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Optimization Evaluation
Lee Chemical Superfund Site

City Of Liberty, Clay County, Missouri

OPTIMIZATION EVALUATION

LEE CHEMICAL SUPERFUND SITE
CITY OF LIBERTY, CLAY COUNTY, MISSOURI

Report of the Optimization Evaluation
Site Visit Conducted at the Lee Chemical Superfund Site
May 18, 2011

January 12, 2012

EXECUTIVE SUMMARY

Optimization Background

For more than a decade, the U.S. Environmental Protection Agency's (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI) has provided technical support to the EPA Regional offices through the use of third-party optimization evaluations. OSRTI has conducted more than 100 optimization studies at Superfund sites nationwide via Independent Design Reviews (IDR), Remediation System Evaluations (RSE), and Long-Term Monitoring Optimization (LTMO) reviews.

OSRTI is now implementing its National Strategy to Expand Superfund Optimization from Remedial Investigation to Site Completion (Strategy). The Strategy unifies previously independent optimization efforts (i.e., RSE, LTMO, Triad Approach, and Green Remediation) under the singular activity and term "optimization," which can be applied at any stage of the Superfund project life cycle. The EPA's working definition of optimization as of June 2011 is as follows:

"A systematic site review by a team of independent technical experts, at any phase of a cleanup process, to identify opportunities to improve remedy protectiveness, effectiveness, and cost efficiency, and to facilitate progress toward site completion."

An optimization review at the remedy stage, therefore, considers the goals of the remedy, available site data, conceptual site model (CSM), remedy performance, protectiveness, cost-effectiveness, and closure strategy. A strong interest in sustainability has also developed in the private sector and within Federal, State, and Municipal governments. Consistent with this interest, optimization now routinely considers environmental footprint reduction during optimization reviews. An optimization review includes reviewing site documents, interviewing site stakeholders, potentially visiting the site for one day, and compiling a report that includes recommendations in the following categories:

- Protectiveness
- Cost-effectiveness
- Technical improvement
- Site closure
- Environmental footprint reduction

The recommendations are intended to help the site team identify opportunities for improvements in these areas. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed prior to implementation of the recommendation. Note that the recommendations are based on an independent evaluation, and represent the opinions of the evaluation team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the Region and other site stakeholders.

Site-Specific Background

The Lee Chemical Superfund Site (site) is located along Missouri Highway 210 in Liberty, Missouri, approximately 15 miles east of Kansas City, Missouri. Currently, the site is a vacant lot of approximately 2.5 acres in a flat alluvial plain. The City of Liberty (City) has a municipal well field located approximately 0.40 miles southeast of the site. There are nine municipal water wells situated in a north-south line in the alluvial aquifer at an approximately perpendicular angle to the site.

Historically, the City leased the land to the Lee Chemical Company, but then filed suit against Lee Chemical Company in 1975 for nonpayment of rent. The City then found and removed approximately 300 abandoned 55-gallon drums containing chemicals and wastes. In 1979, low levels of trichloroethene (TCE) were detected in the public water supply wells Subsequent EPA and State investigations revealed contaminated groundwater and soil, and in 1982 the City and State identified the site as a source of TCE contamination in the public water supply.

The current remedy in place for the Lee Chemical Superfund Site consists of the operation of an *in situ* aqueous soil washing system, the extraction of groundwater from extraction wells (EX) EX-1 and PW-2, and the discharge of the extracted groundwater from both extraction wells to a single, permitted outfall to Town Branch Creek. This Remedial Action (RA) is continually monitored and reported on through monthly and quarterly progress reports. The site remedy was considered Operational and Functional (O&F) on March 26, 1994.

Summary of CSM

Volatile organic compound (VOC) contamination released at the surface infiltrated through soil to groundwater resulting in TCE concentrations in soil up to 11,000 micrograms per kilogram (µg/kg), TCE concentrations in on-site groundwater up to 851 micrograms per liter (µg/L), and TCE concentrations in off-site groundwater up to 330 µg/L at PW-2 in the early to mid-1980s. Initial soil removal and subsequent soil flushing has mobilized the contaminants over time, and extraction well EX-1 has captured some of contamination that has leached to groundwater near the center of the site. The current mass flux of contamination leaching to groundwater is sufficiently low and the groundwater flow sufficiently high that the contamination leaching from the soil is diluted by the groundwater and is generally undetectable with current sampling methods, except for occasional seasonal spikes. Soil contamination that can be flushed by the soil flushing remedy has long since been removed, but soil contamination still remains and may continue to be mobilized when the water table rises to historically high levels and/or remedy pumping decreases substantially. The groundwater contaminant plume, when mobilized from the soil, may be stable due to low levels of contamination, dispersion, and the potential for natural degradation of TCE in groundwater. However, there is insufficient information to confirm a stable plume at this point.

Summary of Findings

The current monitoring program indicates that TCE has occasionally exceeded cleanup levels at EW-4 and EW-5. The extent of the EX-1 capture zone is not known, but it is possible that these two locations are downgradient of it, which means that the observed contamination at EW-4 and EW-5 is not captured. The extent of contamination off-site is unknown, particularly near the water table.

TCE is often detected in the discharge but remains below the permitted limit. No exceedances of the permit conditions have occurred over the past 10 years.

Summary of Recommendations

Recommendations are provided to improve remedy effectiveness, provide technical improvement, and gain site closure. The recommendations in these areas are as follows:

Improving Protectiveness – improve understanding of groundwater flow, sample additional intervals in wells with long screen intervals, sample for 1,4-dioxane, sample for monitored natural attenuation (MNA) parameters, and consider additional potential locations for monitoring points.

Technical Improvement – submit blind field blank samples to the laboratory to evaluate potential for laboratory contamination with acetonitrile and postpone soil vapor sampling until soil flushing has been discontinued and the vadose zone is dewatered.

Site Closure – consider various approaches to proceeding with site remediation based on the information collected from implementing the other recommendations. In addition, evaluate potential for soil vapor intrusion (VI) using existing infrastructure.

No considerations were identified at this time for reducing cost, and no opportunities were identified at this time for meaningful reduction of the remedy environmental footprint.

NOTICE

Work described herein was performed by Tetra Tech GEO (TtGEO) for the EPA. Work conducted by TtGEO, including preparation of this report, was performed under Work Assignment #1-58 of EPA contract EP-W-07-078 with Tetra Tech EM, Inc., Chicago, Illinois. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

This report was prepared as part of a national strategy to expand Superfund optimization from remedial investigation to site completion implemented by the United States Environmental Protection Agency Office of Superfund Remediation and Technology Innovation (EPA OSRTI). The project contacts are as follows:

Organization	Key Contact	Contact Information
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LIST OF ACRONYMS

%	percent
AOC	Administrative Order on Consent
ARAR	Applicable or Relevant and Appropriate Requirement
bgs	below ground surface
BTU	British thermal unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Contaminant of Concern
CSM	Conceptual Site Model
DCA	Dichloroethane
DCE	Dichloroethene
DNAPL	dense non-aqueous phase liquid
DPT	direct-push technology
EPA	United States Environmental Protection Agency
EW	Extraction Well (previously installed for drinking water)
EX	Extraction Well
ft	feet
FS	Feasibility Study
gpm	gallons per minute
HP	horsepower
IC	Institutional Control
IDR	Independent Design Review
ISCO	*In situ* chemical oxidation
Koc	Organic carbon partitioning coefficient
kWh	kilowatt-hour
lbs	pounds
L/kg	liters per kilogram
LTMO	Long-Term Monitoring Optimization
LTRA	Long-Term Response Action
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
mg/L	milligrams per liter
MCL	Maximum Contaminant Level
MDNR	Missouri Department of Natural Resources
MGD	Million gallons per day
MNA	Monitored Natural Attenuation
MSOP	Missouri State Operating Permit
MW	monitoring well
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	Operation and Maintenance
ORD	Office of Research and Development
ORP	Oxidation-reduction potential
OSRTI	Office of Superfund Remediation and Technology Innovation

OSWER	Office of Solid Waste and Emergency Response
O&F	Operational and Functional
OU	Operable Unit
P&T	pump and treat
PDB	passive diffusion bag
ppm	parts per million
PW	Public Well
QAPP	Quality Assurance Project Plan
RA	Remedial Action
RAO	Remedial Action Objective
RD/RA	Remedial Design/Remedial Action
RI	Remedial Investigation
ROD	Record of Decision
RSE	Remediation System Evaluation
SU	Standard Units
SVE	Soil Vapor Extraction
TCA	Trichloroethane
TCE	Trichloroethene
TtGEO	Tetra Tech GEO
VI	vapor intrusion
VOC	Volatile organic compound
WQS	Water Quality Standards
WSW	Water Supply Well

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1.0 INTRODUCTION

1.1 PURPOSE

During fiscal years 2000 and 2001, independent reviews called Remediation System Evaluations (RSEs) were conducted at 20 operating Fund-lead pump and treat (P&T) sites (i.e., those sites with P&T systems funded and managed by Superfund and the States). Due to the opportunities for system optimization that arose from those RSEs, the U.S. Environmental Protection Agency's (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI) has incorporated RSEs into a larger post-construction complete strategy for Fund-lead remedies as documented in the *Office of Solid Waste and Emergency Response* (*OSWER) Directive No. 9283.1-25, Action Plan for Ground Water Remedy Optimization*. Concurrently, the EPA developed and applied the Triad Approach to optimize site characterization and development of a conceptual site model (CSM). The EPA has since expanded the definition of optimization to encompass investigation stage optimization using the Triad Approach, optimization during design, and RSEs. The EPA's working definition of optimization as of June 2011 is as follows:

> *"A systematic site review by a team of independent technical experts, at any phase of a cleanup process, to identify opportunities to improve remedy protectiveness, effectiveness, and cost efficiency, and to facilitate progress toward site completion."*

As stated in the definition, optimization refers to a "systematic site review," indicating that the site as a whole is often considered in the review. Optimization can be applied to a specific aspect of the remedy (e.g., focus on long-term monitoring optimization [LTMO] or focus on one particular operable unit [OU]), but other site or remedy components are still considered to the degree that they affect the focus of the optimization. An optimization evaluation considers the goals of the remedy, available site date, CSM, remedy performance, protectiveness, cost-effectiveness, and closure strategy. A strong interest in sustainability has also developed in the private sector and within Federal, State, and Municipal governments. Consistent with this interest, OSRTI has developed a Green Remediation Primer (http://cluin.org/greenremediation/), and now routinely considers green remediation and environmental footprint reduction during optimization evaluations. The evaluation includes reviewing site documents, potentially visiting the site for one day, and compiling a report that includes recommendations in the following categories:

- Protectiveness
- Cost-effectiveness
- Technical improvement
- Site closure
- Environmental footprint reduction

The recommendations are intended to help the site team identify opportunities for improvements. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed prior to implementation of the recommendation. Note that the recommendations are based on an independent evaluation, and represent the opinions of the evaluation team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the Region and other site stakeholders.

The national optimization strategy includes a system for tracking consideration and implementation of the optimization recommendations and includes a provision for follow-up technical assistance from the optimization team as mutually agreed upon by the site management and EPA OSRTI.

The Lee Chemical Superfund Site (site) is on the Missouri Registry of Confirmed, Abandoned or Uncontrolled Hazardous Waste Disposal Sites (Registry) and is also on the National Priorities List (NPL). The site is located along Old Route 210 in Liberty, Missouri, approximately fifteen miles east of Kansas City, Missouri. The on-site *in situ* aqueous soil washing system has been operated by the City of Liberty during Long-Term Response Action (LTRA). EPA Region 7 and the Missouri Department of Natural Resources (MDNR) agreed that an evaluation should be conducted to determine if there were any optimization opportunities for this system. In addition, the MDNR Hazardous Waste Program conducted a third Five-Year Review for the site in 2009 and identified certain issues relating to plume capture and the remedy's effectiveness. As a result, the Region proposed optimization of the system to EPA Headquarters.

1.2 TEAM COMPOSITION

The optimization team consisted of the following individuals:

Name	Affiliation	Phone	Email
Doug Sutton	Tetra Tech GEO	732-409-0344	doug.sutton@tetratech.com
Sandra Goodrow	Tetra Tech GEO	732-409-0344	sandra.goodrow@tetratech.com

In addition, the following individuals from EPA OSRTI and EPA Office of Research and Development (ORD) participated in the RSE site visit.

- Kathy Yager, EPA OSRTI
- Dave Reisman, EPA ORD
- Dave Burden, EPA ORD

1.3 DOCUMENTS REVIEWED

The following documents were reviewed. The reader is directed to these documents for additional site information that is not provided in this report.

- *TCE Contamination Report* (Layne-Western Co. Inc., March 1984)
- *Geophysical Investigation* (Groundwater Management, Inc., December 31, 1986)
- *Liberty Progress Report No. 1* (Layne Geosciences, Inc. August 21, 1989)
- *Liberty RI/FS Phase II Report* (Layne Geosciences, Inc., December 14, 1989)
- *Remedial Investigation Lee Chemical Site* (Layne Geosciences, Inc., August 14, 1990)
- *Feasibility Study Lee Chemical Site* (Layne Geosciences, Inc., December 1, 1990)
- Record of Decision (US EPA Region 7, March 1991)
- *Risk Evaluation Lee Chemical Final Report* (PRC Environmental Management, May 1991)
- *Final Lee Chemical Site Design Narrative* (B&V Waste Science and Technology Corp., December 29, 1992)
- *Final Remediation Action Report* (February 11, 1994)

- *Superfund Preliminary Close Out Report (LTRA)* (March 23, 1994)
- *Lee Chemical Site Remediation As-Built Drawing Set* (Waste Science and Technology Corp., November 7, 1994)
- *Lee Chemical Land Use Change Request* (Missouri Department of Natural Resources (MDNR), January 5, 1995)
- *First Five-Year Review Report (MDNR and US EPA, May 1999)*
- *Second Five-Year Review Report* (MDNR and US EPA, September 2004)
- *Third Five-Year Review Report* (MDNR and US EPA, July 1, 2009)

1.4 QUALITY ASSURANCE

This optimization evaluation utilizes existing environmental data to interpret the CSM, evaluate remedy performance, and make recommendations to improve the remedy. The quality of the existing data are evaluated by the optimization team prior to using the data for these purposes. The evaluation for data quality includes a brief review of how the data were collected and managed (where practical, the site Quality Assurance Project Plan [QAPP] is considered), the consistency of the data with other site data, and the use of the data in the optimization evaluation. Data that are of suspect quality are either not used as part of the optimization evaluation or are used with the quality concerns noted. Where appropriate, this report provides recommendations made to improve data quality.

