivity
0 ohm-m 100
Depth
1:120
Induction Conductivity#1
0 mS/m 200
Induction Conductivity
0 mS/m 200
Magnetic Suseptability#1
0 10e-3 SI units 10
Magnetic Suseptability
0 10e-3 SI units 10

Attachment B
Mineral Equilibrium Modeling

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Abiotic Transformation of Chloroethenes
Mineral Equilibrium Modeling
Fruit Avenue Plume Superfund Site, Albuquerque NM

PREPARED FOR: Bartolomé Cañellas/ EPA Region 6 Remedial Project Manager

PREPARED BY: CH2M HILL

DATE: October 2012

PROJECT: EPA Region 6 Remedial Action Contract W-EP-06-021
Task Order No. 0003-RALR-06DD
CH2M HILL Project No. 345406.PJ.14

DCN: 0003-02091

Objective

The objective of this evaluation was to determine whether the general groundwater chemistry of the Fruit Avenue Plume is consistent with the presence of any iron sulfide minerals or amorphous phases in the aquifer matrix that have the potential to promote the natural transformation of TCE and cis-1,2-DCE.

Geochemical Basis and Modeling Approach

Saturation of a groundwater with a particular mineral or amorphous phase (hereafter "phase") strongly implies that the phase is present in the aquifer matrix. Conversely, under-saturated phases are unlikely to be present in the aquifer matrix or they are present but attainment of equilibrium with the groundwater is precluded by kinetic factors. Although oversaturated conditions for phases can temporarily develop in groundwaters, strongly oversaturated conditions for a given phase typically indicates that slow kinetics or other factors preclude the oversaturated phase from actually forming and precipitating from the groundwater.

The equilibrium-based geochemical modeling program PHREEQC (Parkhurst and Appelo, 1999) was used to calculate the ion speciation of the groundwater samples and to identify the saturation state of common aquifer phases including ferrous iron and sulfide phases. PHREEQC presents the calculated saturation state for groundwaters using a saturation index (SI). A calculated SI of zero for a phase indicates that it is in equilibrium with the water while a positive or negative value for the SI indicates oversaturated or under-saturated conditions, respectively. However, given the potential uncertainty inherent to the collection and analysis of groundwaters, minerals with a calculated SI of Zero +/- 0.1 are considered to be in equilibrium with the solution. The chemical results for the samples used as input data for PHREEQC modeling are presented in **Table 1**. The input and output files for PHREEQC are presented in **Attachment 1**.

TABLE 1
Analytical Data Used for Modeling
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Analyte	MNW-5-D2-082012	MNW-14-I2-082012	HSM-I2-5-082012
Boron	0.08	0.137	0.112
Aluminum	U	U	U
Iron	U	U	U
Magnesium	16.3	25.4	34
Manganese	0.0053	0.019	U
Potassium	9.84	13.1	15.3

TABLE 1
Analytical Data Used for Modeling
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Analyte	MNW-5-D2-082012	MNW-14-I2-082012	HSM-I2-5-082012
Sodium	68.2	58.6	66.3
Calcium	121	125	132
Chloride	42	34	35
Sulfate	167	188	201
Ammonia as N	<0.05	<0.05	<0.05
Nitrite as N	<0.02	<0.02	<0.02
Nitrate as N	<0.02	<0.02	<0.02
Nitrate + Nitrite as N	<0.04	<0.04	<0.04
Alkalinity, Total as CaCO3	243	264	270
Dissolved Organic Carbon, NPOC	2	2	2
YSI DO	0.34	0.11	0.41
Field DO	0.8	0.6	0.5
Field Sulfide	0	0	0
Ferrous Iron	0.1	0.05	0

Samples collected September 2012.
Concentration Units are mg/L

Results

Due to the extremely low concentrations of sulfide and ferrous iron and the presence of detectable concentrations of DO in each of the three samples, none of the samples were in equilibrium with ferrous sulfide phases such as mackinawite, amorphous FeS or pyrite. However, given that the modeled samples were obtained from monitoring wells with 20 foot screened intervals, it is possible that the three samples represented a mixture of waters collected from strongly reducing anoxic aquifer zones containing ferrous sulfide phases and from less reducing zones that contain low levels of oxygen and no ferrous sulfide phases. Mixing of these different waters would, depending on the relative concentrations of oxygen to ferrous iron and sulfide in the two water types, result in the oxidization of some or all of ferrous iron and sulfide in the combined water, potentially masking the evidence for iron sulfide phases in the reducing zones of the aquifer. This possible scenario is consistent with historical monitoring data from the site (e.g., from 2005) indicating that some samples simultaneously contained low concentrations of oxygen, sulfide, and ferrous iron, as well as detectable levels of methane (e.g., 5-10 µg/L). This masking effect would be most effective under conditions where the dissolved ferrous iron and sulfide concentrations in the reducing zones were relatively low under in situ conditions. In order determine whether the concentrations of ferrous iron or sulfide in the proposed reducing zones could be easily masked (diluted and oxidized) by mixing with very similar but more oxidizing water during sampling, PHREEQC was used to calculate the concentrations ferrous iron and sulfide that would result if the samples from Table 1 (HSM-12-5, HNW-14-12, and MNW-5-D2) were equilibrated with Mackinawite, amorphous FeS and pyrite, respectively.

Key modeling results are presented in **Table 2**. As previously stated, all of the modeling results are presented in **Attachment 1**.

TABLE 2
Modeling Results
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Location HSM-12-5	**Input Values**	**After Equilibration with**		
		Mackinawite	**Amorphous FeS**	**Pyrite**
Ferrous Iron (µg/L)	0.00001	0.33	0.75	0.00003
Sulfate (mg/L)	201	201	201	
Sulfide (mg/L)	0.001	0.166	0.4	0.00023
pH	6.71	6.71	6.71	
pe	-2*	-2.92	-2.97	
Location HNW-14-12	**Input Values**	**Mackinawite**	**Amorphous FeS**	**Pyrite**
Ferrous Iron (mg/L)	0.01	0.2	0.41	0.01278
Sulfate (mg/L)	188	188	188	
Sulfide (mg/L)	0	0.067	0.18	0.0000045
pH	7.1	7.1	7.1	
pe	-2*	-3.3	-3.36	
Location MNW-5 D2	**Input Values**	**Mackinawite**	**Amorphous FeS**	**Pyrite**
Ferrous Iron (mg/L)	0.01	0.37	0.87	0.00012
Sulfate (mg/L)	167	167	167	
Sulfide (mg/L)	0.005	0.2	0.49	0.00012
pH	6.6	6.6	6.6	
pe	-2*	-2.8	-2.8	

Note:
Input value for pe set to -2 for all samples.
Values for DO, ferrous iron, and sulfide prior to pyrite equilibration were set to 0.01 µg/L.

The results presented in **Table 2** indicate that the concentrations of ferrous iron and sulfide necessary for each of the three samples to reach saturation with amorphous FeS are less than 1.0 mg/L and 0.5 mg/L, respectively. The concentrations of ferrous iron and sulfide that must be present for these samples to reach equilibrium with Mackinawite are less than half the values for amorphous FeS. The concentrations of ferrous iron and sulfide that must be present for these samples to reach equilibrium with pyrite are below detection levels of modern methods.

Conclusions

Quite low concentrations of ferrous iron and sulfide (< 1.0 and 0.5 mg/L respectively) would be present in local groundwater that had equilibrated with Mackinawite, amorphous FeS, or pyrite present within highly reducing zones of the Fruit Avenue Plume Aquifer. Mixing of this water with even slightly oxygenated water (e.g., 1-2 mg/L DO) during sampling would likely oxidize the sulfide to sulfate and the ferrous iron to ferric iron, thereby masking the evidence for FeS phases in the aquifer that can contribute to the MNA of TCE.

Works Cited

Parkhurst, D.L. and Appelo, C.A.J., 1999, User's guide to PHREEQC (version 2)--A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Water-Resources Investigations Report 99-4259, 312 p.