1.5 PERSONS CONTACTED

The following individuals associated with the site were present for the visit:

Name	Affiliation	Phone	Email
Candice McGhee	MDNR	573-751-1738	candice.mcghee@dnr.mo.gov
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Brian Hess, PE	City of Liberty	816-439-4502	bhess@ci.liberty.mo.us

MDNR=Missouri Department of Natural Resources

2.0 SITE BACKGROUND

2.1 LOCATION

The former Lee Chemical Superfund Site (site) is located in a rural industrial area on the south side of Old Route 210, approximately one-half mile east of Missouri Highway 291 and approximately three miles southeast of the City of Liberty (City) downtown area, in Clay County, Missouri. The property lies between the Norfolk and Western Railroad to the south and Old Route 210 to the north, approximately 13 miles northeast of downtown Kansas City, Missouri. Currently, the site is a vacant lot of approximately 2.5 acres in a flat alluvial plain. Town Branch Creek is located approximately 0.20 miles west of the site, and enters Shoal Creek approximately 0.40 miles southwest of the site. Shoal Creek enters the Missouri River approximately 2.25 miles south-southeast of the site. The City has a municipal well field located approximately 0.40 miles southeast of the site. The City currently has nine operating municipal wells (PW-1, PW-4, PW-6, PW-7, PW-8, PW-9, PW-11, PW-13, and PW-14) situated in a north-south line in the alluvial aquifer at an approximately perpendicular angle to the site. Groundwater flow for the site is generally in the direction of the city's well field.

2.2 SITE HISTORY

2.2.1 HISTORIC LAND USE AND FACILITY OPERATIONS

The site that Lee Chemical eventually occupied was purchased by the City in 1905 and served as the initial water supply source, with two wells and a water treatment facility on-site. In the 1920s, three new wells were added to the original two, and these served as the principal water supply for many years. In 1959, five exploratory test holes were drilled in the area of what was proposed as the Liberty well field. As a result of test hole work, a new well (No. 5) was drilled in the area in 1962. The old treatment plant was abandoned in 1962 in favor of a new plant constructed closer to the City.

According to the July 2009 Third Five-Year Review, the City leased the former water treatment plant building to the Lee Chemical Company from 1965 to 1975. The Lee Chemical business consisted of packaging and distributing commercial and industrial cleaning solvents and other chemicals. The Lee Chemical Company also arranged for the disposal of chemicals from various commercial companies, which resulted in the on-site stockpiling of numerous 55-gallon drums.

2.2.2 CHRONOLOGY OF ENFORCEMENT AND REMEDIAL ACTIVITIES

In 1975, the City filed suit against the Lee Chemical Company for nonpayment of rent. Upon settlement of the suit, the City regained possession of its property and access to the site. The City found abandoned containers of chemicals and wastes on-site. In 1977, as required by the EPA, the City removed and disposed of approximately three hundred 55-gallon drums of waste off-site. In 1979, low levels of trichloroethene (TCE) were detected in the public water supply wells. Subsequent EPA and State investigations revealed contaminated groundwater and soil, and deteriorated drums and chemical containers, and in 1982, the City and State identified the site as a source of TCE contamination in the public water supply. In 1983, the on-site water treatment plant building and its contents were demolished and disposed of off-site. Due to the groundwater flow and the impact of the City's pumping municipal wells, the on-site groundwater contamination migrated off-site, impacting all of the City's municipal wells.

According to the March 1991 Record of Decision (ROD), in 1984, in an effort to contain the contaminated groundwater plume and reduce TCE levels in the water supply, the City discharged water from the most highly contaminated of its municipal water wells through an abandoned sewer line to the Missouri River and Shoal Creek. Later that year, an abandoned municipal well on-site was added to the plume control measure and the discharge was diverted to an abandoned water main to nearby Town Branch Creek. A Remedial Investigation (RI) was completed in August of 1990 and soil contamination was identified as a continuing source of dissolved groundwater contamination.

A ROD was signed on March 21, 1991 specifying the following Remedial Action (RA) components:

- Extraction of contaminated groundwater to remove contaminants from the aquifer of concern and to control groundwater movement away from the site
- Installation of an on-site *in situ* aqueous soil washing system consisting of infiltration trenches to enhance the flushing of contaminants from site soils
- Review of existing National Pollutant Discharge Elimination System (NPDES) permit limits in the event that additional treatment of the discharge water becomes necessary to meet health-based risk levels

A Third Five-Year Review was prepared in July of 2009, listing several recommendations and follow-up actions. Among the recommendations/follow-up actions that are relevant to this RSE are the following:

- Additional site characterization should be conducted to gather information and data that could be applied to the re-evaluation of the operational (extraction and monitoring) systems, and potential options for optimization or additional institutional controls (ICs).
- Verify optimal passive diffusion bag (PDB) placement and pumping location in wells for repeatable results and maximum extraction of volatile organic compounds (VOCs).
- Implement optimization options; possible avenues include but are not limited to chemical amendments, enhanced bioremediation, and soil removal.
- Resample the impacted private well, near the site, to determine contamination status and future use, closure or ICs.
- 1,4-dioxane should be included in at least two sampling events for each sampling location before the initiation of the next Five-Year Review. This is an emerging VOC contaminant found in some slow moving VOC plumes that has not been included in the list of VOCs sampled at the site.

To address contamination, an on-site groundwater extraction well and an on-site *in situ* aqueous soil washing system that discharges the extracted groundwater under the terms and conditions of a NPDES permit, a Missouri State Operating Permit (MSOP) to Town Branch Creek has been installed. A contingency phase of the RA consisting of air stripping, or other methods of treatment of extracted groundwater prior to discharge, was included in the selected remedy in the event that additional treatment is necessary to meet either the NPDES permit/MSOP limits or other Applicable or Relevant and Appropriate Requirements (ARARs).

This optimization evaluation focuses on verifying the long-term protectiveness of the RA to ensure that plume contaminants do not migrate to create new exposure pathways. According to the Third Five-Year Review Report, the current monitoring data indicates that the remedy is functioning as required to achieve

Remedial Action Objectives (RAOs), although the estimated time to reach these RAOs has already been exceeded.

2.3 POTENTIAL HUMAN AND ECOLOGICAL RECEPTORS

Before the site was leased to the Lee Chemical Company, it was the site for the City's drinking water extraction and treatment operations. When demand increased, new wells located approximately 2,000 feet (ft) to the south east were created and the drinking water operations were relocated. These new wells are the most significant receptors of potential groundwater contaminants emanating from the Lee Chemical grounds. The City has water supply wells PW-1 through PW-14 (A.K.A. WSW-1 through WSW-14). PW-2 was taken offline when contamination was detected in it, and now acts solely as a purge well for the remediation action. PW-3 was abandoned. In 2007, two new wells (PW-13 and PW-14) were added along Shoal Creek, to the south and west of PW-11. Currently, only nine of these wells (PW-1, PW-4, PW-6, PW-7, PW-8, PW-9, PW-11, PW-13, and PW-14) are operating.

A private well, located approximately 1,000 ft east of PW-1 and north of Old Route 210, was sampled in 2003 and found to contain elevated levels of vinyl chloride and trihalomethanes exceeding compliance levels. This well is currently being used only for irrigation purposes and recommendations have been made to resample at a future date.

Contamination that migrates past the production wells, if any, would discharge to either Shoal Creek or the Missouri River.

2.4 EXISTING DATA AND INFORMATION

The information provided in this section is intended to represent interpretations of data already available from existing site documents. The optimization team's interpretation of this data is discussed in Sections 4.0 and 5.0 of this report.

2.4.1 SOURCES OF CONTAMINATION

TCE contamination was discovered in the City's water supply system in 1982. The apparent source of the TCE was leakage of waste material from the storage of numerous 55 gallon drums, stored at the old water plant site, subsequently leased by the Lee Chemical Company. The drums were removed, but this leakage had already contaminated the soils and the aquifer beneath the plant site.

According to the 1991 ROD, the soil sample locations and corresponding data indicate soil contamination at highest levels immediately adjacent to the former Lee Chemical facility with decreasing levels away from the site. TCE and trichloroethane (TCA), the most common constituents, were reported at consistently greater values than other VOCs. In April 1983, the old water treatment plant building on the site was demolished and only its foundation and adjacent concrete storage tank remained. Clean soil was used to restore the surface of the site. Deeper unsaturated zone soil contamination was left in place to be addressed by the soil flushing remedy described in Section 3.

2.4.2 GEOLOGY SETTING AND HYDROGEOLOGY

The Geophysical Investigation report prepared by Groundwater Management, Inc. in December 1986, and the ROD signed in March 1991, provide descriptions of the site geology and hydrogeology. The following description is based on the information provided in those documents.

The geology of the area consists of Pennsylvanian aged bedrock strata overlain by unconformed Pleistocene and Recent unconsolidated alluvial deposits. The topographic relief of the outcropping bedrock upland area can be as high as 200 ft. The topographic relief of the flood plain is approximately 30 ft. The site lies entirely on the Missouri River flood plain.

The bedrock formations that outcrop and subcrop in the vicinity of the site are, in ascending order, the Pleasanton Group and Kansas City Group. Except for minor local structural features, the formations dip gently to the west. The Kansas City and Pleasanton Groups are composed of interbedded layers of limestone, sandstone, and shale. The unconformed surface that separates the bedrock from the alluvium dips sharply to the east from the site to the well field.

A seismic and electrical resistivity survey was performed to more accurately detail the physical geology of the site. The seismic survey did not suggest the presence of a direct channel in the bedrock surface between the source of the contamination and the water supply well locations. The data indicated a depression in the bedrock surface south of the existing monitoring well EW-4 and east of monitoring well I-82. An area of higher bedrock appears to exist between this area and the City’s production wells. Seismic velocities indicate this high area to be composed of shale while the depression and the area around production well PW-2 is limestone. Depth to the limestone at the two locations indicates a dip to the east.

Surface soil in the area consists primarily of the Haynie, Mondale, and Gillam silt loams. These soils are moderately well-drained, moderately permeable soils. They have a clay content range of 15 to 35 percent (%) and permeability ranges from 0.6 to 2.0 inches per hour.

Alluvial Aquifer

The principle aquifer in the area is the Missouri River alluvium. The regional flow of the aquifer within the site area is to the east and is heavily influenced by the pumping of the City’s water supply well field. The depth of groundwater in the site area is approximately 20 ft below ground surface (bgs). Hydraulic conductivity of the material has been estimated to range from 2,000 to 5,000 gallons per day per square foot (270 ft per day to 670 ft per day). The specific yield of the aquifer is estimated to range from 0.10 to 0.20 for the sediments encountered.

According to the 1990 Feasibility Study (FS), the natural hydraulic gradient in the area (without any influence from the pumping wells) is to the south towards the Missouri River. The hydraulic gradient and radius of influence, created by the pumping action of the wells in the Liberty well field, control groundwater flow and contaminant transport in the area and have altered the direction of groundwater flow from the site to the east rather than the south.

Surface Water Hydrology

The site is located within the Missouri River Basin, contributing runoff to Shoal Creek and the Town Branch Creek. . The Shoal Creek discharges to the Missouri River, which is located 2.25 miles south-southeast of the site.

The upper portion of the soils at the site is composed of silt with clay lenses and is somewhat compacted around the infiltration fields. There is an unmapped stream/drainage ditch whose headwaters are located west of the site. This small tributary to the Town Creek Branch discharges in the area of the downstream surface water quality sampling site. It is undetermined at this time if this stream/drainage ditch is ephemeral or is constantly fed by the exfiltration of groundwater.

2.4.3 SOIL CONTAMINATION

Investigation Conducted Prior to RI

In March of 1984, a TCE Contamination Report was prepared for the City by Layne-Western Co., Inc. summarizing a July 1983 investigation. The investigation included the collection of soil samples from the top 20 feet in the area of the old water treatment plant. It was concluded that the presence of TCE in the unsaturated zone is contributing TCE to groundwater. The TCE concentration level determined to be present in the soils during this investigation can be found in the following table.

Table 1: TCE Concentration in March 1984 Soil Samples

	TCE Concentration in Soil Samples (µg/kg)			
Depth	Sample 1	Sample 2	Sample 3	Sample 4
2.5'	5	4,500	64	27
5.0'	310	400	11	4
7.5'	1,550	3,290	1,840	48
10.0'	52	610	730	82
15.5'	1,200	1,750	2,860	2,880
20.0'	3,400	30	57	48

(µg/kg = micrograms per kilogram)

This investigation also noted that the volume of TCE in the form of dense non-aqueous phase liquid (DNAPL), if any, at the bottom of the unconsolidated sediments was undetermined at that time and recommended that a full geophysical survey be performed.

Remedial Investigation

Soil samples collected during the RI phase provided the extent and depth of the contamination. The soil sample locations that were immediately adjacent to the site had the highest levels of TCE and TCA contamination with decreasing levels away from the site. This contamination extended from approximately 1 ft bgs to the phreatic zone. The highest levels of TCE (11,000 µg/kg and 2,000 µg/kg) were found at boring locations 2-89 (20 ft bgs) and 1-89 (5 ft bgs), respectively (Attachment B).

Additional Investigations

Soil and soil gas analyses have shown an isolated and immobile contaminant plume in the vadose zone that is localized within the site.

2.4.4 SOIL VAPOR CONTAMINATION

A limited soil gas survey was conducted in March 1989 to investigate the presence of soil gas contamination in the unsaturated zone near the monitoring wells just east of the sewage disposal ponds (Figure 2). This investigation reported no measurable soil gas contamination in the area of DW 2-89 and MW 2-89.

Soil gas sampling conducted in November 1989 identified two areas of high concentrations of TCE and TCA (Contour maps, Attachment C). A high concentration area for TCE is generally located in the area east of well EW-3 (approximately 50 ft). A high concentration of TCA is generally located northeast and southwest of EW-3. Soil gas concentrations of TCE ranged from 1 part per million (ppm) at test location 27, located approximately 700 ft northeast of the site to 3,000 ppm in the immediate vicinity of the site. Soil gas concentrations of TCA ranged from 1 ppm at test location 27 to 10,000 ppm at the center of the site.

Additional Investigations

The Third Five-Year Review discussed the potential for vapor intrusion (VI) based on the levels of contamination present at this site. It is noted, however, that an incomplete indoor pathway negates the need to conduct VI samples at this time.

2.4.5 GROUNDWATER CONTAMINATION

Five Phase I monitoring wells were installed at the site in accordance with the 1988 work plan. The locations of these monitoring wells, identified as DW 2-89, MW 2-89, TW 5-89, TW 3-89, and MW 1-89, are presented in Figure 2. These wells were intended to monitor the path of the contamination as it migrated away from the source area. Extraction wells previously installed for drinking water, including EW-1, EW-4, and EW-5, were monitored along with MW 2-82, MW 1-83, MW 2-83, MW 3-83, and MW 4-83 to track contaminant concentrations on the site. Monitoring wells north of the site surrounding Douglas Chemical Co. (named as a landmark only) include MW 1-86, MW 2-86, and MW 3-86.

Groundwater contamination prior to 1990 is summarized in the August 14, 1990 RI report. The following results are noteworthy and are representative of groundwater contaminant magnitude and extent:

- The TCE concentration in groundwater from PW-2 in 1982 was 330 micrograms per liter (µg/L). Concentrations decreased over time to 45 µg/L by 1990.

- The TCE concentration in former water supply well WSW No. 3 was as high as 75.5 µg/L in 1986 and subsequently decreased to below 5 µg/L.

- The TCE concentrations in the other water supply wells were substantially lower than those in PW-2 and water supply well WSW No. 3.

- TCE was monitored on-site in monitoring location EW-3 over time. The TCE concentration was as high as 851 µg/L in 1984 and decreased gradually to below 50 µg/L by 1988. In 1989 and 1990 concentrations increased to over 100 µg/L.

Samples for TCE and other VOCs continue to be collected from the outfall discharge, downstream of the outfall, from monitoring wells MW 1-83, MW 1-86, MW 1-93, EW-4, EW-5, and the purge wells, EX-1 and PW-2. The sampling record for all of these locations has been maintained since December 1993.