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Attachment 1 - Input and Output Files for PHREEQC

```
TITLE With and Without Equilibration with Amorphous FeS, Initial O2 and Fe 2+
set to 0.01 mg/L, sulfide set to 0.001 mg/L
SOLUTION 1-2 HSM-I2-5-082012
    temp      20.71
    pH        6.71
    pe        -2
    redox     pe
    units     mmol/kgw
    density   1
    Al        50 ug/kgw
    Alkalinity 270 mg/kgw     gfw 50
    Na        66300 ug/kgw
    O(0)      0.01 mg/kgw
    B         112 ug/kgw
    Fe(2)     0.01 ug/kgw
    Mn(2)     2.5 ug/kgw
    N(-3)     0.025 mg/kgw
    N(5)      0.01 mg/kgw
    S(6)      201 mg/kgw
    Mg        34000 ug/kgw
    K         15300 ug/kgw
    Ca        132000 ug/kgw
    Cl        35 mg/kgw     charge
    S(-2)     0.001 mg/kgw
    -water    1 # kg
EQUILIBRIUM_PHASES 1-2 Equilibration with FeS ppt
    FeS(ppt)  0 10
END
SOLUTION 3-4 HNW-14-12
    temp      19
    pH        7.1
    pe        -2
    redox     pe
    units     mg/kgw
    density   1
    Al        0
    Alkalinity 264
    B         80 ug/kgw
    Ca        121
    Cl        34 charge
    Fe(2)     0.01
    Mg        16.3
    Mn        5.3 ug/kgw
    K         9.84
    N(5)      0.02
    N(-3)     0.02
    Na        68.2
    O(0)      0.01
    S(-2)     0
    S(6)      188
    -water    1 # kg
EQUILIBRIUM_PHASES 1-2 Equilibration with FeS ppt
    FeS(ppt)  0 10
END
SOLUTION 5-6 MNW-5 D2
    temp      21.4
    pH        6.6
```

```
    pe        -2
    redox     pe
    units     mg/kgw
    density   1
    Fe(2)     0.01
    Mg        16.3
    Mn(2)     0.005
    N(5)      0
    N(-3)     0
    S(-2)     0.005
    S(6)      167
    Al        0
    Cl        42 charge
    Ca        121
    Alkalinity 243
    K         9.84
    O(0)      0.01
    Na        68.2
    B         0.08
    -water    1 # kg
EQUILIBRIUM_PHASES 3 Equilibration with FeS ppt
    FeS(ppt)  0 10
END
TITLE With and Without Equilibration with Amorphous FeS, O2 set to 0.01 mg/L
```

```
   Input file: C:\_Jons Work Files\MNA by Abiotic Reduction Job\PHREEQC
Simulations\Final MNA Simulations _ Fe set to 0.01_FeS ppt.pqi
  Output file: C:\_Jons Work Files\MNA by Abiotic Reduction Job\PHREEQC
Simulations\Final MNA Simulations _ Fe set to 0.01_FeS ppt.pqo
Database file: C:\Program Files\USGS\Phreeqc Interactive
2.18.5570\database\phreeqc.dat

------------------
Reading data base.
------------------

      SOLUTION_MASTER_SPECIES
      SOLUTION_SPECIES
      PHASES
      EXCHANGE_MASTER_SPECIES
      EXCHANGE_SPECIES
      SURFACE_MASTER_SPECIES
      SURFACE_SPECIES
      RATES
      END
------------------------------------
Reading input data for simulation 1.
------------------------------------

      DATABASE C:\Program Files\USGS\Phreeqc Interactive
2.18.5570\database\phreeqc.dat
      TITLE With and Without Equilibration with Amorphous FeS, O2 and Fe 2+
set to 0.01 mg/L
      SOLUTION 1-2 HSM-I2-5-082012
          temp      20.71
          pH        6.71
          pe        -2
          redox     pe
          units
          density   1
          Al        50 ug/kgw
          Alkalinity 270 mg/kgw     gfw 50
          Na        66300 ug/kgw
          O(0)      0.01 mg/kgw
          B         112 ug/kgw
          Fe(2)     0.01 ug/kgw
          Mn(2)     2.5 ug/kgw
          N(-3)     0.025 mg/kgw
          N(5)      0.01 mg/kgw
          S(6)      201 mg/kgw
          Mg        34000 ug/kgw
          K         15300 ug/kgw
          Ca        132000 ug/kgw
          Cl        35 mg/kgw     charge
          S(-2)     0.001 mg/kgw
          water    1 # kg
      EQUILIBRIUM_PHASES 1-2 Equilibration with FeS ppt
          FeS(ppt)  0 10
      END
-----
TITLE
-----
```

```
 With and Without Equilibration with Amorphous FeS, O2 and Fe 2+ set to 0.01
mg/L

-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 1.     HSM-I2-5-082012

-----------------------------Solution composition----------------------------
--

      Elements           Molality       Moles

      Al               1.853e-006  1.853e-006
      Alkalinity       5.400e-003  5.400e-003
      B                1.036e-005  1.036e-005
      Ca               3.293e-003  3.293e-003
      Cl               3.081e-003  3.081e-003  Charge balance
      Fe(2)            1.791e-010  1.791e-010
      K                3.913e-004  3.913e-004
      Mg               1.398e-003  1.398e-003
      Mn(2)            4.551e-008  4.551e-008
      N(-3)            1.785e-006  1.785e-006
      N(5)             7.139e-007  7.139e-007
      Na               2.884e-003  2.884e-003
      O(0)             6.250e-007  6.250e-007
      S(-2)            3.119e-008  3.119e-008
      S(6)             2.092e-003  2.092e-003

----------------------------Description of solution--------------------------
--

                                       pH  =   6.710
                                       pe  =  -2.000
       Specific Conductance (uS/cm, 20 oC) = 1071
                          Density (g/cm3)  =   0.99882
                        Activity of water  =   1.000
                           Ionic strength  =  1.721e-002
                       Mass of water (kg)  =  1.000e+000
                    Total carbon (mol/kg)  =  7.525e-003
                       Total CO2 (mol/kg)  =  7.525e-003
                      Temperature (deg C)  =  20.710
                  Electrical balance (eq)  = -2.647e-013
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =   9
                                  Total H  = 1.110179e+002
                                  Total O  = 5.553507e+001

---------------------------------Redox couples-------------------------------
--

      Redox couple             pe  Eh (volts)

      N(-3)/N(5)           6.6985      0.3906
      O(-2)/O(0)          13.5448      0.7897
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      S(-2)/S(6)          -2.6393     -0.1539

----------------------------Distribution of species--------------------------
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                                                   Log       Log         Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   H+                    2.177e-007  1.950e-007    -6.662    -6.710    -0.048
   OH-                   4.206e-008  3.683e-008    -7.376    -7.434    -0.058
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
Al              1.853e-006
   Al(OH)4-              1.418e-006  1.246e-006    -5.848    -5.904    -0.056
   Al(OH)2+              2.834e-007  2.491e-007    -6.548    -6.604    -0.056
   Al(OH)3               1.354e-007  1.360e-007    -6.868    -6.867     0.002
   AlOH+2                1.525e-008  9.103e-009    -7.817    -8.041    -0.224
   AlSO4+                7.805e-010  6.861e-010    -9.108    -9.164    -0.056
   Al+3                  6.383e-010  2.369e-010    -9.195    -9.625    -0.430
   Al(SO4)2-             2.344e-011  2.060e-011   -10.630   -10.686    -0.056
   AlHSO4+2              1.918e-017  1.145e-017   -16.717   -16.941    -0.224
B               1.036e-005
   H3BO3                 1.033e-005  1.037e-005    -4.986    -4.984     0.002
   H2BO3-                3.216e-008  2.827e-008    -7.493    -7.549    -0.056
C(4)            7.525e-003
   HCO3-                 5.224e-003  4.615e-003    -2.282    -2.336    -0.054
   CO2                   2.137e-003  2.145e-003    -2.670    -2.668     0.002
   CaHCO3+               1.080e-004  9.544e-005    -3.966    -4.020    -0.054
   MgHCO3+               4.469e-005  3.928e-005    -4.350    -4.406    -0.056
   NaHCO3                6.517e-006  6.543e-006    -5.186    -5.184     0.002
   CaCO3                 2.727e-006  2.737e-006    -5.564    -5.563     0.002
   CO3-2                 1.663e-006  1.013e-006    -5.779    -5.994    -0.215
   MgCO3                 6.671e-007  6.697e-007    -6.176    -6.174     0.002
   NaCO3-                4.344e-008  3.818e-008    -7.362    -7.418    -0.056
   MnHCO3+               9.085e-009  7.985e-009    -8.042    -8.098    -0.056
   MnCO3                 1.556e-009  1.562e-009    -8.808    -8.806     0.002
   FeHCO3+               4.020e-011  3.534e-011   -10.396   -10.452    -0.056
   FeCO3                 1.853e-012  1.861e-012   -11.732   -11.730     0.002
Ca              3.293e-003
   Ca+2                  2.861e-003  1.741e-003    -2.544    -2.759    -0.216
   CaSO4                 3.220e-004  3.233e-004    -3.492    -3.490     0.002
   CaHCO3+               1.080e-004  9.544e-005    -3.966    -4.020    -0.054
   CaCO3                 2.727e-006  2.737e-006    -5.564    -5.563     0.002
   CaOH+                 1.686e-009  1.482e-009    -8.773    -8.829    -0.056
   CaHSO4+               3.991e-010  3.508e-010    -9.399    -9.455    -0.056
Cl              3.081e-003
   Cl-                   3.081e-003  2.700e-003    -2.511    -2.569    -0.057
   MnCl+                 2.429e-010  2.135e-010    -9.615    -9.671    -0.056
   FeCl+                 3.246e-013  2.853e-013   -12.489   -12.545    -0.056
   MnCl2                 2.506e-013  2.516e-013   -12.601   -12.599     0.002
   MnCl3-                2.128e-016  1.871e-016   -15.672   -15.728    -0.056
Fe(2)           1.791e-010
   Fe+2                  1.244e-010  7.657e-011    -9.905   -10.116    -0.211
   FeHCO3+               4.020e-011  3.534e-011   -10.396   -10.452    -0.056
   FeSO4                 1.214e-011  1.218e-011   -10.916   -10.914     0.002
   FeCO3                 1.853e-012  1.861e-012   -11.732   -11.730     0.002
   FeCl+                 3.246e-013  2.853e-013   -12.489   -12.545    -0.056
   FeOH+                 1.020e-013  8.967e-014   -12.991   -13.047    -0.056
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   FeHSO4+              1.755e-017  1.542e-017   -16.756   -16.812    -0.056
   Fe(HS)2              6.953e-018  6.981e-018   -17.158   -17.156     0.002
   Fe(HS)3-             8.747e-024  7.688e-024   -23.058   -23.114    -0.056
H(0)            5.599e-013
   H2                   2.800e-013  2.811e-013   -12.553   -12.551     0.002
K               3.913e-004
   K+                   3.888e-004  3.407e-004    -3.410    -3.468    -0.057
   KSO4-                2.446e-006  2.150e-006    -5.612    -5.668    -0.056
   KOH                  6.033e-012  6.056e-012   -11.220   -11.218     0.002
Mg              1.398e-003
   Mg+2                 1.203e-003  7.401e-004    -2.920    -3.131    -0.211
   MgSO4                1.497e-004  1.503e-004    -3.825    -3.823     0.002
   MgHCO3+              4.469e-005  3.928e-005    -4.350    -4.406    -0.056
   MgCO3                6.671e-007  6.697e-007    -6.176    -6.174     0.002
   MgOH+                1.058e-008  9.299e-009    -7.976    -8.032    -0.056
Mn(2)           4.551e-008
   Mn+2                 3.155e-008  1.941e-008    -7.501    -7.712    -0.211
   MnHCO3+              9.085e-009  7.985e-009    -8.042    -8.098    -0.056
   MnSO4                3.066e-009  3.079e-009    -8.513    -8.512     0.002
   MnCO3                1.556e-009  1.562e-009    -8.808    -8.806     0.002
   MnCl+                2.429e-010  2.135e-010    -9.615    -9.671    -0.056
   MnOH+                2.041e-012  1.794e-012   -11.690   -11.746    -0.056
   MnCl2                2.506e-013  2.516e-013   -12.601   -12.599     0.002
   MnCl3-               2.128e-016  1.871e-016   -15.672   -15.728    -0.056
   Mn(NO3)2             3.023e-020  3.035e-020   -19.520   -19.518     0.002
N(-3)           1.785e-006
   NH4+                 1.760e-006  1.533e-006    -5.755    -5.814    -0.060
   NH4SO4-              2.177e-008  1.914e-008    -7.662    -7.718    -0.056
   NH3                  3.281e-009  3.294e-009    -8.484    -8.482     0.002
N(5)            7.139e-007
   NO3-                 7.139e-007  6.236e-007    -6.146    -6.205    -0.059
   Mn(NO3)2             3.023e-020  3.035e-020   -19.520   -19.518     0.002
Na              2.884e-003
   Na+                  2.864e-003  2.521e-003    -2.543    -2.598    -0.055
   NaSO4-               1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   NaHCO3               6.517e-006  6.543e-006    -5.186    -5.184     0.002
   NaCO3-               4.344e-008  3.818e-008    -7.362    -7.418    -0.056
   NaOH                 8.507e-011  8.540e-011   -10.070   -10.069     0.002
O(0)            6.250e-007
   O2                   3.125e-007  3.137e-007    -6.505    -6.503     0.002
S(-2)           3.119e-008
   H2S                  1.964e-008  1.972e-008    -7.707    -7.705     0.002
   HS-                  1.155e-008  1.011e-008    -7.937    -7.995    -0.058
   S-2                  7.689e-015  4.650e-015   -14.114   -14.333    -0.218
   Fe(HS)2              6.953e-018  6.981e-018   -17.158   -17.156     0.002
   Fe(HS)3-             8.747e-024  7.688e-024   -23.058   -23.114    -0.056
S(6)            2.092e-003
   SO4-2                1.605e-003  9.689e-004    -2.795    -3.014    -0.219
   CaSO4                3.220e-004  3.233e-004    -3.492    -3.490     0.002
   MgSO4                1.497e-004  1.503e-004    -3.825    -3.823     0.002
   NaSO4-               1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   KSO4-                2.446e-006  2.150e-006    -5.612    -5.668    -0.056
   NH4SO4-              2.177e-008  1.914e-008    -7.662    -7.718    -0.056
   HSO4-                1.906e-008  1.675e-008    -7.720    -7.776    -0.056
   MnSO4                3.066e-009  3.079e-009    -8.513    -8.512     0.002
   AlSO4+               7.805e-010  6.861e-010    -9.108    -9.164    -0.056
   CaHSO4+              3.991e-010  3.508e-010    -9.399    -9.455    -0.056
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   Al(SO4)2-             2.344e-011  2.060e-011   -10.630   -10.686    -0.056
   FeSO4                 1.214e-011  1.218e-011   -10.916   -10.914     0.002
   AlHSO4+2              1.918e-017  1.145e-017   -16.717   -16.941    -0.224
   FeHSO4+               1.755e-017  1.542e-017   -16.756   -16.812    -0.056

------------------------------Saturation indices-----------------------------
--

      Phase               SI log IAP  log KT

      Al(OH)3(a)       -0.58   10.50   11.08  Al(OH)3
      Alunite           2.75    1.89   -0.86  KAl3(SO4)2(OH)6
      Anhydrite        -1.43   -5.77   -4.35  CaSO4
      Aragonite        -0.44   -8.75   -8.31  CaCO3
      Calcite          -0.30   -8.75   -8.46  CaCO3
      CO2(g)           -1.25   -2.67   -1.42  CO2
      Dolomite         -0.89  -17.88  -16.99  CaMg(CO3)2
      FeS(ppt)         -7.49  -11.40   -3.92  FeS
      Gibbsite          2.15   10.50    8.35  Al(OH)3
      Gypsum           -1.19   -5.77   -4.58  CaSO4:2H2O
      H2(g)            -9.42  -12.55   -3.13  H2
      H2O(g)           -1.62   -0.00    1.62  H2O
      H2S(g)           -6.76   -7.71   -0.95  H2S
      Halite           -6.74   -5.17    1.57  NaCl
      Hausmannite     -35.56   26.54   62.11  Mn3O4
      Mackinawite      -6.75  -11.40   -4.65  FeS
      Manganite       -14.92   10.42   25.34  MnOOH
      Melanterite     -10.87  -13.13   -2.26  FeSO4:7H2O
      NH3(g)          -10.34   -8.48    1.86  NH3
      O2(g)            -3.64   -6.50   -2.86  O2
      Pyrite            1.91  -16.69  -18.60  FeS2
      Pyrochroite      -9.49    5.71   15.20  Mn(OH)2
      Pyrolusite      -26.95   15.13   42.08  MnO2
      Rhodochrosite    -2.59  -13.71  -11.11  MnCO3
      Siderite         -5.25  -16.11  -10.86  FeCO3
      Sulfur           -3.27    1.71    4.98  S

-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using solution 1. HSM-I2-5-082012
Using pure phase assemblage 1.      Equilibration with FeS ppt

-------------------------------Phase assemblage------------------------------
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                                                      Moles in assemblage
Phase                  SI log IAP  log KT      Initial       Final
Delta

FeS(ppt)             0.00   -3.91   -3.92   1.000e+001  1.000e+001 -1.349e-
005
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```
-----------------------------Solution composition----------------------------
--

      Elements           Molality       Moles

      Al                 1.853e-006  1.853e-006
      B                  1.036e-005  1.036e-005
      C                  7.525e-003  7.525e-003
      Ca                 3.293e-003  3.293e-003
      Cl                 3.081e-003  3.081e-003
      Fe                 1.349e-005  1.349e-005
      K                  3.913e-004  3.913e-004
      Mg                 1.398e-003  1.398e-003
      Mn                 4.551e-008  4.551e-008
      N                  2.499e-006  2.499e-006
      Na                 2.884e-003  2.884e-003
      S                  2.106e-003  2.106e-003

----------------------------Description of solution--------------------------
--

                                       pH  =   6.716      Charge balance
                                       pe  =  -2.972      Adjusted to redox
equilibrium
       Specific Conductance (uS/cm, 20 oC) = 1073
                          Density (g/cm3)  =   0.99882
                        Activity of water  =   1.000
                           Ionic strength  =  1.724e-002
                       Mass of water (kg)  =  1.000e+000
                 Total alkalinity (eq/kg)  =  5.427e-003
                       Total CO2 (mol/kg)  =  7.525e-003
                      Temperature (deg C)  =  20.710
                  Electrical balance (eq)  = -2.639e-013
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =  27
                                  Total H  = 1.110179e+002
                                  Total O  = 5.553507e+001

----------------------------Distribution of species--------------------------
--

                                                   Log       Log         Log
   Species                   Molality    Activity  Molality  Activity    Gamma

   H+                    2.148e-007  1.924e-007    -6.668    -6.716    -0.048
   OH-                   4.263e-008  3.732e-008    -7.370    -7.428    -0.058
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
Al              1.853e-006
   Al(OH)4-              1.425e-006  1.253e-006    -5.846    -5.902    -0.056
   Al(OH)2+              2.774e-007  2.438e-007    -6.557    -6.613    -0.056
   Al(OH)3               1.343e-007  1.349e-007    -6.872    -6.870     0.002
   AlOH+2                1.473e-008  8.790e-009    -7.832    -8.056    -0.224
   AlSO4+                7.436e-010  6.535e-010    -9.129    -9.185    -0.056
   Al+3                  6.086e-010  2.257e-010    -9.216    -9.646    -0.431
   Al(SO4)2-             2.232e-011  1.962e-011   -10.651   -10.707    -0.056
   AlHSO4+2              1.803e-017  1.076e-017   -16.744   -16.968    -0.224
B               1.036e-005
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```
   H3BO3             1.033e-005  1.037e-005    -4.986    -4.984     0.002
   H2BO3-            3.260e-008  2.865e-008    -7.487    -7.543    -0.056
C(-4)           2.244e-008
   CH4               2.244e-008  2.253e-008    -7.649    -7.647     0.002
C(4)            7.525e-003
   HCO3-             5.242e-003  4.630e-003    -2.281    -2.334    -0.054
   CO2               2.115e-003  2.124e-003    -2.675    -2.673     0.002
   CaHCO3+           1.084e-004  9.571e-005    -3.965    -4.019    -0.054
   MgHCO3+           4.483e-005  3.940e-005    -4.348    -4.405    -0.056
   NaHCO3            6.538e-006  6.564e-006    -5.185    -5.183     0.002
   FeHCO3+           3.015e-006  2.650e-006    -5.521    -5.577    -0.056
   CaCO3             2.771e-006  2.782e-006    -5.557    -5.556     0.002
   CO3-2             1.692e-006  1.030e-006    -5.772    -5.987    -0.216
   MgCO3             6.781e-007  6.808e-007    -6.169    -6.167     0.002
   FeCO3             1.409e-007  1.414e-007    -6.851    -6.849     0.002
   NaCO3-            4.417e-008  3.882e-008    -7.355    -7.411    -0.056
   MnHCO3+           9.102e-009  8.000e-009    -8.041    -8.097    -0.056
   MnCO3             1.580e-009  1.586e-009    -8.801    -8.800     0.002
Ca              3.293e-003
   Ca+2              2.861e-003  1.741e-003    -2.544    -2.759    -0.216
   CaSO4             3.218e-004  3.230e-004    -3.492    -3.491     0.002
   CaHCO3+           1.084e-004  9.571e-005    -3.965    -4.019    -0.054
   CaCO3             2.771e-006  2.782e-006    -5.557    -5.556     0.002
   CaOH+             1.708e-009  1.501e-009    -8.768    -8.824    -0.056
   CaHSO4+           3.936e-010  3.459e-010    -9.405    -9.461    -0.056
Cl              3.081e-003
   Cl-               3.081e-003  2.699e-003    -2.511    -2.569    -0.057
   FeCl+             2.427e-008  2.133e-008    -7.615    -7.671    -0.056
   MnCl+             2.425e-010  2.132e-010    -9.615    -9.671    -0.056
   MnCl2             2.502e-013  2.512e-013   -12.602   -12.600     0.002
   MnCl3-            2.125e-016  1.867e-016   -15.673   -15.729    -0.056
   FeCl+2            5.470e-023  3.264e-023   -22.262   -22.486    -0.224
   FeCl2+            5.140e-025  4.517e-025   -24.289   -24.345    -0.056
   FeCl3             1.214e-028  1.219e-028   -27.916   -27.914     0.002
Fe(2)           1.349e-005
   Fe+2              9.306e-006  5.724e-006    -5.031    -5.242    -0.211
   FeHCO3+           3.015e-006  2.650e-006    -5.521    -5.577    -0.056
   FeSO4             9.070e-007  9.106e-007    -6.042    -6.041     0.002
   FeCO3             1.409e-007  1.414e-007    -6.851    -6.849     0.002
   Fe(HS)2           8.491e-008  8.524e-008    -7.071    -7.069     0.002
   FeCl+             2.427e-008  2.133e-008    -7.615    -7.671    -0.056
   FeOH+             7.730e-009  6.794e-009    -8.112    -8.168    -0.056
   Fe(HS)3-          4.317e-011  3.795e-011   -10.365   -10.421    -0.056
   FeHSO4+           1.294e-012  1.137e-012   -11.888   -11.944    -0.056
Fe(3)           2.947e-014
   Fe(OH)2+          1.981e-014  1.741e-014   -13.703   -13.759    -0.056
   Fe(OH)3           9.601e-015  9.640e-015   -14.018   -14.016     0.002
   Fe(OH)4-          4.364e-017  3.835e-017   -16.360   -16.416    -0.056
   FeOH+2            2.000e-017  1.193e-017   -16.699   -16.923    -0.224
   FeSO4+            5.045e-021  4.433e-021   -20.297   -20.353    -0.056
   Fe+3              1.239e-021  4.596e-022   -20.907   -21.338    -0.431
   Fe(SO4)2-         1.051e-022  9.238e-023   -21.978   -22.034    -0.056
   FeCl+2            5.470e-023  3.264e-023   -22.262   -22.486    -0.224
   FeCl2+            5.140e-025  4.517e-025   -24.289   -24.345    -0.056
   FeHSO4+2          3.845e-027  2.294e-027   -26.415   -26.639    -0.224
   FeCl3             1.214e-028  1.219e-028   -27.916   -27.914     0.002
   Fe2(OH)2+4        3.621e-032  4.589e-033   -31.441   -32.338    -0.897
```

```
   Fe3(OH)4+5             0.000e+000  0.000e+000   -42.201   -43.603    -1.402
H(0)            4.785e-011
   H2                     2.392e-011  2.402e-011   -10.621   -10.619     0.002
K               3.913e-004
   K+                     3.888e-004  3.407e-004    -3.410    -3.468    -0.057
   KSO4-                  2.445e-006  2.149e-006    -5.612    -5.668    -0.056
   KOH                    6.113e-012  6.138e-012   -11.214   -11.212     0.002
Mg              1.398e-003
   Mg+2                   1.203e-003  7.398e-004    -2.920    -3.131    -0.211
   MgSO4                  1.496e-004  1.502e-004    -3.825    -3.823     0.002
   MgHCO3+                4.483e-005  3.940e-005    -4.348    -4.405    -0.056
   MgCO3                  6.781e-007  6.808e-007    -6.169    -6.167     0.002
   MgOH+                  1.072e-008  9.421e-009    -7.970    -8.026    -0.056
Mn(2)           4.551e-008
   Mn+2                   3.152e-008  1.939e-008    -7.501    -7.713    -0.211
   MnHCO3+                9.102e-009  8.000e-009    -8.041    -8.097    -0.056
   MnSO4                  3.061e-009  3.073e-009    -8.514    -8.512     0.002
   MnCO3                  1.580e-009  1.586e-009    -8.801    -8.800     0.002
   MnCl+                  2.425e-010  2.132e-010    -9.615    -9.671    -0.056
   MnOH+                  2.066e-012  1.816e-012   -11.685   -11.741    -0.056
   MnCl2                  2.502e-013  2.512e-013   -12.602   -12.600     0.002
   MnCl3-                 2.125e-016  1.867e-016   -15.673   -15.729    -0.056
   Mn(NO3)2               0.000e+000  0.000e+000  -173.878  -173.877     0.002
Mn(3)           1.082e-036
   Mn+3                   1.082e-036  3.386e-037   -35.966   -36.470    -0.505
N(-3)           2.379e-006
   NH4+                   2.345e-006  2.043e-006    -5.630    -5.690    -0.060
   NH4SO4-                2.901e-008  2.550e-008    -7.537    -7.594    -0.056
   NH3                    4.432e-009  4.449e-009    -8.353    -8.352     0.002
N(0)            1.200e-007
   N2                     5.998e-008  6.022e-008    -7.222    -7.220     0.002
N(3)            0.000e+000
   NO2-                   0.000e+000  0.000e+000   -61.775   -61.834    -0.059
N(5)            0.000e+000
   NO3-                   0.000e+000  0.000e+000   -83.325   -83.384    -0.059
   Mn(NO3)2               0.000e+000  0.000e+000  -173.878  -173.877     0.002
Na              2.884e-003
   Na+                    2.864e-003  2.521e-003    -2.543    -2.598    -0.055
   NaSO4-                 1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   NaHCO3                 6.538e-006  6.564e-006    -5.185    -5.183     0.002
   NaCO3-                 4.417e-008  3.882e-008    -7.355    -7.411    -0.056
   NaOH                   8.621e-011  8.655e-011   -10.064   -10.063     0.002
O(0)            0.000e+000
   O2                     0.000e+000  0.000e+000   -72.548   -72.546     0.002
S(-2)           1.267e-005
   H2S                    7.831e-006  7.862e-006    -5.106    -5.104     0.002
   HS-                    4.669e-006  4.088e-006    -5.331    -5.389    -0.058
   Fe(HS)2                8.491e-008  8.524e-008    -7.071    -7.069     0.002
   Fe(HS)3-               4.317e-011  3.795e-011   -10.365   -10.421    -0.056
   S-2                    3.151e-012  1.905e-012   -11.502   -11.720    -0.219
S(6)            2.093e-003
   SO4-2                  1.605e-003  9.687e-004    -2.795    -3.014    -0.219
   CaSO4                  3.218e-004  3.230e-004    -3.492    -3.491     0.002
   MgSO4                  1.496e-004  1.502e-004    -3.825    -3.823     0.002
   NaSO4-                 1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   KSO4-                  2.445e-006  2.149e-006    -5.612    -5.668    -0.056
   FeSO4                  9.070e-007  9.106e-007    -6.042    -6.041     0.002
```

```
   NH4SO4-               2.901e-008  2.550e-008    -7.537    -7.594    -0.056
   HSO4-                 1.881e-008  1.653e-008    -7.726    -7.782    -0.056
   MnSO4                 3.061e-009  3.073e-009    -8.514    -8.512     0.002
   AlSO4+                7.436e-010  6.535e-010    -9.129    -9.185    -0.056
   CaHSO4+               3.936e-010  3.459e-010    -9.405    -9.461    -0.056
   Al(SO4)2-             2.232e-011  1.962e-011   -10.651   -10.707    -0.056
   FeHSO4+               1.294e-012  1.137e-012   -11.888   -11.944    -0.056
   AlHSO4+2              1.803e-017  1.076e-017   -16.744   -16.968    -0.224
   FeSO4+                5.045e-021  4.433e-021   -20.297   -20.353    -0.056
   Fe(SO4)2-             1.051e-022  9.238e-023   -21.978   -22.034    -0.056
   FeHSO4+2              3.845e-027  2.294e-027   -26.415   -26.639    -0.224

------------------------------Saturation indices-----------------------------
--

      Phase                SI  log IAP  log KT

      Al(OH)3(a)        -0.58   10.50   11.08  Al(OH)3
      Alunite            2.72    1.86   -0.86  KAl3(SO4)2(OH)6
      Anhydrite         -1.43   -5.77   -4.35  CaSO4
      Aragonite         -0.44   -8.75   -8.31  CaCO3
      Calcite           -0.29   -8.75   -8.46  CaCO3
      CH4(g)            -4.82   -7.65   -2.82  CH4
      CO2(g)            -1.26   -2.67   -1.42  CO2
      Dolomite          -0.88  -17.86  -16.99  CaMg(CO3)2
      Fe(OH)3(a)        -6.08   -1.19    4.89  Fe(OH)3
      FeS(ppt)           0.00   -3.91   -3.92  FeS
      Gibbsite           2.15   10.50    8.35  Al(OH)3
      Goethite          -0.35   -1.19   -0.85  FeOOH
      Gypsum            -1.19   -5.77   -4.58  CaSO4:2H2O
      H2(g)             -7.49  -10.62   -3.13  H2
      H2O(g)            -1.62   -0.00    1.62  H2O
      H2S(g)            -4.16   -5.10   -0.95  H2S
      Halite            -6.74   -5.17    1.57  NaCl
      Hausmannite      -37.46   24.65   62.11  Mn3O4
      Hematite           1.30   -2.38   -3.68  Fe2O3
      Jarosite-K       -24.34  -33.21   -8.88  KFe3(SO4)2(OH)6
      Mackinawite        0.73   -3.91   -4.65  FeS
      Manganite        -15.88    9.46   25.34  MnOOH
      Melanterite       -5.99   -8.26   -2.26  FeSO4:7H2O
      N2(g)             -3.97   -7.22   -3.25  N2
      NH3(g)           -10.21   -8.35    1.86  NH3
      O2(g)            -69.69  -72.55   -2.86  O2
      Pyrite            10.07   -8.53  -18.60  FeS2
      Pyrochroite       -9.48    5.72   15.20  Mn(OH)2
      Pyrolusite       -28.87   13.21   42.08  MnO2
      Rhodochrosite     -2.58  -13.70  -11.11  MnCO3
      Siderite          -0.37  -11.23  -10.86  FeCO3
      Sulfur            -2.60    2.38    4.98  S

------------------
End of simulation.
------------------

------------------------------------
Reading input data for simulation 2.
------------------------------------
```

```
      SOLUTION 3-4 HNW-14-12
          temp      19
          pH        7.1
          pe        -2
          redox     pe
          units     mg/kgw
          density   1
          Al        0
          Alkalinity 264
          B         80 ug/kgw
          Ca        121
          Cl        34 charge
          Fe(2)     0.01
          Mg        16.3
          Mn        5.3 ug/kgw
          K         9.84
          N(5)      0.02
          N(-3)     0.02
          Na        68.2
          O(0)      0.01
          S(-2)     0
          S(6)      188
          water    1 # kg
      EQUILIBRIUM_PHASES 1-2 Equilibration with FeS ppt
          FeS(ppt)  0 10
      END
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 3.     HNW-14-12

-----------------------------Solution composition-----------------------------
--

      Elements           Molality       Moles

      Alkalinity       5.275e-003  5.275e-003
      B                7.401e-006  7.401e-006
      Ca               3.019e-003  3.019e-003
      Cl               1.408e-003  1.408e-003  Charge balance
      Fe(2)            1.791e-007  1.791e-007
      K                2.516e-004  2.516e-004
      Mg               6.705e-004  6.705e-004
      Mn               9.647e-008  9.647e-008
      N(-3)            1.428e-006  1.428e-006
      N(5)             1.428e-006  1.428e-006
      Na               2.967e-003  2.967e-003
      O(0)             6.250e-007  6.250e-007
      S(6)             1.957e-003  1.957e-003

----------------------------Description of solution--------------------------
--

                                       pH  =   7.100
                                       pe  =  -2.000
```

```
       Specific Conductance (uS/cm, 19 oC) = 853
                          Density (g/cm3)  =   0.99907
                        Activity of water  =   1.000
                           Ionic strength  =  1.445e-002
                       Mass of water (kg)  =  1.000e+000
                     Total carbon (mol/kg)  =  6.150e-003
                        Total CO2 (mol/kg)  =  6.150e-003
                       Temperature (deg C)  =  19.000
                   Electrical balance (eq)  = -3.500e-016
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =  10
                                  Total H  = 1.110177e+002
                                  Total O  = 5.553164e+001

---------------------------------Redox couples-------------------------------
--

      Redox couple             pe  Eh (volts)

      N(-3)/N(5)            6.3627      0.3688
      O(-2)/O(0)           13.3014      0.7710

----------------------------Distribution of species--------------------------
--

                                                         Log       Log         Log
   Species                  Molality    Activity  Molality  Activity       Gamma

   OH-                     8.916e-008  7.886e-008    -7.050    -7.103      -0.053
   H+                      8.806e-008  7.943e-008    -7.055    -7.100      -0.045
   H2O                     5.551e+001  9.997e-001     1.744    -0.000       0.000
B               7.401e-006
   H3BO3                   7.347e-006  7.371e-006    -5.134    -5.132       0.001
   H2BO3-                  5.382e-008  4.775e-008    -7.269    -7.321      -0.052
C(4)            6.150e-003
   HCO3-                   5.129e-003  4.571e-003    -2.290    -2.340      -0.050
   CO2                     8.858e-004  8.888e-004    -3.053    -3.051       0.001
   CaHCO3+                 9.714e-005  8.657e-005    -4.013    -4.063      -0.050
   MgHCO3+                 2.160e-005  1.916e-005    -4.666    -4.718      -0.052
   NaHCO3                  6.706e-006  6.728e-006    -5.174    -5.172       0.001
   CaCO3                   5.870e-006  5.889e-006    -5.231    -5.230       0.001
   CO3-2                   3.753e-006  2.368e-006    -5.426    -5.626      -0.200
   MgCO3                   7.530e-007  7.555e-007    -6.123    -6.122       0.001
   NaCO3-                  9.552e-008  8.475e-008    -7.020    -7.072      -0.052
   FeHCO3+                 4.005e-008  3.554e-008    -7.397    -7.449      -0.052
   MnHCO3+                 1.862e-008  1.653e-008    -7.730    -7.782      -0.052
   MnCO3                   7.604e-009  7.630e-009    -8.119    -8.117       0.001
   FeCO3                   4.402e-009  4.416e-009    -8.356    -8.355       0.001
Ca              3.019e-003
   Ca+2                    2.612e-003  1.647e-003    -2.583    -2.783      -0.200
   CaSO4                   3.035e-004  3.045e-004    -3.518    -3.516       0.001
   CaHCO3+                 9.714e-005  8.657e-005    -4.013    -4.063      -0.050
   CaCO3                   5.870e-006  5.889e-006    -5.231    -5.230       0.001
   CaOH+                   3.878e-009  3.441e-009    -8.411    -8.463      -0.052
   CaHSO4+                 1.488e-010  1.321e-010    -9.827    -9.879      -0.052
Cl              1.408e-003
   Cl-                     1.408e-003  1.246e-003    -2.851    -2.904      -0.053
```

```
   MnCl+                 2.321e-010  2.060e-010    -9.634    -9.686    -0.052
   FeCl+                 1.508e-010  1.338e-010    -9.822    -9.874    -0.052
   MnCl2                 1.117e-013  1.120e-013   -12.952   -12.951     0.001
   MnCl3-                4.335e-017  3.846e-017   -16.363   -16.415    -0.052
Fe(2)           1.791e-007
   Fe+2                  1.221e-007  7.775e-008    -6.913    -7.109    -0.196
   FeHCO3+               4.005e-008  3.554e-008    -7.397    -7.449    -0.052
   FeSO4                 1.209e-008  1.213e-008    -7.918    -7.916     0.001
   FeCO3                 4.402e-009  4.416e-009    -8.356    -8.355     0.001
   FeOH+                 2.207e-010  1.958e-010    -9.656    -9.708    -0.052
   FeCl+                 1.508e-010  1.338e-010    -9.822    -9.874    -0.052
   FeHSO4+               7.025e-015  6.233e-015   -14.153   -14.205    -0.052
H(0)            9.464e-014
   H2                    4.732e-014  4.748e-014   -13.325   -13.324     0.001
K               2.516e-004
   K+                    2.501e-004  2.213e-004    -3.602    -3.655    -0.053
   KSO4-                 1.545e-006  1.371e-006    -5.811    -5.863    -0.052
   KOH                   9.627e-012  9.659e-012   -11.017   -11.015     0.001
Mg              6.705e-004
   Mg+2                  5.763e-004  3.666e-004    -3.239    -3.436    -0.196
   MgSO4                 7.176e-005  7.200e-005    -4.144    -4.143     0.001
   MgHCO3+               2.160e-005  1.916e-005    -4.666    -4.718    -0.052
   MgCO3                 7.530e-007  7.555e-007    -6.123    -6.122     0.001
   MgOH+                 1.086e-008  9.637e-009    -7.964    -8.016    -0.052
Mn(2)           9.647e-008
   Mn+2                  6.373e-008  4.056e-008    -7.196    -7.392    -0.196
   MnHCO3+               1.862e-008  1.653e-008    -7.730    -7.782    -0.052
   MnCO3                 7.604e-009  7.630e-009    -8.119    -8.117     0.001
   MnSO4                 6.275e-009  6.296e-009    -8.202    -8.201     0.001
   MnCl+                 2.321e-010  2.060e-010    -9.634    -9.686    -0.052
   MnOH+                 8.978e-012  7.966e-012   -11.047   -11.099    -0.052
   MnCl2                 1.117e-013  1.120e-013   -12.952   -12.951     0.001
   MnCl3-                4.335e-017  3.846e-017   -16.363   -16.415    -0.052
   Mn(NO3)2              2.592e-019  2.600e-019   -18.586   -18.585     0.001
Mn(3)           1.504e-035
   Mn+3                  1.504e-035  5.126e-036   -34.823   -35.290    -0.467
N(-3)           1.428e-006
   NH4+                  1.405e-006  1.237e-006    -5.852    -5.908    -0.055
   NH4SO4-               1.762e-008  1.563e-008    -7.754    -7.806    -0.052
   NH3                   5.737e-009  5.756e-009    -8.241    -8.240     0.001
N(5)            1.428e-006
   NO3-                  1.428e-006  1.260e-006    -5.845    -5.900    -0.054
   Mn(NO3)2              2.592e-019  2.600e-019   -18.586   -18.585     0.001
Na              2.967e-003
   Na+                   2.946e-003  2.618e-003    -2.531    -2.582    -0.051
   NaSO4-                1.395e-005  1.238e-005    -4.855    -4.907    -0.052
   NaHCO3                6.706e-006  6.728e-006    -5.174    -5.172     0.001
   NaCO3-                9.552e-008  8.475e-008    -7.020    -7.072    -0.052
   NaOH                  2.169e-010  2.177e-010    -9.664    -9.662     0.001
O(0)            6.250e-007
   O2                    3.125e-007  3.135e-007    -6.505    -6.504     0.001
S(6)            1.957e-003
   SO4-2                 1.566e-003  9.809e-004    -2.805    -3.008    -0.203
   CaSO4                 3.035e-004  3.045e-004    -3.518    -3.516     0.001
   MgSO4                 7.176e-005  7.200e-005    -4.144    -4.143     0.001
   NaSO4-                1.395e-005  1.238e-005    -4.855    -4.907    -0.052
   KSO4-                 1.545e-006  1.371e-006    -5.811    -5.863    -0.052
```

```
   NH4SO4-               1.762e-008  1.563e-008    -7.754    -7.806    -0.052
   FeSO4                 1.209e-008  1.213e-008    -7.918    -7.916     0.001
   HSO4-                 7.515e-009  6.668e-009    -8.124    -8.176    -0.052
   MnSO4                 6.275e-009  6.296e-009    -8.202    -8.201     0.001
   CaHSO4+               1.488e-010  1.321e-010    -9.827    -9.879    -0.052
   FeHSO4+               7.025e-015  6.233e-015   -14.153   -14.205    -0.052

------------------------------Saturation indices-----------------------------
--

      Phase               SI log IAP  log KT

      Anhydrite        -1.45   -5.79   -4.34  CaSO4
      Aragonite        -0.11   -8.41   -8.30  CaCO3
      Calcite           0.04   -8.41   -8.45  CaCO3
      CO2(g)           -1.66   -3.05   -1.39  CO2
      Dolomite         -0.52  -17.47  -16.95  CaMg(CO3)2
      Gypsum           -1.21   -5.79   -4.58  CaSO4:2H2O
      H2(g)           -10.20  -13.32   -3.12  H2
      H2O(g)           -1.67   -0.00    1.67  H2O
      Halite           -7.05   -5.49    1.57  NaCl
      Hausmannite     -31.92   30.62   62.54  Mn3O4
      Manganite       -13.43   11.91   25.34  MnOOH
      Melanterite      -7.83  -10.12   -2.28  FeSO4:7H2O
      NH3(g)          -10.13   -8.24    1.89  NH3
      O2(g)            -3.66   -6.50   -2.85  O2
      Pyrochroite      -8.39    6.81   15.20  Mn(OH)2
      Pyrolusite      -25.35   17.01   42.36  MnO2
      Rhodochrosite    -1.91  -13.02  -11.11  MnCO3
      Siderite         -1.88  -12.73  -10.85  FeCO3

-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using solution 3. HNW-14-12
Using pure phase assemblage 1.      Equilibration with FeS ppt

-------------------------------Phase assemblage------------------------------
--

                                                      Moles in assemblage
Phase                     SI log IAP  log KT      Initial       Final
Delta

FeS(ppt)            -0.00   -3.92   -3.92   1.000e+001  1.000e+001 -7.277e-
006

-----------------------------Solution composition-----------------------------
--

      Elements            Molality       Moles

      B                7.401e-006  7.401e-006
      C                6.150e-003  6.150e-003
```

```
      Ca               3.019e-003  3.019e-003
      Cl               1.408e-003  1.408e-003
      Fe               7.456e-006  7.456e-006
      K                2.516e-004  2.516e-004
      Mg               6.705e-004  6.705e-004
      Mn               9.647e-008  9.647e-008
      N                2.856e-006  2.856e-006
      Na               2.967e-003  2.967e-003
      S                1.964e-003  1.964e-003

----------------------------Description of solution--------------------------
--

                                       pH  =   7.106      Charge balance
                                       pe  =  -3.359      Adjusted to redox
equilibrium
       Specific Conductance (uS/cm, 19 oC) = 854
                          Density (g/cm3)  =   0.99907
                        Activity of water  =   1.000
                           Ionic strength  =  1.447e-002
                       Mass of water (kg)  =  1.000e+000
                 Total alkalinity (eq/kg)  =  5.289e-003
                       Total CO2 (mol/kg)  =  6.150e-003
                      Temperature (deg C)  =  19.000
                  Electrical balance (eq)  = -3.426e-016
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =  12
                                  Total H  = 1.110177e+002
                                  Total O  = 5.553164e+001

----------------------------Distribution of species--------------------------
--

                                                   Log       Log         Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   OH-                   9.036e-008  7.992e-008    -7.044    -7.097    -0.053
   H+                    8.690e-008  7.838e-008    -7.061    -7.106    -0.045
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                 7.346e-006  7.371e-006    -5.134    -5.133     0.001
   H2BO3-                5.454e-008  4.839e-008    -7.263    -7.315    -0.052
C(-4)           1.538e-008
   CH4                   1.538e-008  1.544e-008    -7.813    -7.811     0.001
C(4)            6.150e-003
   HCO3-                 5.137e-003  4.578e-003    -2.289    -2.339    -0.050
   CO2                   8.755e-004  8.784e-004    -3.058    -3.056     0.001
   CaHCO3+               9.726e-005  8.668e-005    -4.012    -4.062    -0.050
   MgHCO3+               2.163e-005  1.919e-005    -4.665    -4.717    -0.052
   NaHCO3                6.716e-006  6.738e-006    -5.173    -5.171     0.001
   CaCO3                 5.956e-006  5.976e-006    -5.225    -5.224     0.001
   CO3-2                 3.810e-006  2.403e-006    -5.419    -5.619    -0.200
   FeHCO3+               1.663e-006  1.476e-006    -5.779    -5.831    -0.052
   MgCO3                 7.640e-007  7.666e-007    -6.117    -6.115     0.001
   FeCO3                 1.852e-007  1.859e-007    -6.732    -6.731     0.001
   NaCO3-                9.695e-008  8.601e-008    -7.013    -7.065    -0.052
   MnHCO3+               1.862e-008  1.652e-008    -7.730    -7.782    -0.052
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   MnCO3             7.706e-009  7.731e-009    -8.113    -8.112     0.001
Ca                3.019e-003
   Ca+2              2.612e-003  1.647e-003    -2.583    -2.783    -0.200
   CaSO4             3.035e-004  3.045e-004    -3.518    -3.516     0.001
   CaHCO3+           9.726e-005  8.668e-005    -4.012    -4.062    -0.050
   CaCO3             5.956e-006  5.976e-006    -5.225    -5.224     0.001
   CaOH+             3.929e-009  3.486e-009    -8.406    -8.458    -0.052
   CaHSO4+           1.469e-010  1.303e-010    -9.833    -9.885    -0.052
Cl                1.408e-003
   Cl-               1.408e-003  1.246e-003    -2.851    -2.904    -0.053
   FeCl+             6.250e-009  5.546e-009    -8.204    -8.256    -0.052
   MnCl+             2.317e-010  2.056e-010    -9.635    -9.687    -0.052
   MnCl2             1.115e-013  1.118e-013   -12.953   -12.951     0.001
   MnCl3-            4.327e-017  3.839e-017   -16.364   -16.416    -0.052
   FeCl+2            4.812e-024  2.982e-024   -23.318   -23.525    -0.208
   FeCl2+            2.272e-026  2.016e-026   -25.644   -25.696    -0.052
   FeCl3             2.504e-030  2.512e-030   -29.601   -29.600     0.001
Fe(2)             7.456e-006
   Fe+2              5.066e-006  3.224e-006    -5.295    -5.492    -0.196
   FeHCO3+           1.663e-006  1.476e-006    -5.779    -5.831    -0.052
   FeSO4             5.013e-007  5.029e-007    -6.300    -6.298     0.001
   FeCO3             1.852e-007  1.859e-007    -6.732    -6.731     0.001
   Fe(HS)2           2.504e-008  2.512e-008    -7.601    -7.600     0.001
   FeOH+             9.274e-009  8.228e-009    -8.033    -8.085    -0.052
   FeCl+             6.250e-009  5.546e-009    -8.204    -8.256    -0.052
   Fe(HS)3-          9.118e-012  8.090e-012   -11.040   -11.092    -0.052
   FeHSO4+           2.875e-013  2.551e-013   -12.541   -12.593    -0.052
Fe(3)             4.429e-014
   Fe(OH)3           2.320e-014  2.327e-014   -13.635   -13.633     0.001
   Fe(OH)2+          2.085e-014  1.850e-014   -13.681   -13.733    -0.052
   Fe(OH)4-          2.386e-016  2.117e-016   -15.622   -15.674    -0.052
   FeOH+2            8.916e-018  5.525e-018   -17.050   -17.258    -0.208
   FeSO4+            1.019e-021  9.040e-022   -20.992   -21.044    -0.052
   Fe+3              2.434e-022  9.621e-023   -21.614   -22.017    -0.403
   Fe(SO4)2-         2.136e-023  1.895e-023   -22.670   -22.722    -0.052
   FeCl+2            4.812e-024  2.982e-024   -23.318   -23.525    -0.208
   FeCl2+            2.272e-026  2.016e-026   -25.644   -25.696    -0.052
   FeHSO4+2          3.086e-028  1.912e-028   -27.511   -27.718    -0.208
   FeCl3             2.504e-030  2.512e-030   -29.601   -29.600     0.001
   Fe2(OH)2+4        7.177e-033  1.058e-033   -32.144   -32.975    -0.831
   Fe3(OH)4+5        0.000e+000  0.000e+000   -42.844   -44.143    -1.299
H(0)              4.823e-011
   H2                2.412e-011  2.420e-011   -10.618   -10.616     0.001
K                 2.516e-004
   K+                2.501e-004  2.213e-004    -3.602    -3.655    -0.053
   KSO4-             1.546e-006  1.371e-006    -5.811    -5.863    -0.052
   KOH               9.755e-012  9.788e-012   -11.011   -11.009     0.001
Mg                6.705e-004
   Mg+2              5.763e-004  3.665e-004    -3.239    -3.436    -0.197
   MgSO4             7.177e-005  7.201e-005    -4.144    -4.143     0.001
   MgHCO3+           2.163e-005  1.919e-005    -4.665    -4.717    -0.052
   MgCO3             7.640e-007  7.666e-007    -6.117    -6.115     0.001
   MgOH+             1.100e-008  9.764e-009    -7.958    -8.010    -0.052
Mn(2)             9.647e-008
   Mn+2              6.364e-008  4.050e-008    -7.196    -7.393    -0.196
   MnHCO3+           1.862e-008  1.652e-008    -7.730    -7.782    -0.052
   MnCO3             7.706e-009  7.731e-009    -8.113    -8.112     0.001
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   MnSO4                 6.267e-009  6.288e-009    -8.203    -8.202     0.001
   MnCl+                 2.317e-010  2.056e-010    -9.635    -9.687    -0.052
   MnOH+                 9.084e-012  8.060e-012   -11.042   -11.094    -0.052
   MnCl2                 1.115e-013  1.118e-013   -12.953   -12.951     0.001
   MnCl3-                4.327e-017  3.839e-017   -16.364   -16.416    -0.052
   Mn(NO3)2              0.000e+000  0.000e+000  -173.563  -173.561     0.001
Mn(3)           6.566e-037
   Mn+3                  6.566e-037  2.237e-037   -36.183   -36.650    -0.468
N(-3)           2.430e-006
   NH4+                  2.390e-006  2.105e-006    -5.622    -5.677    -0.055
   NH4SO4-               2.999e-008  2.661e-008    -7.523    -7.575    -0.052
   NH3                   9.894e-009  9.927e-009    -8.005    -8.003     0.001
N(0)            4.254e-007
   N2                    2.127e-007  2.134e-007    -6.672    -6.671     0.001
N(3)            0.000e+000
   NO2-                  0.000e+000  0.000e+000   -61.597   -61.651    -0.054
N(5)            0.000e+000
   NO3-                  0.000e+000  0.000e+000   -83.333   -83.387    -0.054
   Mn(NO3)2              0.000e+000  0.000e+000  -173.563  -173.561     0.001
Na              2.967e-003
   Na+                   2.946e-003  2.617e-003    -2.531    -2.582    -0.051
   NaSO4-                1.396e-005  1.238e-005    -4.855    -4.907    -0.052
   NaHCO3                6.716e-006  6.738e-006    -5.173    -5.171     0.001
   NaCO3-                9.695e-008  8.601e-008    -7.013    -7.065    -0.052
   NaOH                  2.198e-010  2.206e-010    -9.658    -9.656     0.001
O(0)            0.000e+000
   O2                    0.000e+000  0.000e+000   -73.125   -73.124     0.001
S(-2)           5.837e-006
   HS-                   3.343e-006  2.957e-006    -5.476    -5.529    -0.053
   H2S                   2.444e-006  2.452e-006    -5.612    -5.611     0.001
   Fe(HS)2               2.504e-008  2.512e-008    -7.601    -7.600     0.001
   Fe(HS)3-              9.118e-012  8.090e-012   -11.040   -11.092    -0.052
   S-2                   4.778e-012  2.996e-012   -11.321   -11.523    -0.203
S(6)            1.958e-003
   SO4-2                 1.567e-003  9.813e-004    -2.805    -3.008    -0.203
   CaSO4                 3.035e-004  3.045e-004    -3.518    -3.516     0.001
   MgSO4                 7.177e-005  7.201e-005    -4.144    -4.143     0.001
   NaSO4-                1.396e-005  1.238e-005    -4.855    -4.907    -0.052
   KSO4-                 1.546e-006  1.371e-006    -5.811    -5.863    -0.052
   FeSO4                 5.013e-007  5.029e-007    -6.300    -6.298     0.001
   NH4SO4-               2.999e-008  2.661e-008    -7.523    -7.575    -0.052
   HSO4-                 7.418e-009  6.582e-009    -8.130    -8.182    -0.052
   MnSO4                 6.267e-009  6.288e-009    -8.203    -8.202     0.001
   CaHSO4+               1.469e-010  1.303e-010    -9.833    -9.885    -0.052
   FeHSO4+               2.875e-013  2.551e-013   -12.541   -12.593    -0.052
   FeSO4+                1.019e-021  9.040e-022   -20.992   -21.044    -0.052
   Fe(SO4)2-             2.136e-023  1.895e-023   -22.670   -22.722    -0.052
   FeHSO4+2              3.086e-028  1.912e-028   -27.511   -27.718    -0.208

------------------------------Saturation indices-----------------------------
--

      Phase               SI log IAP  log KT

      Anhydrite        -1.45   -5.79   -4.34  CaSO4
      Aragonite        -0.10   -8.40   -8.30  CaCO3
      Calcite           0.05   -8.40   -8.45  CaCO3
```

```
      CH4(g)           -5.00   -7.81   -2.81  CH4
      CO2(g)           -1.66   -3.06   -1.39  CO2
      Dolomite         -0.51  -17.46  -16.95  CaMg(CO3)2
      Fe(OH)3(a)       -5.59   -0.70    4.89  Fe(OH)3
      FeS(ppt)         -0.00   -3.92   -3.92  FeS
      Goethite          0.08   -0.70   -0.78  FeOOH
      Gypsum           -1.21   -5.79   -4.58  CaSO4:2H2O
      H2(g)            -7.49  -10.62   -3.12  H2
      H2O(g)           -1.67   -0.00    1.67  H2O
      H2S(g)           -4.68   -5.61   -0.93  H2S
      Halite           -7.05   -5.49    1.57  NaCl
      Hausmannite     -34.60   27.95   62.54  Mn3O4
      Hematite          2.14   -1.40   -3.54  Fe2O3
      Jarosite-K      -24.35  -33.09   -8.74  KFe3(SO4)2(OH)6
      Mackinawite       0.73   -3.92   -4.65  FeS
      Manganite       -14.77   10.57   25.34  MnOOH
      Melanterite      -6.22   -8.50   -2.28  FeSO4:7H2O
      N2(g)            -3.43   -6.67   -3.24  N2
      NH3(g)           -9.90   -8.00    1.89  NH3
      O2(g)           -70.28  -73.12   -2.85  O2
      Pyrite            9.59   -9.06  -18.65  FeS2
      Pyrochroite      -8.38    6.82   15.20  Mn(OH)2
      Pyrolusite      -28.05   14.31   42.36  MnO2
      Rhodochrosite    -1.90  -13.01  -11.11  MnCO3
      Siderite         -0.26  -11.11  -10.85  FeCO3
      Sulfur           -3.14    1.88    5.03  S

------------------
End of simulation.
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Reading input data for simulation 3.
------------------------------------

      SOLUTION 5-6 MNW-5 D2
          temp      21.4
          pH        6.6
          pe        -2
          redox     pe
          units     mg/kgw
          density   1
          Fe(2)     0.01
          Mg        16.3
          Mn(2)     0.005
          N(5)      0
          N(-3)     0
          S(-2)     0.005
          S(6)      167
          Al        0
          Cl        42 charge
          Ca        121
          Alkalinity 243
          K         9.84
          O(0)      0.01
          Na        68.2
          B         0.08
```

```
        water    1 # kg
    EQUILIBRIUM_PHASES 3 Equilibration with FeS ppt
        FeS(ppt)  0 10
    END
------------------------------------------
Beginning of initial solution calculations.
------------------------------------------

Initial solution 5.     MNW-5 D2

-----------------------------Solution composition------------------------------
--

    Elements           Molality       Moles

    Alkalinity       4.856e-003  4.856e-003
    B                7.401e-006  7.401e-006
    Ca               3.019e-003  3.019e-003
    Cl               2.265e-003  2.265e-003  Charge balance
    Fe(2)            1.791e-007  1.791e-007
    K                2.516e-004  2.516e-004
    Mg               6.705e-004  6.705e-004
    Mn(2)            9.101e-008  9.101e-008
    Na               2.967e-003  2.967e-003
    O(0)             6.250e-007  6.250e-007
    S(-2)            1.559e-007  1.559e-007
    S(6)             1.738e-003  1.738e-003

----------------------------Description of solution----------------------------
--

                                       pH  =   6.600
                                       pe  =  -2.000
       Specific Conductance (uS/cm, 21 oC) = 925
                          Density (g/cm3)  =   0.99855
                        Activity of water  =   1.000
                           Ionic strength  =  1.438e-002
                       Mass of water (kg)  =  1.000e+000
                    Total carbon (mol/kg)  =  7.342e-003
                       Total CO2 (mol/kg)  =  7.342e-003
                      Temperature (deg C)  =  21.400
                  Electrical balance (eq)  =  1.690e-015
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =   0.00
                               Iterations  =   9
                                  Total H  = 1.110173e+002
                                  Total O  = 5.553273e+001

---------------------------------Redox couples---------------------------------
--

    Redox couple             pe  Eh (volts)

    O(-2)/O(0)          13.5960      0.7946
    S(-2)/S(6)          -2.6142     -0.1528

----------------------------Distribution of species----------------------------
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                                                   Log       Log         Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   H+                    2.785e-007  2.512e-007    -6.555    -6.600    -0.045
   OH-                   3.413e-008  3.019e-008    -7.467    -7.520    -0.053
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                 7.383e-006  7.407e-006    -5.132    -5.130     0.001
   H2BO3-                1.790e-008  1.588e-008    -7.747    -7.799    -0.052
C(4)            7.342e-003
   HCO3-                 4.728e-003  4.213e-003    -2.325    -2.375    -0.050
   CO2                   2.489e-003  2.498e-003    -2.604    -2.602     0.001
   CaHCO3+               9.477e-005  8.445e-005    -4.023    -4.073    -0.050
   MgHCO3+               2.026e-005  1.797e-005    -4.693    -4.745    -0.052
   NaHCO3                6.184e-006  6.205e-006    -5.209    -5.207     0.001
   CaCO3                 1.902e-006  1.908e-006    -5.721    -5.719     0.001
   CO3-2                 1.156e-006  7.290e-007    -5.937    -6.137    -0.200
   MgCO3                 2.427e-007  2.435e-007    -6.615    -6.614     0.001
   FeHCO3+               3.845e-008  3.411e-008    -7.415    -7.467    -0.052
   NaCO3-                3.334e-008  2.958e-008    -7.477    -7.529    -0.052
   MnHCO3+               1.747e-008  1.550e-008    -7.758    -7.810    -0.052
   MnCO3                 2.382e-009  2.390e-009    -8.623    -8.622     0.001
   FeCO3                 1.411e-009  1.416e-009    -8.850    -8.849     0.001
Ca              3.019e-003
   Ca+2                  2.646e-003  1.667e-003    -2.577    -2.778    -0.201
   CaSO4                 2.767e-004  2.776e-004    -3.558    -3.557     0.001
   CaHCO3+               9.477e-005  8.445e-005    -4.023    -4.073    -0.050
   CaCO3                 1.902e-006  1.908e-006    -5.721    -5.719     0.001
   CaOH+                 1.241e-009  1.101e-009    -8.906    -8.958    -0.052
   CaHSO4+               4.410e-010  3.912e-010    -9.356    -9.408    -0.052
Cl              2.265e-003
   Cl-                   2.265e-003  2.004e-003    -2.645    -2.698    -0.053
   MnCl+                 3.799e-010  3.370e-010    -9.420    -9.472    -0.052
   FeCl+                 2.525e-010  2.240e-010    -9.598    -9.650    -0.052
   MnCl2                 2.938e-013  2.948e-013   -12.532   -12.530     0.001
   MnCl3-                1.834e-016  1.627e-016   -15.736   -15.789    -0.052
Fe(2)           1.791e-007
   Fe+2                  1.273e-007  8.096e-008    -6.895    -7.092    -0.196
   FeHCO3+               3.845e-008  3.411e-008    -7.415    -7.467    -0.052
   FeSO4                 1.159e-008  1.163e-008    -7.936    -7.934     0.001
   FeCO3                 1.411e-009  1.416e-009    -8.850    -8.849     0.001
   FeCl+                 2.525e-010  2.240e-010    -9.598    -9.650    -0.052
   FeOH+                 8.747e-011  7.760e-011   -10.058   -10.110    -0.052
   Fe(HS)2               1.366e-013  1.370e-013   -12.865   -12.863     0.001
   FeHSO4+               2.142e-014  1.900e-014   -13.669   -13.721    -0.052
   Fe(HS)3-              7.329e-019  6.502e-019   -18.135   -18.187    -0.052
H(0)            9.233e-013
   H2                    4.617e-013  4.632e-013   -12.336   -12.334     0.001
K               2.516e-004
   K+                    2.502e-004  2.214e-004    -3.602    -3.655    -0.053
   KSO4-                 1.421e-006  1.261e-006    -5.847    -5.899    -0.052
   KOH                   3.045e-012  3.055e-012   -11.516   -11.515     0.001
Mg              6.705e-004
   Mg+2                  5.820e-004  3.699e-004    -3.235    -3.432    -0.197
   MgSO4                 6.796e-005  6.818e-005    -4.168    -4.166     0.001
   MgHCO3+               2.026e-005  1.797e-005    -4.693    -4.745    -0.052
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   MgCO3                 2.427e-007  2.435e-007    -6.615    -6.614     0.001
   MgOH+                 4.336e-009  3.847e-009    -8.363    -8.415    -0.052
Mn(2)           9.101e-008
   Mn+2                  6.488e-008  4.127e-008    -7.188    -7.384    -0.196
   MnHCO3+               1.747e-008  1.550e-008    -7.758    -7.810    -0.052
   MnSO4                 5.893e-009  5.912e-009    -8.230    -8.228     0.001
   MnCO3                 2.382e-009  2.390e-009    -8.623    -8.622     0.001
   MnCl+                 3.799e-010  3.370e-010    -9.420    -9.472    -0.052
   MnOH+                 3.536e-012  3.137e-012   -11.451   -11.503    -0.052
   MnCl2                 2.938e-013  2.948e-013   -12.532   -12.530     0.001
   MnCl3-                1.834e-016  1.627e-016   -15.736   -15.789    -0.052
Na              2.967e-003
   Na+                   2.948e-003  2.619e-003    -2.530    -2.582    -0.051
   NaSO4-                1.249e-005  1.108e-005    -4.904    -4.956    -0.052
   NaHCO3                6.184e-006  6.205e-006    -5.209    -5.207     0.001
   NaCO3-                3.334e-008  2.958e-008    -7.477    -7.529    -0.052
   NaOH                  6.864e-011  6.886e-011   -10.163   -10.162     0.001
O(0)            6.250e-007
   O2                    3.125e-007  3.135e-007    -6.505    -6.504     0.001
S(-2)           1.559e-007
   H2S                   1.067e-007  1.070e-007    -6.972    -6.971     0.001
   HS-                   4.927e-008  4.358e-008    -7.307    -7.361    -0.053
   Fe(HS)2               1.366e-013  1.370e-013   -12.865   -12.863     0.001
   S-2                   2.605e-014  1.633e-014   -13.584   -13.787    -0.203
   Fe(HS)3-              7.329e-019  6.502e-019   -18.135   -18.187    -0.052
S(6)            1.738e-003
   SO4-2                 1.380e-003  8.636e-004    -2.860    -3.064    -0.204
   CaSO4                 2.767e-004  2.776e-004    -3.558    -3.557     0.001
   MgSO4                 6.796e-005  6.818e-005    -4.168    -4.166     0.001
   NaSO4-                1.249e-005  1.108e-005    -4.904    -4.956    -0.052
   KSO4-                 1.421e-006  1.261e-006    -5.847    -5.899    -0.052
   HSO4-                 2.200e-008  1.952e-008    -7.658    -7.710    -0.052
   FeSO4                 1.159e-008  1.163e-008    -7.936    -7.934     0.001
   MnSO4                 5.893e-009  5.912e-009    -8.230    -8.228     0.001
   CaHSO4+               4.410e-010  3.912e-010    -9.356    -9.408    -0.052
   FeHSO4+               2.142e-014  1.900e-014   -13.669   -13.721    -0.052

------------------------------Saturation indices-----------------------------
--

      Phase               SI log IAP  log KT

      Anhydrite        -1.49   -5.84   -4.35  CaSO4
      Aragonite        -0.60   -8.92   -8.31  CaCO3
      Calcite          -0.45   -8.92   -8.46  CaCO3
      CO2(g)           -1.18   -2.60   -1.42  CO2
      Dolomite         -1.48  -18.48  -17.01  CaMg(CO3)2
      FeS(ppt)         -3.94   -7.85   -3.92  FeS
      Gypsum           -1.26   -5.84   -4.58  CaSO4:2H2O
      H2(g)            -9.20  -12.33   -3.13  H2
      H2O(g)           -1.60   -0.00    1.60  H2O
      H2S(g)           -6.01   -6.97   -0.96  H2S
      Halite           -6.85   -5.28    1.57  NaCl
      Hausmannite     -35.29   26.65   61.93  Mn3O4
      Mackinawite      -3.20   -7.85   -4.65  FeS
      Manganite      -14.92   10.42   25.34  MnOOH
      Melanterite      -7.90  -10.16   -2.25  FeSO4:7H2O
```

```
      O2(g)            -3.64   -6.50   -2.87  O2
      Pyrite            5.97  -12.61  -18.58  FeS2
      Pyrochroite      -9.38    5.82   15.20  Mn(OH)2
      Pyrolusite      -26.95   15.02   41.96  MnO2
      Rhodochrosite    -2.40  -13.52  -11.12  MnCO3
      Siderite         -2.36  -13.23  -10.87  FeCO3
      Sulfur           -2.74    2.23    4.97  S

-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using solution 5. MNW-5 D2
Using pure phase assemblage 3.      Equilibration with FeS ppt

-------------------------------Phase assemblage------------------------------
--

                                                      Moles in assemblage
Phase                 SI  log IAP  log KT      Initial       Final
Delta

FeS(ppt)            0.00   -3.91   -3.92   1.000e+001  1.000e+001 -1.547e-
005

-----------------------------Solution composition----------------------------
--

      Elements           Molality       Moles

      B                 7.401e-006  7.401e-006
      C                 7.342e-003  7.342e-003
      Ca                3.019e-003  3.019e-003
      Cl                2.265e-003  2.265e-003
      Fe                1.565e-005  1.565e-005
      K                 2.516e-004  2.516e-004
      Mg                6.705e-004  6.705e-004
      Mn                9.101e-008  9.101e-008
      Na                2.967e-003  2.967e-003
      S                 1.754e-003  1.754e-003

----------------------------Description of solution--------------------------
--

                                       pH  =   6.606      Charge balance
                                       pe  =  -2.871      Adjusted to redox
equilibrium
       Specific Conductance (uS/cm, 21 oC) = 927
                          Density (g/cm3)  =   0.99855
                        Activity of water  =   1.000
                           Ionic strength  =  1.441e-002
                         Mass of water (kg)  =  1.000e+000
                   Total alkalinity (eq/kg)  =  4.886e-003
                         Total CO2 (mol/kg)  =  7.342e-003
                       Temperature (deg C)  =  21.400
```

```
                  Electrical balance (eq)  =  1.676e-015
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =   0.00
                               Iterations  =  10
                                  Total H  = 1.110173e+002
                                  Total O  = 5.553273e+001

----------------------------Distribution of species--------------------------
--

                                                   Log       Log          Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   H+                    2.745e-007  2.475e-007    -6.561    -6.606    -0.045
   OH-                   3.464e-008  3.063e-008    -7.460    -7.514    -0.053
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                 7.382e-006  7.407e-006    -5.132    -5.130     0.001
   H2BO3-                1.816e-008  1.611e-008    -7.741    -7.793    -0.052
C(-4)           2.449e-008
   CH4                   2.449e-008  2.457e-008    -7.611    -7.610     0.001
C(4)            7.342e-003
   HCO3-                 4.749e-003  4.231e-003    -2.323    -2.374    -0.050
   CO2                   2.464e-003  2.472e-003    -2.608    -2.607     0.001
   CaHCO3+               9.515e-005  8.478e-005    -4.022    -4.072    -0.050
   MgHCO3+               2.034e-005  1.804e-005    -4.692    -4.744    -0.052
   NaHCO3                6.210e-006  6.231e-006    -5.207    -5.205     0.001
   FeHCO3+               3.345e-006  2.967e-006    -5.476    -5.528    -0.052
   CaCO3                 1.937e-006  1.944e-006    -5.713    -5.711     0.001
   CO3-2                 1.179e-006  7.429e-007    -5.929    -6.129    -0.201
   MgCO3                 2.472e-007  2.480e-007    -6.607    -6.605     0.001
   FeCO3                 1.246e-007  1.250e-007    -6.905    -6.903     0.001
   NaCO3-                3.398e-008  3.014e-008    -7.469    -7.521    -0.052
   MnHCO3+               1.752e-008  1.554e-008    -7.756    -7.809    -0.052
   MnCO3                 2.424e-009  2.432e-009    -8.616    -8.614     0.001
Ca              3.019e-003
   Ca+2                  2.646e-003  1.666e-003    -2.577    -2.778    -0.201
   CaSO4                 2.764e-004  2.773e-004    -3.559    -3.557     0.001
   CaHCO3+               9.515e-005  8.478e-005    -4.022    -4.072    -0.050
   CaCO3                 1.937e-006  1.944e-006    -5.713    -5.711     0.001
   CaOH+                 1.259e-009  1.117e-009    -8.900    -8.952    -0.052
   CaHSO4+               4.341e-010  3.851e-010    -9.362    -9.414    -0.052
Cl              2.265e-003
   Cl-                   2.265e-003  2.004e-003    -2.645    -2.698    -0.053
   FeCl+                 2.187e-008  1.940e-008    -7.660    -7.712    -0.052
   MnCl+                 3.792e-010  3.364e-010    -9.421    -9.473    -0.052
   MnCl2                 2.933e-013  2.942e-013   -12.533   -12.531     0.001
   MnCl3-                1.831e-016  1.624e-016   -15.737   -15.789    -0.052
   FeCl+2                6.435e-023  3.983e-023   -22.191   -22.400    -0.208
   FeCl2+                4.512e-025  4.002e-025   -24.346   -24.398    -0.052
   FeCl3                 7.993e-029  8.020e-029   -28.097   -28.096     0.001
Fe(2)           1.565e-005
   Fe+2                  1.103e-005  7.012e-006    -4.957    -5.154    -0.197
   FeHCO3+               3.345e-006  2.967e-006    -5.476    -5.528    -0.052
   FeSO4                 1.003e-006  1.007e-006    -5.999    -5.997     0.001
   FeCO3                 1.246e-007  1.250e-007    -6.905    -6.903     0.001
   Fe(HS)2               1.148e-007  1.152e-007    -6.940    -6.939     0.001
   FeCl+                 2.187e-008  1.940e-008    -7.660    -7.712    -0.052
```

```
   FeOH+                 7.689e-009  6.820e-009    -8.114    -8.166    -0.052
   Fe(HS)3-              6.072e-011  5.386e-011   -10.217   -10.269    -0.052
   FeHSO4+               1.827e-012  1.620e-012   -11.738   -11.790    -0.052
Fe(3)           2.847e-014
   Fe(OH)2+              2.041e-014  1.810e-014   -13.690   -13.742    -0.052
   Fe(OH)3               8.009e-015  8.036e-015   -14.096   -14.095     0.001
   Fe(OH)4-              2.882e-017  2.556e-017   -16.540   -16.592    -0.052
   FeOH+2                2.511e-017  1.554e-017   -16.600   -16.808    -0.208
   FeSO4+                7.270e-021  6.449e-021   -20.138   -20.191    -0.052
   Fe+3                  1.873e-021  7.388e-022   -20.728   -21.131    -0.404
   Fe(SO4)2-             1.353e-022  1.200e-022   -21.869   -21.921    -0.052
   FeCl+2                6.435e-023  3.983e-023   -22.191   -22.400    -0.208
   FeCl2+                4.512e-025  4.002e-025   -24.346   -24.398    -0.052
   FeHSO4+2              6.928e-027  4.289e-027   -26.159   -26.368    -0.208
   FeCl3                 7.993e-029  8.020e-029   -28.097   -28.096     0.001
   Fe2(OH)2+4            5.149e-032  7.561e-033   -31.288   -32.121    -0.833
   Fe3(OH)4+5            0.000e+000  0.000e+000   -42.096   -43.398    -1.302
H(0)            4.941e-011
   H2                    2.471e-011  2.479e-011   -10.607   -10.606     0.001
K               2.516e-004
   K+                    2.502e-004  2.214e-004    -3.602    -3.655    -0.053
   KSO4-                 1.420e-006  1.260e-006    -5.848    -5.900    -0.052
   KOH                   3.090e-012  3.100e-012   -11.510   -11.509     0.001
Mg              6.705e-004
   Mg+2                  5.820e-004  3.698e-004    -3.235    -3.432    -0.197
   MgSO4                 6.787e-005  6.810e-005    -4.168    -4.167     0.001
   MgHCO3+               2.034e-005  1.804e-005    -4.692    -4.744    -0.052
   MgCO3                 2.472e-007  2.480e-007    -6.607    -6.605     0.001
   MgOH+                 4.399e-009  3.902e-009    -8.357    -8.409    -0.052
Mn(2)           9.101e-008
   Mn+2                  6.481e-008  4.120e-008    -7.188    -7.385    -0.197
   MnHCO3+               1.752e-008  1.554e-008    -7.756    -7.809    -0.052
   MnSO4                 5.879e-009  5.898e-009    -8.231    -8.229     0.001
   MnCO3                 2.424e-009  2.432e-009    -8.616    -8.614     0.001
   MnCl+                 3.792e-010  3.364e-010    -9.421    -9.473    -0.052
   MnOH+                 3.583e-012  3.178e-012   -11.446   -11.498    -0.052
   MnCl2                 2.933e-013  2.942e-013   -12.533   -12.531     0.001
   MnCl3-                1.831e-016  1.624e-016   -15.737   -15.789    -0.052
Mn(3)           2.964e-036
   Mn+3                  2.964e-036  1.007e-036   -35.528   -35.997    -0.469
Na              2.967e-003
   Na+                   2.948e-003  2.619e-003    -2.530    -2.582    -0.051
   NaSO4-                1.248e-005  1.107e-005    -4.904    -4.956    -0.052
   NaHCO3                6.210e-006  6.231e-006    -5.207    -5.205     0.001
   NaCO3-                3.398e-008  3.014e-008    -7.469    -7.521    -0.052
   NaOH                  6.964e-011  6.987e-011   -10.157   -10.156     0.001
O(0)            0.000e+000
   O2                    0.000e+000  0.000e+000   -72.346   -72.345     0.001
S(-2)           1.544e-005
   H2S                   1.036e-005  1.039e-005    -4.985    -4.983     0.001
   HS-                   4.856e-006  4.294e-006    -5.314    -5.367    -0.053
   Fe(HS)2               1.148e-007  1.152e-007    -6.940    -6.939     0.001
   Fe(HS)3-              6.072e-011  5.386e-011   -10.217   -10.269    -0.052
   S-2                   2.606e-012  1.632e-012   -11.584   -11.787    -0.203
S(6)            1.739e-003
   SO4-2                 1.379e-003  8.629e-004    -2.860    -3.064    -0.204
   CaSO4                 2.764e-004  2.773e-004    -3.559    -3.557     0.001
```

```
   MgSO4                 6.787e-005  6.810e-005    -4.168    -4.167     0.001
   NaSO4-                1.248e-005  1.107e-005    -4.904    -4.956    -0.052
   KSO4-                 1.420e-006  1.260e-006    -5.848    -5.900    -0.052
   FeSO4                 1.003e-006  1.007e-006    -5.999    -5.997     0.001
   HSO4-                 2.167e-008  1.922e-008    -7.664    -7.716    -0.052
   MnSO4                 5.879e-009  5.898e-009    -8.231    -8.229     0.001
   CaHSO4+               4.341e-010  3.851e-010    -9.362    -9.414    -0.052
   FeHSO4+               1.827e-012  1.620e-012   -11.738   -11.790    -0.052
   FeSO4+                7.270e-021  6.449e-021   -20.138   -20.191    -0.052
   Fe(SO4)2-             1.353e-022  1.200e-022   -21.869   -21.921    -0.052
   FeHSO4+2              6.928e-027  4.289e-027   -26.159   -26.368    -0.208

------------------------------Saturation indices-----------------------------
--

      Phase               SI  log IAP  log KT

      Anhydrite        -1.49   -5.84   -4.35  CaSO4
      Aragonite        -0.59   -8.91   -8.31  CaCO3
      Calcite          -0.45   -8.91   -8.46  CaCO3
      CH4(g)           -4.78   -7.61   -2.83  CH4
      CO2(g)           -1.18   -2.61   -1.42  CO2
      Dolomite         -1.46  -18.47  -17.01  CaMg(CO3)2
      Fe(OH)3(a)       -6.20   -1.31    4.89  Fe(OH)3
      FeS(ppt)          0.00   -3.91   -3.92  FeS
      Goethite         -0.44   -1.31   -0.87  FeOOH
      Gypsum           -1.26   -5.84   -4.58  CaSO4:2H2O
      H2(g)            -7.47  -10.61   -3.13  H2
      H2O(g)           -1.60   -0.00    1.60  H2O
      H2S(g)           -4.03   -4.98   -0.96  H2S
      Halite           -6.85   -5.28    1.57  NaCl
      Hausmannite     -36.98   24.95   61.93  Mn3O4
      Hematite          1.11   -2.63   -3.73  Fe2O3
      Jarosite-K      -24.61  -33.54   -8.93  KFe3(SO4)2(OH)6
      Mackinawite       0.73   -3.91   -4.65  FeS
      Manganite       -15.78    9.56   25.34  MnOOH
      Melanterite      -5.97   -8.22   -2.25  FeSO4:7H2O
      O2(g)           -69.48  -72.34   -2.87  O2
      Pyrite           10.16   -8.42  -18.58  FeS2
      Pyrochroite      -9.37    5.83   15.20  Mn(OH)2
      Pyrolusite      -28.66   13.30   41.96  MnO2
      Rhodochrosite    -2.40  -13.51  -11.12  MnCO3
      Siderite         -0.42  -11.28  -10.87  FeCO3
      Sulfur           -2.48    2.49    4.97  S

------------------
End of simulation.
```

```
TITLE With and Without Equilibration with Mackinawite, Initial O2 and Fe 2+
set to 0.01 mg/L, Sulfide to 0.001 mg/L
SOLUTION 1-2 HSM-I2-5-082012
    temp      20.71
    pH        6.71
    pe        -2
    redox     pe
    units     mmol/kgw
    density   1
    Al        50 ug/kgw
    Alkalinity 270 mg/kgw     gfw 50
    Na        66300 ug/kgw
    O(0)      0.01 mg/kgw
    B         112 ug/kgw
    Fe(2)     0.01 ug/kgw
    Mn(2)     2.5 ug/kgw
    N(-3)     0.025 mg/kgw
    N(5)      0.01 mg/kgw
    S(6)      201 mg/kgw
    Mg        34000 ug/kgw
    K         15300 ug/kgw
    Ca        132000 ug/kgw
    Cl        35 mg/kgw     charge
    S(-2)     0.001 mg/kgw
    -water    1 # kg
EQUILIBRIUM_PHASES 1-2 Equilibration with Mackinawite
    Mackinawite 0 10
END
SOLUTION 3-4 HNW-14-12
    temp      19
    pH        7.1
    pe        -2
    redox     pe
    units     mg/kgw
    density   1
    Al        0
    Alkalinity 264
    B         80 ug/kgw
    Ca        121
    Cl        34 charge
    Fe(2)     0.01
    Mg        16.3
    Mn        5.3 ug/kgw
    K         9.84
    N(5)      0.02
    N(-3)     0.02
    Na        68.2
    O(0)      0.01
    S(-2)     0
    S(6)      188
    -water    1 # kg
EQUILIBRIUM_PHASES 1-2 Equilibration with Mackinawite
    Mackinawite 0 10
END
SOLUTION 5-6 MNW-5 D2
    temp      21.4
    pH        6.6
```

```
    pe         -2
    redox      pe
    units      mg/kgw
    density    1
    Fe(2)      0.01
    Mg         16.3
    Mn(2)      0.005
    N(5)       0
    N(-3)      0
    S(-2)      0.005
    S(6)       167
    Al         0
    Cl         42 charge
    Ca         121
    Alkalinity 243
    K          9.84
    O(0)       0.01
    Na         68.2
    B          0.08
    -water     1 # kg
EQUILIBRIUM_PHASES 3 Equilibration with Mackinawite
    Mackinawite 0 10
END
```

```
   Input file: C:\_Jons Work Files\MNA by Abiotic Reduction Job\PHREEQC
Simulations\Sulfide Redox test Final MNA Simulations _ DO and Fe set to
0.01_Mackinawite_Equilib_.pqi
  Output file: C:\_Jons Work Files\MNA by Abiotic Reduction Job\PHREEQC
Simulations\Sulfide Redox test Final MNA Simulations _ DO and Fe set to
0.01_Mackinawite_Equilib_.pqo
Database file: C:\Program Files\USGS\Phreeqc Interactive
2.18.5570\database\phreeqc.dat

------------------
Reading data base.
------------------

      SOLUTION_MASTER_SPECIES
      SOLUTION_SPECIES
      PHASES
      EXCHANGE_MASTER_SPECIES
      EXCHANGE_SPECIES
      SURFACE_MASTER_SPECIES
      SURFACE_SPECIES
      RATES
      END
------------------------------------
Reading input data for simulation 1.
------------------------------------

      DATABASE C:\Program Files\USGS\Phreeqc Interactive
2.18.5570\database\phreeqc.dat
      TITLE With and Without Equilibration with Mackinawite, O2 and Fe 2+ set
to 0.01 mg/L
      SOLUTION 1-2 HSM-I2-5-082012
          temp      20.71
          pH        6.71
          pe        -2
          redox     S(-2)/S(6)
          units     mmol/kgw
          density   1
          Al        50 ug/kgw
          Alkalinity 270 mg/kgw     gfw 50
          Na        66300 ug/kgw
          O(0)      0.01 mg/kgw
          B         112 ug/kgw
          Fe(2)     0.01 ug/kgw
          Mn(2)     2.5 ug/kgw
          N(-3)     0.025 mg/kgw
          N(5)      0.01 mg/kgw
          S(6)      201 mg/kgw
          Mg        34000 ug/kgw
          K         15300 ug/kgw
          Ca        132000 ug/kgw
          Cl        35 mg/kgw     charge
          S(-2)     0.001 mg/kgw
          water    1 # kg
      EQUILIBRIUM_PHASES 1-2 Equilibration with Mackinawite
          Mackinawite 0 10
      END
-----
```

```
TITLE
-----

 With and Without Equilibration with Mackinawite, O2 and Fe 2+ set to 0.01
mg/L

-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 1.     HSM-I2-5-082012

-----------------------------Solution composition----------------------------
--

      Elements           Molality       Moles

      Al                1.853e-006  1.853e-006
      Alkalinity        5.400e-003  5.400e-003
      B                 1.036e-005  1.036e-005
      Ca                3.293e-003  3.293e-003
      Cl                3.081e-003  3.081e-003  Charge balance
      Fe(2)             1.791e-010  1.791e-010
      K                 3.913e-004  3.913e-004
      Mg                1.398e-003  1.398e-003
      Mn(2)             4.551e-008  4.551e-008
      N(-3)             1.785e-006  1.785e-006
      N(5)              7.139e-007  7.139e-007
      Na                2.884e-003  2.884e-003
      O(0)              6.250e-007  6.250e-007
      S(-2)             3.119e-008  3.119e-008
      S(6)              2.092e-003  2.092e-003

----------------------------Description of solution--------------------------
--

                                       pH  =   6.710
                                       pe  =  -2.000
       Specific Conductance (uS/cm, 20 oC) = 1071
                          Density (g/cm3)  =   0.99882
                        Activity of water  =   1.000
                           Ionic strength  =  1.721e-002
                       Mass of water (kg)  =  1.000e+000
                    Total carbon (mol/kg)  =  7.525e-003
                       Total CO2 (mol/kg)  =  7.525e-003
                      Temperature (deg C)  =  20.710
                  Electrical balance (eq)  = -2.647e-013
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =   9
                                  Total H  = 1.110179e+002
                                  Total O  = 5.553507e+001

---------------------------------Redox couples-------------------------------
--

      Redox couple             pe  Eh (volts)
```

```
      N(-3)/N(5)           6.6985      0.3906
      O(-2)/O(0)          13.5448      0.7897
      S(-2)/S(6)          -2.6393     -0.1539

----------------------------Distribution of species--------------------------
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                                                    Log       Log         Log
   Species                  Molality    Activity  Molality  Activity     Gamma

   H+                      2.177e-007  1.950e-007    -6.662    -6.710    -0.048
   OH-                     4.206e-008  3.683e-008    -7.376    -7.434    -0.058
   H2O                     5.551e+001  9.997e-001     1.744    -0.000     0.000
Al              1.853e-006
   Al(OH)4-                1.418e-006  1.246e-006    -5.848    -5.904    -0.056
   Al(OH)2+                2.834e-007  2.491e-007    -6.548    -6.604    -0.056
   Al(OH)3                 1.354e-007  1.360e-007    -6.868    -6.867     0.002
   AlOH+2                  1.525e-008  9.103e-009    -7.817    -8.041    -0.224
   AlSO4+                  7.805e-010  6.861e-010    -9.108    -9.164    -0.056
   Al+3                    6.383e-010  2.369e-010    -9.195    -9.625    -0.430
   Al(SO4)2-               2.344e-011  2.060e-011   -10.630   -10.686    -0.056
   AlHSO4+2                1.918e-017  1.145e-017   -16.717   -16.941    -0.224
B               1.036e-005
   H3BO3                   1.033e-005  1.037e-005    -4.986    -4.984     0.002
   H2BO3-                  3.216e-008  2.827e-008    -7.493    -7.549    -0.056
C(4)            7.525e-003
   HCO3-                   5.224e-003  4.615e-003    -2.282    -2.336    -0.054
   CO2                     2.137e-003  2.145e-003    -2.670    -2.668     0.002
   CaHCO3+                 1.080e-004  9.544e-005    -3.966    -4.020    -0.054
   MgHCO3+                 4.469e-005  3.928e-005    -4.350    -4.406    -0.056
   NaHCO3                  6.517e-006  6.543e-006    -5.186    -5.184     0.002
   CaCO3                   2.727e-006  2.737e-006    -5.564    -5.563     0.002
   CO3-2                   1.663e-006  1.013e-006    -5.779    -5.994    -0.215
   MgCO3                   6.671e-007  6.697e-007    -6.176    -6.174     0.002
   NaCO3-                  4.344e-008  3.818e-008    -7.362    -7.418    -0.056
   MnHCO3+                 9.085e-009  7.985e-009    -8.042    -8.098    -0.056
   MnCO3                   1.556e-009  1.562e-009    -8.808    -8.806     0.002
   FeHCO3+                 4.020e-011  3.534e-011   -10.396   -10.452    -0.056
   FeCO3                   1.853e-012  1.861e-012   -11.732   -11.730     0.002
Ca              3.293e-003
   Ca+2                    2.861e-003  1.741e-003    -2.544    -2.759    -0.216
   CaSO4                   3.220e-004  3.233e-004    -3.492    -3.490     0.002
   CaHCO3+                 1.080e-004  9.544e-005    -3.966    -4.020    -0.054
   CaCO3                   2.727e-006  2.737e-006    -5.564    -5.563     0.002
   CaOH+                   1.686e-009  1.482e-009    -8.773    -8.829    -0.056
   CaHSO4+                 3.991e-010  3.508e-010    -9.399    -9.455    -0.056
Cl              3.081e-003
   Cl-                     3.081e-003  2.700e-003    -2.511    -2.569    -0.057
   MnCl+                   2.429e-010  2.135e-010    -9.615    -9.671    -0.056
   FeCl+                   3.246e-013  2.853e-013   -12.489   -12.545    -0.056
   MnCl2                   2.506e-013  2.516e-013   -12.601   -12.599     0.002
   MnCl3-                  2.128e-016  1.871e-016   -15.672   -15.728    -0.056
Fe(2)           1.791e-010
   Fe+2                    1.244e-010  7.657e-011    -9.905   -10.116    -0.211
   FeHCO3+                 4.020e-011  3.534e-011   -10.396   -10.452    -0.056
   FeSO4                   1.214e-011  1.218e-011   -10.916   -10.914     0.002
   FeCO3                   1.853e-012  1.861e-012   -11.732   -11.730     0.002
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   FeCl+                 3.246e-013  2.853e-013   -12.489   -12.545    -0.056
   FeOH+                 1.020e-013  8.967e-014   -12.991   -13.047    -0.056
   FeHSO4+               1.755e-017  1.542e-017   -16.756   -16.812    -0.056
   Fe(HS)2               6.953e-018  6.981e-018   -17.158   -17.156     0.002
   Fe(HS)3-              8.747e-024  7.688e-024   -23.058   -23.114    -0.056
H(0)            1.064e-011
   H2                    5.318e-012  5.339e-012   -11.274   -11.273     0.002
K               3.913e-004
   K+                    3.888e-004  3.407e-004    -3.410    -3.468    -0.057
   KSO4-                 2.446e-006  2.150e-006    -5.612    -5.668    -0.056
   KOH                   6.033e-012  6.056e-012   -11.220   -11.218     0.002
Mg              1.398e-003
   Mg+2                  1.203e-003  7.401e-004    -2.920    -3.131    -0.211
   MgSO4                 1.497e-004  1.503e-004    -3.825    -3.823     0.002
   MgHCO3+               4.469e-005  3.928e-005    -4.350    -4.406    -0.056
   MgCO3                 6.671e-007  6.697e-007    -6.176    -6.174     0.002
   MgOH+                 1.058e-008  9.299e-009    -7.976    -8.032    -0.056
Mn(2)           4.551e-008
   Mn+2                  3.155e-008  1.941e-008    -7.501    -7.712    -0.211
   MnHCO3+               9.085e-009  7.985e-009    -8.042    -8.098    -0.056
   MnSO4                 3.066e-009  3.079e-009    -8.513    -8.512     0.002
   MnCO3                 1.556e-009  1.562e-009    -8.808    -8.806     0.002
   MnCl+                 2.429e-010  2.135e-010    -9.615    -9.671    -0.056
   MnOH+                 2.041e-012  1.794e-012   -11.690   -11.746    -0.056
   MnCl2                 2.506e-013  2.516e-013   -12.601   -12.599     0.002
   MnCl3-                2.128e-016  1.871e-016   -15.672   -15.728    -0.056
   Mn(NO3)2              3.023e-020  3.035e-020   -19.520   -19.518     0.002
N(-3)           1.785e-006
   NH4+                  1.760e-006  1.533e-006    -5.755    -5.814    -0.060
   NH4SO4-               2.177e-008  1.914e-008    -7.662    -7.718    -0.056
   NH3                   3.281e-009  3.294e-009    -8.484    -8.482     0.002
N(5)            7.139e-007
   NO3-                  7.139e-007  6.236e-007    -6.146    -6.205    -0.059
   Mn(NO3)2              3.023e-020  3.035e-020   -19.520   -19.518     0.002
Na              2.884e-003
   Na+                   2.864e-003  2.521e-003    -2.543    -2.598    -0.055
   NaSO4-                1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   NaHCO3                6.517e-006  6.543e-006    -5.186    -5.184     0.002
   NaCO3-                4.344e-008  3.818e-008    -7.362    -7.418    -0.056
   NaOH                  8.507e-011  8.540e-011   -10.070   -10.069     0.002
O(0)            6.250e-007
   O2                    3.125e-007  3.137e-007    -6.505    -6.503     0.002
S(-2)           3.119e-008
   H2S                   1.964e-008  1.972e-008    -7.707    -7.705     0.002
   HS-                   1.155e-008  1.011e-008    -7.937    -7.995    -0.058
   S-2                   7.689e-015  4.650e-015   -14.114   -14.333    -0.218
   Fe(HS)2               6.953e-018  6.981e-018   -17.158   -17.156     0.002
   Fe(HS)3-              8.747e-024  7.688e-024   -23.058   -23.114    -0.056
S(6)            2.092e-003
   SO4-2                 1.605e-003  9.689e-004    -2.795    -3.014    -0.219
   CaSO4                 3.220e-004  3.233e-004    -3.492    -3.490     0.002
   MgSO4                 1.497e-004  1.503e-004    -3.825    -3.823     0.002
   NaSO4-                1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   KSO4-                 2.446e-006  2.150e-006    -5.612    -5.668    -0.056
   NH4SO4-               2.177e-008  1.914e-008    -7.662    -7.718    -0.056
   HSO4-                 1.906e-008  1.675e-008    -7.720    -7.776    -0.056
   MnSO4                 3.066e-009  3.079e-009    -8.513    -8.512     0.002
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   AlSO4+                7.805e-010  6.861e-010    -9.108    -9.164    -0.056
   CaHSO4+               3.991e-010  3.508e-010    -9.399    -9.455    -0.056
   Al(SO4)2-             2.344e-011  2.060e-011   -10.630   -10.686    -0.056
   FeSO4                 1.214e-011  1.218e-011   -10.916   -10.914     0.002
   AlHSO4+2              1.918e-017  1.145e-017   -16.717   -16.941    -0.224
   FeHSO4+               1.755e-017  1.542e-017   -16.756   -16.812    -0.056

------------------------------Saturation indices-----------------------------
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      Phase               SI  log IAP  log KT

      Al(OH)3(a)       -0.58   10.50   11.08  Al(OH)3
      Alunite           2.75    1.89   -0.86  KAl3(SO4)2(OH)6
      Anhydrite        -1.43   -5.77   -4.35  CaSO4
      Aragonite        -0.44   -8.75   -8.31  CaCO3
      Calcite          -0.30   -8.75   -8.46  CaCO3
      CO2(g)           -1.25   -2.67   -1.42  CO2
      Dolomite         -0.89  -17.88  -16.99  CaMg(CO3)2
      FeS(ppt)         -7.49  -11.40   -3.92  FeS
      Gibbsite          2.15   10.50    8.35  Al(OH)3
      Gypsum           -1.19   -5.77   -4.58  CaSO4:2H2O
      H2(g)            -8.14  -11.27   -3.13  H2
      H2O(g)           -1.62   -0.00    1.62  H2O
      H2S(g)           -6.76   -7.71   -0.95  H2S
      Halite           -6.74   -5.17    1.57  NaCl
      Hausmannite     -36.84   25.27   62.11  Mn3O4
      Mackinawite      -6.75  -11.40   -4.65  FeS
      Manganite       -15.56    9.78   25.34  MnOOH
      Melanterite     -10.87  -13.13   -2.26  FeSO4:7H2O
      NH3(g)          -10.34   -8.48    1.86  NH3
      O2(g)            -3.64   -6.50   -2.86  O2
      Pyrite            0.64  -17.96  -18.60  FeS2
      Pyrochroite      -9.49    5.71   15.20  Mn(OH)2
      Pyrolusite      -28.23   13.85   42.08  MnO2
      Rhodochrosite    -2.59  -13.71  -11.11  MnCO3
      Siderite         -5.25  -16.11  -10.86  FeCO3
      Sulfur           -4.55    0.44    4.98  S

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Beginning of batch-reaction calculations.
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Reaction step 1.

Using solution 1. HSM-I2-5-082012
Using pure phase assemblage 1.      Equilibration with Mackinawite

-------------------------------Phase assemblage------------------------------
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                                                      Moles in assemblage
Phase                  SI  log IAP  log KT      Initial       Final
Delta

Mackinawite         -0.00   -4.65   -4.65   1.000e+001  1.000e+001 -6.005e-
006
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-----------------------------Solution composition----------------------------
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      Elements           Molality       Moles

      Al                1.853e-006  1.853e-006
      B                 1.036e-005  1.036e-005
      C                 7.525e-003  7.525e-003
      Ca                3.293e-003  3.293e-003
      Cl                3.081e-003  3.081e-003
      Fe                6.006e-006  6.006e-006
      K                 3.913e-004  3.913e-004
      Mg                1.398e-003  1.398e-003
      Mn                4.551e-008  4.551e-008
      N                 2.499e-006  2.499e-006
      Na                2.884e-003  2.884e-003
      S                 2.098e-003  2.098e-003

----------------------------Description of solution--------------------------
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                                       pH  =   6.713      Charge balance
                                       pe  =  -2.920      Adjusted to redox
equilibrium
       Specific Conductance (uS/cm, 20 oC) = 1072
                          Density (g/cm3)  =   0.99882
                        Activity of water  =   1.000
                           Ionic strength  =  1.722e-002
                       Mass of water (kg)  =  1.000e+000
                 Total alkalinity (eq/kg)  =  5.412e-003
                       Total CO2 (mol/kg)  =  7.525e-003
                      Temperature (deg C)  =  20.710
                  Electrical balance (eq)  = -2.647e-013
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =  27
                                  Total H  = 1.110179e+002
                                  Total O  = 5.553507e+001

----------------------------Distribution of species--------------------------
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                                                   Log       Log         Log
   Species                   Molality    Activity  Molality  Activity     Gamma

   H+                    2.164e-007  1.938e-007     -6.665     -6.713     -0.048
   OH-                   4.231e-008  3.705e-008     -7.374     -7.431     -0.058
   H2O                   5.551e+001  9.997e-001      1.744     -0.000      0.000
Al              1.853e-006
   Al(OH)4-              1.421e-006  1.249e-006     -5.847     -5.903     -0.056
   Al(OH)2+              2.807e-007  2.467e-007     -6.552     -6.608     -0.056
   Al(OH)3               1.350e-007  1.355e-007     -6.870     -6.868      0.002
   AlOH+2                1.502e-008  8.963e-009     -7.823     -8.048     -0.224
   AlSO4+                7.641e-010  6.715e-010     -9.117     -9.173     -0.056
   Al+3                  6.250e-010  2.319e-010     -9.204     -9.635     -0.431
   Al(SO4)2-             2.295e-011  2.017e-011    -10.639    -10.695     -0.056
   AlHSO4+2              1.867e-017  1.114e-017    -16.729    -16.953     -0.224
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B                1.036e-005
   H3BO3            1.033e-005  1.037e-005    -4.986    -4.984     0.002
   H2BO3-           3.235e-008  2.843e-008    -7.490    -7.546    -0.056
C(-4)            9.315e-009
   CH4              9.315e-009  9.352e-009    -8.031    -8.029     0.002
C(4)             7.525e-003
   HCO3-            5.232e-003  4.622e-003    -2.281    -2.335    -0.054
   CO2              2.127e-003  2.136e-003    -2.672    -2.670     0.002
   CaHCO3+          1.082e-004  9.556e-005    -3.966    -4.020    -0.054
   MgHCO3+          4.475e-005  3.933e-005    -4.349    -4.405    -0.056
   NaHCO3           6.527e-006  6.553e-006    -5.185    -5.184     0.002
   CaCO3            2.746e-006  2.757e-006    -5.561    -5.560     0.002
   CO3-2            1.676e-006  1.021e-006    -5.776    -5.991    -0.215
   FeHCO3+          1.348e-006  1.185e-006    -5.870    -5.926    -0.056
   MgCO3            6.719e-007  6.746e-007    -6.173    -6.171     0.002
   FeCO3            6.252e-008  6.276e-008    -7.204    -7.202     0.002
   NaCO3-           4.377e-008  3.847e-008    -7.359    -7.415    -0.056
   MnHCO3+          9.092e-009  7.991e-009    -8.041    -8.097    -0.056
   MnCO3            1.566e-009  1.573e-009    -8.805    -8.803     0.002
Ca               3.293e-003
   Ca+2             2.861e-003  1.741e-003    -2.544    -2.759    -0.216
   CaSO4            3.219e-004  3.232e-004    -3.492    -3.491     0.002
   CaHCO3+          1.082e-004  9.556e-005    -3.966    -4.020    -0.054
   CaCO3            2.746e-006  2.757e-006    -5.561    -5.560     0.002
   CaOH+            1.696e-009  1.490e-009    -8.771    -8.827    -0.056
   CaHSO4+          3.967e-010  3.487e-010    -9.402    -9.458    -0.056
Cl               3.081e-003
   Cl-              3.081e-003  2.699e-003    -2.511    -2.569    -0.057
   FeCl+            1.087e-008  9.553e-009    -7.964    -8.020    -0.056
   MnCl+            2.427e-010  2.133e-010    -9.615    -9.671    -0.056
   MnCl2            2.504e-013  2.514e-013   -12.601   -12.600     0.002
   MnCl3-           2.127e-016  1.869e-016   -15.672   -15.728    -0.056
   FeCl+2           2.757e-023  1.645e-023   -22.560   -22.784    -0.224
   FeCl2+           2.591e-025  2.277e-025   -24.587   -24.643    -0.056
   FeCl3            6.123e-029  6.147e-029   -28.213   -28.211     0.002
Fe(2)            6.006e-006
   Fe+2             4.168e-006  2.564e-006    -5.380    -5.591    -0.211
   FeHCO3+          1.348e-006  1.185e-006    -5.870    -5.926    -0.056
   FeSO4            4.064e-007  4.080e-007    -6.391    -6.389     0.002
   FeCO3            6.252e-008  6.276e-008    -7.204    -7.202     0.002
   FeCl+            1.087e-008  9.553e-009    -7.964    -8.020    -0.056
   Fe(HS)2          6.580e-009  6.606e-009    -8.182    -8.180     0.002
   FeOH+            3.437e-009  3.020e-009    -8.464    -8.520    -0.056
   Fe(HS)3-         1.392e-012  1.223e-012   -11.856   -11.913    -0.056
   FeHSO4+          5.842e-013  5.134e-013   -12.233   -12.290    -0.056
Fe(3)            1.460e-014
   Fe(OH)2+         9.836e-015  8.645e-015   -14.007   -14.063    -0.056
   Fe(OH)3          4.733e-015  4.751e-015   -14.325   -14.323     0.002
   Fe(OH)4-         2.135e-017  1.876e-017   -16.671   -16.727    -0.056
   FeOH+2           1.001e-017  5.971e-018   -17.000   -17.224    -0.224
   FeSO4+           2.543e-021  2.236e-021   -20.595   -20.651    -0.056
   Fe+3             6.244e-022  2.317e-022   -21.205   -21.635    -0.431
   Fe(SO4)2-        5.301e-023  4.659e-023   -22.276   -22.332    -0.056
   FeCl+2           2.757e-023  1.645e-023   -22.560   -22.784    -0.224
   FeCl2+           2.591e-025  2.277e-025   -24.587   -24.643    -0.056
   FeHSO4+2         1.953e-027  1.165e-027   -26.709   -26.934    -0.224
   FeCl3            6.123e-029  6.147e-029   -28.213   -28.211     0.002
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   Fe2(OH)2+4            9.057e-033  1.149e-033   -32.043   -32.940    -0.897
   Fe3(OH)4+5            0.000e+000  0.000e+000   -43.107   -44.509    -1.401
H(0)            3.835e-011
   H2                    1.918e-011  1.925e-011   -10.717   -10.716     0.002
K               3.913e-004
   K+                    3.888e-004  3.407e-004    -3.410    -3.468    -0.057
   KSO4-                 2.446e-006  2.150e-006    -5.612    -5.668    -0.056
   KOH                   6.068e-012  6.092e-012   -11.217   -11.215     0.002
Mg              1.398e-003
   Mg+2                  1.203e-003  7.399e-004    -2.920    -3.131    -0.211
   MgSO4                 1.497e-004  1.503e-004    -3.825    -3.823     0.002
   MgHCO3+               4.475e-005  3.933e-005    -4.349    -4.405    -0.056
   MgCO3                 6.719e-007  6.746e-007    -6.173    -6.171     0.002
   MgOH+                 1.064e-008  9.352e-009    -7.973    -8.029    -0.056
Mn(2)           4.551e-008
   Mn+2                  3.154e-008  1.940e-008    -7.501    -7.712    -0.211
   MnHCO3+               9.092e-009  7.991e-009    -8.041    -8.097    -0.056
   MnSO4                 3.065e-009  3.077e-009    -8.514    -8.512     0.002
   MnCO3                 1.566e-009  1.573e-009    -8.805    -8.803     0.002
   MnCl+                 2.427e-010  2.133e-010    -9.615    -9.671    -0.056
   MnOH+                 2.052e-012  1.804e-012   -11.688   -11.744    -0.056
   MnCl2                 2.504e-013  2.514e-013   -12.601   -12.600     0.002
   MnCl3-                2.127e-016  1.869e-016   -15.672   -15.728    -0.056
   Mn(NO3)2              0.000e+000  0.000e+000  -173.156  -173.155     0.002
Mn(3)           1.218e-036
   Mn+3                  1.218e-036  3.813e-037   -35.914   -36.419    -0.504
N(-3)           2.287e-006
   NH4+                  2.255e-006  1.964e-006    -5.647    -5.707    -0.060
   NH4SO4-               2.790e-008  2.452e-008    -7.554    -7.611    -0.056
   NH3                   4.229e-009  4.245e-009    -8.374    -8.372     0.002
N(0)            2.121e-007
   N2                    1.061e-007  1.065e-007    -6.974    -6.973     0.002
N(3)            0.000e+000
   NO2-                  0.000e+000  0.000e+000   -61.511   -61.569    -0.059
N(5)            0.000e+000
   NO3-                  0.000e+000  0.000e+000   -82.965   -83.023    -0.059
   Mn(NO3)2              0.000e+000  0.000e+000  -173.156  -173.155     0.002
Na              2.884e-003
   Na+                   2.864e-003  2.521e-003    -2.543    -2.598    -0.055
   NaSO4-                1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   NaHCO3                6.527e-006  6.553e-006    -5.185    -5.184     0.002
   NaCO3-                4.377e-008  3.847e-008    -7.359    -7.415    -0.056
   NaOH                  8.557e-011  8.591e-011   -10.068   -10.066     0.002
O(0)            0.000e+000
   O2                    0.000e+000  0.000e+000   -72.356   -72.354     0.002
S(-2)           5.237e-006
   H2S                   3.282e-006  3.295e-006    -5.484    -5.482     0.002
   HS-                   1.942e-006  1.700e-006    -5.712    -5.769    -0.058
   Fe(HS)2               6.580e-009  6.606e-009    -8.182    -8.180     0.002
   Fe(HS)3-              1.392e-012  1.223e-012   -11.856   -11.913    -0.056
   S-2                   1.301e-012  7.864e-013   -11.886   -12.104    -0.218
S(6)            2.093e-003
   SO4-2                 1.605e-003  9.690e-004    -2.794    -3.014    -0.219
   CaSO4                 3.219e-004  3.232e-004    -3.492    -3.491     0.002
   MgSO4                 1.497e-004  1.503e-004    -3.825    -3.823     0.002
   NaSO4-                1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   KSO4-                 2.446e-006  2.150e-006    -5.612    -5.668    -0.056
```

```
   FeSO4                 4.064e-007  4.080e-007    -6.391    -6.389     0.002
   NH4SO4-               2.790e-008  2.452e-008    -7.554    -7.611    -0.056
   HSO4-                 1.895e-008  1.666e-008    -7.722    -7.778    -0.056
   MnSO4                 3.065e-009  3.077e-009    -8.514    -8.512     0.002
   AlSO4+                7.641e-010  6.715e-010    -9.117    -9.173    -0.056
   CaHSO4+               3.967e-010  3.487e-010    -9.402    -9.458    -0.056
   Al(SO4)2-             2.295e-011  2.017e-011   -10.639   -10.695    -0.056
   FeHSO4+               5.842e-013  5.134e-013   -12.233   -12.290    -0.056
   AlHSO4+2              1.867e-017  1.114e-017   -16.729   -16.953    -0.224
   FeSO4+                2.543e-021  2.236e-021   -20.595   -20.651    -0.056
   Fe(SO4)2-             5.301e-023  4.659e-023   -22.276   -22.332    -0.056
   FeHSO4+2              1.953e-027  1.165e-027   -26.709   -26.934    -0.224

------------------------------Saturation indices-----------------------------
--

      Phase               SI log IAP  log KT

      Al(OH)3(a)       -0.58   10.50   11.08  Al(OH)3
      Alunite           2.74    1.88   -0.86  KAl3(SO4)2(OH)6
      Anhydrite        -1.43   -5.77   -4.35  CaSO4
      Aragonite        -0.44   -8.75   -8.31  CaCO3
      Calcite          -0.29   -8.75   -8.46  CaCO3
      CH4(g)           -5.21   -8.03   -2.82  CH4
      CO2(g)           -1.25   -2.67   -1.42  CO2
      Dolomite         -0.88  -17.87  -16.99  CaMg(CO3)2
      Fe(OH)3(a)       -6.39   -1.50    4.89  Fe(OH)3
      FeS(ppt)         -0.73   -4.65   -3.92  FeS
      Gibbsite          2.15   10.50    8.35  Al(OH)3
      Goethite         -0.65   -1.50   -0.85  FeOOH
      Gypsum           -1.19   -5.77   -4.58  CaSO4:2H2O
      H2(g)            -7.58  -10.72   -3.13  H2
      H2O(g)           -1.62   -0.00    1.62  H2O
      H2S(g)           -4.53   -5.48   -0.95  H2S
      Halite           -6.74   -5.17    1.57  NaCl
      Hausmannite     -37.38   24.72   62.11  Mn3O4
      Hematite          0.68   -3.00   -3.68  Fe2O3
      Jarosite-K      -25.25  -34.13   -8.88  KFe3(SO4)2(OH)6
      Mackinawite      -0.00   -4.65   -4.65  FeS
      Manganite       -15.84    9.50   25.34  MnOOH
      Melanterite      -6.34   -8.61   -2.26  FeSO4:7H2O
      N2(g)            -3.73   -6.97   -3.25  N2
      NH3(g)          -10.23   -8.37    1.86  NH3
      O2(g)           -69.49  -72.35   -2.86  O2
      Pyrite            9.05   -9.55  -18.60  FeS2
      Pyrochroite      -9.49    5.71   15.20  Mn(OH)2
      Pyrolusite      -28.78   13.30   42.08  MnO2
      Rhodochrosite    -2.59  -13.70  -11.11  MnCO3
      Siderite         -0.72  -11.58  -10.86  FeCO3
      Sulfur           -2.88    2.10    4.98  S

------------------
End of simulation.
------------------

------------------------------------
Reading input data for simulation 2.
```

```
------------------------------------

      SOLUTION 3-4 HNW-14-12
          temp      19
          pH        7.1
          pe        -2
          redox     S(-2)/S(6)
          units     mg/kgw
          density   1
          Al        0
          Alkalinity 264
          B         80 ug/kgw
          Ca        121
          Cl        34 charge
          Fe(2)     0.01
          Mg        16.3
          Mn        5.3 ug/kgw
          K         9.84
          N(5)      0.02
          N(-3)     0.02
          Na        68.2
          O(0)      0.01
          S(-2)     0
          S(6)      188
          water    1 # kg
      EQUILIBRIUM_PHASES 1-2 Equilibration with Mackinawite
          Mackinawite 0 10
      END
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 3.     HNW-14-12

WARNING: Analytical data missing for redox couple, S(-2)/S(6)
       Using pe instead.
-----------------------------Solution composition------------------------------
--

      Elements           Molality       Moles

      Alkalinity       5.275e-003  5.275e-003
      B                7.401e-006  7.401e-006
      Ca               3.019e-003  3.019e-003
      Cl               1.408e-003  1.408e-003  Charge balance
      Fe(2)            1.791e-007  1.791e-007
      K                2.516e-004  2.516e-004
      Mg               6.705e-004  6.705e-004
      Mn               9.647e-008  9.647e-008
      N(-3)            1.428e-006  1.428e-006
      N(5)             1.428e-006  1.428e-006
      Na               2.967e-003  2.967e-003
      O(0)             6.250e-007  6.250e-007
      S(6)             1.957e-003  1.957e-003

----------------------------Description of solution----------------------------
--
```

```
                                       pH  =   7.100
                                       pe  =  -2.000
       Specific Conductance (uS/cm, 19 oC) = 853
                          Density (g/cm3)  =   0.99907
                        Activity of water  =   1.000
                           Ionic strength  =  1.445e-002
                       Mass of water (kg)  =  1.000e+000
                    Total carbon (mol/kg)  =  6.150e-003
                       Total CO2 (mol/kg)  =  6.150e-003
                      Temperature (deg C)  =  19.000
                  Electrical balance (eq)  = -3.500e-016
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =  10
                                  Total H  = 1.110177e+002
                                  Total O  = 5.553164e+001

---------------------------------Redox couples-------------------------------
--

      Redox couple             pe  Eh (volts)

      N(-3)/N(5)           6.3627      0.3688
      O(-2)/O(0)          13.3014      0.7710

----------------------------Distribution of species-------------------------
--

                                                   Log       Log         Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   OH-                   8.916e-008  7.886e-008    -7.050    -7.103    -0.053
   H+                    8.806e-008  7.943e-008    -7.055    -7.100    -0.045
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                 7.347e-006  7.371e-006    -5.134    -5.132     0.001
   H2BO3-                5.382e-008  4.775e-008    -7.269    -7.321    -0.052
C(4)            6.150e-003
   HCO3-                 5.129e-003  4.571e-003    -2.290    -2.340    -0.050
   CO2                   8.858e-004  8.888e-004    -3.053    -3.051     0.001
   CaHCO3+               9.714e-005  8.657e-005    -4.013    -4.063    -0.050
   MgHCO3+               2.160e-005  1.916e-005    -4.666    -4.718    -0.052
   NaHCO3                6.706e-006  6.728e-006    -5.174    -5.172     0.001
   CaCO3                 5.870e-006  5.889e-006    -5.231    -5.230     0.001
   CO3-2                 3.753e-006  2.368e-006    -5.426    -5.626    -0.200
   MgCO3                 7.530e-007  7.555e-007    -6.123    -6.122     0.001
   NaCO3-                9.552e-008  8.475e-008    -7.020    -7.072    -0.052
   FeHCO3+               4.005e-008  3.554e-008    -7.397    -7.449    -0.052
   MnHCO3+               1.862e-008  1.653e-008    -7.730    -7.782    -0.052
   MnCO3                 7.604e-009  7.630e-009    -8.119    -8.117     0.001
   FeCO3                 4.402e-009  4.416e-009    -8.356    -8.355     0.001
Ca              3.019e-003
   Ca+2                  2.612e-003  1.647e-003    -2.583    -2.783    -0.200
   CaSO4                 3.035e-004  3.045e-004    -3.518    -3.516     0.001
   CaHCO3+               9.714e-005  8.657e-005    -4.013    -4.063    -0.050
   CaCO3                 5.870e-006  5.889e-006    -5.231    -5.230     0.001
   CaOH+                 3.878e-009  3.441e-009    -8.411    -8.463    -0.052
```

```
   CaHSO4+               1.488e-010  1.321e-010    -9.827    -9.879    -0.052
Cl              1.408e-003
   Cl-                   1.408e-003  1.246e-003    -2.851    -2.904    -0.053
   MnCl+                 2.321e-010  2.060e-010    -9.634    -9.686    -0.052
   FeCl+                 1.508e-010  1.338e-010    -9.822    -9.874    -0.052
   MnCl2                 1.117e-013  1.120e-013   -12.952   -12.951     0.001
   MnCl3-                4.335e-017  3.846e-017   -16.363   -16.415    -0.052
Fe(2)           1.791e-007
   Fe+2                  1.221e-007  7.775e-008    -6.913    -7.109    -0.196
   FeHCO3+               4.005e-008  3.554e-008    -7.397    -7.449    -0.052
   FeSO4                 1.209e-008  1.213e-008    -7.918    -7.916     0.001
   FeCO3                 4.402e-009  4.416e-009    -8.356    -8.355     0.001
   FeOH+                 2.207e-010  1.958e-010    -9.656    -9.708    -0.052
   FeCl+                 1.508e-010  1.338e-010    -9.822    -9.874    -0.052
   FeHSO4+               7.025e-015  6.233e-015   -14.153   -14.205    -0.052
H(0)            9.464e-014
   H2                    4.732e-014  4.748e-014   -13.325   -13.324     0.001
K               2.516e-004
   K+                    2.501e-004  2.213e-004    -3.602    -3.655    -0.053
   KSO4-                 1.545e-006  1.371e-006    -5.811    -5.863    -0.052
   KOH                   9.627e-012  9.659e-012   -11.017   -11.015     0.001
Mg              6.705e-004
   Mg+2                  5.763e-004  3.666e-004    -3.239    -3.436    -0.196
   MgSO4                 7.176e-005  7.200e-005    -4.144    -4.143     0.001
   MgHCO3+               2.160e-005  1.916e-005    -4.666    -4.718    -0.052
   MgCO3                 7.530e-007  7.555e-007    -6.123    -6.122     0.001
   MgOH+                 1.086e-008  9.637e-009    -7.964    -8.016    -0.052
Mn(2)           9.647e-008
   Mn+2                  6.373e-008  4.056e-008    -7.196    -7.392    -0.196
   MnHCO3+               1.862e-008  1.653e-008    -7.730    -7.782    -0.052
   MnCO3                 7.604e-009  7.630e-009    -8.119    -8.117     0.001
   MnSO4                 6.275e-009  6.296e-009    -8.202    -8.201     0.001
   MnCl+                 2.321e-010  2.060e-010    -9.634    -9.686    -0.052
   MnOH+                 8.978e-012  7.966e-012   -11.047   -11.099    -0.052
   MnCl2                 1.117e-013  1.120e-013   -12.952   -12.951     0.001
   MnCl3-                4.335e-017  3.846e-017   -16.363   -16.415    -0.052
   Mn(NO3)2              2.592e-019  2.600e-019   -18.586   -18.585     0.001
Mn(3)           1.504e-035
   Mn+3                  1.504e-035  5.126e-036   -34.823   -35.290    -0.467
N(-3)           1.428e-006
   NH4+                  1.405e-006  1.237e-006    -5.852    -5.908    -0.055
   NH4SO4-               1.762e-008  1.563e-008    -7.754    -7.806    -0.052
   NH3                   5.737e-009  5.756e-009    -8.241    -8.240     0.001
N(5)            1.428e-006
   NO3-                  1.428e-006  1.260e-006    -5.845    -5.900    -0.054
   Mn(NO3)2              2.592e-019  2.600e-019   -18.586   -18.585     0.001
Na              2.967e-003
   Na+                   2.946e-003  2.618e-003    -2.531    -2.582    -0.051
   NaSO4-                1.395e-005  1.238e-005    -4.855    -4.907    -0.052
   NaHCO3                6.706e-006  6.728e-006    -5.174    -5.172     0.001
   NaCO3-                9.552e-008  8.475e-008    -7.020    -7.072    -0.052
   NaOH                  2.169e-010  2.177e-010    -9.664    -9.662     0.001
O(0)            6.250e-007
   O2                    3.125e-007  3.135e-007    -6.505    -6.504     0.001
S(6)            1.957e-003
   SO4-2                 1.566e-003  9.809e-004    -2.805    -3.008    -0.203
   CaSO4                 3.035e-004  3.045e-004    -3.518    -3.516     0.001
```

```
   MgSO4                7.176e-005  7.200e-005    -4.144    -4.143     0.001
   NaSO4-               1.395e-005  1.238e-005    -4.855    -4.907    -0.052
   KSO4-                1.545e-006  1.371e-006    -5.811    -5.863    -0.052
   NH4SO4-              1.762e-008  1.563e-008    -7.754    -7.806    -0.052
   FeSO4                1.209e-008  1.213e-008    -7.918    -7.916     0.001
   HSO4-                7.515e-009  6.668e-009    -8.124    -8.176    -0.052
   MnSO4                6.275e-009  6.296e-009    -8.202    -8.201     0.001
   CaHSO4+              1.488e-010  1.321e-010    -9.827    -9.879    -0.052
   FeHSO4+              7.025e-015  6.233e-015   -14.153   -14.205    -0.052

------------------------------Saturation indices-----------------------------
--

      Phase               SI log IAP  log KT

      Anhydrite        -1.45   -5.79   -4.34  CaSO4
      Aragonite        -0.11   -8.41   -8.30  CaCO3
      Calcite           0.04   -8.41   -8.45  CaCO3
      CO2(g)           -1.66   -3.05   -1.39  CO2
      Dolomite         -0.52  -17.47  -16.95  CaMg(CO3)2
      Gypsum           -1.21   -5.79   -4.58  CaSO4:2H2O
      H2(g)           -10.20  -13.32   -3.12  H2
      H2O(g)           -1.67   -0.00    1.67  H2O
      Halite           -7.05   -5.49    1.57  NaCl
      Hausmannite     -31.92   30.62   62.54  Mn3O4
      Manganite       -13.43   11.91   25.34  MnOOH
      Melanterite      -7.83  -10.12   -2.28  FeSO4:7H2O
      NH3(g)          -10.13   -8.24    1.89  NH3
      O2(g)            -3.66   -6.50   -2.85  O2
      Pyrochroite      -8.39    6.81   15.20  Mn(OH)2
      Pyrolusite      -25.35   17.01   42.36  MnO2
      Rhodochrosite    -1.91  -13.02  -11.11  MnCO3
      Siderite         -1.88  -12.73  -10.85  FeCO3

-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using solution 3. HNW-14-12
Using pure phase assemblage 1.      Equilibration with Mackinawite

-------------------------------Phase assemblage------------------------------
--

                                                      Moles in assemblage
Phase                  SI log IAP  log KT      Initial       Final
Delta

Mackinawite         -0.00   -4.65   -4.65   1.000e+001  1.000e+001 -3.509e-
006

-----------------------------Solution composition----------------------------
--

      Elements           Molality       Moles
```

```
      B                 7.401e-006  7.401e-006
      C                 6.150e-003  6.150e-003
      Ca                3.019e-003  3.019e-003
      Cl                1.408e-003  1.408e-003
      Fe                3.689e-006  3.689e-006
      K                 2.516e-004  2.516e-004
      Mg                6.705e-004  6.705e-004
      Mn                9.647e-008  9.647e-008
      N                 2.856e-006  2.856e-006
      Na                2.967e-003  2.967e-003
      S                 1.961e-003  1.961e-003

----------------------------Description of solution--------------------------
--

                                       pH  =   7.103      Charge balance
                                       pe  =  -3.303      Adjusted to redox
equilibrium
       Specific Conductance (uS/cm, 19 oC) = 853
                          Density (g/cm3)  =   0.99907
                        Activity of water  =   1.000
                           Ionic strength  =  1.446e-002
                       Mass of water (kg)  =  1.000e+000
                 Total alkalinity (eq/kg)  =  5.282e-003
                       Total CO2 (mol/kg)  =  6.150e-003
                      Temperature (deg C)  =  19.000
                  Electrical balance (eq)  = -2.515e-016
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =  11
                                  Total H  = 1.110177e+002
                                  Total O  = 5.553164e+001

----------------------------Distribution of species--------------------------
--

                                                   Log       Log       Log
   Species                   Molality    Activity  Molality  Activity     Gamma

   OH-                    8.975e-008  7.938e-008    -7.047    -7.100    -0.053
   H+                     8.749e-008  7.892e-008    -7.058    -7.103    -0.045
   H2O                    5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                  7.346e-006  7.371e-006    -5.134    -5.132     0.001
   H2BO3-                 5.417e-008  4.806e-008    -7.266    -7.318    -0.052
C(-4)           5.765e-009
   CH4                    5.765e-009  5.785e-009    -8.239    -8.238     0.001
C(4)            6.150e-003
   HCO3-                  5.133e-003  4.574e-003    -2.290    -2.340    -0.050
   CO2                    8.807e-004  8.837e-004    -3.055    -3.054     0.001
   CaHCO3+                9.719e-005  8.662e-005    -4.012    -4.062    -0.050
   MgHCO3+                2.161e-005  1.917e-005    -4.665    -4.717    -0.052
   NaHCO3                 6.711e-006  6.733e-006    -5.173    -5.172     0.001
   CaCO3                  5.912e-006  5.931e-006    -5.228    -5.227     0.001
   CO3-2                  3.781e-006  2.385e-006    -5.422    -5.622    -0.200
   FeHCO3+                8.250e-007  7.319e-007    -6.084    -6.136    -0.052
   MgCO3                  7.583e-007  7.609e-007    -6.120    -6.119     0.001
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```
   NaCO3-                9.622e-008  8.537e-008    -7.017    -7.069    -0.052
   FeCO3                 9.125e-008  9.156e-008    -7.040    -7.038     0.001
   MnHCO3+               1.862e-008  1.652e-008    -7.730    -7.782    -0.052
   MnCO3                 7.654e-009  7.679e-009    -8.116    -8.115     0.001
Ca              3.019e-003
   Ca+2                  2.612e-003  1.647e-003    -2.583    -2.783    -0.200
   CaSO4                 3.036e-004  3.046e-004    -3.518    -3.516     0.001
   CaHCO3+               9.719e-005  8.662e-005    -4.012    -4.062    -0.050
   CaCO3                 5.912e-006  5.931e-006    -5.228    -5.227     0.001
   CaOH+                 3.903e-009  3.463e-009    -8.409    -8.461    -0.052
   CaHSO4+               1.479e-010  1.312e-010    -9.830    -9.882    -0.052
Cl              1.408e-003
   Cl-                   1.408e-003  1.246e-003    -2.851    -2.904    -0.053
   FeCl+                 3.102e-009  2.753e-009    -8.508    -8.560    -0.052
   MnCl+                 2.319e-010  2.058e-010    -9.635    -9.687    -0.052
   MnCl2                 1.116e-013  1.119e-013   -12.952   -12.951     0.001
   MnCl3-                4.331e-017  3.843e-017   -16.363   -16.415    -0.052
   FeCl+2                2.721e-024  1.686e-024   -23.565   -23.773    -0.208
   FeCl2+                1.285e-026  1.140e-026   -25.891   -25.943    -0.052
   FeCl3                 1.416e-030  1.420e-030   -29.849   -29.848     0.001
Fe(2)           3.689e-006
   Fe+2                  2.514e-006  1.600e-006    -5.600    -5.796    -0.196
   FeHCO3+               8.250e-007  7.319e-007    -6.084    -6.136    -0.052
   FeSO4                 2.488e-007  2.497e-007    -6.604    -6.603     0.001
   FeCO3                 9.125e-008  9.156e-008    -7.040    -7.038     0.001
   FeOH+                 4.572e-009  4.057e-009    -8.340    -8.392    -0.052
   FeCl+                 3.102e-009  2.753e-009    -8.508    -8.560    -0.052
   Fe(HS)2               1.749e-009  1.755e-009    -8.757    -8.756     0.001
   Fe(HS)3-              2.389e-013  2.119e-013   -12.622   -12.674    -0.052
   FeHSO4+               1.437e-013  1.275e-013   -12.843   -12.894    -0.052
Fe(3)           2.462e-014
   Fe(OH)3               1.285e-014  1.289e-014   -13.891   -13.890     0.001
   Fe(OH)2+              1.163e-014  1.032e-014   -13.934   -13.986    -0.052
   Fe(OH)4-              1.313e-016  1.165e-016   -15.882   -15.934    -0.052
   FeOH+2                5.006e-018  3.103e-018   -17.300   -17.508    -0.208
   FeSO4+                5.761e-022  5.112e-022   -21.239   -21.291    -0.052
   Fe+3                  1.376e-022  5.440e-023   -21.861   -22.264    -0.403
   Fe(SO4)2-             1.208e-023  1.072e-023   -22.918   -22.970    -0.052
   FeCl+2                2.721e-024  1.686e-024   -23.565   -23.773    -0.208
   FeCl2+                1.285e-026  1.140e-026   -25.891   -25.943    -0.052
   FeHSO4+2              1.757e-028  1.089e-028   -27.755   -27.963    -0.208
   FeCl3                 1.416e-030  1.420e-030   -29.849   -29.848     0.001
   Fe2(OH)2+4            2.262e-033  3.337e-034   -32.645   -33.477    -0.831
   Fe3(OH)4+5            0.000e+000  0.000e+000   -43.599   -44.898    -1.299
H(0)            3.768e-011
   H2                    1.884e-011  1.890e-011   -10.725   -10.723     0.001
K               2.516e-004
   K+                    2.501e-004  2.213e-004    -3.602    -3.655    -0.053
   KSO4-                 1.546e-006  1.372e-006    -5.811    -5.863    -0.052
   KOH                   9.690e-012  9.722e-012   -11.014   -11.012     0.001
Mg              6.705e-004
   Mg+2                  5.763e-004  3.665e-004    -3.239    -3.436    -0.197
   MgSO4                 7.179e-005  7.203e-005    -4.144    -4.143     0.001
   MgHCO3+               2.161e-005  1.917e-005    -4.665    -4.717    -0.052
   MgCO3                 7.583e-007  7.609e-007    -6.120    -6.119     0.001
   MgOH+                 1.093e-008  9.699e-009    -7.961    -8.013    -0.052
Mn(2)           9.647e-008
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   Mn+2                  6.368e-008  4.053e-008    -7.196    -7.392    -0.196
   MnHCO3+               1.862e-008  1.652e-008    -7.730    -7.782    -0.052
   MnCO3                 7.654e-009  7.679e-009    -8.116    -8.115     0.001
   MnSO4                 6.273e-009  6.294e-009    -8.203    -8.201     0.001
   MnCl+                 2.319e-010  2.058e-010    -9.635    -9.687    -0.052
   MnOH+                 9.030e-012  8.012e-012   -11.044   -11.096    -0.052
   MnCl2                 1.116e-013  1.119e-013   -12.952   -12.951     0.001
   MnCl3-                4.331e-017  3.843e-017   -16.363   -16.415    -0.052
   Mn(NO3)2              0.000e+000  0.000e+000  -172.819  -172.817     0.001
Mn(3)           7.483e-037
   Mn+3                  7.483e-037  2.550e-037   -36.126   -36.593    -0.468
N(-3)           2.160e-006
   NH4+                  2.125e-006  1.871e-006    -5.673    -5.728    -0.055
   NH4SO4-               2.666e-008  2.366e-008    -7.574    -7.626    -0.052
   NH3                   8.736e-009  8.765e-009    -8.059    -8.057     0.001
N(0)            6.955e-007
   N2                    3.478e-007  3.489e-007    -6.459    -6.457     0.001
N(3)            0.000e+000
   NO2-                  0.000e+000  0.000e+000   -61.332   -61.387    -0.054
N(5)            0.000e+000
   NO3-                  0.000e+000  0.000e+000   -82.961   -83.016    -0.054
   Mn(NO3)2              0.000e+000  0.000e+000  -172.819  -172.817     0.001
Na              2.967e-003
   Na+                   2.946e-003  2.618e-003    -2.531    -2.582    -0.051
   NaSO4-                1.396e-005  1.238e-005    -4.855    -4.907    -0.052
   NaHCO3                6.711e-006  6.733e-006    -5.173    -5.172     0.001
   NaCO3-                9.622e-008  8.537e-008    -7.017    -7.069    -0.052
   NaOH                  2.184e-010  2.191e-010    -9.661    -9.659     0.001
O(0)            0.000e+000
   O2                    0.000e+000  0.000e+000   -72.911   -72.909     0.001
S(-2)           2.180e-006
   HS-                   1.254e-006  1.109e-006    -5.902    -5.955    -0.053
   H2S                   9.228e-007  9.259e-007    -6.035    -6.033     0.001
   Fe(HS)2               1.749e-009  1.755e-009    -8.757    -8.756     0.001
   S-2                   1.780e-012  1.116e-012   -11.750   -11.952    -0.203
   Fe(HS)3-              2.389e-013  2.119e-013   -12.622   -12.674    -0.052
S(6)            1.958e-003
   SO4-2                 1.567e-003  9.814e-004    -2.805    -3.008    -0.203
   CaSO4                 3.036e-004  3.046e-004    -3.518    -3.516     0.001
   MgSO4                 7.179e-005  7.203e-005    -4.144    -4.143     0.001
   NaSO4-                1.396e-005  1.238e-005    -4.855    -4.907    -0.052
   KSO4-                 1.546e-006  1.372e-006    -5.811    -5.863    -0.052
   FeSO4                 2.488e-007  2.497e-007    -6.604    -6.603     0.001
   NH4SO4-               2.666e-008  2.366e-008    -7.574    -7.626    -0.052
   HSO4-                 7.470e-009  6.628e-009    -8.127    -8.179    -0.052
   MnSO4                 6.273e-009  6.294e-009    -8.203    -8.201     0.001
   CaHSO4+               1.479e-010  1.312e-010    -9.830    -9.882    -0.052
   FeHSO4+               1.437e-013  1.275e-013   -12.843   -12.894    -0.052
   FeSO4+                5.761e-022  5.112e-022   -21.239   -21.291    -0.052
   Fe(SO4)2-             1.208e-023  1.072e-023   -22.918   -22.970    -0.052
   FeHSO4+2              1.757e-028  1.089e-028   -27.755   -27.963    -0.208

------------------------------Saturation indices-----------------------------
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      Phase               SI log IAP  log KT
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      Anhydrite        -1.45   -5.79   -4.34  CaSO4
      Aragonite        -0.11   -8.41   -8.30  CaCO3
      Calcite           0.04   -8.41   -8.45  CaCO3
      CH4(g)           -5.43   -8.24   -2.81  CH4
      CO2(g)           -1.66   -3.05   -1.39  CO2
      Dolomite         -0.52  -17.46  -16.95  CaMg(CO3)2
      Fe(OH)3(a)       -5.85   -0.96    4.89  Fe(OH)3
      FeS(ppt)         -0.73   -4.65   -3.92  FeS
      Goethite         -0.17   -0.96   -0.78  FeOOH
      Gypsum           -1.21   -5.79   -4.58  CaSO4:2H2O
      H2(g)            -7.60  -10.72   -3.12  H2
      H2O(g)           -1.67   -0.00    1.67  H2O
      H2S(g)           -5.11   -6.03   -0.93  H2S
      Halite           -7.05   -5.49    1.57  NaCl
      Hausmannite     -34.51   28.04   62.54  Mn3O4
      Hematite          1.63   -1.91   -3.54  Fe2O3
      Jarosite-K      -25.11  -33.85   -8.74  KFe3(SO4)2(OH)6
      Mackinawite      -0.00   -4.65   -4.65  FeS
      Manganite       -14.73   10.61   25.34  MnOOH
      Melanterite      -6.52   -8.80   -2.28  FeSO4:7H2O
      N2(g)            -3.22   -6.46   -3.24  N2
      NH3(g)           -9.95   -8.06    1.89  NH3
      O2(g)           -70.06  -72.91   -2.85  O2
      Pyrite            8.54  -10.11  -18.65  FeS2
      Pyrochroite      -8.39    6.81   15.20  Mn(OH)2
      Pyrolusite      -27.95   14.41   42.36  MnO2
      Rhodochrosite    -1.91  -13.01  -11.11  MnCO3
      Siderite         -0.57  -11.42  -10.85  FeCO3
      Sulfur           -3.46    1.57    5.03  S

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End of simulation.
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Reading input data for simulation 3.
------------------------------------

      SOLUTION 5-6 MNW-5 D2
          temp      21.4
          pH        6.6
          pe        -2
          redox     pe
          units     mg/kgw
          density   1
          Fe(2)     0.01
          Mg        16.3
          Mn(2)     0.005
          N(5)      0
          N(-3)     0
          S(-2)     0.005
          S(6)      167
          Al        0
          Cl        42 charge
          Ca        121
          Alkalinity 243
          K         9.84
```

```
          O(0)      0.01
          Na        68.2
          B         0.08
          water    1 # kg
      EQUILIBRIUM_PHASES 3 Equilibration with Mackinawite
          Mackinawite 0 10
      END
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 5.     MNW-5 D2

-----------------------------Solution composition----------------------------
--

      Elements           Molality       Moles

      Alkalinity       4.856e-003  4.856e-003
      B                7.401e-006  7.401e-006
      Ca               3.019e-003  3.019e-003
      Cl               2.265e-003  2.265e-003  Charge balance
      Fe(2)            1.791e-007  1.791e-007
      K                2.516e-004  2.516e-004
      Mg               6.705e-004  6.705e-004
      Mn(2)            9.101e-008  9.101e-008
      Na               2.967e-003  2.967e-003
      O(0)             6.250e-007  6.250e-007
      S(-2)            1.559e-007  1.559e-007
      S(6)             1.738e-003  1.738e-003

----------------------------Description of solution--------------------------
--

                                       pH  =   6.600
                                       pe  =  -2.000
       Specific Conductance (uS/cm, 21 oC) = 925
                          Density (g/cm3)  =   0.99855
                        Activity of water  =   1.000
                           Ionic strength  =  1.438e-002
                       Mass of water (kg)  =  1.000e+000
                    Total carbon (mol/kg)  =  7.342e-003
                       Total CO2 (mol/kg)  =  7.342e-003
                      Temperature (deg C)  =  21.400
                  Electrical balance (eq)  =  1.690e-015
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =   0.00
                               Iterations  =   9
                                  Total H  = 1.110173e+002
                                  Total O  = 5.553273e+001

---------------------------------Redox couples-------------------------------
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      Redox couple             pe  Eh (volts)

      O(-2)/O(0)          13.5960      0.7946
      S(-2)/S(6)          -2.6142     -0.1528
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----------------------------Distribution of species--------------------------
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                                                   Log       Log         Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   H+                    2.785e-007  2.512e-007    -6.555    -6.600    -0.045
   OH-                   3.413e-008  3.019e-008    -7.467    -7.520    -0.053
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                 7.383e-006  7.407e-006    -5.132    -5.130     0.001
   H2BO3-                1.790e-008  1.588e-008    -7.747    -7.799    -0.052
C(4)            7.342e-003
   HCO3-                 4.728e-003  4.213e-003    -2.325    -2.375    -0.050
   CO2                   2.489e-003  2.498e-003    -2.604    -2.602     0.001
   CaHCO3+               9.477e-005  8.445e-005    -4.023    -4.073    -0.050
   MgHCO3+               2.026e-005  1.797e-005    -4.693    -4.745    -0.052
   NaHCO3                6.184e-006  6.205e-006    -5.209    -5.207     0.001
   CaCO3                 1.902e-006  1.908e-006    -5.721    -5.719     0.001
   CO3-2                 1.156e-006  7.290e-007    -5.937    -6.137    -0.200
   MgCO3                 2.427e-007  2.435e-007    -6.615    -6.614     0.001
   FeHCO3+               3.845e-008  3.411e-008    -7.415    -7.467    -0.052
   NaCO3-                3.334e-008  2.958e-008    -7.477    -7.529    -0.052
   MnHCO3+               1.747e-008  1.550e-008    -7.758    -7.810    -0.052
   MnCO3                 2.382e-009  2.390e-009    -8.623    -8.622     0.001
   FeCO3                 1.411e-009  1.416e-009    -8.850    -8.849     0.001
Ca              3.019e-003
   Ca+2                  2.646e-003  1.667e-003    -2.577    -2.778    -0.201
   CaSO4                 2.767e-004  2.776e-004    -3.558    -3.557     0.001
   CaHCO3+               9.477e-005  8.445e-005    -4.023    -4.073    -0.050
   CaCO3                 1.902e-006  1.908e-006    -5.721    -5.719     0.001
   CaOH+                 1.241e-009  1.101e-009    -8.906    -8.958    -0.052
   CaHSO4+               4.410e-010  3.912e-010    -9.356    -9.408    -0.052
Cl              2.265e-003
   Cl-                   2.265e-003  2.004e-003    -2.645    -2.698    -0.053
   MnCl+                 3.799e-010  3.370e-010    -9.420    -9.472    -0.052
   FeCl+                 2.525e-010  2.240e-010    -9.598    -9.650    -0.052
   MnCl2                 2.938e-013  2.948e-013   -12.532   -12.530     0.001
   MnCl3-                1.834e-016  1.627e-016   -15.736   -15.789    -0.052
Fe(2)           1.791e-007
   Fe+2                  1.273e-007  8.096e-008    -6.895    -7.092    -0.196
   FeHCO3+               3.845e-008  3.411e-008    -7.415    -7.467    -0.052
   FeSO4                 1.159e-008  1.163e-008    -7.936    -7.934     0.001
   FeCO3                 1.411e-009  1.416e-009    -8.850    -8.849     0.001
   FeCl+                 2.525e-010  2.240e-010    -9.598    -9.650    -0.052
   FeOH+                 8.747e-011  7.760e-011   -10.058   -10.110    -0.052
   Fe(HS)2               1.366e-013  1.370e-013   -12.865   -12.863     0.001
   FeHSO4+               2.142e-014  1.900e-014   -13.669   -13.721    -0.052
   Fe(HS)3-              7.329e-019  6.502e-019   -18.135   -18.187    -0.052
H(0)            9.233e-013
   H2                    4.617e-013  4.632e-013   -12.336   -12.334     0.001
K               2.516e-004
   K+                    2.502e-004  2.214e-004    -3.602    -3.655    -0.053
   KSO4-                 1.421e-006  1.261e-006    -5.847    -5.899    -0.052
   KOH                   3.045e-012  3.055e-012   -11.516   -11.515     0.001
Mg              6.705e-004
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   Mg+2                  5.820e-004  3.699e-004    -3.235    -3.432    -0.197
   MgSO4                 6.796e-005  6.818e-005    -4.168    -4.166     0.001
   MgHCO3+               2.026e-005  1.797e-005    -4.693    -4.745    -0.052
   MgCO3                 2.427e-007  2.435e-007    -6.615    -6.614     0.001
   MgOH+                 4.336e-009  3.847e-009    -8.363    -8.415    -0.052
Mn(2)           9.101e-008
   Mn+2                  6.488e-008  4.127e-008    -7.188    -7.384    -0.196
   MnHCO3+               1.747e-008  1.550e-008    -7.758    -7.810    -0.052
   MnSO4                 5.893e-009  5.912e-009    -8.230    -8.228     0.001
   MnCO3                 2.382e-009  2.390e-009    -8.623    -8.622     0.001
   MnCl+                 3.799e-010  3.370e-010    -9.420    -9.472    -0.052
   MnOH+                 3.536e-012  3.137e-012   -11.451   -11.503    -0.052
   MnCl2                 2.938e-013  2.948e-013   -12.532   -12.530     0.001
   MnCl3-                1.834e-016  1.627e-016   -15.736   -15.789    -0.052
Na              2.967e-003
   Na+                   2.948e-003  2.619e-003    -2.530    -2.582    -0.051
   NaSO4-                1.249e-005  1.108e-005    -4.904    -4.956    -0.052
   NaHCO3                6.184e-006  6.205e-006    -5.209    -5.207     0.001
   NaCO3-                3.334e-008  2.958e-008    -7.477    -7.529    -0.052
   NaOH                  6.864e-011  6.886e-011   -10.163   -10.162     0.001
O(0)            6.250e-007
   O2                    3.125e-007  3.135e-007    -6.505    -6.504     0.001
S(-2)           1.559e-007
   H2S                   1.067e-007  1.070e-007    -6.972    -6.971     0.001
   HS-                   4.927e-008  4.358e-008    -7.307    -7.361    -0.053
   Fe(HS)2               1.366e-013  1.370e-013   -12.865   -12.863     0.001
   S-2                   2.605e-014  1.633e-014   -13.584   -13.787    -0.203
   Fe(HS)3-              7.329e-019  6.502e-019   -18.135   -18.187    -0.052
S(6)            1.738e-003
   SO4-2                 1.380e-003  8.636e-004    -2.860    -3.064    -0.204
   CaSO4                 2.767e-004  2.776e-004    -3.558    -3.557     0.001
   MgSO4                 6.796e-005  6.818e-005    -4.168    -4.166     0.001
   NaSO4-                1.249e-005  1.108e-005    -4.904    -4.956    -0.052
   KSO4-                 1.421e-006  1.261e-006    -5.847    -5.899    -0.052
   HSO4-                 2.200e-008  1.952e-008    -7.658    -7.710    -0.052
   FeSO4                 1.159e-008  1.163e-008    -7.936    -7.934     0.001
   MnSO4                 5.893e-009  5.912e-009    -8.230    -8.228     0.001
   CaHSO4+               4.410e-010  3.912e-010    -9.356    -9.408    -0.052
   FeHSO4+               2.142e-014  1.900e-014   -13.669   -13.721    -0.052

------------------------------Saturation indices-----------------------------
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      Phase               SI  log IAP  log KT

      Anhydrite        -1.49   -5.84   -4.35  CaSO4
      Aragonite        -0.60   -8.92   -8.31  CaCO3
      Calcite          -0.45   -8.92   -8.46  CaCO3
      CO2(g)           -1.18   -2.60   -1.42  CO2
      Dolomite         -1.48  -18.48  -17.01  CaMg(CO3)2
      FeS(ppt)         -3.94   -7.85   -3.92  FeS
      Gypsum           -1.26   -5.84   -4.58  CaSO4:2H2O
      H2(g)            -9.20  -12.33   -3.13  H2
      H2O(g)           -1.60   -0.00    1.60  H2O
      H2S(g)           -6.01   -6.97   -0.96  H2S
      Halite           -6.85   -5.28    1.57  NaCl
      Hausmannite     -35.29   26.65   61.93  Mn3O4
```

```
      Mackinawite      -3.20   -7.85   -4.65  FeS
      Manganite       -14.92   10.42   25.34  MnOOH
      Melanterite      -7.90  -10.16   -2.25  FeSO4:7H2O
      O2(g)            -3.64   -6.50   -2.87  O2
      Pyrite            5.97  -12.61  -18.58  FeS2
      Pyrochroite      -9.38    5.82   15.20  Mn(OH)2
      Pyrolusite      -26.95   15.02   41.96  MnO2
      Rhodochrosite    -2.40  -13.52  -11.12  MnCO3
      Siderite         -2.36  -13.23  -10.87  FeCO3
      Sulfur           -2.74    2.23    4.97  S

-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using solution 5. MNW-5 D2
Using pure phase assemblage 3.      Equilibration with Mackinawite

-------------------------------Phase assemblage------------------------------
--

                                                      Moles in assemblage
Phase                  SI  log IAP  log KT      Initial       Final
Delta

Mackinawite         -0.00   -4.65   -4.65   1.000e+001  1.000e+001 -6.585e-
006

-----------------------------Solution composition----------------------------
--

      Elements           Molality       Moles

      B                 7.401e-006  7.401e-006
      C                 7.342e-003  7.342e-003
      Ca                3.019e-003  3.019e-003
      Cl                2.265e-003  2.265e-003
      Fe                6.764e-006  6.764e-006
      K                 2.516e-004  2.516e-004
      Mg                6.705e-004  6.705e-004
      Mn                9.101e-008  9.101e-008
      Na                2.967e-003  2.967e-003
      S                 1.745e-003  1.745e-003

----------------------------Description of solution--------------------------
--

                                       pH  =   6.603      Charge balance
                                       pe  =  -2.820      Adjusted to redox
equilibrium
       Specific Conductance (uS/cm, 21 oC) = 926
                          Density (g/cm3)  =   0.99855
                        Activity of water  =   1.000
                           Ionic strength  =  1.439e-002
                       Mass of water (kg)  =  1.000e+000
```

```
                 Total alkalinity (eq/kg)  =  4.868e-003
                       Total CO2 (mol/kg)  =  7.342e-003
                      Temperature (deg C)  =  21.400
                  Electrical balance (eq)  =  1.686e-015
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =   0.00
                               Iterations  =  10
                                  Total H  = 1.110173e+002
                                  Total O  = 5.553273e+001

----------------------------Distribution of species--------------------------
--

                                                     Log       Log          Log
   Species                  Molality    Activity  Molality  Activity        Gamma

   H+                    2.768e-007  2.496e-007    -6.558    -6.603       -0.045
   OH-                   3.435e-008  3.037e-008    -7.464    -7.518       -0.053
   H2O                   5.551e+001  9.997e-001     1.744    -0.000        0.000
B               7.401e-006
   H3BO3                 7.383e-006  7.407e-006    -5.132    -5.130        0.001
   H2BO3-                1.801e-008  1.597e-008    -7.745    -7.797       -0.052
C(-4)           1.046e-008
   CH4                   1.046e-008  1.049e-008    -7.980    -7.979        0.001
C(4)            7.342e-003
   HCO3-                 4.737e-003  4.221e-003    -2.325    -2.375       -0.050
   CO2                   2.479e-003  2.487e-003    -2.606    -2.604        0.001
   CaHCO3+               9.493e-005  8.458e-005    -4.023    -4.073       -0.050
   MgHCO3+               2.029e-005  1.800e-005    -4.693    -4.745       -0.052
   NaHCO3                6.195e-006  6.216e-006    -5.208    -5.207        0.001
   CaCO3                 1.917e-006  1.923e-006    -5.717    -5.716        0.001
   FeHCO3+               1.452e-006  1.288e-006    -5.838    -5.890       -0.052
   CO3-2                 1.166e-006  7.348e-007    -5.933    -6.134       -0.200
   MgCO3                 2.446e-007  2.454e-007    -6.612    -6.610        0.001
   FeCO3                 5.362e-008  5.380e-008    -7.271    -7.269        0.001
   NaCO3-                3.361e-008  2.982e-008    -7.473    -7.526       -0.052
   MnHCO3+               1.749e-008  1.551e-008    -7.757    -7.809       -0.052
   MnCO3                 2.399e-009  2.407e-009    -8.620    -8.618        0.001
Ca              3.019e-003
   Ca+2                  2.646e-003  1.667e-003    -2.577    -2.778       -0.201
   CaSO4                 2.766e-004  2.775e-004    -3.558    -3.557        0.001
   CaHCO3+               9.493e-005  8.458e-005    -4.023    -4.073       -0.050
   CaCO3                 1.917e-006  1.923e-006    -5.717    -5.716        0.001
   CaOH+                 1.249e-009  1.108e-009    -8.904    -8.956       -0.052
   CaHSO4+               4.381e-010  3.886e-010    -9.358    -9.410       -0.052
Cl              2.265e-003
   Cl-                   2.265e-003  2.004e-003    -2.645    -2.698       -0.053
   FeCl+                 9.518e-009  8.443e-009    -8.021    -8.073       -0.052
   MnCl+                 3.796e-010  3.367e-010    -9.421    -9.473       -0.052
   MnCl2                 2.936e-013  2.946e-013   -12.532   -12.531        0.001
   MnCl3-                1.833e-016  1.626e-016   -15.737   -15.789       -0.052
   FeCl+2                3.143e-023  1.946e-023   -22.503   -22.711       -0.208
   FeCl2+                2.205e-025  1.956e-025   -24.657   -24.709       -0.052
   FeCl3                 3.906e-029  3.919e-029   -28.408   -28.407        0.001
Fe(2)           6.764e-006
   Fe+2                  4.799e-006  3.052e-006    -5.319    -5.515       -0.197
   FeHCO3+               1.452e-006  1.288e-006    -5.838    -5.890       -0.052
   FeSO4                 4.369e-007  4.384e-007    -6.360    -6.358        0.001
```

```
   FeCO3                 5.362e-008  5.380e-008    -7.271    -7.269     0.001
   FeCl+                 9.518e-009  8.443e-009    -8.021    -8.073    -0.052
   Fe(HS)2               9.175e-009  9.206e-009    -8.037    -8.036     0.001
   FeOH+                 3.318e-009  2.944e-009    -8.479    -8.531    -0.052
   Fe(HS)3-              2.079e-012  1.844e-012   -11.682   -11.734    -0.052
   FeHSO4+               8.022e-013  7.116e-013   -12.096   -12.148    -0.052
Fe(3)           1.364e-014
   Fe(OH)2+              9.804e-015  8.697e-015   -14.009   -14.061    -0.052
   Fe(OH)3               3.815e-015  3.827e-015   -14.419   -14.417     0.001
   Fe(OH)4-              1.361e-017  1.207e-017   -16.866   -16.918    -0.052
   FeOH+2                1.216e-017  7.531e-018   -16.915   -17.123    -0.208
   FeSO4+                3.553e-021  3.152e-021   -20.449   -20.501    -0.052
   Fe+3                  9.145e-022  3.610e-022   -21.039   -21.443    -0.404
   Fe(SO4)2-             6.617e-023  5.870e-023   -22.179   -22.231    -0.052
   FeCl+2                3.143e-023  1.946e-023   -22.503   -22.711    -0.208
   FeCl2+                2.205e-025  1.956e-025   -24.657   -24.709    -0.052
   FeHSO4+2              3.414e-027  2.114e-027   -26.467   -26.675    -0.208
   FeCl3                 3.906e-029  3.919e-029   -28.408   -28.407     0.001
   Fe2(OH)2+4            1.207e-032  1.774e-033   -31.918   -32.751    -0.833
   Fe3(OH)4+5            0.000e+000  0.000e+000   -43.044   -44.346    -1.301
H(0)            3.989e-011
   H2                    1.994e-011  2.001e-011   -10.700   -10.699     0.001
K               2.516e-004
   K+                    2.502e-004  2.214e-004    -3.602    -3.655    -0.053
   KSO4-                 1.421e-006  1.260e-006    -5.847    -5.900    -0.052
   KOH                   3.064e-012  3.074e-012   -11.514   -11.512     0.001
Mg              6.705e-004
   Mg+2                  5.820e-004  3.699e-004    -3.235    -3.432    -0.197
   MgSO4                 6.792e-005  6.815e-005    -4.168    -4.167     0.001
   MgHCO3+               2.029e-005  1.800e-005    -4.693    -4.745    -0.052
   MgCO3                 2.446e-007  2.454e-007    -6.612    -6.610     0.001
   MgOH+                 4.362e-009  3.870e-009    -8.360    -8.412    -0.052
Mn(2)           9.101e-008
   Mn+2                  6.485e-008  4.124e-008    -7.188    -7.385    -0.197
   MnHCO3+               1.749e-008  1.551e-008    -7.757    -7.809    -0.052
   MnSO4                 5.887e-009  5.907e-009    -8.230    -8.229     0.001
   MnCO3                 2.399e-009  2.407e-009    -8.620    -8.618     0.001
   MnCl+                 3.796e-010  3.367e-010    -9.421    -9.473    -0.052
   MnOH+                 3.556e-012  3.154e-012   -11.449   -11.501    -0.052
   MnCl2                 2.936e-013  2.946e-013   -12.532   -12.531     0.001
   MnCl3-                1.833e-016  1.626e-016   -15.737   -15.789    -0.052
Mn(3)           3.328e-036
   Mn+3                  3.328e-036  1.132e-036   -35.478   -35.946    -0.468
Na              2.967e-003
   Na+                   2.948e-003  2.619e-003    -2.530    -2.582    -0.051
   NaSO4-                1.248e-005  1.107e-005    -4.904    -4.956    -0.052
   NaHCO3                6.195e-006  6.216e-006    -5.208    -5.207     0.001
   NaCO3-                3.361e-008  2.982e-008    -7.473    -7.526    -0.052
   NaOH                  6.906e-011  6.929e-011   -10.161   -10.159     0.001
O(0)            0.000e+000
   O2                    0.000e+000  0.000e+000   -72.160   -72.159     0.001
S(-2)           6.574e-006
   H2S                   4.475e-006  4.490e-006    -5.349    -5.348     0.001
   HS-                   2.080e-006  1.840e-006    -5.682    -5.735    -0.053
   Fe(HS)2               9.175e-009  9.206e-009    -8.037    -8.036     0.001
   Fe(HS)3-              2.079e-012  1.844e-012   -11.682   -11.734    -0.052
   S-2                   1.107e-012  6.934e-013   -11.956   -12.159    -0.203
```

```
S(6)            1.739e-003
   SO4-2                1.380e-003  8.633e-004    -2.860    -3.064    -0.204
   CaSO4                2.766e-004  2.775e-004    -3.558    -3.557     0.001
   MgSO4                6.792e-005  6.815e-005    -4.168    -4.167     0.001
   NaSO4-               1.248e-005  1.107e-005    -4.904    -4.956    -0.052
   KSO4-                1.421e-006  1.260e-006    -5.847    -5.900    -0.052
   FeSO4                4.369e-007  4.384e-007    -6.360    -6.358     0.001
   HSO4-                2.186e-008  1.939e-008    -7.660    -7.712    -0.052
   MnSO4                5.887e-009  5.907e-009    -8.230    -8.229     0.001
   CaHSO4+              4.381e-010  3.886e-010    -9.358    -9.410    -0.052
   FeHSO4+              8.022e-013  7.116e-013   -12.096   -12.148    -0.052
   FeSO4+               3.553e-021  3.152e-021   -20.449   -20.501    -0.052
   Fe(SO4)2-            6.617e-023  5.870e-023   -22.179   -22.231    -0.052
   FeHSO4+2             3.414e-027  2.114e-027   -26.467   -26.675    -0.208

------------------------------Saturation indices-------------------------------
--

      Phase               SI  log IAP   log KT

      Anhydrite        -1.49   -5.84   -4.35  CaSO4
      Aragonite        -0.60   -8.91   -8.31  CaCO3
      Calcite          -0.45   -8.91   -8.46  CaCO3
      CH4(g)           -5.15   -7.98   -2.83  CH4
      CO2(g)           -1.18   -2.60   -1.42  CO2
      Dolomite         -1.47  -18.48  -17.01  CaMg(CO3)2
      Fe(OH)3(a)       -6.53   -1.63    4.89  Fe(OH)3
      FeS(ppt)         -0.73   -4.65   -3.92  FeS
      Goethite         -0.76   -1.63   -0.87  FeOOH
      Gypsum           -1.26   -5.84   -4.58  CaSO4:2H2O
      H2(g)            -7.56  -10.70   -3.13  H2
      H2O(g)           -1.60   -0.00    1.60  H2O
      H2S(g)           -4.39   -5.35   -0.96  H2S
      Halite           -6.85   -5.28    1.57  NaCl
      Hausmannite     -36.91   25.03   61.93  Mn3O4
      Hematite          0.46   -3.27   -3.73  Fe2O3
      Jarosite-K      -25.57  -34.49   -8.93  KFe3(SO4)2(OH)6
      Mackinawite      -0.00   -4.65   -4.65  FeS
      Manganite       -15.74    9.60   25.34  MnOOH
      Melanterite      -6.33   -8.58   -2.25  FeSO4:7H2O
      O2(g)           -69.29  -72.16   -2.87  O2
      Pyrite            9.16   -9.42  -18.58  FeS2
      Pyrochroite      -9.38    5.82   15.20  Mn(OH)2
      Pyrolusite      -28.58   13.38   41.96  MnO2
      Rhodochrosite    -2.40  -13.52  -11.12  MnCO3
      Siderite         -0.78  -11.65  -10.87  FeCO3
      Sulfur           -2.75    2.22    4.97  S

------------------
End of simulation.
```

```
   Input file: C:\_Jons Work Files\Fruit Ave_ MNA_Abiotic Reduction\PHREEQC Simulations
\Final MNA Simulations _ DO and Fe set to 0.01_Pyrite_Equilib_.pqi
  Output file: C:\_Jons Work Files\Fruit Ave_ MNA_Abiotic Reduction\PHREEQC Simulations
\Final MNA Simulations _ DO and Fe set to 0.01_Pyrite_Equilib_.pqo
Database file: C:\Program Files\USGS\Phreeqc Interactive 2.18.5570\database\phreeqc.dat

------------------
Reading data base.
------------------

      SOLUTION_MASTER_SPECIES
      SOLUTION_SPECIES
      PHASES
      EXCHANGE_MASTER_SPECIES
      EXCHANGE_SPECIES
      SURFACE_MASTER_SPECIES
      SURFACE_SPECIES
      RATES
      END
------------------------------------
Reading input data for simulation 1.
------------------------------------

      DATABASE C:\Program Files\USGS\Phreeqc Interactive 2.18.5570\database\phreeqc.dat
      TITLE With and Without Equilibration with Pyrite, O2, sulfide and Fe 2+ set to
0.00001 mg/kgw
      SOLUTION 1-2 HSM-I2-5-082012
          temp      20.71
          pH        6.71
          pe        -2
          redox     pe
          units     mmol/kgw
          density   1
          Al        50 ug/kgw
          Alkalinity 270 mg/kgw     gfw 50
          Na        66300 ug/kgw
          O(0)      0.00001 mg/kgw
          B         112 ug/kgw
          Fe(2)     0.00001 mg/kgw
          Mn(2)     0.05 ug/kgw
          N(-3)     0.025 mg/kgw
          N(5)      0.01 mg/kgw
          S(6)      201 mg/kgw
          Mg        34000 ug/kgw
          K         15300 ug/kgw
          Ca        132000 ug/kgw
          Cl        35 mg/kgw     charge
          S(-2)     0.00001 mg/kgw
          water    1 # kg
      EQUILIBRIUM_PHASES 1-2 Equilibration with Pyrite
          Pyrite 0 10
      END
-----
TITLE
-----

 With and Without Equilibration with Pyrite, O2, sulfide and Fe 2+ set to 0.00001 mg/kgw

-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 1.     HSM-I2-5-082012

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles
```

```
      Al               1.853e-006  1.853e-006
      Alkalinity       5.400e-003  5.400e-003
      B                1.036e-005  1.036e-005
      Ca               3.293e-003  3.293e-003
      Cl               3.081e-003  3.081e-003  Charge balance
      Fe(2)            1.791e-010  1.791e-010
      K                3.913e-004  3.913e-004
      Mg               1.398e-003  1.398e-003
      Mn(2)            9.101e-010  9.101e-010
      N(-3)            1.785e-006  1.785e-006
      N(5)             7.139e-007  7.139e-007
      Na               2.884e-003  2.884e-003
      O(0)             6.250e-010  6.250e-010
      S(-2)            3.119e-010  3.119e-010
      S(6)             2.092e-003  2.092e-003

----------------------------Description of solution----------------------------

                                       pH  =   6.710
                                       pe  =  -2.000
       Specific Conductance (uS/cm, 20 oC) = 1071
                          Density (g/cm3)  =   0.99882
                        Activity of water  =   1.000
                           Ionic strength  =  1.721e-002
                       Mass of water (kg)  =  1.000e+000
                    Total carbon (mol/kg)  =  7.525e-003
                       Total CO2 (mol/kg)  =  7.525e-003
                      Temperature (deg C)  =  20.710
                  Electrical balance (eq)  = -2.649e-013
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =   9
                                  Total H  = 1.110179e+002
                                  Total O  = 5.553507e+001

---------------------------------Redox couples---------------------------------

      Redox couple             pe  Eh (volts)

      N(-3)/N(5)           6.6985      0.3906
      O(-2)/O(0)          12.7948      0.7460
      S(-2)/S(6)          -2.3893     -0.1393

----------------------------Distribution of species----------------------------

                                                   Log       Log       Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   H+                    2.177e-007  1.950e-007    -6.662    -6.710    -0.048
   OH-                   4.206e-008  3.683e-008    -7.376    -7.434    -0.058
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
Al              1.853e-006
   Al(OH)4-              1.418e-006  1.246e-006    -5.848    -5.904    -0.056
   Al(OH)2+              2.834e-007  2.491e-007    -6.548    -6.604    -0.056
   Al(OH)3               1.354e-007  1.360e-007    -6.868    -6.867     0.002
   AlOH+2                1.525e-008  9.103e-009    -7.817    -8.041    -0.224
   AlSO4+                7.805e-010  6.861e-010    -9.108    -9.164    -0.056
   Al+3                  6.383e-010  2.369e-010    -9.195    -9.625    -0.430
   Al(SO4)2-             2.344e-011  2.060e-011   -10.630   -10.686    -0.056
   AlHSO4+2              1.918e-017  1.145e-017   -16.717   -16.941    -0.224
B               1.036e-005
   H3BO3                 1.033e-005  1.037e-005    -4.986    -4.984     0.002
   H2BO3-                3.216e-008  2.827e-008    -7.493    -7.549    -0.056
C(4)            7.525e-003
   HCO3-                 5.224e-003  4.615e-003    -2.282    -2.336    -0.054
   CO2                   2.137e-003  2.145e-003    -2.670    -2.668     0.002
   CaHCO3+               1.080e-004  9.544e-005    -3.966    -4.020    -0.054
```

```
   MgHCO3+               4.469e-005  3.928e-005    -4.350    -4.406    -0.056
   NaHCO3                6.517e-006  6.543e-006    -5.186    -5.184     0.002
   CaCO3                 2.727e-006  2.737e-006    -5.564    -5.563     0.002
   CO3-2                 1.663e-006  1.013e-006    -5.779    -5.994    -0.215
   MgCO3                 6.671e-007  6.697e-007    -6.176    -6.174     0.002
   NaCO3-                4.344e-008  3.818e-008    -7.362    -7.418    -0.056
   MnHCO3+               1.817e-010  1.597e-010    -9.741    -9.797    -0.056
   FeHCO3+               4.020e-011  3.534e-011   -10.396   -10.452    -0.056
   MnCO3                 3.112e-011  3.124e-011   -10.507   -10.505     0.002
   FeCO3                 1.853e-012  1.861e-012   -11.732   -11.730     0.002
Ca              3.293e-003
   Ca+2                  2.861e-003  1.741e-003    -2.544    -2.759    -0.216
   CaSO4                 3.220e-004  3.233e-004    -3.492    -3.490     0.002
   CaHCO3+               1.080e-004  9.544e-005    -3.966    -4.020    -0.054
   CaCO3                 2.727e-006  2.737e-006    -5.564    -5.563     0.002
   CaOH+                 1.686e-009  1.482e-009    -8.773    -8.829    -0.056
   CaHSO4+               3.991e-010  3.508e-010    -9.399    -9.455    -0.056
Cl              3.081e-003
   Cl-                   3.081e-003  2.699e-003    -2.511    -2.569    -0.057
   MnCl+                 4.858e-012  4.270e-012   -11.314   -11.370    -0.056
   FeCl+                 3.246e-013  2.853e-013   -12.489   -12.545    -0.056
   MnCl2                 5.012e-015  5.031e-015   -14.300   -14.298     0.002
   MnCl3-                4.256e-018  3.741e-018   -17.371   -17.427    -0.056
Fe(2)           1.791e-010
   Fe+2                  1.244e-010  7.657e-011    -9.905   -10.116    -0.211
   FeHCO3+               4.020e-011  3.534e-011   -10.396   -10.452    -0.056
   FeSO4                 1.214e-011  1.218e-011   -10.916   -10.914     0.002
   FeCO3                 1.853e-012  1.861e-012   -11.732   -11.730     0.002
   FeCl+                 3.246e-013  2.853e-013   -12.489   -12.545    -0.056
   FeOH+                 1.020e-013  8.967e-014   -12.991   -13.047    -0.056
   FeHSO4+               1.755e-017  1.542e-017   -16.756   -16.812    -0.056
   Fe(HS)2               6.953e-022  6.981e-022   -21.158   -21.156     0.002
   Fe(HS)3-              8.747e-030  7.688e-030   -29.058   -29.114    -0.056
H(0)            5.599e-013
   H2                    2.800e-013  2.811e-013   -12.553   -12.551     0.002
K               3.913e-004
   K+                    3.888e-004  3.407e-004    -3.410    -3.468    -0.057
   KSO4-                 2.446e-006  2.150e-006    -5.612    -5.668    -0.056
   KOH                   6.033e-012  6.056e-012   -11.220   -11.218     0.002
Mg              1.398e-003
   Mg+2                  1.203e-003  7.401e-004    -2.920    -3.131    -0.211
   MgSO4                 1.497e-004  1.503e-004    -3.825    -3.823     0.002
   MgHCO3+               4.469e-005  3.928e-005    -4.350    -4.406    -0.056
   MgCO3                 6.671e-007  6.697e-007    -6.176    -6.174     0.002
   MgOH+                 1.058e-008  9.299e-009    -7.976    -8.032    -0.056
Mn(2)           9.101e-010
   Mn+2                  6.311e-010  3.883e-010    -9.200    -9.411    -0.211
   MnHCO3+               1.817e-010  1.597e-010    -9.741    -9.797    -0.056
   MnSO4                 6.133e-011  6.157e-011   -10.212   -10.211     0.002
   MnCO3                 3.112e-011  3.124e-011   -10.507   -10.505     0.002
   MnCl+                 4.858e-012  4.270e-012   -11.314   -11.370    -0.056
   MnOH+                 4.083e-014  3.588e-014   -13.389   -13.445    -0.056
   MnCl2                 5.012e-015  5.031e-015   -14.300   -14.298     0.002
   MnCl3-                4.256e-018  3.741e-018   -17.371   -17.427    -0.056
   Mn(NO3)2              6.046e-022  6.070e-022   -21.219   -21.217     0.002
N(-3)           1.785e-006
   NH4+                  1.760e-006  1.533e-006    -5.755    -5.814    -0.060
   NH4SO4-               2.177e-008  1.914e-008    -7.662    -7.718    -0.056
   NH3                   3.281e-009  3.294e-009    -8.484    -8.482     0.002
N(5)            7.139e-007
   NO3-                  7.139e-007  6.236e-007    -6.146    -6.205    -0.059
   Mn(NO3)2              6.046e-022  6.070e-022   -21.219   -21.217     0.002
Na              2.884e-003
   Na+                   2.864e-003  2.521e-003    -2.543    -2.598    -0.055
   NaSO4-                1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   NaHCO3                6.517e-006  6.543e-006    -5.186    -5.184     0.002
   NaCO3-                4.344e-008  3.818e-008    -7.362    -7.418    -0.056
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   NaOH                 8.507e-011  8.540e-011   -10.070   -10.069     0.002
O(0)            6.250e-010
   O2                   3.125e-010  3.137e-010    -9.505    -9.503     0.002
S(-2)           3.119e-010
   H2S                  1.964e-010  1.972e-010    -9.707    -9.705     0.002
   HS-                  1.155e-010  1.011e-010    -9.937    -9.995    -0.058
   S-2                  7.689e-017  4.650e-017   -16.114   -16.333    -0.218
   Fe(HS)2              6.953e-022  6.981e-022   -21.158   -21.156     0.002
   Fe(HS)3-             8.747e-030  7.688e-030   -29.058   -29.114    -0.056
S(6)            2.092e-003
   SO4-2                1.605e-003  9.689e-004    -2.795    -3.014    -0.219
   CaSO4                3.220e-004  3.233e-004    -3.492    -3.490     0.002
   MgSO4                1.497e-004  1.503e-004    -3.825    -3.823     0.002
   NaSO4-               1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   KSO4-                2.446e-006  2.150e-006    -5.612    -5.668    -0.056
   NH4SO4-              2.177e-008  1.914e-008    -7.662    -7.718    -0.056
   HSO4-                1.906e-008  1.675e-008    -7.720    -7.776    -0.056
   AlSO4+               7.805e-010  6.861e-010    -9.108    -9.164    -0.056
   CaHSO4+              3.991e-010  3.508e-010    -9.399    -9.455    -0.056
   MnSO4                6.133e-011  6.157e-011   -10.212   -10.211     0.002
   Al(SO4)2-            2.344e-011  2.060e-011   -10.630   -10.686    -0.056
   FeSO4                1.214e-011  1.218e-011   -10.916   -10.914     0.002
   AlHSO4+2             1.918e-017  1.145e-017   -16.717   -16.941    -0.224
   FeHSO4+              1.755e-017  1.542e-017   -16.756   -16.812    -0.056

------------------------------Saturation indices-------------------------------

      Phase               SI log IAP  log KT

      Al(OH)3(a)       -0.58   10.50   11.08  Al(OH)3
      Alunite           2.75    1.89   -0.86  KAl3(SO4)2(OH)6
      Anhydrite        -1.43   -5.77   -4.35  CaSO4
      Aragonite        -0.44   -8.75   -8.31  CaCO3
      Calcite          -0.30   -8.75   -8.46  CaCO3
      CO2(g)           -1.25   -2.67   -1.42  CO2
      Dolomite         -0.89  -17.88  -16.99  CaMg(CO3)2
      FeS(ppt)         -9.49  -13.40   -3.92  FeS
      Gibbsite          2.15   10.50    8.35  Al(OH)3
      Gypsum           -1.19   -5.77   -4.58  CaSO4:2H2O
      H2(g)            -9.42  -12.55   -3.13  H2
      H2O(g)           -1.62   -0.00    1.62  H2O
      H2S(g)           -8.76   -9.71   -0.95  H2S
      Halite           -6.74   -5.17    1.57  NaCl
      Hausmannite     -40.66   21.45   62.11  Mn3O4
      Mackinawite      -8.75  -13.40   -4.65  FeS
      Manganite       -16.62    8.72   25.34  MnOOH
      Melanterite     -10.87  -13.13   -2.26  FeSO4:7H2O
      NH3(g)          -10.34   -8.48    1.86  NH3
      O2(g)            -6.64   -9.50   -2.86  O2
      Pyrite           -2.09  -20.69  -18.60  FeS2
      Pyrochroite     -11.19    4.01   15.20  Mn(OH)2
      Pyrolusite      -28.65   13.43   42.08  MnO2
      Rhodochrosite    -4.29  -15.41  -11.11  MnCO3
      Siderite         -5.25  -16.11  -10.86  FeCO3
      Sulfur           -5.27   -0.29    4.98  S

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Beginning of batch-reaction calculations.
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Reaction step 1.

Using solution 1.	HSM-I2-5-082012
Using pure phase assemblage 1.      Equilibration with Pyrite

-------------------------------Phase assemblage--------------------------------
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                                                      Moles in assemblage
Phase                  SI log IAP  log KT      Initial       Final       Delta

Pyrite               0.00  -18.60  -18.60   1.000e+001  1.000e+001 -3.827e-010

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Al                 1.853e-006  1.853e-006
      B                  1.036e-005  1.036e-005
      C                  7.525e-003  7.525e-003
      Ca                 3.293e-003  3.293e-003
      Cl                 3.081e-003  3.081e-003
      Fe                 5.617e-010  5.617e-010
      K                  3.913e-004  3.913e-004
      Mg                 1.398e-003  1.398e-003
      Mn                 9.101e-010  9.101e-010
      N                  2.499e-006  2.499e-006
      Na                 2.884e-003  2.884e-003
      S                  2.092e-003  2.092e-003

----------------------------Description of solution----------------------------

                                       pH  =   6.710      Charge balance
                                       pe  =  -2.558      Adjusted to redox equilibrium
       Specific Conductance (uS/cm, 20 oC) = 1071
                          Density (g/cm3)  =   0.99882
                        Activity of water  =   1.000
                           Ionic strength  =  1.721e-002
                       Mass of water (kg)  =  1.000e+000
                 Total alkalinity (eq/kg)  =  5.400e-003
                       Total CO2 (mol/kg)  =  7.525e-003
                      Temperature (deg C)  =  20.710
                  Electrical balance (eq)  = -2.649e-013
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =  29
                                  Total H  = 1.110179e+002
                                  Total O  = 5.553507e+001

----------------------------Distribution of species----------------------------

                                                   Log       Log         Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   H+                      2.178e-007  1.950e-007    -6.662    -6.710    -0.048
   OH-                     4.204e-008  3.682e-008    -7.376    -7.434    -0.058
   H2O                     5.551e+001  9.997e-001     1.744    -0.000     0.000
Al              1.853e-006
   Al(OH)4-                1.417e-006  1.246e-006    -5.849    -5.905    -0.056
   Al(OH)2+                2.836e-007  2.492e-007    -6.547    -6.603    -0.056
   Al(OH)3                 1.355e-007  1.360e-007    -6.868    -6.866     0.002
   AlOH+2                  1.526e-008  9.111e-009    -7.816    -8.040    -0.224
   AlSO4+                  7.814e-010  6.868e-010    -9.107    -9.163    -0.056
   Al+3                    6.390e-010  2.372e-010    -9.194    -9.625    -0.430
   Al(SO4)2-               2.346e-011  2.062e-011   -10.630   -10.686    -0.056
   AlHSO4+2                1.921e-017  1.146e-017   -16.717   -16.941    -0.224
B               1.036e-005
   H3BO3                   1.033e-005  1.037e-005    -4.986    -4.984     0.002
   H2BO3-                  3.215e-008  2.826e-008    -7.493    -7.549    -0.056
C(-4)           1.248e-011
   CH4                     1.248e-011  1.253e-011   -10.904   -10.902     0.002
C(4)            7.525e-003
   HCO3-                   5.224e-003  4.615e-003    -2.282    -2.336    -0.054
   CO2                     2.137e-003  2.146e-003    -2.670    -2.668     0.002
   CaHCO3+                 1.080e-004  9.543e-005    -3.966    -4.020    -0.054
   MgHCO3+                 4.469e-005  3.928e-005    -4.350    -4.406    -0.056
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   NaHCO3                6.517e-006  6.543e-006    -5.186    -5.184     0.002
   CaCO3                 2.726e-006  2.736e-006    -5.565    -5.563     0.002
   CO3-2                 1.663e-006  1.013e-006    -5.779    -5.995    -0.215
   MgCO3                 6.668e-007  6.695e-007    -6.176    -6.174     0.002
   NaCO3-                4.343e-008  3.817e-008    -7.362    -7.418    -0.056
   MnHCO3+               1.817e-010  1.597e-010    -9.741    -9.797    -0.056
   FeHCO3+               1.261e-010  1.108e-010    -9.899    -9.955    -0.056
   MnCO3                 3.111e-011  3.123e-011   -10.507   -10.505     0.002
   FeCO3                 5.811e-012  5.834e-012   -11.236   -11.234     0.002
Ca              3.293e-003
   Ca+2                  2.861e-003  1.741e-003    -2.544    -2.759    -0.216
   CaSO4                 3.220e-004  3.233e-004    -3.492    -3.490     0.002
   CaHCO3+               1.080e-004  9.543e-005    -3.966    -4.020    -0.054
   CaCO3                 2.726e-006  2.736e-006    -5.565    -5.563     0.002
   CaOH+                 1.685e-009  1.481e-009    -8.773    -8.829    -0.056
   CaHSO4+               3.992e-010  3.509e-010    -9.399    -9.455    -0.056
Cl              3.081e-003
   Cl-                   3.081e-003  2.699e-003    -2.511    -2.569    -0.057
   MnCl+                 4.858e-012  4.270e-012   -11.314   -11.370    -0.056
   FeCl+                 1.018e-012  8.951e-013   -11.992   -12.048    -0.056
   MnCl2                 5.012e-015  5.032e-015   -14.300   -14.298     0.002
   MnCl3-                4.256e-018  3.741e-018   -17.371   -17.427    -0.056
   FeCl+2                5.945e-027  3.548e-027   -26.226   -26.450    -0.224
   FeCl2+                5.588e-029  4.912e-029   -28.253   -28.309    -0.056
   FeCl3                 1.321e-032  1.326e-032   -31.879   -31.877     0.002
Fe(2)           5.617e-010
   Fe+2                  3.904e-010  2.402e-010    -9.408    -9.619    -0.211
   FeHCO3+               1.261e-010  1.108e-010    -9.899    -9.955    -0.056
   FeSO4                 3.807e-011  3.822e-011   -10.419   -10.418     0.002
   FeCO3                 5.811e-012  5.834e-012   -11.236   -11.234     0.002
   FeCl+                 1.018e-012  8.951e-013   -11.992   -12.048    -0.056
   FeOH+                 3.199e-013  2.812e-013   -12.495   -12.551    -0.056
   FeHSO4+               5.507e-017  4.840e-017   -16.259   -16.315    -0.056
   Fe(HS)2               1.110e-018  1.114e-018   -17.955   -17.953     0.002
   Fe(HS)3-              3.149e-025  2.768e-025   -24.502   -24.558    -0.056
Fe(3)           3.103e-018
   Fe(OH)2+              2.095e-018  1.841e-018   -17.679   -17.735    -0.056
   Fe(OH)3               1.002e-018  1.006e-018   -17.999   -17.998     0.002
   Fe(OH)4-              4.490e-021  3.946e-021   -20.348   -20.404    -0.056
   FeOH+2                2.144e-021  1.280e-021   -20.669   -20.893    -0.224
   FeSO4+                5.485e-025  4.821e-025   -24.261   -24.317    -0.056
   Fe+3                  1.346e-025  4.997e-026   -24.871   -25.301    -0.430
   Fe(SO4)2-             1.143e-026  1.005e-026   -25.942   -25.998    -0.056
   FeCl+2                5.945e-027  3.548e-027   -26.226   -26.450    -0.224
   FeCl2+                5.588e-029  4.912e-029   -28.253   -28.309    -0.056
   FeHSO4+2              4.237e-031  2.529e-031   -30.373   -30.597    -0.224
   FeCl3                 1.321e-032  1.326e-032   -31.879   -31.877     0.002
   Fe2(OH)2+4            4.157e-040  0.000e+000   -39.381   -40.278    -0.896
   Fe3(OH)4+5            0.000e+000  0.000e+000   -54.117   -55.518    -1.401
H(0)            7.329e-012
   H2                    3.664e-012  3.679e-012   -11.436   -11.434     0.002
K               3.913e-004
   K+                    3.888e-004  3.407e-004    -3.410    -3.468    -0.057
   KSO4-                 2.446e-006  2.150e-006    -5.612    -5.668    -0.056
   KOH                   6.031e-012  6.055e-012   -11.220   -11.218     0.002
Mg              1.398e-003
   Mg+2                  1.203e-003  7.401e-004    -2.920    -3.131    -0.211
   MgSO4                 1.497e-004  1.503e-004    -3.825    -3.823     0.002
   MgHCO3+               4.469e-005  3.928e-005    -4.350    -4.406    -0.056
   MgCO3                 6.668e-007  6.695e-007    -6.176    -6.174     0.002
   MgOH+                 1.058e-008  9.296e-009    -7.976    -8.032    -0.056
Mn(2)           9.101e-010
   Mn+2                  6.311e-010  3.883e-010    -9.200    -9.411    -0.211
   MnHCO3+               1.817e-010  1.597e-010    -9.741    -9.797    -0.056
   MnSO4                 6.133e-011  6.157e-011   -10.212   -10.211     0.002
   MnCO3                 3.111e-011  3.123e-011   -10.507   -10.505     0.002
   MnCl+                 4.858e-012  4.270e-012   -11.314   -11.370    -0.056
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   MnOH+                 4.081e-014  3.587e-014   -13.389   -13.445    -0.056
   MnCl2                 5.012e-015  5.032e-015   -14.300   -14.298     0.002
   MnCl3-                4.256e-018  3.741e-018   -17.371   -17.427    -0.056
   Mn(NO3)2              0.000e+000  0.000e+000  -170.310  -170.308     0.002
Mn(3)           5.611e-038
   Mn+3                  5.611e-038  1.757e-038   -37.251   -37.755    -0.504
N(-3)           5.784e-007
   NH4+                  5.702e-007  4.968e-007    -6.244    -6.304    -0.060
   NH4SO4-               7.055e-009  6.201e-009    -8.152    -8.208    -0.056
   NH3                   1.063e-009  1.067e-009    -8.974    -8.972     0.002
N(0)            1.920e-006
   N2                    9.602e-007  9.640e-007    -6.018    -6.016     0.002
N(3)            0.000e+000
   NO2-                  0.000e+000  0.000e+000   -59.957   -60.015    -0.059
N(5)            0.000e+000
   NO3-                  0.000e+000  0.000e+000   -80.692   -80.751    -0.059
   Mn(NO3)2              0.000e+000  0.000e+000  -170.310  -170.308     0.002
Na              2.884e-003
   Na+                   2.864e-003  2.521e-003    -2.543    -2.598    -0.055
   NaSO4-                1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   NaHCO3                6.517e-006  6.543e-006    -5.186    -5.184     0.002
   NaCO3-                4.343e-008  3.817e-008    -7.362    -7.418    -0.056
   NaOH                  8.504e-011  8.538e-011   -10.070   -10.069     0.002
O(0)            0.000e+000
   O2                    0.000e+000  0.000e+000   -70.918   -70.916     0.002
S(-2)           7.036e-009
   H2S                   4.431e-009  4.449e-009    -8.354    -8.352     0.002
   HS-                   2.605e-009  2.281e-009    -8.584    -8.642    -0.058
   S-2                   1.734e-015  1.049e-015   -14.761   -14.979    -0.218
   Fe(HS)2               1.110e-018  1.114e-018   -17.955   -17.953     0.002
   Fe(HS)3-              3.149e-025  2.768e-025   -24.502   -24.558    -0.056
S(6)            2.092e-003
   SO4-2                 1.605e-003  9.690e-004    -2.795    -3.014    -0.219
   CaSO4                 3.220e-004  3.233e-004    -3.492    -3.490     0.002
   MgSO4                 1.497e-004  1.503e-004    -3.825    -3.823     0.002
   NaSO4-                1.355e-005  1.191e-005    -4.868    -4.924    -0.056
   KSO4-                 2.446e-006  2.150e-006    -5.612    -5.668    -0.056
   HSO4-                 1.907e-008  1.676e-008    -7.720    -7.776    -0.056
   NH4SO4-               7.055e-009  6.201e-009    -8.152    -8.208    -0.056
   AlSO4+                7.814e-010  6.868e-010    -9.107    -9.163    -0.056
   CaHSO4+               3.992e-010  3.509e-010    -9.399    -9.455    -0.056
   MnSO4                 6.133e-011  6.157e-011   -10.212   -10.211     0.002
   FeSO4                 3.807e-011  3.822e-011   -10.419   -10.418     0.002
   Al(SO4)2-             2.346e-011  2.062e-011   -10.630   -10.686    -0.056
   FeHSO4+               5.507e-017  4.840e-017   -16.259   -16.315    -0.056
   AlHSO4+2              1.921e-017  1.146e-017   -16.717   -16.941    -0.224
   FeSO4+                5.485e-025  4.821e-025   -24.261   -24.317    -0.056
   Fe(SO4)2-             1.143e-026  1.005e-026   -25.942   -25.998    -0.056
   FeHSO4+2              4.237e-031  2.529e-031   -30.373   -30.597    -0.224

------------------------------Saturation indices-------------------------------

      Phase               SI log IAP  log KT

      Al(OH)3(a)       -0.58   10.50   11.08  Al(OH)3
      Alunite           2.75    1.89   -0.86  KAl3(SO4)2(OH)6
      Anhydrite        -1.43   -5.77   -4.35  CaSO4
      Aragonite        -0.44   -8.75   -8.31  CaCO3
      Calcite          -0.30   -8.75   -8.46  CaCO3
      CH4(g)           -8.08  -10.90   -2.82  CH4
      CO2(g)           -1.25   -2.67   -1.42  CO2
      Dolomite         -0.89  -17.88  -16.99  CaMg(CO3)2
      Fe(OH)3(a)      -10.06   -5.17    4.89  Fe(OH)3
      FeS(ppt)         -7.64  -11.55   -3.92  FeS
      Gibbsite          2.15   10.50    8.35  Al(OH)3
      Goethite         -4.33   -5.17   -0.85  FeOOH
      Gypsum           -1.19   -5.77   -4.58  CaSO4:2H2O
```

```
      H2(g)            -8.30  -11.43   -3.13  H2
      H2O(g)           -1.62   -0.00    1.62  H2O
      H2S(g)           -7.40   -8.35   -0.95  H2S
      Halite           -6.74   -5.17    1.57  NaCl
      Hausmannite     -41.78   20.33   62.11  Mn3O4
      Hematite         -6.67  -10.34   -3.68  Fe2O3
      Jarosite-K      -36.27  -45.14   -8.88  KFe3(SO4)2(OH)6
      Mackinawite      -6.90  -11.55   -4.65  FeS
      Manganite       -17.18    8.16   25.34  MnOOH
      Melanterite     -10.37  -12.63   -2.26  FeSO4:7H2O
      N2(g)            -2.77   -6.02   -3.25  N2
      NH3(g)          -10.83   -8.97    1.86  NH3
      O2(g)           -68.06  -70.92   -2.86  O2
      Pyrite            0.00  -18.60  -18.60  FeS2
      Pyrochroite     -11.19    4.01   15.20  Mn(OH)2
      Pyrolusite      -29.77   12.31   42.08  MnO2
      Rhodochrosite    -4.29  -15.41  -11.11  MnCO3
      Siderite         -4.75  -15.61  -10.86  FeCO3
      Sulfur           -5.03   -0.05    4.98  S

------------------
End of simulation.
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------------------------------------
Reading input data for simulation 2.
------------------------------------

      SOLUTION 3-4 HNW-14-12
          temp      19
          pH        7.1
          pe        -2
          redox     pe
          units     mg/kgw
          density   1
          Al        0
          Alkalinity 264
          B         80 ug/kgw
          Ca        121
          Cl        34 charge
          Fe(2)     0.00001
          Mg        16.3
          Mn        5.3 ug/kgw
          K         9.84
          N(5)      0.02
          N(-3)     0.02
          Na        68.2
          O(0)      0.00001
          S(-2)     0.00001
          S(6)      188
          water    1 # kg
      EQUILIBRIUM_PHASES 1-2 Equilibration with Pyrite
          Pyrite 0 10
      END
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 3.     HNW-14-12

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Alkalinity        5.275e-003  5.275e-003
      B                 7.401e-006  7.401e-006
      Ca                3.019e-003  3.019e-003
```

```
      Cl               1.408e-003  1.408e-003  Charge balance
      Fe(2)            1.791e-010  1.791e-010
      K                2.516e-004  2.516e-004
      Mg               6.705e-004  6.705e-004
      Mn               9.647e-008  9.647e-008
      N(-3)            1.428e-006  1.428e-006
      N(5)             1.428e-006  1.428e-006
      Na               2.967e-003  2.967e-003
      O(0)             6.250e-010  6.250e-010
      S(-2)            3.119e-010  3.119e-010
      S(6)             1.957e-003  1.957e-003

----------------------------Description of solution----------------------------

                                       pH  =   7.100
                                       pe  =  -2.000
       Specific Conductance (uS/cm, 19 oC) = 853
                          Density (g/cm3)  =   0.99907
                        Activity of water  =   1.000
                           Ionic strength  =  1.445e-002
                       Mass of water (kg)  =  1.000e+000
                    Total carbon (mol/kg)  =  6.150e-003
                       Total CO2 (mol/kg)  =  6.150e-003
                      Temperature (deg C)  =  19.000
                  Electrical balance (eq)  = -3.604e-016
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =  10
                                  Total H  = 1.110177e+002
                                  Total O  = 5.553164e+001

---------------------------------Redox couples---------------------------------

      Redox couple             pe  Eh (volts)

      N(-3)/N(5)           6.3627      0.3688
      O(-2)/O(0)          12.5514      0.7275
      S(-2)/S(6)          -2.8191     -0.1634

----------------------------Distribution of species----------------------------

                                                   Log       Log          Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   OH-                   8.916e-008  7.886e-008    -7.050    -7.103    -0.053
   H+                    8.806e-008  7.943e-008    -7.055    -7.100    -0.045
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                 7.347e-006  7.371e-006    -5.134    -5.132     0.001
   H2BO3-                5.382e-008  4.775e-008    -7.269    -7.321    -0.052
C(4)            6.150e-003
   HCO3-                 5.129e-003  4.571e-003    -2.290    -2.340    -0.050
   CO2                   8.859e-004  8.888e-004    -3.053    -3.051     0.001
   CaHCO3+               9.714e-005  8.657e-005    -4.013    -4.063    -0.050
   MgHCO3+               2.160e-005  1.916e-005    -4.666    -4.718    -0.052
   NaHCO3                6.706e-006  6.728e-006    -5.174    -5.172     0.001
   CaCO3                 5.870e-006  5.889e-006    -5.231    -5.230     0.001
   CO3-2                 3.753e-006  2.368e-006    -5.426    -5.626    -0.200
   MgCO3                 7.530e-007  7.555e-007    -6.123    -6.122     0.001
   NaCO3-                9.552e-008  8.475e-008    -7.020    -7.072    -0.052
   MnHCO3+               1.862e-008  1.653e-008    -7.730    -7.782    -0.052
   MnCO3                 7.605e-009  7.630e-009    -8.119    -8.117     0.001
   FeHCO3+               4.005e-011  3.554e-011   -10.397   -10.449    -0.052
   FeCO3                 4.402e-012  4.417e-012   -11.356   -11.355     0.001
Ca              3.019e-003
   Ca+2                  2.612e-003  1.647e-003    -2.583    -2.783    -0.200
   CaSO4                 3.035e-004  3.045e-004    -3.518    -3.516     0.001
   CaHCO3+               9.714e-005  8.657e-005    -4.013    -4.063    -0.050
```

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   CaCO3                 5.870e-006  5.889e-006    -5.231    -5.230     0.001
   CaOH+                 3.878e-009  3.441e-009    -8.411    -8.463    -0.052
   CaHSO4+               1.488e-010  1.321e-010    -9.827    -9.879    -0.052
Cl              1.408e-003
   Cl-                   1.408e-003  1.246e-003    -2.851    -2.904    -0.053
   MnCl+                 2.321e-010  2.059e-010    -9.634    -9.686    -0.052
   FeCl+                 1.507e-013  1.337e-013   -12.822   -12.874    -0.052
   MnCl2                 1.116e-013  1.120e-013   -12.952   -12.951     0.001
   MnCl3-                4.331e-017  3.843e-017   -16.363   -16.415    -0.052
Fe(2)           1.791e-010
   Fe+2                  1.221e-010  7.775e-011    -9.913   -10.109    -0.196
   FeHCO3+               4.005e-011  3.554e-011   -10.397   -10.449    -0.052
   FeSO4                 1.209e-011  1.213e-011   -10.918   -10.916     0.001
   FeCO3                 4.402e-012  4.417e-012   -11.356   -11.355     0.001
   FeOH+                 2.207e-013  1.958e-013   -12.656   -12.708    -0.052
   FeCl+                 1.507e-013  1.337e-013   -12.822   -12.874    -0.052
   FeHSO4+               7.025e-018  6.233e-018   -17.153   -17.205    -0.052
   Fe(HS)2               1.735e-021  1.740e-021   -20.761   -20.759     0.001
   Fe(HS)3-              3.385e-029  3.003e-029   -28.470   -28.522    -0.052
H(0)            9.464e-014
   H2                    4.732e-014  4.748e-014   -13.325   -13.324     0.001
K               2.516e-004
   K+                    2.501e-004  2.213e-004    -3.602    -3.655    -0.053
   KSO4-                 1.545e-006  1.371e-006    -5.811    -5.863    -0.052
   KOH                   9.627e-012  9.659e-012   -11.017   -11.015     0.001
Mg              6.705e-004
   Mg+2                  5.763e-004  3.666e-004    -3.239    -3.436    -0.196
   MgSO4                 7.177e-005  7.200e-005    -4.144    -4.143     0.001
   MgHCO3+               2.160e-005  1.916e-005    -4.666    -4.718    -0.052
   MgCO3                 7.530e-007  7.555e-007    -6.123    -6.122     0.001
   MgOH+                 1.086e-008  9.637e-009    -7.964    -8.016    -0.052
Mn(2)           9.647e-008
   Mn+2                  6.373e-008  4.056e-008    -7.196    -7.392    -0.196
   MnHCO3+               1.862e-008  1.653e-008    -7.730    -7.782    -0.052
   MnCO3                 7.605e-009  7.630e-009    -8.119    -8.117     0.001
   MnSO4                 6.275e-009  6.296e-009    -8.202    -8.201     0.001
   MnCl+                 2.321e-010  2.059e-010    -9.634    -9.686    -0.052
   MnOH+                 8.978e-012  7.966e-012   -11.047   -11.099    -0.052
   MnCl2                 1.116e-013  1.120e-013   -12.952   -12.951     0.001
   MnCl3-                4.331e-017  3.843e-017   -16.363   -16.415    -0.052
   Mn(NO3)2              2.592e-019  2.600e-019   -18.586   -18.585     0.001
Mn(3)           1.504e-035
   Mn+3                  1.504e-035  5.126e-036   -34.823   -35.290    -0.467
N(-3)           1.428e-006
   NH4+                  1.405e-006  1.237e-006    -5.852    -5.908    -0.055
   NH4SO4-               1.762e-008  1.563e-008    -7.754    -7.806    -0.052
   NH3                   5.737e-009  5.756e-009    -8.241    -8.240     0.001
N(5)            1.428e-006
   NO3-                  1.428e-006  1.260e-006    -5.845    -5.900    -0.054
   Mn(NO3)2              2.592e-019  2.600e-019   -18.586   -18.585     0.001
Na              2.967e-003
   Na+                   2.946e-003  2.618e-003    -2.531    -2.582    -0.051
   NaSO4-                1.395e-005  1.238e-005    -4.855    -4.907    -0.052
   NaHCO3                6.706e-006  6.728e-006    -5.174    -5.172     0.001
   NaCO3-                9.552e-008  8.475e-008    -7.020    -7.072    -0.052
   NaOH                  2.169e-010  2.177e-010    -9.664    -9.662     0.001
O(0)            6.250e-010
   O2                    3.125e-010  3.135e-010    -9.505    -9.504     0.001
S(-2)           3.119e-010
   HS-                   1.792e-010  1.585e-010    -9.747    -9.800    -0.053
   H2S                   1.327e-010  1.332e-010    -9.877    -9.876     0.001
   S-2                   2.526e-016  1.584e-016   -15.598   -15.800    -0.203
   Fe(HS)2               1.735e-021  1.740e-021   -20.761   -20.759     0.001
   Fe(HS)3-              3.385e-029  3.003e-029   -28.470   -28.522    -0.052
S(6)            1.957e-003
   SO4-2                 1.566e-003  9.810e-004    -2.805    -3.008    -0.203
   CaSO4                 3.035e-004  3.045e-004    -3.518    -3.516     0.001
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   MgSO4                 7.177e-005  7.200e-005    -4.144    -4.143     0.001
   NaSO4-                1.395e-005  1.238e-005    -4.855    -4.907    -0.052
   KSO4-                 1.545e-006  1.371e-006    -5.811    -5.863    -0.052
   NH4SO4-               1.762e-008  1.563e-008    -7.754    -7.806    -0.052
   HSO4-                 7.515e-009  6.668e-009    -8.124    -8.176    -0.052
   MnSO4                 6.275e-009  6.296e-009    -8.202    -8.201     0.001
   CaHSO4+               1.488e-010  1.321e-010    -9.827    -9.879    -0.052
   FeSO4                 1.209e-011  1.213e-011   -10.918   -10.916     0.001
   FeHSO4+               7.025e-018  6.233e-018   -17.153   -17.205    -0.052

------------------------------Saturation indices-------------------------------

      Phase               SI log IAP  log KT

      Anhydrite        -1.45   -5.79   -4.34  CaSO4
      Aragonite        -0.11   -8.41   -8.30  CaCO3
      Calcite           0.04   -8.41   -8.45  CaCO3
      CO2(g)           -1.66   -3.05   -1.39  CO2
      Dolomite         -0.52  -17.47  -16.95  CaMg(CO3)2
      FeS(ppt)         -8.89  -12.81   -3.92  FeS
      Gypsum           -1.21   -5.79   -4.58  CaSO4:2H2O
      H2(g)           -10.20  -13.32   -3.12  H2
      H2O(g)           -1.67   -0.00    1.67  H2O
      H2S(g)           -8.95   -9.88   -0.93  H2S
      Halite           -7.05   -5.49    1.57  NaCl
      Hausmannite     -31.92   30.62   62.54  Mn3O4
      Mackinawite      -8.16  -12.81   -4.65  FeS
      Manganite       -13.43   11.91   25.34  MnOOH
      Melanterite     -10.83  -13.12   -2.28  FeSO4:7H2O
      NH3(g)          -10.13   -8.24    1.89  NH3
      O2(g)            -6.66   -9.50   -2.85  O2
      Pyrite           -0.86  -19.51  -18.65  FeS2
      Pyrochroite      -8.39    6.81   15.20  Mn(OH)2
      Pyrolusite      -25.35   17.01   42.36  MnO2
      Rhodochrosite    -1.91  -13.02  -11.11  MnCO3
      Siderite         -4.88  -15.73  -10.85  FeCO3
      Sulfur           -4.70    0.32    5.03  S

-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using solution 3. HNW-14-12
Using pure phase assemblage 1.      Equilibration with Pyrite

-------------------------------Phase assemblage--------------------------------

                                                      Moles in assemblage
Phase                  SI log IAP  log KT      Initial       Final       Delta

Pyrite               0.00  -18.65  -18.65   1.000e+001  1.000e+001 -2.287e-007

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      B                 7.401e-006  7.401e-006
      C                 6.150e-003  6.150e-003
      Ca                3.019e-003  3.019e-003
      Cl                1.408e-003  1.408e-003
      Fe                2.289e-007  2.289e-007
      K                 2.516e-004  2.516e-004
      Mg                6.705e-004  6.705e-004
      Mn                9.647e-008  9.647e-008
      N                 2.856e-006  2.856e-006
```

```
      Na                2.967e-003  2.967e-003
      S                 1.957e-003  1.957e-003

----------------------------Description of solution----------------------------

                                       pH  =   7.100      Charge balance
                                       pe  =  -2.775      Adjusted to redox equilibrium
       Specific Conductance (uS/cm, 19 oC) = 853
                          Density (g/cm3)  =   0.99907
                        Activity of water  =   1.000
                           Ionic strength  =  1.445e-002
                       Mass of water (kg)  =  1.000e+000
                 Total alkalinity (eq/kg)  =  5.275e-003
                       Total CO2 (mol/kg)  =  6.150e-003
                      Temperature (deg C)  =  19.000
                  Electrical balance (eq)  = -4.419e-016
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =   9
                                  Total H  = 1.110177e+002
                                  Total O  = 5.553164e+001

----------------------------Distribution of species----------------------------

                                                   Log       Log         Log
   Species                 Molality    Activity  Molality  Activity     Gamma

   OH-                   8.912e-008  7.883e-008    -7.050    -7.103    -0.053
   H+                    8.810e-008  7.947e-008    -7.055    -7.100    -0.045
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                 7.347e-006  7.371e-006    -5.134    -5.132     0.001
   H2BO3-                5.380e-008  4.773e-008    -7.269    -7.321    -0.052
C(-4)           3.698e-013
   CH4                   3.698e-013  3.710e-013   -12.432   -12.431     0.001
C(4)            6.150e-003
   HCO3-                 5.128e-003  4.571e-003    -2.290    -2.340    -0.050
   CO2                   8.862e-004  8.891e-004    -3.052    -3.051     0.001
   CaHCO3+               9.713e-005  8.657e-005    -4.013    -4.063    -0.050
   MgHCO3+               2.160e-005  1.916e-005    -4.666    -4.718    -0.052
   NaHCO3                6.706e-006  6.728e-006    -5.174    -5.172     0.001
   CaCO3                 5.867e-006  5.886e-006    -5.232    -5.230     0.001
   CO3-2                 3.751e-006  2.367e-006    -5.426    -5.626    -0.200
   MgCO3                 7.526e-007  7.551e-007    -6.123    -6.122     0.001
   NaCO3-                9.547e-008  8.471e-008    -7.020    -7.072    -0.052
   FeHCO3+               5.119e-008  4.542e-008    -7.291    -7.343    -0.052
   MnHCO3+               1.862e-008  1.653e-008    -7.730    -7.782    -0.052
   MnCO3                 7.601e-009  7.626e-009    -8.119    -8.118     0.001
   FeCO3                 5.623e-009  5.642e-009    -8.250    -8.249     0.001
Ca              3.019e-003
   Ca+2                  2.612e-003  1.647e-003    -2.583    -2.783    -0.200
   CaSO4                 3.036e-004  3.046e-004    -3.518    -3.516     0.001
   CaHCO3+               9.713e-005  8.657e-005    -4.013    -4.063    -0.050
   CaCO3                 5.867e-006  5.886e-006    -5.232    -5.230     0.001
   CaOH+                 3.876e-009  3.439e-009    -8.412    -8.464    -0.052
   CaHSO4+               1.489e-010  1.322e-010    -9.827    -9.879    -0.052
Cl              1.408e-003
   Cl-                   1.408e-003  1.246e-003    -2.851    -2.904    -0.053
   MnCl+                 2.321e-010  2.059e-010    -9.634    -9.686    -0.052
   FeCl+                 1.926e-010  1.709e-010    -9.715    -9.767    -0.052
   MnCl2                 1.116e-013  1.120e-013   -12.952   -12.951     0.001
   MnCl3-                4.332e-017  3.843e-017   -16.363   -16.415    -0.052
   FeCl+2                5.690e-025  3.527e-025   -24.245   -24.453    -0.208
   FeCl2+                2.686e-027  2.384e-027   -26.571   -26.623    -0.052
   FeCl3                 2.960e-031  2.970e-031   -30.529   -30.527     0.001
Fe(2)           2.289e-007
   Fe+2                  1.561e-007  9.938e-008    -6.807    -7.003    -0.196
   FeHCO3+               5.119e-008  4.542e-008    -7.291    -7.343    -0.052
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   FeSO4                 1.545e-008  1.550e-008    -7.811    -7.810     0.001
   FeCO3                 5.623e-009  5.642e-009    -8.250    -8.249     0.001
   FeOH+                 2.820e-010  2.502e-010    -9.550    -9.602    -0.052
   FeCl+                 1.926e-010  1.709e-010    -9.715    -9.767    -0.052
   FeHSO4+               8.985e-015  7.972e-015   -14.046   -14.098    -0.052
   Fe(HS)2               4.473e-019  4.488e-019   -18.349   -18.348     0.001
   Fe(HS)3-              3.921e-027  3.479e-027   -26.407   -26.459    -0.052
Fe(3)           5.060e-015
   Fe(OH)3               2.633e-015  2.642e-015   -14.580   -14.578     0.001
   Fe(OH)2+              2.399e-015  2.129e-015   -14.620   -14.672    -0.052
   Fe(OH)4-              2.671e-017  2.370e-017   -16.573   -16.625    -0.052
   FeOH+2                1.040e-018  6.446e-019   -17.983   -18.191    -0.208
   FeSO4+                1.205e-022  1.069e-022   -21.919   -21.971    -0.052
   Fe+3                  2.878e-023  1.138e-023   -22.541   -22.944    -0.403
   Fe(SO4)2-             2.526e-024  2.241e-024   -23.598   -23.650    -0.052
   FeCl+2                5.690e-025  3.527e-025   -24.245   -24.453    -0.208
   FeCl2+                2.686e-027  2.384e-027   -26.571   -26.623    -0.052
   FeHSO4+2              3.700e-029  2.293e-029   -28.432   -28.640    -0.208
   FeCl3                 2.960e-031  2.970e-031   -30.529   -30.527     0.001
   Fe2(OH)2+4            9.760e-035  1.441e-035   -34.011   -34.841    -0.831
   Fe3(OH)4+5            0.000e+000  0.000e+000   -45.650   -46.948    -1.298
H(0)            3.367e-012
   H2                    1.683e-012  1.689e-012   -11.774   -11.772     0.001
K               2.516e-004
   K+                    2.501e-004  2.213e-004    -3.602    -3.655    -0.053
   KSO4-                 1.546e-006  1.371e-006    -5.811    -5.863    -0.052
   KOH                   9.623e-012  9.655e-012   -11.017   -11.015     0.001
Mg              6.705e-004
   Mg+2                  5.763e-004  3.666e-004    -3.239    -3.436    -0.196
   MgSO4                 7.178e-005  7.202e-005    -4.144    -4.143     0.001
   MgHCO3+               2.160e-005  1.916e-005    -4.666    -4.718    -0.052
   MgCO3                 7.526e-007  7.551e-007    -6.123    -6.122     0.001
   MgOH+                 1.086e-008  9.633e-009    -7.964    -8.016    -0.052
Mn(2)           9.647e-008
   Mn+2                  6.373e-008  4.057e-008    -7.196    -7.392    -0.196
   MnHCO3+               1.862e-008  1.653e-008    -7.730    -7.782    -0.052
   MnCO3                 7.601e-009  7.626e-009    -8.119    -8.118     0.001
   MnSO4                 6.277e-009  6.298e-009    -8.202    -8.201     0.001
   MnCl+                 2.321e-010  2.059e-010    -9.634    -9.686    -0.052
   MnOH+                 8.975e-012  7.963e-012   -11.047   -11.099    -0.052
   MnCl2                 1.116e-013  1.120e-013   -12.952   -12.951     0.001
   MnCl3-                4.332e-017  3.843e-017   -16.363   -16.415    -0.052
   Mn(NO3)2              0.000e+000  0.000e+000  -166.985  -166.983     0.001
Mn(3)           2.522e-036
   Mn+3                  2.522e-036  8.598e-037   -35.598   -36.066    -0.467
N(-3)           1.153e-007
   NH4+                  1.134e-007  9.990e-008    -6.945    -7.000    -0.055
   NH4SO4-               1.423e-009  1.263e-009    -8.847    -8.899    -0.052
   NH3                   4.631e-010  4.647e-010    -9.334    -9.333     0.001
N(0)            2.740e-006
   N2                    1.370e-006  1.375e-006    -5.863    -5.862     0.001
N(3)            0.000e+000
   NO2-                  0.000e+000  0.000e+000   -59.464   -59.519    -0.054
N(5)            0.000e+000
   NO3-                  0.000e+000  0.000e+000   -80.044   -80.099    -0.054
   Mn(NO3)2              0.000e+000  0.000e+000  -166.985  -166.983     0.001
Na              2.967e-003
   Na+                   2.946e-003  2.618e-003    -2.531    -2.582    -0.051
   NaSO4-                1.396e-005  1.238e-005    -4.855    -4.907    -0.052
   NaHCO3                6.706e-006  6.728e-006    -5.174    -5.172     0.001
   NaCO3-                9.547e-008  8.471e-008    -7.020    -7.072    -0.052
   NaOH                  2.168e-010  2.176e-010    -9.664    -9.662     0.001
O(0)            0.000e+000
   O2                    0.000e+000  0.000e+000   -70.813   -70.812     0.001
S(-2)           1.401e-010
   HS-                   8.048e-011  7.118e-011   -10.094   -10.148    -0.053
   H2S                   5.964e-011  5.984e-011   -10.224   -10.223     0.001
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   S-2                  1.134e-016  7.113e-017   -15.945   -16.148    -0.203
   Fe(HS)2              4.473e-019  4.488e-019   -18.349   -18.348     0.001
   Fe(HS)3-             3.921e-027  3.479e-027   -26.407   -26.459    -0.052
S(6)             1.957e-003
   SO4-2                1.567e-003  9.812e-004    -2.805    -3.008    -0.203
   CaSO4                3.036e-004  3.046e-004    -3.518    -3.516     0.001
   MgSO4                7.178e-005  7.202e-005    -4.144    -4.143     0.001
   NaSO4-               1.396e-005  1.238e-005    -4.855    -4.907    -0.052
   KSO4-                1.546e-006  1.371e-006    -5.811    -5.863    -0.052
   FeSO4                1.545e-008  1.550e-008    -7.811    -7.810     0.001
   HSO4-                7.520e-009  6.673e-009    -8.124    -8.176    -0.052
   MnSO4                6.277e-009  6.298e-009    -8.202    -8.201     0.001
   NH4SO4-              1.423e-009  1.263e-009    -8.847    -8.899    -0.052
   CaHSO4+              1.489e-010  1.322e-010    -9.827    -9.879    -0.052
   FeHSO4+              8.985e-015  7.972e-015   -14.046   -14.098    -0.052
   FeSO4+               1.205e-022  1.069e-022   -21.919   -21.971    -0.052
   Fe(SO4)2-            2.526e-024  2.241e-024   -23.598   -23.650    -0.052
   FeHSO4+2             3.700e-029  2.293e-029   -28.432   -28.640    -0.208

------------------------------Saturation indices-------------------------------

      Phase                SI log IAP  log KT

      Anhydrite         -1.45   -5.79   -4.34  CaSO4
      Aragonite         -0.11   -8.41   -8.30  CaCO3
      Calcite            0.04   -8.41   -8.45  CaCO3
      CH4(g)            -9.62  -12.43   -2.81  CH4
      CO2(g)            -1.66   -3.05   -1.39  CO2
      Dolomite          -0.52  -17.47  -16.95  CaMg(CO3)2
      Fe(OH)3(a)        -6.54   -1.64    4.89  Fe(OH)3
      FeS(ppt)          -6.14  -10.05   -3.92  FeS
      Goethite          -0.86   -1.64   -0.78  FeOOH
      Gypsum            -1.21   -5.79   -4.58  CaSO4:2H2O
      H2(g)             -8.65  -11.77   -3.12  H2
      H2O(g)            -1.67   -0.00    1.67  H2O
      H2S(g)            -9.29  -10.22   -0.93  H2S
      Halite            -7.05   -5.49    1.57  NaCl
      Hausmannite      -33.47   29.07   62.54  Mn3O4
      Hematite           0.25   -3.29   -3.54  Fe2O3
      Jarosite-K       -27.17  -35.90   -8.74  KFe3(SO4)2(OH)6
      Mackinawite       -5.40  -10.05   -4.65  FeS
      Manganite        -14.21   11.13   25.34  MnOOH
      Melanterite       -7.73  -10.01   -2.28  FeSO4:7H2O
      N2(g)             -2.62   -5.86   -3.24  N2
      NH3(g)           -11.23   -9.33    1.89  NH3
      O2(g)            -67.97  -70.81   -2.85  O2
      Pyrite             0.00  -18.65  -18.65  FeS2
      Pyrochroite       -8.39    6.81   15.20  Mn(OH)2
      Pyrolusite       -26.90   15.46   42.36  MnO2
      Rhodochrosite     -1.91  -13.02  -11.11  MnCO3
      Siderite          -1.78  -12.63  -10.85  FeCO3
      Sulfur            -6.60   -1.57    5.03  S

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End of simulation.
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Reading input data for simulation 3.
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      SOLUTION 5-6 MNW-5 D2
          temp      21.4
          pH        6.6
          pe        -2
          redox     pe
          units     mg/kgw
```

```
            density   1
            Fe(2)     0.00001
            Mg        16.3
            Mn(2)     0.05 ug/kgw
            N(5)      0
            N(-3)     0
            S(-2)     0.00001
            S(6)      167
            Al        0
            Cl        42 charge
            Ca        121
            Alkalinity 243
            K         9.84
            O(0)      0.00001
            Na        68.2
            B         0.08
            water    1 # kg
        EQUILIBRIUM_PHASES 3 Equilibration with Pyrite
            Pyrite 0 10
        END
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 5.     MNW-5 D2

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      Alkalinity       4.856e-003  4.856e-003
      B                7.401e-006  7.401e-006
      Ca               3.019e-003  3.019e-003
      Cl               2.265e-003  2.265e-003  Charge balance
      Fe(2)            1.791e-010  1.791e-010
      K                2.516e-004  2.516e-004
      Mg               6.705e-004  6.705e-004
      Mn(2)            9.101e-010  9.101e-010
      Na               2.967e-003  2.967e-003
      O(0)             6.250e-010  6.250e-010
      S(-2)            3.119e-010  3.119e-010
      S(6)             1.738e-003  1.738e-003

----------------------------Description of solution----------------------------

                                       pH  =   6.600
                                       pe  =  -2.000
       Specific Conductance (uS/cm, 21 oC) = 925
                          Density (g/cm3)  =   0.99855
                        Activity of water  =   1.000
                           Ionic strength  =  1.438e-002
                       Mass of water (kg)  =  1.000e+000
                    Total carbon (mol/kg)  =  7.342e-003
                       Total CO2 (mol/kg)  =  7.342e-003
                      Temperature (deg C)  =  21.400
                  Electrical balance (eq)  = -5.521e-016
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =   9
                                  Total H  = 1.110173e+002
                                  Total O  = 5.553273e+001

---------------------------------Redox couples---------------------------------

      Redox couple             pe  Eh (volts)

      O(-2)/O(0)          12.8460      0.7507
      S(-2)/S(6)          -2.2768     -0.1331
```

```
----------------------------Distribution of species----------------------------

                                                   Log       Log        Log
   Species                  Molality    Activity  Molality  Activity     Gamma

   H+                    2.785e-007  2.512e-007    -6.555    -6.600    -0.045
   OH-                   3.413e-008  3.019e-008    -7.467    -7.520    -0.053
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                 7.383e-006  7.407e-006    -5.132    -5.130     0.001
   H2BO3-                1.790e-008  1.588e-008    -7.747    -7.799    -0.052
C(4)            7.342e-003
   HCO3-                 4.728e-003  4.213e-003    -2.325    -2.375    -0.050
   CO2                   2.489e-003  2.498e-003    -2.604    -2.602     0.001
   CaHCO3+               9.477e-005  8.445e-005    -4.023    -4.073    -0.050
   MgHCO3+               2.026e-005  1.797e-005    -4.693    -4.745    -0.052
   NaHCO3                6.184e-006  6.205e-006    -5.209    -5.207     0.001
   CaCO3                 1.902e-006  1.908e-006    -5.721    -5.719     0.001
   CO3-2                 1.156e-006  7.290e-007    -5.937    -6.137    -0.200
   MgCO3                 2.427e-007  2.435e-007    -6.615    -6.614     0.001
   NaCO3-                3.335e-008  2.958e-008    -7.477    -7.529    -0.052
   MnHCO3+               1.747e-010  1.550e-010    -9.758    -9.810    -0.052
   FeHCO3+               3.845e-011  3.411e-011   -10.415   -10.467    -0.052
   MnCO3                 2.382e-011  2.390e-011   -10.623   -10.622     0.001
   FeCO3                 1.411e-012  1.416e-012   -11.850   -11.849     0.001
Ca              3.019e-003
   Ca+2                  2.646e-003  1.667e-003    -2.577    -2.778    -0.201
   CaSO4                 2.767e-004  2.776e-004    -3.558    -3.557     0.001
   CaHCO3+               9.477e-005  8.445e-005    -4.023    -4.073    -0.050
   CaCO3                 1.902e-006  1.908e-006    -5.721    -5.719     0.001
   CaOH+                 1.241e-009  1.101e-009    -8.906    -8.958    -0.052
   CaHSO4+               4.410e-010  3.912e-010    -9.356    -9.408    -0.052
Cl              2.265e-003
   Cl-                   2.265e-003  2.004e-003    -2.645    -2.698    -0.053
   MnCl+                 3.798e-012  3.369e-012   -11.420   -11.473    -0.052
   FeCl+                 2.524e-013  2.239e-013   -12.598   -12.650    -0.052
   MnCl2                 2.937e-015  2.947e-015   -14.532   -14.531     0.001
   MnCl3-                1.833e-018  1.626e-018   -17.737   -17.789    -0.052
Fe(2)           1.791e-010
   Fe+2                  1.273e-010  8.096e-011    -9.895   -10.092    -0.196
   FeHCO3+               3.845e-011  3.411e-011   -10.415   -10.467    -0.052
   FeSO4                 1.159e-011  1.163e-011   -10.936   -10.934     0.001
   FeCO3                 1.411e-012  1.416e-012   -11.850   -11.849     0.001
   FeCl+                 2.524e-013  2.239e-013   -12.598   -12.650    -0.052
   FeOH+                 8.747e-014  7.760e-014   -13.058   -13.110    -0.052
   FeHSO4+               2.142e-017  1.900e-017   -16.669   -16.721    -0.052
   Fe(HS)2               5.462e-022  5.481e-022   -21.263   -21.261     0.001
   Fe(HS)3-              5.863e-030  5.201e-030   -29.232   -29.284    -0.052
H(0)            9.233e-013
   H2                    4.617e-013  4.632e-013   -12.336   -12.334     0.001
K               2.516e-004
   K+                    2.502e-004  2.214e-004    -3.602    -3.655    -0.053
   KSO4-                 1.421e-006  1.261e-006    -5.847    -5.899    -0.052
   KOH                   3.045e-012  3.055e-012   -11.516   -11.515     0.001
Mg              6.705e-004
   Mg+2                  5.820e-004  3.699e-004    -3.235    -3.432    -0.197
   MgSO4                 6.796e-005  6.818e-005    -4.168    -4.166     0.001
   MgHCO3+               2.026e-005  1.797e-005    -4.693    -4.745    -0.052
   MgCO3                 2.427e-007  2.435e-007    -6.615    -6.614     0.001
   MgOH+                 4.336e-009  3.847e-009    -8.363    -8.415    -0.052
Mn(2)           9.101e-010
   Mn+2                  6.488e-010  4.127e-010    -9.188    -9.384    -0.196
   MnHCO3+               1.747e-010  1.550e-010    -9.758    -9.810    -0.052
   MnSO4                 5.893e-011  5.913e-011   -10.230   -10.228     0.001
   MnCO3                 2.382e-011  2.390e-011   -10.623   -10.622     0.001
   MnCl+                 3.798e-012  3.369e-012   -11.420   -11.473    -0.052
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   MnOH+                 3.536e-014  3.137e-014   -13.451   -13.503    -0.052
   MnCl2                 2.937e-015  2.947e-015   -14.532   -14.531     0.001
   MnCl3-                1.833e-018  1.626e-018   -17.737   -17.789    -0.052
Na              2.967e-003
   Na+                   2.948e-003  2.619e-003    -2.530    -2.582    -0.051
   NaSO4-                1.249e-005  1.108e-005    -4.904    -4.956    -0.052
   NaHCO3                6.184e-006  6.205e-006    -5.209    -5.207     0.001
   NaCO3-                3.335e-008  2.958e-008    -7.477    -7.529    -0.052
   NaOH                  6.864e-011  6.886e-011   -10.163   -10.162     0.001
O(0)            6.250e-010
   O2                    3.125e-010  3.135e-010    -9.505    -9.504     0.001
S(-2)           3.119e-010
   H2S                   2.133e-010  2.140e-010    -9.671    -9.670     0.001
   HS-                   9.855e-011  8.715e-011   -10.006   -10.060    -0.053
   S-2                   5.210e-017  3.265e-017   -16.283   -16.486    -0.203
   Fe(HS)2               5.462e-022  5.481e-022   -21.263   -21.261     0.001
   Fe(HS)3-              5.863e-030  5.201e-030   -29.232   -29.284    -0.052
S(6)            1.738e-003
   SO4-2                 1.380e-003  8.636e-004    -2.860    -3.064    -0.204
   CaSO4                 2.767e-004  2.776e-004    -3.558    -3.557     0.001
   MgSO4                 6.796e-005  6.818e-005    -4.168    -4.166     0.001
   NaSO4-                1.249e-005  1.108e-005    -4.904    -4.956    -0.052
   KSO4-                 1.421e-006  1.261e-006    -5.847    -5.899    -0.052
   HSO4-                 2.200e-008  1.952e-008    -7.658    -7.710    -0.052
   CaHSO4+               4.410e-010  3.912e-010    -9.356    -9.408    -0.052
   MnSO4                 5.893e-011  5.913e-011   -10.230   -10.228     0.001
   FeSO4                 1.159e-011  1.163e-011   -10.936   -10.934     0.001
   FeHSO4+               2.142e-017  1.900e-017   -16.669   -16.721    -0.052

------------------------------Saturation indices-------------------------------

      Phase               SI  log IAP  log KT

      Anhydrite        -1.49   -5.84   -4.35  CaSO4
      Aragonite        -0.60   -8.92   -8.31  CaCO3
      Calcite          -0.45   -8.92   -8.46  CaCO3
      CO2(g)           -1.18   -2.60   -1.42  CO2
      Dolomite         -1.48  -18.48  -17.01  CaMg(CO3)2
      FeS(ppt)         -9.64  -13.55   -3.92  FeS
      Gypsum           -1.26   -5.84   -4.58  CaSO4:2H2O
      H2(g)            -9.20  -12.33   -3.13  H2
      H2O(g)           -1.60   -0.00    1.60  H2O
      H2S(g)           -8.71   -9.67   -0.96  H2S
      Halite           -6.85   -5.28    1.57  NaCl
      Hausmannite     -41.29   20.65   61.93  Mn3O4
      Mackinawite      -8.90  -13.55   -4.65  FeS
      Manganite       -16.92    8.42   25.34  MnOOH
      Melanterite     -10.90  -13.16   -2.25  FeSO4:7H2O
      O2(g)            -6.64   -9.50   -2.87  O2
      Pyrite           -2.43  -21.01  -18.58  FeS2
      Pyrochroite     -11.38    3.82   15.20  Mn(OH)2
      Pyrolusite      -28.95   13.02   41.96  MnO2
      Rhodochrosite    -4.40  -15.52  -11.12  MnCO3
      Siderite         -5.36  -16.23  -10.87  FeCO3
      Sulfur           -5.44   -0.47    4.97  S

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Beginning of batch-reaction calculations.
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Reaction step 1.

Using solution 5. MNW-5 D2
Using pure phase assemblage 3.      Equilibration with Pyrite

-------------------------------Phase assemblage--------------------------------
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                                                      Moles in assemblage
Phase                  SI log IAP  log KT      Initial       Final       Delta

Pyrite               0.00  -18.58  -18.58   1.000e+001  1.000e+001 -2.054e-009

-----------------------------Solution composition------------------------------

      Elements           Molality       Moles

      B                 7.401e-006  7.401e-006
      C                 7.342e-003  7.342e-003
      Ca                3.019e-003  3.019e-003
      Cl                2.265e-003  2.265e-003
      Fe                2.233e-009  2.233e-009
      K                 2.516e-004  2.516e-004
      Mg                6.705e-004  6.705e-004
      Mn                9.101e-010  9.101e-010
      Na                2.967e-003  2.967e-003
      S                 1.738e-003  1.738e-003

----------------------------Description of solution----------------------------

                                       pH  =   6.600      Charge balance
                                       pe  =  -2.412      Adjusted to redox equilibrium
       Specific Conductance (uS/cm, 21 oC) = 925
                          Density (g/cm3)  =   0.99855
                        Activity of water  =   1.000
                           Ionic strength  =  1.438e-002
                       Mass of water (kg)  =  1.000e+000
                 Total alkalinity (eq/kg)  =  4.856e-003
                       Total CO2 (mol/kg)  =  7.342e-003
                      Temperature (deg C)  =  21.400
                  Electrical balance (eq)  = -5.508e-016
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                               Iterations  =   8
                                  Total H  = 1.110173e+002
                                  Total O  = 5.553273e+001

----------------------------Distribution of species----------------------------

                                                   Log       Log        Log
   Species                   Molality    Activity  Molality  Activity     Gamma

   H+                    2.785e-007  2.512e-007    -6.555    -6.600    -0.045
   OH-                   3.413e-008  3.019e-008    -7.467    -7.520    -0.053
   H2O                   5.551e+001  9.997e-001     1.744    -0.000     0.000
B               7.401e-006
   H3BO3                 7.383e-006  7.407e-006    -5.132    -5.130     0.001
   H2BO3-                1.790e-008  1.588e-008    -7.747    -7.799    -0.052
C(-4)           5.935e-012
   CH4                   5.935e-012  5.955e-012   -11.227   -11.225     0.001
C(4)            7.342e-003
   HCO3-                 4.728e-003  4.213e-003    -2.325    -2.375    -0.050
   CO2                   2.489e-003  2.498e-003    -2.604    -2.602     0.001
   CaHCO3+               9.477e-005  8.445e-005    -4.023    -4.073    -0.050
   MgHCO3+               2.026e-005  1.797e-005    -4.693    -4.745    -0.052
   NaHCO3                6.184e-006  6.205e-006    -5.209    -5.207     0.001
   CaCO3                 1.902e-006  1.908e-006    -5.721    -5.719     0.001
   CO3-2                 1.156e-006  7.290e-007    -5.937    -6.137    -0.200
   MgCO3                 2.427e-007  2.435e-007    -6.615    -6.614     0.001
   NaCO3-                3.335e-008  2.958e-008    -7.477    -7.529    -0.052
   FeHCO3+               4.794e-010  4.253e-010    -9.319    -9.371    -0.052
   MnHCO3+               1.747e-010  1.550e-010    -9.758    -9.810    -0.052
   MnCO3                 2.382e-011  2.390e-011   -10.623   -10.622     0.001
   FeCO3                 1.760e-011  1.765e-011   -10.755   -10.753     0.001
Ca              3.019e-003
   Ca+2                  2.646e-003  1.667e-003    -2.577    -2.778    -0.201
```

```
   CaSO4                 2.767e-004  2.776e-004    -3.558    -3.557     0.001
   CaHCO3+               9.477e-005  8.445e-005    -4.023    -4.073    -0.050
   CaCO3                 1.902e-006  1.908e-006    -5.721    -5.719     0.001
   CaOH+                 1.241e-009  1.101e-009    -8.906    -8.958    -0.052
   CaHSO4+               4.410e-010  3.912e-010    -9.356    -9.408    -0.052
Cl              2.265e-003
   Cl-                   2.265e-003  2.004e-003    -2.645    -2.698    -0.053
   MnCl+                 3.798e-012  3.369e-012   -11.420   -11.473    -0.052
   FeCl+                 3.148e-012  2.792e-012   -11.502   -11.554    -0.052
   MnCl2                 2.937e-015  2.947e-015   -14.532   -14.531     0.001
   MnCl3-                1.833e-018  1.626e-018   -17.737   -17.789    -0.052
   FeCl+2                2.663e-026  1.649e-026   -25.575   -25.783    -0.208
   FeCl2+                1.868e-028  1.657e-028   -27.729   -27.781    -0.052
   FeCl3                 3.309e-032  3.320e-032   -31.480   -31.479     0.001
Fe(2)           2.233e-009
   Fe+2                  1.587e-009  1.010e-009    -8.799    -8.996    -0.196
   FeHCO3+               4.794e-010  4.253e-010    -9.319    -9.371    -0.052
   FeSO4                 1.446e-010  1.450e-010    -9.840    -9.838     0.001
   FeCO3                 1.760e-011  1.765e-011   -10.755   -10.753     0.001
   FeCl+                 3.148e-012  2.792e-012   -11.502   -11.554    -0.052
   FeOH+                 1.091e-012  9.677e-013   -11.962   -12.014    -0.052
   FeHSO4+               2.671e-016  2.369e-016   -15.573   -15.625    -0.052
   Fe(HS)2               9.813e-019  9.846e-019   -18.008   -18.007     0.001
   Fe(HS)3-              1.264e-025  1.122e-025   -24.898   -24.950    -0.052
Fe(3)           1.140e-017
   Fe(OH)2+              8.208e-018  7.281e-018   -17.086   -17.138    -0.052
   Fe(OH)3               3.174e-018  3.185e-018   -17.498   -17.497     0.001
   Fe(OH)4-              1.126e-020  9.985e-021   -19.949   -20.001    -0.052
   FeOH+2                1.024e-020  6.344e-021   -19.990   -20.198    -0.208
   FeSO4+                3.013e-024  2.673e-024   -23.521   -23.573    -0.052
   Fe+3                  7.749e-025  3.060e-025   -24.111   -24.514    -0.404
   Fe(SO4)2-             5.612e-026  4.978e-026   -25.251   -25.303    -0.052
   FeCl+2                2.663e-026  1.649e-026   -25.575   -25.783    -0.208
   FeCl2+                1.868e-028  1.657e-028   -27.729   -27.781    -0.052
   FeHSO4+2              2.912e-030  1.804e-030   -29.536   -29.744    -0.208
   FeCl3                 3.309e-032  3.320e-032   -31.480   -31.479     0.001
   Fe2(OH)2+4            8.559e-039  1.259e-039   -38.068   -38.900    -0.832
   Fe3(OH)4+5            0.000e+000  0.000e+000   -52.271   -53.572    -1.300
H(0)            6.150e-012
   H2                    3.075e-012  3.085e-012   -11.512   -11.511     0.001
K               2.516e-004
   K+                    2.502e-004  2.214e-004    -3.602    -3.655    -0.053
   KSO4-                 1.421e-006  1.261e-006    -5.847    -5.899    -0.052
   KOH                   3.045e-012  3.055e-012   -11.516   -11.515     0.001
Mg              6.705e-004
   Mg+2                  5.820e-004  3.699e-004    -3.235    -3.432    -0.197
   MgSO4                 6.796e-005  6.818e-005    -4.168    -4.166     0.001
   MgHCO3+               2.026e-005  1.797e-005    -4.693    -4.745    -0.052
   MgCO3                 2.427e-007  2.435e-007    -6.615    -6.614     0.001
   MgOH+                 4.336e-009  3.847e-009    -8.363    -8.415    -0.052
Mn(2)           9.101e-010
   Mn+2                  6.488e-010  4.127e-010    -9.188    -9.384    -0.196
   MnHCO3+               1.747e-010  1.550e-010    -9.758    -9.810    -0.052
   MnSO4                 5.893e-011  5.913e-011   -10.230   -10.228     0.001
   MnCO3                 2.382e-011  2.390e-011   -10.623   -10.622     0.001
   MnCl+                 3.798e-012  3.369e-012   -11.420   -11.473    -0.052
   MnOH+                 3.536e-014  3.137e-014   -13.451   -13.503    -0.052
   MnCl2                 2.937e-015  2.947e-015   -14.532   -14.531     0.001
   MnCl3-                1.833e-018  1.626e-018   -17.737   -17.789    -0.052
Mn(3)           8.530e-038
   Mn+3                  8.530e-038  2.903e-038   -37.069   -37.537    -0.468
Na              2.967e-003
   Na+                   2.948e-003  2.619e-003    -2.530    -2.582    -0.051
   NaSO4-                1.249e-005  1.108e-005    -4.904    -4.956    -0.052
   NaHCO3                6.184e-006  6.205e-006    -5.209    -5.207     0.001
   NaCO3-                3.335e-008  2.958e-008    -7.477    -7.529    -0.052
   NaOH                  6.864e-011  6.886e-011   -10.163   -10.162     0.001
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O(0)            0.000e+000
   O2                    0.000e+000  0.000e+000   -70.536   -70.535     0.001
S(-2)           3.743e-009
   H2S                   2.561e-009  2.569e-009    -8.592    -8.590     0.001
   HS-                   1.183e-009  1.046e-009    -8.927    -8.980    -0.053
   S-2                   6.253e-016  3.919e-016   -15.204   -15.407    -0.203
   Fe(HS)2               9.813e-019  9.846e-019   -18.008   -18.007     0.001
   Fe(HS)3-              1.264e-025  1.122e-025   -24.898   -24.950    -0.052
S(6)            1.738e-003
   SO4-2                 1.380e-003  8.636e-004    -2.860    -3.064    -0.204
   CaSO4                 2.767e-004  2.776e-004    -3.558    -3.557     0.001
   MgSO4                 6.796e-005  6.818e-005    -4.168    -4.166     0.001
   NaSO4-                1.249e-005  1.108e-005    -4.904    -4.956    -0.052
   KSO4-                 1.421e-006  1.261e-006    -5.847    -5.899    -0.052
   HSO4-                 2.200e-008  1.952e-008    -7.658    -7.710    -0.052
   CaHSO4+               4.410e-010  3.912e-010    -9.356    -9.408    -0.052
   FeSO4                 1.446e-010  1.450e-010    -9.840    -9.838     0.001
   MnSO4                 5.893e-011  5.913e-011   -10.230   -10.228     0.001
   FeHSO4+               2.671e-016  2.369e-016   -15.573   -15.625    -0.052
   FeSO4+                3.013e-024  2.673e-024   -23.521   -23.573    -0.052
   Fe(SO4)2-             5.612e-026  4.978e-026   -25.251   -25.303    -0.052
   FeHSO4+2              2.912e-030  1.804e-030   -29.536   -29.744    -0.208

------------------------------Saturation indices-------------------------------

      Phase               SI log IAP  log KT

      Anhydrite        -1.49   -5.84   -4.35  CaSO4
      Aragonite        -0.60   -8.92   -8.31  CaCO3
      Calcite          -0.45   -8.92   -8.46  CaCO3
      CH4(g)           -8.40  -11.23   -2.83  CH4
      CO2(g)           -1.18   -2.60   -1.42  CO2
      Dolomite         -1.48  -18.48  -17.01  CaMg(CO3)2
      Fe(OH)3(a)       -9.61   -4.71    4.89  Fe(OH)3
      FeS(ppt)         -7.46  -11.38   -3.92  FeS
      Goethite         -3.84   -4.71   -0.87  FeOOH
      Gypsum           -1.26   -5.84   -4.58  CaSO4:2H2O
      H2(g)            -8.38  -11.51   -3.13  H2
      H2O(g)           -1.60   -0.00    1.60  H2O
      H2S(g)           -7.63   -8.59   -0.96  H2S
      Halite           -6.85   -5.28    1.57  NaCl
      Hausmannite     -42.11   19.82   61.93  Mn3O4
      Hematite         -5.70   -9.43   -3.73  Fe2O3
      Jarosite-K      -34.80  -43.73   -8.93  KFe3(SO4)2(OH)6
      Mackinawite      -6.73  -11.38   -4.65  FeS
      Manganite       -17.34    8.00   25.34  MnOOH
      Melanterite      -9.81  -12.06   -2.25  FeSO4:7H2O
      O2(g)           -67.67  -70.53   -2.87  O2
      Pyrite            0.00  -18.58  -18.58  FeS2
      Pyrochroite     -11.38    3.82   15.20  Mn(OH)2
      Pyrolusite      -29.77   12.19   41.96  MnO2
      Rhodochrosite    -4.40  -15.52  -11.12  MnCO3
      Siderite         -4.27  -15.13  -10.87  FeCO3
      Sulfur           -5.18   -0.21    4.97  S

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End of simulation.
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Reading input data for simulation 4.
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End of run.
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Appendix I
Attenuation Rate Evaluation Results

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Fruit Avenue Plume Superfund Site Long-Term Remedial Action Appendix I – Attenuation Rate Evaluation Results

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PREPARED BY:	CH2M HILL
DATE:	October 2012
PROJECT:	EPA Region 6 Remedial Action Contract W-EP-06-021 Task Order No. 0003-RALR-06DD CH2M HILL Project No. 345406.PJ.14
DCN:	0003-02091

Attenuation rates describe the rate at which chemical contaminant concentrations are reduced by physical, chemical, and/or biological processes without human intervention (Newell et. al, 2002). A variety of attenuation evaluations are used for different purposes. *Bulk attenuation* is evaluated to estimate if a contaminant plume is increasing, stable, or decreasing in mass and in area, and to estimate if the plume is advancing or retreating. *Point decay rates* are used to estimate how quickly contaminant concentrations are changing, and may be used to determine when remediation goals may be met. *Degradation rates* are used to characterize the rate of contaminant transformation and to provide a quantitative estimate of degradation for use in contaminant fate and transport models.

This technical memorandum (TM) describes the approach used to estimate degradation rates for use in modeling the fate and transport of trichloroethene (TCE) at the Fruit Avenue Plume (FAP) Superfund site located in Albuquerque, NM.

Bulk Attenuation and Migration of the TCE Plume

Bulk attenuation and migration of the TCE plume at the site were evaluated using Monitoring and Remediation Optimization System (MAROS) (Aziz, et al., 2006) and reported in the 2009 Long Term Monitoring Optimization (LTMO) report (CH2M HILL, 2009). The 2009 LTMO report analyzed TCE plume-wide concentrations to evaluate whether the plume was increasing or decreasing in total mass (0^{th} moment), retreating towards or advancing away from the source area (1^{st} moment), and changing in length and width (2^{nd} moment). The Mann-Kendall analysis in MAROS is appropriately performed on two-dimensional data. To facilitate the analyses at the site, field data were segregated and analyzed by aquifer zone. The aquifer zones at the site are designated from shallowest to deepest as follows: Shallow (S), Intermediate-1(I1), Intermediate-2(I2), Deep-1(D1), Deep-2(D2), Deep-3(D3), and Deep-4 (D4) aquifer zones.

The Mann-Kendall analysis of historical data (**Table 1**) suggests that the total mass of TCE in the aquifer zones evaluated, as defined by the $zero^{th}$ moment, is generally decreasing. The western portion of the plume near the presumed source area, as represented by the analysis of data from the I2 aquifer zone, is decreasing in mass, retreating towards the source area, and becoming shorter and wider.

The eastern portion of the plume, downgradient of the P&T system as represented by the analysis of data from the D1, D2, and D3 aquifer zones (**Table 1**), is generally decreasing in mass, moving away from the source area under the influence of the regional groundwater flow gradient, and becoming shorter and wider. The apparent increasing mass in the D3 aquifer zone may be caused by previously undetected occurrences of TCE moving past monitor well MNW-5(D3) or by mass entering this aquifer zone from the overlying D2 aquifer zone. The TCE plume in these aquifer zones is becoming shorter and wider.

TABLE 1
MAROS Evaluation of Plume Dynamics – 2009 LTMO
Fruit Avenue Plume Superfund Site, Albuquerque NM

Plume Area – Aquifer Zone	0th moment Mass	1st moment Position	2nd moment Length	2nd moment Width
Shallow	N/A	N/A	N/A	N/A
Intermediate-1 (I1)	N/A	N/A	N/A	N/A
Intermediate-2 (I2)	D 96.4%	D 100%	D 100%	PI 95.6%
Deep 1 (D1)	D 97.7%	NT 63.6%	NT 63.6%	PI 92.2%
Deep 2 (D2)	D 97.7%	I 99.2%	PD 92.2%	I 99.5%
Deep 3 (D3)	I 99.2%	I 99.5%	D 100%	I 99.5%
Deep 4 (D4)	N/A	N/A	N/A	N/A

Notes:
Mann-Kendall Trend test performed on all sample events.
Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No-Trend (NT);
Not Applicable (N/A) – due to insufficient data (less than 4 sample locations)

Point Decay Rates

Point decay rates at 20 individual monitor wells were estimated according to the guidance in Appendix A of Wilson (2011). Decay rates at individual wells are analyzed in terms of concentration per time (µg/L per year). Decay rate analysis was completed at locations where: (1) the Mann-Kendall analysis (**Appendix D, Statistical Evaluation of TCE and Cis 1,2-DCE Concentration Data**) indicated a decreasing trend; (2) historical TCE concentrations exceeded the 5 µg/L remedial goal; and (3) TCE concentrations were unlikely to have been affected by the P&T system (e.g. **Figure 1**). At monitoring wells DM-13(I1), SFMW-6(I1), HSM-I2-5, and MNW-5(D2), the evaluated data were limited to more-recent results, which clearly indicate a decreasing TCE concentration trend, and where earlier data were excluded from the analysis. At DM-13(I1) post-1996 data were analyzed, at SFMW-6(I1) post-1995 data were analyzed, and at both HSM-I2-5 and MNW-5(D2) post-2006 data were analyzed.

Because the rate of decay from all natural in situ processes depends upon the contaminant concentration, the decay rate is approximated by a first-order rate constant. Concentration trends observed at the site were thus used to estimate first-order point decay constants. The appropriateness of this assumption was also evaluated using the method described in Appendix A of Wilson (2011).

First-order decay is described by the following (**Equation 1**).

$$Ln\,(C_t) = kt + Ln\,(C_0) \qquad \text{Equation 1}$$

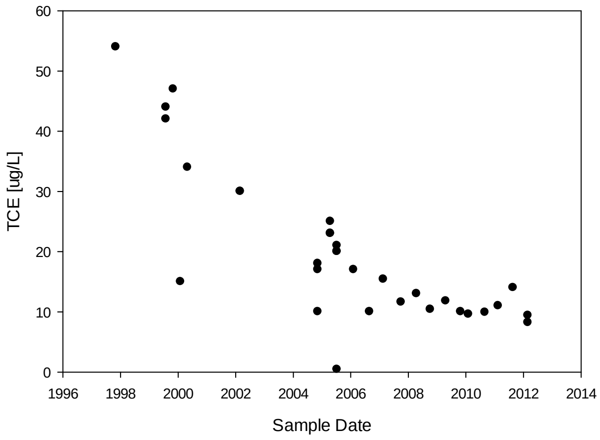
Where

Ln = natural logarithm
C_0 = initial concentration of TCE [µg/L]
C_t = concentration of TCE [µg/L] at time *t*
t = time in decimal years
k = first-order decay rate constant [1/year]

FIGURE 1

TCE Concentration Trend at SFWM-25(I1/I2)

Fruit Avenue Plume Superfund Site, Albuquerque NM



The plot of the natural log (Ln) of concentration vs. time can be approximated by a straight line with a slope of k. Plots of the data described above are included in **Attachment 1**. Regression analysis was performed on TCE concentrations as transformed into Ln (µg/L) units. For each data set, the best estimate of the decay rate is the slope of the mean regression line, which *defines the mean point decay rate*. The upper confidence interval estimates the *slowest point decay rate* at 95 percent confidence. Point decay rate constants estimated from TCE concentrations are summarized in **Table 2**. The units on the rate constants are 1/year with a negative value indicating that concentrations are decreasing.

The *mean point decay rates* varied across the site from -0.08 to -0.32 per year averaging -0.17/year. The *slowest point decay rates* at 95 percent confidence varied across the site from +0.008 to -0.24 per year, averaging -0.12/year.

A comparison of decay rates from the S, I1, and I2 aquifer zones and the decay rates from the D1 and D2 aquifer zones, made using an F-Test and T-test[1], shows there is a 50 to 77 percent chance that there is no difference between the two sets of decay rates.

An estimate of the length of time before the TCE remedial goal can be achieved at a specific location can be made by rearranging **Equation 1** and applying the point decay rates to monitor wells with TCE concentrations greater than the 5-µg/L cleanup goal (**Equation 2**):

$$t = \frac{Ln\ (C_t) - Ln\ (C_0)}{k} \qquad \text{Equation 2}$$

The estimated date that TCE concentrations at specific locations decay to the 5-µg/L remedial goal (**Table 2**) based on the location-specific mean point decay rate constants ranges from the present (at locations that have already achieved the remedial goal) to 2029 at DM-13(I1). The longest restoration timeframe at 95 percent confidence is at SFMW-27(I2) which is predicted to achieve the remedial goal by 2023. At 95 percent confidence, the estimated remedial timeframe at DM-13(I1)is unknown.

As described in Appendix A of Wilson (2011), the appropriateness of using the regression analysis method was evaluated by comparing the standard residuals to a normal distribution (**Attachment 1**). The standard residuals from the regression analysis generally demonstrate a normal distribution and the data set was considered suitable for the regression analysis.

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[1] The F-Test returns the likelihood that the variances in two samples are not significantly different. This test is used to determine whether two samples have different variances. Student's T-Test is used to determine whether two samples, with equal variances, are likely to have come from the same population.

Note that the point decay rate estimation process does not consider processes that may reduce the decay rate in the future, such as a source term that increases with rising water levels or changes in the decay processes that may be affected by the TCE concentration.

The decay rate constants estimated in this Technical Memorandum are considered representative of all natural attenuation processes operating: including degradation, diffusion, dispersion, and sorption which are considered active natural attenuation processes at this site. The restoration times estimated in this section should be compared to those estimated by the flow and transport model (**Appendix J**).

Because the decay rates include the effects of degradation, diffusion, dispersion, and sorption, the estimated rates are greater than that attributable to degradation (transformation of parent compounds to daughter compounds) alone.

TABLE 2

Estimated First Order TCE Decay Rates

Fruit Avenue Plume Superfund Site, Albuquerque NM

	Point Decay Rate k = 1/year		TCE Concentration (Most Recent)		Date TCE Concentration decays to Less Than 5 µg/L	
Well Location (aquifer zone)	**Mean**	**Slowest**	**µg/L**	**Ln (µg/L)**	**Mean Rate**	**Slowest Rate**
Upgradient						
SFMW-13_(I2)	-0.11	-0.077	<5		Not Applicable	
Presumed Source Area						
DM-01_(S)	-0.26	-0.22	<5		Not Applicable	
DM-13_(S)	-0.14	-0.086	<5		Not Applicable	
SFMW-03_(S)	-0.15	-0.092	<5		Not Applicable	
SFMW-04_(S)	-0.22	-0.13	<5		Not Applicable	
DM-13_(I1)	-0.08	+0.008	54	4.0	12/29/2029	NA
SFMW-6_(I1)	-0.21	-0.10	11	2.4	5/21/2006	4/14/2014
SFMW-18_(I1)	-0.22	-0.19	<5		Not Applicable	
DM-03_(I1/I2)	-0.14	-0.090	10	2.3	8/10/2007	9/27/2012
DM-06_(I1/I2)	-0.08	-0.066	<5		Not Applicable	
DM-12_(I1/I2)	-0.20	-0.18	<5		Not Applicable	
SFMW-25_(I1/I2)	-0.13	-0.12	9.4	2.2	9/27/2015	9/23/2016
SFMW-47_(I1/I2)	-0.14	-0.11	15	2.7	3/5/2020	2/20/2023
HSM-I2-5_(I2)	-0.26	-0.17	20	3.0	7/3/2017	3/14/2021
SFMW-26_(I2)	-0.17	-0.14	<5		Not Applicable	
SFMW-27_(I2)	-0.09	-0.062	9.5	2.3	7/11/2018	9/21/2023
SFMW-28_(I2)	-0.35	-0.32	<5		Not Applicable	
Downgradient Plume						
MNW-5_(D1)	-0.11	-0.076	6.9	1.9	8/25/2011	3/27/2013
SFMW-46_(D1/D2)	-0.19	-0.15	<5		Not Applicable	

MNW-5_(D2)	-0.14	-0.11	9.1	2.2	1/13/2016	1/30/2018

Notes: Decay rate at 95% confidence was not calculated at DM-13 (I1) because that decay rate is positive.

As indicated in **Appendix D**, several locations currently have increasing TCE concentrations. Increasing concentrations were observed immediately down gradient of the presumed source area where the plume may be migrating eastward from the presumed source area, near the down gradient end of the plume, where increasing concentrations reflect the natural migration of the TCE plume, and where the up gradient off-site plume is commingling with the remnants of the presumed source area plume. Although locations with increasing concentration cannot be included in a decay rate estimation, their presence is noted and tempers the conclusion of rate constant estimates.

Degradation Rates

Degradation rates (transformation of parent compounds to daughter compounds) were estimated from compound-specific stable isotope analyses (CSIA) data because CSIA typically provides a more conservative estimate of the degradation rate compared to estimates made using concentration data (Hunkeler et. al, 2008). Estimates of degradation underestimate the total apparent decay of the plume at this site because degradation estimates do not include the effects of diffusion, dispersion, and sorption.

Estimating Degradation Rates from Fraction of TCE Remaining

The degradation rate estimates are based on several variables: 1) the fraction of original mass remaining (***f***), 2) the distance from the source area along a flow path (δx), 3) seepage velocity (ν), and 4) the time since the original release (δt). The fraction of mass remaining is a calculation that depends on the field data and an assumed fractionation factor (α), and was calculated for a range of fractionation factors presented in **Appendix E**. The selected fractionation factors correspond to average and low degradation rates, the range of which was considered reasonable in the CSIA Technical Memorandum. The fraction of mass remaining presented in **Appendix E**, and the distance from the source area along a flow path are listed in **Table 3**.

TABLE 3

Fraction of Original Mass Remaining (*f*) Estimated from Average and Maximum Fractionation Factors (α, and from CSIA TM), and Distance from Source Area

Fruit Avenue Plume Superfund Site, Albuquerque NM

Well ID	Sample Date	*f* Fraction of original TCE Mass Remaining		ln(*f*) Fraction of Mass Remaining		δx Distance from Source [feet]
		low-rate	avg.-rate	low-rate	avg.-rate	
Source Areas						
HSM-I2-5	9/14/2010	66%	44%	-0.42	-0.83	0
HSM-I2-5	9/14/2010	66%	44%	-0.41	-0.81	0
MNW-14 (I2)	9/7/2010	57%	33%	-0.57	-1.12	0
Down-Gradient						
SFMW-40 (D3)	8/31/2010	55%	31%	-0.59	-1.17	2200
SFMW-44 (D2)	8/31/2010	58%	34%	-0.55	-1.09	2500
SFMW-44 (D2)	8/31/2010	58%	34%	-0.54	-1.06	2500

MNW-5 (D2)	9/8/2010	56%	32%	-0.58	-1.15	2900

Notes:
"Rate" refers to degradation rates affecting the isotopes.

Degradation Rate Estimates

Degradation rates were estimated from the fraction of the original TCE mass remaining (***f***) as described in the CSIA Technical Memorandum (**Appendix E**). First-order degradation rates along a groundwater flow path in terms of distance (λ_d) were estimated by dividing the natural log of the fraction of the original mass remaining (ln(*f*)) by the distance from the source (δx).

$$\lambda_\mathrm{d} = \frac{\ln(f)}{\delta x}$$

First-order degradation rates along a groundwater flow path in terms of time (λ_t) were estimated by multiplying λ_d by the seepage velocity along that flow path (ν). Because the seepage velocity for aquifer zones I1 through D2 varies from 12.6 to 637 feet/year (CH2M HILL, 2009) a value of 100 feet/year was selected as being representative for all zones.

$$\lambda_\mathrm{t} = \nu \cdot \frac{\ln(f)}{\delta x}$$

Another first-order degradation rate (λ_t) was estimated by dividing the natural log of the fraction of the original mass remaining (ln(***f***)) by the time since the release (δt). This time was considered the time between the demolition of the former dry cleaner facility (1973) and the time of sample collection (2011), or 38 years.

$$\lambda_\mathrm{t} = \frac{\ln(f)}{\delta t}$$

The results of these calculations are presented in **Table 4**.

Degradation rates were not estimated using the methods used previously in the 2005 NA Evaluation (CH2M HILL, 2005) because the conceptual site model is no longer compatible with the assumptions in the BIOCHLOR (EPA, 2000) and Natural Attenuation System (NAS) models. That is, BIOCHLOR and NAS cannot account for the presence of the pump and treat facility midway along the axis of the plume.

TABLE 4

Degradation Rate Estimates Based on CSIA Data

Fruit Avenue Plume Superfund Site, Albuquerque NM

Seepage Velocity	ν =	100	ft/year
Final Release Date	t_i =	1973	year
Current Date	t =	2011	year
Time of Decay	$\delta t = t - t_i$	38	years

		Degradation Rates					
		In Distance Along Flow Path		**In Time Along Flow Path**		**In Time Based on Estimated Release Date**	
Well ID	**Sample Date**	**λ_d = ln(*f*)/δx [1/ft]**		**λ_t = ν•ln(*f*)/δx [1/yr]**		**λ_t = ln(*f*)/δt [1/yr]**	
		low-rate	**avg.-rate**	**low-rate**	**avg.-rate**	**low-rate**	**avg.-rate**
Source Area							
HSM-I2-5	9/14/2010	*na*	*na*	*na*	*na*	-0.011	-0.022

HSM-I2-5	9/14/2010	*na*	*na*	*na*	*na*	-0.011	-0.021
MNW-14 (I2)	9/7/2010	*na*	*na*	*na*	*na*	-0.015	-0.029
Down-Gradient							
SFMW-40 (D3)	8/31/2010	-0.00027	-0.00053	-0.027	-0.053	-0.016	-0.031
SFMW-44 (D2)	8/31/2010	-0.00022	-0.00044	-0.022	-0.044	-0.015	-0.029
SFMW-44 (D2)	8/31/2010	-0.00022	-0.00043	-0.022	-0.043	-0.014	-0.028
MNW-5 (D2)	9/8/2010	-0.00020	-0.00040	-0.020	-0.040	-0.015	-0.030

Notes:

"Rate" refers to degradation rates affecting the isotopes.

na: analysis is not appropriate for locations coincident with the source area.

ν = Representative approximate value reported in the LTMO for aquifer zones and locations where the TCE plume is present. That is, I1 & I2 aquifer zones in the western portion of the site and D1 & D2 aquifer zones in the eastern Portion of the site.

Comparison of Degradation Rate Estimates to Point Decay Rate Estimates

Point decay rates estimated from TCE concentration data and point degradation rates estimated from the CSIA data (averages and where both are available at a given location) are compared in **Table 5**. This comparison shows the following:

- Across the site, average degradation rates are about 16 percent of the average decay rates.
- At well HSM-I2-5 in the presumed source area, degradation accounts for about 8 percent of the observed decay.
- At MNW-5(D2) in the downgradient plume, degradation accounts for about 30 percent of the observed decay.

TABLE 5
Degradation Rates Based on CSIA Data Compared to Point Decay Rates Based on Concentration Data
Fruit Avenue Plume Superfund Site, Albuquerque NM

Well ID and (Aquifer Zone)	**Degradation Rate Based on CSIA Fraction of Mass Remaining (*f*) and Estimated Release Date $\lambda_t = \ln(f)/\delta t$ [1/year]**		**Point Decay Rate Based on Observed TCE Concentrations over Time $\lambda t = \ln(C)/\delta t$ [1/year]**		**Fraction of Decay Resulting from Degradation (Based on average rates)**
	low-rate	**avg.-rate**	**low-rate**	**avg.-rate**	
Mean of the Rates	-0.014	-0.027	-0.12	-0.17	16%
MNW-5 (D2)	-0.015	-0.030	-0.07	-0.10	30%
HSM-I2-5 (I2)	-0.011	-0.022	-0.17	-0.26	8%
HSM-I2-5 (I2)	-0.011	-0.021			

Notes:
"Rate" refers to degradation rates affecting the isotopes or concentration.