The following list shows the most recently detected contaminants and the maximum concentrations detected.

Table 2: Maximum Detected Contaminant Concentrations since 12/1993

Contaminants of Concern (COC)	Cleanup Levels (WQS)	Maximum Concentration (µg/L) (Current review period- 12/1993 to 3/2011)
Trichloroethene (TCE)	5 µg/L	450 µg /L (EW-5) (2/15/94)
1,1-Dichloroethane (1,1-DCA)	70 µg/L	7.4 µg /L (EW-4) (12/1/06)
1,1-Dichloroethene (1,1-DCE)	7 µg/L	46 µg /L (EX-1) (12/2/93)
Trans-1,2-dichloroethene	100 µg/L	4.9 µg /L (EX-1) (2/15/94)
1,1,1-Trichloroethane (TCA)	200 µg/L	190 µg /L (EX-1) (12/2/93)
Cis-1,2-dichlorethene (1,2-DCE)	70 µg/L	680 µg /L (EW-5) (9/19/94)
1,2-dichloroethane (1,2-DCA)	5 µg/L	<1 µg /L (all sampling sites)
Vinyl chloride	2 µg/L	9.1 µg /L (EW-4) (1/20/10)
Acetonitrile	200 µg/L	383 µg /L (EW-5) (2/17/10)

WQS = Maximum Contaminant Level/Water Quality Standards

Groundwater quality data has been collected by the City at the required intervals at designated monitoring and pumping wells (Attachment A, Figure 3). VOC data collected at each of the sampling stations is summarized below.

PW-2: This is the former water supply well that has been converted to a remedy well. It is sampled quarterly. Since 1993 this well has had two samples with results that exceed the WQS. These exceedances included a concentration of TCE of 15 µg/L in March 1995 and TCE of 13.8 µg/L in February 2001. The only detections of site-related contaminants since 2009 have been three detections of cis-1,2-dichloroethene (cis-1,2-DCE) ranging in concentration between 1.2 and 2 µg/L, well below the cleanup limit of 70 µg/L. No detections have been recorded for acetonitrile in this well.

MW 1-83: This well is located on the western edge of the former Lee Chemical Site (upgradient) and is sampled quarterly. Since sampling began in 1993, three exceedances of the WQS have been documented: 2.1 µg/L of vinyl chloride in May 2005 (was not analyzed for prior to 2005), 228 µg/L of acetonitrile in November 2008, and 321 µg/L of acetonitrile in February 2010. Acetonitrile was not detected in samples from this well until May 2007.

MW 1-86: This well is located north of the former Lee Chemical Site across Old Route 210 (cross-gradient). It is sampled quarterly. Since sampling began in 1993, there have been six exceedances of WQS. Four of these were for TCE and cis-1,2-DCE in 1994. The other two were 268 µg/L and 295 µg/L of acetonitrile in 2010. Acetonitrile was first detected in 2007.

EX-1: This on-site extraction well is located near the center of the presumed source area and is sampled monthly. Detections of TCE and other contaminants were above WQS for all samples into 2001. Sporadic exceedances have occurred since 2001. No detections have been recorded for acetonitrile in this well.

MW 1-93: This monitoring well is sampled monthly. The most recent exceedance of WQS was acetonitrile in 2008. Prior to that, there were seven exceedances of vinyl chloride in 2006 in which the maximum vinyl chloride concentration was 3.5 µg/L. Prior to that, the last exceedance was for TCE in 2000.

<u>EW-4</u>: This on-site monitoring well immediately east of the source area is sampled monthly and has had sporadic exceedances of WQS for TCE, cis-1,2-DCE, and vinyl chloride that are more prevalent in the Spring. Acetonitrile was first detected in 2006.

<u>EW-5</u>: This on-site monitoring well is located near the eastern boundary of the former Lee Chemical operation and is sampled monthly. Exceedances of TCE (some of the highest TCE detections measured at the site since 1993) have been detected in samples from this well. However, TCE concentrations exceeding 100 µg/L were generally limited to 1995 or earlier. The highest TCE concentration in samples from this well since 2009 was 2.9 µg/L in May of 2009. Acetonitrile was first detected in 2006.

A private well located approximately 1,000 ft east of PW-1 and north of Old Route 210 was sampled in 2003 and found to contain elevated levels of vinyl chloride and trihalomethanes exceeding cleanup levels. This well is currently being used only for irrigation purposes and recommendations have been made to resample at a future date.

2.4.6 SURFACE WATER CONTAMINATION

Investigation Conducted Prior to RI

It is not evident that any surface water quality investigations have taken place.

The Town Branch Creek is the MSOP-permitted receiving water body for the discharge of the water purged from the two remediation extraction wells. Data has been collected quarterly at the outfall site and also at a water quality monitoring location established downstream (south of Old Route 210). These sites are evaluated for permit compliance to be protective of the effects of this discharge.

<u>*Downstream*</u>*:* The surface water sampling station located downstream of the site location has had one detection of TCE in surface water at 2.9 µg/L since 2009. In the previous 20 quarterly samples, a very low detection of cis-1,2-DCE (well below MSOP compliance limits) was reported.

<u>*Outfall*</u>*:* Since 2009, 16 detections of TCE and four detections of cis-1,2-DCE in surface water were reported, all below MCL/WQS. Before 2009, TCE was detected in 22 of the 52 monthly samples and 1,1,1-TCA was detected in three of the monthly samples, with no samples exceeding the compliance limit.

3.0 DESRIPTION OF PLANNED OR EXISTING REMEDIES

3.1 REMEDY AND REMEDY COMPONENTS

According to the Third Five-Year Review, the City and the MDNR entered into an Administrative Order on Consent (AOC) to conduct the Remedial Design/Remedial Action (RD/RA) on March 23, 1992. The City agreed to complete the RD/RA activities and to reimburse all future response costs incurred by the MDNR under the AOC. The RD/RA work plans were prepared by representatives of the City and approved by the MDNR. Once the Final Lee Chemical Site Design Narrative and the accompanying documents were received by the MDNR, which occurred on January 4, 1993, the construction of the new on-site groundwater EX-1 well and the on-site *in situ* aqueous soil washing system was initiated.

The full remedy consists of an on-site *in situ* aqueous soil washing system, extraction of groundwater from two extractions wells (EX-1 and PW-2), the discharge of the extracted groundwater from both extraction wells to a single MSOP -permitted outfall to Town Branch Creek and the continued monitoring and reporting of the RA system through monthly and quarterly progress reports. This remedy was considered operational and functional on March 26, 1994.

The on-site *in situ* aqueous soil washing system that is currently in place was introduced in the 1992 Site Design Narrative. Potable water from the municipal water supply is pumped to four infiltration galleries where the water infiltrates through the contaminated soil and flushes contamination to the underlying groundwater, whereupon it is extracted by the remedy wells and discharged to Town Branch Creek. The field sizing and site layout is illustrated in Attachment A, Figure 7. With four infiltration fields as shown on the plans, the anticipated total infiltration rate was 6 to 60 gallons per minute (gpm) of potable water from the City water supply. Each field distributes water through the use of perforated pipe laterals embedded in a 9-inch layer of highly permeable crushed rock, all encased in a layer of geotextile fabric. Laterals are perforated only above the springline. Each infiltration field is controlled from a valve vault at each field. Each vault contains, in the direction of flow, a ball valve, a check valve, flow rate meter with gauge read-out calibrated zero to 50 gpm, a flow rate totalizing meter calibrated to gallons, a pressure reducing valve, and a globe valve.

The Third Five-Year Review detailed the major components of the groundwater RA alternative selected in the ROD as including the following:

1. The on-site extraction well (EX-1) is located near the center of on-site contamination to extract contamination in groundwater beneath the site. The groundwater extraction system continues to use existing well PW-2, which was already being used as a groundwater extraction well for the interim response action. Several other wells, located both on-site and off-site, are available for use as extraction wells, should they be needed.

2. Contamination in groundwater extracted from the on-site groundwater wells EX-1 and PW-2 are piped together to Town Branch Creek, where aeration and mixing occurs as the water flows over riprap to the creek.

3. Groundwater and surface water monitoring are conducted to monitor the effectiveness of the RA system.

A contingency phase of the RA consisting of air stripping, or other methods of treatment of extracted groundwater prior to discharge, was included in the selected remedy in the event that additional treatment of the extracted groundwater prior to discharge was necessary to meet either the NPDES permit/MSOP limits or other ARARs.

The following table contains the total volume of water applied and extracted annually. These values were calculated from data reported in the Appendix 3 of the Third Five-Year Review.

Table 3: Volume of Water Applied to Infiltration Fields and Extracted Annually

Year	Total Volume of Potable Water Applied to Four Infiltration Fields (gallons)	Total Volume of Groundwater Extracted by EX-1 (gallons)	Total Volume of Groundwater Extracted by PW-2 (gallons)
1997	655,729	94,135,000	303,264,000
1998	3,287,609*	288,180,000	269,542,128
1999	2,395,836	304,448,000	162,334,100
2000	3,256,683	278,451,000	284,985,500
2001	2,761,737	465,657,000	375,014,500
2002	2,561,733	461,619,000	364,802,000
2003	2,540,753	185,102,000	348,304,000
2004	2,701,657	17,748,000	320,670,000
2005	2,564,681	53,555,000	226,356,000
2006	1,949,931	6,003,000	273,486,000
2007	2,626,405	13,132,000	192,600,000
2008	3,376,198	177,000	249,086,000
2009	2,756,713	204,780,000	121,245,000
2010	828,954	183,437,000	112,582,000

** Injection rates for first three quarters of 1998 were comparable to those in 1997, but fourth quarter injection rates were substantially higher.*

3.2 RAOS AND STANDARDS

The Third Five-Year Review notes that although the remedy is operating as intended by design, the goal to achieve RAOs is taking longer than anticipated.

According to the Third Five-Year Review, the City currently samples for nine VOC analytes, including TCE. Five indicator contaminants or VOCs, as found in the ROD, are the site's contaminants of concern (COCs). The following table lists those contaminants and the site-specific compliance limits.

Table 4: Initial Groundwater RAOs

Contaminants of Concern (COCs)	Compliance Levels (µg/L)
1,1-dichloroethane (1,1-DCA)	70
1,1-dichloroethene (1,1-DCE)	7
trans-1,2-dichloroethene (trans-1,2-DCE)	100
1,1,1-trichloroethane (1,1,1-TCA)	200
1,1,2-trichloroethene or trichloroethene (TCE)	5

Prior to the initiation of the RA system, the City conducted baseline sampling of the groundwater and surface water monitoring locations in December of 1993. Since January of 1994, the City has conducted routine monitoring and sampling at the site. After evaluation of original data (in September 1995), the MDNR requested that the City include three additional parameters in the analysis. In the Second Five-Year Review (September 2004), it was also recommended that the City include vinyl chloride to its list of contaminants at all sampling locations.

Table 5: Additional Groundwater RAOs

Volatile Organic Carbons	Compliance Levels (µg/L)
cis-1,2-dichloroethene (cis-1,2-DCE)	70
1,2-dichloroethane (1,2-DCA)	5
Vinyl chloride	2
Acetonitrile	200

The Third Five-Year Review has noted that 1,4-dioxane is an emerging VOC contaminant found in some slow moving VOC plumes. Since this has not been included in the list of VOCs sampled at the site, MDNR has requested that it be included in at least two sampling events for each sampling location before the initiation of the next Five-Year Review.

3.3 PERFORMANCE MONITORING PROGRAMS

The following table lists the well and stream locations included in the monitoring plan. This table also includes the events where those locations are sampled.

Table 6: Monitoring Sampling Schedule

Monitoring Site	Monitored Quarterly	Monitored Monthly
Wells:		
MW 1-83	X	
MW 1-86	X	
MW 1-93		X
EW-4		X
EW-5		X
EX-1		X
PW-2	X	
Outfall		X
Downstream	X	

The monitoring wells are sampled with (PDBs), which are generally set in the middle of the screened interval (e.g., 46 ft deep in EW-4 for a well that is screened from approximately 30 to 68 ft deep).

3.3.1 TREATMENT PLANT OPERATION STANDARDS

The standards for discharging the water to the Town Branch Creek are based on a NPDES/MDOS permit (#MO-0102172) with the monitoring and reporting requirements found in the following table.

Table 7: Surface Water Permit Standards

OUTFALL NUMBER AND PARAMETERS	UNITS	FINAL EFFLUENT LIMITATIONS		MONITORING REQUIREMENTS	
		DAILY MAXIMUM	MONTHLY AVERAGE	MEASUREMENT FREQUENCY	SAMPLE TYPE
Outfall #001-Purge Well and Drinking Water Production Well					
Flow	MGD	*	*	Daily	24-hour total
pH-Units	SU	***	***	Once/month**	Grab
Trichloroethene (TCE)	mg/L	0.01	0.005	Once/month**	Grab
1,1 Dichloroethene (1,1-DCE)	mg/L	0.014	0.007	Once/month**	Grab
Vinyl Chloride	mg/L	0.004	0.002	Once/month**	Grab
Outfall S1-Downstream in Town Branch before Mixing with the Discharge for Liberty's East Lagoon					
Trichloroethene (TCE)	mg/L	*	*		Once/quarter**** grab
Vinyl Chloride	mg/L	*	*		Once/quarter**** grab
Aquifer Monitoring					
Trichloroethene (TCE)	mg/L	*	*		Once/quarter**** grab
Vinyl Chloride	mg/L	*	*		Once/quarter**** grab

4.0 CONCEPTUAL SITE MODEL

This section discusses the optimization team's interpretation of existing characterization and remedy operation data to explain how historic events and site characteristics have led to current conditions. This CSM may differ from that described in other site documents. Section 4.1 provides a brief summary of the optimization team's interpretation of the CSM, and the following sections provide additional detail to help support that interpretation.

4.1 CSM OVERVIEW

VOC contamination released at the surface infiltrated through soil to groundwater resulting in TCE concentrations in soil up to 11,000 µg/kg, TCE concentrations in on-site groundwater up to 851 µg/L, and TCE concentrations in off-site groundwater up to 330 µg/L at PW-2 in the early to mid-1980s. Removal of sources at the surface and removal of shallow contaminated soil in 1983 helped reduce contaminant contributions to the subsurface. Since that time the soil flushing remedy has operated to flush contaminants from the soil into groundwater, and soil contamination has also been mobilized when the water table rises and contacts contaminated soil. Over time, the peak concentrations of the temporary contaminant concentration spikes have decreased as the soil is flushed by the remedy and as soil is repeatedly flushed by the rising and falling water table. Extraction from EX-1 keeps the water table in that part of the site lower than at other locations (e.g., EW-4 and EW-5, which are non-pumping wells). Although EX-1 captures some contamination near the center of the site, contamination may also be mobilized in other locations (e.g., EW-4 and EW-5) that may or may not be within the EX-1 capture zone.

Contamination concentrations detected in groundwater are a function of the background groundwater flow rate and the contaminant mass flux from the soil to the groundwater. Therefore, although contamination may be mobilized into groundwater, the mass flux may be sufficiently low that contaminant concentrations in groundwater generally remain below WQS. Concentrations detected at EX-1 are representative of the average concentration across the saturated thickness because EX-1 is an operating extraction well. The concentrations detected at EW-4, EW-5, and other sampling locations may be representative of a fairly limited interval where a PDB is present. Higher levels of contamination that are detected may be present in EW-4, EW-5, and other monitoring locations because the PDBs are set approximately 15 ft below the water table rather than at or near the water table where contamination is presumably entering groundwater.