Summary

The degradation rates estimated from the CSIA data can be used in the fate and transport model. It is recommended that model layers representative of the shallow, I1, and I2 aquifer zones use a value of -0.022 per year, and model layers representative of the deep aquifer zones use a value of -0.030 per year. These rates correspond to half-lives of 45 years and 33 years, respectively.

Works Cited

Aziz, Vanderford, Newell, Ling, Rifai, and Gonzales. 2006. Monitoring and Remediation Optimization System (MAROS) User's Guide, Version 2.2. Air Force Center for Environmental Excellence, Brooks City Base, Texas.

CH2M HILL. 2005. Natural Attenuation Evaluation, Fruit Avenue Plume Superfund Site, Albuquerque, NM. v1.1 DCN 05-8326, December 2005.

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Hunkeler, D., R. Meckenstock, B. Sherwood-Lollar, T. Schmidt, J. Wilson. 2008. *Guide for Assessing Biodegradation and Source Identification of Organic Groundwater Contaminants using Compound Specific Isotope Analysis.* EPA 600/R-08/148.

Newell, Charles J., H. Rifai, J. Wilson, J. Connor, J. Aziz, and M. Suarez. 2002. *Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies.* EPA 504/S-02/500.

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Attachment 1

TCE Concentration Trend Analysis and Regression Statistics

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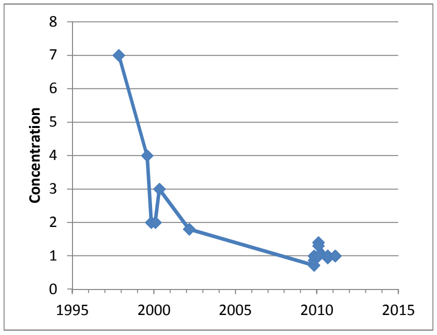
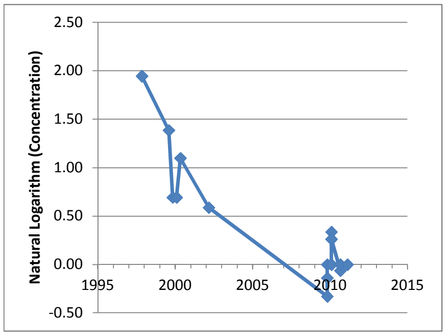
Raw Results

SFMW-13_I2

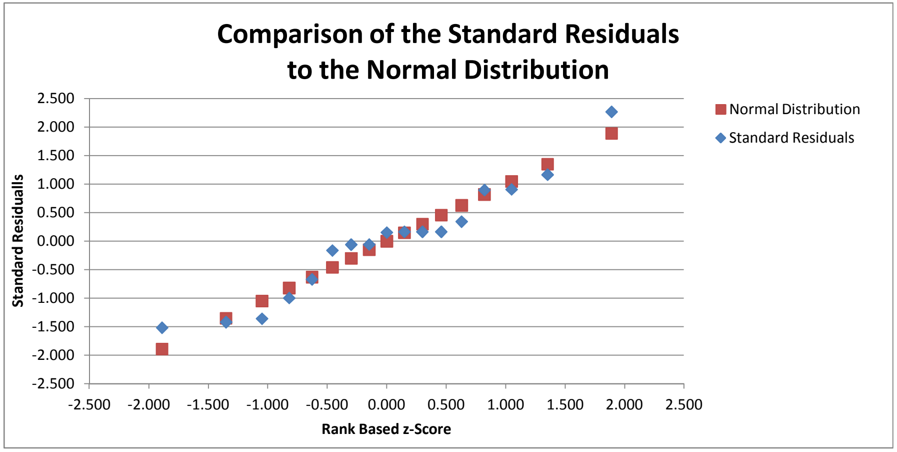




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-13_I	03-Nov-97	TCE	7	=	0.5	µg/L	1997.84	1.95
SFMW-13_I	01-Aug-99	TCE	4	=	0.5	µg/L	1999.58	1.39
SFMW-13_I	01-Nov-99	TCE	2	=	0.5	µg/L	1999.84	0.69
SFMW-13_I	01-Feb-00	TCE	2	=	0.5	µg/L	2000.09	0.69
SFMW-13_I	01-May-00	TCE	3	=	0.5	µg/L	2000.33	1.10
SFMW-13_I	01-Mar-02	TCE	1.8	=	0.5	µg/L	2002.17	0.59
SFMW-13_I	26-Oct-09	TCE	0.72	=	0.5	µg/L	2009.82	-0.33
SFMW-13_I	26-Oct-09	TCE	0.87	=	0.5	µg/L	2009.82	-0.14
SFMW-13_I	26-Oct-09	TCE	1	=	0.5	µg/L	2009.82	0.00
SFMW-13_I	01-Feb-10	TCE	1	=	0.5	µg/L	2010.09	0.00
SFMW-13_I	01-Feb-10	TCE	1.4	=	0.5	µg/L	2010.09	0.34
SFMW-13_I	01-Feb-10	TCE	1.3	=	0.5	µg/L	2010.09	0.26
SFMW-13_I	30-Aug-10	TCE	0.94	=	0.5	µg/L	2010.66	-0.06
SFMW-13_I	30-Aug-10	TCE	1	=	0.5	µg/L	2010.66	0.00
SFMW-13_I	30-Aug-10	TCE	1	=	0.5	µg/L	2010.66	0.00
SFMW-13_I	30-Aug-10	TCE	1	=	0.5	µg/L	2010.66	0.00
SFMW-13_I	14-Feb-11	TCE	1	=	0.5	µg/L	2011.12	0.00

Regression Analysis

SFMW-13_I2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.895046672
R Square	0.801108545
Adjusted R Square	0.787849114
Standard Error	0.283684081
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.862240428	4.862240428	60.41802117	1.22542E-06
Residual	15	1.20714987	0.080476658		
Total	16	6.069390299			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	214.4875408	27.5453559	7.786704284	1.1992E-06	155.7760048	273.1990769	155.7760048	273.1990769
X Variable 1	-0.10669762	0.013726869	-7.772903008	1.22542E-06	-0.135955748	-0.077439492	-0.135955748	-0.077439492

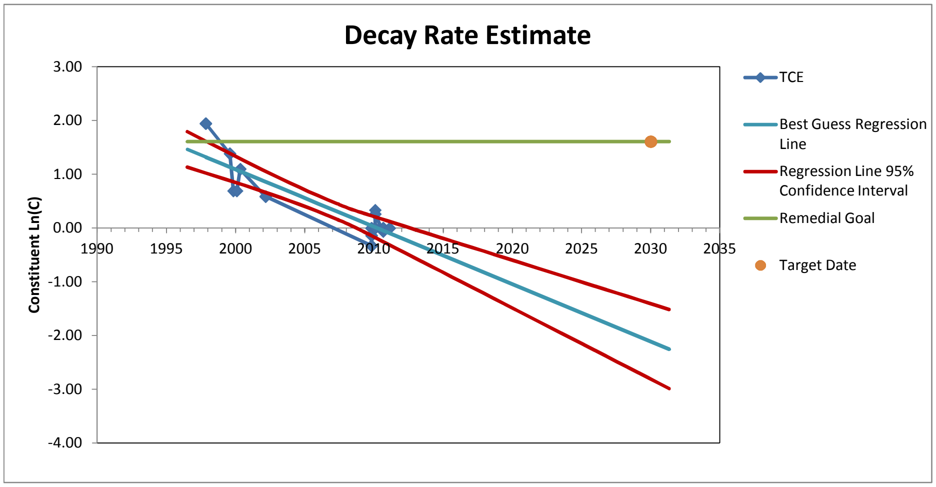
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
3	1.109828436	-0.416681255	-1.51699224	1	0.03	-1.890
4	1.082953197	-0.389806016	-1.419148796	2	0.09	-1.352
7	0.044458909	-0.372962976	-1.357829116	3	0.15	-1.049
6	0.861232476	-0.273445811	-0.995521559	4	0.21	-0.821
8	0.044458909	-0.183720977	-0.668864491	5	0.26	-0.629
9	0.044458909	-0.044458909	-0.161859501	6	0.32	-0.458
13	-0.045514717	-0.016360687	-0.059563599	7	0.38	-0.299
10	0.015830937	-0.015830937	-0.057634964	8	0.44	-0.148
5	1.056662202	0.041950086	0.152725746	9	0.50	0.000
14	-0.045514717	0.045514717	0.165703332	10	0.56	0.148
15	-0.045514717	0.045514717	0.165703332	11	0.62	0.299
16	-0.045514717	0.045514717	0.165703332	12	0.68	0.458
17	-0.09459124	0.09459124	0.344373968	13	0.74	0.629
12	0.015830937	0.246533327	0.897542521	14	0.79	0.821
2	1.136703675	0.249590686	0.908673307	15	0.85	1.049
11	0.015830937	0.320641299	1.167343999	16	0.91	1.352
1	1.32249337	0.623416779	2.269644731	17	0.97	1.890

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-13_I2



Decay Rate Estimate Results

Analyte	Rate Ln(µg/L)/year Mean	Upper 95%	Constituent Concentration (Most Recent) Sample Date	µg/L	Ln(µg/L)	Remdial Goal µg/L	Date constituent decays below goal Mean	Upper 95%
TCE	-0.11	-0.08	2/14/2011	1	0.0	5	RG Met	RG Met

Rows of Data		17
Confidence		95%
Remedial Goal		5 µg/L
Remedial Goal		1.609438 Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.10669762
Intercept	b	214.487541
Observations	n	17
Std error in estimat	SYX	0.28368408
Average X	XAVE	2006.67
Average Y	YAVE	0.38
SSX	SSX	427.097439
t(α,δf)	t	2.13144954
Minimum X	Xmin	1997.84
Maximum X	Xmax	2011.12
Range X	Xrange	13.28
Extend plot beyond		10%

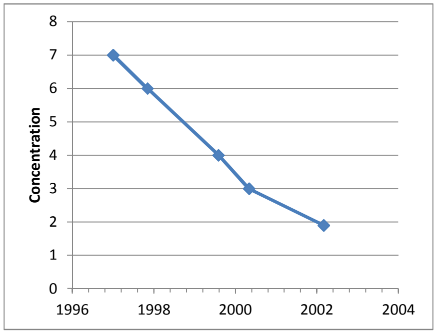
Date constituent decays below goal Mean	Upper 95%
1995.15325	1990.802711

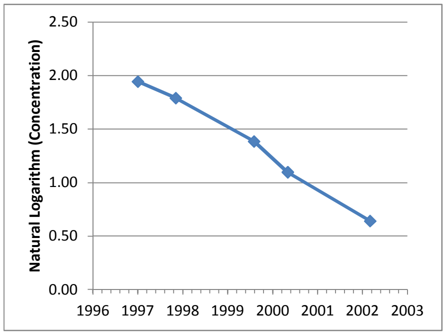
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1997	1.464202	0.33130289	1.79550472	1.13289894	1.60943791
1	1998	1.320359	0.29644846	1.61680787	1.023910961	1.60943791
2	1999	1.176517	0.26289427	1.43941127	0.913622735	1.60943791
3	2001	1.032675	0.23120712	1.26388171	0.80146747	1.60943791
4	2002	0.888832	0.2022664	1.09109858	0.68656578	1.60943791
5	2003	0.74499	0.17742121	0.92241097	0.567568555	1.60943791
6	2005	0.601147	0.15860801	0.75975537	0.442539336	1.60943791
7	2006	0.457305	0.14814299	0.60544793	0.309161944	1.60943791
8	2007	0.313463	0.14781007	0.4612726	0.165652452	1.60943791
9	2009	0.16962	0.15767344	0.32729356	0.011946666	1.60943791
10	2031	-2.25077	0.73637675	-1.51439738	-2.987150883	1.60943791

Raw Results

DM-01_S

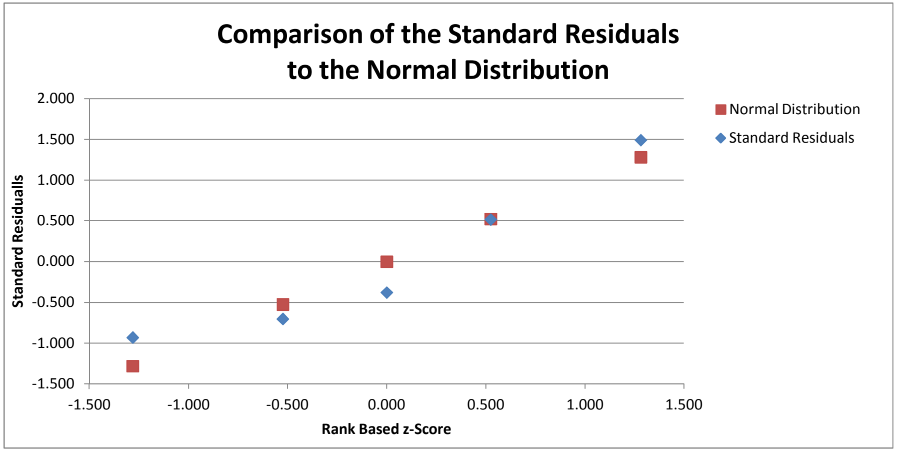




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
DM-01_S	30-Dec-96	TCE	7	=	0.5	µg/L	1997.00	1.95
DM-01_S	03-Nov-97	TCE	6	=	0.5	µg/L	1997.84	1.79
DM-01_S	01-Aug-99	TCE	4	=	0.5	µg/L	1999.58	1.39
DM-01_S	01-May-00	TCE	3	=	0.5	µg/L	2000.33	1.10
DM-01_S	01-Mar-02	TCE	1.9	=	0.5	µg/L	2002.17	0.64

Regression Analysis

DM-01_S



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.996642098
R Square	0.993295472
Adjusted R Square	0.991060629
Standard Error	0.049887652
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.10615913	1.10615913	444.4587763	0.000233462
Residual	3	0.007466333	0.002488778		
Total	4	1.113625463			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	515.2892703	24.3768117	21.13850149	0.000231612	437.711376	592.8671646	437.711376	592.8671646
X Variable 1	-0.257037221	0.012192149	-21.08219098	0.000233462	-0.295838082	-0.21823636	-0.295838082	-0.21823636

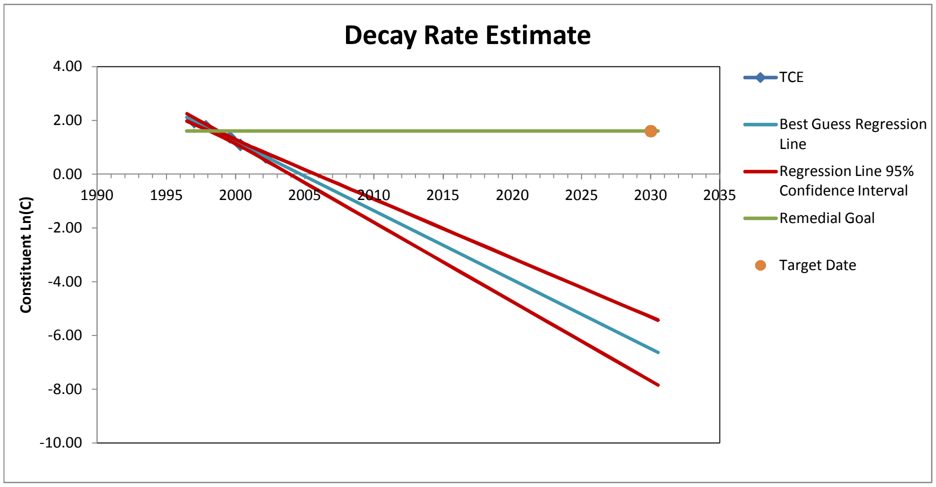
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
1	1.986115967	-0.040205818	-0.930604642	1	0.10	-1.282
4	1.128973366	-0.030361077	-0.702738079	2	0.30	-0.524
5	0.658178292	-0.016324406	-0.377845009	3	0.50	0.000
2	1.769367264	0.022392206	0.518290417	4	0.70	0.524
3	1.321795265	0.064499096	1.492897312	5	0.90	1.282

x

Regression Analysis - Confidence Interval of the Line of Best Fit

DM-01_S



Decay Rate Estimate Results

	Rate Ln(µg/L)/year		*Constituent Concentration (Most Recent)*			Remdial Goal	*Date constituent decays below goal*	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	*µg/L*	*Mean*	*Upper 95%*
TCE	-0.26	-0.22	3/1/2002	2	0.6	5	RG Met	RG Met

Rows of Data	5	
Confidence	95%	
Remedial Goal	5	µg/L
Remedial Goal	1.609438	Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.25703722
Intercept	b	515.28927
Observations	n	5
Std error in estimate	SYX	0.04988765
Average X	XAVE	1999.39

Average Y	YAVE	1.37
SSX	SSX	16.742703
t(α,δf)	t	3.1824463
Minimum X	Xmin	1997.00
Maximum X	Xmax	2002.17
Range X	Xrange	5.17
Extend plot beyond		10%

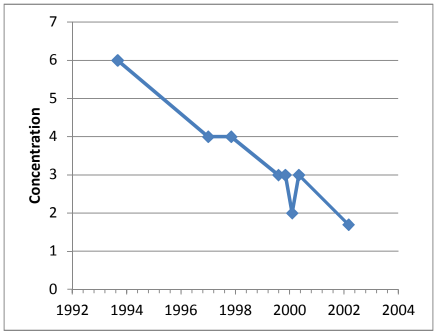
Date constituent decays below goal	
Mean	*Upper 95%*
1998.46478	1998.301154

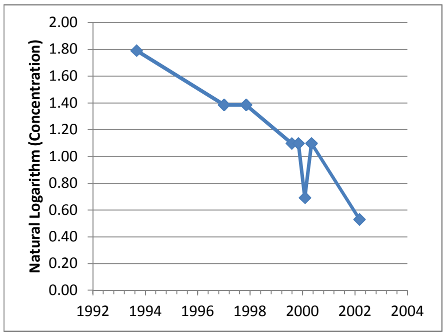
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1996	2.11891	0.1331296	2.25203933	1.985780138	1.60943791
1	1997	1.980975	0.1160488	2.09702402	1.864926422	1.60943791
2	1998	1.843041	0.10039051	1.94343122	1.742650205	1.60943791
3	1998	1.705106	0.08692685	1.79203305	1.618179346	1.60943791
4	1999	1.567172	0.07682055	1.64399224	1.490351139	1.60943791
5	1999	1.429237	0.07150951	1.50074669	1.357727664	1.60943791
6	2000	1.291303	0.07206191	1.36336457	1.219240755	1.60943791
7	2000	1.153368	0.07835382	1.23172198	1.075014327	1.60943791
8	2001	1.015434	0.08917858	1.10461222	0.926255056	1.60943791
9	2001	0.877499	0.10311844	0.98061757	0.774380689	1.60943791
10	2031	-6.63014	1.21017508	-5.41996254	-7.840312699	1.60943791

Raw Results

DM-13_S

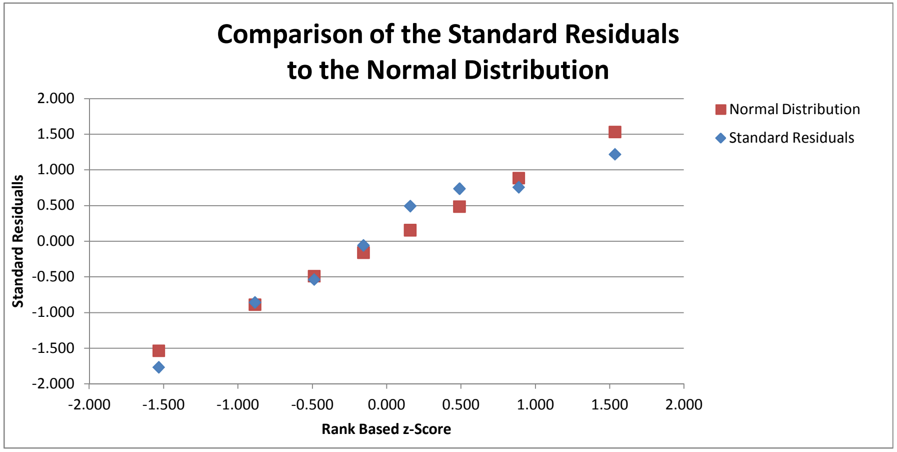




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
DM-13_S	30-Aug-93	TCE	6	=	0.5	µg/L	1993.66	1.79
DM-13_S	30-Dec-96	TCE	4	=	0.5	µg/L	1997.00	1.39
DM-13_S	03-Nov-97	TCE	4	=	0.5	µg/L	1997.84	1.39
DM-13_S	01-Aug-99	TCE	3	=	0.5	µg/L	1999.58	1.10
DM-13_S	01-Nov-99	TCE	3	=	0.5	µg/L	1999.84	1.10
DM-13_S	01-Feb-00	TCE	2	=	0.5	µg/L	2000.09	0.69
DM-13_S	01-May-00	TCE	3	=	0.5	µg/L	2000.33	1.10
DM-13_S	01-Mar-02	TCE	1.7	=	0.5	µg/L	2002.17	0.53

Regression Analysis

DM-13_S



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.929635718
R Square	0.864222567
Adjusted R Square	0.841592995
Standard Error	0.159350697
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.969744206	0.969744206	38.18996501	0.000825641
Residual	6	0.152355867	0.025392645		
Total	7	1.122100073			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	286.5659974	46.18767218	6.204382769	0.000808494	173.5488352	399.5831597	173.5488352	399.5831597
X Variable 1	-0.14279992	0.02310752	-6.179802991	0.000825641	-0.199341983	-0.086257856	-0.199341983	-0.086257856

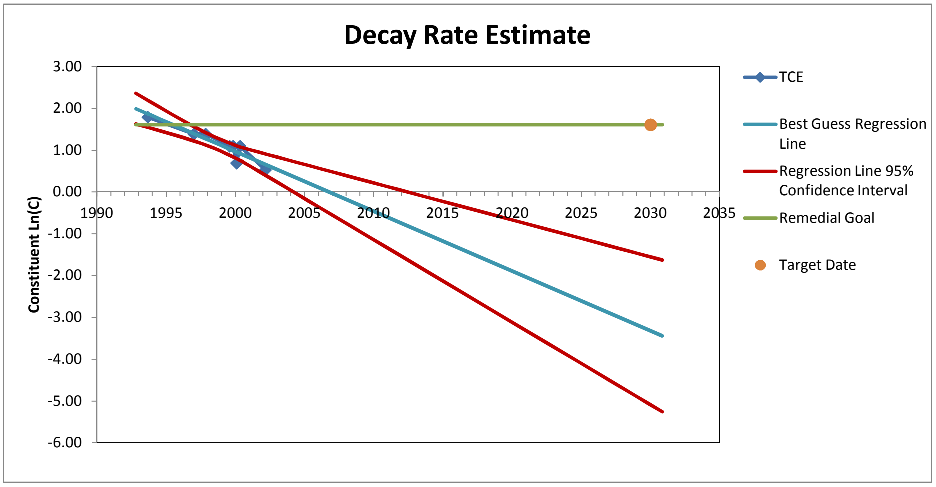
RESIDUAL OUTPUT

				Normal Distribution		
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
6	0.953647525	-0.260500344	-1.765743964	1	0.06	-1.534
8	0.656905187	-0.126276936	-0.855940279	2	0.19	-0.887
1	1.870851115	-0.079091646	-0.536105225	3	0.31	-0.489
2	1.394655901	-0.00836154	-0.056676847	4	0.44	-0.157
4	1.025585061	0.073027227	0.494998906	5	0.56	0.157
5	0.989616293	0.108995995	0.738805246	6	0.69	0.489
3	1.27423872	0.112055641	0.759544376	7	0.81	0.887
7	0.918460687	0.180151602	1.221117786	8	0.94	1.534

x

Regression Analysis - Confidence Interval of the Line of Best Fit

DM-13_S



Decay Rate Estimate Results

Analyte	Rate Ln(µg/L)/year Mean	Rate Ln(µg/L)/year Upper 95%	Constituent Concentration (Most Recent) Sample Date	Constituent Concentration (Most Recent) µg/L	Constituent Concentration (Most Recent) Ln(µg/L)	Remdial Goal µg/L	Date constituent decays below goal Mean	Date constituent decays below goal Upper 95%
TCE	-0.14	-0.09	3/1/2002	2	0.5	5	RG Met	RG Met

Rows of Data		8
Confidence		95%
Remedial Goal		5 µg/L
Remedial Goal		1.609438 Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.14279992
Intercept	b	286.565997
Observations	n	8
Std error in estimate	SYX	0.1593507
Average X	XAVE	1998.81
Average Y	YAVE	1.14
SSX	SSX	47.5555565
t(α,δf)	t	2.44691185
Minimum X	Xmin	1993.66
Maximum X	Xmax	2002.17
Range X	Xrange	8.50
Extend plot beyond		10%

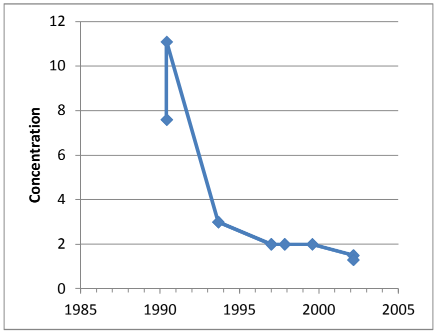
Date constituent decays below goal Mean	Date constituent decays below goal Upper 95%
1995.49524	1993.319679

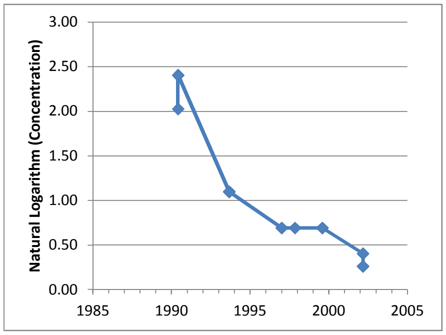
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1993	1.992246	0.3661741	2.3584198	1.626071611	1.60943791
1	1994	1.867995	0.32113095	2.18912607	1.546864168	1.60943791
2	1995	1.743745	0.2775022	2.02124673	1.466242323	1.60943791
3	1995	1.619494	0.23607335	1.85556728	1.383420584	1.60943791
4	1996	1.495243	0.19822853	1.69347187	1.297014815	1.60943791
5	1997	1.370993	0.16643089	1.53742364	1.204561863	1.60943791
6	1998	1.246742	0.14472284	1.391465	1.10201932	1.60943791
7	1999	1.122492	0.13795263	1.2604442	0.984538937	1.60943791
8	2000	0.998241	0.14818207	1.14642305	0.85005891	1.60943791
9	2001	0.87399	0.1724114	1.04640179	0.701578988	1.60943791
10	2031	-3.43982	1.81684765	-1.62297258	-5.256667872	1.60943791

Raw Results

SFMW-03_S

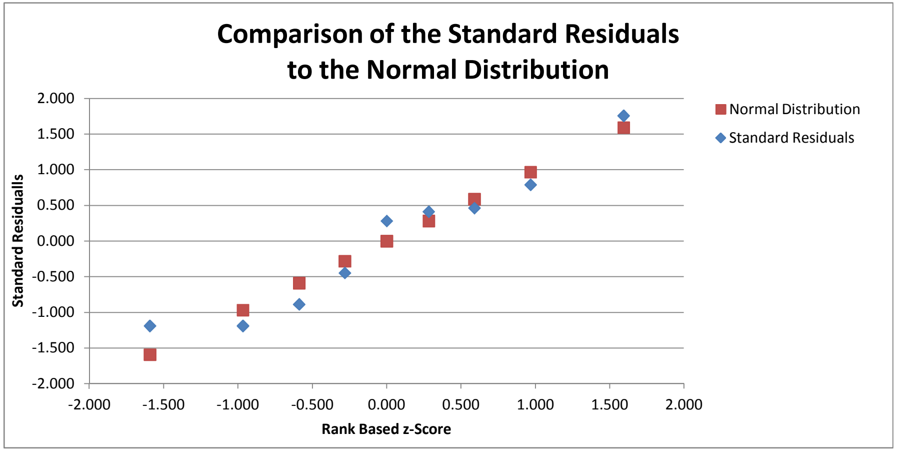




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-03_	31-May-90	TCE	7.6	=	0.5	µg/L	1990.41	2.03
SFMW-03_	31-May-90	TCE	11.1	=	0.5	µg/L	1990.41	2.41
SFMW-03_	30-Aug-93	TCE	3	=	0.5	µg/L	1993.66	1.10
SFMW-03_	30-Aug-93	TCE	3	=	0.5	µg/L	1993.66	1.10
SFMW-03_	30-Dec-96	TCE	2	=	0.5	µg/L	1997.00	0.69
SFMW-03_	03-Nov-97	TCE	2	=	0.5	µg/L	1997.84	0.69
SFMW-03_	01-Aug-99	TCE	2	=	0.5	µg/L	1999.58	0.69
SFMW-03_	01-Mar-02	TCE	1.5	=	0.5	µg/L	2002.17	0.41
SFMW-03_	01-Mar-02	TCE	1.3	=	0.5	µg/L	2002.17	0.26

Regression Analysis

SFMW-03_S



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.921785675
R Square	0.84968883
Adjusted R Square	0.828215806
Standard Error	0.301027916
Observations	9

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.585751911	3.585751911	39.57005874	0.000407891
Residual	7	0.634324643	0.090617806		
Total	8	4.220076554			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	294.7827988	46.69621347	6.312777351	0.000399229	184.3638	405.2017976	184.3638	405.2017976
X Variable 1	-0.147140757	0.023391046	-6.29047365	0.000407891	-0.202451792	-0.091829723	-0.202451792	-0.091829723

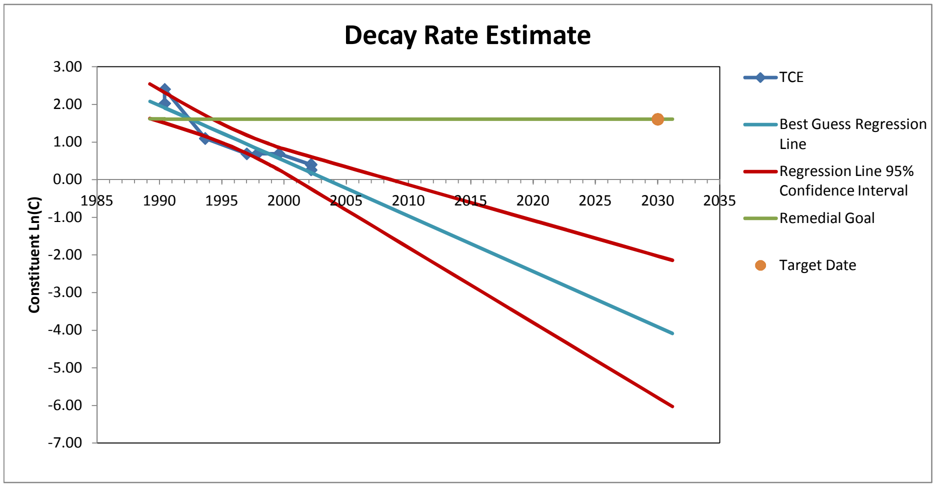
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
3	1.433477626	-0.334865338	-1.189212313	1	0.06	-1.593
4	1.433477626	-0.334865338	-1.189212313	2	0.17	-0.967
5	0.94280701	-0.24965983	-0.886620711	3	0.28	-0.589
6	0.818729383	-0.125582203	-0.445981967	4	0.39	-0.282
9	0.18263012	0.079734144	0.283161066	5	0.50	0.000
1	1.91165991	0.116488338	0.413686786	6	0.61	0.282
7	0.562517141	0.13063004	0.463908427	7	0.72	0.589
8	0.18263012	0.222834988	0.791357246	8	0.83	0.967
2	1.91165991	0.495285199	1.758913779	9	0.94	1.593

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-03_S



Decay Rate Estimate Results

			Constituent Concentration			Remdial	*Date constituent decays*	
	Rate Ln(µg/L)/year		*(Most Recent)*			Goal	*below goal*	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	*µg/L*	*Mean*	*Upper 95%*
TCE	-0.15	-0.09	3/1/2002	2	0.4	5	RG Met	RG Met

Rows of Data		9
Confidence		95%
Remedial Goal		5 µg/L
Remedial Goal		1.609438 Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.14714076
Intercept	b	294.782799
Observations	n	9
Std error in estimate	SYX	0.30102792
Average X	XAVE	1996.32
Average Y	YAVE	1.04
SSX	SSX	165.620566
t(α,δf)	t	2.36462425
Minimum X	Xmin	1990.41
Maximum X	Xmax	2002.17
Range X	Xrange	11.75
Extend plot beyond		10%

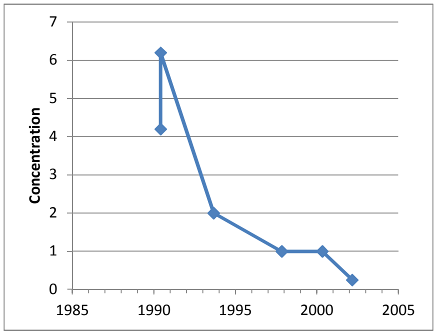
Date constituent decays below goal	
Mean	*Upper 95%*
1992.46875	1990.146661

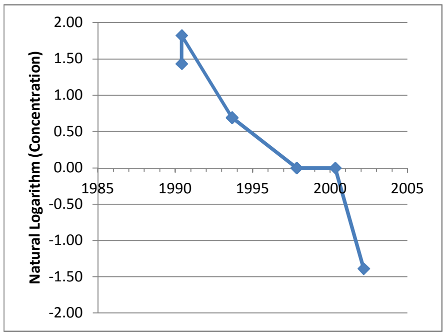
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1989	2.084563	0.45807859	2.54264148	1.626484294	1.60943791
1	1990	1.908717	0.40299279	2.31170988	1.505724307	1.60943791
2	1992	1.732871	0.35172314	2.08459445	1.381148156	1.60943791
3	1993	1.557026	0.30619267	1.86321817	1.25083284	1.60943791
4	1994	1.38118	0.26932791	1.65050762	1.111851804	1.60943791
5	1995	1.205334	0.24507119	1.45040511	0.960262724	1.60943791
6	1996	1.029488	0.23732057	1.2668087	0.792167553	1.60943791
7	1998	0.853642	0.2476308	1.10127313	0.606011533	1.60943791
8	1999	0.677797	0.27397037	0.95176691	0.403826163	1.60943791
9	2000	0.501951	0.31230964	0.81426038	0.189641099	1.60943791
10	2031	-4.08645	1.94242413	-2.14402182	-6.028870075	1.60943791

Raw Results

SFMW-04_S

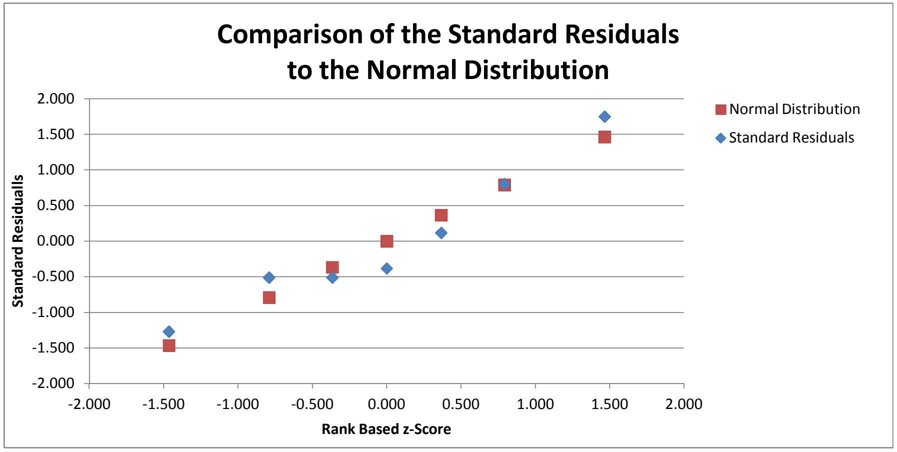




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-04_	31-May-90	TCE	4.2	=	0.5	µg/L	1990.41	1.44
SFMW-04_	31-May-90	TCE	6.2	=	0.5	µg/L	1990.41	1.82
SFMW-04_	30-Aug-93	TCE	2	=	0.5	µg/L	1993.66	0.69
SFMW-04_	30-Aug-93	TCE	2	=	0.5	µg/L	1993.66	0.69
SFMW-04_	03-Nov-97	TCE	1	=	0.5	µg/L	1997.84	0.00
SFMW-04_	01-May-00	TCE	1	=	0.5	µg/L	2000.33	0.00
SFMW-04_	01-Mar-02	TCE	0.25	ND	0.5	µg/L	2002.17	-1.39

Regression Analysis

SFMW-04_S



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.950838885
R Square	0.904094585
Adjusted R Square	0.884913502
Standard Error	0.359909976
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.105602326	6.105602326	47.1346998	0.001002244
Residual	5	0.647675953	0.129535191		
Total	6	6.75327828			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	430.0549735	62.57258845	6.872897289	0.000997285	269.2070143	590.9029328	269.2070143	590.9029328
X Variable 1	-0.215279018	0.031356771	-6.865471564	0.001002244	-0.295884163	-0.134673873	-0.295884163	-0.134673873

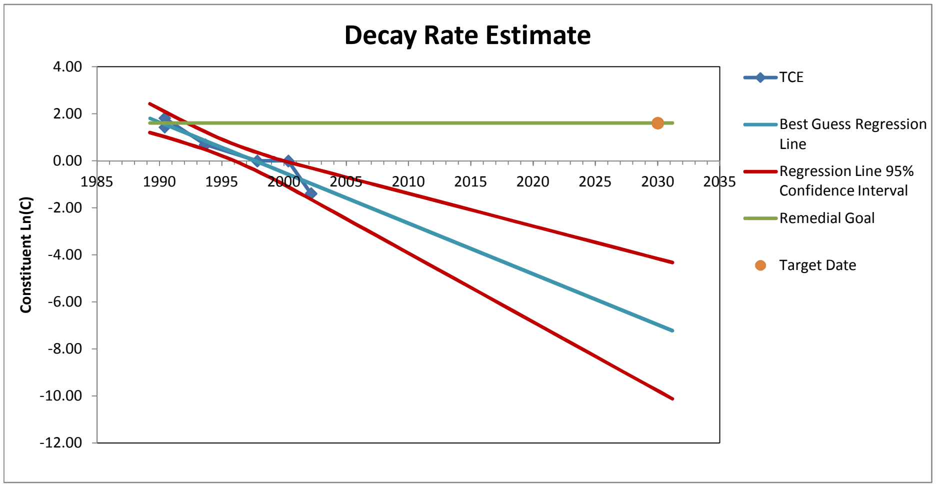
RESIDUAL OUTPUT

				Normal Distribution		
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
7	-0.969278877	-0.417015484	-1.269255107	1	0.07	-1.465
3	0.8608138	-0.167666619	-0.510320889	2	0.21	-0.792
4	0.8608138	-0.167666619	-0.510320889	3	0.36	-0.366
1	1.56043377	-0.125349245	-0.38152101	4	0.50	0.000
5	-0.03861339	0.03861339	0.117526194	5	0.64	0.366
2	1.56043377	0.264115522	0.803878964	6	0.79	0.792
6	-0.574969054	0.574969054	1.750012736	7	0.93	1.465

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-04_S



Decay Rate Estimate Results

Analyte	*Rate Ln(µg/L)/year Mean*	*Upper 95%*	*Constituent Concentration (Most Recent) Sample Date*	*µg/L*	*Ln(µg/L)*	Remdial Goal µg/L	*Date constituent decays below goal Mean*	*Upper 95%*
TCE	-0.22	-0.13	3/1/2002	0	-1.4	5	RG Met	RG Met

Rows of Data		7
Confidence		95%
Remedial Goal		5 µg/L
Remedial Goal	1.609438	Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.21527902
Intercept	b	430.054974
Observations	n	7
Std error in estimat	SYX	0.35990998
Average X	XAVE	1995.50
Average Y	YAVE	0.47
SSX	SSX	131.742259
t(α,δf)	t	2.57058183
Minimum X	Xmin	1990.41
Maximum X	Xmax	2002.17
Range X	Xrange	11.75
Extend plot beyond		10%

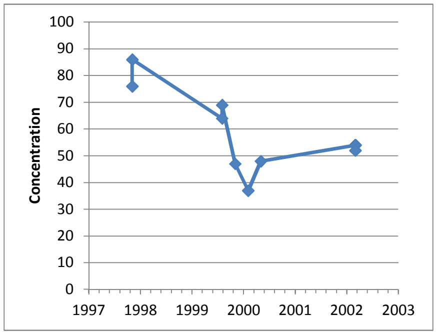
Date constituent decays below goal Mean	*Upper 95%*
1990.18715	1987.007215

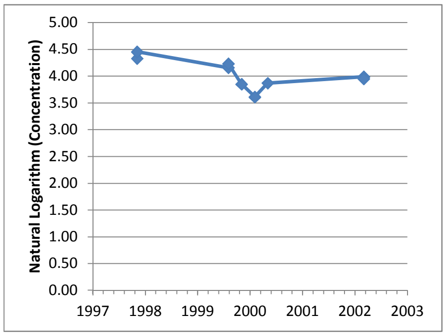
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1989	1.813405	0.61394209	2.42734713	1.199462942	1.60943791
1	1990	1.556128	0.53757177	2.09369996	1.018556421	1.60943791
2	1992	1.298851	0.46861591	1.76746726	0.83023543	1.60943791
3	1993	1.041574	0.41082514	1.45239964	0.630749356	1.60943791
4	1994	0.784298	0.36947622	1.15377387	0.414821434	1.60943791
5	1995	0.527021	0.35043831	0.87745912	0.176582497	1.60943791
6	1996	0.269744	0.35729582	0.62703978	-0.087551851	1.60943791
7	1998	0.012467	0.38868052	0.40114764	-0.376213397	1.60943791
8	1999	-0.24481	0.43936743	0.19455771	-0.684177161	1.60943791
9	2000	-0.50209	0.50356121	0.00147464	-1.005647786	1.60943791
10	2031	-7.21529	2.89709584	-4.31819209	-10.11238377	1.60943791

Raw Results

DM-13_I1

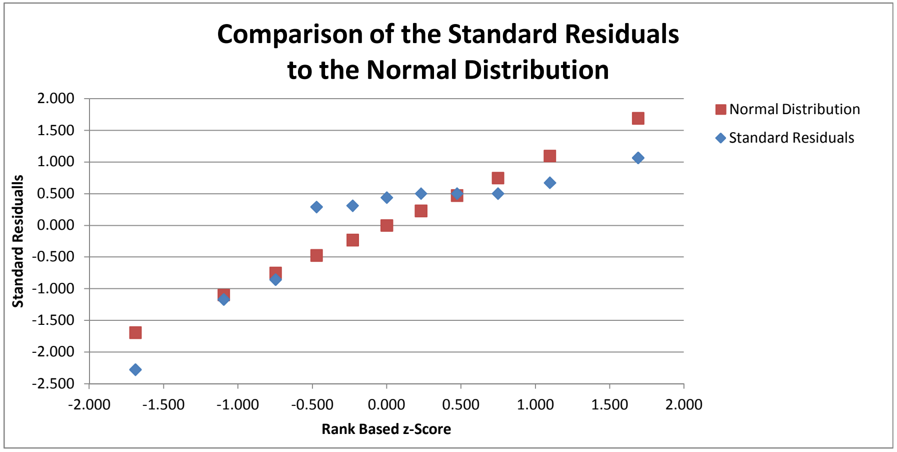




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
DM-13_I1	03-Nov-97	TCE	76	=	0.5	µg/L	1997.84	4.33
DM-13_I1	03-Nov-97	TCE	86	=	0.5	µg/L	1997.84	4.45
DM-13_I1	01-Aug-99	TCE	64	=	0.5	µg/L	1999.58	4.16
DM-13_I1	01-Aug-99	TCE	69	=	0.5	µg/L	1999.58	4.23
DM-13_I1	01-Nov-99	TCE	47	=	0.5	µg/L	1999.84	3.85
DM-13_I1	01-Feb-00	TCE	37	=	0.5	µg/L	2000.09	3.61
DM-13_I1	01-May-00	TCE	48	=	0.5	µg/L	2000.33	3.87
DM-13_I1	01-Mar-02	TCE	54	=	0.5	µg/L	2002.17	3.99
DM-13_I1	01-Mar-02	TCE	54	=	0.5	µg/L	2002.17	3.99
DM-13_I1	01-Mar-02	TCE	54	=	0.5	µg/L	2002.17	3.99
DM-13_I1	01-Mar-02	TCE	52	=	0.5	µg/L	2002.17	3.95

Regression Analysis

DM-13_I1



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.565480398
R Square	0.319768081
Adjusted R Square	0.244186756
Standard Error	0.207986485
Observations	11

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.183016752	0.183016752	4.230781653	0.069831219
Residual	9	0.389325402	0.043258378		
Total	10	0.572342155			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	167.919179	79.67395404	2.107579335	0.064322078	-12.3158264	348.1541845	-12.3158264	348.1541845
X Variable 1	-0.081926061	0.039830134	-2.056886398	0.069831219	-0.172028085	0.008175962	-0.172028085	0.008175962

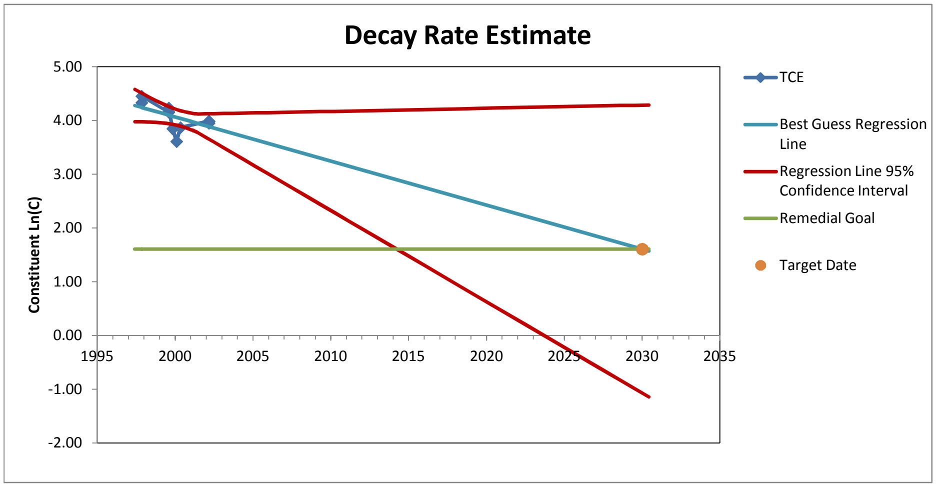
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
6	4.059878707	-0.448960794	-2.2753701	1	0.05	-1.691
5	4.080514429	-0.230366828	-1.167517962	2	0.14	-1.097
7	4.039691587	-0.168490576	-0.853924048	3	0.23	-0.748
3	4.101150152	0.057732932	0.292595229	4	0.32	-0.473
11	3.889633996	0.061609722	0.312243123	5	0.41	-0.230
1	4.243805799	0.086927542	0.440555906	6	0.50	0.000
8	3.889633996	0.09935005	0.503514198	7	0.59	0.230
9	3.889633996	0.09935005	0.503514198	8	0.68	0.473
10	3.889633996	0.09935005	0.503514198	9	0.77	0.748
4	4.101150152	0.132956353	0.673833693	10	0.86	1.097
2	4.243805799	0.210541498	1.067041566	11	0.95	1.691

x

Regression Analysis - Confidence Interval of the Line of Best Fit

DM-13_I1



Decay Rate Estimate Results

Analyte	Rate Ln(µg/L)/year Mean	 Upper 95%	Constituent Concentration (Most Recent) Sample Date	 µg/L	 Ln(µg/L)	Remdial Goal µg/L	Date constituent decays below goal Mean	 Upper 95%
TCE	-0.08	0.01	3/1/2002	54	4.0	5	12/29/2029	No Decay

Rows of Data	11	
Confidence	95%	
Remedial Goal	5	µg/L
Remedial Goal	1.609438	Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.08192606
Intercept	b	167.919179
Observations	n	11
Std error in estimate	SYX	0.20798649
Average X	XAVE	2000.34
Average Y	YAVE	4.04
SSX	SSX	27.267586
t(α,δf)	t	2.26215716
Minimum X	Xmin	1997.84
Maximum X	Xmax	2002.17
Range X	Xrange	4.32
Extend plot beyond		10%

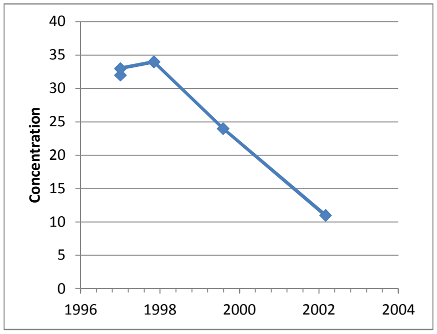
Date constituent decays below goal Mean	 Upper 95%
2029.99801	1703.189003

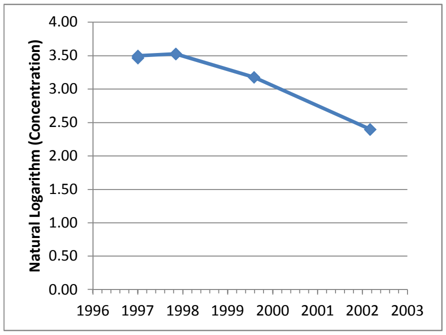
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1997	4.279223	0.29991478	4.57913776	3.979308195	1.60943791
1	1998	4.242167	0.26471106	4.50687834	3.977456216	1.60943791
2	1998	4.205112	0.23133687	4.43644845	3.973774702	1.60943791
3	1999	4.168056	0.20070697	4.36876284	3.967348904	1.60943791
4	1999	4.131	0.17427439	4.30527456	3.956725787	1.60943791
5	2000	4.093944	0.15421274	4.24815722	3.939731727	1.60943791
6	2000	4.056889	0.1432247	4.20011347	3.91366407	1.60943791
7	2001	4.019833	0.14341128	4.16324434	3.876421792	1.60943791
8	2001	3.982777	0.15473205	4.13750942	3.828045312	1.60943791
9	2001	3.945722	0.17503988	4.12076154	3.770681789	1.60943791
10	2030	1.573521	2.71518784	4.28870872	-1.141666968	1.60943791

Raw Results

SFMW-06_I1

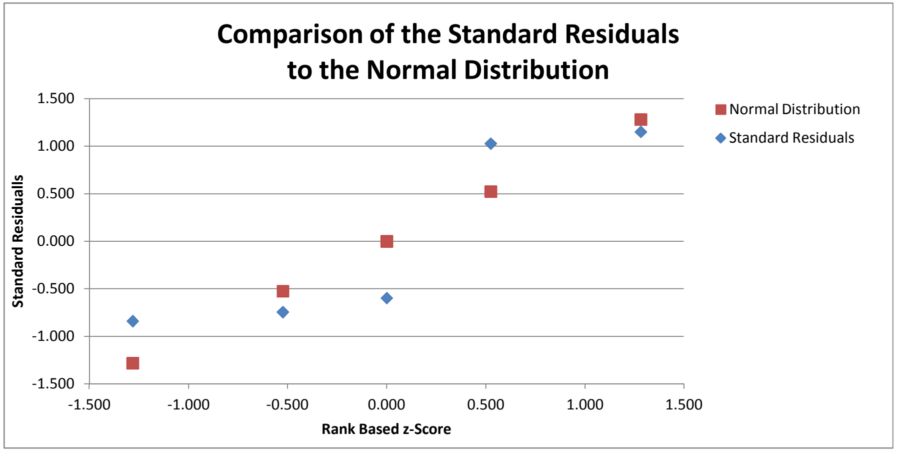




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-06_I	30-Dec-96	TCE	32	=	0.5	µg/L	1997.00	3.47
SFMW-06_I	30-Dec-96	TCE	33	=	0.5	µg/L	1997.00	3.50
SFMW-06_I	03-Nov-97	TCE	34	=	0.5	µg/L	1997.84	3.53
SFMW-06_I	01-Aug-99	TCE	24	=	0.5	µg/L	1999.58	3.18
SFMW-06_I	01-Mar-02	TCE	11	=	0.5	µg/L	2002.17	2.40

Regression Analysis

SFMW-06_I1



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.963928503
R Square	0.92915816
Adjusted R Square	0.905544213
Standard Error	0.146434176
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.8437348	0.8437348	39.34785535	0.008179301
Residual	3	0.064328904	0.021442968		
Total	4	0.908063703			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	421.0076774	66.60436202	6.321022598	0.008003865	209.0428717	632.9724832	209.0428717	632.9724832
X Variable 1	-0.209031358	0.033323523	-6.272786889	0.008179301	-0.315081681	-0.102981035	-0.315081681	-0.102981035

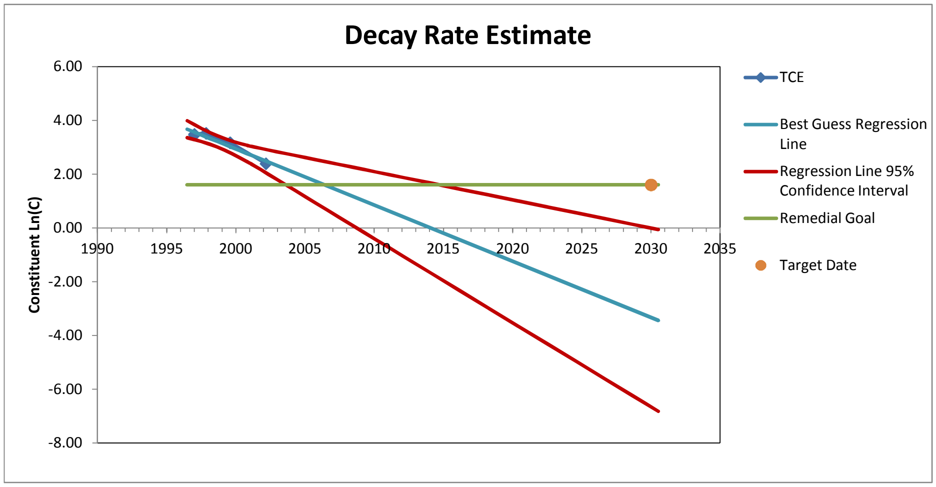
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
1	3.572198467	-0.106462564	-0.839506071	1	0.10	-1.282
5	2.492274654	-0.094379381	-0.744224641	2	0.30	-0.524
2	3.572198467	-0.075690905	-0.596857451	3	0.50	0.000
3	3.395931093	0.130429432	1.0284958	4	0.70	0.524
4	3.031950412	0.146103418	1.152092363	5	0.90	1.282

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-06_I1



Decay Rate Estimate Results

	Rate Ln(µg/L)/year		Constituent Concentration (Most Recent)			Remdial Goal	Date constituent decays below goal	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	*µg/L*	*Mean*	*Upper 95%*
TCE	-0.21	-0.10	3/1/2002	11	2.4	5	5/21/2006	4/14/2014

Rows of Data	5	
Confidence	95%	
Remedial Goal	5	µg/L
Remedial Goal	1.609438	Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.20903136
Intercept	b	421.007677
Observations	n	5
Std error in estimat	SYX	0.14643418
Average X	XAVE	1998.72
Average Y	YAVE	3.21
SSX	SSX	19.3100357
t(α,δf)	t	3.1824463
Minimum X	Xmin	1997.00
Maximum X	Xmax	2002.17
Range X	Xrange	5.17
Extend plot beyond		10%

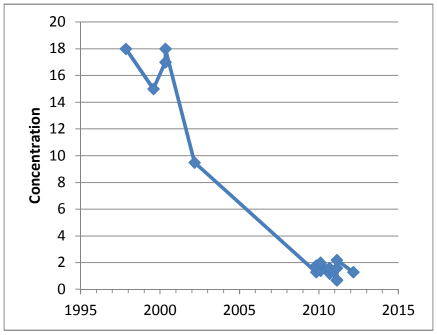
Date constituent decays below goal	
Mean	*Upper 95%*
2006.38911	2014.288701

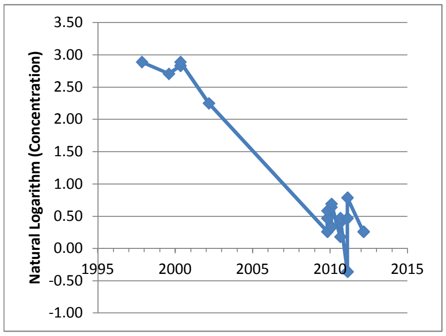
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1996	3.680191	0.3156537	3.99584455	3.364537145	1.60943791
1	1997	3.568018	0.27548612	3.84350396	3.292531723	1.60943791
2	1998	3.455845	0.24212692	3.69797175	3.213717907	1.60943791
3	1998	3.343672	0.21871397	3.56238579	3.124957854	1.60943791
4	1999	3.231499	0.20862325	3.44012206	3.022875567	1.60943791
5	1999	3.119326	0.21374991	3.33307572	2.905575895	1.60943791
6	2000	3.007153	0.23309203	3.24024483	2.774060765	1.60943791
7	2000	2.89498	0.26353799	3.15851778	2.631441797	1.60943791
8	2001	2.782807	0.30174518	3.08455197	2.481061595	1.60943791
9	2001	2.670634	0.34514569	3.01577946	2.325488083	1.60943791
10	2031	-3.43483	3.37910916	-0.05572109	-6.813939413	1.60943791

Raw Results

SFMW-18_I1

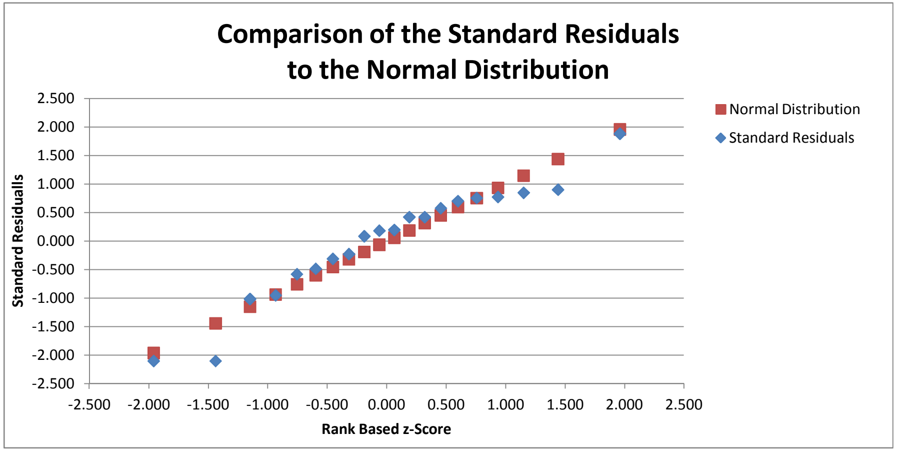




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-18_I	03-Nov-97	TCE	18	=	0.5	µg/L	1997.84	2.89
SFMW-18_I	01-Aug-99	TCE	15	=	0.5	µg/L	1999.58	2.71
SFMW-18_I	01-May-00	TCE	17	=	0.5	µg/L	2000.33	2.83
SFMW-18_I	01-May-00	TCE	18	=	0.5	µg/L	2000.33	2.89
SFMW-18_I	01-Mar-02	TCE	9.5	=	0.5	µg/L	2002.17	2.25
SFMW-18_I	26-Oct-09	TCE	1.3	=	0.5	µg/L	2009.82	0.26
SFMW-18_I	26-Oct-09	TCE	1.6	=	0.5	µg/L	2009.82	0.47
SFMW-18_I	26-Oct-09	TCE	1.8	=	0.5	µg/L	2009.82	0.59
SFMW-18_I	01-Feb-10	TCE	1.4	=	0.5	µg/L	2010.09	0.34
SFMW-18_I	01-Feb-10	TCE	1.9	=	0.5	µg/L	2010.09	0.64
SFMW-18_I	01-Feb-10	TCE	2	=	0.5	µg/L	2010.09	0.69
SFMW-18_I	30-Aug-10	TCE	1.2	=	0.5	µg/L	2010.66	0.18
SFMW-18_I	30-Aug-10	TCE	1.5	=	0.5	µg/L	2010.66	0.41
SFMW-18_I	30-Aug-10	TCE	1.6	=	0.5	µg/L	2010.66	0.47
SFMW-18_I	30-Aug-10	TCE	1.6	=	0.5	µg/L	2010.66	0.47
SFMW-18_I	14-Feb-11	TCE	0.7	=	0.5	µg/L	2011.12	-0.36
SFMW-18_I	14-Feb-11	TCE	0.7	=	0.5	µg/L	2011.12	-0.36
SFMW-18_I	14-Feb-11	TCE	1.6	=	0.5	µg/L	2011.12	0.47
SFMW-18_I	14-Feb-11	TCE	2.2	=	0.5	µg/L	2011.12	0.79
SFMW-18_I	27-Feb-12	TCE	1.3	=	0.5	µg/L	2012.16	0.26

Regression Analysis

SFMW-18_I1



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.96486545
R Square	0.930965337
Adjusted R Square	0.927130078
Standard Error	0.295207699
Observations	20

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	21.15408126	21.15408126	242.7385812	6.8205E-12
Residual	18	1.568656539	0.087147586		
Total	19	22.7227378			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	444.6101572	28.47653055	15.61321371	6.58099E-12	384.7831866	504.4371277	384.7831866	504.4371277
X Variable 1	-0.220952635	0.014181749	-15.58007	6.8205E-12	-0.250747383	-0.191157887	-0.250747383	-0.191157887

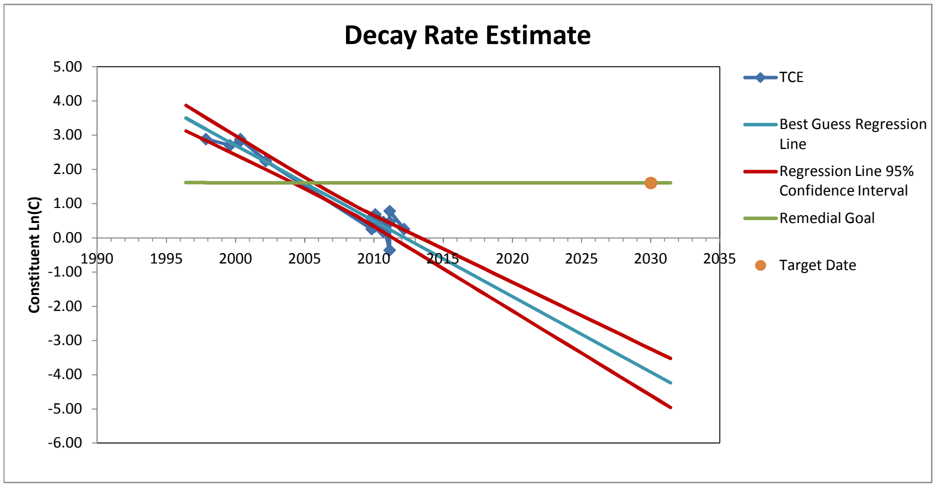
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
16	0.2470354	-0.603710344	-2.101074661	1	0.03	-1.960
17	0.2470354	-0.603710344	-2.101074661	2	0.08	-1.440
1	3.181576758	-0.291205	-1.013471863	3	0.13	-1.150
6	0.534984624	-0.272620359	-0.948792306	4	0.18	-0.935
12	0.348664538	-0.166342981	-0.578918393	5	0.23	-0.755
9	0.47570096	-0.139228723	-0.484553471	6	0.28	-0.598
2	2.796837878	-0.088787677	-0.30900504	7	0.33	-0.454
7	0.534984624	-0.064980995	-0.22615137	8	0.38	-0.319
5	2.226383848	0.02490795	0.086686379	9	0.43	-0.189
8	0.534984624	0.052802041	0.18376533	10	0.48	-0.063
13	0.348664538	0.056800571	0.19768129	11	0.53	0.063
14	0.348664538	0.121339092	0.422292733	12	0.58	0.189
15	0.348664538	0.121339092	0.422292733	13	0.63	0.319
10	0.47570096	0.166152926	0.578256952	14	0.68	0.454
3	2.631085594	0.20212775	0.703459032	15	0.73	0.598
11	0.47570096	0.217446221	0.756771437	16	0.78	0.755
18	0.2470354	0.22296823	0.775989516	17	0.83	0.935
20	0.018369839	0.243994425	0.849166342	18	0.88	1.150
4	2.631085594	0.259286164	0.902385713	19	0.93	1.440
19	0.2470354	0.541421961	1.884294306	20	0.98	1.960

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-18_I1



Decay Rate Estimate Results

Analyte	*Rate Ln(µg/L)/year* *Mean*	*Upper 95%*	*Constituent Concentration (Most Recent)* *Sample Date*	*µg/L*	*Ln(µg/L)*	Remdial Goal µg/L	*Date constituent decays below goal* *Mean*	*Upper 95%*
TCE	-0.22	-0.19	2/27/2012	1	0.3	5	RG Met	RG Met

Rows of Data		20
Confidence		95%
Remedial Goal		5 µg/L
Remedial Goal		1.609438 Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.22095263
Intercept	b	444.610157
Observations	n	20
Std error in estimate	SYX	0.2952077
Average X	XAVE	2007.96
Average Y	YAVE	0.95
SSX	SSX	433.307094
t(α,δf)	t	2.10092204
Minimum X	Xmin	1997.84
Maximum X	Xmax	2012.16
Range X	Xrange	14.32
Extend plot beyond		10%

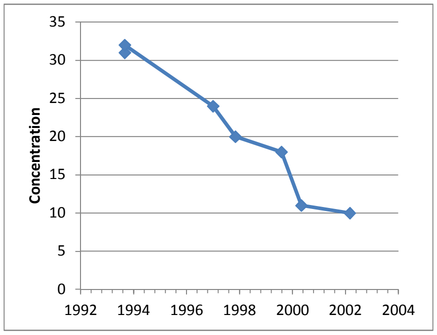
Date constituent decays below goal *Mean*	*Upper 95%*
2004.95785	2004.489148

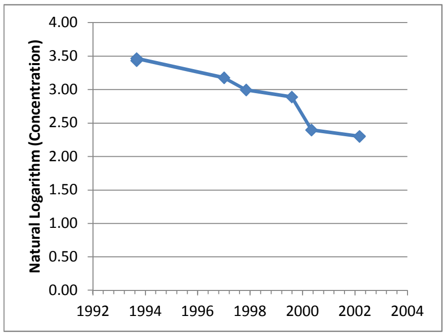
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1996	3.497897	0.37113346	3.86903091	3.126763987	1.60943791
1	1998	3.177158	0.33141012	3.50856783	2.845747581	1.60943791
2	1999	2.856418	0.29268847	3.14910644	2.563729486	1.60943791
3	2001	2.535678	0.25542448	2.7911027	2.280253737	1.60943791
4	2002	2.214938	0.22035888	2.43529735	1.994579593	1.60943791
5	2004	1.894199	0.1887211	2.08291983	1.705477623	1.60943791
6	2005	1.573459	0.16252545	1.73598444	1.410933527	1.60943791
7	2007	1.252719	0.14475718	1.39747642	1.107962058	1.60943791
8	2008	0.931979	0.13869394	1.07067343	0.793285557	1.60943791
9	2009	0.61124	0.14580337	0.75704312	0.465436376	1.60943791
10	2031	-4.24092	0.71292461	-3.52799482	-4.953844037	1.60943791

Raw Results

DM-03_I1-I2

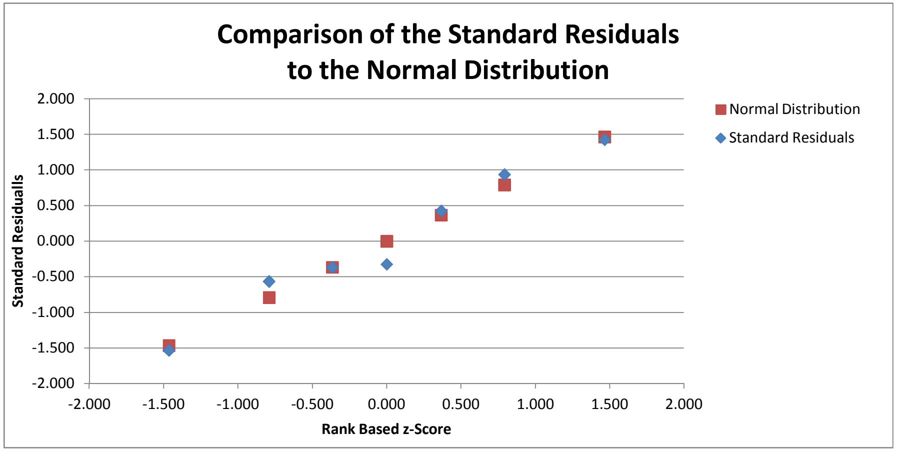




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
DM-03_I1-I2	30-Aug-93	TCE	31	=	0.5	µg/L	1993.66	3.43
DM-03_I1-I2	30-Aug-93	TCE	32	=	0.5	µg/L	1993.66	3.47
DM-03_I1-I2	30-Dec-96	TCE	24	=	0.5	µg/L	1997.00	3.18
DM-03_I1-I2	03-Nov-97	TCE	20	=	0.5	µg/L	1997.84	3.00
DM-03_I1-I2	01-Aug-99	TCE	18	=	0.5	µg/L	1999.58	2.89
DM-03_I1-I2	01-May-00	TCE	11	=	0.5	µg/L	2000.33	2.40
DM-03_I1-I2	01-Mar-02	TCE	10	=	0.5	µg/L	2002.17	2.30

Regression Analysis

DM-03_I1-I2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.958396106
R Square	0.918523096
Adjusted R Square	0.902227715
Standard Error	0.144525869
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.177380246	1.177380246	56.36708354	0.00066304
Residual	5	0.104438634	0.020887727		
Total	6	1.281818881			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	274.9990745	36.23528561	7.589261957	0.000630567	181.8533076	368.1448415	181.8533076	368.1448415
X Variable 1	-0.136176665	0.018138022	-7.507801512	0.00066304	-0.182801934	-0.089551397	-0.182801934	-0.089551397

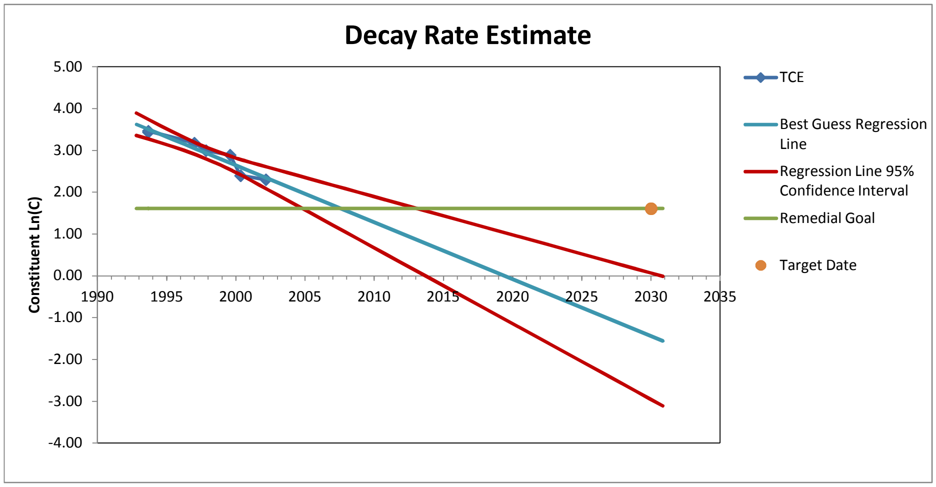
RESIDUAL OUTPUT

				Normal Distribution		
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
6	2.600258572	-0.202363299	-1.533828431	1	0.07	-1.465
1	3.508475838	-0.074488634	-0.564592419	2	0.21	-0.792
7	2.350834372	-0.048249279	-0.365709177	3	0.36	-0.366
2	3.508475838	-0.042739936	-0.32395068	4	0.50	0.000
4	2.939535137	0.056197137	0.425950587	5	0.64	0.366
3	3.054367205	0.123686625	0.937492438	6	0.79	0.792
5	2.702414373	0.187957385	1.424637682	7	0.93	1.465

x

Regression Analysis - Confidence Interval of the Line of Best Fit

DM-03_I1-I2



Decay Rate Estimate Results

Analyte	*Rate Ln(µg/L)/year* *Mean*	*Upper 95%*	*Constituent Concentration (Most Recent)* *Sample Date*	*µg/L*	*Ln(µg/L)*	Remdial Goal *µg/L*	*Date constituent decays below goal* *Mean*	*Upper 95%*
TCE	-0.14	-0.09	3/1/2002	10	2.3	5	8/10/2007	9/27/2012

Rows of Data	7		
Confidence	95%		
Remedial Goal	5	µg/L	
Remedial Goal	1.609438	Ln(µg/L)	
Remedial Goal Date	1/1/2030	2030.00411	
Derived Values			
Slope	m	-0.13617667	
Intercept	b	274.999075	
Observations	n	7	
Std error in estimate	SYX	0.14452587	
Average X	XAVE	1997.75	
Average Y	YAVE	2.95	
SSX	SSX	63.4908813	
t(α,δf)	t	2.57058183	
Minimum X	Xmin	1993.66	
Maximum X	Xmax	2002.17	
Range X	Xrange	8.50	
Extend plot beyond		10%	

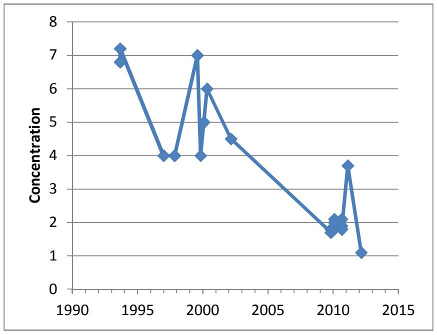
Date constituent decays below goal *Mean*	*Upper 95%*
2007.61001	2012.743321

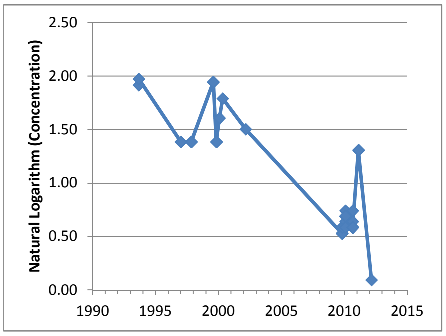
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1993	3.62424	0.26960413	3.89384411	3.354635858	1.60943791
1	1994	3.505752	0.23592046	3.74167276	3.269831846	1.60943791
2	1995	3.387265	0.20474909	3.59201372	3.182515533	1.60943791
3	1995	3.268777	0.17741919	3.44619613	3.091357756	1.60943791
4	1996	3.150289	0.15596345	3.30625271	2.994325817	1.60943791
5	1997	3.031802	0.14304991	3.17485149	2.888751678	1.60943791
6	1998	2.913314	0.14104469	3.0543586	2.772269214	1.60943791
7	1999	2.794826	0.15038479	2.94521101	2.644441438	1.60943791
8	2000	2.676339	0.1692017	2.84554024	2.50713685	1.60943791
9	2001	2.557851	0.19476779	2.75261866	2.363083071	1.60943791
10	2031	-1.55588	1.54983621	-0.00604314	-3.10571556	1.60943791

Raw Results

DM-06_I1-I2

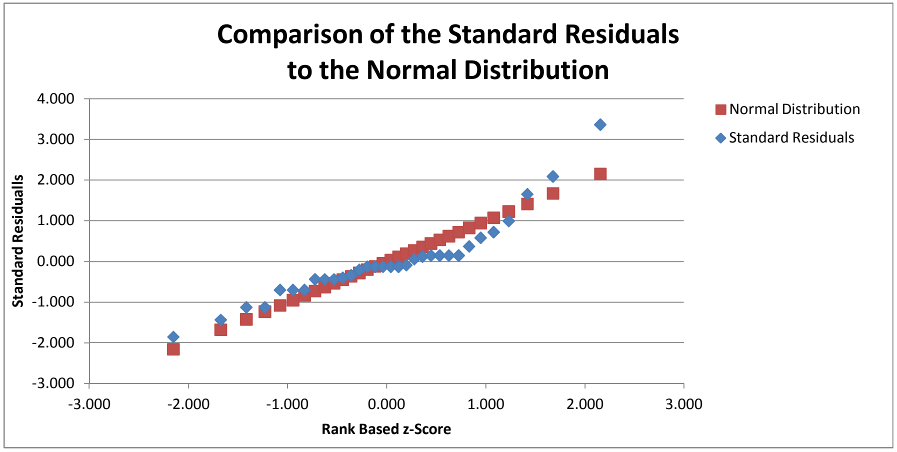




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
DM-06_I1-I2	30-Aug-93	TCE	6.8	=	0.5	µg/L	1993.66	1.92
DM-06_I1-I2	30-Aug-93	TCE	7.2	=	0.5	µg/L	1993.66	1.97
DM-06_I1-I2	30-Dec-96	TCE	4	=	0.5	µg/L	1997.00	1.39
DM-06_I1-I2	03-Nov-97	TCE	4	=	0.5	µg/L	1997.84	1.39
DM-06_I1-I2	03-Nov-97	TCE	4	=	0.5	µg/L	1997.84	1.39
DM-06_I1-I2	01-Aug-99	TCE	7	=	0.5	µg/L	1999.58	1.95
DM-06_I1-I2	01-Nov-99	TCE	4	=	0.5	µg/L	1999.84	1.39
DM-06_I1-I2	01-Feb-00	TCE	5	=	0.5	µg/L	2000.09	1.61
DM-06_I1-I2	01-May-00	TCE	6	=	0.5	µg/L	2000.33	1.79
DM-06_I1-I2	01-Mar-02	TCE	4.5	=	0.5	µg/L	2002.17	1.50
DM-06_I1-I2	26-Oct-09	TCE	1.7	=	0.5	µg/L	2009.82	0.53
DM-06_I1-I2	26-Oct-09	TCE	1.7	=	0.5	µg/L	2009.82	0.53
DM-06_I1-I2	26-Oct-09	TCE	1.8	=	0.5	µg/L	2009.82	0.59
DM-06_I1-I2	26-Oct-09	TCE	1.8	=	0.5	µg/L	2009.82	0.59
DM-06_I1-I2	26-Oct-09	TCE	1.7	=	0.5	µg/L	2009.82	0.53
DM-06_I1-I2	26-Oct-09	TCE	1.8	=	0.5	µg/L	2009.82	0.59
DM-06_I1-I2	01-Feb-10	TCE	1.9	=	0.5	µg/L	2010.09	0.64
DM-06_I1-I2	01-Feb-10	TCE	2.1	=	0.5	µg/L	2010.09	0.74
DM-06_I1-I2	01-Feb-10	TCE	2	=	0.5	µg/L	2010.09	0.69
DM-06_I1-I2	01-Feb-10	TCE	1.8	=	0.5	µg/L	2010.09	0.59
DM-06_I1-I2	01-Feb-10	TCE	2	=	0.5	µg/L	2010.09	0.69
DM-06_I1-I2	01-Feb-10	TCE	2	=	0.5	µg/L	2010.09	0.69
DM-06_I1-I2	01-Feb-10	TCE	2	=	0.5	µg/L	2010.09	0.69
DM-06_I1-I2	30-Aug-10	TCE	2.1	=	0.5	µg/L	2010.66	0.74
DM-06_I1-I2	30-Aug-10	TCE	1.8	=	0.5	µg/L	2010.66	0.59
DM-06_I1-I2	30-Aug-10	TCE	1.8	=	0.5	µg/L	2010.66	0.59
DM-06_I1-I2	30-Aug-10	TCE	1.8	=	0.5	µg/L	2010.66	0.59
DM-06_I1-I	8/30/2010	TCE	1.8	=	0.5	µg/L	2010.66	0.59
DM-06_I1-I	8/30/2010	TCE	1.9	=	0.5	µg/L	2010.66	0.64
DM-06_I1-I	8/30/2010	TCE	1.8	=	0.5	µg/L	2010.66	0.59
DM-06_I1-I	2/14/2011	TCE	3.7	=	0.5	µg/L	2011.12	1.31
DM-06_I1-I	2/27/2012	TCE	1.1	=	0.5	µg/L	2012.16	0.10

Regression Analysis

DM-06_I1-I2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.907935325
R Square	0.824346555
Adjusted R Square	0.81849144
Standard Error	0.220348151
Observations	32

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.835861123	6.835861123	140.7908436	7.39108E-13
Residual	30	1.456599226	0.048553308		
Total	31	8.292460349			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	159.7818316	13.3867973	11.93577732	6.38015E-13	132.4423443	187.1213189	132.4423443	187.1213189
X Variable 1	-0.079161271	0.006671532	-11.86553174	7.39108E-13	-0.092786357	-0.065536186	-0.092786357	-0.065536186

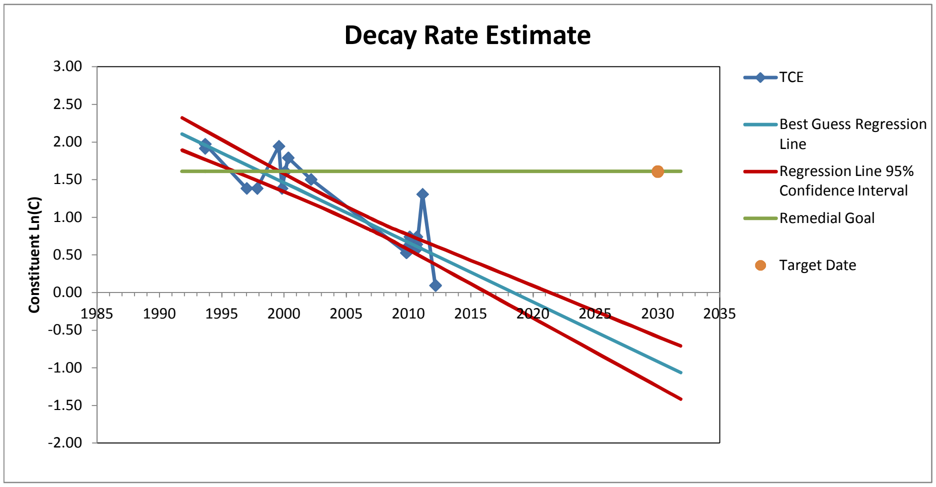
RESIDUAL OUTPUT

						Normal Distribution
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
32	0.496783103	-0.401472923	-1.852111251	1	0.02	-2.154
3	1.696826799	-0.310532438	-1.432576365	2	0.05	-1.676
4	1.63007342	-0.243779059	-1.124623633	3	0.08	-1.418
5	1.63007342	-0.243779059	-1.124623633	4	0.11	-1.230
11	0.681872017	-0.151243766	-0.697731439	5	0.14	-1.078
12	0.681872017	-0.151243766	-0.697731439	6	0.17	-0.947
15	0.681872017	-0.151243766	-0.697731439	7	0.20	-0.831
13	0.681872017	-0.094085352	-0.434043068	8	0.23	-0.725
14	0.681872017	-0.094085352	-0.434043068	9	0.27	-0.626
16	0.681872017	-0.094085352	-0.434043068	10	0.30	-0.533
7	1.472292706	-0.085998345	-0.396735355	11	0.33	-0.445
20	0.660632306	-0.072845641	-0.336058108	12	0.36	-0.360
1	1.960806069	-0.043883457	-0.202447138	13	0.39	-0.278
25	0.615118638	-0.027331973	-0.126090335	14	0.42	-0.197
26	0.615118638	-0.027331973	-0.126090335	15	0.45	-0.118
27	0.615118638	-0.027331973	-0.126090335	16	0.48	-0.039
28	0.615118638	-0.027331973	-0.126090335	17	0.52	0.039
30	0.615118638	-0.027331973	-0.126090335	18	0.55	0.118
17	0.660632306	-0.01877842	-0.086630306	19	0.58	0.197
2	1.960806069	0.013274957	0.061241233	20	0.61	0.278
29	0.615118638	0.026735248	0.123337467	21	0.64	0.360
19	0.660632306	0.032514875	0.150000566	22	0.67	0.445
21	0.660632306	0.032514875	0.150000566	23	0.70	0.533
22	0.660632306	0.032514875	0.150000566	24	0.73	0.626
23	0.660632306	0.032514875	0.150000566	25	0.77	0.725
18	0.660632306	0.081305039	0.37508377	26	0.80	0.831
24	0.615118638	0.126818706	0.585051542	27	0.83	0.947
8	1.452353386	0.157084527	0.724676566	28	0.86	1.078

x

Regression Analysis - Confidence Interval of the Line of Best Fit

DM-06_I1-I2



Decay Rate Estimate Results

Analyte	Rate Ln(µg/L)/year Mean	Upper 95%	Constituent Concentration (Most Recent) Sample Date	µg/L	Ln(µg/L)	Remdial Goal µg/L	Date constituent decays below goal Mean	Upper 95%
TCE	-0.08	-0.07	2/27/2012	1	0.1	5	RG Met	RG Met

Rows of Data		32	
Confidence		95%	
Remedial Goal		5	µg/L
Remedial Goal		1.609438	Ln(µg/L)
Remedial Goal Date		1/1/2030	2030.00411
Derived Values			
Slope	m		-0.07916127
Intercept	b		159.781832
Observations	n		32
Std error in estimat	SYX		0.22034815
Average X	XAVE		2006.55
Average Y	YAVE		0.94
SSX	SSX		1090.85672
t(α,δf)	t		2.04227245
Minimum X	Xmin		1993.66
Maximum X	Xmax		2012.16
Range X	Xrange		18.49
Extend plot beyond			10%

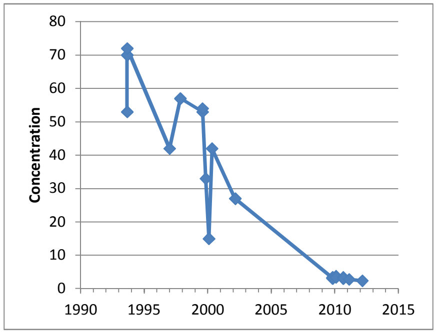
Date constituent decays below goal Mean	Upper 95%
1998.10325	1996.347822

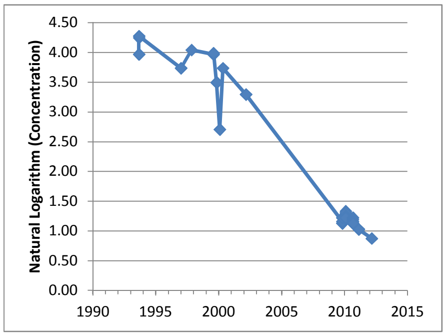
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1992	2.107208	0.21590901	2.32311738	1.891299353	1.60943791
1	1994	1.959223	0.19245891	2.15168176	1.766763931	1.60943791
2	1996	1.811237	0.16959277	1.98083009	1.641644556	1.60943791
3	1997	1.663252	0.14758225	1.81083405	1.515669546	1.60943791
4	1999	1.515266	0.12687347	1.64213975	1.388392803	1.60943791
5	2001	1.367281	0.10821635	1.4754971	1.259064409	1.60943791
6	2003	1.219295	0.0928559	1.31215114	1.126439331	1.60943791
7	2005	1.07131	0.08265108	1.1539608	0.988658628	1.60943791
8	2007	0.923324	0.07960984	1.00293403	0.843714351	1.60943791
9	2009	0.775339	0.08450913	0.8598478	0.690829537	1.60943791
10	2032	-1.06228	0.35386411	-0.70841262	-1.416140846	1.60943791

Raw Results

DM-12_I1-I2

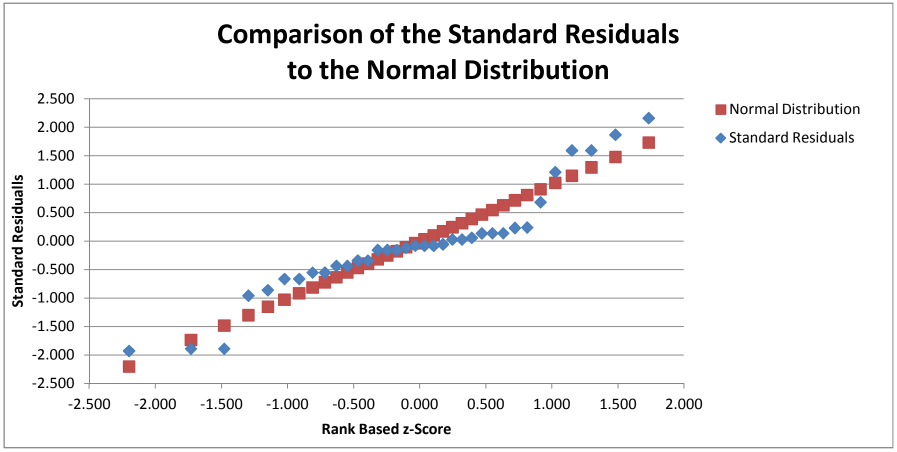




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
DM-12_I1-I2	30-Aug-93	TCE	53	=	0.5	µg/L	1993.66	3.97
DM-12_I1-I2	30-Aug-93	TCE	70	=	0.5	µg/L	1993.66	4.25
DM-12_I1-I2	30-Aug-93	TCE	72	=	0.5	µg/L	1993.66	4.28
DM-12_I1-I2	30-Dec-96	TCE	42	=	0.5	µg/L	1997.00	3.74
DM-12_I1-I2	30-Dec-96	TCE	42	=	0.5	µg/L	1997.00	3.74
DM-12_I1-I2	03-Nov-97	TCE	57	=	0.5	µg/L	1997.84	4.04
DM-12_I1-I2	01-Aug-99	TCE	53	=	0.5	µg/L	1999.58	3.97
DM-12_I1-I2	01-Aug-99	TCE	54	=	0.5	µg/L	1999.58	3.99
DM-12_I1-I2	01-Nov-99	TCE	33	=	0.5	µg/L	1999.84	3.50
DM-12_I1-I2	01-Feb-00	TCE	15	=	0.5	µg/L	2000.09	2.71
DM-12_I1-I2	01-Feb-00	TCE	15	=	0.5	µg/L	2000.09	2.71
DM-12_I1-I2	01-May-00	TCE	42	=	0.5	µg/L	2000.33	3.74
DM-12_I1-I2	01-Mar-02	TCE	27	=	0.5	µg/L	2002.17	3.30
DM-12_I1-I2	01-Mar-02	TCE	27	=	0.5	µg/L	2002.17	3.30
DM-12_I1-I2	26-Oct-09	TCE	3.2	=	0.5	µg/L	2009.82	1.16
DM-12_I1-I2	26-Oct-09	TCE	3.1	=	0.5	µg/L	2009.82	1.13
DM-12_I1-I2	26-Oct-09	TCE	3.1	=	0.5	µg/L	2009.82	1.13
DM-12_I1-I2	26-Oct-09	TCE	3.2	=	0.5	µg/L	2009.82	1.16
DM-12_I1-I2	26-Oct-09	TCE	3.4	=	0.5	µg/L	2009.82	1.22
DM-12_I1-I2	26-Oct-09	TCE	3.4	=	0.5	µg/L	2009.82	1.22
DM-12_I1-I2	01-Feb-10	TCE	3.7	=	0.5	µg/L	2010.09	1.31
DM-12_I1-I2	01-Feb-10	TCE	3.8	=	0.5	µg/L	2010.09	1.34
DM-12_I1-I2	01-Feb-10	TCE	3.7	=	0.5	µg/L	2010.09	1.31
DM-12_I1-I2	01-Feb-10	TCE	3.4	=	0.5	µg/L	2010.09	1.22
DM-12_I1-I2	01-Feb-10	TCE	3.4	=	0.5	µg/L	2010.09	1.22
DM-12_I1-I2	01-Feb-10	TCE	3.5	=	0.5	µg/L	2010.09	1.25
DM-12_I1-I2	01-Feb-10	TCE	3.4	=	0.5	µg/L	2010.09	1.22
DM-12_I1-I2	8/30/2010	TCE	3.4	=	0.5	µg/L	2010.66	1.22
DM-12_I1-I2	8/30/2010	TCE	3.1	=	0.5	µg/L	2010.66	1.13
DM-12_I1-I2	8/30/2010	TCE	3.2	=	0.5	µg/L	2010.66	1.16
DM-12_I1-I2	8/30/2010	TCE	3.1	=	0.5	µg/L	2010.66	1.13
DM-12_I1-I2	8/30/2010	TCE	3.3	=	0.5	µg/L	2010.66	1.19
DM-12_I1-I2	8/30/2010	TCE	3.2	=	0.5	µg/L	2010.66	1.16
DM-12_I1-I2	8/30/2010	TCE	3.1	=	0.5	µg/L	2010.66	1.13
DM-12_I1-I2	2/14/2011	TCE	2.8	=	0.5	µg/L	2011.12	1.03
DM-12_I1-I2	2/27/2012	TCE	2.4	=	0.5	µg/L	2012.16	0.88

Regression Analysis

DM-12_I1-I2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.973934225
R Square	0.948547875
Adjusted R Square	0.947034577
Standard Error	0.291243557
Observations	36

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	53.16765508	53.16765508	626.8084667	1.72855E-23
Residual	34	2.883975518	0.084822809		
Total	35	56.0516306			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	399.5883176	15.87491091	25.17105891	1.45303E-23	367.3266173	431.850018	367.3266173	431.850018
X Variable 1	-0.198160458	0.007914975	-25.03614321	1.72855E-23	-0.214245624	-0.182075293	-0.214245624	-0.182075293

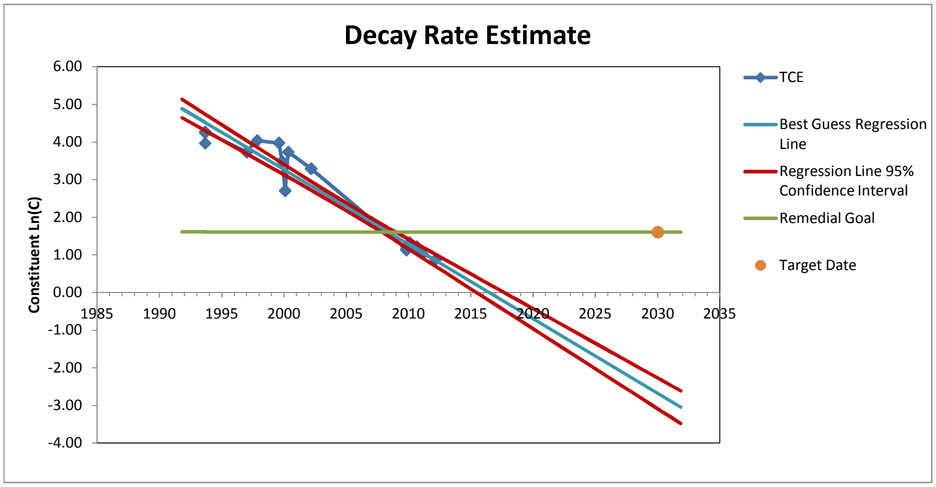
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
1	4.522824127	-0.552532213	-1.924845342	1	0.01	-2.200
10	3.25003991	-0.541989709	-1.888118632	2	0.04	-1.732
11	3.25003991	-0.541989709	-1.888118632	3	0.07	-1.480
2	4.522824127	-0.274328885	-0.95567401	4	0.10	-1.298
3	4.522824127	-0.246158008	-0.857535694	5	0.13	-1.150
16	1.321332369	-0.189930258	-0.661656213	6	0.15	-1.025
17	1.321332369	-0.189930258	-0.661656213	7	0.18	-0.913
15	1.321332369	-0.158181559	-0.551053912	8	0.21	-0.812
18	1.321332369	-0.158181559	-0.551053912	9	0.24	-0.719
4	3.862017999	-0.124348381	-0.433189949	10	0.26	-0.631
5	3.862017999	-0.124348381	-0.433189949	11	0.29	-0.549
19	1.321332369	-0.097556937	-0.339857138	12	0.32	-0.469
20	1.321332369	-0.097556937	-0.339857138	13	0.35	-0.393
24	1.26816406	-0.044388628	-0.15463577	14	0.38	-0.319
25	1.26816406	-0.044388628	-0.15463577	15	0.40	-0.246
27	1.26816406	-0.044388628	-0.15463577	16	0.43	-0.175
35	1.063086296	-0.033466879	-0.116587892	17	0.46	-0.105
29	1.154231969	-0.022829857	-0.079531914	18	0.49	-0.035
31	1.154231969	-0.022829857	-0.079531914	19	0.51	0.035
34	1.154231969	-0.022829857	-0.079531914	20	0.54	0.105
26	1.26816406	-0.015401091	-0.053652472	21	0.57	0.175
30	1.154231969	0.008918841	0.031070386	22	0.60	0.246
33	1.154231969	0.008918841	0.031070386	23	0.63	0.319
36	0.858008532	0.017460205	0.060825765	24	0.65	0.393
32	1.154231969	0.0396905	0.138268994	25	0.68	0.469
21	1.26816406	0.04016876	0.139935099	26	0.71	0.549
23	1.26816406	0.04016876	0.139935099	27	0.74	0.631
22	1.26816406	0.066837007	0.232838734	28	0.76	0.719

x

Regression Analysis - Confidence Interval of the Line of Best Fit

DM-12_I1-I2



Decay Rate Estimate Results

	Rate Ln(µg/L)/year		Constituent Concentration (Most Recent)			Remdial Goal	Date constituent decays below goal	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	µg/L	*Mean*	*Upper 95%*
TCE	-0.20	-0.18	2/27/2012	2	0.9	5	RG Met	RG Met

Rows of Data		36
Confidence		95%
Remedial Goal		5 µg/L
Remedial Goal		1.609438 Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.19816046
Intercept	b	399.588318
Observations	n	36
Std error in estimat	SYX	0.29124356
Average X	XAVE	2005.67
Average Y	YAVE	2.14
SSX	SSX	1353.98393
t(α,δf)	t	2.0322445
Minimum X	Xmin	1993.66
Maximum X	Xmax	2012.16
Range X	Xrange	18.49
Extend plot beyond		10%

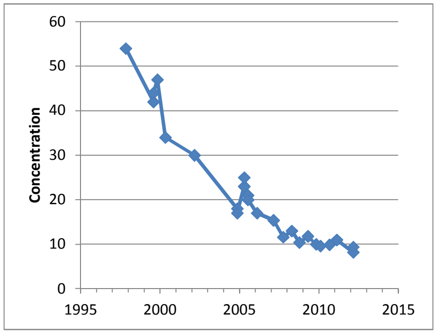
Date constituent decays below goal	
Mean	*Upper 95%*
2008.36677	2008.604924

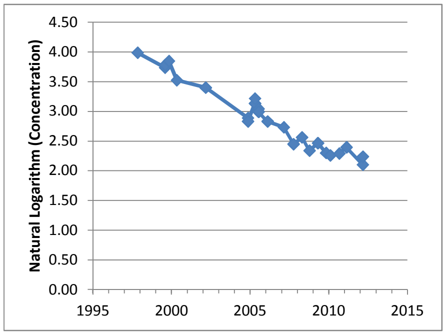
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1992	4.889306	0.24372823	5.13303391	4.645577458	1.60943791
1	1994	4.518861	0.21657358	4.73543449	4.302287341	1.60943791
2	1996	4.148416	0.1902976	4.33871375	3.958118549	1.60943791
3	1997	3.777971	0.1653198	3.94329118	3.612651578	1.60943791
4	1999	3.407527	0.14232531	3.54985193	3.265201297	1.60943791
5	2001	3.037082	0.12243672	3.15951857	2.914645119	1.60943791
6	2003	2.666637	0.10739369	2.77403077	2.559243381	1.60943791
7	2005	2.296192	0.09942061	2.39561291	2.196771698	1.60943791
8	2007	1.925748	0.10021929	2.02596683	1.825528243	1.60943791
9	2009	1.555303	0.10959815	1.66490092	1.445704618	1.60943791
10	2032	-3.04471	0.43254896	-2.61215915	-3.477257084	1.60943791

Raw Results

SFMW-25_I1-I2

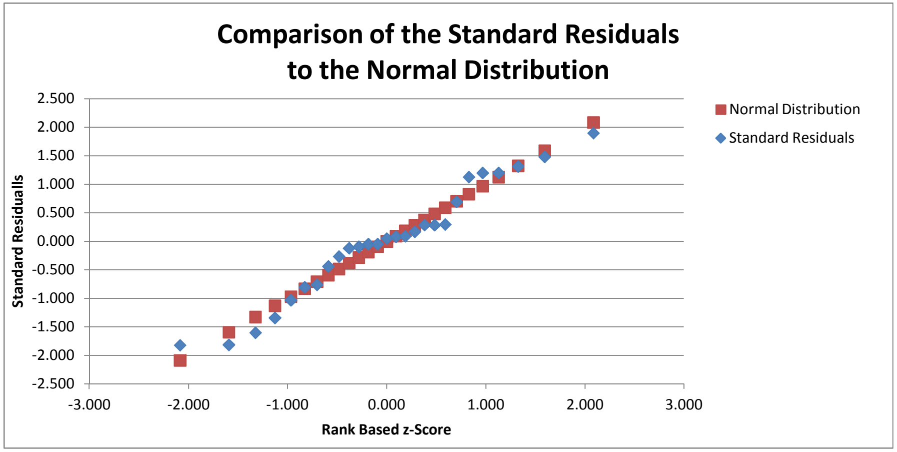




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-25_I	03-Nov-97	TCE	54	=	0.5	µg/L	1997.84	3.99
SFMW-25_I	01-Aug-99	TCE	42	=	0.5	µg/L	1999.58	3.74
SFMW-25_I	01-Aug-99	TCE	44	=	0.5	µg/L	1999.58	3.78
SFMW-25_I	01-Nov-99	TCE	47	=	0.5	µg/L	1999.84	3.85
SFMW-25_I	01-May-00	TCE	34	=	0.5	µg/L	2000.33	3.53
SFMW-25_I	01-Mar-02	TCE	30	=	0.5	µg/L	2002.17	3.40
SFMW-25_I	01-Mar-02	TCE	30	=	0.5	µg/L	2002.17	3.40
SFMW-25_I	08-Nov-04	TCE	18	=	0.5	µg/L	2004.86	2.89
SFMW-25_I	08-Nov-04	TCE	17	=	0.5	µg/L	2004.86	2.83
SFMW-25_I	18-Apr-05	TCE	23	=	0.5	µg/L	2005.30	3.14
SFMW-25_I	18-Apr-05	TCE	23	=	0.5	µg/L	2005.30	3.14
SFMW-25_I	18-Apr-05	TCE	25	=	0.5	µg/L	2005.30	3.22
SFMW-25_I	11-Jul-05	TCE	20	=	0.5	µg/L	2005.53	3.00
SFMW-25_I	11-Jul-05	TCE	21	=	0.5	µg/L	2005.53	3.04
SFMW-25_I	11-Jul-05	TCE	20	=	0.5	µg/L	2005.53	3.00
SFMW-25_I	06-Feb-06	TCE	17	=	0.5	µg/L	2006.10	2.83
SFMW-25_I	19-Feb-07	TCE	15.4	=	0.5	µg/L	2007.14	2.73
SFMW-25_I	01-Oct-07	TCE	11.6	=	0.5	µg/L	2007.75	2.45
SFMW-25_I	14-Apr-08	TCE	13	=	0.5	µg/L	2008.29	2.56
SFMW-25_I	06-Oct-08	TCE	10.4	=	0.5	µg/L	2008.77	2.34
SFMW-25_I	20-Apr-09	TCE	11.8	=	0.5	µg/L	2009.30	2.47
SFMW-25_I	26-Oct-09	TCE	10	=	0.5	µg/L	2009.82	2.30
SFMW-25_I	01-Feb-10	TCE	9.6	=	0.5	µg/L	2010.09	2.26
SFMW-25_I	30-Aug-10	TCE	9.9	=	0.5	µg/L	2010.66	2.29
SFMW-25_I	14-Feb-11	TCE	11	=	0.5	µg/L	2011.12	2.40
SFMW-25_I	27-Feb-12	TCE	8.2	=	0.5	µg/L	2012.16	2.10
SFMW-25_I	27-Feb-12	TCE	9.4	=	0.5	µg/L	2012.16	2.24

Regression Analysis

SFMW-25_I1-I2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.976575794
R Square	0.953700281
Adjusted R Square	0.951848293
Standard Error	0.12176431
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7.635079945	7.635079945	514.9600854	3.37189E-18
Residual	25	0.370663677	0.014826547		
Total	26	8.005743622			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	268.4792009	11.70226295	22.94250284	2.59578E-18	244.3779394	292.5804624	244.3779394	292.5804624
X Variable 1	-0.132392813	0.00583415	-22.69273199	3.37189E-18	-0.144408471	-0.120377155	-0.144408471	-0.120377155

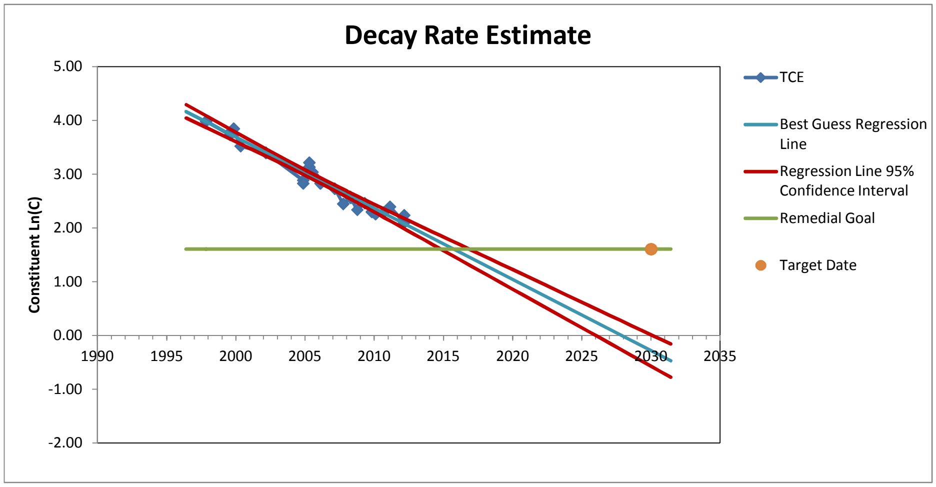
RESIDUAL OUTPUT

				Normal Distribution		
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
9	3.050550107	-0.217336763	-1.820245025	1	0.02	-2.085
18	2.667417449	-0.216412351	-1.812502864	2	0.06	-1.593
20	2.532940423	-0.191134617	-1.600796072	3	0.09	-1.325
8	3.050550107	-0.160178349	-1.341530255	4	0.13	-1.128
5	3.649353466	-0.122992941	-1.030093975	5	0.17	-0.967
23	2.35786656	-0.096103461	-0.804888436	6	0.20	-0.828
22	2.393388793	-0.0908037	-0.760501725	7	0.24	-0.704
16	2.885625453	-0.052412108	-0.438963379	8	0.28	-0.589
19	2.596372982	-0.031423625	-0.263180036	9	0.31	-0.482
17	2.748611125	-0.014243615	-0.11929353	10	0.35	-0.380
2	3.74867073	-0.011001112	-0.092136825	11	0.39	-0.282
6	3.406859854	-0.005662472	-0.047424497	12	0.43	-0.187
7	3.406859854	-0.005662472	-0.047424497	13	0.46	-0.093
21	2.461895957	0.006203575	0.051956355	14	0.50	0.000
1	3.979202774	0.009781272	0.081920391	15	0.54	0.093
24	2.281747488	0.010787269	0.090345839	16	0.57	0.187
26	2.083837904	0.020296251	0.169985735	17	0.61	0.282
13	2.961744524	0.03398775	0.284655168	18	0.65	0.380
15	2.961744524	0.03398775	0.284655168	19	0.69	0.482
3	3.74867073	0.035518904	0.297478931	20	0.72	0.589
14	2.961744524	0.082777914	0.693283936	21	0.76	0.704
4	3.715323328	0.134824274	1.129184089	22	0.80	0.828
10	2.992192152	0.143302064	1.200187514	23	0.83	0.967
11	2.992192152	0.143302064	1.200187514	24	0.87	1.128
27	2.083837904	0.156871786	1.313837034	25	0.91	1.325
25	2.220852232	0.177043041	1.482775906	26	0.94	1.593
12	2.992192152	0.226683673	1.898527533	27	0.98	2.085

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-25_I1-I2



Decay Rate Estimate Results

	Rate Ln(µg/L)/year		Constituent Concentration (Most Recent)			Remdial Goal	Date constituent decays below goal	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	*µg/L*	*Mean*	*Upper 95%*
TCE	-0.13	-0.12	2/27/2012	8	2.1	5	9/27/2015	9/23/2016

Rows of Data		27
Confidence		95%
Remedial Goal		5 µg/L
Remedial Goal		1.609438 Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.13239281
Intercept	b	268.479201
Observations	n	27
Std error in estimate	SYX	0.12176431
Average X	XAVE	2005.82
Average Y	YAVE	2.92
SSX	SSX	435.596889
t(α,δf)	t	2.05953854
Minimum X	Xmin	1997.84
Maximum X	Xmax	2012.16
Range X	Xrange	14.32
Extend plot beyond		10%

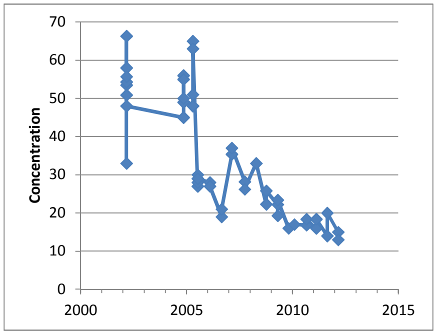
Date constituent decays below goal	
Mean	*Upper 95%*
2015.74207	2016.732738

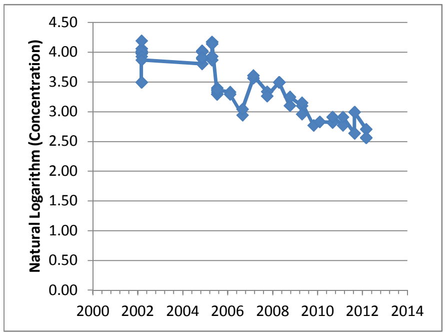
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1996	4.168739	0.12289567	4.29163493	4.045843595	1.60943791
1	1998	3.976555	0.10707405	4.08362897	3.869480866	1.60943791
2	1999	3.784371	0.09184128	3.87621185	3.692529295	1.60943791
3	2001	3.592186	0.07754514	3.66973137	3.514641089	1.60943791
4	2002	3.400002	0.06480847	3.46481036	3.335193418	1.60943791
5	2004	3.207818	0.05473104	3.26254859	3.153086503	1.60943791
6	2005	3.015633	0.04898261	3.06461581	2.966650589	1.60943791
7	2007	2.823449	0.0491077	2.87255656	2.774341159	1.60943791
8	2008	2.631265	0.05506629	2.6863308	2.576198225	1.60943791
9	2009	2.43908	0.06528006	2.50436024	2.373800107	1.60943791
10	2031	-0.46829	0.31158365	-0.15670591	-0.779873212	1.60943791

Raw Results

SFMW-47_I1-I2

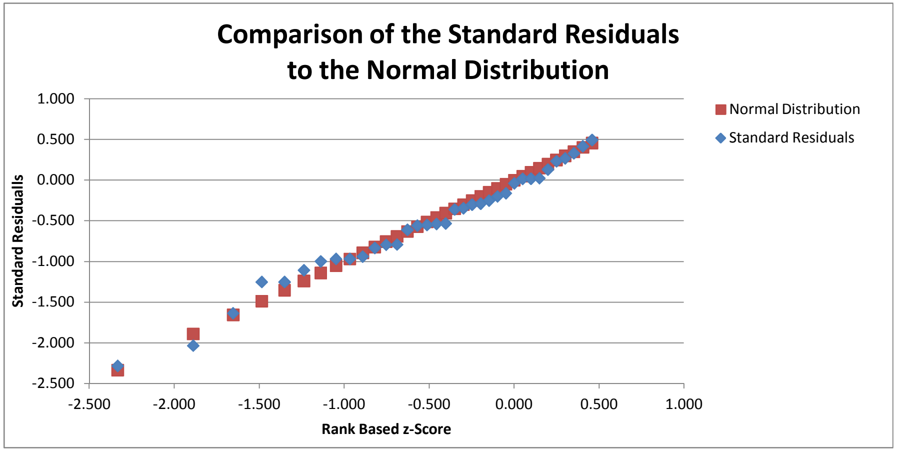




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-47_I	01-Mar-02	TCE	33	=	0.5	µg/L	2002.17	3.50
SFMW-47_I	01-Mar-02	TCE	58	=	0.5	µg/L	2002.17	4.06
SFMW-47_I	01-Mar-02	TCE	53.5	=	0.5	µg/L	2002.17	3.98
SFMW-47_I	01-Mar-02	TCE	54.3	=	0.5	µg/L	2002.17	3.99
SFMW-47_I	01-Mar-02	TCE	66.3	=	0.5	µg/L	2002.17	4.19
SFMW-47_I	01-Mar-02	TCE	55.7	=	0.5	µg/L	2002.17	4.02
SFMW-47_I	01-Mar-02	TCE	50.9	=	0.5	µg/L	2002.17	3.93
SFMW-47_I	01-Mar-02	TCE	48	=	0.5	µg/L	2002.17	3.87
SFMW-47_I	08-Nov-04	TCE	45	=	0.5	µg/L	2004.86	3.81
SFMW-47_I	08-Nov-04	TCE	49	=	0.5	µg/L	2004.86	3.89
SFMW-47_I	08-Nov-04	TCE	56	=	0.5	µg/L	2004.86	4.03
SFMW-47_I	08-Nov-04	TCE	55	=	0.5	µg/L	2004.86	4.01
SFMW-47_I	08-Nov-04	TCE	49	=	0.5	µg/L	2004.86	3.89
SFMW-47_I	08-Nov-04	TCE	50	=	0.5	µg/L	2004.86	3.91
SFMW-47_I	18-Apr-05	TCE	48	=	0.5	µg/L	2005.30	3.87
SFMW-47_I	18-Apr-05	TCE	48	=	0.5	µg/L	2005.30	3.87
SFMW-47_I	18-Apr-05	TCE	51	=	0.5	µg/L	2005.30	3.93
SFMW-47_I	18-Apr-05	TCE	65	=	0.5	µg/L	2005.30	4.17
SFMW-47_I	18-Apr-05	TCE	65	=	0.5	µg/L	2005.30	4.17
SFMW-47_I	18-Apr-05	TCE	63	=	0.5	µg/L	2005.30	4.14
SFMW-47_I	11-Jul-05	TCE	27	=	0.5	µg/L	2005.53	3.30
SFMW-47_I	11-Jul-05	TCE	27	=	0.5	µg/L	2005.53	3.30
SFMW-47_I	11-Jul-05	TCE	28	=	0.5	µg/L	2005.53	3.33
SFMW-47_I	11-Jul-05	TCE	29	=	0.5	µg/L	2005.53	3.37
SFMW-47_I	11-Jul-05	TCE	30	=	0.5	µg/L	2005.53	3.40
SFMW-47_I	11-Jul-05	TCE	29	=	0.5	µg/L	2005.53	3.37
SFMW-47_I	06-Feb-06	TCE	28	=	0.5	µg/L	2006.10	3.33
SFMW-47_I:	2/6/2006	TCE	27	=	0.5	µg/L	2006.10	3.30
SFMW-47_I:	8/28/2006	TCE	19	=	0.5	µg/L	2006.66	2.94
SFMW-47_I:	8/28/2006	TCE	21	=	0.5	µg/L	2006.66	3.04
SFMW-47_I:	2/19/2007	TCE	35.4	=	0.5	µg/L	2007.14	3.57
SFMW-47_I:	2/19/2007	TCE	37	=	0.5	µg/L	2007.14	3.61
SFMW-47_I:	10/1/2007	TCE	28.2	=	0.5	µg/L	2007.75	3.34
SFMW-47_I:	10/1/2007	TCE	26.2	=	0.5	µg/L	2007.75	3.27
SFMW-47_I:	4/14/2008	TCE	33	=	0.5	µg/L	2008.29	3.50
SFMW-47_I:	4/14/2008	TCE	33	=	0.5	µg/L	2008.29	3.50
SFMW-47_I:	10/6/2008	TCE	22.3	=	0.5	µg/L	2008.77	3.10
SFMW-47_I:	10/6/2008	TCE	25.8	=	0.5	µg/L	2008.77	3.25
SFMW-47_I:	4/20/2009	TCE	22.2	=	0.5	µg/L	2009.30	3.10
SFMW-47_I:	4/20/2009	TCE	19.3	=	0.5	µg/L	2009.30	2.96
SFMW-47_I:	4/20/2009	TCE	23.4	=	0.5	µg/L	2009.30	3.15
SFMW-47_I:	10/26/2009	TCE	16	=	0.5	µg/L	2009.82	2.77
SFMW-47_I:	2/1/2010	TCE	17	=	0.5	µg/L	2010.09	2.83
SFMW-47_I:	8/30/2010	TCE	16.8	=	0.5	µg/L	2010.66	2.82
SFMW-47_I:	8/30/2010	TCE	18.4	=	0.5	µg/L	2010.66	2.91
SFMW-47_I:	2/14/2011	TCE	16	=	0.5	µg/L	2011.12	2.77
SFMW-47_I:	2/14/2011	TCE	18.4	=	0.5	µg/L	2011.12	2.91
SFMW-47_I:	8/22/2011	TCE	14	=	0.5	µg/L	2011.64	2.64
SFMW-47_I:	8/22/2011	TCE	20	=	0.5	µg/L	2011.64	3.00
SFMW-47_I	27-Feb-12	TCE	15	=	0.5	µg/L	2012.16	2.71
SFMW-47_I	27-Feb-12	TCE	13	=	0.5	µg/L	2012.16	2.56

Regression Analysis

SFMW-47_I1-I2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.850627733
R Square	0.72356754
Adjusted R Square	0.717926061
Standard Error	0.253944812
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	8.271129203	8.271129203	128.2584881	2.75817E-15
Residual	49	3.159910403	0.064487967		
Total	50	11.43103961			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	277.869926	24.23066268	11.46769817	1.76163E-15	229.1765872	326.5632648	229.1765872	326.5632648
X Variable 1	-0.13675191	0.012075089	-11.32512641	2.75817E-15	-0.16101771	-0.112486111	-0.16101771	-0.112486111

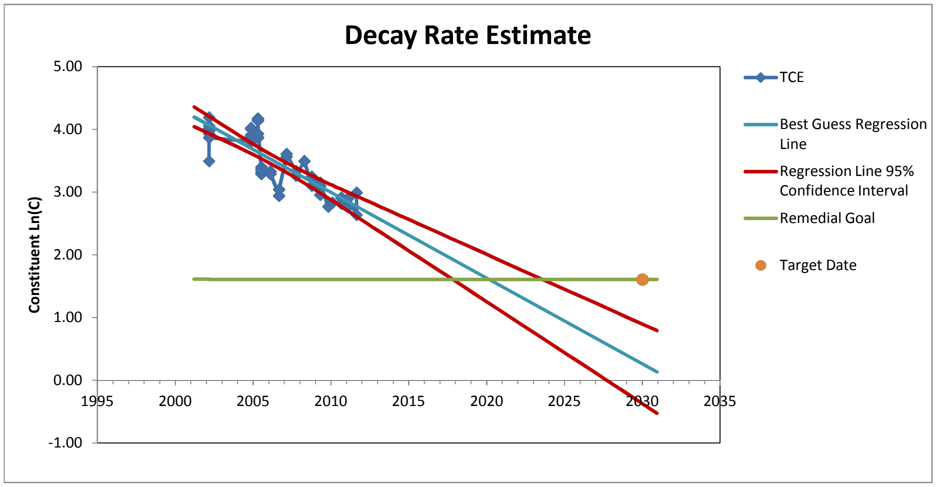
RESIDUAL OUTPUT

				Normal Distribution		
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
1	4.069950526	-0.573442965	-2.281065977	1	0.01	-2.334
29	3.455549748	-0.511110769	-2.033118299	2	0.03	-1.890
30	3.455549748	-0.41102731	-1.635002032	3	0.05	-1.654
21	3.61017956	-0.314342694	-1.250405826	4	0.07	-1.486
22	3.61017956	-0.314342694	-1.250405826	5	0.09	-1.352
23	3.61017956	-0.27797505	-1.105741054	6	0.11	-1.238
42	3.023110443	-0.250521721	-0.996536027	7	0.13	-1.139
24	3.61017956	-0.24288373	-0.9661533	8	0.15	-1.049
26	3.61017956	-0.24288373	-0.9661533	9	0.17	-0.967
28	3.531554232	-0.235717366	-0.937646629	10	0.19	-0.892
25	3.61017956	-0.208982178	-0.831298256	11	0.21	-0.821
27	3.531554232	-0.199349722	-0.792981857	12	0.23	-0.754
8	4.069950526	-0.198749515	-0.790594332	13	0.25	-0.690
43	2.986418623	-0.153205279	-0.609426519	14	0.26	-0.629
7	4.069950526	-0.140087603	-0.557246464	15	0.28	-0.570
51	2.703367442	-0.138418084	-0.550605383	16	0.30	-0.513
48	2.774130237	-0.135072908	-0.537298795	17	0.32	-0.458
40	3.093873238	-0.133768142	-0.532108644	18	0.34	-0.404
3	4.069950526	-0.090268872	-0.359075386	19	0.36	-0.351
44	2.907793295	-0.086414409	-0.343742935	20	0.38	-0.299
4	4.069950526	-0.075426299	-0.300033963	21	0.40	-0.248
46	2.844893033	-0.07230431	-0.287615181	22	0.42	-0.198
37	3.167256878	-0.0626702	-0.249292203	23	0.44	-0.148
6	4.069950526	-0.049970379	-0.198774315	24	0.46	-0.098
34	3.306161624	-0.040402214	-0.160713655	25	0.48	-0.049
2	4.069950526	-0.009507516	-0.037819404	26	0.50	0.000
45	2.907793295	0.00455737	0.0181285	27	0.52	0.049
50	2.703367442	0.004682759	0.01862728	28	0.54	0.098

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-47_I1-I2



Decay Rate Estimate Results

	Rate Ln(µg/L)/year		*Constituent Concentration (Most Recent)*			Remdial Goal	*Date constituent decays below goal*	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	*µg/L*	*Mean*	*Upper 95%*
TCE	-0.14	-0.11	8/22/2011	14	2.6	5	3/5/2020	2/20/2023

Rows of Data		50	
Confidence		95%	
Remedial Goal		5	µg/L
Remedial Goal		1.609438	Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411	
Derived Values			
Slope	m	-0.13473574	
Intercept	b	273.827343	
Observations	n	50	
Std error in estimate	SYX	0.25842492	
Average X	XAVE	2006.44	
Average Y	YAVE	3.49	
SSX	SSX	379.411624	
t(α,δf)	t	2.01063472	
Minimum X	Xmin	2002.17	
Maximum X	Xmax	2011.64	
Range X	Xrange	9.48	
Extend plot beyond		10%	

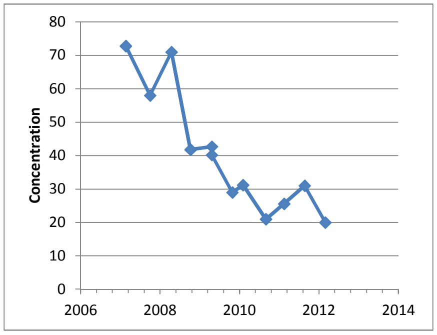
Date constituent decays below goal	
Mean	*Upper 95%*
2020.17813	2023.141996

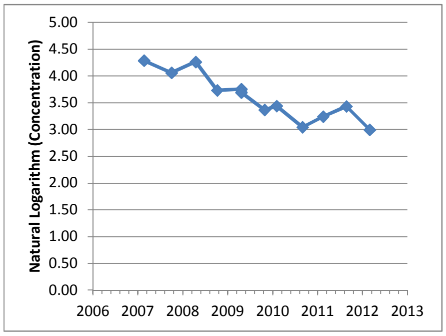
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	2001	4.199533	0.15746432	4.35699688	4.042068234	1.60943791
1	2002	4.067215	0.13517434	4.20238983	3.932041148	1.60943791
2	2003	3.934898	0.11437458	4.04927301	3.820523837	1.60943791
3	2004	3.802581	0.09603823	3.89861959	3.706543121	1.60943791
4	2005	3.670264	0.08183821	3.75210249	3.58842608	1.60943791
5	2006	3.537947	0.07418892	3.61213614	3.463758302	1.60943791
6	2007	3.40563	0.07511892	3.48074907	3.330511231	1.60943791
7	2008	3.273313	0.0843449	3.35765799	3.188968183	1.60943791
8	2009	3.140996	0.09958728	3.2405833	3.04140874	1.60943791
9	2010	3.008679	0.11854764	3.12722659	2.890131311	1.60943791
10	2031	0.133405	0.6580069	0.79141189	-0.524601915	1.60943791

Raw Results

HSM-I2-5_I2

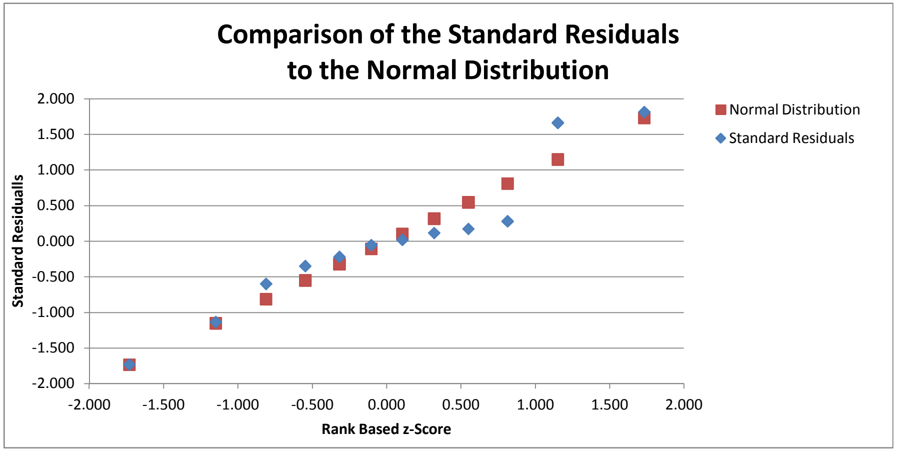




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
HSM-I2-5_I	19-Feb-07	TCE	72.8	=	0.5	µg/L	2007.14	4.29
HSM-I2-5_I	01-Oct-07	TCE	58	=	0.5	µg/L	2007.75	4.06
HSM-I2-5_I	14-Apr-08	TCE	71	=	0.5	µg/L	2008.29	4.26
HSM-I2-5_I	06-Oct-08	TCE	41.8	=	0.5	µg/L	2008.77	3.73
HSM-I2-5_I	20-Apr-09	TCE	42.7	=	0.5	µg/L	2009.30	3.75
HSM-I2-5_I	20-Apr-09	TCE	40.2	=	0.5	µg/L	2009.30	3.69
HSM-I2-5_I	26-Oct-09	TCE	29	=	0.5	µg/L	2009.82	3.37
HSM-I2-5_I	01-Feb-10	TCE	31.2	=	0.5	µg/L	2010.09	3.44
HSM-I2-5_I	30-Aug-10	TCE	21	=	0.5	µg/L	2010.66	3.04
HSM-I2-5_I	14-Feb-11	TCE	25.6	=	0.5	µg/L	2011.12	3.24
HSM-I2-5_I	22-Aug-11	TCE	31	=	0.5	µg/L	2011.64	3.43
HSM-I2-5_I	27-Feb-12	TCE	20	=	0.5	µg/L	2012.16	3.00

Regression Analysis

HSM-I2-5_I2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.910228882
R Square	0.828516618
Adjusted R Square	0.81136828
Standard Error	0.1889447
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.724839184	1.724839184	48.31468841	3.94295E-05
Residual	10	0.357000995	0.0357001		
Total	11	2.081840179			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	516.5856674	73.80020187	6.999786643	3.71655E-05	352.148571	681.0227637	352.148571	681.0227637
X Variable 1	-0.255253764	0.036722527	-6.950876809	3.94295E-05	-0.337076654	-0.173430874	-0.337076654	-0.173430874

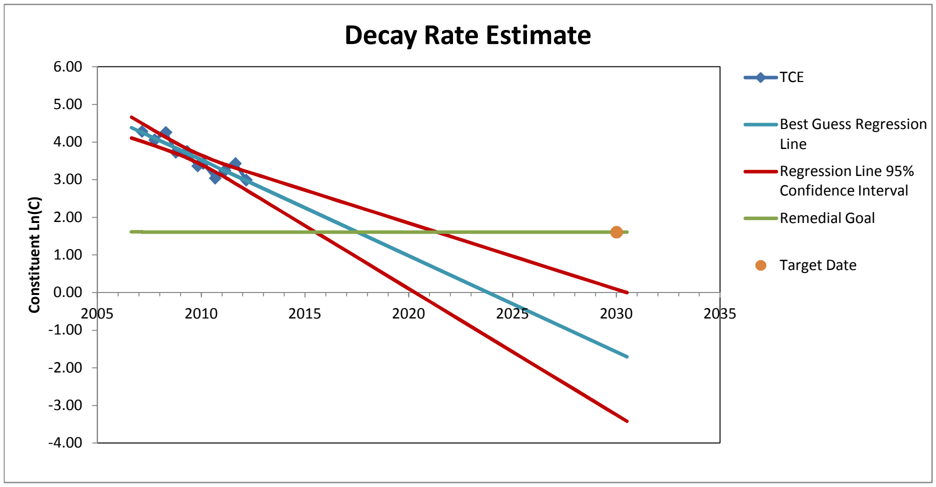
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
9	3.35613089	-0.311608452	-1.729700288	1	0.04	-1.732
7	3.571375679	-0.204079849	-1.132822206	2	0.13	-1.150
4	3.840431666	-0.107535326	-0.596915405	3	0.21	-0.812
8	3.502888701	-0.062470606	-0.346766669	4	0.29	-0.549
2	4.099703799	-0.039260788	-0.21793182	5	0.38	-0.319
6	3.703457709	-0.009590713	-0.053236874	6	0.46	-0.105
10	3.238724641	0.003867711	0.021469188	7	0.54	0.105
12	2.974560581	0.021171693	0.11752147	8	0.63	0.319
1	4.256245464	0.031470491	0.174688836	9	0.71	0.549
5	3.703457709	0.050741211	0.281658239	10	0.79	0.812
3	3.962729842	0.299950035	1.664985848	11	0.88	1.150
11	3.106642611	0.327344594	1.817049682	12	0.96	1.732

x

Regression Analysis - Confidence Interval of the Line of Best Fit

HSM-I2-5_I2



Decay Rate Estimate Results

	Rate Ln(µg/L)/year		Constituent Concentration (Most Recent)			Remdial Goal	Date constituent decays below goal	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	*µg/L*	*Mean*	*Upper 95%*
TCE	-0.26	-0.17	2/27/2012	20	3.0	5	7/3/2017	3/14/2021

Rows of Data		12	
Confidence		95%	
Remedial Goal		5	µg/L
Remedial Goal		1.609438	Ln(µg/L)
Remedial Goal Date		1/1/2030	2030.00411
Derived Values			
Slope	m		-0.25525376
Intercept	b		516.585667
Observations	n		12
Std error in estimate	SYX		0.1889447
Average X	XAVE		2009.67
Average Y	YAVE		3.61
SSX	SSX		26.4730694
t(α,δf)	t		2.22813884
Minimum X	Xmin		2007.14
Maximum X	Xmax		2012.16
Range X	Xrange		5.02
Extend plot beyond			10%

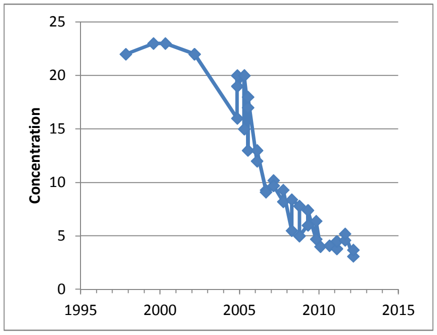
Date constituent decays below goal	
Mean	*Upper 95%*
2017.5069	2021.204004

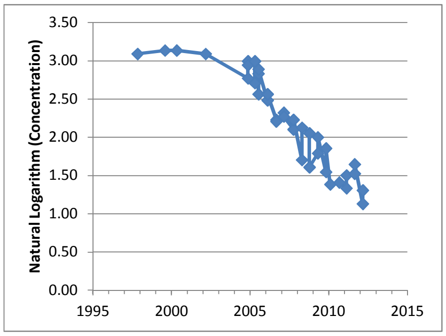
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	2007	4.384414	0.27648221	4.66089616	4.107931742	1.60943791
1	2007	4.25114	0.23884855	4.48998894	4.012291837	1.60943791
2	2008	4.117867	0.20323657	4.3211034	3.914630252	1.60943791
3	2008	3.984593	0.1709147	4.15550796	3.81367856	1.60943791
4	2009	3.85132	0.14411392	3.99543362	3.707205779	1.60943791
5	2009	3.718046	0.12639646	3.84444259	3.591649679	1.60943791
6	2010	3.584773	0.12179311	3.70656568	3.462979457	1.60943791
7	2010	3.451499	0.13168643	3.58318544	3.319812572	1.60943791
8	2011	3.318225	0.1532949	3.47152035	3.164930539	1.60943791
9	2011	3.184952	0.18250368	3.36745556	3.002448196	1.60943791
10	2031	-1.70869	1.70916205	0.00047122	-3.417852872	1.60943791

Raw Results

SFMW-26_I2

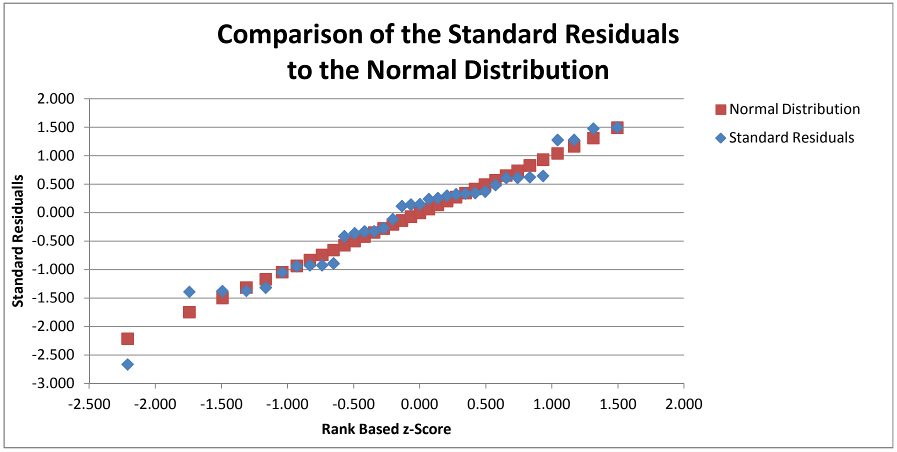




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-26_I	03-Nov-97	TCE	22	=	0.5	µg/L	1997.84	3.09
SFMW-26_I	01-Aug-99	TCE	23	=	0.5	µg/L	1999.58	3.14
SFMW-26_I	01-May-00	TCE	23	=	0.5	µg/L	2000.33	3.14
SFMW-26_I	01-Mar-02	TCE	22	=	0.5	µg/L	2002.17	3.09
SFMW-26_I	08-Nov-04	TCE	16	=	0.5	µg/L	2004.86	2.77
SFMW-26_I	08-Nov-04	TCE	20	=	0.5	µg/L	2004.86	3.00
SFMW-26_I	08-Nov-04	TCE	19	=	0.5	µg/L	2004.86	2.94
SFMW-26_I	18-Apr-05	TCE	20	=	0.5	µg/L	2005.30	3.00
SFMW-26_I	18-Apr-05	TCE	15	=	0.5	µg/L	2005.30	2.71
SFMW-26_I	18-Apr-05	TCE	20	=	0.5	µg/L	2005.30	3.00
SFMW-26_I	11-Jul-05	TCE	17	=	0.5	µg/L	2005.53	2.83
SFMW-26_I	11-Jul-05	TCE	13	=	0.5	µg/L	2005.53	2.56
SFMW-26_I	11-Jul-05	TCE	18	=	0.5	µg/L	2005.53	2.89
SFMW-26_I	06-Feb-06	TCE	12	=	0.5	µg/L	2006.10	2.48
SFMW-26_I	06-Feb-06	TCE	13	=	0.5	µg/L	2006.10	2.56
SFMW-26_I	28-Aug-06	TCE	9.3	=	0.5	µg/L	2006.66	2.23
SFMW-26_I	28-Aug-06	TCE	9.1	=	0.5	µg/L	2006.66	2.21
SFMW-26_I	19-Feb-07	TCE	10.2	=	0.5	µg/L	2007.14	2.32
SFMW-26_I	19-Feb-07	TCE	9.7	=	0.5	µg/L	2007.14	2.27
SFMW-26_I	01-Oct-07	TCE	8.2	=	0.5	µg/L	2007.75	2.10
SFMW-26_I	01-Oct-07	TCE	9.3	=	0.5	µg/L	2007.75	2.23
SFMW-26_I	14-Apr-08	TCE	5.5	=	0.5	µg/L	2008.29	1.70
SFMW-26_I	14-Apr-08	TCE	8.4	=	0.5	µg/L	2008.29	2.13
SFMW-26_I	06-Oct-08	TCE	7.8	=	0.5	µg/L	2008.77	2.05
SFMW-26_I	06-Oct-08	TCE	5	=	0.5	µg/L	2008.77	1.61
SFMW-26_I	20-Apr-09	TCE	6	=	0.5	µg/L	2009.30	1.79
SFMW-26_I	20-Apr-09	TCE	7.4	=	0.5	µg/L	2009.30	2.00
SFMW-26_I	10/26/2009	TCE	4.7	=	0.5	µg/L	2009.82	1.55
SFMW-26_I	10/26/2009	TCE	6.4	=	0.5	µg/L	2009.82	1.86
SFMW-26_I	2/1/2010	TCE	4	=	0.5	µg/L	2010.09	1.39
SFMW-26_I	8/30/2010	TCE	4.1	=	0.5	µg/L	2010.66	1.41
SFMW-26_I	2/14/2011	TCE	3.8	=	0.5	µg/L	2011.12	1.34
SFMW-26_I	2/14/2011	TCE	4.5	=	0.5	µg/L	2011.12	1.50
SFMW-26_I	8/22/2011	TCE	4.6	=	0.5	µg/L	2011.64	1.53
SFMW-26_I	8/22/2011	TCE	5.2	=	0.5	µg/L	2011.64	1.65
SFMW-26_I	2/27/2012	TCE	3.1	=	0.5	µg/L	2012.16	1.13
SFMW-26_I	2/27/2012	TCE	3.7	=	0.5	µg/L	2012.16	1.31

Regression Analysis

SFMW-26_I2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.91127453
R Square	0.83042127
Adjusted R Square	0.825576163
Standard Error	0.262144977
Observations	37

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	11.77818067	11.77818067	171.3938089	4.77296E-15
Residual	35	2.405199617	0.068719989		
Total	36	14.18338028			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	335.5996182	25.46413298	13.17930669	3.92729E-15	283.9046803	387.2945561	283.9046803	387.2945561
X Variable 1	-0.166089445	0.012686577	-13.09174583	4.77296E-15	-0.191844566	-0.140334324	-0.191844566	-0.140334324

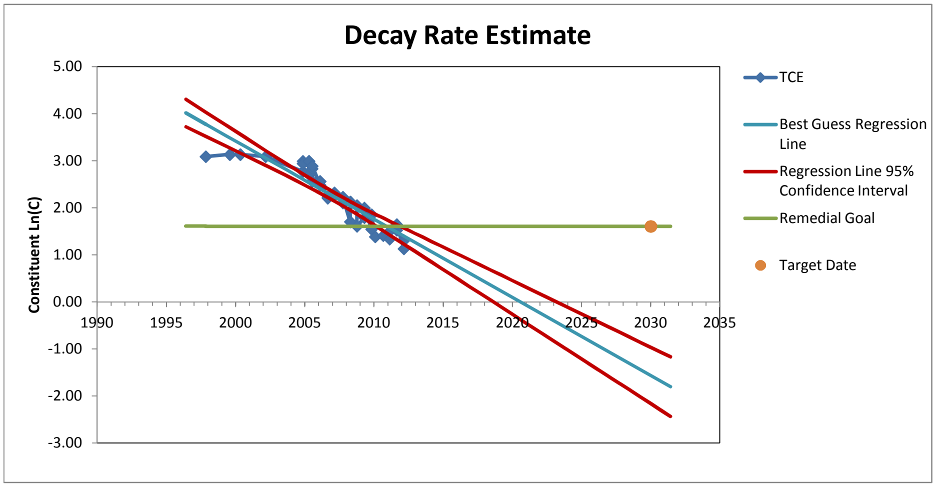
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
1	3.779053515	-0.688011062	-2.661773569	1	0.01	-2.211
30	1.745054642	-0.358760281	-1.387969882	2	0.04	-1.744
25	1.964688323	-0.35525041	-1.374390915	3	0.07	-1.494
2	3.489846432	-0.354352216	-1.370915985	4	0.09	-1.313
22	2.044265744	-0.339517651	-1.3135241	5	0.12	-1.167
36	1.401280184	-0.269878073	-1.044102865	6	0.15	-1.042
28	1.789617997	-0.242055489	-0.936462998	7	0.18	-0.932
31	1.649561737	-0.238574763	-0.922996786	8	0.20	-0.832
32	1.573167413	-0.238166346	-0.921416705	9	0.23	-0.740
3	3.365250927	-0.229756711	-0.888881554	10	0.26	-0.653
17	2.314828974	-0.10655456	-0.412237722	11	0.28	-0.572
37	1.401280184	-0.092947365	-0.359594274	12	0.31	-0.494
16	2.314828974	-0.084814574	-0.328130176	13	0.34	-0.418
26	1.875561612	-0.083802142	-0.324213287	14	0.36	-0.345
33	1.573167413	-0.069090016	-0.26729509	15	0.39	-0.274
20	2.133392455	-0.0292583	-0.113194359	16	0.42	-0.205
4	3.061037816	0.030004637	0.116081782	17	0.45	-0.136
19	2.235251553	0.036874332	0.142659222	18	0.47	-0.068
34	1.487223799	0.038832505	0.15023499	19	0.50	0.000
12	2.502631687	0.062317671	0.241094276	20	0.53	0.068
29	1.789617997	0.066679993	0.257971206	21	0.55	0.136
14	2.407138782	0.077767868	0.300867917	22	0.58	0.205
23	2.044265744	0.083965962	0.324847072	23	0.61	0.274
18	2.235251553	0.087136167	0.337111944	24	0.64	0.345
24	1.964688323	0.089435411	0.346007246	25	0.66	0.418
21	2.133392455	0.096621945	0.373810473	26	0.69	0.494
27	1.875561612	0.125918389	0.487152398	27	0.72	0.572
15	2.407138782	0.157810575	0.610536722	28	0.74	0.653

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-26_I2



Decay Rate Estimate Results

	Rate Ln(µg/L)/year		*Constituent Concentration (Most Recent)*			Remdial Goal	*Date constituent decays below goal*	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	*µg/L*	*Mean*	*Upper 95%*
TCE	-0.17	-0.14	2/27/2012	3	1.1	5	RG Met	RG Met

Rows of Data		37
Confidence		95%
Remedial Goal		5 µg/L
Remedial Goal	1.609438	Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.16608945
Intercept	b	335.599618
Observations	n	37
Std error in estimate	SYX	0.26214498
Average X	XAVE	2007.17
Average Y	YAVE	2.23
SSX	SSX	426.966836
t(α,δf)	t	2.03010792
Minimum X	Xmin	1997.84
Maximum X	Xmax	2012.16
Range X	Xrange	14.32
Extend plot beyond		10%

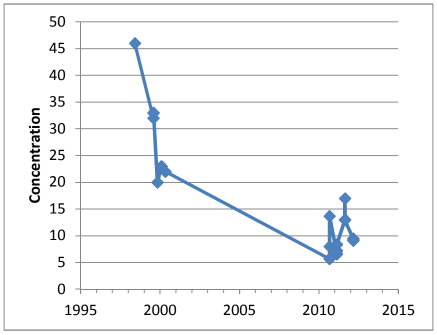
Date constituent decays below goal	
Mean	*Upper 95%*
2010.90551	2011.591376

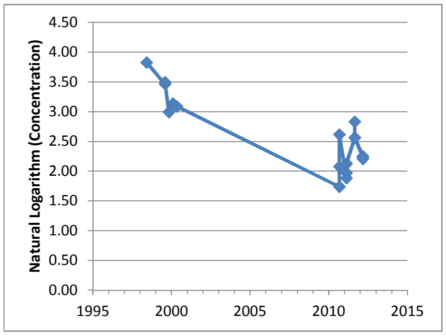
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1996	4.016831	0.2905441	4.30737495	3.726286748	1.60943791
1	1998	3.775732	0.25514122	4.03087295	3.520590505	1.60943791
2	1999	3.534633	0.22039452	3.75502712	3.314238087	1.60943791
3	2001	3.293533	0.18667077	3.48020425	3.106862717	1.60943791
4	2002	3.052434	0.15464067	3.20707503	2.897793688	1.60943791
5	2004	2.811335	0.12560666	2.93694189	2.685728583	1.60943791
6	2005	2.570236	0.10215605	2.67239216	2.468080071	1.60943791
7	2007	2.329137	0.08882688	2.41796387	2.240310113	1.60943791
8	2008	2.088038	0.09022252	2.17826039	1.997815352	1.60943791
9	2009	1.846939	0.10576163	1.95270038	1.741177117	1.60943791
10	2031	-1.80042	0.63110288	-1.16931214	-2.431517908	1.60943791

Raw Results

SFMW-27_I2

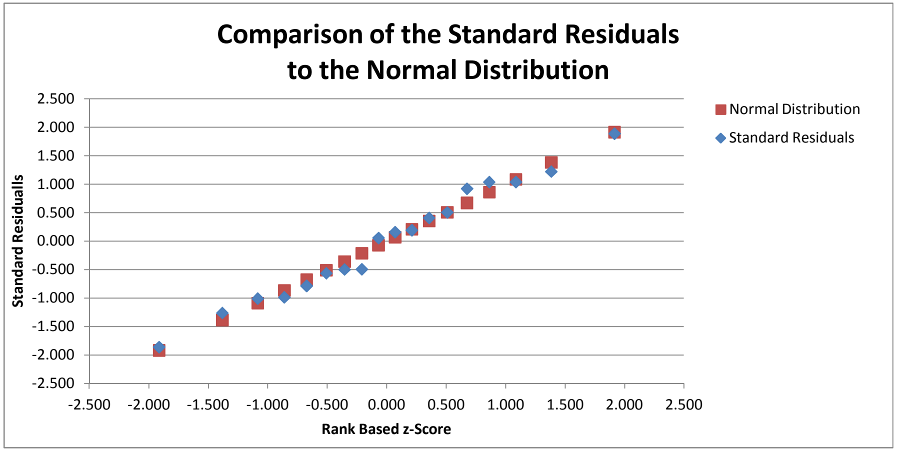




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-27_I	01-Jun-98	TCE	46	=	0.5	µg/L	1998.42	3.83
SFMW-27_I	01-Aug-99	TCE	32	=	0.5	µg/L	1999.58	3.47
SFMW-27_I	01-Aug-99	TCE	33	=	0.5	µg/L	1999.58	3.50
SFMW-27_I	01-Nov-99	TCE	20	=	0.5	µg/L	1999.84	3.00
SFMW-27_I	01-Feb-00	TCE	23	=	0.5	µg/L	2000.09	3.14
SFMW-27_I	01-May-00	TCE	22	=	0.5	µg/L	2000.33	3.09
SFMW-27_I	30-Aug-10	TCE	5.7	=	0.5	µg/L	2010.66	1.74
SFMW-27_I	30-Aug-10	TCE	8	=	0.5	µg/L	2010.66	2.08
SFMW-27_I	30-Aug-10	TCE	13.7	=	0.5	µg/L	2010.66	2.62
SFMW-27_I	14-Feb-11	TCE	6.6	=	0.5	µg/L	2011.12	1.89
SFMW-27_I	14-Feb-11	TCE	7.2	=	0.5	µg/L	2011.12	1.97
SFMW-27_I	14-Feb-11	TCE	8.4	=	0.5	µg/L	2011.12	2.13
SFMW-27_I	22-Aug-11	TCE	13	=	0.5	µg/L	2011.64	2.56
SFMW-27_I	22-Aug-11	TCE	17	=	0.5	µg/L	2011.64	2.83
SFMW-27_I	22-Aug-11	TCE	13	=	0.5	µg/L	2011.64	2.56
SFMW-27_I	27-Feb-12	TCE	9.5	=	0.5	µg/L	2012.16	2.25
SFMW-27_I	27-Feb-12	TCE	9.4	=	0.5	µg/L	2012.16	2.24
SFMW-27_I	27-Feb-12	TCE	9.1	=	0.5	µg/L	2012.16	2.21

Regression Analysis

SFMW-27_I2



Comparison of the Standard Residuals to the Normal Distribution

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.856152469
R Square	0.73299705
Adjusted R Square	0.716309366
Standard Error	0.325162005
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.644144606	4.644144606	43.92443152	5.81099E-06
Residual	16	1.691685268	0.105730329		
Total	17	6.335829874			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	185.6199407	27.61258287	6.72229547	4.90092E-06	127.0838804	244.1560011	127.0838804	244.1560011
X Variable 1	-0.091160691	0.013754808	-6.627550944	5.81099E-06	-0.120319582	-0.062001801	-0.120319582	-0.062001801

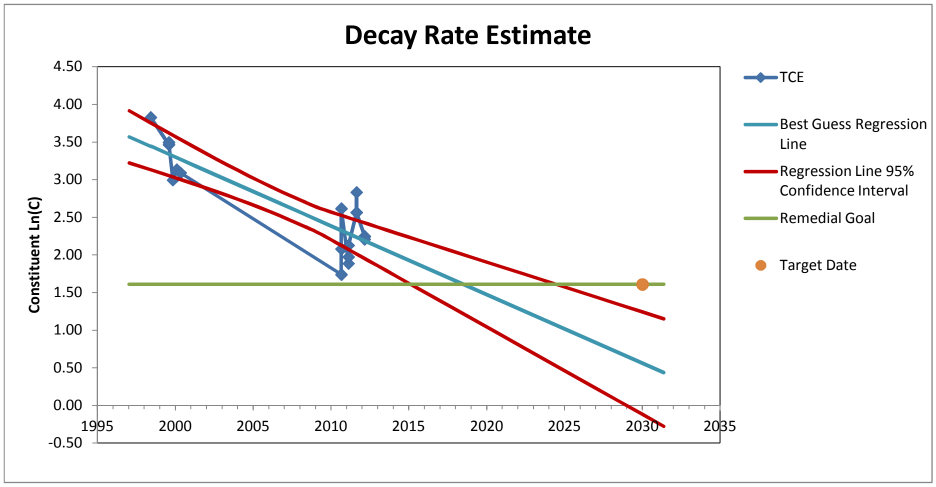
RESIDUAL OUTPUT

				Normal Distribution		
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
7	2.326426836	-0.585960661	-1.857518456	1	0.03	-1.915
10	2.284496662	-0.397427013	-1.259859339	2	0.08	-1.383
4	3.313533022	-0.317800749	-1.007440934	3	0.14	-1.085
11	2.284496662	-0.310415636	-0.984029835	4	0.19	-0.862
8	2.326426836	-0.246985294	-0.782953145	5	0.25	-0.674
6	3.268108667	-0.177066213	-0.561306895	6	0.31	-0.508
12	2.284496662	-0.156264956	-0.495366087	7	0.36	-0.355
5	3.29057126	-0.155077044	-0.491600359	8	0.42	-0.210
18	2.19015377	0.018120644	0.057443157	9	0.47	-0.070
17	2.19015377	0.05055592	0.160264263	10	0.53	0.070
16	2.19015377	0.061138029	0.193809968	11	0.58	0.210
2	3.336494784	0.129241119	0.409699454	12	0.64	0.355
3	3.336494784	0.160012777	0.507246828	13	0.69	0.508
9	2.326426836	0.290968997	0.92238322	14	0.75	0.674
13	2.237325216	0.327624142	1.038581478	15	0.81	0.862
15	2.237325216	0.327624142	1.038581478	16	0.86	1.085
1	3.442817726	0.38582367	1.223076284	17	0.92	1.383
14	2.237325216	0.595888128	1.888988919	18	0.97	1.915

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-27_I2



Decay Rate Estimate Results

			Constituent Concentration			Remdial	*Date constituent decays*	
	Rate Ln(µg/L)/year		*(Most Recent)*			Goal	*below goal*	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	*µg/L*	*Mean*	*Upper 95%*
TCE	-0.09	-0.06	2/27/2012	10	2.3	5	7/11/2018	9/21/2023

Rows of Data	18	
Confidence	95%	
Remedial Goal	5	µg/L
Remedial Goal	1.609438	Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.09116069
Intercept	b	185.619941
Observations	n	18
Std error in estimate	SYX	0.325162
Average X	XAVE	2007.48
Average Y	YAVE	2.62
SSX	SSX	558.843898
t(α,δf)	t	2.11990529
Minimum X	Xmin	1998.42
Maximum X	Xmax	2012.16
Range X	Xrange	13.74
Extend plot beyond		10%

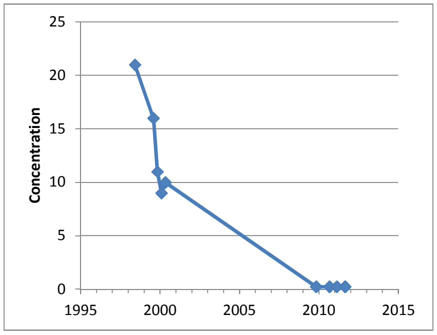
Date constituent decays below goal	
Mean	*Upper 95%*
2018.52904	2023.726181

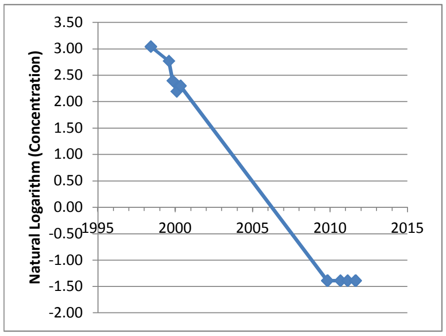
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1997	3.568084	0.34492723	3.91301135	3.223156894	1.60943791
1	1998	3.440995	0.30966078	3.75065529	3.131333733	1.60943791
2	2000	3.313905	0.27588013	3.58978503	3.038024774	1.60943791
3	2001	3.186815	0.24420265	3.43101794	2.942612645	1.60943791
4	2003	3.059726	0.21555756	3.27528325	2.844168122	1.60943791
5	2004	2.932636	0.19131187	3.12394795	2.741324202	1.60943791
6	2005	2.805546	0.17332179	2.97886826	2.632224672	1.60943791
7	2007	2.678457	0.16366336	2.84212022	2.514793494	1.60943791
8	2008	2.551367	0.16381694	2.71518418	2.387550309	1.60943791
9	2010	2.424278	0.1737565	2.59803414	2.250521132	1.60943791
10	2031	0.438096	0.71558888	1.15368533	-0.277492434	1.60943791

Raw Results

SFMW-28_I2

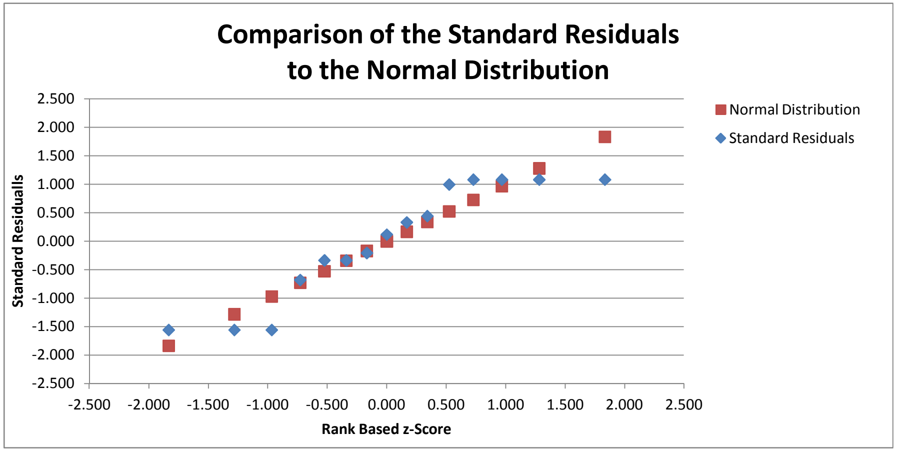




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-28_I	01-Jun-98	TCE	21	=	0.5	µg/L	1998.42	3.04
SFMW-28_I	01-Aug-99	TCE	16	=	0.5	µg/L	1999.58	2.77
SFMW-28_I	01-Nov-99	TCE	11	=	0.5	µg/L	1999.84	2.40
SFMW-28_I	01-Feb-00	TCE	9	=	0.5	µg/L	2000.09	2.20
SFMW-28_I	01-May-00	TCE	10	=	0.5	µg/L	2000.33	2.30
SFMW-28_I	26-Oct-09	TCE	0.25	ND	0.5	µg/L	2009.82	-1.39
SFMW-28_I	26-Oct-09	TCE	0.25	ND	0.5	µg/L	2009.82	-1.39
SFMW-28_I	26-Oct-09	TCE	0.25	ND	0.5	µg/L	2009.82	-1.39
SFMW-28_I	30-Aug-10	TCE	0.25	ND	0.5	µg/L	2010.66	-1.39
SFMW-28_I	30-Aug-10	TCE	0.25	ND	0.5	µg/L	2010.66	-1.39
SFMW-28_I	14-Feb-11	TCE	0.25	ND	0.5	µg/L	2011.12	-1.39
SFMW-28_I	22-Aug-11	TCE	0.25	ND	0.5	µg/L	2011.64	-1.39
SFMW-28_I	22-Aug-11	TCE	0.25	ND	0.5	µg/L	2011.64	-1.39
SFMW-28_I	22-Aug-11	TCE	0.25	ND	0.5	µg/L	2011.64	-1.39
SFMW-28_I	22-Aug-11	TCE	0.25	ND	0.5	µg/L	2011.64	-1.39

Regression Analysis

SFMW-28_I2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.992268787
R Square	0.984597347
Adjusted R Square	0.983412527
Standard Error	0.248134175
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	51.16578417	51.16578417	831.010417	3.62172E-13
Residual	13	0.800417396	0.061570569		
Total	14	51.96620156			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	695.6081944	24.1329699	28.82397803	3.62699E-13	643.4720828	747.7443061	643.4720828	747.7443061
X Variable 1	-0.346609158	0.012023663	-28.82725129	3.62172E-13	-0.372584702	-0.320633613	-0.372584702	-0.320633613

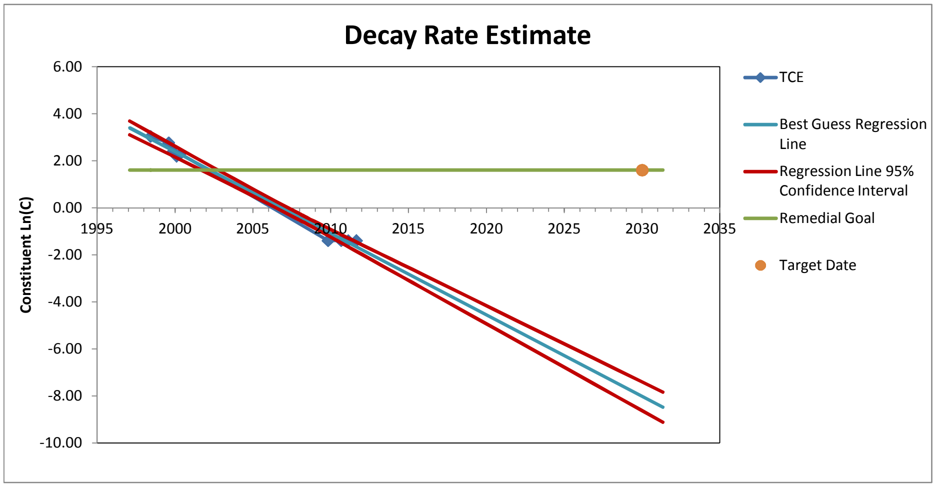
RESIDUAL OUTPUT

				Normal Distribution		
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
6	-1.014055155	-0.372239206	-1.556782253	1	0.03	-1.834
7	-1.014055155	-0.372239206	-1.556782253	2	0.10	-1.282
8	-1.014055155	-0.372239206	-1.556782253	3	0.17	-0.967
4	2.359512416	-0.162287839	-0.678721701	4	0.23	-0.728
9	-1.306336114	-0.079958247	-0.334402119	5	0.30	-0.524
10	-1.306336114	-0.079958247	-0.334402119	6	0.37	-0.341
3	2.446817118	-0.048921846	-0.204601395	7	0.43	-0.168
5	2.274105642	0.028479451	0.119107023	8	0.50	0.000
11	-1.465762092	0.079467731	0.332350681	9	0.57	0.168
1	2.938380551	0.106141887	0.443907582	10	0.63	0.341
2	2.534121821	0.238466902	0.997318482	11	0.70	0.524
12	-1.645116318	0.258821957	1.082447581	12	0.77	0.728
13	-1.645116318	0.258821957	1.082447581	13	0.83	0.967
14	-1.645116318	0.258821957	1.082447581	14	0.90	1.282
15	-1.645116318	0.258821957	1.082447581	15	0.97	1.834

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-28_I2



Decay Rate Estimate Results

	Rate Ln(µg/L)/year		Constituent Concentration (Most Recent)			Remdial Goal	Date constituent decays below goal	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	µg/L	*Mean*	*Upper 95%*
TCE	-0.35	-0.32	8/22/2011	0	-1.4	5	RG Met	RG Met

Rows of Data	15	
Confidence	95%	
Remedial Goal	5	µg/L
Remedial Goal	1.609438	Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.34660916
Intercept	b	695.608194
Observations	n	15
Std error in estimate	SYX	0.24813418
Average X	XAVE	2007.12
Average Y	YAVE	-0.08
SSX	SSX	425.892085
t(α,δf)	t	2.16036865
Minimum X	Xmin	1998.42
Maximum X	Xmax	2011.64
Range X	Xrange	13.22
Extend plot beyond		10%

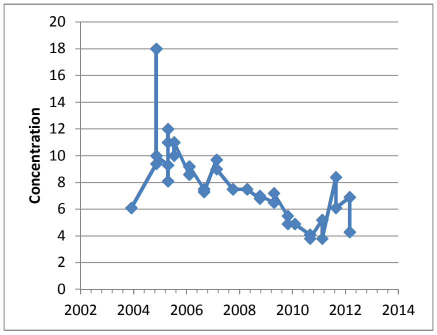
Date constituent decays below goal	
Mean	*Upper 95%*
2002.25165	2001.857582

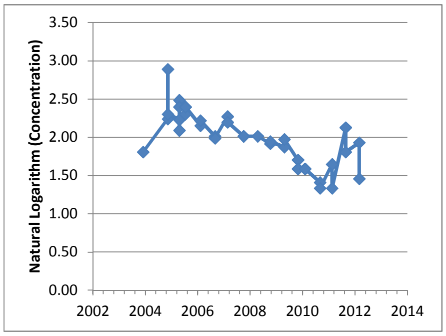
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	1997	3.39673	0.29480534	3.69153558	3.101924896	1.60943791
1	1998	2.931448	0.26452531	3.19597367	2.666923062	1.60943791
2	2000	2.466166	0.23551814	2.70168464	2.230648358	1.60943791
3	2001	2.000885	0.20831625	2.20920088	1.792568378	1.60943791
4	2002	1.535603	0.18372325	1.71932601	1.351879505	1.60943791
5	2004	1.070321	0.16292488	1.23324577	0.907396009	1.60943791
6	2005	0.605039	0.14753477	0.75257378	0.457504252	1.60943791
7	2006	0.139757	0.1393564	0.27911355	0.000400746	1.60943791
8	2008	-0.32552	0.1396625	-0.18586222	-0.465187226	1.60943791
9	2009	-0.79081	0.14840058	-0.64240601	-0.939207171	1.60943791
10	2031	-8.46817	0.64393554	-7.82423305	-9.112104133	1.60943791

Raw Results

MNW-5_D1

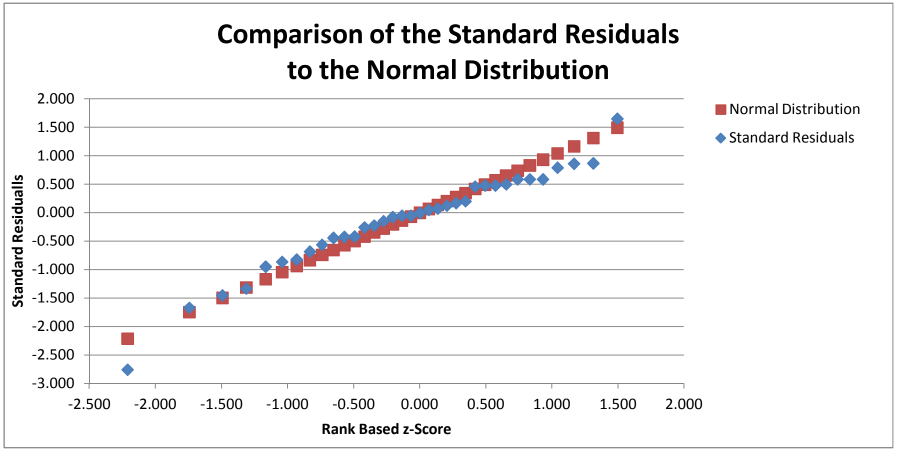




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
MNW-5_D1	30-Nov-03	TCE	6.1	=	0.5	µg/L	2003.92	1.81
MNW-5_D1	08-Nov-04	TCE	9.4	=	0.5	µg/L	2004.86	2.24
MNW-5_D1	08-Nov-04	TCE	18	=	0.5	µg/L	2004.86	2.89
MNW-5_D1	08-Nov-04	TCE	10	=	0.5	µg/L	2004.86	2.30
MNW-5_D1	18-Apr-05	TCE	9.3	=	0.5	µg/L	2005.30	2.23
MNW-5_D1	18-Apr-05	TCE	8.1	=	0.5	µg/L	2005.30	2.09
MNW-5_D1	18-Apr-05	TCE	11	=	0.5	µg/L	2005.30	2.40
MNW-5_D1	18-Apr-05	TCE	12	=	0.5	µg/L	2005.30	2.48
MNW-5_D1	18-Apr-05	TCE	11	=	0.5	µg/L	2005.30	2.40
MNW-5_D1	11-Jul-05	TCE	11	=	0.5	µg/L	2005.53	2.40
MNW-5_D1	11-Jul-05	TCE	10	=	0.5	µg/L	2005.53	2.30
MNW-5_D1	11-Jul-05	TCE	11	=	0.5	µg/L	2005.53	2.40
MNW-5_D1	11-Jul-05	TCE	11	=	0.5	µg/L	2005.53	2.40
MNW-5_D1	06-Feb-06	TCE	8.6	=	0.5	µg/L	2006.10	2.15
MNW-5_D1	06-Feb-06	TCE	9.2	=	0.5	µg/L	2006.10	2.22
MNW-5_D1	28-Aug-06	TCE	7.5	=	0.5	µg/L	2006.66	2.01
MNW-5_D1	28-Aug-06	TCE	7.3	=	0.5	µg/L	2006.66	1.99
MNW-5_D1	19-Feb-07	TCE	9.7	=	0.5	µg/L	2007.14	2.27
MNW-5_D1	19-Feb-07	TCE	9	=	0.5	µg/L	2007.14	2.20
MNW-5_D1	01-Oct-07	TCE	7.5	=	0.5	µg/L	2007.75	2.01
MNW-5_D1	01-Oct-07	TCE	7.5	=	0.5	µg/L	2007.75	2.01
MNW-5_D1	14-Apr-08	TCE	7.5	=	0.5	µg/L	2008.29	2.01
MNW-5_D1	06-Oct-08	TCE	6.8	=	0.5	µg/L	2008.77	1.92
MNW-5_D1	06-Oct-08	TCE	7	=	0.5	µg/L	2008.77	1.95
MNW-5_D1	20-Apr-09	TCE	6.5	=	0.5	µg/L	2009.30	1.87
MNW-5_D1	20-Apr-09	TCE	7.2	=	0.5	µg/L	2009.30	1.97
MNW-5_D1	26-Oct-09	TCE	5.5	=	0.5	µg/L	2009.82	1.70
MNW-5_D1	10/26/2009	TCE	4.9	=	0.5	µg/L	2009.82	1.59
MNW-5_D1	2/1/2010	TCE	4.9	=	0.5	µg/L	2010.09	1.59
MNW-5_D1	8/30/2010	TCE	4.1	=	0.5	µg/L	2010.66	1.41
MNW-5_D1	8/30/2010	TCE	3.8	=	0.5	µg/L	2010.66	1.34
MNW-5_D1	2/14/2011	TCE	5.2	=	0.5	µg/L	2011.12	1.65
MNW-5_D1	2/14/2011	TCE	3.8	=	0.5	µg/L	2011.12	1.34
MNW-5_D1	8/22/2011	TCE	8.4	=	0.5	µg/L	2011.64	2.13
MNW-5_D1	8/22/2011	TCE	6.1	=	0.5	µg/L	2011.64	1.81
MNW-5_D1	2/27/2012	TCE	6.9	=	0.5	µg/L	2012.16	1.93
MNW-5_D1	2/27/2012	TCE	4.3	=	0.5	µg/L	2012.16	1.46

Regression Analysis

MNW-5_D1



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.763052512
R Square	0.582249136
Adjusted R Square	0.570313397
Standard Error	0.231248467
Observations	37

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.608658705	2.608658705	48.78199303	4.00162E-08
Residual	35	1.871654867	0.053475853		
Total	36	4.480313572			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	216.6404042	30.72798533	7.050263851	3.29083E-08	154.2592779	279.0215304	154.2592779	279.0215304
X Variable 1	-0.106892745	0.015304476	-6.984410715	4.00162E-08	-0.137962483	-0.075823008	-0.137962483	-0.075823008

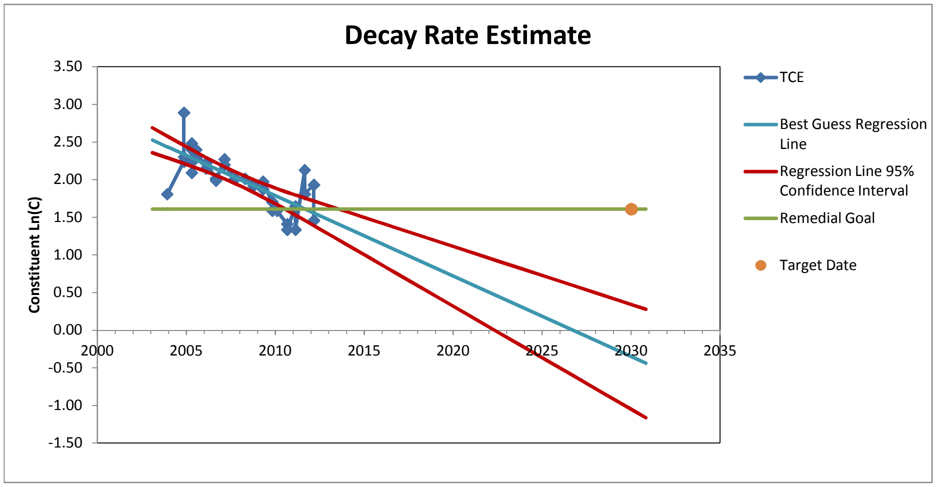
RESIDUAL OUTPUT

						Normal Distribution
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
1	2.436415167	-0.628126395	-2.754770416	1	0.01	-2.211
31	1.715017174	-0.380016107	-1.666634513	2	0.04	-1.744
33	1.665850901	-0.330849834	-1.451006265	3	0.07	-1.494
30	1.715017174	-0.3040302	-1.333383546	4	0.09	-1.313
28	1.805155341	-0.215920136	-0.94695973	5	0.12	-1.167
6	2.288623691	-0.19675963	-0.862927607	6	0.15	-1.042
29	1.776475015	-0.18723981	-0.821176586	7	0.18	-0.932
17	2.143173467	-0.155299119	-0.681094477	8	0.20	-0.832
16	2.143173467	-0.128270447	-0.56255498	9	0.23	-0.740
27	1.805155341	-0.100407249	-0.440355508	10	0.26	-0.653
37	1.555226787	-0.096611764	-0.423709672	11	0.28	-0.572
2	2.33574137	-0.09503168	-0.416779909	12	0.31	-0.494
5	2.288623691	-0.058609291	-0.257042441	13	0.34	-0.418
14	2.202582714	-0.050820511	-0.222883228	14	0.36	-0.345
4	2.33574137	-0.033156277	-0.145413297	15	0.39	-0.274
32	1.665850901	-0.017192275	-0.075400065	16	0.42	-0.205
20	2.026403569	-0.011500549	-0.050437891	17	0.45	-0.136
21	2.026403569	-0.011500549	-0.050437891	18	0.47	-0.068
23	1.91782805	-0.000905437	-0.003970972	19	0.50	0.000
25	1.860467398	0.011334779	0.049710877	20	0.53	0.068
15	2.202582714	0.01662077	0.072893619	21	0.55	0.136
24	1.91782805	0.028082099	0.123159506	22	0.58	0.205
11	2.264040555	0.038544538	0.169044565	23	0.61	0.274
22	1.969042917	0.045860103	0.201128398	24	0.64	0.345
19	2.0919586	0.105265978	0.461664409	25	0.66	0.418
7	2.288623691	0.109271581	0.479231763	26	0.69	0.494
9	2.288623691	0.109271581	0.479231763	27	0.72	0.572
26	1.860467398	0.113613628	0.498274653	28	0.74	0.653

x

Regression Analysis - Confidence Interval of the Line of Best Fit

MNW-5_D1



Decay Rate Estimate Results

Analyte	*Rate Ln(µg/L)/year* *Mean*	*Upper 95%*	*Constituent Concentration* *(Most Recent)* *Sample Date*	*µg/L*	*Ln(µg/L)*	Remdial Goal *µg/L*	*Date constituent decays below goal* *Mean*	*Upper 95%*
TCE	-0.11	-0.08	2/27/2012	7	1.9	5	8/25/2011	3/27/2013

Rows of Data	37		
Confidence	95%		
Remedial Goal	5	µg/L	
Remedial Goal	1.609438	Ln(µg/L)	
Remedial Goal Date	1/1/2030	2030.00411	
Derived Values			
Slope	m		-0.10689275
Intercept	b		216.640404
Observations	n		37
Std error in estimat	SYX		0.23124847
Average X	XAVE		2007.78

Average Y	YAVE	2.02
SSX	SSX	228.307828
t(α,δf)	t	2.03010792
Minimum X	Xmin	2003.92
Maximum X	Xmax	2012.16
Range X	Xrange	8.24
Extend plot beyond		10%

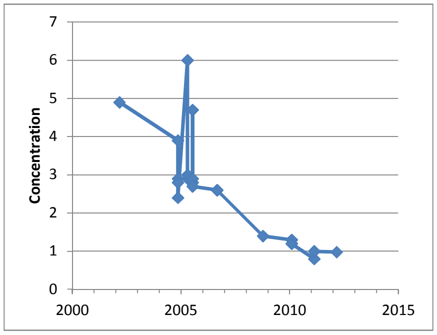
Date constituent decays below goal	
Mean	*Upper 95%*
2011.65164	2013.239683

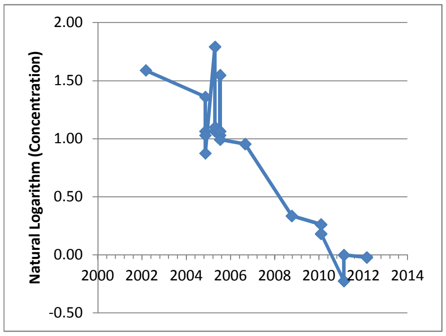
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	2003	2.524534	0.16476771	2.68930171	2.359766297	1.60943791
1	2004	2.434277	0.14212167	2.57639899	2.292155637	1.60943791
2	2005	2.344021	0.12093476	2.46495538	2.22308586	1.60943791
3	2006	2.253764	0.10211921	2.35588314	2.151644712	1.60943791
4	2006	2.163507	0.08722342	2.25073065	2.076283817	1.60943791
5	2007	2.073251	0.07851106	2.1517616	1.994739476	1.60943791
6	2008	1.982994	0.07808023	2.06107408	1.904913615	1.60943791
7	2009	1.892737	0.08605539	1.97879255	1.806681762	1.60943791
8	2010	1.80248	0.10045402	1.90293449	1.702026437	1.60943791
9	2011	1.712224	0.11896623	1.83119	1.593257538	1.60943791
10	2031	-0.44043	0.72037553	0.27994915	-1.16080191	1.60943791