Water from soil flushing follows preferential pathways such that soil flushing does not necessarily uniformly address all site soils, and the large majority of soil contamination in these preferential pathways that can be flushed by the soil flushing remedy has long since been removed. Soil contamination still remains and may be mobilized to groundwater by the soil flushing as the contamination slowly diffuses out of relatively impermeable zones or as the water table rises and flushes contamination from the soil that is temporarily saturated. The low concentration groundwater contaminant plumes that result from mobilized soil contamination may be stable due to dispersion and the potential for natural degradation of TCE in groundwater; however, there is insufficient information regarding water quality, contaminant distribution, and groundwater flow directions to confirm this hypothesis.

The source of the acetonitrile is uncertain and might not be associated with the site.

4.2 CSM DETAILS AND EXPLANATION

4.2.1 INFLUENCE OF WATER TABLE ON GROUNDWATER CONTAMINATION

Water level information from site wells was not available. However, water levels have been recorded at USGS site 374254094524501 in St. Joseph, approximately 45 miles from the site. Although a single water level measurement from this well is not inferred to be representative of the water level at the site, the changes in water levels over time and the general hydrographic trends at this well are presumed to be similar to those at Lee Chemical. Attachment E presents three charts in which the TCE concentrations trends at EX-1, EW-4, and EW-5 at the site are plotted with a hydrograph for the St. Joseph well. Observations are as follows:

- EX-1 Plot – Peak water levels remained relatively high from 1993 through 2001, and during that time, TCE concentrations at EX-1 decreased to below WQS. The peak water levels remained relatively low from approximately 2002 through 2006, and TCE concentrations remained below the cleanup limit. Peak water levels from 2007 on have increased to relatively high levels. In Spring 2008, when the regional water level increased to relatively high levels and remedy pumping was very low (see Table 3), the water level in the vicinity of EX-1 increased sufficiently high to mobilize additional TCE contamination. The peak TCE concentration was only approximately 25 µg/L. The relatively high regional water tables in 2009 and 2010 did not result in TCE releases above the cleanup limit, but this may be due to resumed high capacity pumping from EX-1 (see Table 3) that helped mitigate the rise of the water table.

- EW-4 Plot – TCE concentrations were high in 1994 and the first part of 1995 when remedy soil flushing started and flushing rates were high. TCE concentrations dropped to non-detectable concentrations in 1996, 1997, and 1998 when remedy soil flushing volumes were very low. A substantial spike in remedy soil flushing rates in the fourth quarter of 1998 (and relatively high flushing rates from 1999 forward) likely led to TCE concentration spikes in 1999. Subsequent to the 1999 spikes, TCE concentrations have had seasonal spikes, but not to the same high level, despite relatively consistent soil flushing rates through 2008. The TCE seasonal contaminant concentration spikes observed from 2000 forward have generally been as high as 30 µg/L and have been decreasing over time. It is noted that the remedy soil flushing rates in the easternmost infiltration field in the third quarter of 2009 may partially be responsible for the low concentrations of TCE observed in 2010. It may also be possible that the low concentrations of TCE observed in 2010 are due to continued decreases of contamination resulting from the historically fluctuating water table flushing the soils. EW-4 is approximately 200 ft from EX-1, and given the transmissive aquifer, the water table near EW-4 is likely not substantially lowered by the EX-1 pumping. Therefore, a rise in the water table is likely to reach higher into the overlying silts and clays and contact soil contamination near EW-4 than it is near EX-1. More remedial progress appears to have been made at EX-1 and EW-5 (see below) relative to EW-4. The location of EW-4 with respect to the infiltration fields may be responsible for less progress at EW-4 because it is further from the infiltration fields than EX-1 and EW-5, but continued soil flushing with the same system may not result in measureable contaminant flushing. The soil flushing rates have been relatively consistent since 2000, but the release of contamination to groundwater has not been consistent and is more indicative of a seasonal pattern than of continuous flushing.

- EW-5 Plot – The TCE trends at this location appears to have a strong correlation between peak water levels and the flushing of contamination rather than continuous flushing.

Occasional/seasonal concentration spikes since 2000 have been as high as 30 µg/L and may be decreasing. There has only been one exceedance of the WQS since 2004 in this well.

4.2.2 ANALYSIS OF FLUSHING RATES

Based on the values provided in Table 3, a representative remedy soil flushing rate is approximately 2,500,000 gallons per year for the four infiltration fields combined. In general, these fields appear to occupy an area of approximately 60,000 square ft, accounting for some area beyond the immediate footprint of the fields. These two values suggest that the infiltration rate per square foot is approximately 0.015 ft per day according to the following equation:

$$f\ iltration\ ratei \quad \frac{\frac{2\,50 \quad g \quad lonsi}{eari} \quad \frac{134\ cubic\ feeti}{g \quad lon} \quad \frac{1i\ \ eari}{365\ di \quad si}}{60 \quad squareifeet} \qquad 015\ feet\ per\ di$$

Accounting for water transport only through the pore space of the soil and an effective porosity of 0.25, the water transport velocity would be approximately 0.06 ft per day (0.015 ft per day divided by 0.25). Given that depth to water is approximately 16 ft below the bottom of the infiltration fields, water passes from the infiltration fields to the water table in approximately 267 days. A reasonable upper range retardation factor for TCE is approximately 4, suggesting that (in the absence of diffusion into and out of immobile zones) the rate at which contamination moves through the soil is 0.015 ft per day (0.06 ft per day divided by 4). Given this rate of contamination flushing, TCE may be flushed from the pore spaces of the vadose zone within approximately 3 years because a thickness of 16 ft divided by 0.015 ft per day is approximately 3 years. The remedy, however, has been operating for over 17 years. Infiltration rates per area from infiltration fields 1 through 3 are higher than the infiltration rate per area assumed here, suggesting that more pore volumes may have been flushed through these areas. The infiltration rate per square foot for field 4 is substantially less (approximately 0.005 ft per day). Using the same effective porosity and the same assumed upper range retardation factor, the TCE in the vadose zone beneath infiltration field 4 would have been flushed within 9 years.

In reality, the 60,000 square-foot area was probably not uniformly addressed by soil flushing. Water from soil flushing likely followed preferential pathways, resulting in increased pore volume flushes of these preferential pathways, but few or no pore volume flushes of the less permeable zones. For example, soil flushing water may not have flushed contamination near or upgradient of EW-4 as well as at the EX-1 and EW-5 locations.

These approximations support the concept that the soil flushing remedy has already contributed the majority of what it will likely contribute to soil remediation. Additional contamination may be present in the soil but may not have been located within the preferential flow paths of the infiltrating water and therefore would not have been flushed. In contrast, when the water table rises into the area of contamination, saturation occurs and flushing is not susceptible to preferential water transport.

4.2.3 EX-1 CAPTURE ZONE

Insufficient information is available to determine the capture zone of remedy well EX-1. The spacing of water level measurement points is too sparse to interpret capture based on a potentiometric surface map, the hydraulic conductivity and hydraulic gradient in the immediate vicinity of EX-1 are not known for use in using analytical capture zone equations, and potential sources of contamination exist upgradient and downgradient of EW-4 (the closest monitoring well) such that EW-4 cannot be used as a downgradient performance monitoring well.

4.2.4 MASS FLUX

Based on Table 3, a reasonable infiltrate rate is 2,500,000 gallons of water per year. The background groundwater flow rate is not well known, but the extraction rate at EX-1 is approximately 200,000,000 gallons per year. This is a reasonable estimate of the groundwater flow rate passing through the site. If this is the case, the background groundwater flow rate is approximately 80 times higher than the infiltration rate. The detection limit for TCE is typically 1 µg/L, which means that the infiltrating water from the soil flushing remedy may have a concentration as high as 80 µg/L and be sufficiently diluted to be undetected in groundwater samples.

4.2.5 ACETONITRILE

Based on the data record provided in the Third Five-Year Review, acetonitrile has not been present at EX-1, but has been present at wells in the presumed upgradient (MW 1-83), cross-gradient (MW 1-86), and downgradient (MW 1-93) locations. Also, according to the data record in the Third Five-Year Review, acetonitrile concentrations were first detected in approximately 2006 and not in the previous 13 years of monitoring.

A 1994 EPA chemical summary of acetonitrile (http://www.epa.gov/chemfact/s_acenit.txt) states that acetonitrile has an organic carbon partitioning coefficient (Koc) of 16 liters per kilogram (L/kg), which is approximately 6 to 10 times lower than the Koc for TCE and at least two times lower than the Koc for cis-1,2-DCE (http://www.epa.gov/superfund/health/conmedia/soil/pdfs/appd_k.pdf). Therefore, acetonitrile would be expected to have a much lower retardation coefficient than TCE and a lower retardation coefficient than cis-1,2-DCE and should have been flushed out of the vadose zone faster than these two compounds. Contaminant trends should also suggest the migration of acetonitrile from one location to another; however, the analytical results show an erratic pattern of results and generally show similar acetonitrile results at multiple well locations for a given sampling event. The locations, timing, chemical nature of acetonitrile relative to other site contaminants (e.g., TCE and cis-1,2-DCE), and pattern of detections suggest to the optimization team that acetonitrile may not be site-related and may instead be a laboratory contaminant. The optimization team queried other environmental consultants and has learned of incidents where consultants have identified acetonitrile as a laboratory contaminant.

4.3 DATA GAPS

There are several data gaps in the existing CSM, including the following:

- In the absence of reliable, consistent water level measurements at site wells, there is a limited understanding about the groundwater flow direction at the site and a limited understanding of the capture zone of EX-1. There is also a limited understanding of how much remedy well EX-1 lowers the water table and prevents groundwater from flushing contamination from the vadose zone.

- Sampling locations are relatively limited; therefore, there is a limited understanding regarding the extent of off-site contamination, if any.

- Sampling is conducted at one interval within the monitoring points with PDBs, and some of the monitoring points are former extraction wells that presumably have long screen intervals. The vertical distribution of contamination is unclear and is likely shallower than the interval sampled by the PDBs.

- Water quality data provided to the optimization team is limited to VOC results presented in the Five-Year Review and recent VOC analytical reports. Other water quality parameters such as oxidation-reduction potential (ORP), nitrates, and sulfates are not known. Total dissolved carbon and iron are measured from the city water supply wells and indicate high iron content (presumably dissolved), which suggests reducing conditions and the potential for TCE to degrade. TCE degradation daughter products (cis-1,2-DCE and vinyl chloride) are also present, further suggesting the potential for TCE degradation. Other than this limited information, the potential for natural degradation of TCE and other site-related contaminants is not known.

- The current soil contamination or soil vapor contamination is not known; therefore, the potential for the soil to serve as a continuing source of groundwater contamination is not known.

- The contaminant concentration of the infiltrating water after passing through the vadose zone is not known. The initial declines in contaminant concentrations in groundwater were likely due to the soil flushing remedy, but the more recent occasional detections and exceedances of contamination in groundwater are likely predominantly due to the rising water level. However, insufficient information is available to confirm this.

- The Five-Year Review indicated the potential for 1,4-dioxane to be present at the site. Monitoring for this chemical has not been done, presenting another uncertainty. Because 1,4-dioxane is substantially more mobile than TCE, does not degrade in the subsurface, and is typically found in lower concentrations than solvents at solvent sites, the optimization team finds it unlikely that 1,4-dioxane is present at detectable levels at the site. Nevertheless, sampling for 1,4-dioxane is appropriate given that the contaminant does not degrade and public water supply wells are located downgradient of the site.

4.4 IMPLICATIONS FOR REMEDIAL STRATEGY

The implications of this CSM and related data gaps on the remedy are significant.

- If the mass flux of contamination to groundwater from the soil flushing remedy has decreased sufficiently to result in limited detections and even more limited exceedances of cleanup criteria, then it may be appropriate to discontinue the soil flushing remedy.

- If a fluctuating water table and historically high water tables are critical for flushing soil contamination from the vadose zone, then pumping on-site may be slowing or preventing soil flushing by lowering the water table.

- If occasional contaminant concentrations that exceed cleanup criteria degrade or attenuate in a reasonable distance, then the plume may be stable and hydraulic plume capture may not be necessary. If contamination is entering the aquifer downgradient of the EX-1 capture zone (e.g., at EW-4 or EW-5), then contamination may already be migrating off-site (and may be degrading). Contamination that is extracted by remedy well EX-1 is transferred to the atmosphere prior to discharge. Contamination that migrates and then degrades in the subsurface is destroyed.

- If the PDBs are not set at the appropriate interval, and higher concentrations of contamination are present, then contamination may be migrating off-site at higher than expected concentrations.

5.0 FINDINGS

5.1 GENERAL FINDINGS

The observations provided below are not intended to imply a deficiency in the work of the system designers, system operators, or site managers but are offered as constructive suggestions in the best interest of the EPA and the public. These observations have the benefit of being formulated based upon operational data unavailable to the original designers. Furthermore, it is likely that site conditions and general knowledge of groundwater remediation have changed over time.

5.2 SUBSURFACE PERFORMANCE AND RESPONSE

5.2.1 PLUME CAPTURE

Potentiometric Surface Maps

Current water level data was not available to the optimization team and may not be collected, and potentiometric surface maps prepared during the RI are not reliable because they are heavily dependent on the water levels measured in operating production wells. There is, therefore, insufficient evidence to evaluate this line of evidence regarding plume capture.

Concentration Trends

The current monitoring program indicates that TCE has occasionally exceeded WQS at EW-4 and EW-5. The extent of the EX-1 capture zone is not known, but it is possible that these two locations are downgradient of it, which means that the observed contamination at EW-4 and EW-5 is not captured. For the past several years, the observed concentrations at EW-4 and EW-5 have been slightly above or below the cleanup limit for TCE and other site-related contaminants. However, the PDBs in EW-4 and EW-5 may be set too low to intercept the highest groundwater concentrations.

Groundwater Flow and Extraction

Given the absence of reliable water levels, insufficient information is available to calculate the flow of groundwater through the site and compare it to the extraction rate.

5.2.2 GROUNDWATER CONTAMINANT CONCENTRATIONS

As described in Section 4.0, the contaminant concentrations are low and seasonally variable with peak concentrations generally decreasing over time. The extent of contamination off-site is unknown, particularly near the water table. Contaminant concentrations in samples from PW-2 have been below standards since 2001. MDNR has collected split VOC analysis for all operating municipal wells as part of the previous Five-Year Reviews. The results for the November 20, 2008; May 12, 2010; and August 17, 2011 events have shown no exceedances of applicable water quality standards (Superfund Chemical Data Matrix, EPA Screening Levels or Missouri WQS). In August 2011, there were detections of cis-1,2-DCE in PW-1 and PW-4 at concentrations more than an order of magnitude below the MCL of 70 µg/L and less than half the concentration detected at PW-2. The plume core appears to be migrating generally toward PW-2 with the plume fringe reaching as far as PW-1 to the north and PW-4 to the south. Although contamination is not present in PW-2 or the operating supply wells above WQS, contamination may be present above WQS downgradient of the site but upgradient of these wells.