Raw Results

SFMW-46_D1-D2

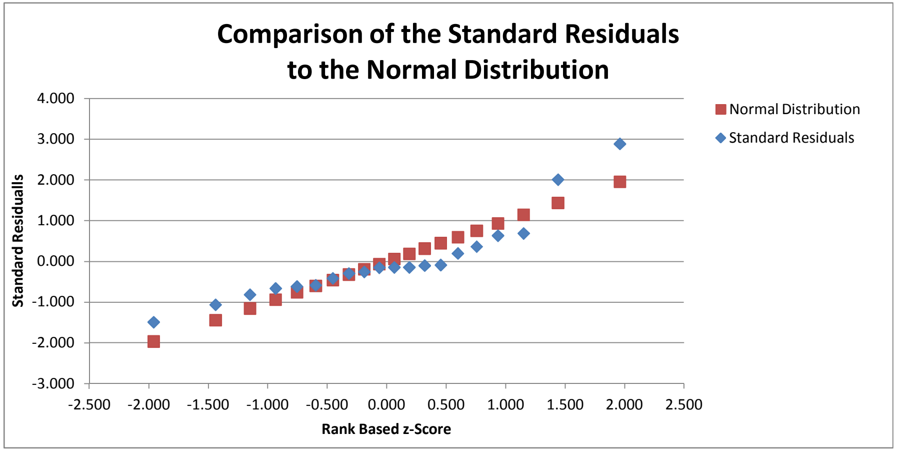




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
SFMW-46_[	01-Mar-02	TCE	4.9	=	0.5	µg/L	2002.17	1.59
SFMW-46_[	08-Nov-04	TCE	3.9	=	0.5	µg/L	2004.86	1.36
SFMW-46_[	08-Nov-04	TCE	2.9	=	0.5	µg/L	2004.86	1.06
SFMW-46_[	08-Nov-04	TCE	2.8	=	0.5	µg/L	2004.86	1.03
SFMW-46_[	08-Nov-04	TCE	2.4	=	0.5	µg/L	2004.86	0.88
SFMW-46_[	18-Apr-05	TCE	6	=	0.5	µg/L	2005.30	1.79
SFMW-46_[	18-Apr-05	TCE	3	=	0.5	µg/L	2005.30	1.10
SFMW-46_[	18-Apr-05	TCE	2.9	=	0.5	µg/L	2005.30	1.06
SFMW-46_[	18-Apr-05	TCE	3	=	0.5	µg/L	2005.30	1.10
SFMW-46_[	11-Jul-05	TCE	2.8	=	0.5	µg/L	2005.53	1.03
SFMW-46_[	11-Jul-05	TCE	2.9	=	0.5	µg/L	2005.53	1.06
SFMW-46_[	11-Jul-05	TCE	4.7	=	0.5	µg/L	2005.53	1.55
SFMW-46_[	11-Jul-05	TCE	2.7	=	0.5	µg/L	2005.53	0.99
SFMW-46_[	28-Aug-06	TCE	2.6	=	0.5	µg/L	2006.66	0.96
SFMW-46_[	06-Oct-08	TCE	1.4	=	0.5	µg/L	2008.77	0.34
SFMW-46_[	01-Feb-10	TCE	1.3	=	0.5	µg/L	2010.09	0.26
SFMW-46_[	01-Feb-10	TCE	1.2	=	0.5	µg/L	2010.09	0.18
SFMW-46_[	14-Feb-11	TCE	0.8	=	0.5	µg/L	2011.12	-0.22
SFMW-46_[	14-Feb-11	TCE	1	=	0.5	µg/L	2011.12	0.00
SFMW-46_[	27-Feb-12	TCE	0.98	=	0.5	µg/L	2012.16	-0.02

Regression Analysis

SFMW-46_D1-D2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.91679751
R Square	0.840517673
Adjusted R Square	0.831657544
Standard Error	0.234859078
Observations	20

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5.232647713	5.232647713	94.86517066	1.33776E-08
Residual	18	0.99285816	0.055158787		
Total	19	6.225505873			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	383.8535882	39.32276438	9.761612497	1.29297E-08	301.2395259	466.4676504	301.2395259	466.4676504
X Variable 1	-0.190855556	0.019595277	-9.73987529	1.33776E-08	-0.232023706	-0.149687407	-0.232023706	-0.149687407

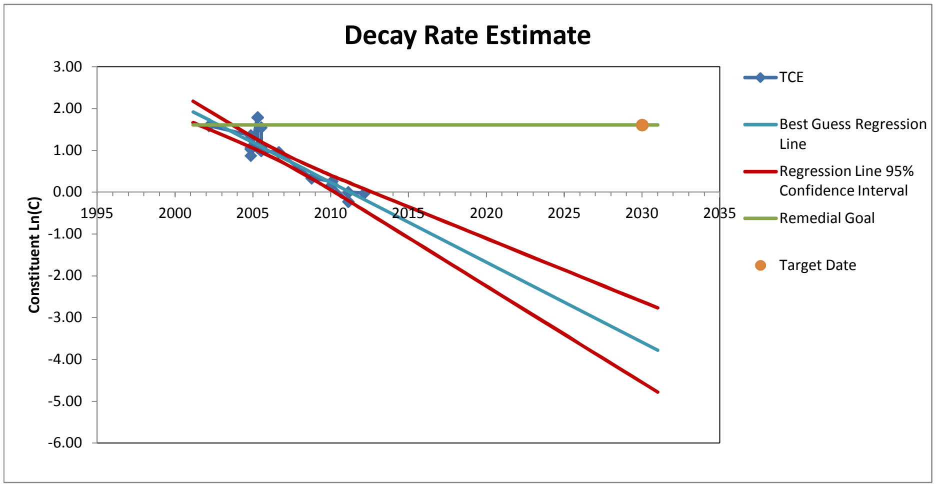
RESIDUAL OUTPUT

					Normal Distribution	
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
5	1.215500379	-0.340031642	-1.487484772	1	0.03	-1.960
18	0.019419974	-0.242563525	-1.061105807	2	0.08	-1.440
4	1.215500379	-0.185880962	-0.813145209	3	0.13	-1.150
3	1.215500379	-0.150789642	-0.659636543	4	0.18	-0.935
1	1.729151336	-0.139916131	-0.612069842	5	0.23	-0.755
15	0.469321778	-0.132849541	-0.581156707	6	0.28	-0.598
13	1.087479541	-0.094227768	-0.412203903	7	0.33	-0.454
8	1.1313724	-0.066661663	-0.29161465	8	0.38	-0.319
10	1.087479541	-0.057860124	-0.253111894	9	0.43	-0.189
17	0.216937839	-0.034616282	-0.151430591	10	0.48	-0.063
7	1.1313724	-0.032760111	-0.143310682	11	0.53	0.063
9	1.1313724	-0.032760111	-0.143310682	12	0.58	0.189
11	1.087479541	-0.022768804	-0.099603228	13	0.63	0.319
19	0.019419974	-0.019419974	-0.08495361	14	0.68	0.454
16	0.216937839	0.045426425	0.198720083	15	0.73	0.598
14	0.871672985	0.08383846	0.366755377	16	0.78	0.755
2	1.215500379	0.145476174	0.636392518	17	0.83	0.935
20	-0.178097891	0.157895184	0.690720076	18	0.88	1.150
12	1.087479541	0.460082968	2.01265507	19	0.93	1.440
6	1.1313724	0.660387069	2.888894996	20	0.98	1.960

x

Regression Analysis - Confidence Interval of the Line of Best Fit

SFMW-46_D1-D2



Decay Rate Estimate Results

	Rate Ln(µg/L)/year		Constituent Concentration (Most Recent)			Remdial Goal	Date constituent decays below goal	
Analyte	*Mean*	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*	µg/L	*Mean*	*Upper 95%*
TCE	-0.19	-0.15	2/27/2012	1	0.0	5	RG Met	RG Met

Rows of Data		20
Confidence		95%
Remedial Goal		5 µg/L
Remedial Goal		1.609438 Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411
Derived Values		
Slope	m	-0.19085556
Intercept	b	383.853588
Observations	n	20
Std error in estimate	SYX	0.23485908
Average X	XAVE	2006.75
Average Y	YAVE	0.86
SSX	SSX	143.652068
t(α,δf)	t	2.10092204
Minimum X	Xmin	2002.17
Maximum X	Xmax	2012.16
Range X	Xrange	9.99
Extend plot beyond		10%

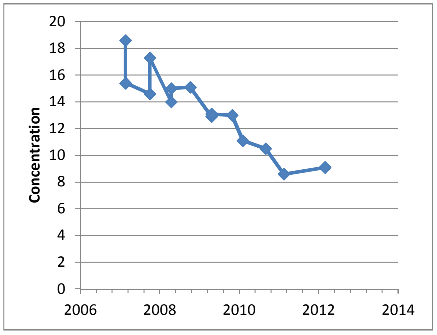
Date constituent decays below goal	
Mean	*Upper 95%*
2002.79289	2001.705879

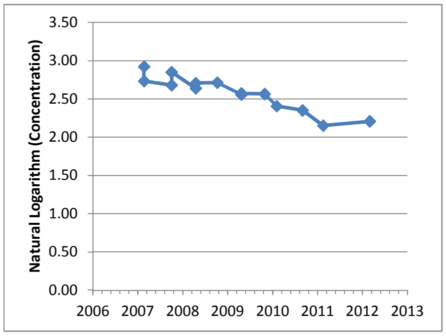
Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	2001	1.919876	0.25480037	2.17467663	1.665075889	1.60943791
1	2002	1.725334	0.21773469	1.94306892	1.507599531	1.60943791
2	2003	1.530792	0.18279882	1.71359101	1.347993373	1.60943791
3	2004	1.33625	0.15147363	1.48772379	1.184776523	1.60943791
4	2005	1.141708	0.12647118	1.2681793	1.015236945	1.60943791
5	2006	0.947166	0.11210486	1.05927095	0.835061233	1.60943791
6	2007	0.752624	0.11252503	0.86514908	0.640099029	1.60943791
7	2008	0.558082	0.12758569	0.68566771	0.430496336	1.60943791
8	2009	0.36354	0.15302345	0.51656344	0.210516539	1.60943791
9	2010	0.168998	0.18459709	0.35359505	-0.015599141	1.60943791
10	2031	-3.7747	1.00474061	-2.76995904	-4.779440263	1.60943791

Raw Results

MNW-5_D2

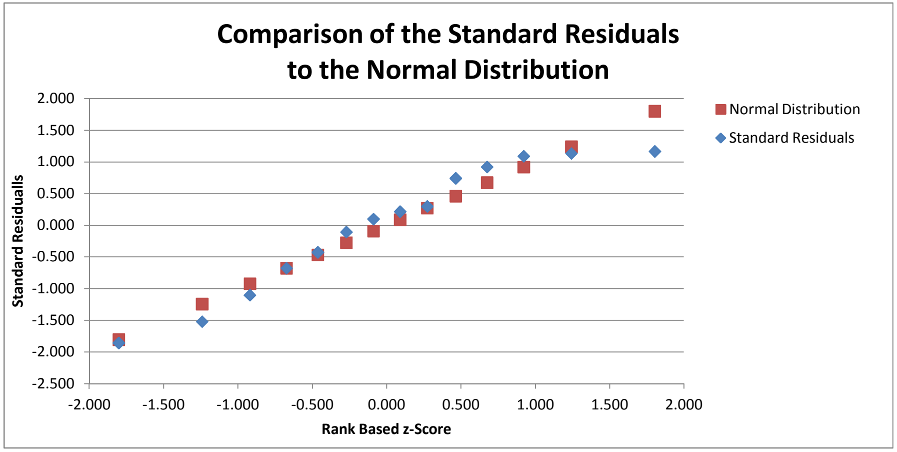




WellName	EventDate	Constituent	Result	Flags	DetLim	Units	DecDate	Value
MNW-5_D2	19-Feb-07	TCE	18.6	=	0.5	µg/L	2007.14	2.92
MNW-5_D2	19-Feb-07	TCE	15.4	=	0.5	µg/L	2007.14	2.73
MNW-5_D2	01-Oct-07	TCE	14.6	=	0.5	µg/L	2007.75	2.68
MNW-5_D2	01-Oct-07	TCE	17.3	=	0.5	µg/L	2007.75	2.85
MNW-5_D2	14-Apr-08	TCE	14	=	0.5	µg/L	2008.29	2.64
MNW-5_D2	14-Apr-08	TCE	15	=	0.5	µg/L	2008.29	2.71
MNW-5_D2	06-Oct-08	TCE	15.1	=	0.5	µg/L	2008.77	2.71
MNW-5_D2	20-Apr-09	TCE	12.9	=	0.5	µg/L	2009.30	2.56
MNW-5_D2	20-Apr-09	TCE	13.1	=	0.5	µg/L	2009.30	2.57
MNW-5_D2	26-Oct-09	TCE	13	=	0.5	µg/L	2009.82	2.56
MNW-5_D2	01-Feb-10	TCE	11.1	=	0.5	µg/L	2010.09	2.41
MNW-5_D2	30-Aug-10	TCE	10.5	=	0.5	µg/L	2010.66	2.35
MNW-5_D2	14-Feb-11	TCE	8.6	=	0.5	µg/L	2011.12	2.15
MNW-5_D2	27-Feb-12	TCE	9.1	=	0.5	µg/L	2012.16	2.21

Regression Analysis

MNW-5_D2



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.939929903
R Square	0.883468223
Adjusted R Square	0.873757242
Standard Error	0.080509314
Observations	14

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.589684984	0.589684984	90.97620389	5.95484E-07
Residual	12	0.077780997	0.00648175		
Total	13	0.66746598			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	283.0878727	29.40948608	9.625733409	5.39946E-07	219.0101072	347.1656382	219.0101072	347.1656382
X Variable 1	-0.139619756	0.014638041	-9.538144678	5.95484E-07	-0.171513308	-0.107726204	-0.171513308	-0.107726204

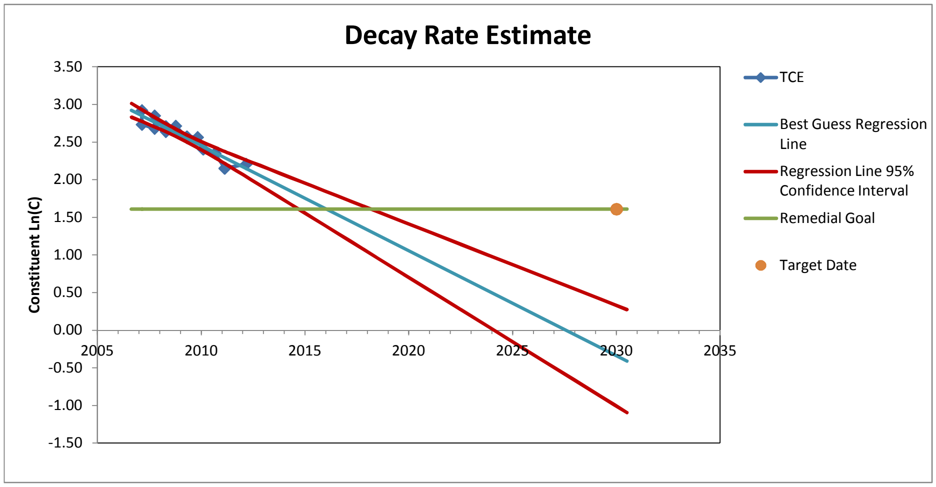
RESIDUAL OUTPUT

				Normal Distribution		
Observation	*Predicted Y*	*Residuals*	*Standard Residuals*	*Rank*	*Quantile*	*Z-Score*
13	2.295246118	-0.143483915	-1.854975349	1	0.04	-1.803
2	2.851813852	-0.117446343	-1.518358838	2	0.11	-1.242
3	2.766188047	-0.085166518	-1.101041826	3	0.18	-0.921
5	2.691265467	-0.052208138	-0.67495237	4	0.25	-0.674
11	2.439739665	-0.032794556	-0.423971519	5	0.32	-0.464
12	2.359465472	-0.008090215	-0.104591162	6	0.39	-0.272
8	2.549447727	0.007779584	0.10057529	7	0.46	-0.090
6	2.691265467	0.016784734	0.216994827	8	0.54	0.090
9	2.549447727	0.023164503	0.299473161	9	0.61	0.272
14	2.150752572	0.057521842	0.743648499	10	0.68	0.464
1	2.851813852	0.071347729	0.922391041	11	0.75	0.674
4	2.766188047	0.084518455	1.092663591	12	0.82	0.921
10	2.477200954	0.087748403	1.13442071	13	0.89	1.242
7	2.624370307	0.090324437	1.167723947	14	0.96	1.803

x

Regression Analysis - Confidence Interval of the Line of Best Fit

MNW-5_D2



Decay Rate Estimate Results

Analyte	Rate Ln(µg/L)/year		Constituent Concentration (Most Recent)			Remdial Goal µg/L	Date constituent decays below goal	
	Mean	*Upper 95%*	*Sample Date*	*µg/L*	*Ln(µg/L)*		*Mean*	*Upper 95%*
TCE	-0.14	-0.11	2/27/2012	9	2.2	5	1/13/2016	1/30/2018

Rows of Data		14	
Confidence		95%	
Remedial Goal		5	µg/L
Remedial Goal		1.609438	Ln(µg/L)
Remedial Goal Date	1/1/2030	2030.00411	
Derived Values			
Slope	m	-0.13961976	
Intercept	b	283.087873	
Observations	n	14	
Std error in estimate	SYX	0.08050931	
Average X	XAVE	2009.11	
Average Y	YAVE	2.58	
SSX	SSX	30.2500655	
t(α,δf)	t	2.17881283	
Minimum X	Xmin	2007.14	
Maximum X	Xmax	2012.16	
Range X	Xrange	5.02	
Extend plot beyond		10%	

Date constituent decays below goal	
Mean	*Upper 95%*
2016.03586	2018.085468

Regression Line 95% Confidence Interval

	X	Ymean	CI	Y+CI	Y-CI	Remedial Goal
0	2007	2.92192	0.09187686	3.01379684	2.83004312	1.60943791
1	2007	2.849021	0.07801967	2.92704112	2.771001789	1.60943791
2	2008	2.776123	0.06547808	2.84160102	2.710644852	1.60943791
3	2008	2.703224	0.05515695	2.75838136	2.648067458	1.60943791
4	2009	2.630326	0.04849535	2.67882124	2.581830536	1.60943791
5	2009	2.557427	0.04707344	2.6045008	2.510353929	1.60943791
6	2010	2.484529	0.05132852	2.53585736	2.43320032	1.60943791
7	2010	2.41163	0.06006601	2.47169633	2.35156431	1.60943791
8	2011	2.338732	0.07166473	2.41039652	2.267067068	1.60943791
9	2011	2.265833	0.08496082	2.35079409	2.180872455	1.60943791
10	2031	-0.41091	0.68391681	0.27300523	-1.094828394	1.60943791

Appendix J
Groundwater Flow and TCE Fate and Transport Modeling

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Fruit Avenue Plume Superfund Site Long-Term Remedial Action

Appendix J – Groundwater Flow and TCE Fate and Transport Modeling

PREPARED FOR: Bartolomé Cañellas /EPA Region 6 Remedial Project Manager
PREPARED BY: CH2M HILL
DATE: August, 2013
PROJECT: EPA Region 6 Remedial Action Contract W-EP-06-021
Task Order No. 0003-RALR-06DD
CH2M HILL Project No. 345406.PJ.14
DCN: 0003-02102

Preface

This memorandum discusses the use of the Fruit Avenue Plume (FAP) Superfund Site numerical flow and transport models (RD Model) to examine changes in plume concentrations and location under a number of different scenarios. This analysis was completed to examine the long-term potential for trichloroethene (TCE) concentrations above 5 µg/L (micrograms per liter) to move beyond the current groundwater use restriction boundary to active water supply well locations. The outcome of the model simulations will be used with other information to guide decisions on the need for further active remedial action at the site.

The following sections present a brief background of model development, methods used in this analysis, and results. Animations of plume movement that were completed as part of this analysis are included as a DVD attachment (**Attachment 1**) to this memorandum.

1. Model Development Background

1.1 Flow Model Development

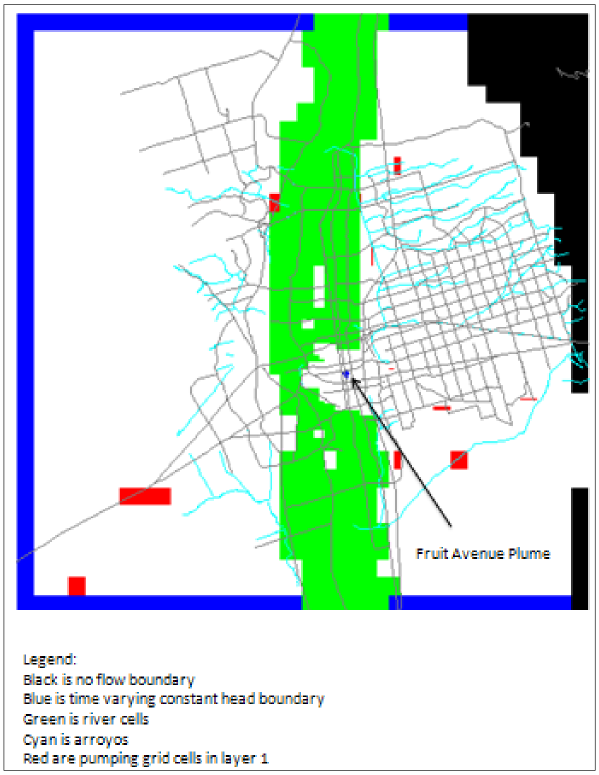
As documented in the *25% Design Deliverable Report Fruit Avenue Plume (FAP) Superfund Site* (EPA, 2002), the FAP Remedial Design (RD) groundwater flow model was developed using a Telescoping Mesh Refinement (TMR) procedure from the MODFLOW (McDonald and Harbaugh, 1998) New Mexico Office of the State Engineer Middle Rio Grande Administrative Area Model (OSE model). The OSE model is a 113-row by 60-column by 6-layer transient groundwater flow model covering the Middle Rio Grande Basin, which extends from Cochiti Lake in the north to San Acacia in the south. The minimum model grid cell size is 2,461 feet by 2,461 feet.

After an initial long stress period that simulates basin predevelopment, the model has 31 stress periods that cover the 1901 through 2000 period. The top three layers of the model are represented as unconfined while the bottom three layers of the model are represented as confined. The confined model layers in the OSE model are each 1-foot thick with the true model layer thicknesses and hydraulic conductivities combined into layer transmissivities. The OSE model has a no-flow boundary on all sides except for very limited areas of basin inflow from the north, basin outflow to the south, and basin inflow from the east. The relatively coarse horizontal and vertical discretization, and the lack of true model layer thicknesses in the bottom three layers, made the OSE model unsuitable for FAP contaminant transport modeling. The following paragraphs describe the modifications made to the OSE model to make it useful for contaminant transport modeling.

The OSE model was imported into Ground Water VISTAS (Rumbaugh, J.O., and D.B. Rumbaugh, 1998). A transient simulation was run with the OSE model using the existing pumping rates to generate the simulated heads corresponding to the year 1993. The OSE model is populated with most of the known wells located in the Middle Rio Grande Basin. These simulated water levels were used as the starting heads for all other simulations using the OSE and FAP RD groundwater flow models for the period between 1993 and 2060.

The FAP RD model is a 137-row by 151-column by 9-layer transient groundwater flow model that extends from Bernalillo in the north to the Isleta Indian Reservation in the south. The model grid and boundary conditions are shown in **Figure 1-1**. The minimum model grid cell size is 50 feet by 42 feet. The FAP RD model was refined from the OSE model with additional layers to better represent the hydrostratigraphic layering observed in the monitor well boreholes drilled at the site. The top six model layers are unconfined and the bottom three model layers are confined with true model layer thicknesses. Vertically, the model extends from elevations of approximately 4,955 to 3,347 ft above mean sea level (amsl) near the Fruit Avenue TCE plume. The FAP RD model has a time-varying head boundary along the northern, western, and southern sides of the model grid and a no-flow boundary along the eastern side of the model grid. The no-flow boundary along the eastern side of the model, which is also present in the OSE model, corresponds to the Sandia and Manzano mountain fronts. The head values assigned to these boundary cells are based on transient simulation output from the OSE groundwater flow model. The purpose of the peripheral time-varying head boundary cells is to couple the detailed flow simulation of the FAP RD plume-scale model with regional hydrology and hydrogeology, as represented in the OSE model. Another refinement made to the FAP RD model was to include a fault in the model that was not represented in the OSE model. Site water level information indicated the presence of a fault or other anomaly near the Burlington Northern Santa Fe railroad tracks running generally in a north-south direction. This anomaly was represented in the FAP RD model as a zone of lower permeability to better simulate site water levels.

FIGURE 1-1
FAP RD Model Grid
Fruit Avenue Plume Superfund Site, Albuquerque, NM



The FAP RD groundwater flow model was developed in Ground Water VISTAS. All the refinements made to OSE model to develop the FAP RD model (described previously), and any changes made to other aquifer properties during the calibration of the FAP RD model, are documented in the *25% Design Deliverable Report Fruit Avenue Plume (FAP) Superfund Site* (EPA, 2002).

1.2 Contaminant Transport Model Development

To provide an estimate of future TCE plume behavior and concentration trends, a contaminant transport model is required. A MT3DMS (Zheng and Wang, 1999) numerical contaminant transport model was developed as part of the Remedial Investigation (RI) to aid in examining potential groundwater remedial action options. CH2M HILL evaluated this coupled MODFLOW-MT3DMS model in the *25% Design Deliverable Report Fruit Avenue Plume (FAP) Superfund Site* (EPA, 2002) to determine its usefulness with respect to remedial design. It was determined that the model needed to be calibrated for effective transport porosity, dispersivity, and retardation to historical site data.

A data evaluation conducted in 2002 suggested that sufficient data to define a model starting condition was available only after year 2000. Attempts to define initial concentrations prior to 2000 were going to require extensive speculation resulting in uncertainty, particularly in the deep aquifer zones. As such, with the more recently collected 2002 sample data, only a 2-year period was available for calibration. Given the sparse data set, limited calibration was performed on the FAP RD contaminant transport model in 2002 and the following contaminant transport parameters were chosen:

<u>Dispersion Parameters - 2002</u>

- Longitudinal Dispersivity (ft) = 450
- Transverse Dispersivity (ft) = 2.5
- Vertical Dispersivity (ft) = 0

<u>Soil Parameters - 2002</u>

- Effective Porosity (dimensionless) = 0.2
- Bulk Density (µg/L) = $1.93\text{x}10^{9}$

<u>Chemical-Specific Transport Parameters for TCE - 2002</u>

- Soil/Water Partition Coefficient K_d (L/µg) = $3.44\text{x}10^{-11}$
- Degradation Rate (years^{-1}) = 0.20
- Calculated Retardation Coefficient (dimensionless) = 1.33
- Calculated Degradation Half-Life (years) = 3.47

1.3 Current Model

For the purpose of this analysis, the FAP RD flow and contaminant transport models were converted from MODFLOW and MT3DMS to a MODFLOW-SURFACT (HydroGeoLogic, Inc. 1996) model. MODFLOW-SURFACT is a fully integrated flow and transport code, based on the U.S. Geological Survey's (USGS) groundwater flow model MODFLOW. MODFLOW-SURFACT adds additional modules to MODFLOW to improve its robustness and increase its physical simulation capabilities to include complex saturated-unsaturated subsurface flow analysis, and contaminant fate and transport calculations. The conversion from a coupled MODFLOW-MT3DMS model to a MODFLOW-SURFACT model was made largely to allow for the use of a number of independently developed visualization tools.

1.3.1 Current Groundwater Flow Model

For the 2012 MNA evaluation, the MODFLOW-SURFACT groundwater flow model, including the block-centered flow, well, river, evapotranspiration, recharge, and time-variant specific head packages, were exported and/or built from the existing FAP RD calibrated groundwater flow model developed using the Ground Water VISTAS platform. Except for updating pumping rates from 1993 to 2060, no other changes were made to the Ground Water VISTAS flow model to produce the updated MODFLOW-SURFACT flow model.

The current FAP RD MODFLOW-SURFACT model is a 68-stress-period model that runs from the years 1993 to 2060. The FAP pump-and-treat (P&T) system began operation in 2005, which corresponds to stress period 13 in the FAP RD model. At the beginning of stress period 16, which corresponds to 2008 in the FAP RD model, the Albuquerque-Bernalillo County Water Utility Authority's (WATER AUTHORITY's) new surface water treatment plant began operating, allowing the WATER AUTHORITY to significantly reduce its groundwater withdrawals. In order to accommodate these changes and projected future changes to the pumping regime, the pumping rates in both the OSE and FAP RD groundwater flow models were updated from 1993 through 2060. Actual pumping rates were used for most WATER AUTHORITY, Kirtland Air Force Base (KAFB), University of New Mexico (UNM), and the FAP P&T system wells from 1993 through 2011. Projected pumping rates were used for most WATER AUTHORITY wells past 2011, while KAFB, UNM, and FAP P&T system well pumping rates were left constant at their 2011 rates. Drought conditions are included in the historical pumping records which were used to develop the projected pumping schedule. Additional pumping was added to projected rates to simulate exceptional drought conditions such as the region is currently experiencing. The projected pumping rates were based on a WATER AUTHORITY pumping schedule with used the historical 1971 to 1998 period, which includes drought, and included an artificial three-year “extreme” drough period. Other public, commercial, and private well pumping rates were left unchanged from the existing OSE model pumping rates. After 2011, the FAP P&T system wells were assigned constant pumping rates of -82, 41, 14, and 27 gallons per minute (gpm) for extraction well D2E-P1, injection well D2E-I3, injection well I2/D1E-I1 (upper screen), and I2/D1E-I1 (lower screen), respectively, in all modeling scenarios with the system operating.

An effort was made to evaluate the usefulness of the current FAP RD MODFLOW-SURFACT flow model to generate a reasonable flow solution at the scale of the FAP site. A transient simulation was run using the current FAP RD MODFLOW-SURFACT flow model to compare the simulated heads for 2012 with the FAP water levels measured in February 2012. **Table 1-1** shows a comparison of the simulated heads for stress period 19 and the measured water levels at a set of selected monitor wells. The head residuals are calculated by subtracting the simulated water levels from the measured water levels. **Table 1-1** shows that all the water level (WL) residuals are positive and the average residual is 15.11 feet. This indicates that the simulated water levels are too low reflecting too much drawdown from the WATER AUTHORITY pumping wells located east of the FAP site. This over estimation of drawdown from WATER AUTHORITY pumping is present in both the OSE and USGS models for the Middle Rio Grande Basin. One probable cause for a portion of this discrepancy is that neither model includes recharge due to leakage from the WATER AUTHORITY water and sewer systems.

TABLE 1-1
Comparison of Observed and Simulated Water Levels
Fruit Avenue Plume Superfund Site, Albuquerque, NM

NAD83 Easting (ft)	NAD83 Northing (ft)	February 2012 Observed WL Elevation (ft amsl)	Stress Period 19 Simulated WL Elevation (ft amsl)	Monitor Well ID	Model Layer	WL Residual (ft)
1521087.2	1488088.2	4920.29	4911.87	DM-01 (S)	1	8.42
1521100.7	1488148.3	4919.65	4911.87	DM-05 (S)	1	7.78
1521687.2	1487818.3	4914.43	4900.04	DM-06 (I1/I2)	2	14.39
1521748.3	1487424.5	4915.23	4899.39	DM-07 (I1/I2)	2	15.84
1521733.0	1488176.0	4915.45	4899.71	DM-08 (I1/I2)	2	15.74
1521726.9	1488176.6	4917.16	4911.87	DM-09 (S)	1	5.29
1521723.6	1487430.2	4915.61	4906.54	DM-10 (S)	1	9.07
1520560.1	1488220.1	4923.61	4911.87	DM-11 (S)	1	11.74
1520561.6	1488227.2	4924.60	4913.22	DM-12 (I1)	2	11.38
1521222.9	1488094.1	4924.18	4909.54	DM-13 (D1)	4	14.64
1521222.9	1488094.1	4921.20	4910.11	DM-13 (D2)	5	11.09
1521223.1	1488093.7	4920.19	4909.29	DM-13 (I1)	2	10.90
1521222.9	1488093.7	4919.41	4911.87	DM-13 (S)	1	7.54

TABLE 1-1

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Fruit Avenue Plume Superfund Site, Albuquerque, NM

NAD83 Easting (ft)	NAD83 Northing (ft)	February 2012 Observed WL Elevation (ft amsl)	Stress Period 19 Simulated WL Elevation (ft amsl)	Monitor Well ID	Model Layer	WL Residual (ft)
1521080.6	1488106.0	4924.02	4910.19	HSM-I2-4	2	13.83
1521368.3	1488101.9	4922.37	4903.75	HSM-I2-5	3	18.62
1522915.3	1488063.3	4910.33	4890.25	McDonalds (D2)	6	20.08
1520122.9	1487516.9	4928.38	4915.35	MNW-1 (I2)	2	13.03
1520425.3	1489117.3	4927.18	4914.24	MNW-10 (I1)	2	12.94
1520425.3	1489117.1	4927.21	4914.37	MNW-10 (I2)	3	12.84
1518695.7	1487769.8	4932.55	4921.73	MNW-11 (D1)	3	10.82
1518695.9	1487770.2	4932.54	4921.79	MNW-11 (D2)	5	10.75
1518696.0	1487769.7	4932.56	4921.71	MNW-11 (I1)	2	10.85
1518695.7	1487770.1	4932.58	4921.71	MNW-11 (I2)	2	10.87
1518789.4	1487277.2	4932.59	4921.45	MNW-12 (D1)	3	11.14
1518789.5	1487276.9	4932.58	4921.52	MNW-12 (D2)	5	11.06
1518789.3	1487277.0	4932.58	4921.43	MNW-12 (I1)	2	11.15
1518789.3	1487277.1	4932.62	4921.43	MNW-12 (I2)	2	11.19
1525503.4	1488076.7	4903.02	4878.27	MNW-13 (D1)	6	24.75
1525503.3	1488076.4	4903.27	4878.98	MNW-13 (D2)	7	24.29
1525503.2	1488076.6	4903.91	4878.98	MNW-13 (D3)	7	24.93
1525503.5	1488076.4	4904.64	4870.35	MNW-13 (D4)	8	34.29
1520827.7	1487883.7	4927.53	4912.52	MNW-14 (D1)	5	15.01
1520828.1	1487883.8	4927.10	4913.18	MNW-14 (D2)	6	13.92
1520828.3	1487883.7	4925.32	4911.83	MNW-14 (I2)	3	13.49
1526557.6	1486943.8	4886.96	4873.44	MNW-15 (D1)	7	13.52
1526557.6	1486943.8	4899.50	4873.44	MNW-15 (D2)	7	26.06
1526557.6	1486943.8	4900.06	4873.44	MNW-15 (D3)	7	26.62
1521408.0	1488743.3	4923.59	4908.24	MNW-2 (I2)	3	15.35
1522668.9	1486556.7	4911.66	4891.92	MNW-3 (D1)	5	19.74
1522669.3	1486556.4	4910.66	4891.66	MNW-3 (D2)	6	19.00
1522669.0	1486556.5	4909.89	4891.17	MNW-3 (D3)	7	18.72
1525404.2	1486296.7	4902.04	4877.16	MNW-4 (D1)	6	24.88
1525404.3	1486296.4	4902.34	4877.71	MNW-4 (D2)	7	24.63
1525404.0	1486296.3	4902.84	4877.71	MNW-4 (D3)	7	25.13
1524090.8	1487416.6	4906.41	4884.19	MNW-5 (D1)	5	22.22

TABLE 1-1

Comparison of Observed and Simulated Water Levels

Fruit Avenue Plume Superfund Site, Albuquerque, NM

NAD83 Easting (ft)	NAD83 Northing (ft)	February 2012 Observed WL Elevation (ft amsl)	Stress Period 19 Simulated WL Elevation (ft amsl)	Monitor Well ID	Model Layer	WL Residual (ft)
1524090.6	1487417.0	4907.76	4884.28	MNW-5 (D2)	6	23.48
1524090.6	1487416.8	4906.96	4884.50	MNW-5 (D3)	7	22.46
1524092.2	1487430.7	4907.73	4871.97	MNW-5 (D4)	8	35.76
1523548.0	1488070.2	4908.50	4887.49	MNW-6 (D1)	5	21.01
1523548.0	1488070.0	4908.55	4887.29	MNW-6 (D2)	6	21.26
1523548.4	1488070.0	4908.69	4887.25	MNW-6 (D3)	7	21.44
1519960.3	1487208.1	4928.59	4916.13	MNW-8 (I1)	2	12.46
1519960.5	1487207.9	4928.78	4916.23	MNW-8 (I2)	3	12.55
1519509.4	1487421.8	4930.17	4918.38	MNW-9 (D1)	4	11.79
1519509.5	1487421.6	4930.33	4918.49	MNW-9 (D2)	5	11.84
1519508.1	1487412.8	4930.20	4918.24	MNW-9 (I1)	2	11.96
1519508.3	1487412.6	4930.25	4918.31	MNW-9 (I2)	3	11.94
1521225.4	1487995.0	4919.50	4911.87	SFMW-03 (S)	1	7.63
1520842.2	1487890.9	4921.84	4912.47	SFMW-07 (S)	1	9.37
1520608.5	1488512.9	4924.22	4913.21	SFMW-10 (I2)	3	11.01
1520056.5	1488338.7	4925.65	4911.87	SFMW-11 (S)	1	13.78
1520055.0	1488327.6	4925.69	4915.82	SFMW-12 (I1)	2	9.87
1520053.0	1488315.5	4925.74	4915.91	SFMW-13 (I2)	3	9.83
1520041.0	1488416.0	4925.92	4916.26	SFMW-14 (D1)	5	9.66
1521376.5	1488389.3	4917.72	4911.87	SFMW-15 (S)	1	5.85
1521381.7	1488384.2	4918.81	4906.58	SFMW-16 (I1)	2	12.23
1521374.4	1488383.8	4920.39	4906.82	SFMW-17 (I2)	3	13.57
1520839.1	1487885.2	4922.33	4911.58	SFMW-18 (I1)	2	10.75
1522539.4	1487663.3	4908.17	4893.72	SFMW-20 (I1)	2	14.45
1522550.2	1487662.0	4908.46	4893.57	SFMW-21 (I2)	3	14.89
1522511.7	1487667.3	4909.41	4893.40	SFMW-22 (D1)	5	16.01
1522529.6	1487664.6	4909.07	4892.76	SFMW-23 (D2)	6	16.31
1521393.1	1487612.6	4917.59	4906.54	SFMW-24 (S)	1	11.05
1521396.1	1487628.6	4916.51	4902.43	SFMW-25 (I1)	2	14.08
1521394.6	1487621.5	4916.14	4901.56	SFMW-26 (I2)	3	14.58
1520602.7	1487659.6	4923.78	4913.05	SFMW-27 (I2)	3	10.73
1520826.1	1487338.5	4922.30	4911.66	SFMW-28 (I2)	3	10.64

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Fruit Avenue Plume Superfund Site, Albuquerque, NM

NAD83 Easting (ft)	NAD83 Northing (ft)	February 2012 Observed WL Elevation (ft amsl)	Stress Period 19 Simulated WL Elevation (ft amsl)	Monitor Well ID	Model Layer	WL Residual (ft)
1522979.2	1487848.0	4899.35	4890.73	SFMW-31 (I2)	3	8.62
1522954.1	1487296.4	4900.33	4890.70	SFMW-32 (I2)	3	9.63
1522568.7	1487658.0	4907.80	4891.82	SFMW-35 (D3)	7	15.98
1522558.8	1487658.8	4907.48	4874.44	SFMW-36 (D4)	8	33.04
1522105.1	1487548.1	4913.69	4900.39	SFMW-37 (I2)	3	13.30
1522952.3	1487286.6	4904.54	4890.13	SFMW-38 (D1)	5	14.41
1522959.6	1487324.6	4903.69	4889.16	SFMW-39 (D2)	6	14.53
1522956.1	1487307.1	4904.32	4889.48	SFMW-40 (D3)	7	14.84
1522956.1	1487307.1	4904.13	4889.48	SFMW-41 (D3/D4)	7	14.65
1523443.8	1487529.0	4898.71	4888.24	SFMW-43 (I1)	2	10.47
1523444.1	1487529.2	4905.59	4887.25	SFMW-44 (D2)	6	18.34
1523550.8	1486136.2	4905.23	4886.96	SFMW-45 (D2)	6	18.27
1524435.6	1486692.1	4902.28	4882.07	SFMW-46 (D1/D2)	5	20.21
1521334.0	1488098.2	4919.95	4906.86	SFMW-47 (I1/I2)	2	13.09
1520102.8	1487901.2	4926.34	4915.51	WB-01 (I1/I2)	2	10.83
1519849.0	1487940.0	4927.51	4916.71	WB-02 (I1/I2)	2	10.80
			Average			**15.11**

Notes:
ft = feet
ft amsl = feet above mean sea level

Although the simulated water levels are too low, what is more important to this evaluation is the simulated groundwater flow direction. In order to compare the simulated and measured groundwater flow directions, two surfaces were generated from the set of measured and simulated water levels at the monitor wells using a geostatistical technique (kriging). The measured and simulated hydraulic gradient vectors were displayed for three multi-or single aquifer zones (I1/I2, D1/D2, and D3).

All data points within 100 feet of each other were averaged prior to the kriging. **Figure 1-2** compares the observed and simulated gradient vectors for the I1/I2 aquifer zones. The hydraulic gradient vectors generated from the measured data show more variability. The measured gradients are slightly larger at the downgradient (eastern) end of the **Figure 1-2**, as indicated by the longer gradient vectors. However, the two sets of gradient vectors are generally similar, especially at the upgradient (western) and downgradient (eastern) ends of **Figure 1-2**.

FIGURE 1-2
Comparison of Measured and Simulated Groundwater Gradient Vectors in Aquifer Zones I1/I2 for February 2012
Fruit Avenue Plume Superfund Site, Albuquerque , NM

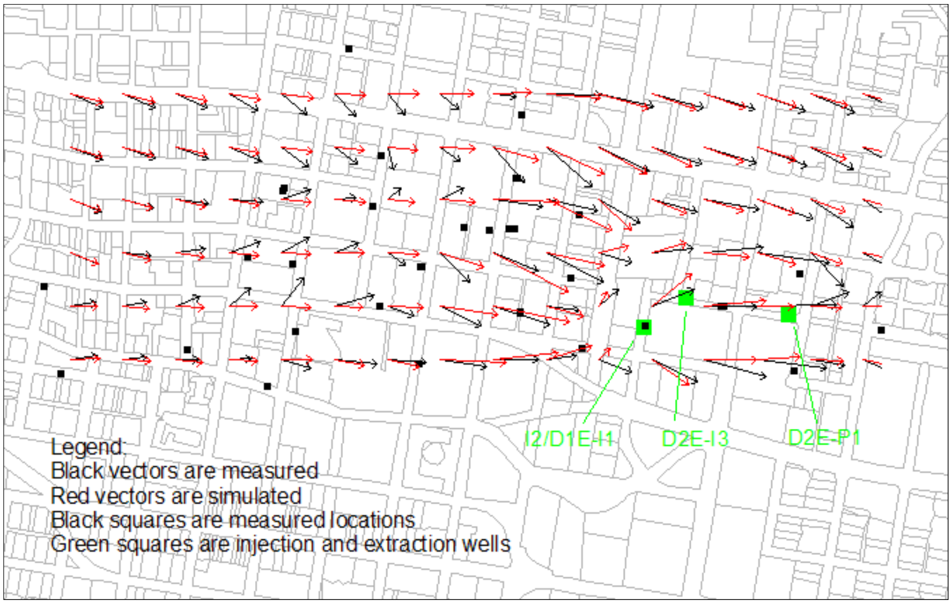


Figure 1-3 compares the observed and simulated gradient vectors for the D1/D2 aquifer zones. Again, the hydraulic gradient vectors generated from the measured data show more variability. The measured gradients show a stronger influence from the FAP P&T system extraction and injection wells than do the simulated gradients. The simulated vectors may show a more subdued response to the extraction well pumping because the pumping is distributed over an entire model grid cell in plan view and encompasses two model layers for a total vertical thickness of 200 feet. The actual extraction well screen length is 55 feet. Likewise, most of the monitor wells have 10- to 20-foot screen lengths, while the simulated heads at each of the monitor well locations reflect the head in the model layer in which the well resides. Model layer thicknesses near the extraction well range from 25 feet to 80 feet. The measured gradients in these aquifer zones are also slightly larger at the downgradient (eastern) end of the figure, as indicated by the longer gradient vectors, but the flow directions are similar.

Figure 1-4 compares the observed and simulated gradient vectors for the D3 aquifer zone. Again, the measured gradients show a stronger influence from the P&T system extraction well than do the simulated gradients. At the downgradient end of the **Figure 1-4**, the simulated gradients are slightly larger than the measured gradients, which could be due to the model simulating too much drawdown from the WATER AUTHORITY pumping wells located east of the FAP site, but the flow directions show good agreement. Overall, the FAP RD MODFLOW-SURFACT flow model seems to generate a reasonable approximation of the groundwater flow field.

FIGURE 1-3

Comparison of Measured and Simulated Groundwater Gradient Vectors in Aquifer Zones D1/D2 for February 2012

Fruit Avenue Plume Superfund Site, Albuquerque, NM

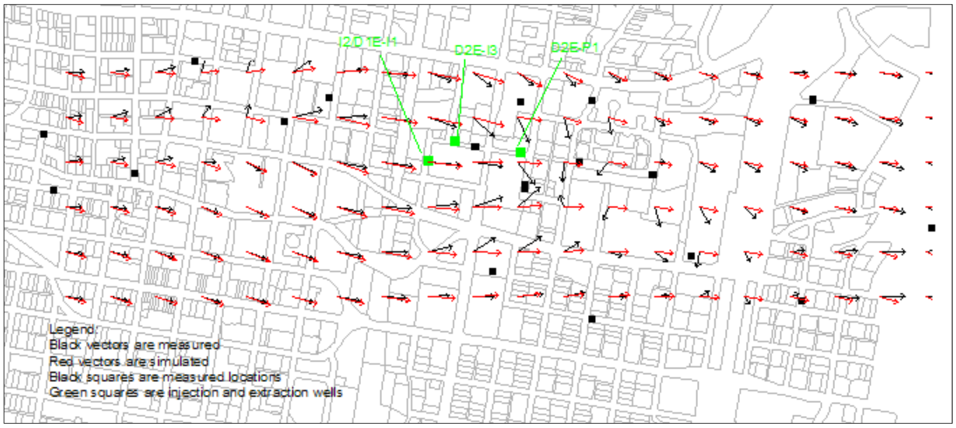
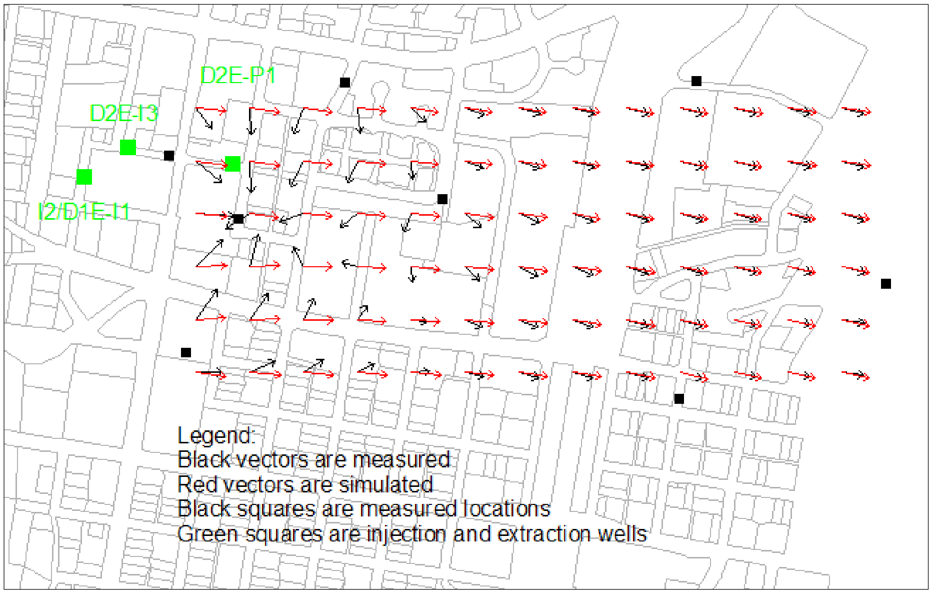


FIGURE 1-4

Comparison of Measured and Simulated Groundwater Gradient Vectors in Aquifer Zone D3 for February 2012

Fruit Avenue Plume Superfund Site, Albuquerque, NM



1.3.2 Current Contaminant Transport Model

The MODFLOW-SURFACT contaminant transport model, including the basic transport and prescribed-head-concentration boundary packages were exported and/or built from the existing FAP RD MT3DMS contaminant transport model developed in Ground Water VISTAS. The MODFLOW-SURFACT basic transport package was updated with the latest TCE concentration information used to develop the new FAP 2012 TCE plume shell as the initial concentration condition. It should be noted that no continuous or pulsed contaminant source term was used for this modeling because the remedial design investigation did not identify the presence of a vadose zone or saturated zone source. While there are low-level TCE and PCE detections in shallow soil samples collected from the presumed source area, the available groundwater samples do not indicate that vadose zone soil is leaching TCE to groundwater. This situation could change in the future, however, as groundwater elevations are expected to rise as the WATER AUTHORITY reduces groundwater withdrawals. The rising groundwater elevations could possibly mobilize some adsorbed contaminant currently located above the water table.

TCE degradation rates, for the shallow/intermediate and deep aquifer zones, were estimated based on compound specific isotope analysis (CSIA). The derivation of the degradation rates is described in Appendix I. A low degradation rate (TCE half life of 63.0 years) and an average rate (TCE half life of 32.2 years) are presented for the S, I1, I2 combined aquifer zone (encompasses model layers 1, 2 and 3), and a low rate (TCE half life of 46.2 years) and an average rate (TCE half life of 23.5 years) are presented for the D1, D2, D3, and D4 combined aquifer zone (encompasses model layers 5, 6, 7, 8, and 9). From the two combined S/I1/I2 and D1/D2/D3/D4 aquifer zones, a low and an average TCE degradation rate were assigned to each of the nine FAP RD model layers. Since model layer 4 spans both the shallower and deeper combined aquifer zones, the degradation rates from above and below were averaged (weighted by the layer thickness) to assign the low and average rates to model layer 4. The degradation rates used for this contaminant fate and transport modeling are listed in **Table 1-2.**

In an effort to better estimate the MODFLOW-SURFACT basic transport package aquifer dispersivity factors, the 2005 TCE plume shell version was used as the initial contaminant concentration condition and migrated forward in time to 2012. The average degradation rates described above and the other base case contaminant transport parameters presented in **Table 1-2** were used for this simulation. The FAP P&T system was operating for this comparison. The migrated plume was then compared to the new 2012 TCE plume shell and the longitudinal, transverse, and vertical dispersivity factors were adjusted until the two contaminant distributions looked similar. This task was complicated by the fact that the 2005 TCE plume shell included the upgradient offsite plume and the 2012 TCE plume shell does not. In addition, the 2005 TCE plume shell included more high concentration data points in the source area from the 2002 sampling event, and did not include data from the downgradient MNW-14 and MNW-15 well clusters. It appears that the area of the plume downgradient from the FAP extraction well and north of the St. Joseph Hospital well is the best area of the two contaminant distributions to compare. Unfortunately, the St. Joseph Hospital well has not been sampled since 2002. Given these limitations, appropriate longitudinal, transverse, and vertical dispersivity factors of 40, 4, and 0.4 were developed. The migrated 2005 TCE plume shell is shown in **Figure 1-5** and the 2012 TCE plume shell is shown in **Figure 1-6**.

Given the uncertainty associated with the contaminant transport parameters, a best guess base case scenario was simulated and several sensitivity scenarios were run. The base case scenario was run with the FAP P&T system on after 2012 and off after 2012. The two base case scenarios represent the best estimate of FAP TCE plume migration. The sensitivity scenarios were run to conservatively bound the modeling results and estimate worst case (most conservative) FAP TCE plume migration. The full set of contaminant transport parameters used for the base case and sensitivity scenarios are listed in **Table 1-2**.

TABLE 1-2
Contaminant Transport Parameters
Fruit Avenue Plume Superfund Site, Albuquerque, NM

	Base Case Scenario		Sensitivity Analysis Scenario					
Parameters	**P&T System Off Year 2012**	**P&T System On 2060**	**Low Degradation**	**Low Dispersivity**	**Low K_d**	**Low Porosity**	**High Porosity**	**No Degradation Low Dispersivity Low K_d**
Dispersion Parameters								
Longitudinal Dispersivity (ft)	40	40	40	20	40	40	40	20
Transverse Dispersivity (ft)	4	4	4	2	4	4	4	2
Vertical Dispersivity (ft)	0.4	0.4	0.4	0.2	0.4	0.4	0.4	0.2
Soil Parameters								
Effective Porosity (dimensionless)	0.2	0.2	0.2	0.2	0.2	0.13	0.28	0.2
Bulk Density (µg/L)	1.93×10^9	1.93×10^9	1.93×10^9	1.93×10^9	1.93×10^9	1.93×10^9	1.93×10^9	1.93×10^9

TABLE 1-2

Contaminant Transport Parameters

Fruit Avenue Plume Superfund Site, Albuquerque, NM

	Base Case Scenario		**Sensitivity Analysis Scenario**					
Parameters	**P&T System Off Year 2012**	**P&T System On 2060**	**Low Degradation**	**Low Dispersivity**	**Low K_d**	**Low Porosity**	**High Porosity**	**No Degradation Low Dispersivity Low K_d**
				Chemical-Specific Transport Parameters				
Soil/Water Partition Coefficient K_d (L/µg)	3.44×10^{-11}	3.44×10^{-11}	3.44×10^{-11}	3.44×10^{-11}	1.04×10^{-11}	3.44×10^{-11}	3.44×10^{-11}	1.04×10^{-11}
Degradation Rate for layers 1-3 (years^{-1})	0.0215	0.0215	0.011	0.0215	0.0215	0.0215	0.0215	0
Degradation Rate for layers 4 (years^{-1})	0.0255	0.0255	0.013	0.0255	0.0255	0.0255	0.0255	0
Degradation Rate for layers 5-9 (years^{-1})	0.0295	0.0295	0.015	0.0295	0.0295	0.0295	0.0295	0
Calculated Retardation Factor (dimensionless)	1.33	1.33	1.33	1.33	1.1	1.33	1.33	1.1
Calculated Decay Half Life for layers 1-3 (years)	32.2	32.2	63	32.2	32.2	32.2	32.2	NA
Calculated Decay Half Life for layers 4 (years)	27.2	27.2	53.3	27.2	27.2	27.2	27.2	NA
Calculated Decay Half Life for layers 5-9 (years)	23.5	23.5	46.2	23.5	23.5	23.5	23.5	NA

Notes:
ft = feet
K_d = soil water partition coefficient
NA = not applicable
L/µg = liters per microgram
µg/L = micrograms per liter
(Bulk Density/Effective Porosity)
Retardation Factor = 1 + K_d*
Decay Half Life = Ln(2)/Degradation Rate

FIGURE 1-5

2005 TCE Plume Shell Migrated to 2012

Fruit Avenue Plume Superfund Site, Albuquerque, NM

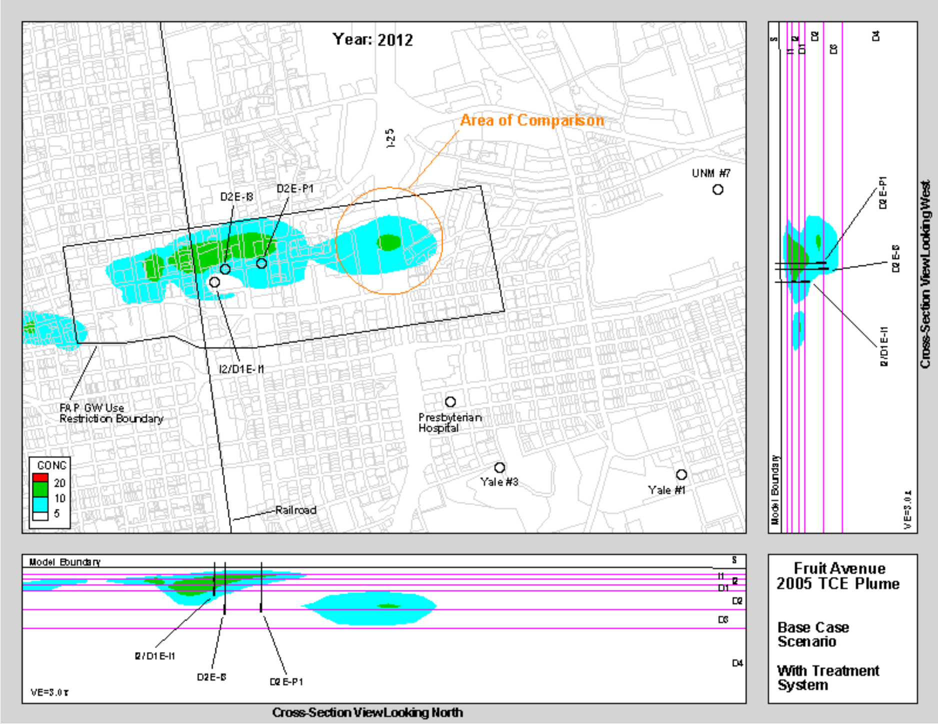
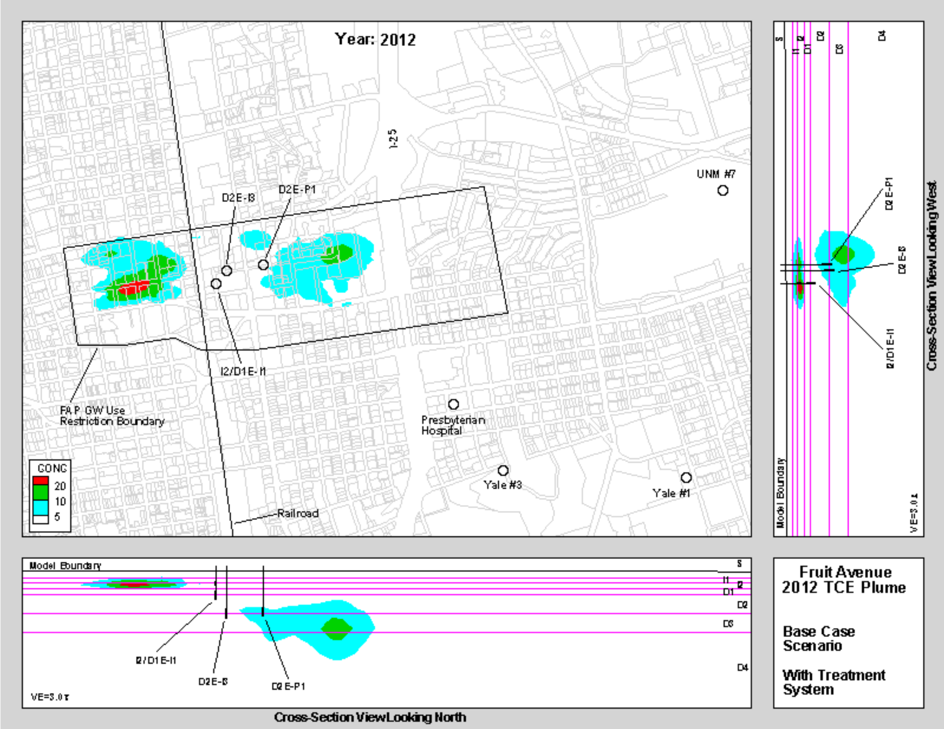


FIGURE 1-6

2012 TCE Plume Shell Contoured from Sample Measurements

Fruit Avenue Plume Superfund Site, Albuquerque, NM



2. Methods

The FAP RD MODFLOW-SURFACT model was used, along with the 2012 TCE plume shell, to simulate the future migration of the TCE plume and to estimate the potential hydraulic capture zone for the P&T system extraction well. One base case simulations were run to provide an estimate of TCE plume migration with the FAP P&T system turned off starting in 2012 (no action scenario) and the second with the P&T system operating through 2060. In addition, several sensitivity analysis fate and transport simulations were run to investigate the effects of varying some of the more uncertain transport model parameters like dispersivity, TCE degradation rate, TCE soil/water partition coefficient, and effective porosity. The following paragraphs describe the derivation of the new TCE plume shell, contaminant transport modeling, and evaluation of the hydraulic capture zone of the remedial system extraction well.

2.1 TCE Plume Shell Development

Figure 1-6 shows a two-dimensional representation of the 2012 TCE plume shell that was constructed for the FAP. A three-dimensional representation can be seen in the animations in **Attachment 1**. A geostatistical interpolation method called kriging, as implemented by Ground Water Modeling System (GMS) (Brigham Young University, 1994), was used to construct the plume shell. Contaminant plume shells provide a tool for visualizing plumes in three dimensions as well as initializing models for running contaminant transport simulations. The following text further describes the plume shell development approach.

2.1.1 TCE Concentration Data Set

Table 2-1 lists the data used to develop the TCE plume shell and includes groundwater sample dates ranging from April 2008 to April 2012. In addition, some older sample data collected in 2000 and 2002 were used to help delineate the shallow portion of the plume near the presumed source area, some outlying locations, and the St. Josephs Hospital well. Sampling data associated with the upgradient offsite contaminant plume were not included in the plume shell data set except where the two plumes are commingled. Where this occurred at wells WB-01 (I1/I2), 0.2 µg/L was used instead of 1.2 µg/L, and at SFMW-27 (I2), 4.75 µg/L was used instead of 9.5 µg/L. The TCE concentration/mass at these two locations was split between the two plumes by allocating half to each plume. The maximum TCE concentration in the plume shell data set is 39 µg/L from the February 27, 2012 groundwater sample collected at location MNW-14 (I2). Representative elevations for the chemical data were assumed to be the midpoint of the screen interval of the well from which the sample was collected for pumped samples, or the actual sample elevation for passive diffusion bag samples. One-half the detection limit was substituted for all contaminant nondetect values.

Some control points were added to the data set to limit unreasonable horizontal and vertical extensions of the interpolated TCE plume into areas with no data. Control points were used to prevent interpolated concentrations from extending above the water table, extending above the D1 aquifer zone in the eastern portion of the plume, and extending beyond the manually interpreted plume boundary. Sampling data collected in 2002 from locations FHMW-3, FHMW-4, FHMW-6, SFMW-30, and SFMW-42 were migrated in the groundwater flow model using particle tracking and were used as control points to build the plume shell in areas with no available current sampling data. In addition, clean (0 µg/L for TCE) groundwater control points were used at the location of the two remedial system injection wells.

TABLE 2-1
FAP 2012 TCE Plume Shell Data Set
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Location	Easting (ft)	Northing (ft)	Mid Sample Elevation (ft amsl)	TCE Concentration (µg/L)	Sample Date
DM-01	1521087.2	1488088.2	4913.3	1.9	02/22/02
DM-04	1520975.7	1488124.1	4915.14	0.5	02/22/02
DM-05 (S)	1521100.7	1488148.3	4914.42	0.36	02/28/2012
DM-06 (I1/I2)	1521687.2	1487818.3	4873.6	1.1	02/27/2012

TABLE 2-1

FAP 2012 TCE Plume Shell Data Set

Fruit Avenue Plume Superfund Site, Albuquerque, NM

Location	Easting (ft)	Northing (ft)	Mid Sample Elevation (ft amsl)	TCE Concentration (µg/L)	Sample Date
DM-07 (I1/I2)	1521748.3	1487424.5	4867.35	0.25	02/28/2012
DM-08 (1/I2)	1521733.0	1488176.0	4868.35	0.20	02/27/2012
DM-09 (S)	1521726.9	1488176.6	4907.33	0.25	02/27/2012
DM-10	1521723.6	1487430.2	4909.24	0.5	02/26/02
DM-11	1520560.1	1488220.1	4916.65	0.5	02/26/02
DM-12 (I1)	1520561.6	1488227.2	4871.79	2.4	02/27/2012
DM-13 (D1)	1521222.9	1488094.1	4826.59	0.5	02/21/02
DM-13 (D2)	1521222.7	1488093.8	4781.08	0.5	02/20/02
DM-13 (S)	1521222.9	1488093.7	4915.11	1.7	02/21/02
HSM-I2-4	1521080.6	1488106.0	4862.1	8.8	08/31/10
HSM-I2-5	1521368.3	1488101.9	4860.1	20	02/27/2012
McDonalds (D2)	1522915.3	1488063.3	4719	8.0	02/27/2012
MNW-10 (I1)	1520425.3	1489117.3	4884.8	0.25	04/20/09
MNW-10 (I2)	1520425.3	1489117.1	4857.3	0.25	02/15/11
MNW-11 (D2)	1518695.9	1487770.2	4776.76	0.15	02/27/2012
MNW-11 (I1)	1518696.0	1487769.7	4887.14	0.25	02/16/11
MNW-11 (I2)	1518695.7	1487770.1	4862.17	0.6	02/16/11
MNW-12 (D1)	1518789.4	1487277.2	4834.32	0.25	02/27/2012
MNW-12 (D2)	1518789.5	1487276.9	4776.76	0.25	02/27/2012
MNW-12 (I1)	1518789.3	1487277.0	4887.14	0.75	02/27/2012
MNW-12 (I2)	1518789.3	1487277.1	4861.87	0.25	02/16/11
MNW-13 (D1)	1525503.4	1488076.7	4704.72	1.4	02/28/2012
MNW-13 (D2)	1525503.3	1488076.4	4658.26	0.25	02/28/2012
MNW-13 (D3)	1525503.2	1488076.6	4572.64	0.25	02/28/2012
MNW-13 (D4)	1525503.5	1488076.4	4428.11	0.25	04/21/09
MNW-14 (D2)	1520828.1	1487883.8	4729.23	0.25	04/20/09
MNW-14 (I2)	1520828.3	1487883.7	4855.24	39	02/27/2012
MNW-15 (D1)	1526557.6	1486943.8	4693.53	0.25	02/28/2012
MNW-15 (D2)	1526557.6	1486943.8	4653.52	0.25	02/28/12
MNW-15 (D3)	1526557.6	1486943.8	4565.45	0.25	02/28/12
MNW-16 (D1)	1525319.1	1487162.9	4680	0.25	04/11/2012
MNW-16 (D2)	1525319.1	1487162.9	4586	0.25	04/11/2012

TABLE 2-1
FAP 2012 TCE Plume Shell Data Set
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Location	Easting (ft)	Northing (ft)	Mid Sample Elevation (ft amsl)	TCE Concentration (µg/L)	Sample Date
MNW-16 (D3)	1525319.1	1487162.9	4522	0.25	04/11/2012
MNW-16 (D4)	1525319.1	1487162.9	4397	0.25	04/10/2012
MNW-2 (I2)	1521408.0	1488743.3	4861.1	0.25	02/15/11
MNW-3 (D1)	1522668.9	1486556.7	4772.5	0.25	02/15/11
MNW-3 (D2)	1522669.3	1486556.4	4698.5	0.25	02/15/11
MNW-3 (D3)	1522669.0	1486556.5	4622.5	0.31	02/15/11
MNW-4 (D1)	1525404.2	1486296.7	4714.4	0.25	02/28/2012
MNW-4 (D2)	1525404.3	1486296.4	4649.4	1.4	02/28/2012
MNW-4 (D3)	1525404.0	1486296.3	4587.7	0.25	02/28/2012
MNW-5 (D1)	1524090.8	1487416.6	4767.6	6.9	02/28/2012
MNW-5 (D2)	1524090.6	1487417.0	4711.6	9.1	02/28/2012
MNW-5 (D3)	1524090.6	1487416.8	4623.6	15	02/28/2012
MNW-5 (D4)	1524092.2	1487430.7	4434.51	0.25	02/28/2012
MNW-6 (D1)	1523548.0	1488070.2	4767.9	1	02/14/11
MNW-6 (D2)	1523548.0	1488070.0	4707.9	0.25	02/14/11
MNW-6 (D3)	1523548.4	1488070.0	4637.9	0.25	02/28/2012
MNW-7 (D4)	1523739.4	1485309.4	4417.3	0.25	02/15/11
MNW-8 (I1)	1519960.3	1487208.1	4882.1	0.25	02/16/11
MNW-9 (D2)	1519509.5	1487421.6	4759.36	0.25	02/16/11
MNW-9 (I1)	1519508.1	1487412.8	4882.6	0.25	02/16/11
Presbyterian	1524811.9	1484750.8	4725	0.61	01/13/10
SFMW-01	1520990.2	1488217.3	4918.79	0.5	02/22/02
SFMW-02	1521116.9	1488086.7	4917.48	2.1	02/22/02
SFMW-03	1521225.4	1487995.0	4916.09	1.5	03/11/02
SFMW-04	1521173.9	1487932.3	4918.48	0.5	02/25/02
SFMW-05	1521206.8	1488192.0	4916.87	1.4	02/25/02
SFMW-07	1520842.2	1487890.9	4915.98	0.5	02/28/02
SFMW-10 (I2)	1520608.5	1488512.9	4856.45	12	02/27/2012
SFMW-11	1520056.5	1488338.7	4922.33	0.5	02/28/02
SFMW-12 (I1)	1520055.0	1488327.6	4880.69	0.25	02/14/11
SFMW-13 (I2)	1520053.0	1488315.5	4854.89	1	02/14/11
SFMW-15	1521376.5	1488389.3	4909.3	0.5	02/21/02

TABLE 2-1

FAP 2012 TCE Plume Shell Data Set

Fruit Avenue Plume Superfund Site, Albuquerque, NM

Location	Easting (ft)	Northing (ft)	Mid Sample Elevation (ft amsl)	TCE Concentration (µg/L)	Sample Date
SFMW-15 (S)	1521376.5	1488389.3	4909.31	0.25	04/14/08
SFMW-16 (I1)	1521381.7	1488384.2	4874.53	7.6	02/27/2012
SFMW-17 (I2)	1521374.4	1488383.8	4856.85	5.7	02/27/2012
SFMW-18 (I1)	1520839.1	1487885.2	4873.16	1.3	02/27/2012
SFMW-20 (I1)	1522539.4	1487663.3	4875.16	0.23	02/28/2012
SFMW-21 (I2)	1522550.2	1487662.0	4861.31	0.25	02/28/2012
SFMW-22 (D1)	1522511.7	1487667.3	4767.9	0.69	02/28/2012
SFMW-23 (D2)	1522529.6	1487664.6	4720.16	0.39	02/28/2012
SFMW-24	1521393.1	1487612.6	4907.75	1	03/06/02
SFMW-25 (I1)	1521396.1	1487628.6	4872.85	9.4	02/28/2012
SFMW-26 (I2)	1521394.6	1487621.5	4852.89	3.7	02/28/2012
SFMW-27 (I2)	1520602.7	1487659.6	4855	4.75	02/28/2012
SFMW-28 (I2)	1520826.1	1487338.5	4852.54	2.5	08/22/11
SFMW-29 (I2)	1521243.8	1486973.8	4853.61	0.25	04/21/09
SFMW-31 (I2)	1522979.2	1487848.0	4855.66	0.76	02/15/11
SFMW-32 (I2)	1522954.1	1487296.4	4859.83	0.25	02/14/11
SFMW-33 (D2)	1521843.6	1487676.4	4729.36	0.25	02/15/11
SFMW-34	1521843.6	1487676.2	4540.54	0.5	02/25/02
SFMW-35 (D3)	1522568.7	1487658.0	4639.34	0.25	02/28/2012
SFMW-36	1522558.8	1487658.8	4517.44	0.5	02/27/02
SFMW-37 (I2)	1522105.1	1487548.1	4853.76	0.25	02/27/2012
SFMW-38 (D1)	1522952.3	1487286.6	4779.725	0.38	02/28/2012
SFMW-39 (D2)	1522959.6	1487324.6	4715.4	3.1	02/28/2012
SFMW-40 (D3)	1522956.1	1487307.1	4631.18	7.2	02/28/2012
SFMW-41 (D3/D4)	1522956.1	1487307.1	4558.14	0.31	02/28/2012
SFMW-42	1522006.7	1486813.4	4901.77	0.5	02/21/02
SFMW-43 (I1)	1523443.8	1487529.0	4867.52	0.57	09/02/10
SFMW-44 (D2)	1523444.1	1487529.2	4709.57	9.8	02/28/2012
SFMW-45 (D2)	1523550.8	1486136.2	4736.06	3.6	02/15/11
SFMW-46 (D1/D2)	1524435.6	1486692.1	4755.02	0.98	02/28/2012
SFMW-47 (I1/I2)	1521334.0	1488098.2	4858.91	15	02/27/2012
SPSC-MW4	1521838.0	1487724.6	4917.2	2.8	02/21/02

TABLE 2-1
FAP 2012 TCE Plume Shell Data Set
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Location	Easting (ft)	Northing (ft)	Mid Sample Elevation (ft amsl)	TCE Concentration (µg/L)	Sample Date
St. Joseph Well	1524043.0	1486982.2	4673	5.3	02/27/02
WB-01 (I1/I2)	1520102.8	1487901.2	4872.75	0.2	02/27/2012
WB-01 (S)	1520108.4	1487905.0	4921.84	0.5	05/02/00

Notes:
ft = feet
ft amsl = feet above mean sea level
µg/L = micrograms per liter

2.1.2 Interpolation of TCE Concentrations

TCE concentrations from the sampling data set were interpolated to the plume shell grid using kriging. Kriging is a linear, unbiased, least-squares spatial interpolation method that uses a weighted-average estimator to approximate the value of a regionalized variable at a spatial location while maintaining actual sample data. The interpolated TCE concentrations were contoured and visualized using wire-net isosurfaces. The kriging process was adjusted until the resulting plume shell fit the known data as closely as possible within the known hydrostratigraphic zones. The isosurface representing the concentration of 5 µg/L was considered the plume shell boundary to correspond with the 5 µg/L remedial goal.

2.1.3 Plume Shell Masking

The plume shell was masked to eliminate artifacts of the kriging process that would otherwise produce hydraulically unreasonable extensions of a plume into areas with no data coverage. The mask is the plan view of the maximum lateral extent of TCE contamination present at a concentration of 5.0 µg/L. Interpolated concentrations located outside of the mask were set to zero and the concentrations inside the mask remained unaltered.

2.1.4 Plume Shell Contaminant Mass and Volume

The resulting kriged and masked TCE plume shell is shown in **Figure 1-6** with the 5, 10, and 20 µg/L isosurfaces displayed. Assuming an effective aquifer porosity of 20 percent and a 5.0 µg/L plume boundary (consistent with the TCE MCL), the plume shell contaminated groundwater volume and dissolved phase contaminant mass are 33.5 million cubic feet ($ft^{3)}$ and 6.5 kilograms (kg), respectively.

2.1.5 Areas of Plume Shell Uncertainty

A few areas of the plume shell with greater uncertainty should be noted. While the sampling density is highly variable, many sample locations are more than 1,500 feet apart along the direction of groundwater flow with 1,000 feet of separation perpendicular to the direction of flow. In the vertical direction, there is often 40 feet or more of separation between samples. Therefore, it is unreasonable to expect reliable plume shell detail on a finer scale than this in these areas. The more significant areas of uncertainty are as follows:

1. Toward the southeast leading edge of the plume, there is a relatively large distance between the available sampling data points, which are SFMW-40 (D3) - 7.2 µg/L in February 2012, SFMW-45 (D2) - 3.6 µg/L in February 2011, SFMW-46 (D1/D2) - 0.98 µg/L in February 2012, MNW-4 (D2) - 1.4 µg/L in February 2012, St. Joseph Hospital well - 5.3 µg/L in February 2002, and Presbyterian Hospital well - 0.61 µg/L in January 2010. Within the deep aquifer zones, wells SFMW-40 (D3) and MNW-4 (D2) are approximately 2,600 feet apart. Adding to this uncertainty is the age of the St. Joseph Hospital well sample (February 2002) and the uncertainty in the hospital well screen intervals.

2. Toward the northeast leading edge of the plume, there is a relatively large distance between the available sampling data points, which are MNW-13 (D2) - nondetect in February 2012, MNW-6 (D1) - 1.0 µg/L in

February 2011, and MNW-5 (D3) - 15 µg/L in February 2012. New sampling location MNW-16 helped to reduce this uncertainty considerably at the leading edge.

3. In the western portion of the plume, near the presumed source area, west of the apparent fault zone, there is only one (DM-09 [S]) recent shallow sampling data point near the water table interface. The plume shell data set was supplemented with older data from 2002 to build this portion of the plume shell. Future samples collected in the shallow zone of the aquifer could reduce the uncertainty in this area of the plume shell.

2.1.6 Translation of Plume Shell to Model Grid

In order to populate the FAP RD model with initial TCE concentrations, the plume shell was interpolated from the plume shell grid to the model grid. This interpolation between grids resulted in the following statistics. Assuming an aquifer porosity of 20 percent and a 5 µg/L plume boundary, the contaminated groundwater volume and dissolved contaminant mass that were carried into the model are 33.5 million ft^3 and 6.5 kg, respectively. Given the base case retardation coefficient of 1.33, the adsorbed contaminant mass initialized in the model is 2.1 kg. This gives a total initial contaminant mass in the model of 8.6 kg.

2.2 Modeling Scenarios

The FAP RD MODFLOW-SURFACT model was used, along with the new 2012 TCE plume shell, to simulate the future migration of the TCE plume and to estimate the potential hydraulic capture zone of the P&T system extraction well. The base case simulation was run to provide the best estimate of the contaminant plume migration with the P&T system operating. A simulation was also run using the base case contaminant transport parameters with the FAP P&T system turned off starting in 2012 (no action scenario).

In addition, several sensitivity analysis fate and transport simulations were also run to investigate the effects of varying some of the more uncertain transport model parameters like dispersivity, TCE degradation rate, TCE soil/water partition coefficient, and effective porosity. The FAP P&T system was turned off starting in 2012 for each of the sensitivity analysis simulations. The contaminant transport parameters used for these sensitivity runs are summarized in **Table 1-2**, along with the base case parameters, which are presented for comparison. Animations of the 49-year migration of the FAP 2012 TCE plume shell under the base cases and sensitivity scenarios are included as **Attachment 1** to this memorandum. The animations depict the time progression of the TCE plume starting at year 2012 (initial conditions) through the year 2060. They include a plan view of the simulated plume and two cross-sectional views, one looking to the north and one looking west. In each view, the maximum simulated concentration projected through the model grid in the direction of the view is shown using color-filled contour intervals.

2.2.1 Pump-and-Treat System Turned Off

This base case scenario examines the path of the plume given no further P&T system operation, starting in 2012. This scenario uses the base case contaminant transport parameters presented in **Table 1-2** to provide a projection of future TCE fate and transport, assuming no further active remedial action at the site.

2.2.2 Pump-and-Treat System Remains On

For this base case simulation, the FAP P&T system (extraction well D2E-P1 and injection wells D2E-I3 and I2/D1E-I1) remain on for the entire 2012 through 2060 simulation period (note: the location of P&T system is shown on **Figure 1-6**). After 2011, extraction well D2E-P1 was assumed to pump at a constant rate of 82 gpm. Injection wells D2E-I3, I2/D1E-I1 (I2 zone), and I2/D1E-I1 (D1 zone) were assumed to inject at constant rates of 41, 14, and 27 gpm, respectively, based on current operating conditions (CH2M HILL, 2012). This scenario uses the base case contaminant transport parameters presented in **Table 1-2**.

2.2.3 Sensitivity

Simulations were completed to estimate the sensitivity of the TCE fate and transport simulations to parameters estimated with more uncertainty, such as dispersivity, effective porosity, soil water partition coefficient (K_d), and degradation. The contaminant transport parameters used for these sensitivity runs are summarized in **Table 1-2**, along with the base case parameters, which are presented for comparison. The low degradation and low dispersivity scenarios used input values equal to approximately 50 percent of the base case values. The low K_d

scenario used an input value equal to 29 percent of the base case value, which resulted in a retardation coefficient of 1.1 versus 1.33 for the base case. The high and low porosity scenarios used input values equal to 140 and 65 percent of the base case values, respectively. As a worst case, a no degradation, low dispersivity, low K_d simulation was run using the same low dispersivity and low K_d values described previously.

3. Results

3.1 Extraction Well Hydraulic Capture Zone Analysis

Figures 3-1A and **3-1B** show a two-dimensional plan view and a cross section view of the extraction well D2E-P1 simulated hydraulic capture zone after 8 years of remedial system operation. The new 2012 TCE plume shell is also shown on both figures for comparison, and the aquifer zone designations are shown on the cross section view for elevation reference. **Figures 3-2A** and **3-2B** are a similar set of figures showing the extraction well D2E-P1 simulated hydraulic capture zone after 16 years of continuous operation. This evaluation of the hydraulic capture performance of the extraction well was generated by using a transient flow simulation to drive a particle tracking run using MODPATH (Pollock, 1994). MODPATH is a particle tracking post-processing package that was developed to compute 3D flow paths using output from steady state or transient groundwater flow simulations. One particle was started in each model cell within an area that exceeded the boundaries of the total capture zone, and was allowed to migrate from 2005 (the year the FAP remedial system started operating) through either 2012 or 2020. Particles that were started in cells within the capture zone migrated to the extraction well and were captured. Particles that started in cells outside the capture zone discharged to exit points other than the extraction well. The capture-zone delineation was then generated by three-dimensional visualization software, which created a bounding isosurface between the captured and uncaptured portions of the aquifer. It should be noted that the vertical exaggeration in both cross section views is 10 times.

Figures 3-1A and **3-1B** show that the simulated extraction well capture zone is not predicted to extend laterally (north and south) to cover the full width of the plume. In addition, in the 8 years that the remedial system has been operating, the extraction well capture zone is not predicted to extend to the FAP source area. The lateral extension of the capture zone is hindered by the presence of the two upgradient injection wells, which focus the extraction well capture zone inward. The two injection wells and the simulated fault zone (a roughly north-south trending low hydraulic conductivity zone) near the Burlington Northern Santa Fe railroad tracks also slow the westward extension of the capture zone past the two injection wells. Vertically, the predicted capture zone extends into aquifer zones D1, D2, D3, and D4 and only partially penetrates upward into aquifer zone I2.

Figures 3-2A and **3-2B** show the expansion of the simulated extraction well capture zone after 16 years of operation. The capture zone covers more of the lateral width of the plume, and may capture the portion of plume with TCE concentrations above 5 µg/L. After 16 years of operation, the capture zone is starting to approach the higher concentration areas near the FAP source area. Vertically, the predicted capture zone extends into aquifer zones I2, D1, D2, D3, and D4 and only partially penetrates upward into aquifer zone I1.

FIGURE 3-1A

2012 Extraction Well D2E-P1 Hydraulic Capture Zone (Plan View)

Fruit Avenue Plume Superfund Site, Albuquerque, NM

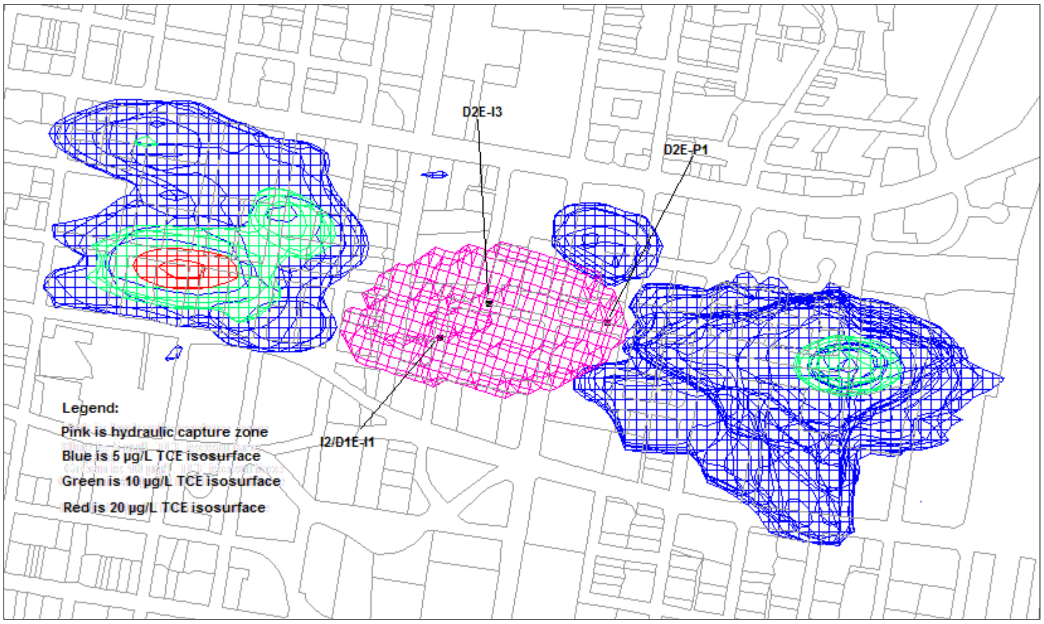


FIGURE 3-1B

2012 Extraction Well D2E-P1 Hydraulic Capture Zone (Cross Section Looking North)

Fruit Avenue Plume Superfund Site, Albuquerque, NM

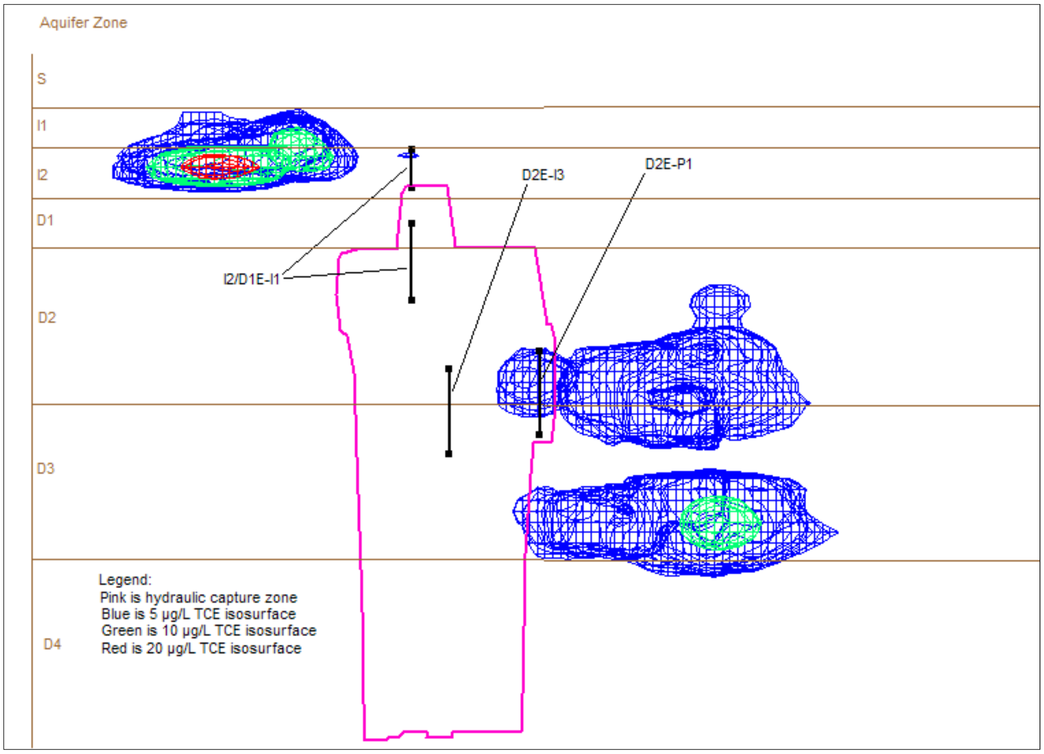


FIGURE 3-2A

2020 Extraction Well D2E-P1 Hydraulic Capture Zone (Plan View)

Fruit Avenue Plume Superfund Site, Albuquerque, NM

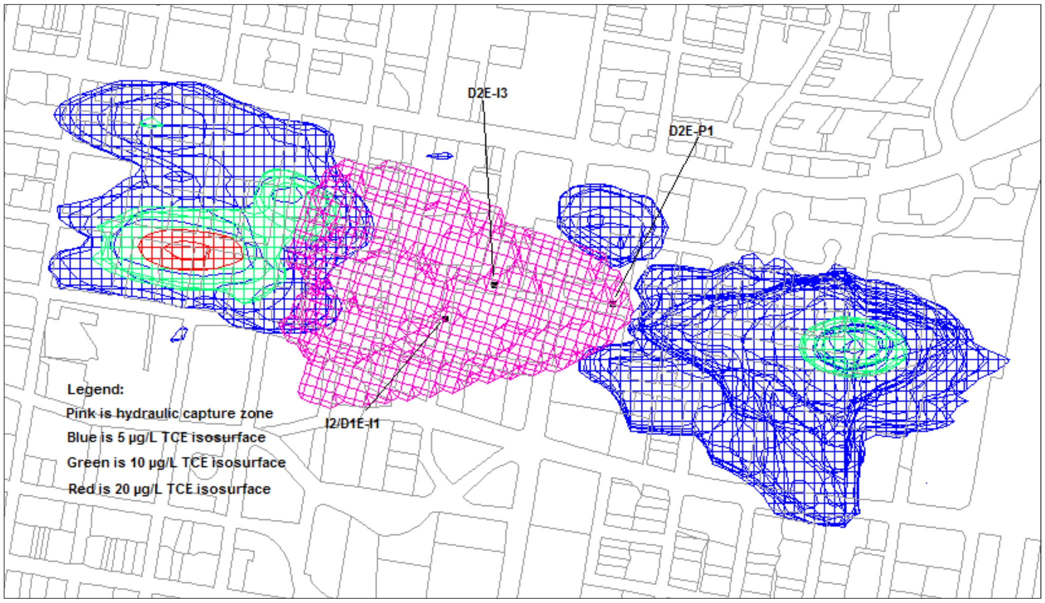
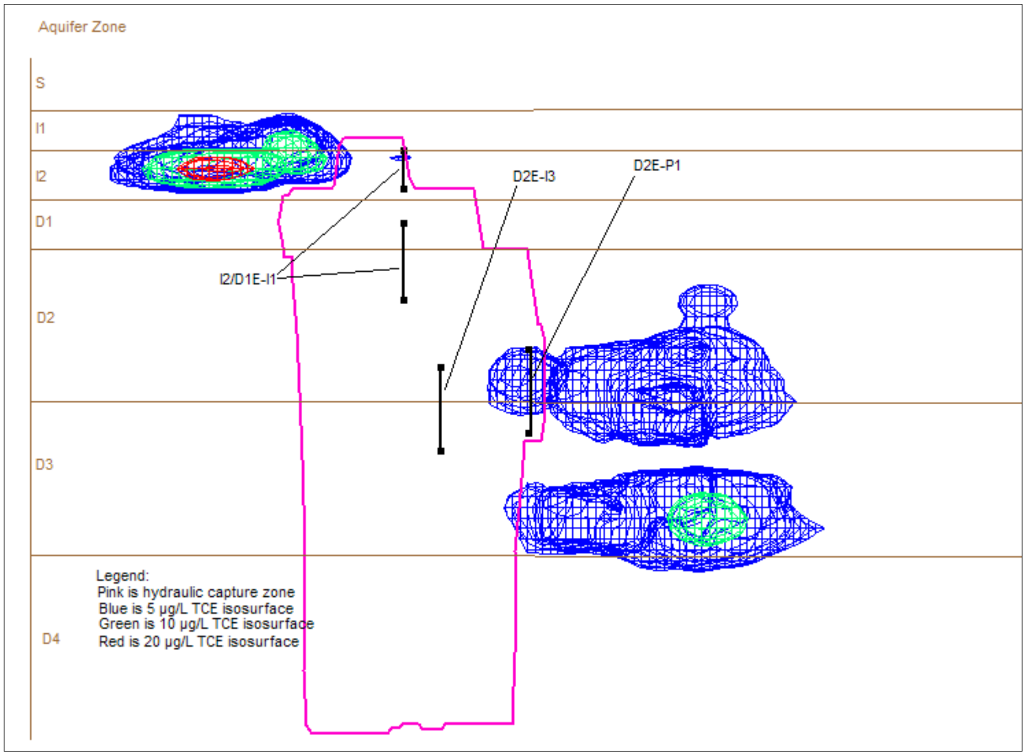


FIGURE 3-2B

2020 Extraction Well D2E-P1 Hydraulic Capture Zone (Cross Section Looking North)

Fruit Avenue Plume Superfund Site, Albuquerque, NM



3.2 Base Case Scenarios

The following two subsections summarize the base case simulation results for the no action and current remedial system scenarios. Simulation years 2015, 2020, 2025, and 2030 for both of these base case scenarios are presented in the figures, and animations of the simulations are included as **Attachment 1** to this memorandum. For comparison purposes, the same time steps are presented for all the sensitivity analysis scenarios. The simulation years presented in the figures were chosen to be informative for the majority of the base case and sensitivity analysis scenarios. In both the figures and the animations, the maximum TCE concentration is projected to the surface within the horizontal and vertical boundaries of the model domain for better visualization. A summary of milestone dates is presented in **Table 3-1** to aid in the comparison of the performance of the base case and sensitivity analysis modeling scenarios. The milestones are the dates when TCE concentrations decrease to below 10 µg/L (in the source area and downgradient area), when TCE concentrations decrease to below 5 µg/L (in the source area and downgradient area), and when the TCE concentration of 5 µg/L crosses the FAP site groundwater use restriction boundary.