5.3 COMPONENT PERFORMANCE

5.3.1 EXTRACTION SYSTEM

EX-1 is outfitted with a 20 horsepower (HP) turbine pump that has a pressure cutoff switch and is otherwise manually controlled. According to data in the Third Five-Year Review, and averaging over each year, the extraction rate has ranged from 0.33 gpm (2008) to over 800 gpm (2001 and 2002). The extraction rate from 2004 through 2008 was generally significantly lower than the average pumping rate, which was likely in part due to iron fouling. In 2009 and 2010, the average extraction rate was 350 gpm to 390 gpm, likely reflecting recent well maintenance activities addressing iron fouling. At the time of the optimization site visit, the flow meter indicated the well was pumping at approximately 220 gpm unrestricted. This flow rate is likely low given the pump size and total dynamic head on the pump. The optimization team suspects this may be due to the pressure head caused by blending the flow from PW-2 and EX-1 and potentially from iron fouling in the EX-1 piping.

PW-2 is outfitted with a 30 HP turbine pump that has a pressure cutoff switch and is otherwise manually controlled. According to data in the Third Five-Year Review, and averaging over each year, the extraction rate has ranged from 210 gpm (2010) to over 700 gpm (2001). At the time of the optimization site visit, the flow meter indicated the extraction rate was 250 gpm. This well is also affected by iron fouling and was treated for iron fouling in the fall of 2010.

The flow of the two wells is blended in a single discharge pipe, and the two wells need to be balanced to keep them operating. For example, if PW-2 shuts down, then EX-1 needs to be throttled back to avoid pumping the well dry.

5.3.2 INFILTRATION FIELDS

The site team reports that the infiltration fields are generally maintenance free. The City recently reconditioned some of the vault interiors given the age and condition of the equipment in the vaults. The injection rates are generally 1.6 gpm for field 1, 1.5 gpm for field 2, 1.2 gpm for field 3, and 0.4 gpm for field 4. The variation in flow rates is likely due to the permeability underlying each field. All injected water is potable water from the City water supply.

5.3.3 DISCHARGE TO TOWN BRANCH CREEK

According to the Third Five-Year Review, if the TCE level in the groundwater extracted from EX-1 and PW-2 was found to exceed the discharge limitations set forth in the NPDES permit/MSOP, then it would become necessary to invoke the contingency phase of the remedy consisting of further treatment of the water prior to discharge to remove VOCs from the extracted groundwater. TCE is often detected in the discharge but remains below the permitted limit.

5.4 REGULATORY COMPLIANCE

No exceedances of the permit conditions have occurred over the past 10 years.

5.5 COMPONENTS OR PROCESSES THAT ACCOUNT FOR MAJORITY OF ANNUAL COSTS

The City did not provide a comprehensive cost for operating the remedy, but provided relevant information to the optimization team. The following table summarizes the primary costs for operating the remedy.

Table 8: Estimated Annual Cost Breakdown

Cost Category	Estimated Annual Cost
Project management and reporting	Not provided
Operation and Maintenance (O&M) labor	Not provided
Electrical costs	$25,000
Potable water cost	$14,000
Analytical costs	$7,500

5.5.1 UTILITIES

Utilities include electricity for operating EX-1 and PW-2 and the potable water for the infiltration fields. The electricity cost is based on a 20 HP pump, a 30 HP pump, motor efficiencies of 80%, operating load of 80%, and an average electricity rate of $0.075 per kilowatt-hour (kWh). The electricity rate is based on the optimization team’s interpretation of the Kansas City Power & Light rates and tariffs. Any heating for the pump houses is assumed to be relatively small given the small pump houses and large motors housed in the pump houses. The cost for the potable water usage was provided by the City.

5.5.2 NON-UTILITY CONSUMABLES AND DISPOSAL COSTS

Limited materials and consumables are used in association with the remedy.

5.5.3 LABOR

The remedy is managed and operated by City employees, and although the time spent on this remedy is a cost to the City, the cost is not estimated here. Operations and maintenance (O&M) labor is likely approximately 1 hour per weekday on average. If an environmental consultant were providing the services, this would cost approximately $17,000 to $20,000 per year. The time spent on managing the site is not estimated.

5.5.4 CHEMICAL ANALYSIS

The chemical analysis cost is based on the sampling program described in Section 3, a cost of $75 per sample, and a courier charge. This information was provided by the City.

5.6 APPROXIMATE ENVIRONMENTAL FOOTPRINTS ASSOCIATED WITH REMEDY

5.6.1 ENERGY, AIR EMISSIONS, AND GREENHOUSE GASES

The energy, emissions, and greenhouse gas footprint of the remedy is primarily due to the electricity usage for operating the pumps. An estimated 325,000 kWh of electricity is used each year to operate the pumps. Assuming 33% efficiency of thermal power plants and 10% loss of electricity through transmission and distribution, this translates to annual energy usage of approximately 3,700 million British thermal units (BTUs) per year. Based on this electricity usage and the average fuel mix for electricity generation in Missouri (Attachment F), annual greenhouse gas emissions are approximately 700,000 pounds (lbs) of carbon dioxide equivalents, and criteria pollutant emissions (i.e., nitrogen oxides, sulfur oxides, particulate matter) are approximately 7,000 lbs per year. Hazardous air pollutants are released from the generation of electricity and the off-gas of TCE during aeration at the discharge location.

5.6.2 WATER RESOURCES

The primary uses of water are associated with the infiltration fields and groundwater extraction. Approximately 2,500,000 gallons of potable water is used in the infiltration fields each year. Water is also extracted from the EX-1 and PW-2 and discharged to surface water. Extraction rates have been declining over the past several years. As of 2010, approximately 300,000,000 gallons of groundwater from these two extraction locations combined were discharged to surface water, representing a loss of a groundwater resource. Water is also used in some manner during electricity generation and is estimated to be in the range of 325,000 gallons per year.

5.6.3 LAND AND ECOSYSTEMS

Land and ecosystems are not directly affected by the current operation of the remedy.

5.6.4 MATERIALS USAGE AND WASTE DISPOSAL

There is no significant use of materials or waste generation at the site with the exception of well maintenance activities that occur approximately once every 3 to 4 years.

5.7 SAFETY RECORD

The site team did not report any safety concerns or incidents.

6.0 RECOMMENDATIONS

Cost estimates provided herein have levels of certainty comparable to those done for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Feasibility Studies (-30%/+50%), and these cost estimates have been prepared in a manner generally consistent with EPA 540-R-00-002, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, July, 2000. The costs presented do not include potential costs associated with community or public relations activities that may be conducted prior to field activities. The costs and sustainability impacts of these recommendations are summarized in Tables 9 and 10.

Groundwater concentrations generally meet WQS in all sampled locations, with the exception of periodic low-level increases above criteria in on-site wells. In general, it appears that a combination of the soil flushing remedy and a fluctuating water table have been successful in reducing the contaminant mass flux from the soil to the groundwater to sufficiently low levels to provide the above observations. However, significant information is missing regarding groundwater flow directions, the potential for contaminant degradation, and horizontal and vertical plume delineation. Several recommendations are provided in Section 6.1 to address this missing information. Limited recommendations are also provided in Section 6.3 regarding technical improvement. Focus is then placed on an exit strategy in Section 6.4. No recommendations for the cost reduction and environmental footprint reduction categories are made, but the outcome of implementing the strategy in Section 6.4 could result in significant improvements in these three categories.

6.1 RECOMMENDATIONS TO IMPROVE EFFECTIVENESS

6.1.1 SURVEY WELLS, MEASURE WATER LEVELS, AND PREPARE POTENTIOMETRIC SURFACE MAPS TO CONFIRM GROUNDWATER FLOW DIRECTIONS

All site-related monitoring wells that have not been destroyed should be located and resurveyed consistent with general practice in the remediation field. A table should be developed that provides this new survey information and the well construction information, including well diameter, casing material, top of casing elevation, ground surface elevation, total depth, and screened interval(s). Water levels should be measured quarterly for one year and the results used to make potentiometric surface maps to better understand groundwater flow directions. Water levels from operating extraction wells should not be used in developing the potentiometric surface maps. Where well clusters are located, vertical gradients should be documented. This information is important to understand where contamination leaves the site (if at all) and the fate of any contamination that leaves the site. Current practice assumes that the contamination will migrate past EW-5 toward PW-2. The improved water level information will either confirm this finding or help determine if the primary contaminant migration pathway has shifted to the north or south of PW-2. It will also help determine the direction downgradient of EW-4 in case a monitoring well is appropriate for that location. The optimization team estimates that implementing this recommendation should cost approximately $15,000 if outside resources are used. If the City can use its own survey team and its own labor for water level measurements, the cost will likely be substantially lower.

6.1.2 SAMPLE ADDITIONAL INTERVALS IN EW-4, EW-5, AND MW 1-93

The PDBs in these locations may be set too deep to detect contamination infiltrating into groundwater from the overlying soil and may be too shallow to detect potentially deeper contamination. Placing PDBs at depths 5 ft below the top of the screened interval, in the middle of the screened interval, and 5 ft above the bottom of the screened interval will help identify if higher levels of contamination are present in these locations. Sampling should occur in this manner during each sampling event for one year and then be reevaluated. After one year, it may be appropriate to continue the sampling in this manner or adjust PDB placement to the depth of a single interval. The estimated increased cost of this sampling for one year is approximately $5,400 (72 samples at $75 per sample).

6.1.3 ANALYZE GROUNDWATER FOR 1,4-DIOXANE

Consistent with the Five-Year Review, samples should be collected and analyzed for 1,4- dioxane. The PDBs cannot be used for sampling 1,4-dioxane, so the optimization team recommends conducting one year of quarterly sampling using low-flow sampling in addition to collecting the PDB samples. This low-flow sampling can be limited to EW-4, EW-5, and MW 1-93. Samples for 1,4-dioxane should also be collected from EX-1 and PW-2. The pump for low-flow sampling should be placed at the same or similar interval as the PDB. The low-flow sampling will allow 1,4-dioxane to be sampled. The low-flow sample should also be analyzed for VOCs, and the VOC data from the low-flow sampling can be compared to the VOC data from the PDB sampling to determine if the results are consistent. The optimization team estimates that the cost for implementing this recommendation is approximately $10,000. This recommendation should be implemented after the optimal PDB depth interval has been established from recommendation 6.1.2. Although 1,4-dioxane may not appear in the first sampling events, the optimization team suggests conducting the sampling for four quarters due to the variable nature of contaminant detections at the site.

If 1,4-dioxane were to be detected above levels that warrant remediation, the site team should likely conduct additional sampling to understand the distribution and magnitude of the contamination prior to considering a remedial option. Remediation of 1,4-dioxane would likely involve *in situ* chemical oxidation (ISCO) with activated persulfate or groundwater extraction and treatment with an advanced oxidation process. Ongoing research is occurring with regard to bioremediation of 1,4-dioxane, but it is unclear if this technology would be available or sufficiently refined for use in the near future.

6.1.4 ANALYZE GROUNDWATER SAMPLES FOR MONITORED NATURAL ATTENUATION PARAMETERS

Limited available information suggests potential for natural degradation of TCE, including the presence of degradation compounds (‘daughter products’) and high iron concentrations. Documentation of conditions that promote natural degradation would be helpful in utilizing natural degradation as part of the remedial strategy. Monitored natural attenuation (MNA) parameters (nitrate, sulfate, total organic carbon, dissolved oxygen, ferrous iron, ORP, and methane/ethane/ethene) should be analyzed in each monitoring location (excluding the outfall and downstream sample) quarterly for one year. The dissolved oxygen and ferrous iron can be measured using field test kits, and the ORP can be measured with a portable field instrument. The other parameters will involve laboratory analysis for approximately $200 per sample. The estimated cost for implementing this recommendation for one year is $6,000. The sampling should be coordinated with the low-flow sampling discussed in Section 6.1.3 because PDBs are not appropriate for sampling most natural attenuation parameters.

6.1.5 EVALUATE NEED FOR ADDITIONAL MONITORING POINTS

Based on the findings from the above four recommendations, the site team should identify if additional monitoring points are needed for plume delineation and/or confirmation that the groundwater plume is stable. For example, the new water level information (see Section 6.1.1) may suggest that there is not a well located downgradient of EW-4, and a new monitoring well in this location might be appropriate to evaluate degradation of the contamination observed at EW-4. The additional monitoring points may be helpful for supporting a MNA remedy or other alternative remedy if conditions are appropriate.

6.2 RECOMMENDATIONS TO REDUCE COSTS

No specific recommendations are provided to reduce costs; however, the considerations in Section 6.4 may lead to a reduction in remedy life-cycle costs.

6.3 RECOMMENDATIONS FOR TECHNICAL IMPROVEMENT

6.3.1 SUBMIT BLIND PDB BLANK SAMPLES FOR EACH SAMPLING EVENT

As discussed in Section 4.2.5, the optimization team suspects that acetonitrile may be a laboratory contaminant and not a site-related contaminant. The optimization team recommends submitting a field-collected blank sample along with each sampling event. Acetonitrile is only detected in samples collected with PDBs and has not been detected at EX-1 or PW-2. The acetonitrile may be associated with the PDBs or with the methods the laboratory uses to extract water from the PDBs. Therefore, the blank samples should be collected by filling a PDB with the same clean water source used for other PDBs, storing that filled PDB in a safe and uncontaminated location while the other PDBs are in the wells, filling laboratory bottles with the blank PDB sample during the sampling event, and marking the sample as a field sample with a unique identifier (i.e., not as a blank). This will serve as a blind blank sample to the laboratory. If acetonitrile is identified in the blank samples as well as the field samples, then the site team has confirmation that acetonitrile is a manifestation of the sampling and analysis procedures and not a site-related contaminant. The cost for implementing this recommendation would be approximately $100 per sampling event until sufficient data are available for the site team to make a determination.

6.3.2 POSTPONE SOIL AND SOIL VAPOR SAMPLING

The consent order between the State and the City (through plans outlined in the 1994 Remedial Action Report) requires that soil gas sampling occur at 10 locations when concentrations at EW-5 approach cleanup standards and prior to discontinuation of the soil flushing remedy. Based on the sampling results at EW-5, it is appropriate to conduct this sampling at this point. However, the optimization team has identified the following shortcomings associated with this approach:

- The soil is saturated during soil flushing operation, and this would prevent soil vapor samples from being collected until the vadose zone soils dewater. To conduct meaningful soil vapor sampling, the system would need to be shut down and the soil allowed to dewater prior to sampling.

- The concentrations at EW-4 are generally higher than those at EW-5 and given the lack of information regarding the groundwater flow direction at the site, EW-5 may not be directly downgradient of EW-4. As a result, the improved conditions at EW-5 may not be the appropriate trigger for the sampling.

- It is unclear how the results will be used to evaluate remedy effectiveness. The results could be used to simply show reductions, but the resulting information would likely not provide additional information regarding the potential for future impacts to groundwater because there is no established link between soil concentrations in given soil intervals and resulting groundwater impacts at this site.

One potential way of addressing these shortcomings would be to wait until concentrations at EW-4 are closer to those currently observed at EW-5, shut down the system, wait for a set amount of time for the vadose zone soils to dewater, and then collect the soil vapor samples as originally intended. The set amount of time for adequate dewatering is uncertain. The optimization team estimates that at infiltration rate of 0.015 ft per day (see Section 4.0) it will take approximately 1 year to dewater the upper 5 ft beneath the infiltration fields. Therefore, absent other information the optimization team would suggest waiting 1 to 3 years before conducting the prescribed vapor samples. At that time, the soil vapor sampling at 10 locations could likely be done for approximately $30,000, including preparation of a plan, vapor sampling with a direct-push rig in the field for 2 days, laboratory analysis, and reporting.

6.4 CONSIDERATIONS FOR GAINING SITE CLOSE OUT

6.4.1 POTENTIAL REMEDIAL APPROACHES FOR CONSIDERATION BY THE SITE STAKEHOLDERS

Significant remedial progress has been made at the site over the past 15 or more years, and the current site conditions merit consideration of different remedial approaches. It is difficult to outline a clear path forward for the remedy because critical information is not available. Implementing the recommendations in the above sections will likely provide the needed information, but the optimization team would like to present several potential approaches at this time for consideration so that the site team can evaluate and discuss them as the new information becomes available. Several remedial approaches are provided below based on different outcomes from the new information. Some of the approaches discuss more focused remediation for EW-4 and assume an area of 50 ft by 50 ft. The basis for this assumption is that the approximate area between infiltration fields 2 and 3 is the primary cause of the more persistent contamination observed at EW-4, but this might not be the case. All of the approaches assume that 1,4-dioxane is not present at concentrations that require active remediation (e.g., groundwater extraction and treatment or ISCO with activated persulfate).

Potential Approach #1 - Change Remedy to MNA

This remedy would involve discontinuing the soil flushing remedy, discontinuing extraction from EX-1 and PW-2, and continuing to monitor groundwater quality to confirm natural attenuation is occurring as intended. Natural infiltration from rainfall and a rising and falling water table would continue to flush contamination from soils over time such that the site would eventually meet performance criteria. Additional data analysis and study of the new information would be required to confirm MNA is appropriate. If MNA is appropriate, the optimization team estimates that this approach would require the same amount of time to reach remedial goals as the current remedy because the optimization team believes that the soil flushing system and groundwater extraction are no longer contributing meaningfully to soil and groundwater remediation (see Section 4.0). The optimization team cannot effectively estimate the time frame to reach site closure, but an estimate of 20 years is likely reasonable, primarily due to the observed contamination at EW-4. However, because the pump house and infiltration galleries would no longer be needed, the property could be reused in a timely manner. Prior to property development, soil vapor concentrations would need to be monitored to determine if a soil vapor barrier and/or passive venting were merited to reduce the potential for VI in newly constructed buildings.

This potential approach might be appropriate if the following occurs:

- The new information and data evaluation confirms that groundwater contamination observed on-site degrades below WQS within a reasonable distance from the site boundary.

- The site stakeholders agree with the optimization team that the soil flushing remedy is providing little or no measureable soil remediation beyond flushing from natural infiltration and a rising and falling water table.

The optimization team estimates that quarterly sampling for VOCs with PDBs would be conducted at EX-1, MW 1-93, PW-2, and perhaps two or three other downgradient locations (existing or new). Monthly sampling for VOCs with PDBs would continue at EW-4 and EW-5. Once per year or once every 2 years, low-flow sampling could be conducted for MNA parameters to confirm MNA conditions still exist. Assuming the information from the recommendations in Sections 6.1 and 6.3 are already available, the approximate life-cycle cost for this potential approach might be on the order of $240,000 (excluding system abandonment and confirmation sampling). This assumes approximately $20,000 of upfront data analysis followed by approximately 20 years of sampling. The sampling is assumed to cost $11,000 per year for laboratory analysis and 2 days per year for low-flow sampling.

Potential Approach #2 – Expand Soil Flushing Remedy to Address the Area Near EW-4 with MNA

This potential approach would be similar to Potential Approach #1 with the exception that an existing infiltration field would be extended to the vicinity around EW-4 or a new infiltration field would be installed in the vicinity of EW-4 to better flush that area. The approach would also involve continued operation of the soil flushing remedy for the new EW-4 field only. This approach assumes that EX-1 does not need to continue operating because it is assumed that after data evaluation, MNA would be deemed an appropriate groundwater remedy. The optimization team cannot effectively estimate the time frame to reach site closure, but an estimate of 10 years may be a reasonable estimate given that remediation near EW-4 should be somewhat faster than with the current system. The pump house and infiltration galleries would need to remain on the property for this duration limiting alternate land uses during this time period.

This potential approach might be appropriate if the following occurs:

- The new information and data evaluation confirms that groundwater contamination observed on-site degrades below WQS within a reasonable distance from the site boundary.

- The site stakeholders believe the soil flushing remedy would more effectively address the area around EW-4 than flushing from natural infiltration and a rising and falling water table.

- Construction of an infiltration field in the vicinity of EW-4 is feasible.

The optimization team assumes the same sampling program as for Potential Approach #1. Potable water injection and operation of the soil flushing remedy would continue. Assuming the information from implementing the recommendations in Sections 6.1 and 6.3 is already available, the approximate life-cycle cost for this potential approach might be on the order of $240,000 (excluding system abandonment and confirmation sampling) but is highly variable depending on the effectiveness of soil flushing at EW-4. This assumes approximately $20,000 of upfront MNA data evaluation, $25,000 to sample soils in the vicinity of EW-4 to identify the potential area for treatment, $50,000 to expand or construct and test a new infiltration field, $3,500 per year in potable water usage (25% of the current usage), and 10 years of sampling. The sampling is assumed to cost $11,000 per year for laboratory analysis and 2 days per year for low-flow sampling.

Potential Approach #3 – Expand Soil Flushing Remedy to Address the Area near EW-4 with Continued Groundwater Extraction

This potential approach would be similar to Potential Approach #2 with the exception that data evaluation suggests that MNA is not an appropriate groundwater remedy and EX-1 needs to continue operating or pumping needs to occur at EW-4 instead of EX-1 to capture groundwater contamination. The estimated time frame for this remedy would be the same as that for Potential Approach #2. The pump house and infiltration galleries would need to remain on the property for this duration and reuse of the property would be limited during remediation.

This potential approach might be appropriate if the following occurs:

- The new information and data evaluation finds that MNA is not an appropriate groundwater remedy.

- The site stakeholders believe the soil flushing remedy would more effectively address the area around EW-4 than flushing from natural infiltration and a rising and falling water table.

- Construction of an infiltration field in the vicinity of EW-4 is feasible.

The costs for this approach would be the same as those for Potential Approach #2 with the added cost of operating EX-1 (or EW-4) and PW-2 and sampling the outfall monthly. These added costs would be approximately $26,000 per year. The approximate life cycle cost for this potential approach might therefore be on the order of $510,000 (excluding system abandonment and confirmation sampling) but is highly variable depending on the effectiveness of soil flushing at EW-4.

Potential Approach #4 – Expand Soil Flushing Remedy to Address the Area near EW-4 with Treatment Amendments

This potential approach would be similar to Potential Approach #2 with the exception that treatment amendments such as potassium permanganate (for ISCO) or emulsified vegetable oil (for bioremediation) would be applied to the soil flushing remedy instead of groundwater extraction from EX-1. The amendments would likely be metered into the potable water and mixed in line prior to distribution to the infiltration fields. Assuming amendments are only added to treat in the vicinity of EW-4 and that the volume to be treated is approximately 2,000 cubic yards, chemical oxidation or bioremediation amendments (materials only) would likely cost on the order of $40,000 to over $100,000 depending on site-specific conditions. Tanks, feed pumps, an in-line mixer, and controls would be needed to meter the amendments into the potable water. These items might cost $25,000 to design and install. Soil flushing with the amendments would likely need to occur for 1 to 3 years (refer to Section 4.2.2 for a discussion of flushing rates) to allow amendments a reasonable opportunity to reach the water table. The amendment addition would have the same limitations regarding preferential pathway flow as historic flushing. Remediation at EW-4 might (or might not) be complete after that 3-year period, but it is unclear if EW-5 will consistently meet WQS at that point. Up to 10 years (or more) might be needed before EW-5 can consistently meet the WQS. In sum, the cost of this approach would likely add up to $65,000 or more to the cost of Potential Approach #2 and may or may not improve performance and timeliness of remediation.

Potential Approach #5 – Use Soil Vapor Extraction to Address Soil Contamination at EW-4 with MNA for Groundwater Remediation

This approach would be similar to Potential Approach #2 but would use soil vapor extraction (SVE) instead of soil flushing to address the contaminated soils contributing to groundwater contamination near EW-4. Design of the SVE system would need to account for the tight soils. Pneumatic fracturing of the clay or the construction of several SVE trenches might be needed to provide adequate vapor recovery. Soil sampling could be conducted during SVE installation to help evaluate the size and extent of the SVE system. Design and installation of the system would likely be over $350,000, and up to 5 years of operation might be required at approximately $6,000 per year for electricity costs alone. Additional labor would be required to check and monitor the system. The MNA evaluation and annual groundwater sampling consistent with Potential Approach #1 would also apply for approximately 10 years until EW-5 can consistently meet WQS. In sum, the life cycle costs would likely be over $500,000 (excluding system abandonment and confirmation sampling). SVE effectiveness will be dependent on the ability of the extraction system to pull vapors from the subsurface, which cannot be accurately estimated without on-site pilot testing.

Potential Approach #6 – Mix Chemical Oxidants with Soil in Vicinity of EW-4

Similar to Potential Approaches #4 and #5, this approach would involve targeted remediation in the vicinity of EW-4. The optimistic scenario of MNA is assumed for other parts of the site. This approach would involve characterizing a particular area for treatment, excavating the treated soil, mixing the excavated soil with a chemical oxidant (e.g., potassium permanganate), and backfilling the amended soil in the excavation. The optimization team estimates that this approach might cost $200,000 (or possibly more depending on the soil oxidant demand) to only address the soils in the area of EW-4. Similar to Potential Approaches #4 and #5, costs would still be required for groundwater monitoring and allowing time for EW-5 to consistently meet WQS. It is a more certain method of addressing the contamination at EW-4, but does not improve the certainty of the cleanup time for EW-5.

Potential Approach #7 – Expand Soil Flushing Remedy to EW-4 and Apply Amendments to Infiltration Fields for EW-4 and EW-5

This approach is similar to Potential Approach #4 except that the amendments are also added to infiltration fields 3 and 4 to attempt to accelerate the remediation of contamination observed at EW-5. The optimization team estimates that the costs for the additional amendment to add to these two other infiltration fields is on the order of $400,000 to $1,000,0000, assuming a treatment area of 30,000 square ft and a treatment depth of 20 ft and a range of potential site-specific soil characteristics. Operation of the system would likely need to occur for approximately 3 years to allow for distribution of the amendment. An optimistic scenario is that EW-4 and EW-5 consistently meet the WQS after this 3 year period. Optimistically, total costs of the potential approach might range from $500,000 to over $1,000,000. However, if soil remediation has been limited by preferential flow from the infiltration fields to groundwater, then the application of amendments would likely be limited by the same preferential flow, and there is no guarantee that the amendments will accelerate remediation. For this reason, if the resources are going to be invested in more aggressive remediation of site soils, another technology that does not suffer from the uncertainty related to preferential flow through soils, should be considered (see below).

Other Potential Approaches

Other potential approaches would involve broader application of the above technologies (e.g., ISCO mixing) or the use of other technologies such as *in situ* thermal remediation to more aggressively address site soils and reduce uncertainty associated with preferential flow during soil flushing. Absent other information, it is reasonable to assume that remediation would require approximately $100 per cubic yard and that remediation could be achieved in a few years. Application of an aggressive remedy for soils across the site could likely exceed $2,500,000. Given this scale of cost, a pre-remedy characterization effort would be merited to better understand the CSM and better identify target areas for remediation.

Optimization Team Input

Given the above potential approaches and the need for more information, the optimization team suggests moving forward with the recommendations in Sections 6.1 and 6.3 to better understand the nature of the problem. Determining if 1,4-dioxane is present, if MNA is appropriate, and if acetonitrile is a site-related contaminant are all important questions for considering a path forward. Unfortunately, soil sampling through the infiltration fields could affect the future performance of the fields by damaging pipes or accentuating preferential flow paths. Soil sampling outside of the infiltration fields may be helpful for identifying soil contamination that might be causing the observed contamination at EW-4. If no other subsurface obstructions are present in this location, direct-push technology (DPT) could be used to perform higher-resolution sampling to better understand the extent and magnitude of contamination in this area and the potential to address it. The decision to address potential soil contamination near EW-4 will likely depend on the results of that investigation, the applicability of MNA as a remedy, and the sampling results at EW-5 over the next few years as the site team collects additional information. The site team might consider obtaining the information from the recommendations in Sections 6.1 and 6.3 and determine if the findings strongly suggest a particular path forward. If focus on the EW-4 area is of interest, a field event consisting of 2 or 3 days of DPT soil sampling could be conducted to evaluate potential areas for target remediation. The cost for this field event might be approximately $40,000, including a field sampling plan, 3 days in the field, laboratory analysis, and reporting.

6.4.2 EVALUATING POTENTIAL FOR SOIL VI

Once WQS have been met for groundwater and/or the soil flushing system has been discontinued and vadose zone dewatered, the site team can evaluate the potential for VI for future structures on the site. Soil vapor samples can be collected from the dry infiltration field sumps because the infiltration fields cover the majority of the property, represent the preferential path for soil vapor migration in the subsurface, and will be in equilibrium with the underlying soil vapor contamination. Prior to sampling, the sumps should be fitted with air tight caps. Pulling vapor samples from each of the four fields would cost approximately $1,200 in analytical costs ($300 per summa canister sample analyzed for VOCs). These samples could be collected by City employees in 1 day with limited instruction from a qualified laboratory. If an environmental consultant is hired to conduct the work, the cost for contracting, a work plan, health and safety plan, and sample collection may be as much as $10,000. If soil vapor concentrations suggest a potential risk, the site team could decide to pursue more aggressive soil remediation (see above) or to require vapor barriers, passive venting, or other VI mitigation approaches for future buildings.

6.5 RECOMMENDATIONS RELATED TO FOOTPRINT REDUCTION

No green remediation recommendations are provided, but recommendations in Section 6.2 may result in reducing the remedy footprint.

6.6 SUGGESTED APPROACH TO IMPLEMENTING RECOMMENDATIONS

The recommendations in Sections 6.1 and 6.3 can be implemented immediately and are necessary for considering a path forward as discussed in Section 6.4.