TABLE 3-1
Summary of Remediation Performance for Modeling Scenarios
Fruit Avenue Plume Superfund Site, Albuquerque, NM

Simulation Type	Selected Years From 2012 TCE Plume Migration Simulations				
	< 10 µg/L in Source Area	**< 10 µg/L Down Gradient**	**< 5 µg/L in Source Area**	**< 5 µg/L Down Gradient**	**5µg/L Reaches GW Use Boundary**
Base Case Scenarios					
No Treatment System	**2019**	**2016**	**2026**	**2030**	**NA**
Current Treatment System	**2019**	**2017**	**2026**	**2031**	**NA**
Sensitivity Analysis Scenarios					
Low Dispersivity	**2021**	**2017**	**2028**	**2032**	**NA**
Low Degradation	**2019**	**2018**	**2026**	**2037**	**NA**
Low K_d	**2017**	**2016**	**2024**	**2029**	**NA**
Low Porosity	**2017**	**2016**	**2022**	**2028**	**NA**
High Porosity	**2021**	**2017**	**2028**	**2032**	**NA**
No Degradation Low Dispersivity Low K_d	**2021**	**2023**	**2029**	**2054**	**2038**

Notes:
K_d = soil water partition coefficient
NA = not applicable
µg/L = micrograms per liter

3.2.1 Pump-and-Treat System Turned Off

An animation of the 49-year migration of the FAP 2012 TCE plume shell for the P&T system turned off scenario is included as **Attachment 1** to this memorandum, and selected simulation time steps are shown on **Figures 3-3A** though **3-3D**. The animation shows that the maximum TCE concentration in the plume is predicted to be less than 10 µg/L in the presumed source area in 2019 and in the downgradient area in 2016. The maximum TCE concentration in the plume is predicted to be less than 5 µg/L in the source area in 2026 and in the downgradient area in 2030. A concentration of 5 µg/L is not predicted to reach the FAP groundwater use restriction boundary.

The MODFLOW-SURFACT summary output file generated from the no action scenario contaminant transport simulation lists the degradation mass fluxes for each stress period of the simulation. These statistics indicate that the total mass of TCE removed by degradation over the period of the simulation is 32.5 kg. This is 80 percent of the total initial dissolved and adsorbed TCE mass (40.4 kg).

The simulated contaminant mass discharged and the contaminant concentration in the discharged water were calculated for the remedial system extraction well (not operating for this scenario) and potential receptor wells in the estimated path of the TCE plume migration. The simulated contaminant mass discharged was calculated from the model cell-by-cell mass-flux output for model well cells. The mass flux per time step was multiplied by the length of the time step to estimate the contaminant mass discharged to each well per time step. Simulated contaminant concentrations in potential receptor wells were calculated by dividing the model cell-by-cell mass-flux output for model well cells, for each time step, by the volume of water pumped during each time step.

The potential receptor wells are St. Joseph Hospital (now the Albuquerque Regional Medical Center), Presbyterian Hospital, the Water Authorities Yale well field, and UNM#7. The St. Joseph Hospital well, which is already located within the TCE plume shell boundary, had a TCE concentration of 5.3 µg/L the last time it was sampled in 2002. The well was shut down at the beginning of 1997.While St. Joseph Hospital, UNM#2, UNM#3, and UNM#5 are in the path of predicted plume migration, they are not pumping during any of the simulations. UNM#7 is pumping during all of the simulations, but it is not impacted during the period of the simulations for any of the base case or sensitivity scenarios. Therefore, only the simulated contaminant mass discharged and the contaminant concentration for the remedial system extraction well will be presented for the subsequent scenarios.

FIGURE 3-3A

Year 2015 Time Step From P&T Off Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque, NM

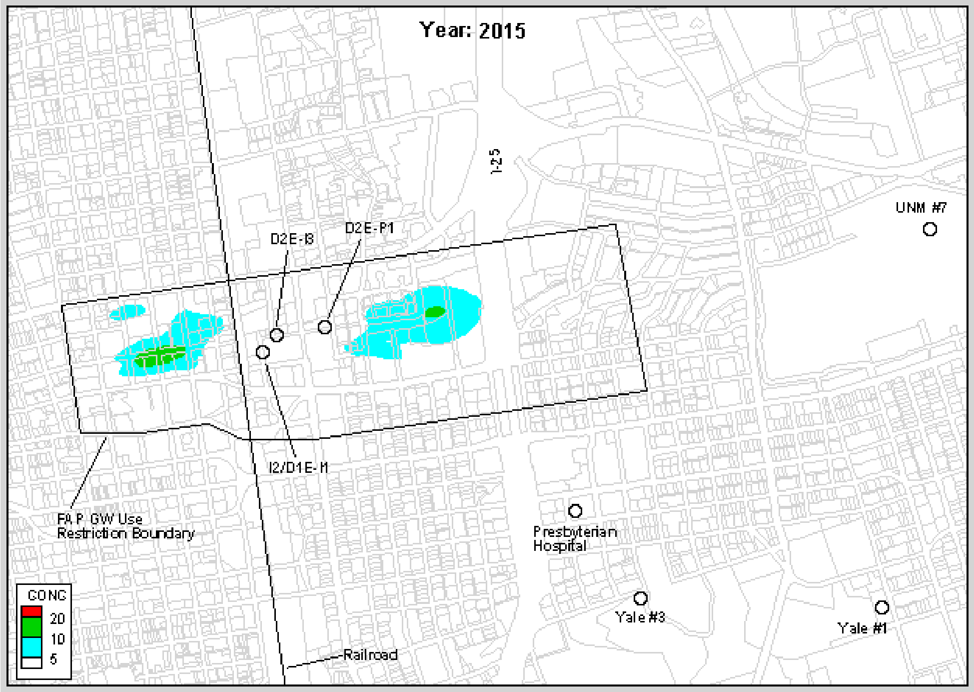


FIGURE 3-3B

Year 2020 Time Step From P&T System Off Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque, NM

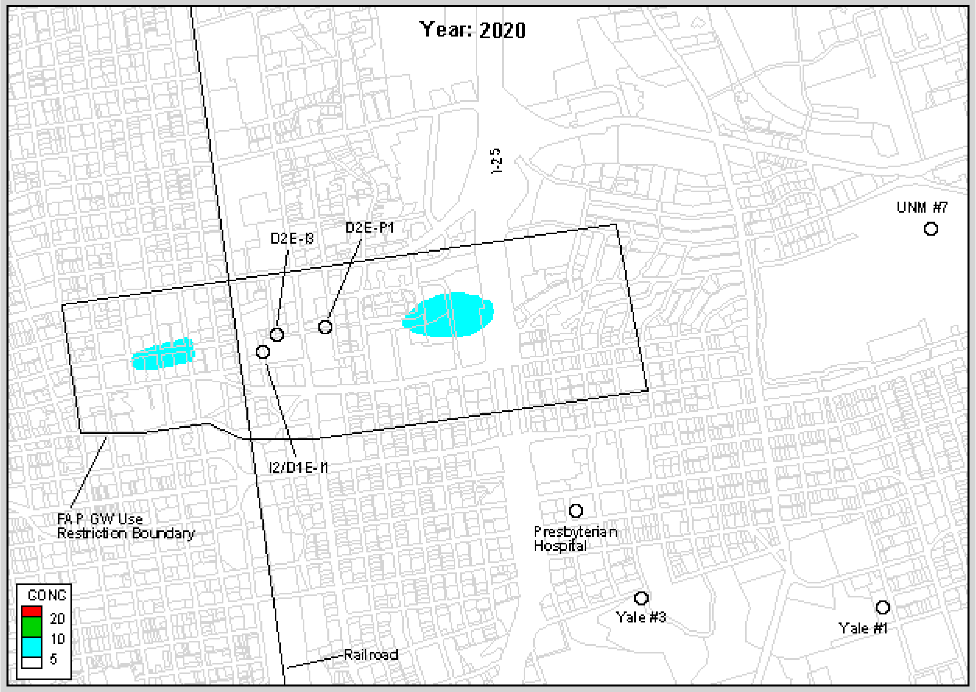


FIGURE 3-3C

Year 2025 Time Step From P&T System Off Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque, NM

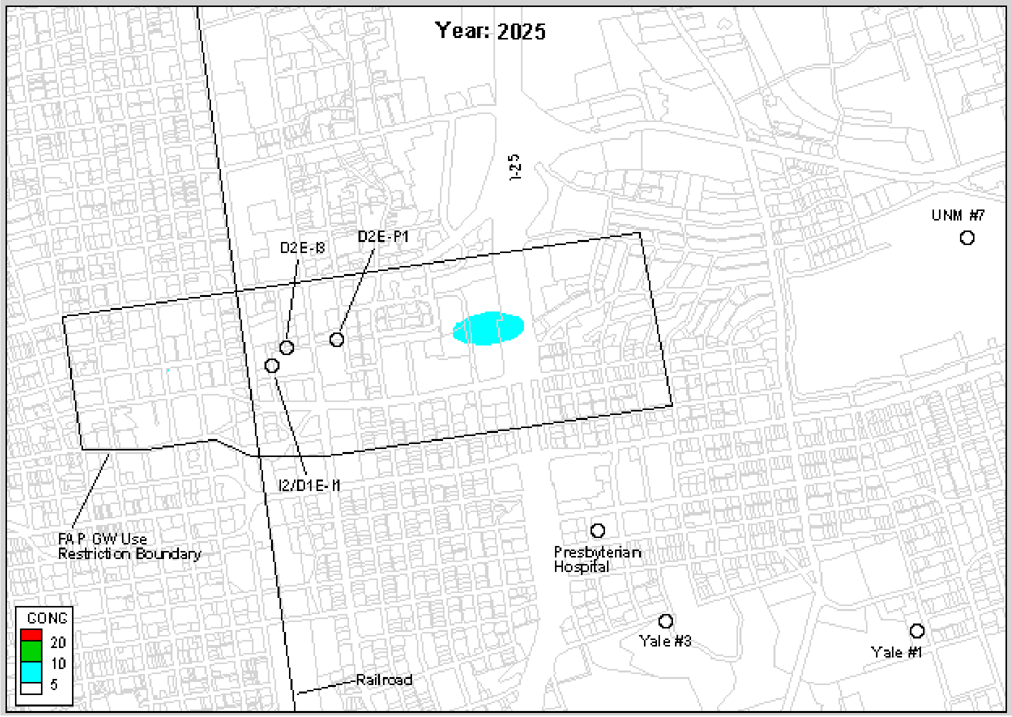
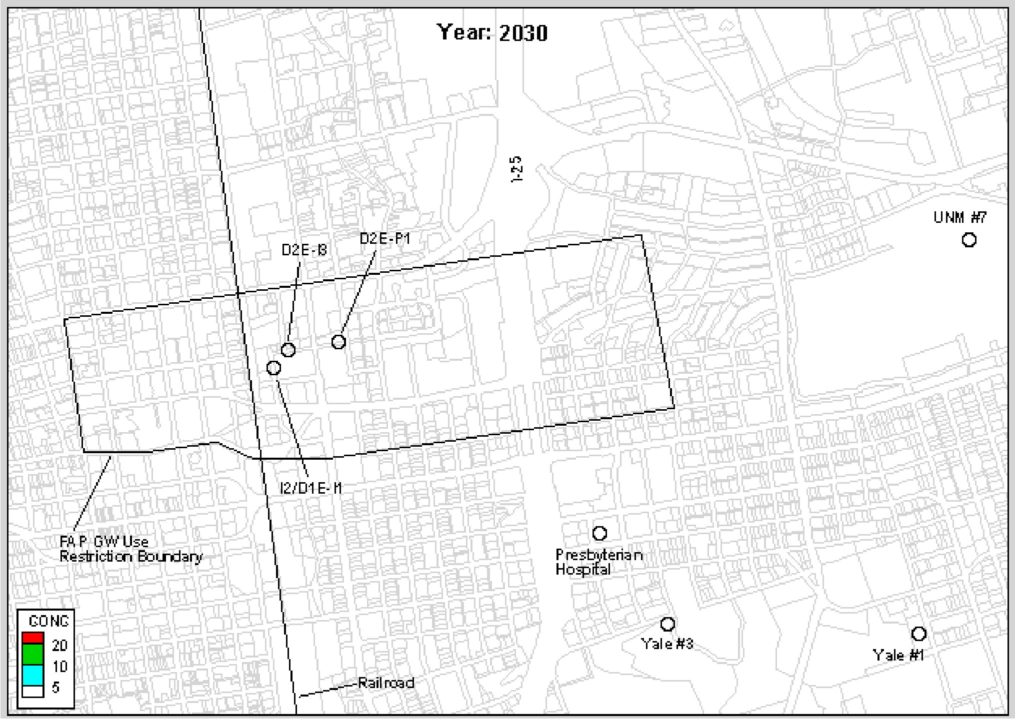


FIGURE 3-3D

Year 2030 Time Step From P&T System Off Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque, NM



3.2.2 Pump-and-Treat System Remains on Until 2061.

An animation of the 49-year migration of the FAP 2012 TCE plume shell under the current P&T system remains on scenario is included as **Attachment 1** to this memorandum, and selected simulation time steps are shown on **Figures 3-4A** through **3-4D**. The animation shows that the maximum TCE concentration in the plume is predicted to be less than 10 µg/L in the source area in 2019 and in the downgradient area in 2017. The maximum TCE concentration in the plume is predicted to be less than 5 µg/L in the source area in 2026 and in the downgradient area in 2031. A concentration of 5 µg/L is not predicted to reach the FAP groundwater use restriction boundary. These remedial performance statistics are approximately the same as for the P&T system turned off base case simulation, indicating that continued operation of this system provides no measureable benefit relative to accelerating the cleanup timeframe.

The MODFLOW-SURFACT summary output file generated from the current remediation system scenario contaminant transport simulation lists the degradation mass fluxes for each stress period of the simulation. These statistics indicate that the total mass of TCE removed by degradation over the period of the simulation is 30.7 kg. This is 76 percent of the total initial dissolved and adsorbed TCE mass (40.4 kg). Comparison of these degradation performance statistics with the no action base case statistics indicates that continued operation of the remedial system results in 4 percent less degradation of the initial TCE dissolved and adsorbed contaminant mass.

The simulated influent TCE concentration and cumulative mass discharged from extraction well D2E-P1 since 2012 are both shown on **Figure 3-5**. The simulated TCE concentration in extraction well D2E-P1 is 2.44 µg/L in 2012 and is less than 1 µg/L in 2018. Recent samples from the extraction well have been fluctuating around the TCE MCL of 5 µg/L, so the simulated extraction well concentration is lower than observed. This most likely occurs because the extraction well screen is 150 ft long in the model while the actual screen length is 55 ft. The additional screen length draws in water from lower portions of the aquifer, diluting the TCE concentration present in the simulated extraction well flow.

The P&T system is predicted to extract 3.1 kg of TCE from 2012 until the end of 2060, which is approximately 10.2 percent of the initial dissolved contaminant mass (30.4 kg) present in the model. This amounts to 0.27 kg (0.59 pounds) per year on average between 2012 and 2019, and 0.08 kg (0.17 pounds) per year on average between 2019 and 2061. The 0.27 kg per year average for the 2012 to 2019 time period is less than the 0.9 kg of TCE mass actually recovered for the August 2011 through June 2012 period. Approximately one-tenth of the initial contaminant mass is captured because the injection well placement prevents expansion of the hydraulic capture zone to intercept the western portion of the plume, and because a majority of contaminant mass is already downgradient of the extraction well.

FIGURE 3-4A

Year 2015 Time Step From P&T System Remains On Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque, NM

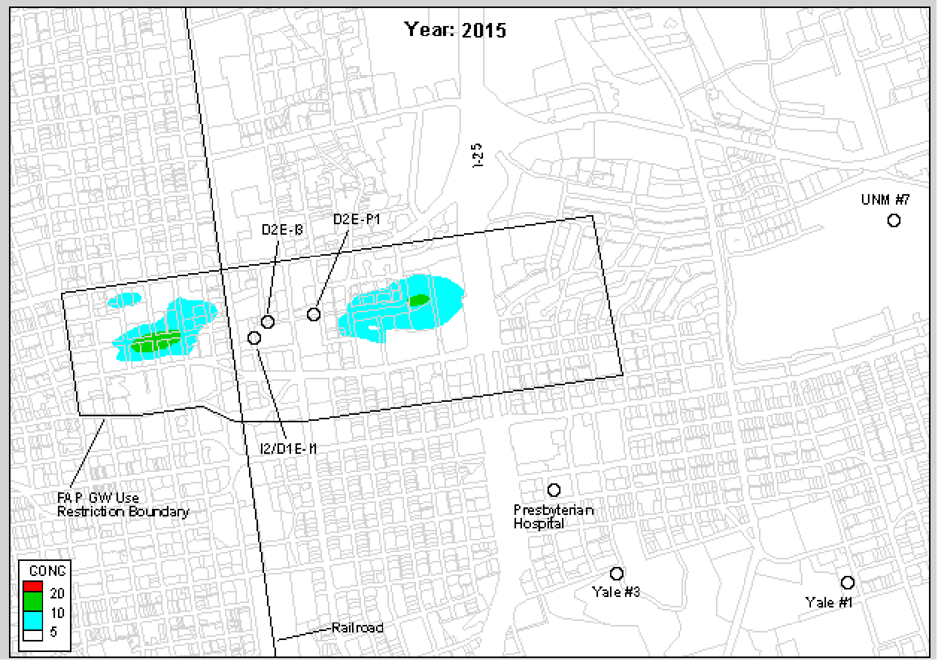


FIGURE 3-4B

Year 2020 Time Step From P&T System Remains on Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque, NM

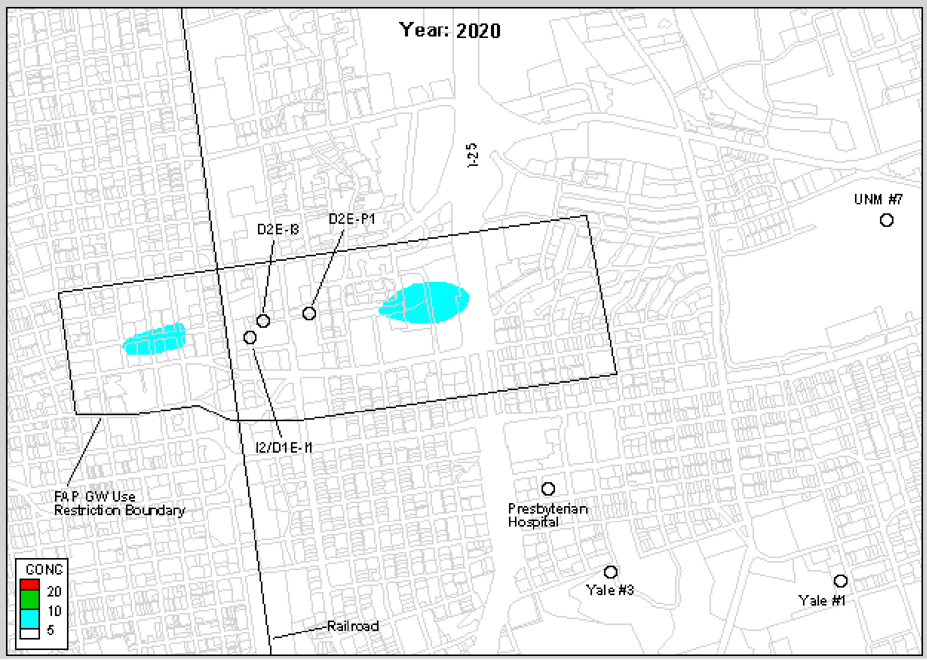


FIGURE 3-4C

Year 2025 Time Step From P&T System Remains On Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque, NM

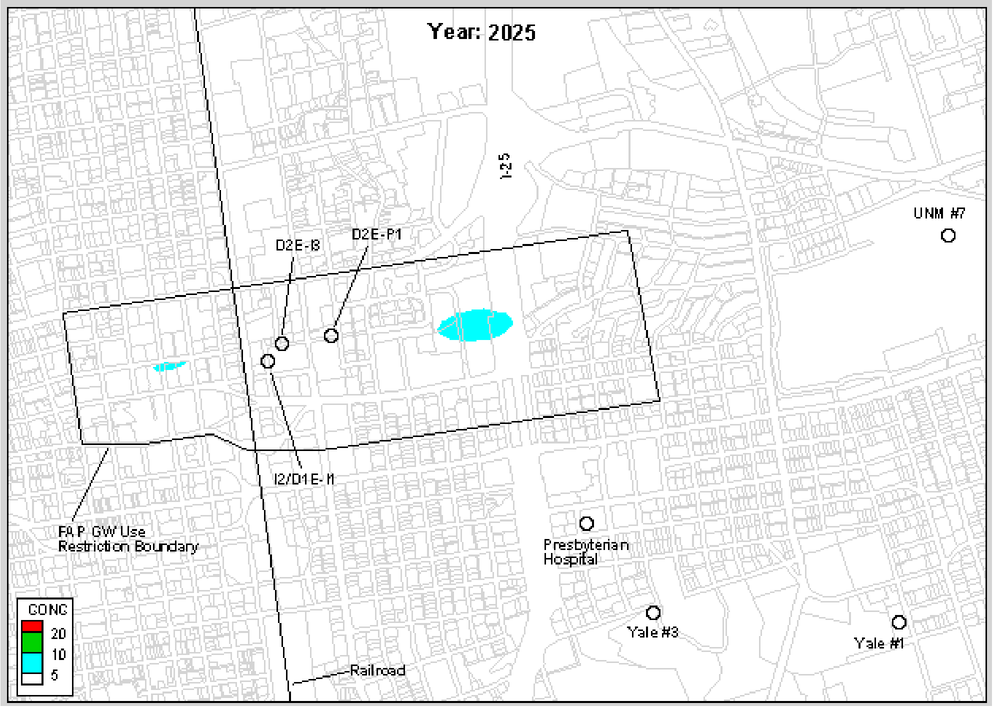


FIGURE 3-4D

Year 2030 Time Step From P&T System Remains On Base Case Scenario

Fruit Avenue Plume Superfund Site, Albuquerque, NM

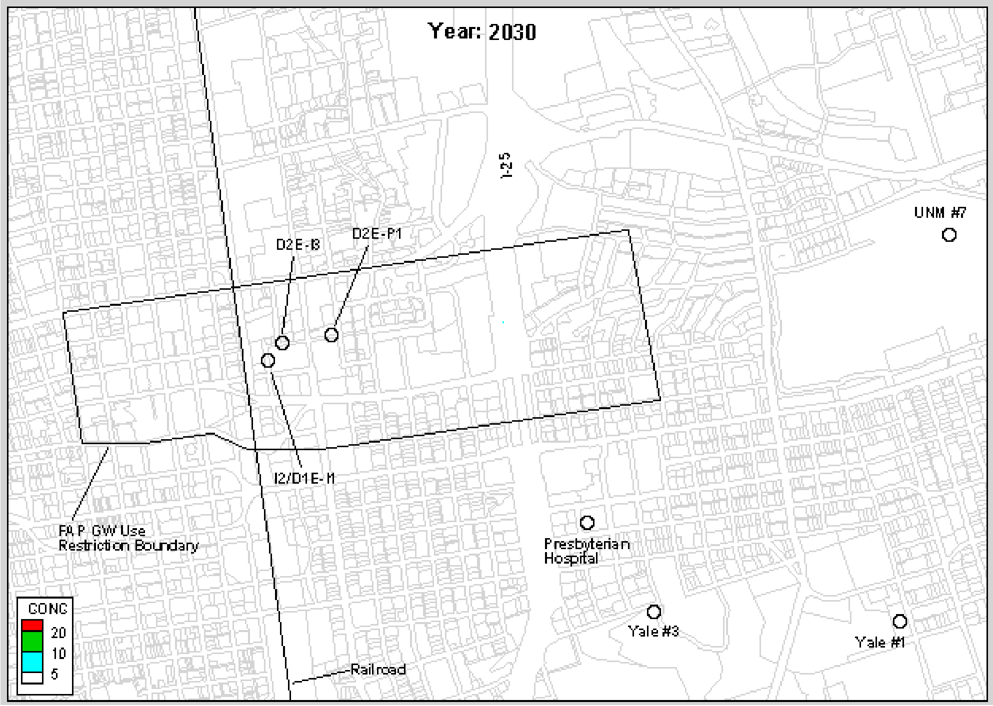
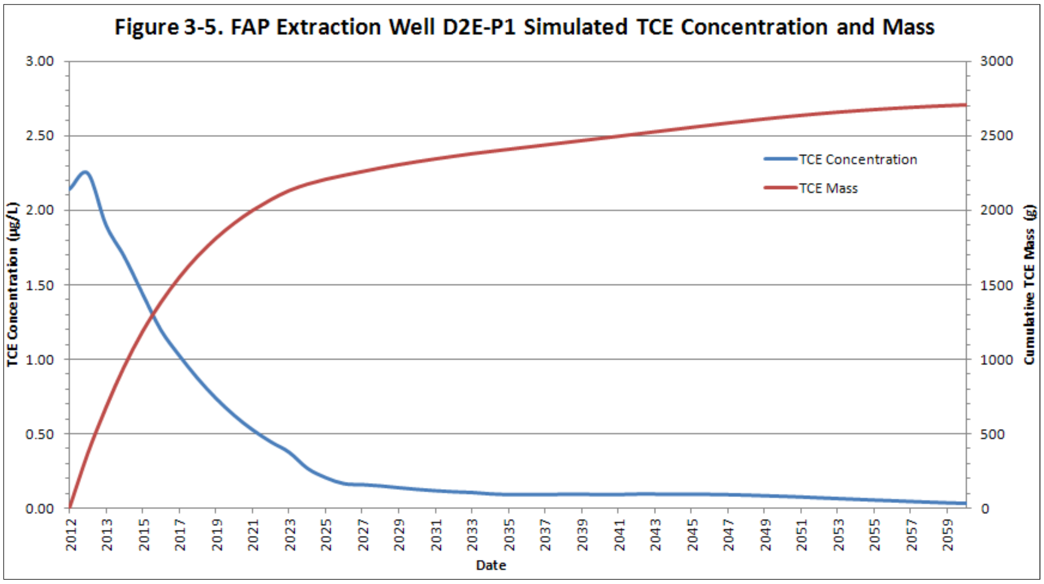


FIGURE 3-5

FAP Extraction Well D2E-P1 Simulated TCE Concentration and Mass

Fruit Avenue Plume Superfund Site, Albuquerque, NM



3.3 Sensitivity Analysis

The following six subsections summarize the simulation results for the sensitivity analysis scenarios. The contaminant transport parameters used for the various sensitivity analysis scenarios are presented in **Table 1-2**. The FAP remedial system was not operating past 2012 for these simulations. Simulation years 2015, 2020, 2025, and 2030 are presented in the figures, for these scenarios, and animations of the simulations are included as **Attachment 1** to this memorandum. For comparison purposes, the same time steps are presented for all these sensitivity analysis scenarios as was presented for the base case scenarios. The simulation years presented in the figures were chosen to be informative for the majority of the base case and sensitivity analysis scenarios. In both the figures and the animations, the maximum TCE concentration is projected to the surface within the horizontal and vertical boundaries of the model domain for better visualization. A summary of milestone dates is presented in **Table 3-1** to aid in the comparison of the performance of the base case and sensitivity analysis modeling scenarios. The milestones are the dates when TCE concentrations decrease to below 10 µg/L (in the source area and downgradient area), when TCE concentrations decrease to below 5 µg/L (in the source area and downgradient area), and when the TCE concentration of 5 µg/L crosses the FAP site groundwater use restriction boundary.

3.3.1 Low Dispersivity

Figures 3-6A through **3-6D** show selected time steps from the low dispersivity scenario simulation, which is characterized by longitudinal, transverse, and vertical dispersivities that are half of the base case dispersivities. The animation shows that the maximum TCE concentration in the plume is predicted to be less than 10 µg/L in the source area in 2021 and in the downgradient area in 2017. The maximum TCE concentration in the plume is predicted to be less than 5 µg/L in the source area in 2028 and in the downgradient area in 2032. A concentration of 5 µg/L is not predicted to reach the FAP groundwater use restriction boundary. When the low dispersivity scenario is compared to the base case scenario, the overall footprint of the plume is similar but the low dispersivity scenario shows slightly higher internal plume concentrations. Compared to the base case current remediation system scenario, concentrations above the TCE MCL appear to persist 2 years longer and migrate 150 feet further under the low dispersivity scenario. Further reduction in the dispersivity factors resulted in only small changes to the plume migration so the low dispersivity case is probably close to where dispersion is no longer a significant factor in the plume migration.

FIGURE 3-6A

Year 2015 Time Step From Low Dispersivity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

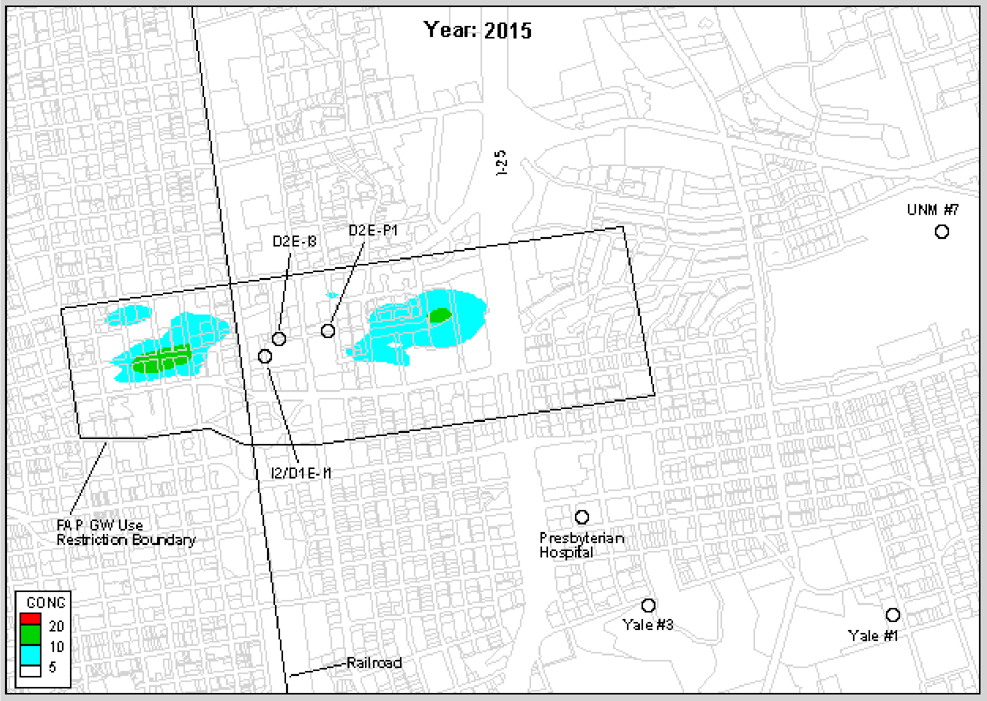


FIGURE 3-6B

Year 2020 Time Step From Low Dispersivity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

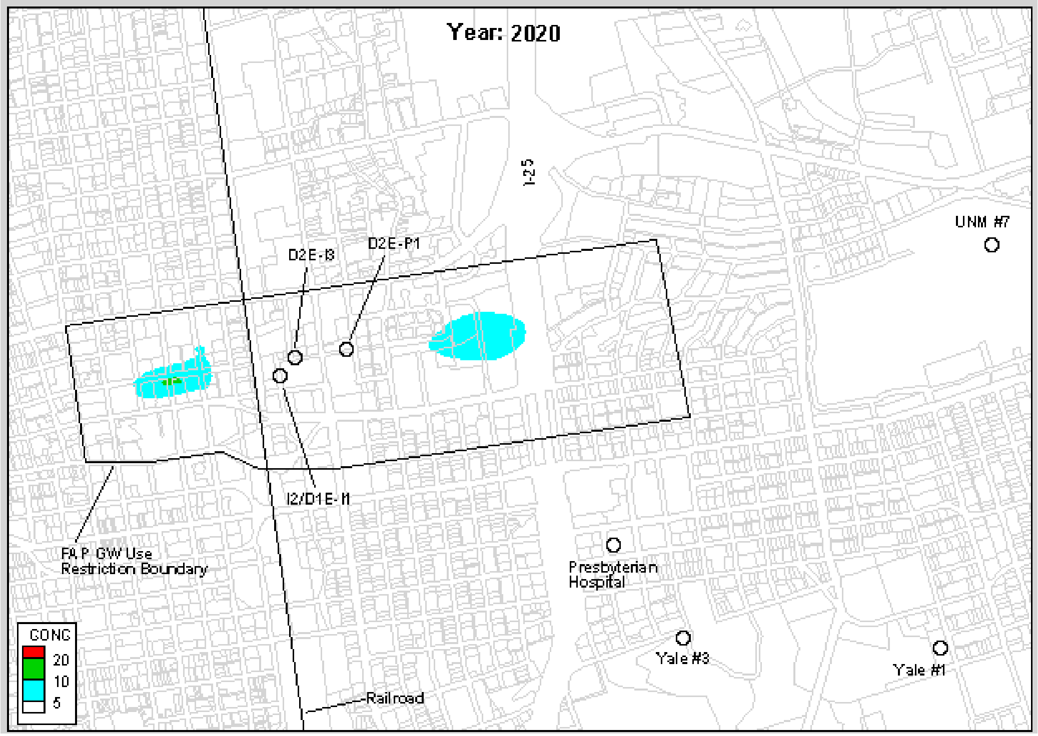


FIGURE 3-6C

Year 2025 Time Step From Low Dispersivity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

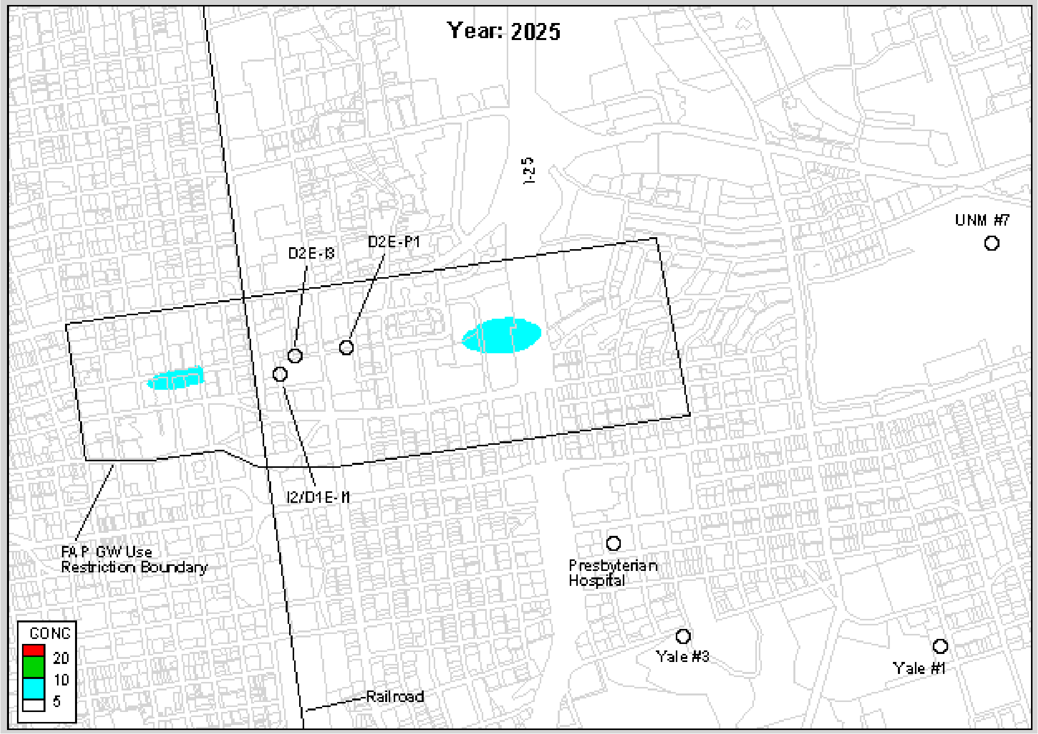
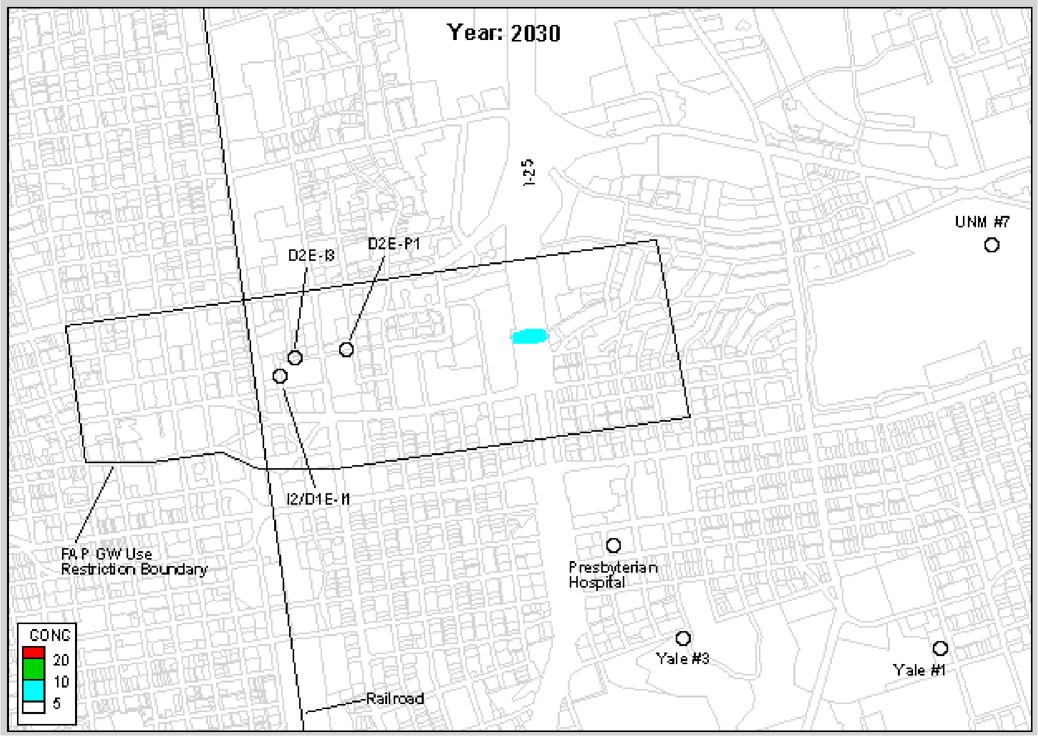


FIGURE 3-6D

Year 2030 Time Step From Low Dispersivity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque NM



3.3.2 Low Degradation

Figures 3-7A through 3-7D show selected time steps from the low degradation scenario simulation, which is characterized by a TCE degradation half-life of 63 years (the low degradation rate from the compound specific isotope analysis), which is approximately twice the base case TCE degradation half-life. The animation shows that the maximum TCE concentration in the plume is predicted to be less than 10 µg/L in the source area in 2019 and in the downgradient area in 2018. The maximum TCE concentration in the plume is predicted to be less than 5 µg/L in the source area in 2026 and in the downgradient area in 2037. A concentration of 5 µg/L is not predicted to reach the FAP groundwater use restriction boundary. Compared to the base case current remediation system scenario, concentrations above the TCE MCL appear to persist 7 years longer and migrate 550 feet further under the low degradation scenario.

FIGURE 3-7A

Year 2015 Time Step From Low Degradation Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

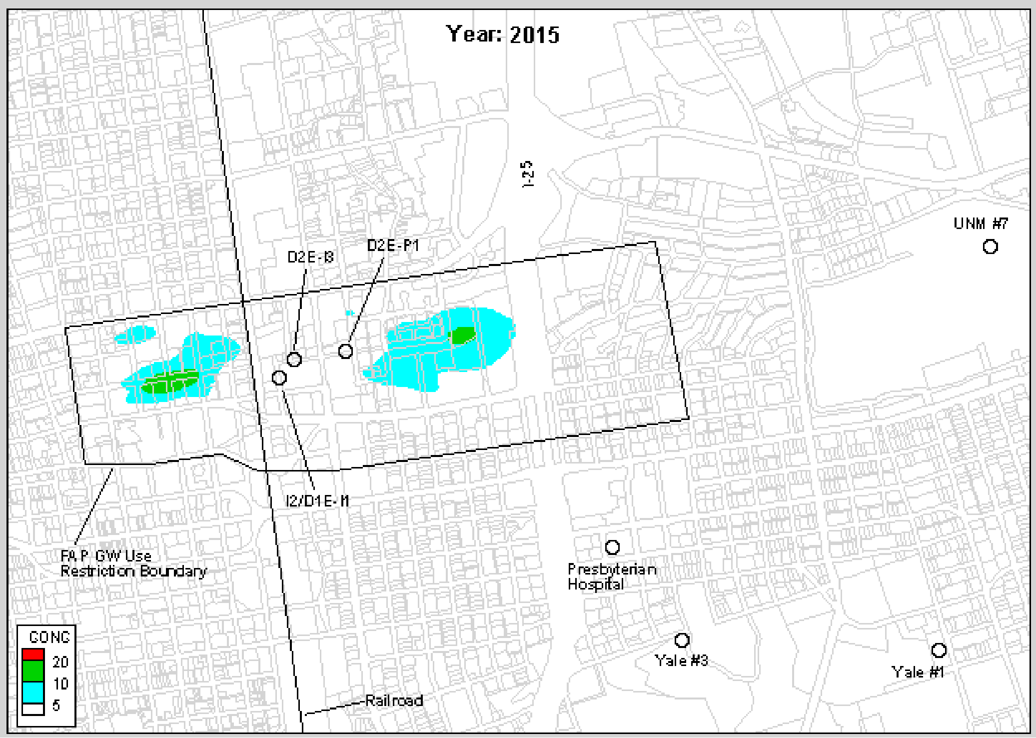


FIGURE 3-7B

Year 2020 Time Step From Low Degradation Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

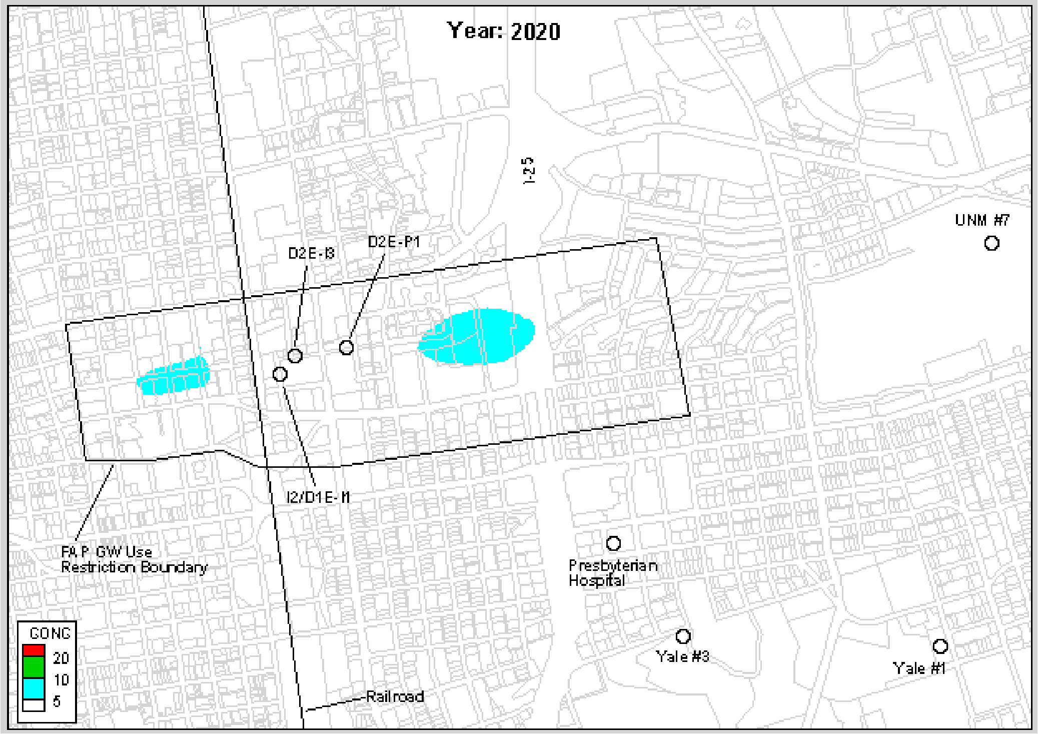


FIGURE 3-7C

Year 2025 Time Step From Low Degradation Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

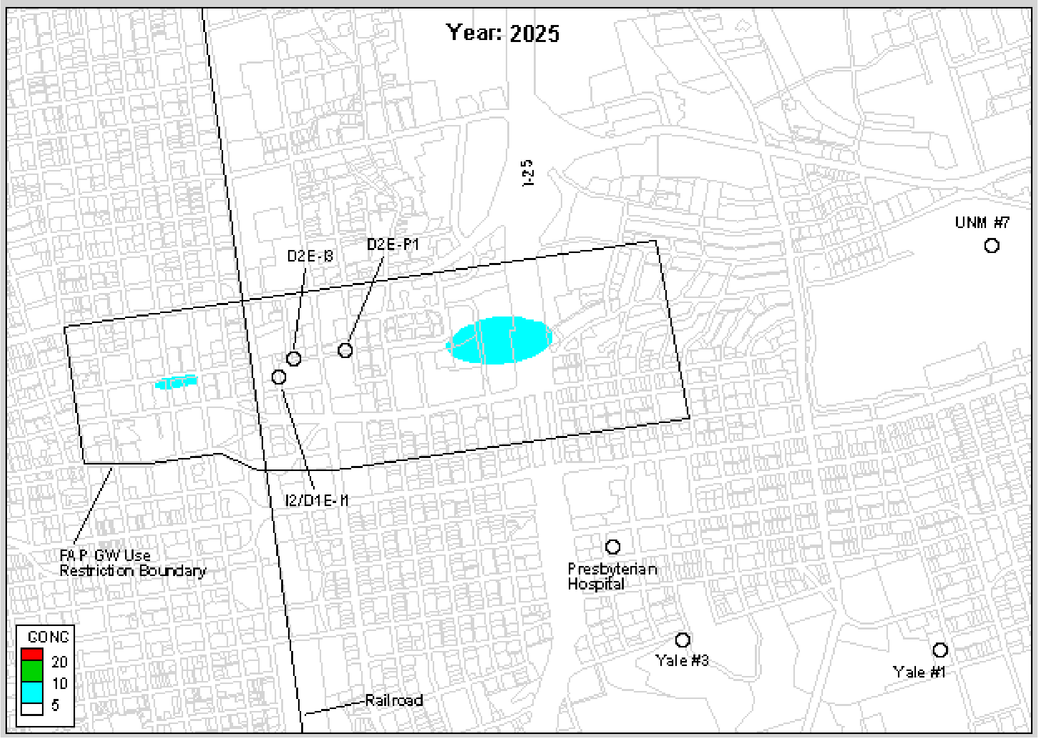
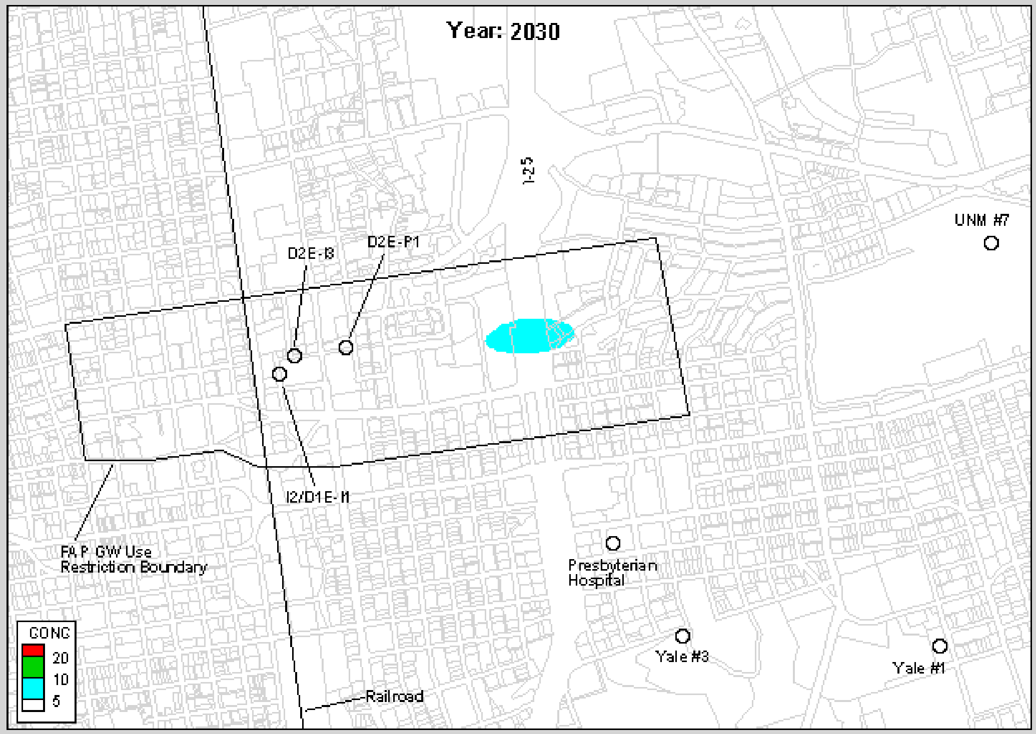


FIGURE 3-7D

Year 2030 Time Step From Low Degradation Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM



3.3.3 Low K_d

Figures 3-8A through 3-8D show selected time steps from the low K_d scenario simulation, which is characterized by a soil/water partition coefficient (K_d) that is approximately 30 percent of the base case K_d. The animation shows that the maximum TCE concentration in the plume is predicted to be less than 10 µg/L in the source area in 2017 and in the downgradient area in 2016. The maximum TCE concentration in the plume is predicted to be less than 5 µg/L in the source area in 2024 and in the downgradient area in 2029. A concentration of 5 µg/L is not predicted to reach the FAP groundwater use restriction boundary. Compared to the base case scenario, TCE concentrations appear to decrease slightly faster because the lower K_d causes less TCE to be adsorbed and results in a smaller retardation coefficient (1.10 compared to 1.33). Compared to the base case current remediation system scenario, concentrations above the TCE MCL appear to persist about the same amount of time and migrate about 50 feet further under the low K_d scenario.

FIGURE 3-8A

Year 2015 Time Step From Low K_d Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

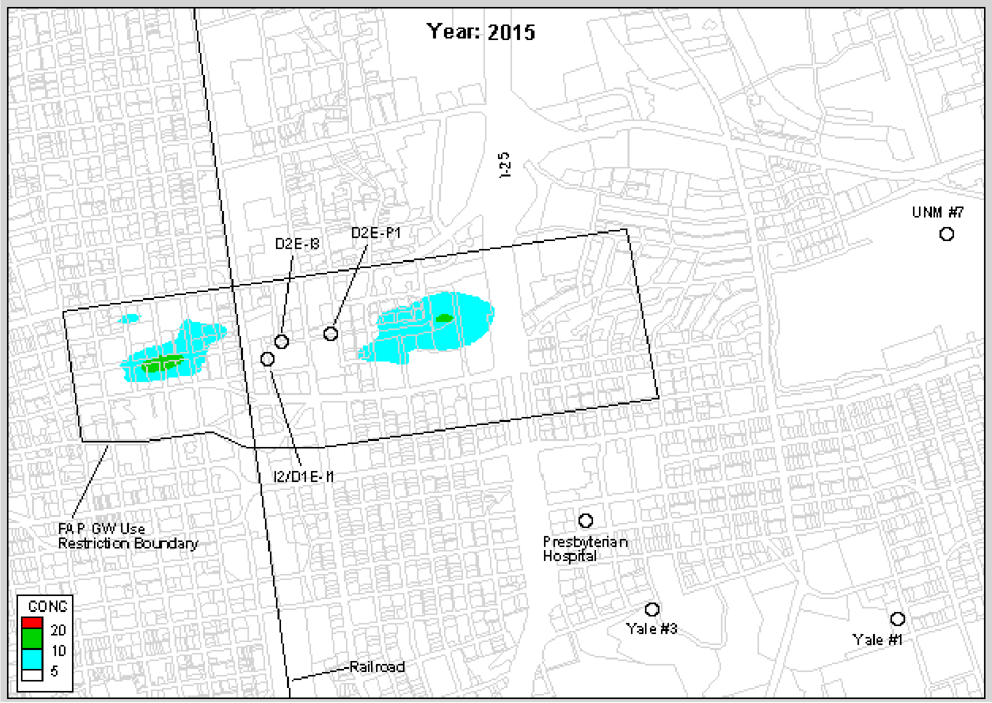


FIGURE 3-8B

Year 2020 Time Step From Low K_d Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

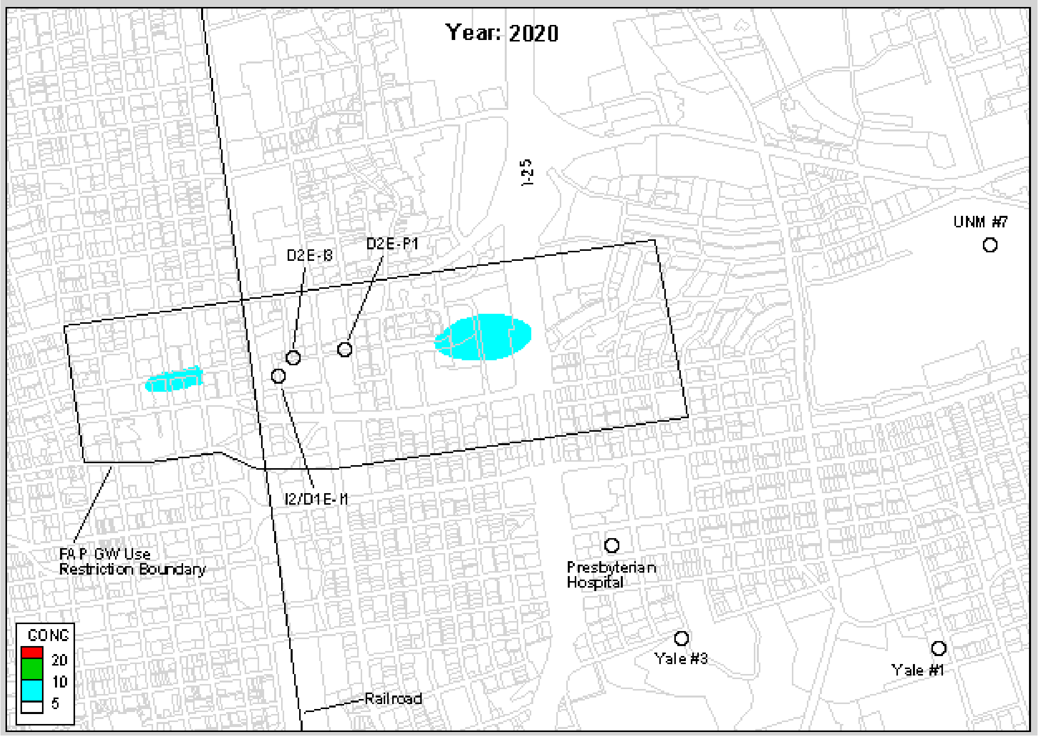


FIGURE 3-8C

Year 2025 Time Step From Low K_d Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

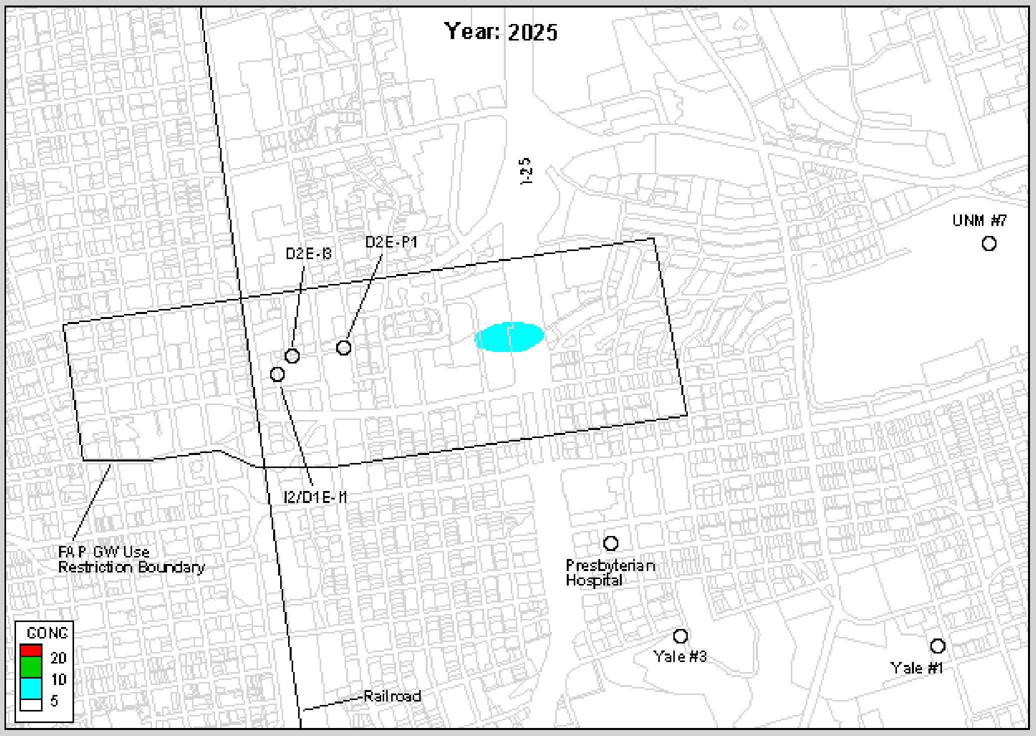
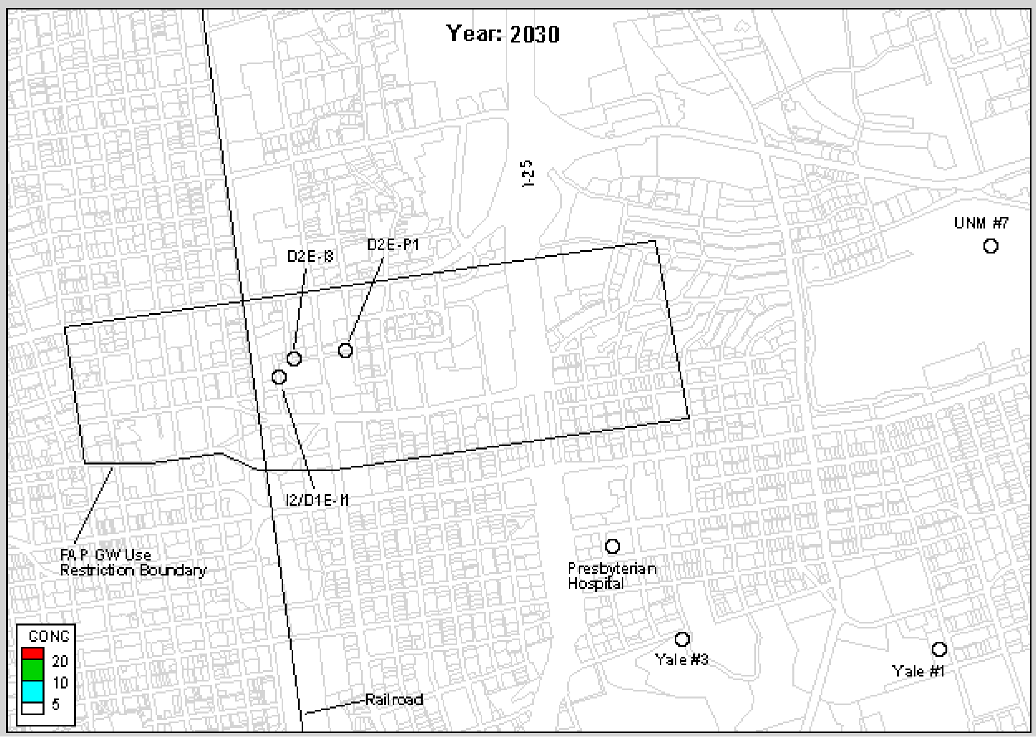


FIGURE 3-8D

Year 2030 Time Step From Low K_d Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM



3.3.4 No Degradation, Low Dispersivity, and Low K_d

Figures 3-9A through **3-9D** show selected time steps from the no degradation low dispersivity low K_d scenario simulation. This scenario has a TCE degradation rate of 0/year and dispersivities that are half of the base case dispersivities. The soil water partition coefficient is approximately 30 percent of the base case K_d, which corresponds to a retardation coefficient of 1.1 versus 1.33 for the base case. This scenario represents a worst-case simulation of the TCE migration. The animation shows that the maximum TCE concentration in the plume is predicted to be less than 10 µg/L in the source area in 2021 and in the downgradient area in 2023. The maximum TCE concentration in the plume is predicted to be less than 5 µg/L in the source area in 2029 and in the downgradient area in 2054. A concentration of 5 µg/L is predicted to reach the FAP groundwater use restriction boundary in 2038, but does not reach water supply well UNM #7. Compared to the base case current remediation system scenario, concentrations above the TCE MCL appear to persist about 24 years longer and migrate about 2,000 feet further under the no degradation low dispersivity low K_d scenario.

FIGURE 3-9A

Year 2015 Time Step From No Degradation Low Dispersivity Low K_d Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

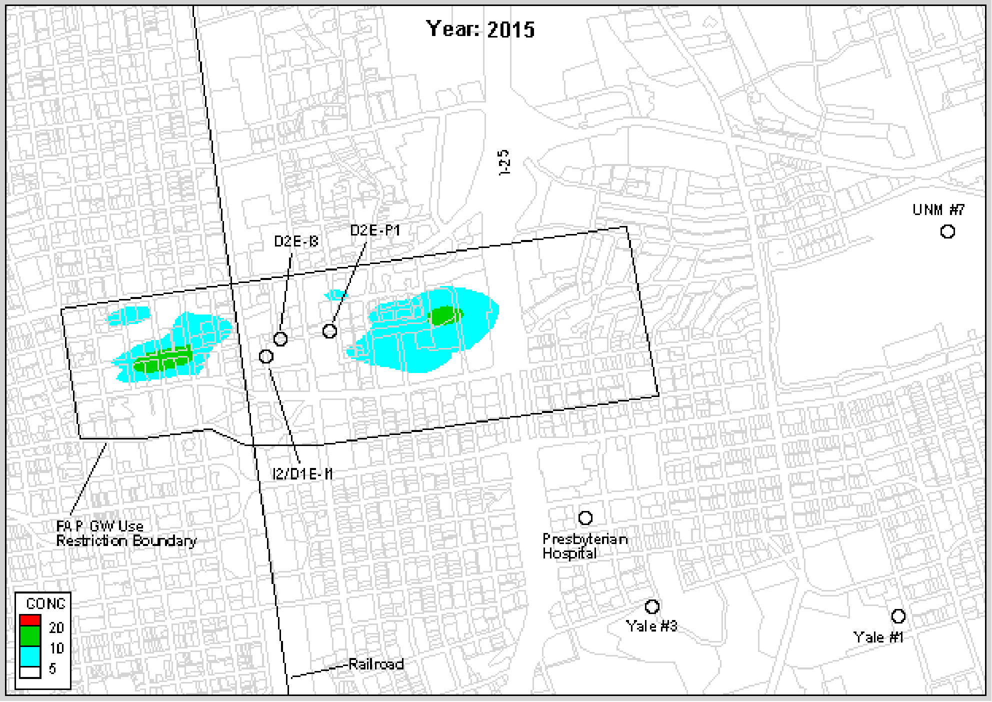


FIGURE 3-9B

Year 2020 Time Step From No Degradation Low Dispersivity Low K_d Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

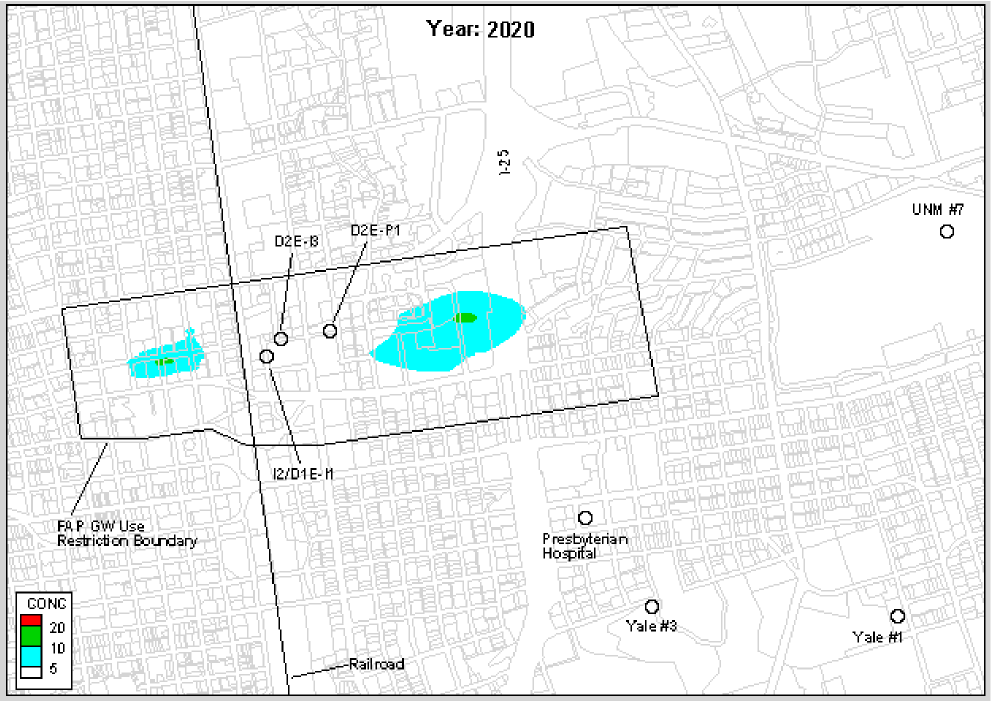


FIGURE 3-9C

Year 2025 Time Step From No Degradation Low Dispersivity Low K_d Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

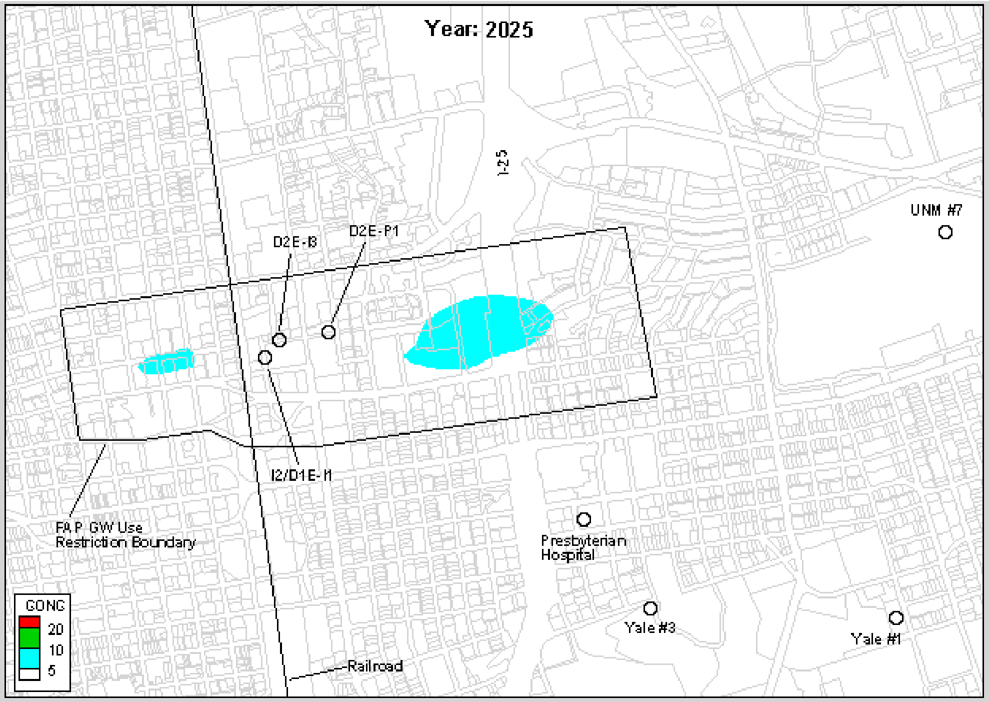
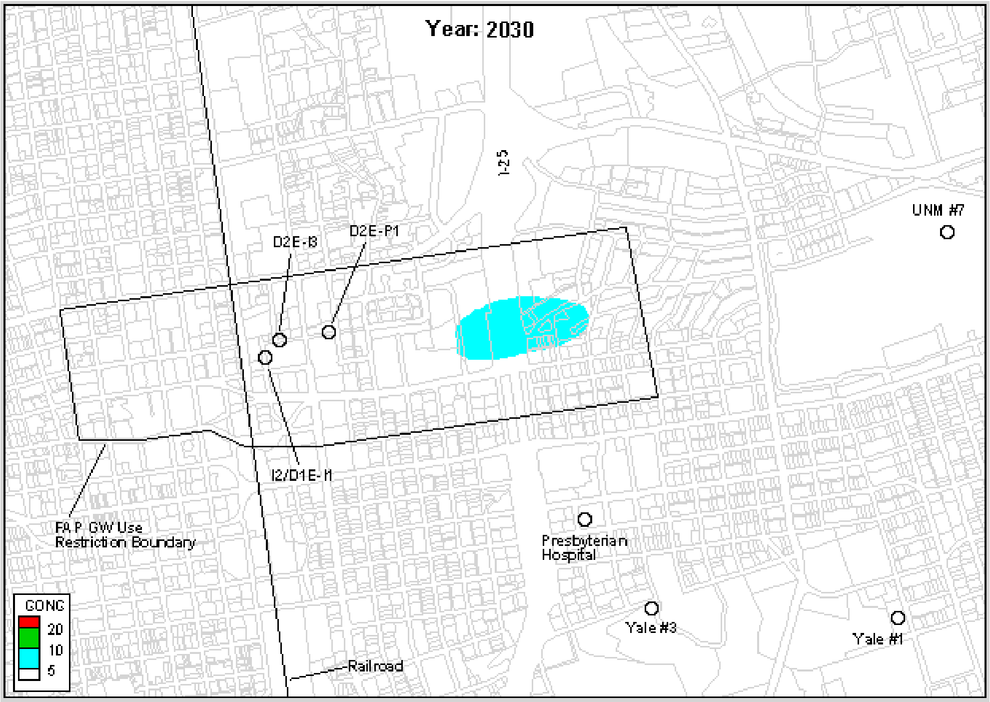


FIGURE 3-9D

Year 2030 Time Step From No Degradation Low Dispersivity Low K_d Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM



3.3.5 High Porosity

Figures 3-10A through **3-10D** show selected time steps from the high porosity scenario simulation, which is characterized by an effective porosity of 0.28 instead of 0.20 as in the base case scenario. Increasing the effective porosity primarily decreases the pore flow velocities and subsequently decreases the dispersivity, and to a lesser extent decreases the adsorbed contaminant mass in the model. The net effect is that contaminant mass migrates less far and persists longer. The animation shows that the maximum TCE concentration in the plume is predicted to be less than 10 µg/L in the source area in 2021 and in the downgradient area in 2017. The maximum TCE concentration in the plume is predicted to be less than 5 µg/L in the source area in 2028 and in the downgradient area in 2032. A concentration of 5 µg/L is not predicted to reach the FAP groundwater use restriction boundary. When the high porosity scenario is compared to the base case scenario, the overall plume footprint is larger and the areas with concentrations above the MCL are larger due to the smaller pore velocities and accompanying smaller dispersivities. Compared to the base case current remediation system scenario, concentrations above the TCE MCL appear to persist about 2 years longer and migrate about 100 feet less far under the high porosity scenario.

FIGURE 3-10A

Year 2015 Time Step From High Porosity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

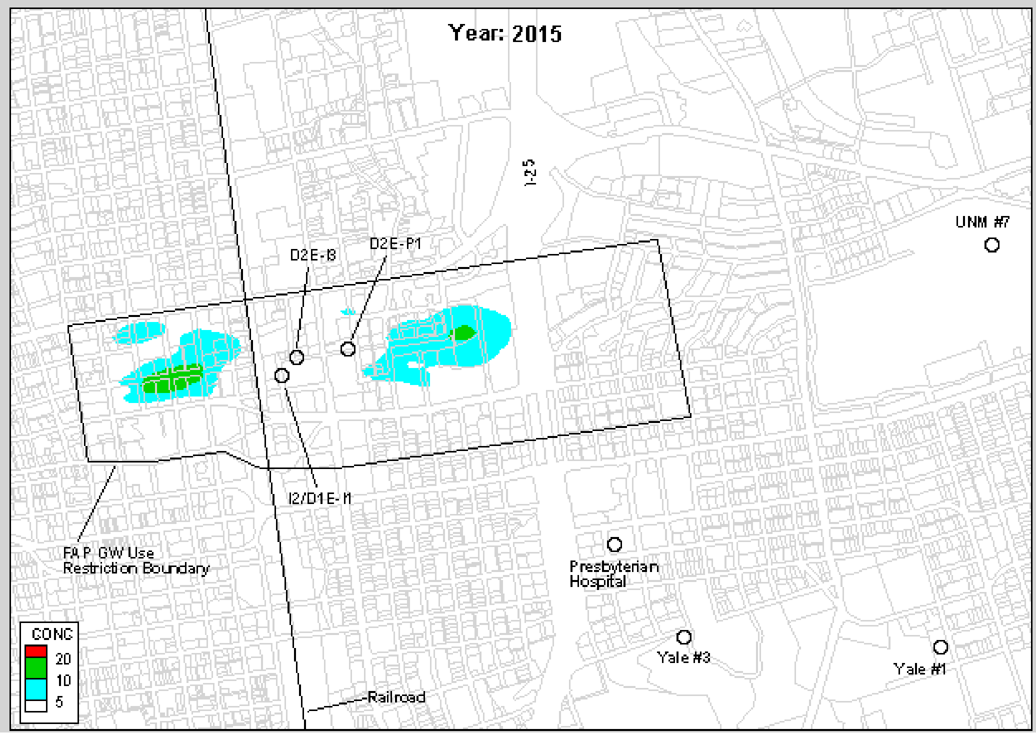


FIGURE 3-10B

Year 2020 Time Step From High Porosity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

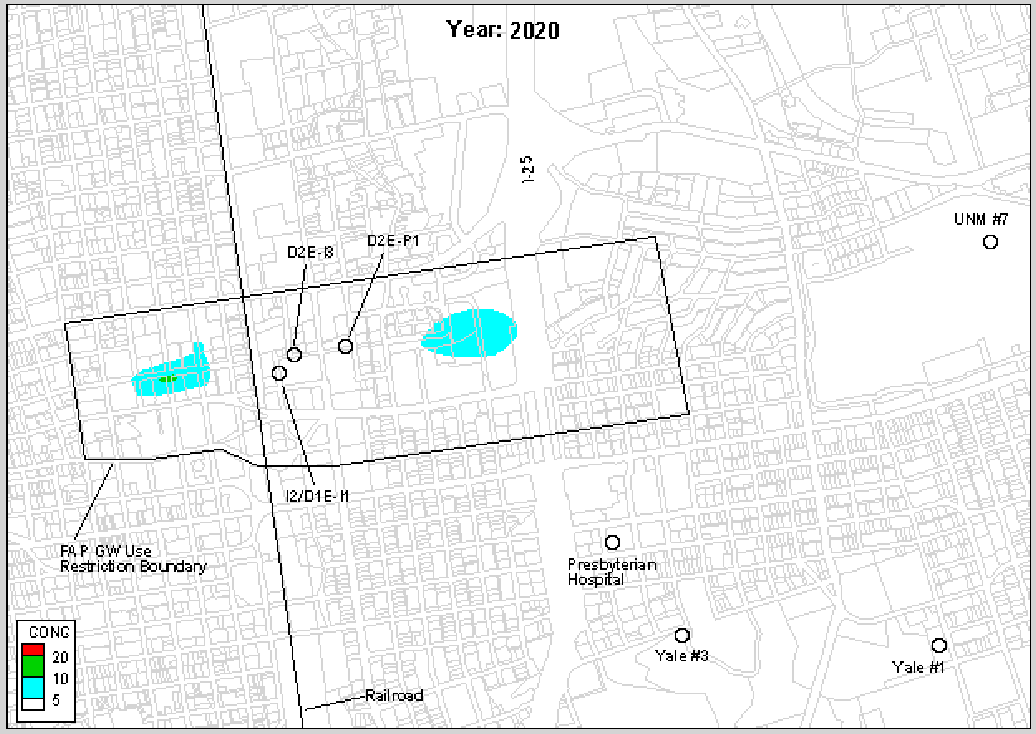


FIGURE 3-10C

Year 2025 Time Step From High Porosity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

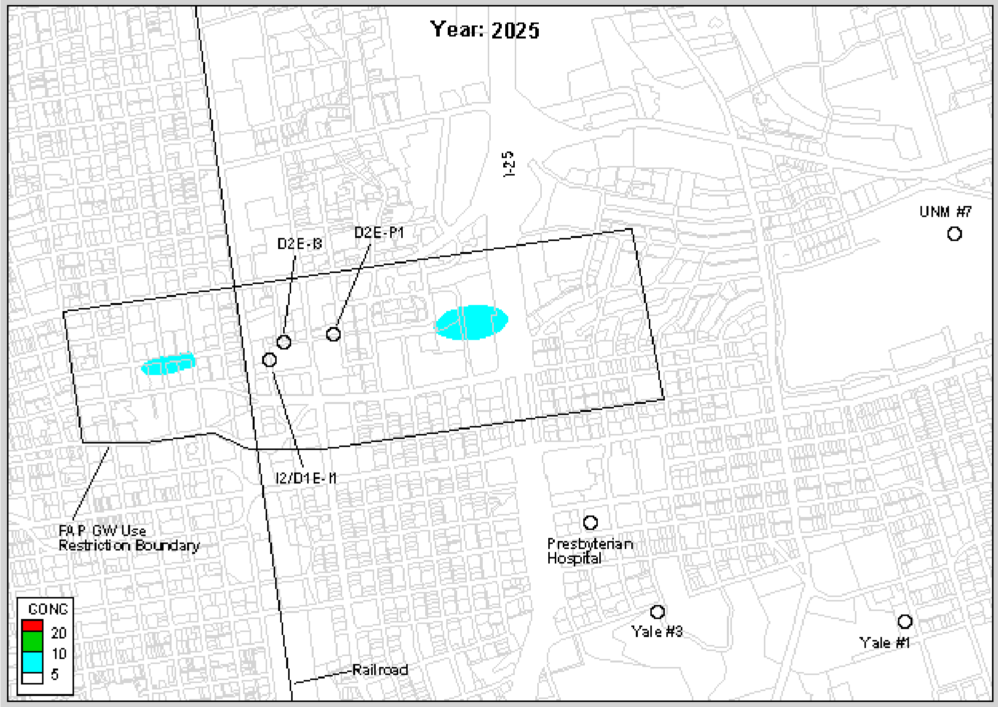
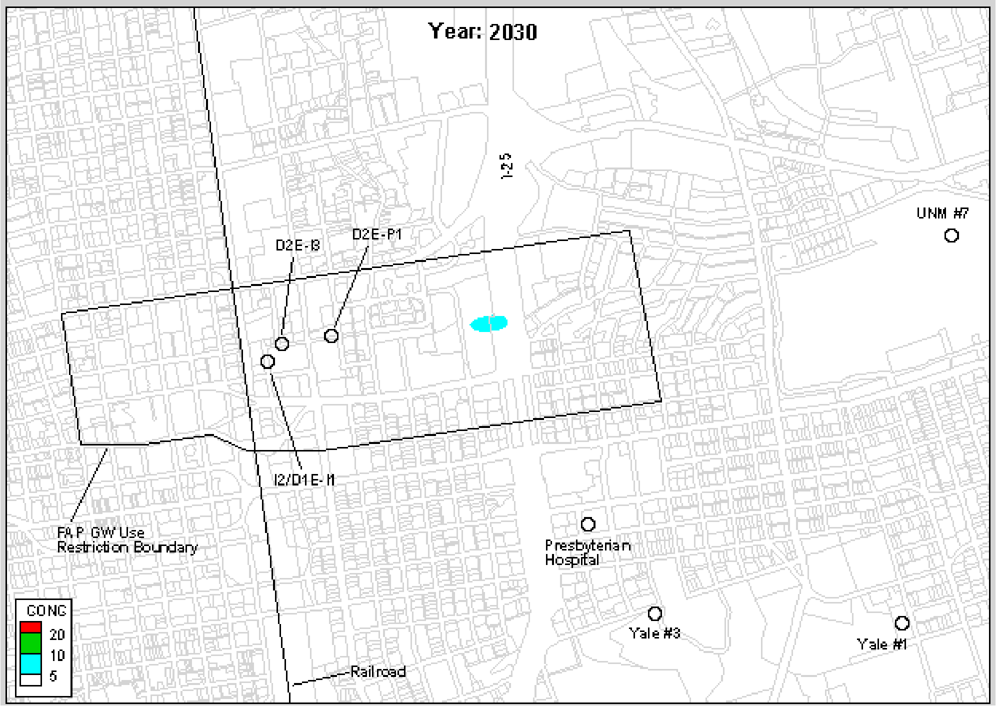


FIGURE 3-10D

Year 2030 Time Step From High Porosity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque NM



3.3.6 Low Porosity

Figures 3-11A through **3-11D** show selected time steps from the low porosity scenario simulation, which is characterized by an effective porosity of 0.13 instead of 0.20 as in the base case scenario. Decreasing the effective porosity primarily increases the pore flow velocities and subsequently increases the dispersivity, and to a lesser extent increases the adsorbed contaminant mass in the model. The net effect is that contaminant mass migrates farther, faster, and disperses more rapidly. The animation shows that the maximum TCE concentration in the plume is predicted to be less than 10 µg/L in the source area in 2017 and in the downgradient area in 2016. The maximum TCE concentration in the plume is predicted to be less than 5 µg/L in the source area in 2022 and in the downgradient area in 2028. A concentration of 5 µg/L is not predicted to reach the FAP groundwater use restriction boundary. When the low porosity scenario is compared to the base case scenario, the overall plume footprint is smaller and the areas with concentrations above the MCL are smaller due to the larger pore velocities and accompanying larger dispersivities. Compared to the base case current remediation system scenario, concentrations above the TCE MCL appear to persist about 2 years shorter and migrate about 100 feet further under the low porosity scenario.

FIGURE 3-11A

Year 2015 Time Step From Low Porosity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

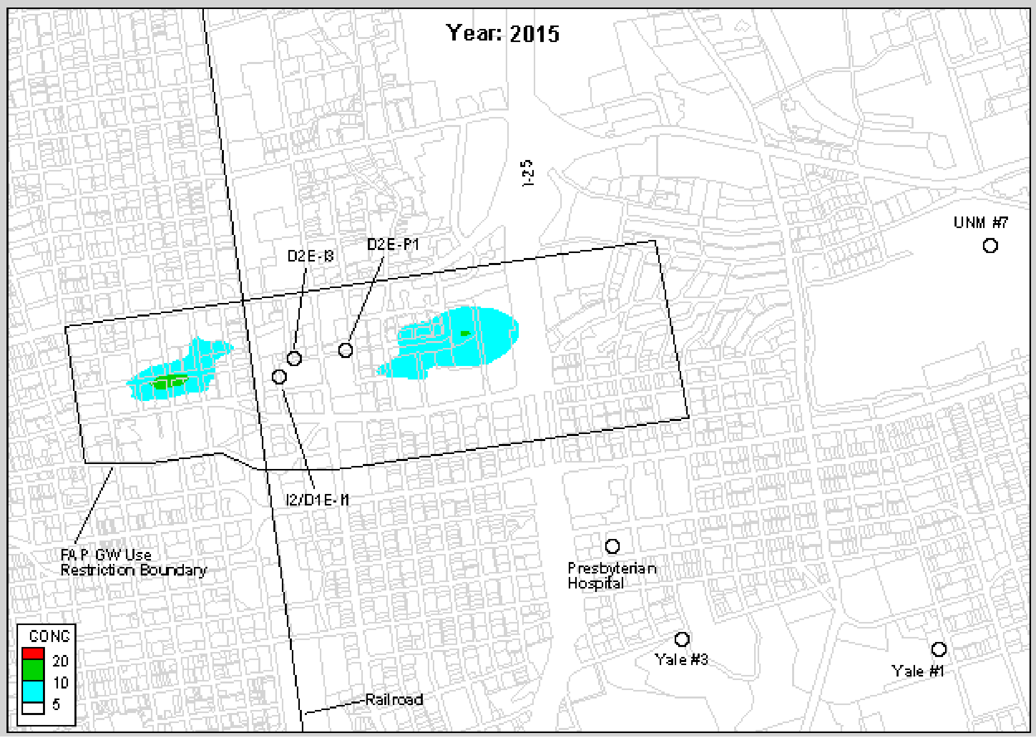


FIGURE 3-11B

Year 2020 Time Step From Low Porosity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

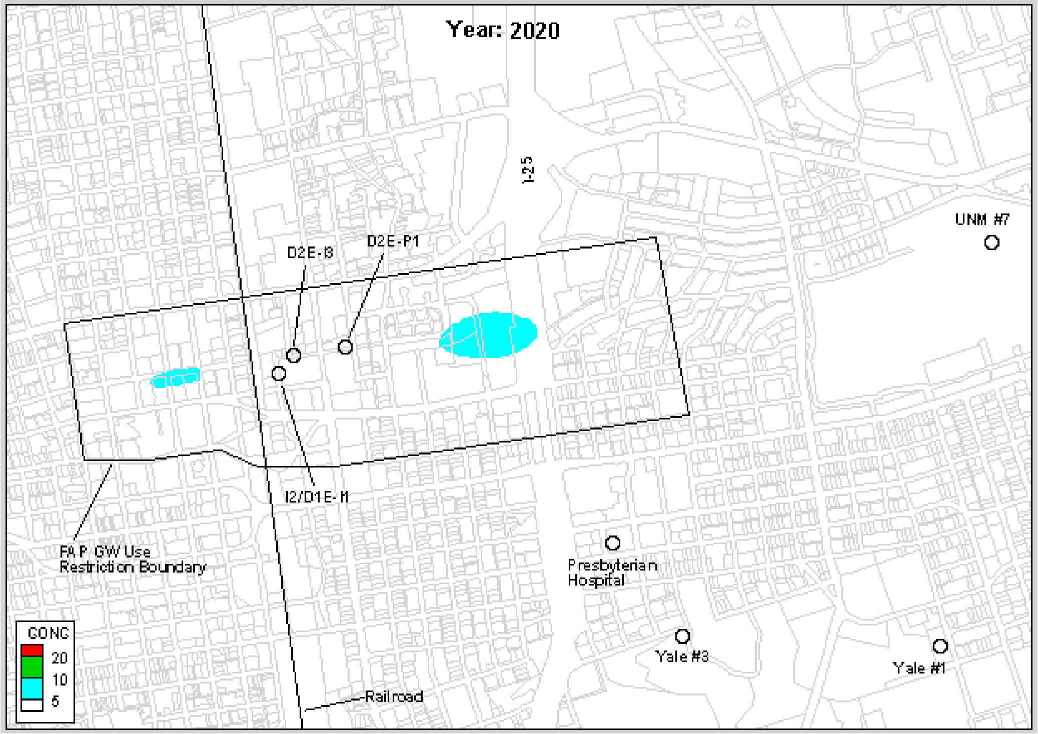


FIGURE 3-11C

Year 2025 Time Step From Low Porosity Sensitivity Scenario Animation

Fruit Avenue Plume Superfund Site, Albuquerque, NM

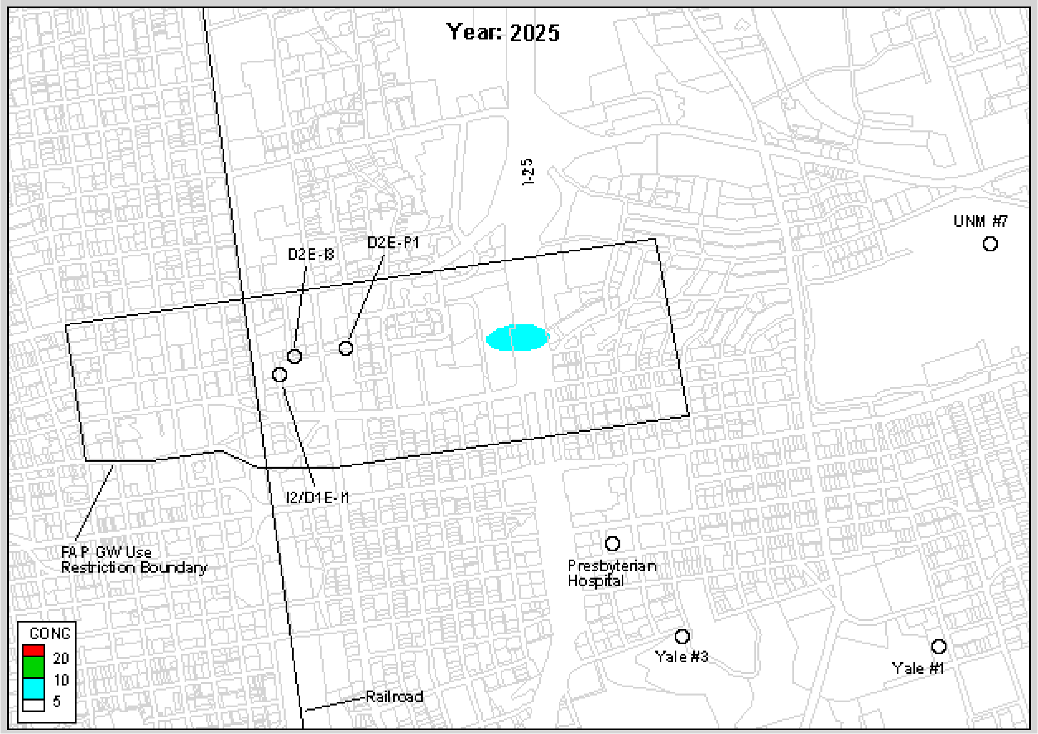
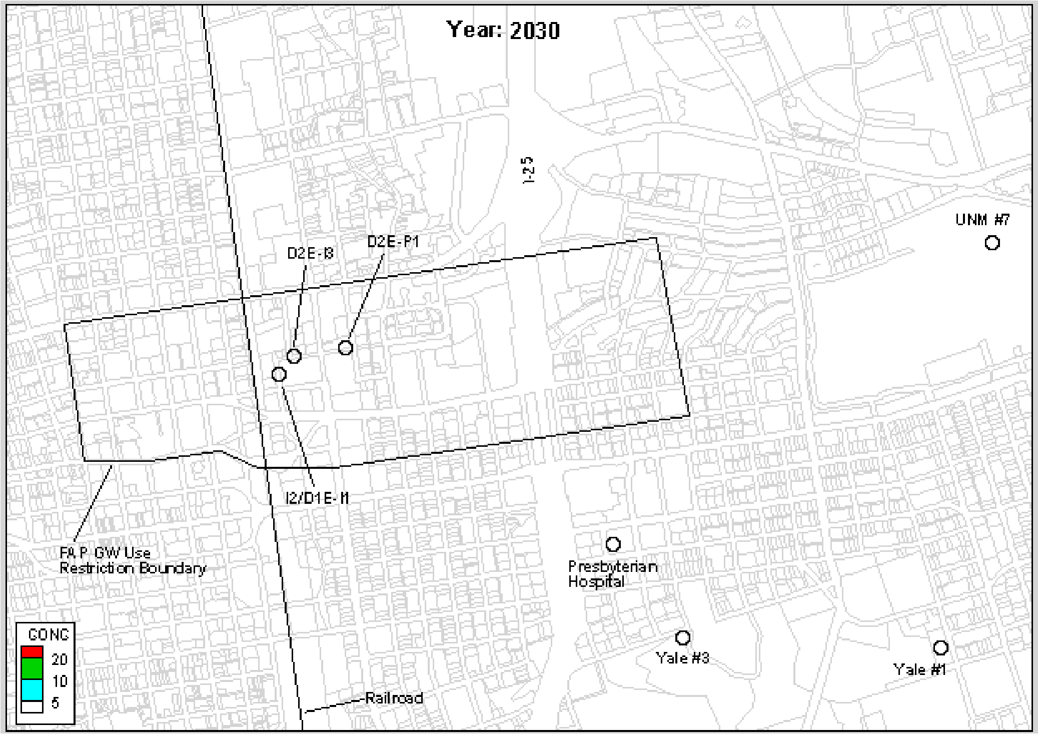


FIGURE 3-11D
Year 2030 Time Step From Low Porosity Sensitivity Scenario Animation
Fruit Avenue Plume Superfund Site, Albuquerque, NM



4. Uncertainties

It should be noted that in addition to the uncertainty regarding transport parameters such as degradation rate, dispersivity, and effective porosity, there is inherent uncertainty in the FAP conceptual model that could lead to different conclusions than those stated previously. Installation of new monitor well MNW-16 indicates that the plume has not migrated further east than expected; therefore, the current conceptual site model has been validated. Likewise, if there is a continuing source in the presumed source area, additional mass would continue to be released to the groundwater, resulting in more persistent and widespread TCE concentrations. While the effects of a residual vadose zone source won't be fully known until water levels rise further, in response to regional declines in groundwater pumping, comprehensive groundwater monitoring in the presumed source area and elimination of source area remedial actions in the Explanation of Significant Differences (EPA, 2006) indicates the potential for a residual source is low. Therefore, the model simulations presented provide reasonable projections of future TCE plume behavior for the site.

5. Conclusions

The following conclusions can be drawn from this analysis:

- Under the base case scenario, with the P&T system turned off in 2012 and assuming there is no continuous source, a 5 µg/L or greater TCE concentration is not predicted to reach the FAP site groundwater use restriction boundary.
- The maximum projected TCE concentrations within the model domain achieve the 5 µg/L remedial goal in 2030 and 2031 for the base case P&T system off and the P&T system on scenarios, respectively. Comparison of the two scenarios indicates there is no improvement in aquifer restoration timeframe from continued operation of the FAP P&T system.

- The current remediation system does not provide complete hydraulic capture of the TCE plume, and it is predicted to recover approximately 10.2 percent of the initial dissolved TCE contaminant mass after 49 years of pumping.
- Under the base case scenario, with the P&T system turned off in 2012, 80 percent of the initial total contaminant mass is predicted to be lost to degradation over 49 years of simulation. With the P&T system on, 76 percent of the initial total contaminant mass is predicted to be lost to degradation over 49 years of simulation.
- The predicted migration of the TCE plume is more sensitive to changes in the degradation rate and porosity, and less sensitive to changes in the dispersivity and soil/water partition coefficient. The sensitivity analysis illustrates that within a range of reasonably expected values for contaminant transport parameters, all TCE concentrations are expected to achieve the 5 µg/L remedial goal between 2028 and 2037 if the P&T system is turned off in 2012.
- Under the worst case scenario, with the P&T system turned off in 2012, and with no degradation, low dispersivity, and low soil/water partition coefficient, a 5 µg/L or greater TCE concentration is predicted to reach the FAP site groundwater use restriction boundary in 2038. However, a 5 µg/L or greater TCE concentration is not predicted to reach the nearest operating water supply well (UNM #7).

6. Works Cited

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Attachment 1
TCE Plume Shell Transport Animations (Provided on DVD)

Attachment 1, TCE Plume Shell Transport Animations is provided on the DVD submitted with this report.

TARGET SHEET

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Appendix K
Aquifer Test Results

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Fruit Avenue Plume Superfund Site Long-Term Remedial Action Appendix K - Aquifer Test Results

PREPARED FOR:	Bartolomé Cañellas /EPA Region 6 Remedial Project Manager
PREPARED BY:	CH2M HILL
DATE:	October 2012
PROJECT:	EPA Region 6 Remedial Action Contract W-EP-06-021 Task Order No. 0003-RALR-06DD CH2M HILL Project No. 345406.PJ.14
DCN:	0003-02091

This memorandum documents the analysis of aquifer test data that were collected during the Fruit Avenue Air Stripper Treatment Plant (ASTP) system shutdown, which took place between May 29 and June 14, 2012. The ASTP includes both an extraction well (D2E-P1) and three injection well screens at two locations (I2/D1E-I1 and D2E-I3). The ASTP had been running for several weeks prior to data collection. During the estimation period, both injection and extraction wells were shut down. As expected, at the start of the estimation period, water levels decreased in monitor wells nearest the injection wells and increased in monitor wells nearest the extraction well.

Groundwater pressure heads were measured at 10-minute intervals from 11 monitoring wells (**Figure 1**) between May 23 and June 22, 2012 using pressure transducers that were installed in each monitoring well. Atmospheric barometric pressure data also were gathered using a similar pressure transducer, over the same interval, and with the same frequency. Pumping and injection rate data for the ASTP wells were collected at 10-minute intervals throughout the aquifer test.

TABLE 1
Pumping Rates Before, During and After ASTP Shut-Down
Fruit Avenue Plume Superfund Site, Albuquerque NM

Time Period	Dates	Pumping Well D2E-P1	Single Injection Well D2E-I3	Dual Injection Well I2/D1E-I1
Pre-ASTP Shutdown	May 20 through May 29, 2012	81	39.5	40.6
During ASTP Shutdown*	May 29 through June 14, 2012	0	0	0
Post ASTP Shutdown	June 14 through June 22, 2012	78	40	39

Note: All pumping and injection rates are in gallons per minute (gpm)
*The ASTP shutdown was from approximately 11:30 a.m. May 29 to approximately 4:00 p.m. June 14, 2012.

Data Analysis

The following sections describe the process that was followed to analyze the aquifer test data and thereby generate sitewide estimates of aquifer hydraulic properties.

Deconvolution

In order to clarify the effects of the treatment system shutdown and restart on water level measurements, the pressure transducer data were processed via deconvolution. This involves the creation of an empirical model of pre- and post- aquifer test transducer data, so estimates can be calculated of what the aquifer water levels would

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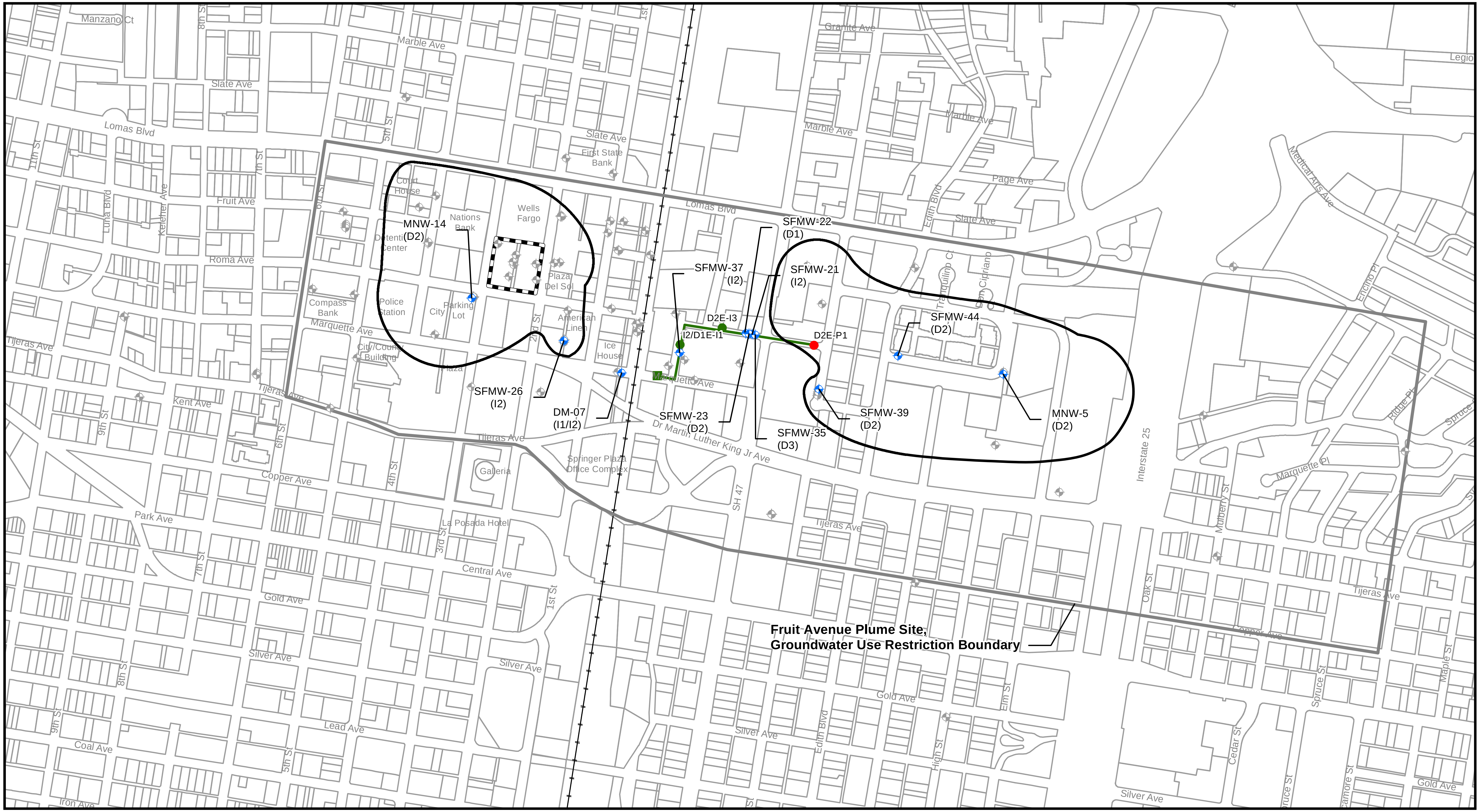

LEGEND

- ✦ D4 Zone Monitor Well
- ✦ Other Site Monitor Well
- ▨ Presumed Source Area
- 🔴 Extraction Well
- 🟩 Air Stripper Treatment Plant
- ● Injection Well
- ┼ Railroad
- ━ FAP TCE Composite Plume Boundary at 5 ug/L (dashed where inferred). The upgradient TCE plume located west of the Site is not shown. This plume is not part of FAP Site.

Aquifer Zones:

S- Shallow Aquifer Zone - Above 4912 ft MSL
I1- Intermediate 1 Aquifer Zone - 4912 ft to 4872 ft MSL
I2- Intermediate 2 Aquifer Zone - 4872 ft to 4847 ft MSL
D1 - Deep 1 Aquifer Zone - 4847 ft to 4752 ft MSL
D2 - Deep 2 Aquifer Zone - 4752 ft to 4647 ft MSL
D3 - Deep 3 Aquifer Zone - 4647 ft to 4552 ft MSL
D4 - Deep 4 Aquifer Zone - 4552 ft to 4400 ft MSL

FIGURE 1
Aquifer Test Pumping, Injection, and Monitor Wells
February 2012
Fruit Avenue Plume Superfund Site
Albuquerque, NM

J:\FRUITAVENUE_345406\MAPFILES\FEB_2012\UPDATE\AQUIFER_TEST_PUMPING.MXD FLONDON 9/4/2012 10:44:34 AM

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have been if the aquifer test had never occurred. That calculated time series is referred to as a synthetic water level data series.

The synthetic water level data are formed from a linear combination of the background forces that are known to cause groundwater fluctuations not related to the aquifer test. The types of background forces that are typically incorporated into the synthetic data include barometric pressure, stages of nearby rivers, tidal influences, effects of other surface water bodies, and groundwater pumping that is unrelated to the aquifer test. The term "noise" has been borrowed from signal processing to describe groundwater fluctuations due to these background forces, to differentiate these fluctuations from the desired "signal" fluctuations that are due to the aquifer test. Thus, the purpose of deconvolution is to remove the background noise in the water level measurements from the measured groundwater fluctuations so that the signal of the aquifer test can be evaluated more clearly. For more details on the deconvolution process, and on the particular utility that was used to perform this analysis, please refer to the US Geological Survey *Scientific Investigations Report* 2006-5024 (Halford, 2006).

For the Fruit Avenue aquifer test, it was known that barometric pressure and groundwater pumping rate variations at regional water supply wells could potentially impact the aquifer test. Because the site and treatment system are in downtown Albuquerque (with other groundwater pumping nearby), it also was possible that unforeseen or unknown influence could have been exerted upon water levels during the aquifer test. For this reason, two background monitoring wells, MNW-5(D2) and MNW-14(D2), were instrumented with pressure transducers. These are wells that were thought to be far enough away from the pumping and injection that water levels in them would be unaffected by the ASTP shutdown and restart. Thus, groundwater fluctuations within them should only reflect background forces and, therefore, these fluctuations could be used as a proxy estimate for the effects of the background forces upon water levels in monitoring wells that are closer to the ASTP.

However, it turned out that pressure head time series from MNW-5(D2) showed sudden changes at the times of the ASTP system shutdown and restart. For this reason, it was included in the aquifer test analysis as a non-background monitoring well. The pressure heads at MNW-14(D2) showed no such sudden fluctuations; therefore, MNW-14(D2) was used as the sole background well.

Figures 2 through **10** show the measured and synthetic pressure data from the monitoring wells in which drawdown was detectable. Several data series are included on each figure so the relative timing of events and fluctuations can be compared between series. The data series include measured pressure heads, synthetic pressure heads, inferred drawdowns (which are the measured pressure heads minus the synthetic pressure heads, inverted so that drawdown increases as water levels decrease), the barometric pressure, background water level fluctuations from MNW-14, and the pumping series from ASTP extraction well D2E-P1. The ASTP injection wells were shut off and restarted at approximately the same time, so including their injection rates on the figures would serve little illustrative purpose.

Most of the deconvolutions for this aquifer test follow a similar pattern, which **Figure 2** (for monitoring well DM-07) illustrates. Prior to the pump shutdown, the measured pressure heads (the purple series) fluctuated a few tenths of an inch of water. Then they drop or rise precipitously at pump shutdown (depending upon the proximity of the monitor wells to an injection or extraction well), and continue to drop throughout most of the 17-day shutdown. At pump restart, the measured pressure heads recover, but not to their pre-aquifer test levels.

Without creating a synthetic pressure head series from the barometric pressure and background water levels, the task of estimating how much of the pressure head drop is due to the change in pumping would be subjective. However, with the synthetic pressure heads (blue series), the regional decline in water levels can be subtracted from the aquifer test data. The result is a drawdown series (in red) that levels out much more quickly and suggests less storage in the aquifer system than would result from estimating drawdowns from the raw measured pressure heads.

The pressure head series from a few of the wells indicated little or no detectable drawdown, even after deconvolution. This includes monitoring wells SFMW-21(I2), SFMW-22(D1), and SFMW-23(D2), which are between injection well D2E-I3 and injection well D2E-P1. This may indicate that the influences of the injection and pumping wells largely cancel each other out in this vicinity. SFMW-22(D1), in particular, had no detectable

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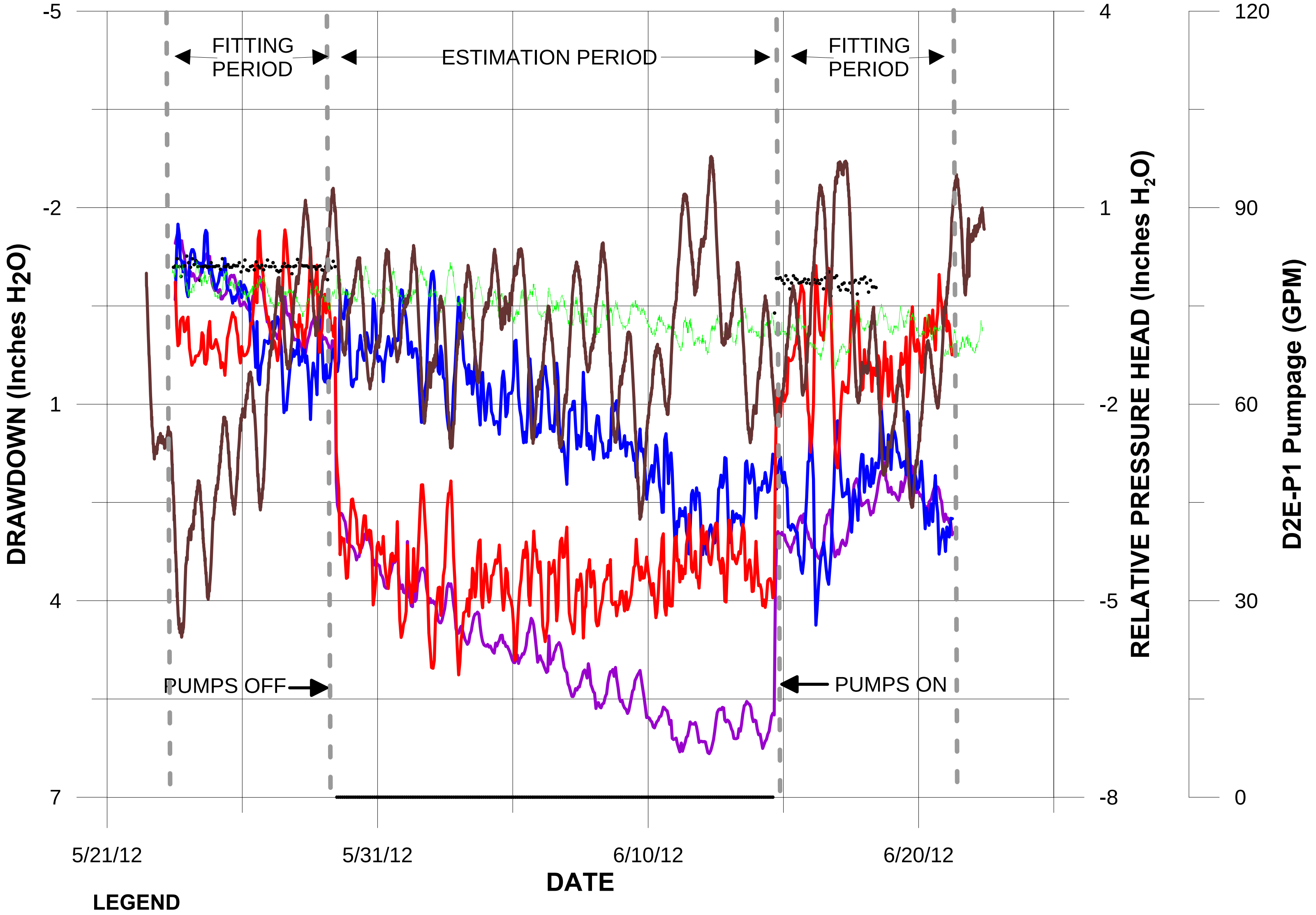


LEGEND

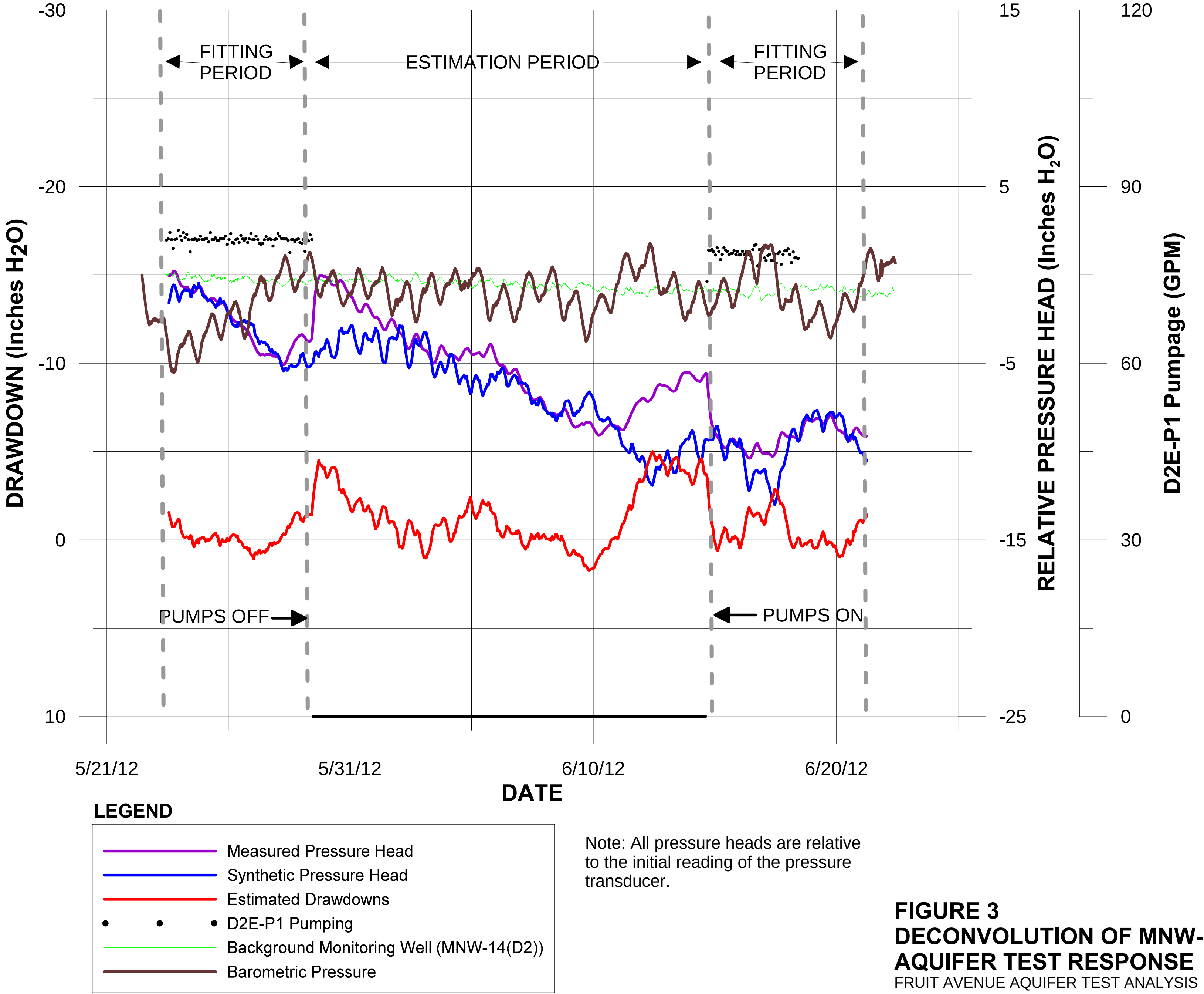
▬	Measured Pressure Head
▬	Synthetic Pressure Head
▬	Estimated Drawdowns
• • •	D2E-P1 Pumping
▬	Background Monitoring Well (MNW-14(D2))
▬	Barometric Pressure

Note: All pressure heads are relative to the initial reading of the pressure transducer.

FIGURE 2
DECONVOLUTION OF DM-07(I1/I2) AQUIFER TEST RESPONSE

FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY

CH2MHILL

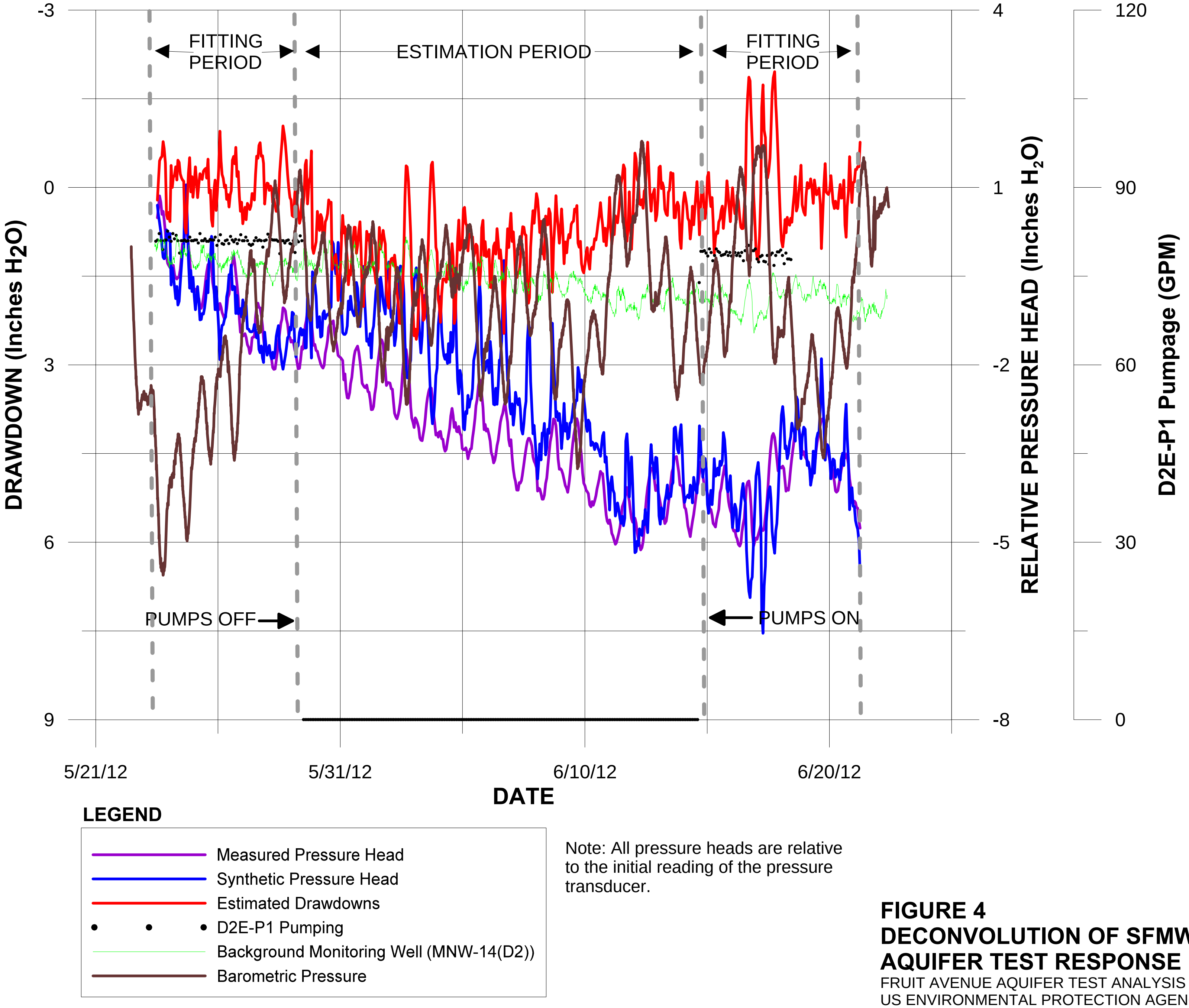


Note: All pressure heads are relative to the initial reading of the pressure transducer.

FIGURE 3
DECONVOLUTION OF MNW-5 (D2) AQUIFER TEST RESPONSE

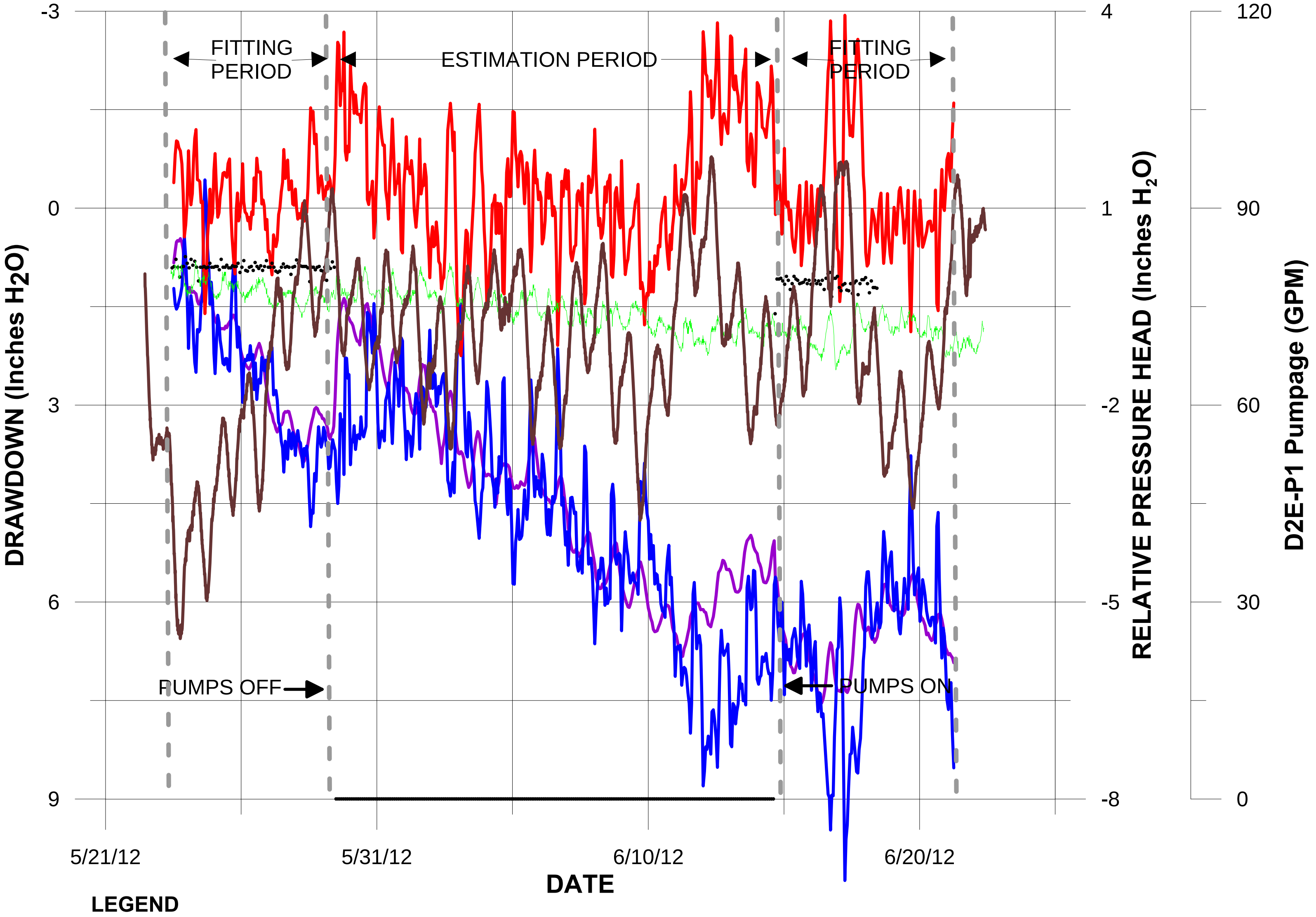
FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY

CH2MHILL



Note: All pressure heads are relative to the initial reading of the pressure transducer.

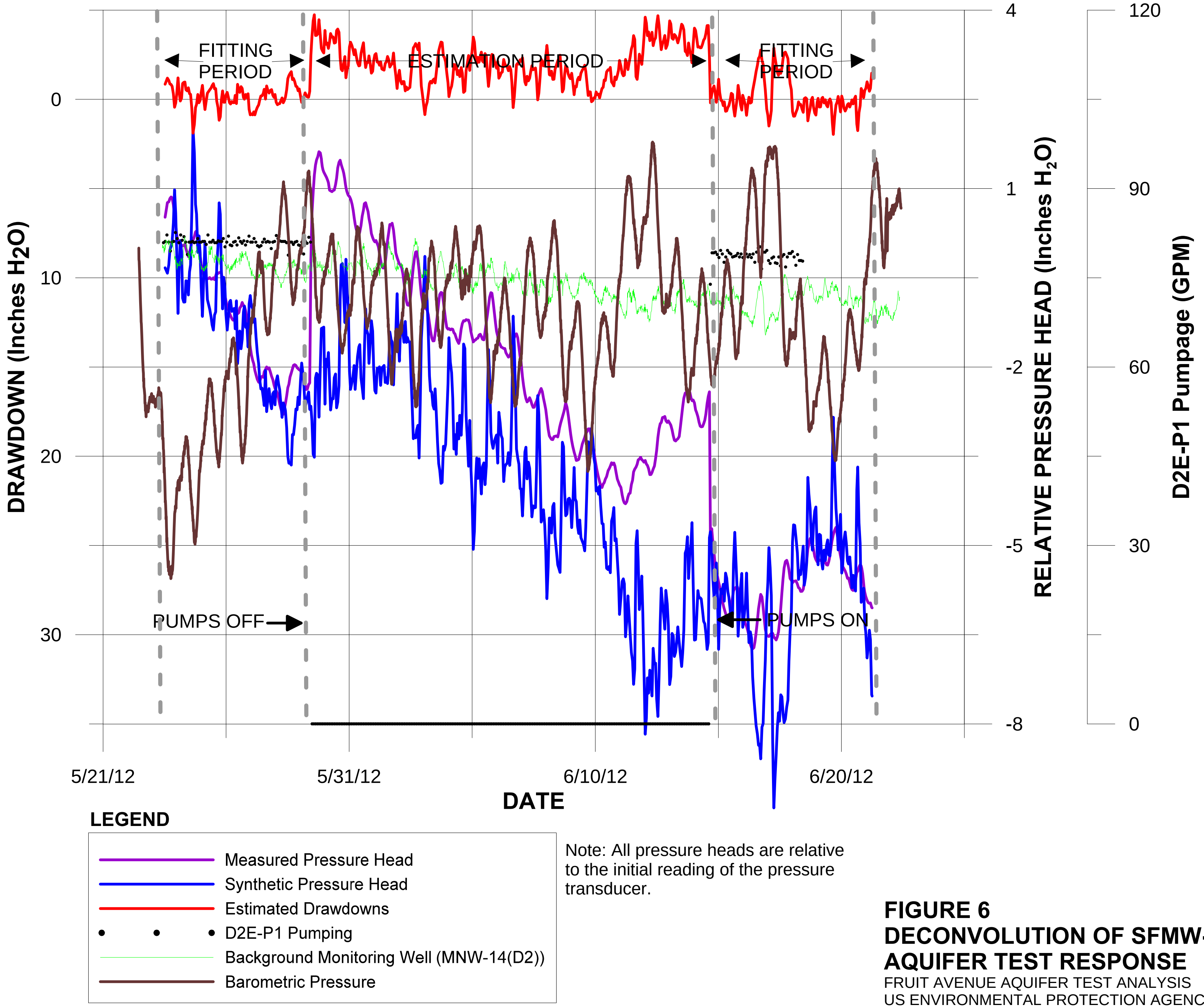
FIGURE 4
DECONVOLUTION OF SFMW-21(I2) AQUIFER TEST RESPONSE
FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY



Note: All pressure heads are relative to the initial reading of the pressure transducer.

FIGURE 5
DECONVOLUTION OF SFMW-22(D1) AQUIFER TEST RESPONSE
FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY

CH2MHILL

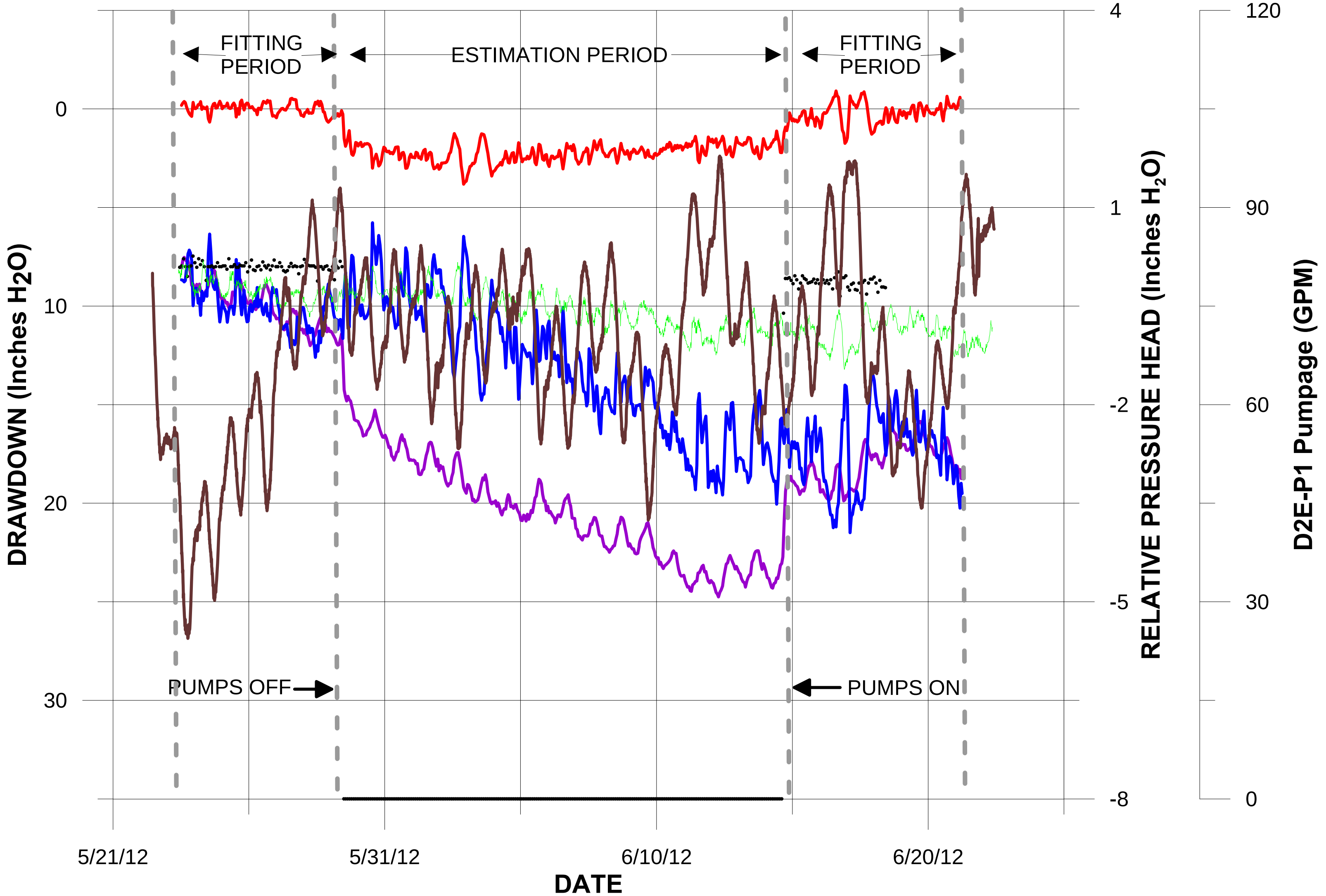


Note: All pressure heads are relative to the initial reading of the pressure transducer.

FIGURE 6
DECONVOLUTION OF SFMW-23(D2) AQUIFER TEST RESPONSE

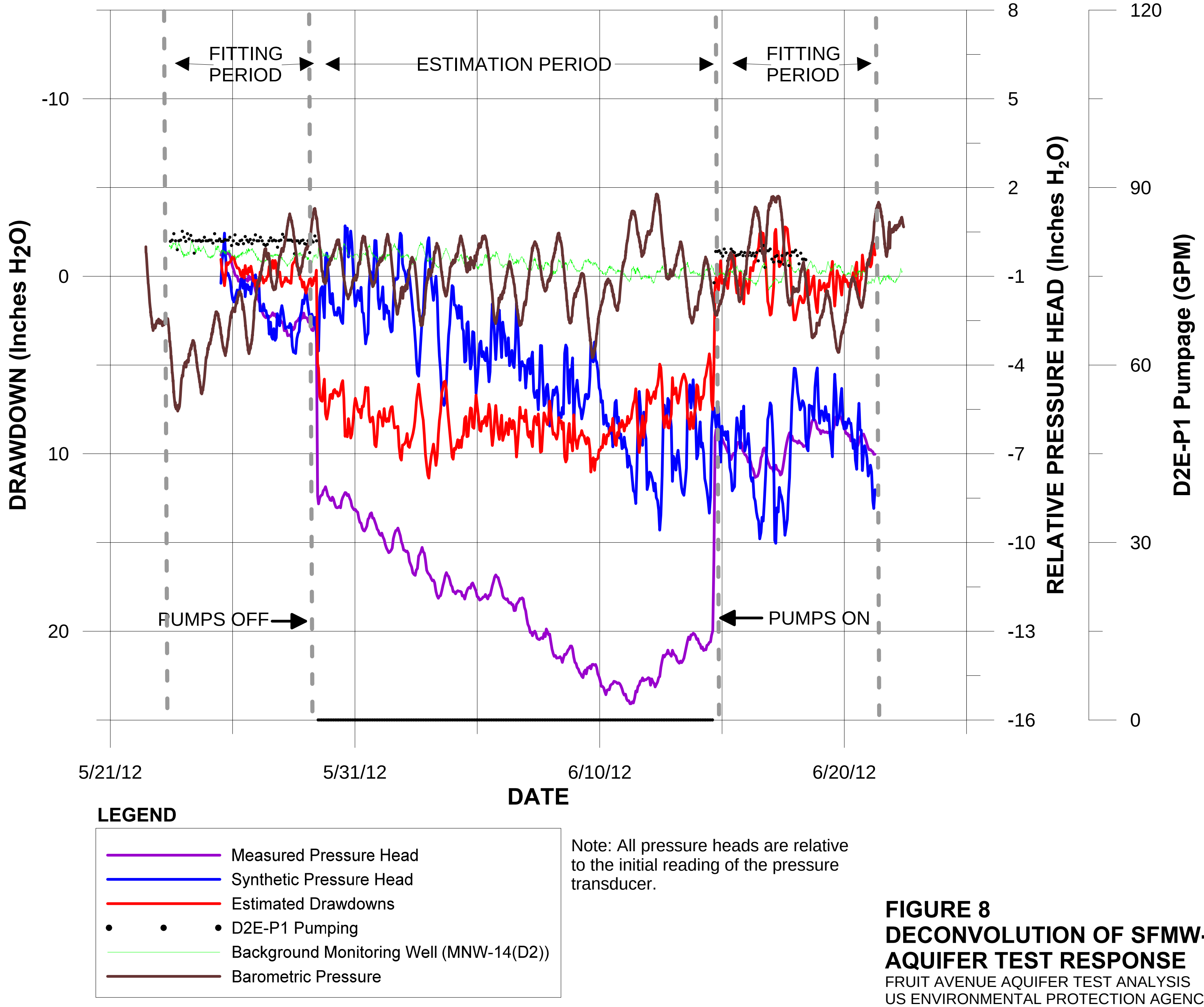
FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY

CH2MHILL



Note: All pressure heads are relative to the initial reading of the pressure transducer.

FIGURE 7
DECONVOLUTION OF SFMW-26(D2)
AQUIFER TEST RESPONSE
FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY

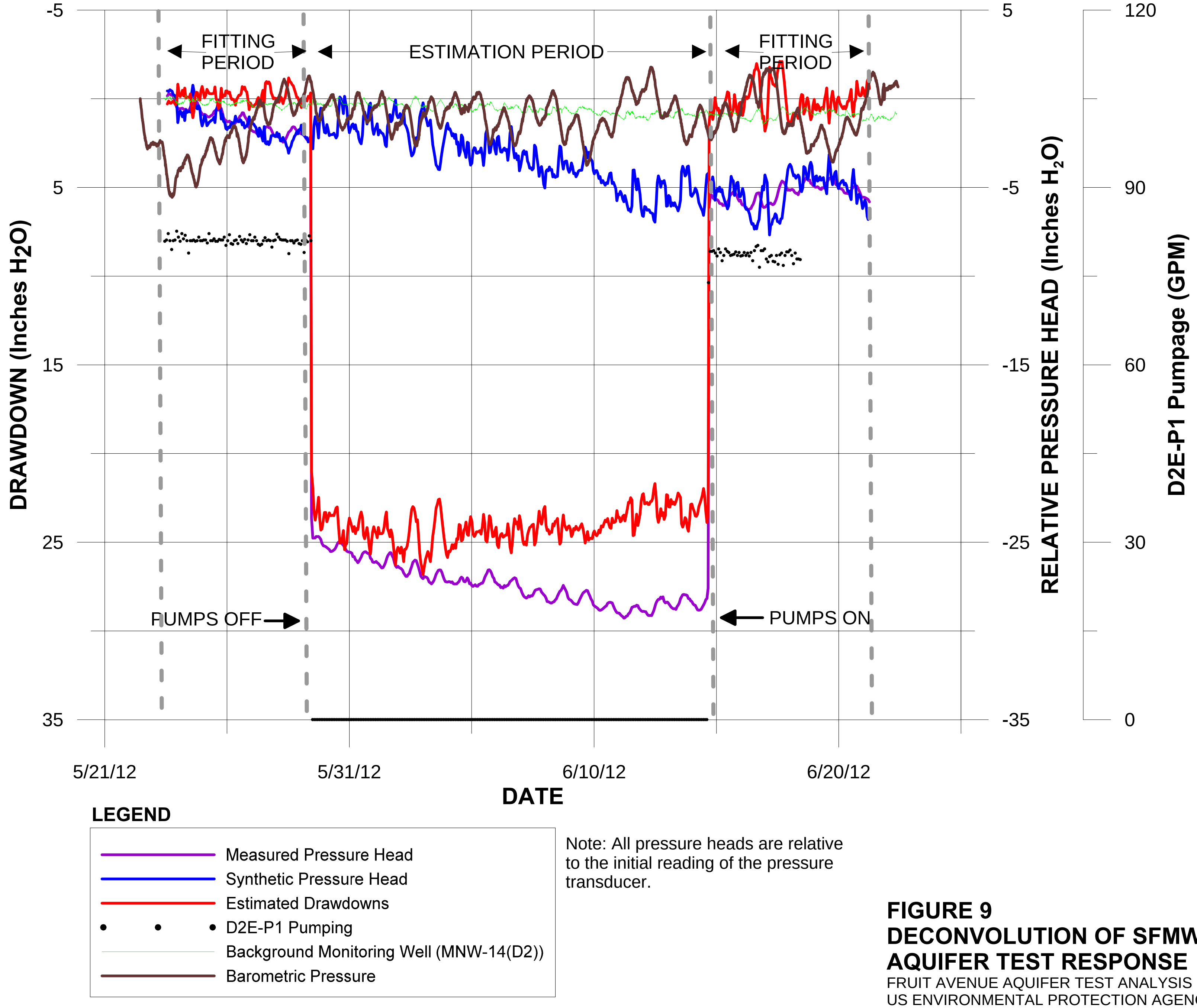


Note: All pressure heads are relative to the initial reading of the pressure transducer.

FIGURE 8
DECONVOLUTION OF SFMW-35(D3) AQUIFER TEST RESPONSE

FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY

CH2MHILL

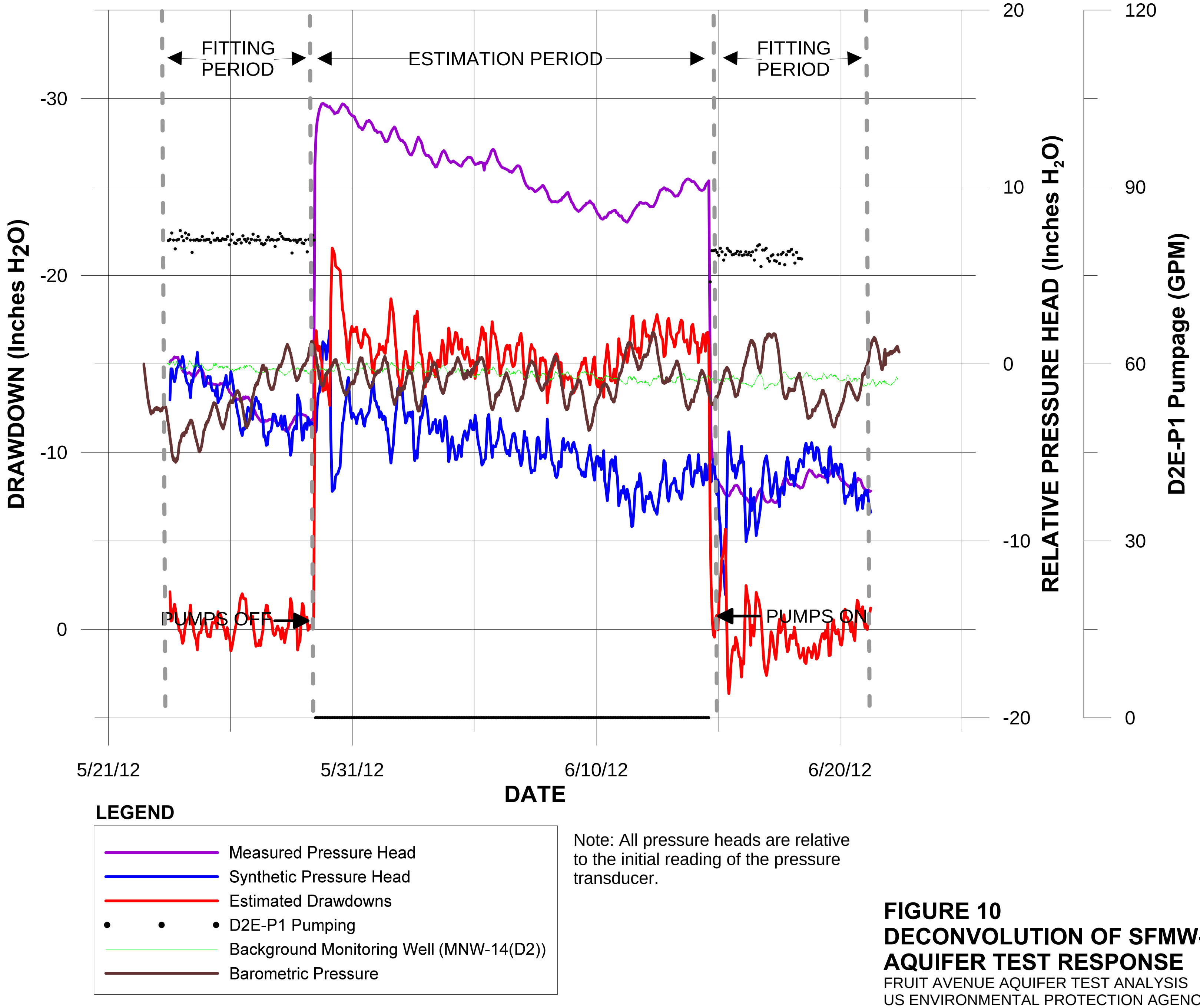


Note: All pressure heads are relative to the initial reading of the pressure transducer.

FIGURE 9
DECONVOLUTION OF SFMW-37(I2) AQUIFER TEST RESPONSE

FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY

CH2MHILL



Note: All pressure heads are relative to the initial reading of the pressure transducer.

FIGURE 10
DECONVOLUTION OF SFMW-39(D2) AQUIFER TEST RESPONSE

FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY

CH2MHILL

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drawdown and, therefore, was omitted from the subsequent aquifer test analysis. Monitoring well MNW-5(D2), which was intended as a background well, had relatively small though detectable responses to the system shutdown and restart. Therefore, it was included as an observation well for the aquifer test.

Sudden drops in pressure head were measured at monitoring wells DM-07(I1/I2), SFMW-21(I2), SFMW-26(I2), SFMW-35(D3), and SFMW-37(I2) at ASTP shutdown. These pressure head drops were followed by sharp increases in pressure head at ASTP restart. Sudden increases in pressure head at ASTP shutdown were measured at MNW-5(D2), SFMW-23(D2), SFMW-39(D2), and SFMW-44(D2), followed by sudden decreases in pressure head at ASTP restart.

MLU Analysis

The pressure transducer data from the aquifer test were analyzed using MLU™ (**Table 2**). MLU™ is a Windows application designed for the analysis of aquifer tests and the design of well fields in multi-layered systems (Hemker, 2012). A previously-existing nine aquifer zone conceptual model of the subsurface was used to be consistent with a MODFLOW-based groundwater model of the site (**Table 3**). The aquifer thicknesses that were provided by the CH2M HILL project team were assumed. This conceptual model was not reviewed or evaluated as part of the aquifer test analysis.

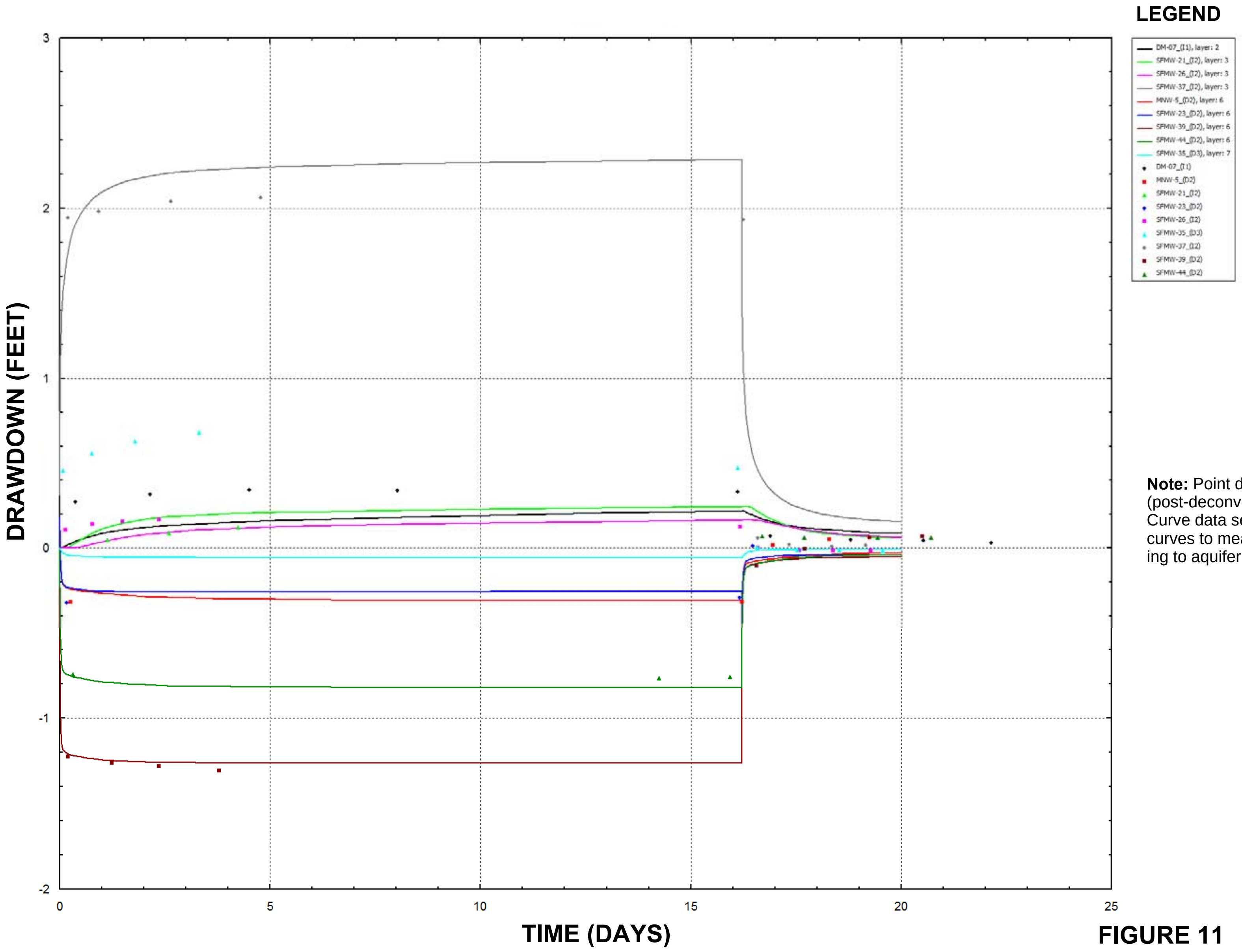
Drawdowns from both the system shutdown (recovery) phase and the restart phase from most monitoring wells were used to constrain the search for aquifer parameters that match the aquifer test. **Figure 11** shows how the MLU drawdown curves compare to the deconvolved, measured drawdowns. The MLU solution mirrors the maximum aquifer responses in both directions, with initially increasing water levels at SFMW-37(I2) and initially decreasing water levels at SFMW-39(D2). The MLU curves also indicate small responses to the aquifer test at SFMW-21(I2) and SFMW-23(D2). This result is consistent with the measured data as well, suggesting that aquifer responses to injection and extraction are nearly balanced in the area between the injection and extraction wells.

The only observation well for which the MLU curve is a very poor match to measurement is SFMW-35(D3), which is also the only observation well that is completed in Aquifer D3. The MLU model suggests that water levels should have decreased in SFMW-35(D3), whereas in reality they increased. Several attempts were made to rectify this discrepancy using different approaches to solution within MLU, but it appears that this can only be done at the expense of the fit to measured water levels at several other monitoring wells. This suggests that a more complex model than the relatively simple “layer-cake” that MLU assumes (such as a full groundwater model), with more parameters, or laterally-varying parameters, would be required to match both SFMW-35(D3) and the other monitoring wells.

None of the monitoring wells in this aquifer test were screened in model layers 1, 2, 4, 5, 8, or 9. For this reason, several of the aquifer’s properties were tied together in the MLU analysis, so that the inferred aquifer hydraulic conductivities for each of the upper eight layers of the model were connected to drawdowns from at least one well. The model layers were tied together as follows: a) layers 1 and 2; b) layers 3, 4, and 5; c) layers 6, 7, and 8. This consolidation of parameters coincides with the MODFLOW model layers that were given the same hydraulic conductivity. The aquifer properties of model layer 9 were not modified or evaluated by this aquifer test because none of the monitoring wells were sufficiently deep to estimate its properties. Layer 9 was just included in the MLU model to be certain that the inferred hydraulic properties were consistent with this layer and its hydraulic properties (which were assumed from the MODFLOW model).

Table 2 provides the results of the MLU analysis. The hydraulic conductivities estimated in this analysis are in a relatively narrow range, from 24 to 40 feet per day (ft/day). (The conductivity in layer 9 was not fit to the aquifer test due to a lack of data from wells screened at an appropriate depth interval.) Because of the large range of aquifer thicknesses, however, the transmissivity range is also large: from 930 to 16,000 square feet per day (ft^2/day).

The storativities were 0.09 for the uppermost (unconfined) layer, and from $3x10^{-4}$ to $8x10^{-3}$ in the eight lower (confined) layers. The MODFLOW conceptual model suggested that the upper six layers may function as unconfined layers. However, the MLU model could not accommodate storativities (specific yields) greater than 0.01 in layers 2 through 6 without a significant degradation of the MLU fit to measured drawdowns. Pore water drainage, which is the process that specific yield represents, is only possible in the uppermost aquifer layer unless it is dewatered, so this limitation is expected.



Note: Point data series are measured (post-deconvolution) drawdowns. Curve data series are MLU best-fit curves to measured data, corresponding to aquifer parameter estimates.

FIGURE 11
COMPARISON OF ESTIMATED ACTUAL DRAWDOWNS WITH MLU PREDICTION

FRUIT AVENUE AQUIFER TEST ANALYSIS
US ENVIRONMENTAL PROTECTION AGENCY

CH2MHILL

The vertical conductivities in **Table 2** were back-calculated from MLU, which actually calculates vertical conductivities between layers. With nine layers in the conceptual model, MLU calculates eight vertical conductivities (one for each adjacent pair of layers). In order to calculate layer-specific hydraulic conductivities, it was assumed that the top two layers had the same vertical hydraulic conductivities. The calculation of the layer-specific vertical hydraulic conductivities was performed using the harmonic mean formula (Fetter, 1988).

Comparison of MLU Results to Flow Model Parameters

This section compares the results of the aquifer test results (**Table 2**) with the analogous parameters from the flow model near the aquifer test (**Table 3** and **Appendix J**).

TABLE 2
Aquifer Parameter Results of Fruit Avenue Aquifer Test MLU Analysis
Fruit Avenue Plume Superfund Site, Albuquerque NM

Layer	Assumed Thickness (feet)	Estimated Transmissivity (ft^2/day)	Estimated Storativity (-)	Estimated Horizontal Hydraulic Conductivity (ft/day)	Estimated Vertical Hydraulic Conductivity (ft/day)
1	42	1,000	0.09	24	0.45
2	40	950	0.0003	24	0.45
3	25	830	0.008	33	0.25
4	40	1,300	0.008	33	0.16
5	55	1,800	0.008	33	0.25
6	50	2,000	0.00012	40	0.088
7	150	6,000	0.00012	40	0.044
8	400	16,000	0.00012	40	0.053
9	800	6,800	0.0008	8.5	0.012
Total		37,000			

Notes:
Geological layer thickness estimated from the F& T Model discussed in Appendix J.
ft^2/day = square feet per day
ft/day = feet per day

TABLE 3
Aquifer Parameters from Fruit Avenue Plume Numerical Groundwater Flow Model in the vicinity of the Extraction Well
Fruit Avenue Plume Superfund Site, Albuquerque NM

Layer	Assumed Thickness (feet)	Estimated Transmissivity (ft^2/day)	Estimated Storativity (-)	Estimated Horizontal Hydraulic Conductivity (ft/day)	Estimated Vertical Hydraulic Conductivity (ft/day)
1	42	1,300	0.2	31.9	0.42
2	40	1,300	0.00004	31.9	0.43
3	25	190	0.0012	7.5	0.22
4	40	300	0.0012	7.5	0.25
5	55	410	0.0012	7.5	0.28
6	50	750	0.0002	15	0.12
7	150	2,300	0.0002	15	0.00028
8	400	6,000	0.0004	15	0.0088
9	800	6,800	0.0008	8.5	NA
TOTAL		19,000			

Notes:
Geological layer thickness estimated from the groundwater model
ft^2/day = square feet per day
ft/day = feet per day

Table 3 indicates the hydraulic properties that were assigned to the nine-layer groundwater flow model near the Fruit Avenue ASTP. The horizontal hydraulic conductivities in the model ranged from 7.5 ft/day to 31.9 ft/day. The vertical hydraulic conductivities generally decreased with depth, from 0.45 ft/day in the upper layers to 0.012 ft/day at depth. The aquifer storativities in the model range from 4 x 10^{-5} to 8 x 10^{-4} for the confined storage of layers 2 through 9, while the specific yield was 0.2 for the unconfined model layers.

The parameters resulting from the MLU analysis (**Table 2**) were compared to analogous parameters in the flow model (**Table 3** and **Appendix J**). The range of conductivities in the model is consistent with the range obtained from the aquifer test analysis, although the aquifer test suggests slightly higher conductivities on average and a somewhat higher total transmissivity. The vertical conductivities for the upper five layers in the model are very similar to those obtained from the aquifer test analysis. The difference between the aquifer test and model vertical conductivities of layers 7 and 8 may be significant if understanding the vertical flow between these layers becomes important at some point in the future.

The model and aquifer test storages differ somewhat, with the aquifer test analysis resulting in a specific yield (0.09), which is less than half the specific yield used in the model (0.2), as well as somewhat different confined storages.

The basin-scale model was calibrated with approximately a century of water level data with significant and ongoing withdrawals from storage resulting in hundreds of feet of water level fluctuations over time. It, therefore, follows that the model has storage parameter values that are required for the simulated water levels to respond appropriately to the water budget and boundary conditions.

By contrast, the aquifer test occurred over a relatively small area for 16 days, and the maximum change in head that resulted from this test was a relatively modest 2.1 feet (at monitoring well SFMW-37 (I2)).

Therefore, there are at least three possible explanations for the specific yield discrepancy between calibrated model and aquifer test: a) the test insufficiently stressed the aquifer to fully drain available water from storage, resulting in a lower specific yield than would otherwise have been obtained; b) the MLU analysis was insufficiently sensitive to shallow specific yield because of a lack of very shallow monitoring wells in the test and analysis; and/or c) the very localized aquifer storativity that responded to the aquifer test is different from the regional storativity as a whole.

However, the storage discrepancies are made largely irrelevant for predictive simulations by the relatively steady flow conditions onsite. For example, prior to the aquifer test shutdown and restart, the ASTP had been pumping at approximately the same continuous rates indicated in the first row of **Table 1** for the previous two years. The storage in the local aquifer is made still less relevant by the multi-year remediation time frame, which should exceed the time required for any transient fluctuations in the ASTP capture zone to re-equilibrate many times over.

Implementation of the aquifer test hydraulic properties (particularly the hydraulic conductivities) in the model would result in reduced estimates of remediation time frames. Therefore, the model parameters tend to be somewhat more conservative than the aquifer test parameters (i.e., tend to generate longer remediation time frame estimates), for the purpose of addressing the travel-time-related questions for which the model is applied. This is not the case for model layers 1 and 2, for which the model has slightly higher conductivities than those of the aquifer test analysis. However, the conductivities of these layers (24 ft/day for the aquifer test, 32 ft/day for the model) are close enough to be well within the bounds of uncertainty for most aquifer tests of this kind.

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Appendix L
TCE Plume Volume and Mass Estimation Results

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Fruit Avenue Plume Superfund Site Long-Term Remedial Action

Appendix L – Mass of Trichloroethene Removed by Monitored Natural Attenuation

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PREPARED BY:	CH2M HILL
DATE:	October 2012
PROJECT:	EPA Region 6 Remedial Action Contract W-EP-06-021 Task Order No. 0003-RALR-06DD CH2M HILL Project No. 345406.PJ.14
DCN:	0003-02091

This technical memorandum estimates the mass of trichloroethene (TCE) removed by natural attenuation (NA) processes from groundwater at the Fruit Avenue Plume (FAP) Superfund site.

The mass of TCE removed by NA from groundwater was estimated by subtracting the mass of TCE removed by the air stripper treatment plant (ASTP) from the total mass present within the groundwater plume shell. The mass removed by the ASTP is calculated in the Quarterly Cleanup Status Reports (CH2M HILL, 2012a). The historical groundwater TCE plume shells were developed with the aid of a numerical model by interpolating historical TCE groundwater sampling results (CH2M HILL, 2012b) from approximately 100 existing monitor wells.

The model estimates the initial mass of TCE in the plume (M_O), and mass at time T (M_T), initial volume of the plume shell (V_O), and volume at time T (V_T). Snapshot illustrations of the model are included as **Figure 1** and **Figure 2**. An animation of the plume shell for the time period between 1998 and 2012 and a viewer for the animation are included in the attached DVD (**Attachment M**). Cumulative estimates of these parameters are presented in **Table 1** and illustrated on **Figure 3**.

Trichloroethene Mass Removal Estimation Approach

The volume and mass of the calculated plume shell generally increased between discovery in 1986 through 1998, because additional wells were added to delineate the extent of the plume. No plume volume or TCE mass calculations are provided for the 1986 through 1998 period. Between 1998 and 2005, an expected increase in the plume volume and mass resulting from installation and sampling of new monitor wells is partially offset by decreasing TCE concentrations, resulting in an overall decline in TCE mass as the plume is more thoroughly characterized. The 1998 plume shell was selected as a starting point for this evaluation, because it represented the highest observed volume and mass of TCE present within the plume shell.

The total mass lost from the plume (M_0-M_T) can be attributed to (1) mass lost due to monitored natural attenuation (MNA) processes (M_{MNA}), and (2) mass lost due to the pump and treat (P&T) remedy (M_{ASTP}). The mass removed by MNA (M_{MNA}) can be calculated from the following equation:

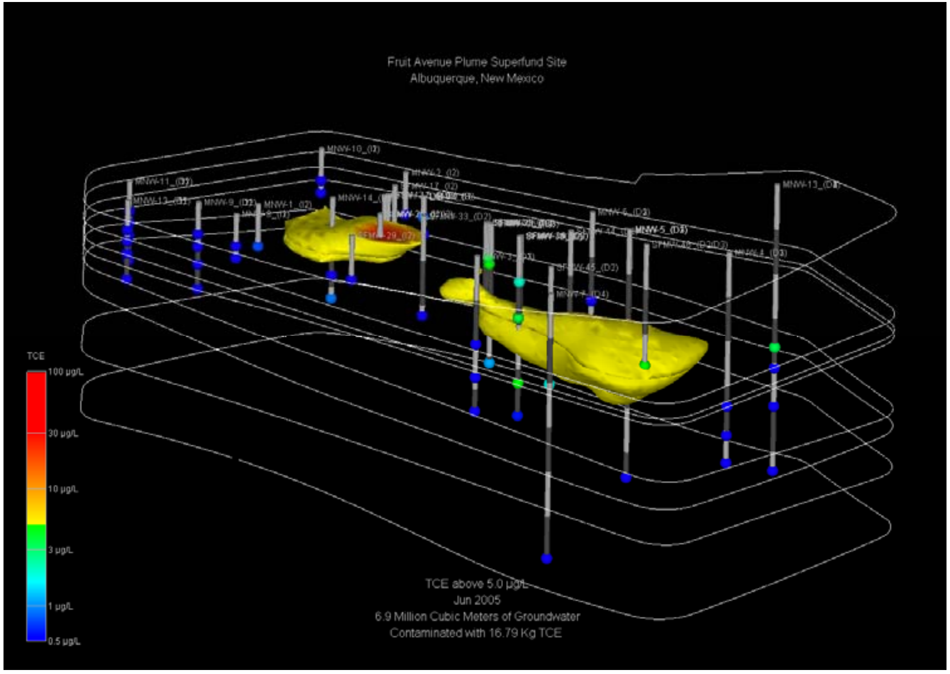
$$\mathrm{M_{MNA}} = (\mathrm{M_0} - \mathrm{M_t}) - \mathrm{M_{ASTP}}$$

Fluctuations in the mass of dissolved TCE plume shell result from variations in the TCE concentration at monitor wells that represent larger volumes of the plume (for example, MNW-5[D2]). The estimate of TCE mass removed by the ASTP is skewed high in this analysis because concentrations less than the 5-microgram-per-liter (µg/L) remedial goal are included, whereas the MNA remedy is assumed to act on only the TCE plume greater than 5 µg/L.

FIGURE 1

June 2005 TCE Plume Shell (> 5 µg/L) with Total Volume and Mass Estimates

Fruit Avenue Plume Superfund Site, Albuquerque NM



Note:

>:	greater than
µg/L:	micrograms per liter
kg:	kilogram

FIGURE 2

February 2012 TCE Plume Shell (> 5 µg/L) with Total Volume and Mass Estimates

Fruit Avenue Plume Superfund Site, Albuquerque NM

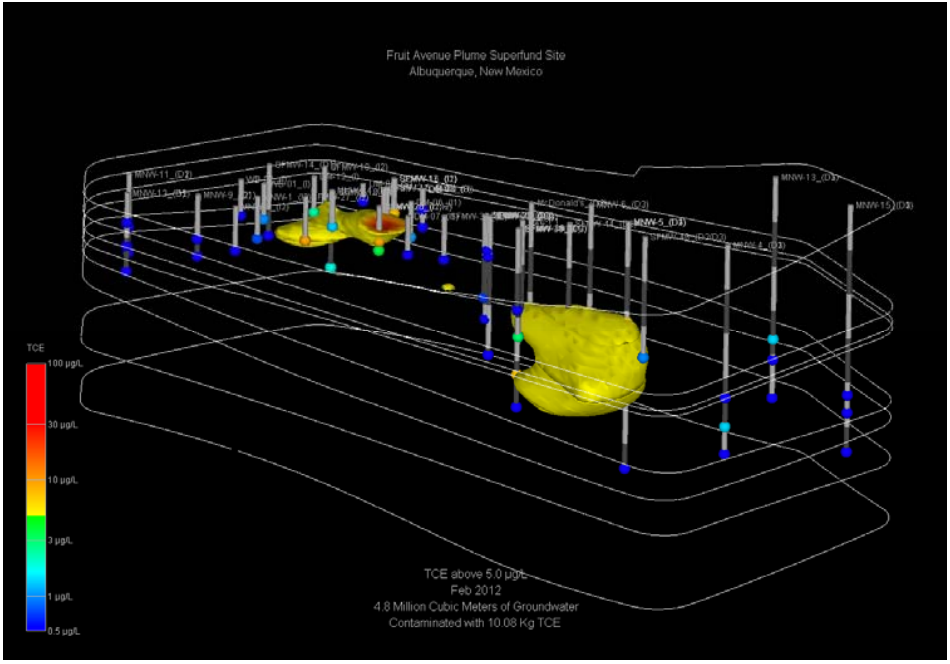


FIGURE 3

Cumulative Dissolved TCE Plume Shell (> 5 µg/L)Mass Estimates

Fruit Avenue Plume Superfund Site, Albuquerque NM

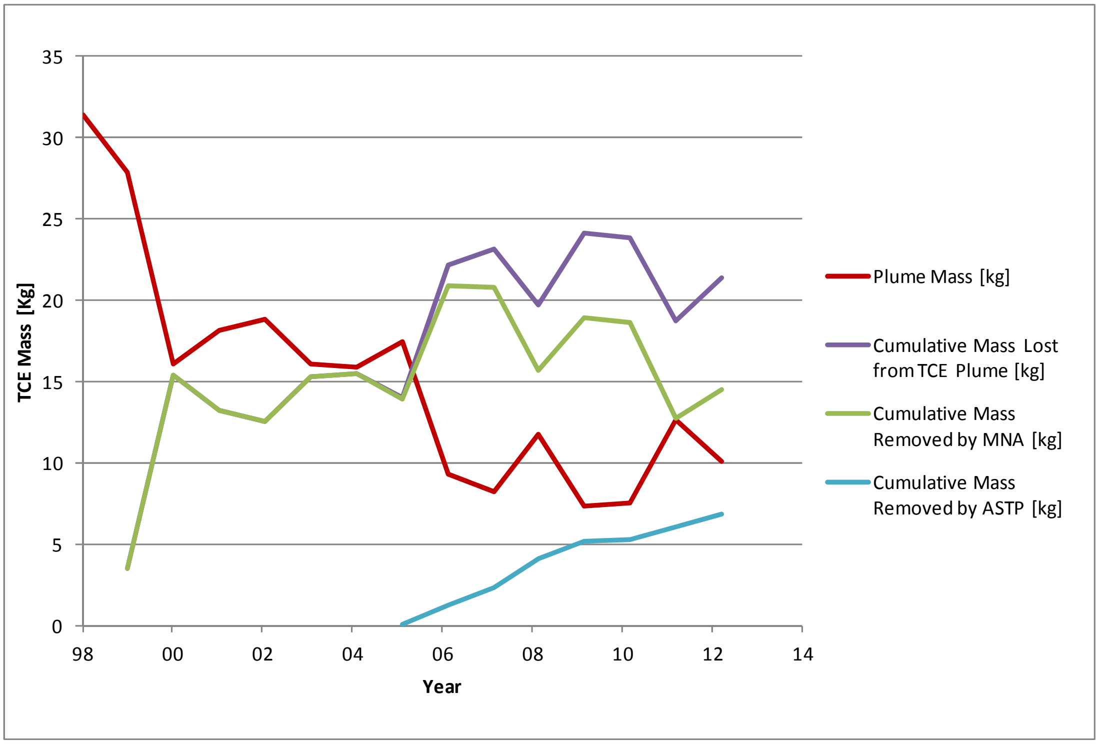


TABLE 1

Cumulative TCE Mass Removed by MNA Remedy

Fruit Avenue Plume Superfund Site, Albuquerque NM

	Estimated 5 µg/L TCE Plume Volume (V_0 & V_T)	**Estimated 5 µg/L TCE Plume Mass (M_0 & M_T)**	**Cumulative Mass Lost from 5 µg/L TCE Plume (M_0 - M_T) or (M_{ASTP} + M_{MNA})**	**Cumulative TCE Mass Removed [kg]**		**Cumulative Annual Fraction of TCE Removed By**	
Date	**[10^6 M^3]**	**[kg]**	**[kg]**	**ASTP (M_{ASTP})**	**MNA (M_{MNA})**	**ASTP**	**MNA**
Jun-98	8.6	31.4					
Jun-99	8.1	27.9	3.54	0	3.54	0%	100%
Jun-00	5.9	16.1	15.4	0	15.4	0%	100%
Jun-01	6.8	18.2	13.3	0	13.3	0%	100%
Jun-02	7.2	18.9	12.6	0	12.6	0%	100%
Jun-03	6.4	16.1	15.3	0	15.3	0%	100%
Jun-04	6.0	15.9	15.5	0	15.5	0%	100%
Jun-05	7.2	17.4	14.0	0.0590	13.9	0%	100%
Jun-06	4.0	9.26	22.2	1.30	20.9	6%	94%
Jun-07	3.4	8.24	23.2	2.35	20.8	10%	90%
Jun-08	5.1	11.7	19.7	4.06	15.6	21%	79%
Jun-09	3.3	7.32	24.1	5.21	18.9	22%	78%
Jun-10	3.8	7.57	23.9	5.25	18.6	22%	78%
Jun-11	5.7	12.7	18.8	6.04	12.7	32%	68%
Jun-12	4.8	10.1	21.3	6.88	14.5	32%	68%

Note:

The starting date of 1998 for this table was selected because the highest observed plume mass and plume volume was estimated to occur at that time. Additional monitor wells have been installed since then (such as MNW-5 and MNW-6), which did expand the plume footprint, and thus this evaluation underestimates the mass lost from the plume, and underestimates the mass removed by MNA.

Three-Dimensional Contaminated Groundwater Plume Volume and Mass Estimation

The historical volume and mass of the TCE-contaminated groundwater plume were calculated using a numerical three-dimensional (3D) solid model created using the C-Tech's Premier Environmental Visualization System (EVS). The historical plume shells are illustrated as changing over time in video time-series animations. The animations allow the 3D numerical model to be manipulated (using a computer mouse and grab/drag approach) such that all sides of the TCE plume can be viewed (note that vertical exaggeration is 5 times, which is accounted for in the volume and mass calculations).

The animations show five components: (1) The model outline at the contacts between each geologic layer, (2) the posted sampling results for a given time step, (3) the modeled plume shell, (4) a legend to indicate the TCE concentration in the posted sample results and the plume shell, and (5) a title block indicating the plume shell iso-concentration, model date, volume of contaminated groundwater, and mass of TCE in the plume shell.

Seven geologic layers corresponding to the S, I1, I2, D1, D2, D3, and D4 aquifer zones were modeled. Geologic surfaces were interpolated in the model using visual logging data collected at 147 locations across the site. The ground surface was modeled from surveyed monitor well elevations. The water table was modeled from water level measurements collected in February 2012.

The distribution of TCE in groundwater was interpolated by the EVS model using laboratory analysis results collected from a subset of the 139 monitor, injection, and pumping wells over 31 sampling events conducted between December 1986 and February 2012. To accomplish the time animation, sample dates were rounded to the nearest quarter. The TCE concentrations are approximately log-normally distributed and were preprocessed to account for that distribution. Non-detects were included in the model at 0.25 µg/L, which is generally one-half of the reporting limit. The TCE plume shells were modeled assuming a horizontal to vertical anisotropy ratio of 10:1. Any portion of the modeled TCE plume shell that extended above the water table was truncated from the animation. Sample results from wells in the upgradient offsite plume were excluded from the model and concentrations from wells where the plumes overlap (such as MNW-1[I2] and SFMW-27[I2]) were partitioned to both plumes. An estimated mass of sorbed-phase TCE was not included in this model due to the low fraction of organic carbon present in the aquifer.

Sample locations in the animation are indicated by spheres along the well bores for which depth is indicted by 50-foot gradations. The well identification is indicated at top of each well; it is possible to zoom in to reduce the relative size of the text and investigate smaller portions of the plume shell. The sample spheres are color-coded by the TCE concentration. Samples with contaminant of concern concentrations less than the 5-µg/L maximum contaminant level are shown in greens and blues. Higher concentration samples are typically obscured by the plume shell. The remediation goal (5-µg/L) was chosen as the iso-concentration for the plume shell.

The 3D TCE concentration distribution in the animation (the plume shell) was estimated using an accurate and geostatistically defensible process called Kriging (Clark, 1979). Kriging is a mathematical process recognized by EPA as the best and standard means for interpolation and extrapolation of measured data. The models utilize expert systems to analyze the spatial distribution and number of field data points, construct a multidimensional variogram which is a best fit to the dataset being analyzed, and then perform kriging in the domain of the model. One of the fundamental design criteria used in developing the variogram and kriging algorithms was to produce modeled distributions that honor the measured distributions as closely as possible. MVS's variogram modules utilize a nugget of zero, which cannot be changed, and which basically require the calculated value to be equal to the known value of data points that fall exactly on a grid point in the modeled domain.

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Attachment 1 3-D User-Interactive Animation of Historic Plume Shell and Mass and Volume Estimates (Provided on CD)

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3-D User-Interactive Animation of Historic Plume Shell and Mass and Volume Estimates are included in Attachment 1, which is provided on the CD submitted with this report.

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