Table 9: Cost Summary Table

Recommendation	Reason	Additional Capital Costs ($)	Estimated Change in Annual Costs ($/yr)	Estimated Change in Life-Cycle Costs $*	Discounted Estimated Change in Life-Cycle Costs $**
6.1.1 SURVEY WELLS, MEASURE WATER LEVELS, AND PREPARE POTENTIOMETRIC SURFACE MAPS TO CONFIRM GROUNDWATER FLOW DIRECTION	Effectiveness	$15,000	$0	$15,000	$15,000
6.1.2 SAMPLE ADDITIONAL INTERVAL IN EW-4, EW-5 AND MW-1-93	Effectiveness	$5,400	$0	$5,400	$5,400
6.1.3 ANAYLZE GROUNDWATER FOR 1,4-DIOXANE	Effectiveness	$10,000	$0	$10,000	$10,000
6.1.4 ANALYZE GROUNDWATER SAMPLES FOR MNA PARAMETERS	Effectiveness	$6,000	$0	$6,000	$6,000
6.1.5 EVALUATE NEED FOR ADDITIONAL MONITORING POINTS	Effectiveness	Not quantified			
6.3.1 SUBMIT BLIND PDB BLANK SAMPLES FOR EACH SAMPLING EVENT	Technical Improvement	$100 per sampling event until issue is resolved			
6.3.2 POSTPONE SOIL AND SOIL VAPOR SAMPLING	Technical Improvement	$0	$0	$0	$0
6.4.1 POTENTIAL REMEDIAL APPROACHES FOR CONSIDERATION BY THE SITE STAKEHOLDERS	Site Closure	See text			
6.4.2 EVALUATING POTENTIAL FOR SOIL VAPOR INTRUSION	Site Closure	See text			

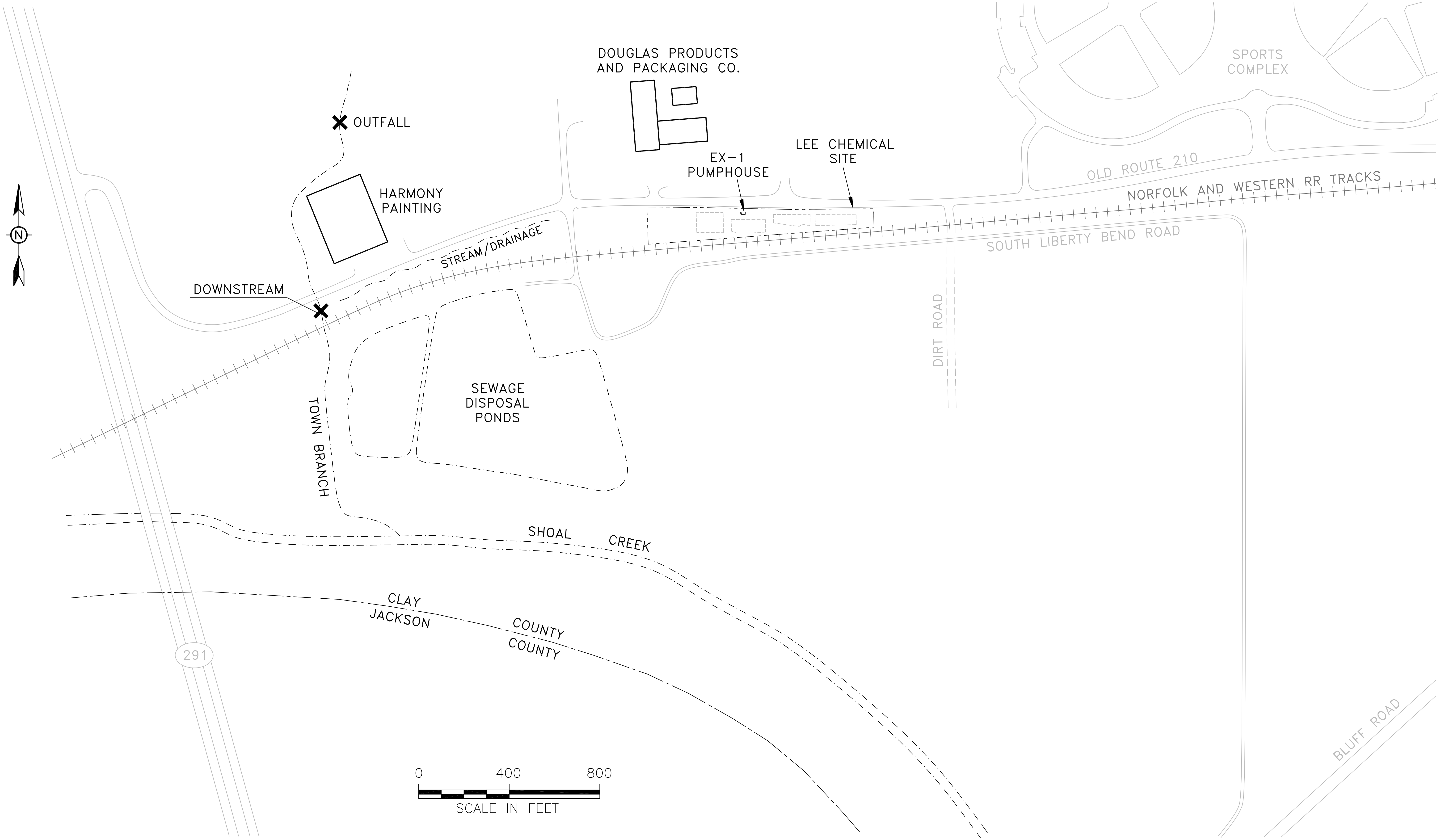
** Assumes additional 20 years of system operation*
*** Assumes a discount rate of 3%*

Table 10: Summary Table Related to Footprint Reduction

Recommendation	Reason	Effects on Footprint
6.1.1 SURVEY WELLS, MEASURE WATER LEVELS, AND PREPARE POTENTIOMETRIC SURFACE MAPS TO CONFIRM GROUNDWATER FLOW DIRECTION	Effectiveness	Minimal effect on all green remediation footprint parameters
6.1.2 SAMPLE ADDITIONAL INTERVAL IN EW-4, EW-5 AND MW-1-93	Effectiveness	Increase in all green remediation footprint parameters due to increased footprint from laboratory activities
6.1.3 ANAYLZE GROUNDWATER FOR 1,4-DIOXANE	Effectiveness	Increase in all green remediation footprint parameters due to increased footprint from laboratory activities
6.1.4 ANALYZE GROUNDWATER SAMPLES FOR MNA PARAMETERS	Effectiveness	Increase in all green remediation footprint parameters due to increased footprint from laboratory activities
6.1.5 EVALUATE NEED FOR ADDITIONAL MONITORING POINTS	Effectiveness	None.
6.3.1 SUBMIT BLIND PDB BLANK SAMPLES FOR EACH SAMPLING EVENT	Technical Improvement	Negligible
6.3.2 POSTPONE SOIL AND SOIL VAPOR SAMPLING	Technical Improvement	Potential decrease in footprint parameters by avoiding a sampling event that may not have yielded useable information
6.4.1 POTENTIAL REMEDIAL APPROACHES FOR CONSIDERATION BY THE SITE STAKEHOLDERS	Site closure	Variable depending on approach taken
6.4.2 EVALUATING POTENTIAL FOR SOIL VAPOR INTRUSION	Site closure	Potential decrease in footprint from utilizing existing infrastructure to assist in sampling.

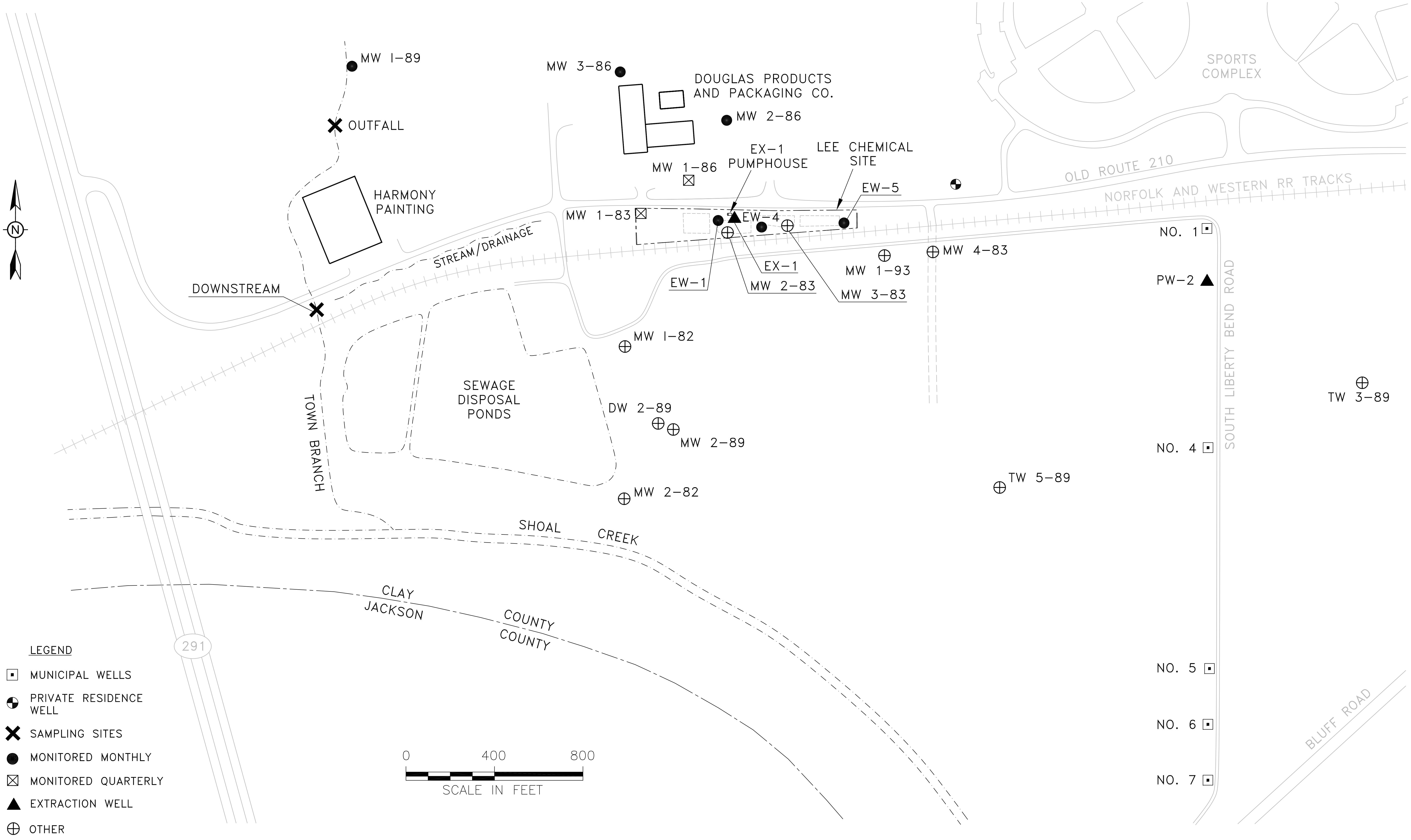
ATTACHMENT A:
FIGURES

FIGURE 1. LEE CHEMICAL SITE LOCATION AND COMPONENTS



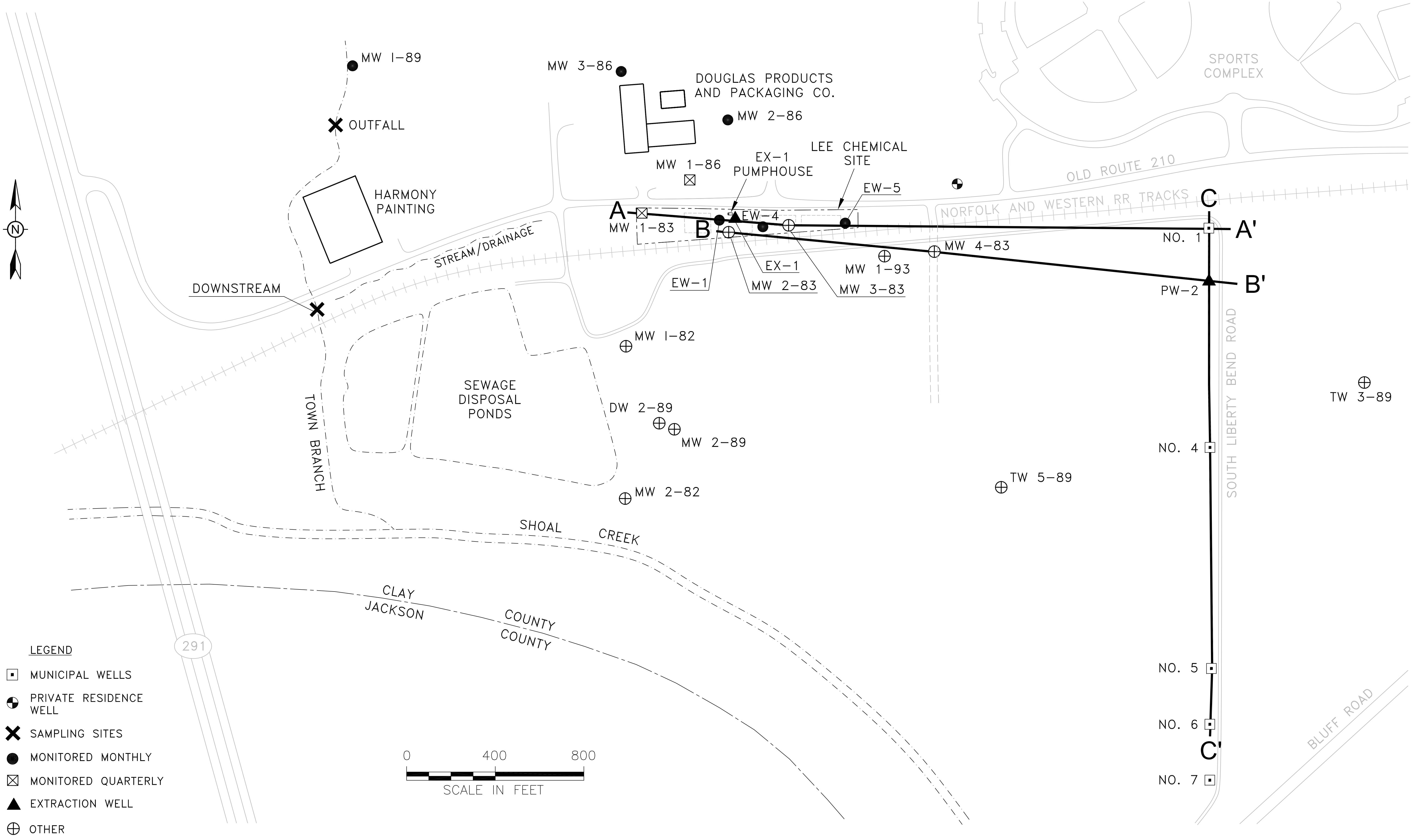
(Note: This figure is based on site maps provided by Layne Geosciences, Inc. hydrogeologist and Figure 1-2 from the Feasibility Study Lee Chemical Site, December 1, 1990, Layne Geosciences, Inc.)

FIGURE 2. LEE CHEMICAL SITE MONITORING WELLS



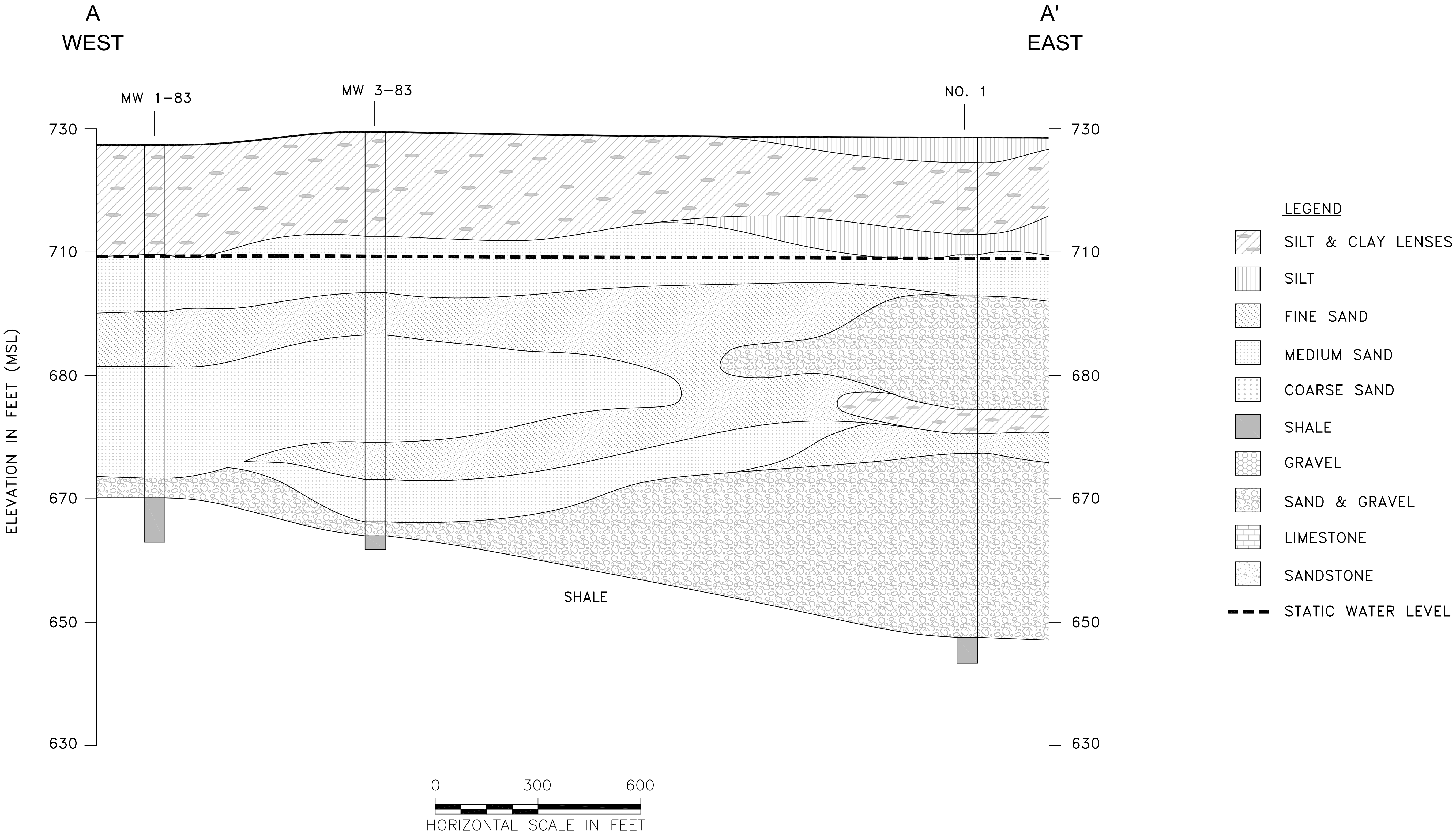
(Note: This figure is based on site maps provided by Layne Geosciences, Inc. hydrogeologist and Figure 1-2 and 1-7 from the Feasibility Study Lee Chemical Site, December 1, 1990, Layne Geosciences, Inc.)

FIGURE 3. CROSS SECTION LOCATIONS



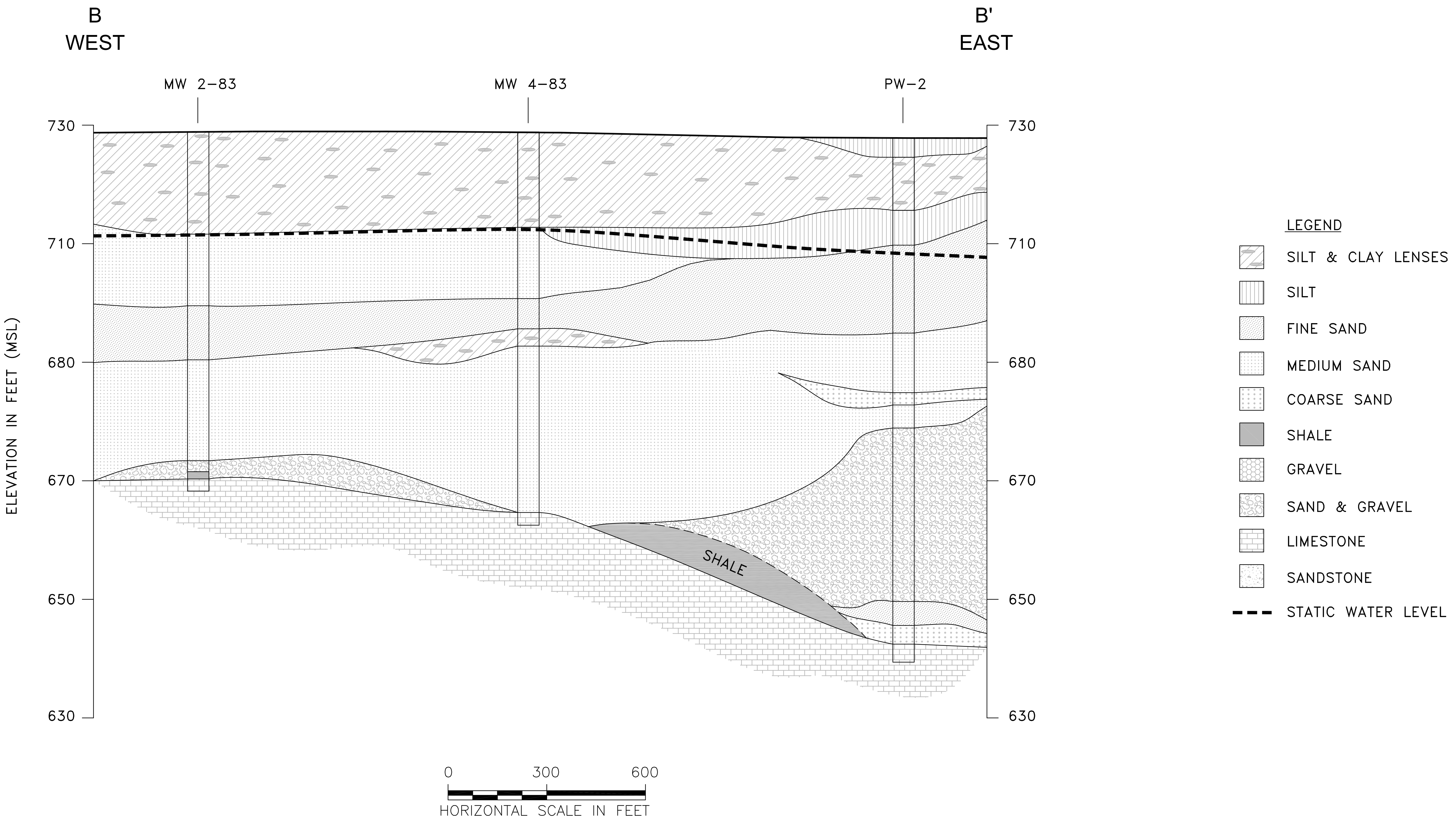
(Note: This figure is based on site maps provided by Layne Geosciences, Inc. hydrogeologist and Figure 1-2 and 1-7 from the Feasibility Study Lee Chemical Site, December 1, 1990, Layne Geosciences, Inc.)

FIGURE 4. CROSS SECTION A-A'



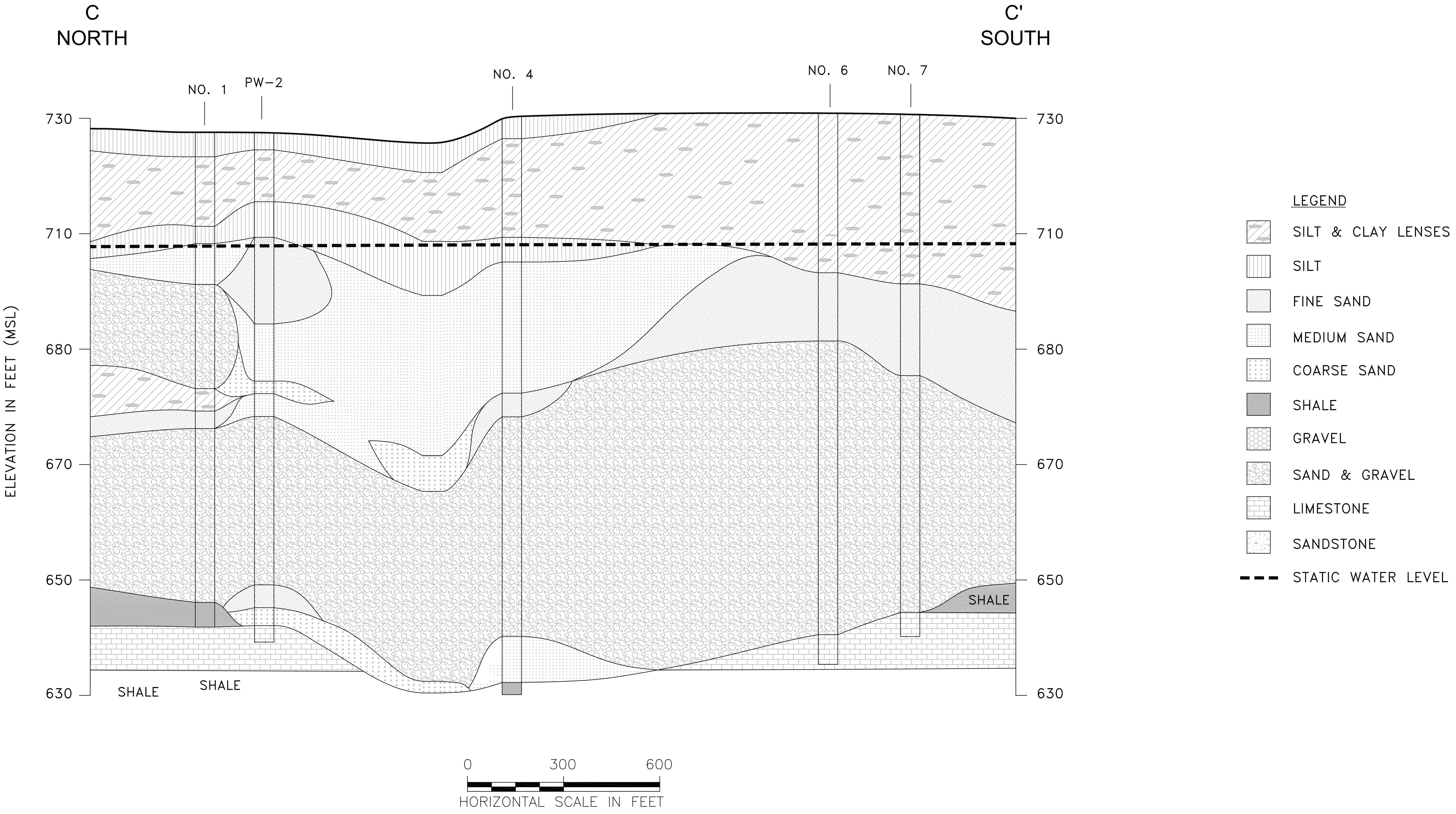
(Note: This figure is based on site maps provided by Groundwater Management, Inc. Groundwater Hydrogeologist from the Geophysical Survey, Groundwater Management, Inc. December 31, 1986.)

FIGURE 5. CROSS SECTION B-B'



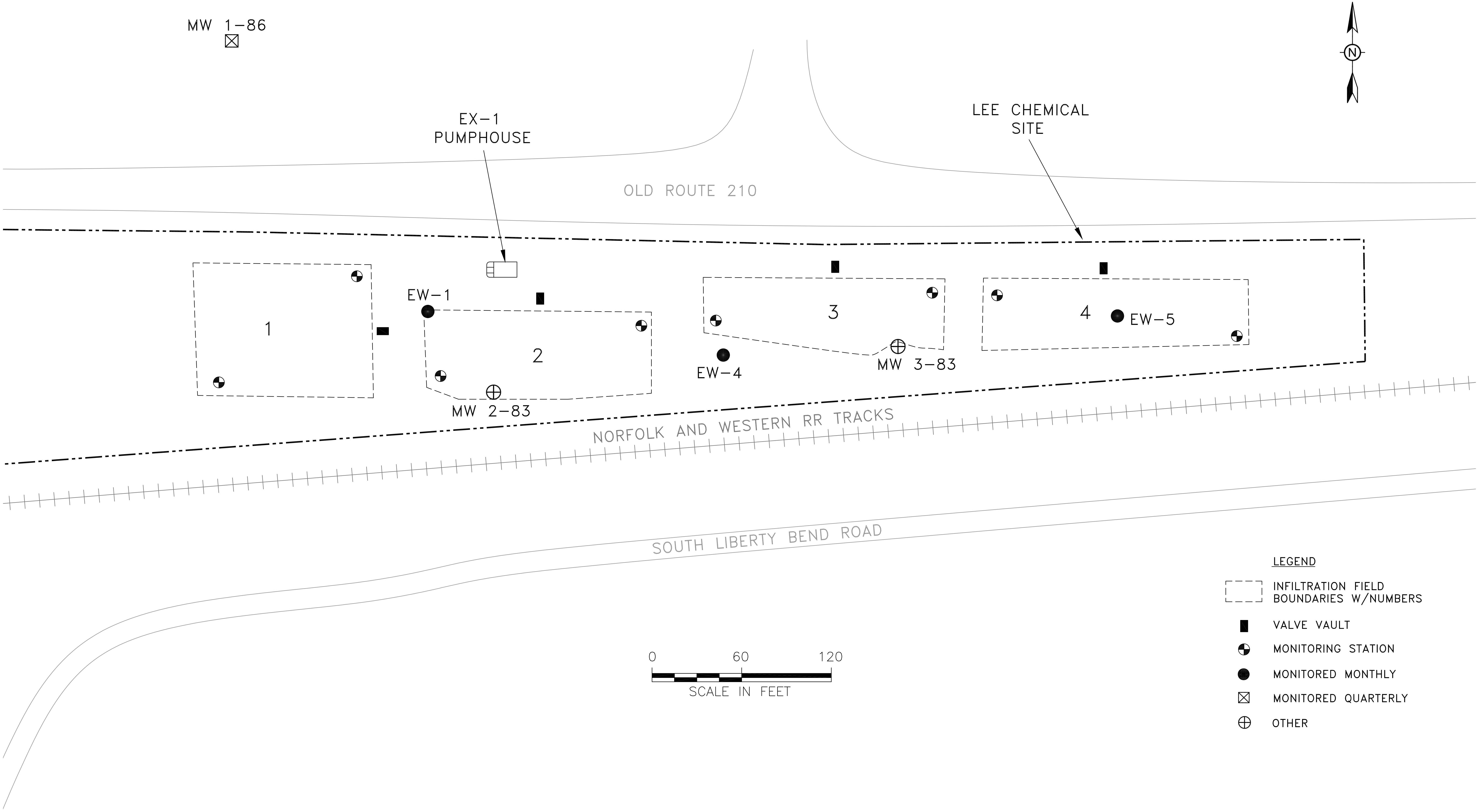
(Note: This figure is based on site maps provided by Groundwater Management, Inc. Groundwater Hydrogeologist from the Geophysical Survey, Groundwater Management, Inc. December 31, 1986.)

FIGURE 6. CROSS SECTION C-C'



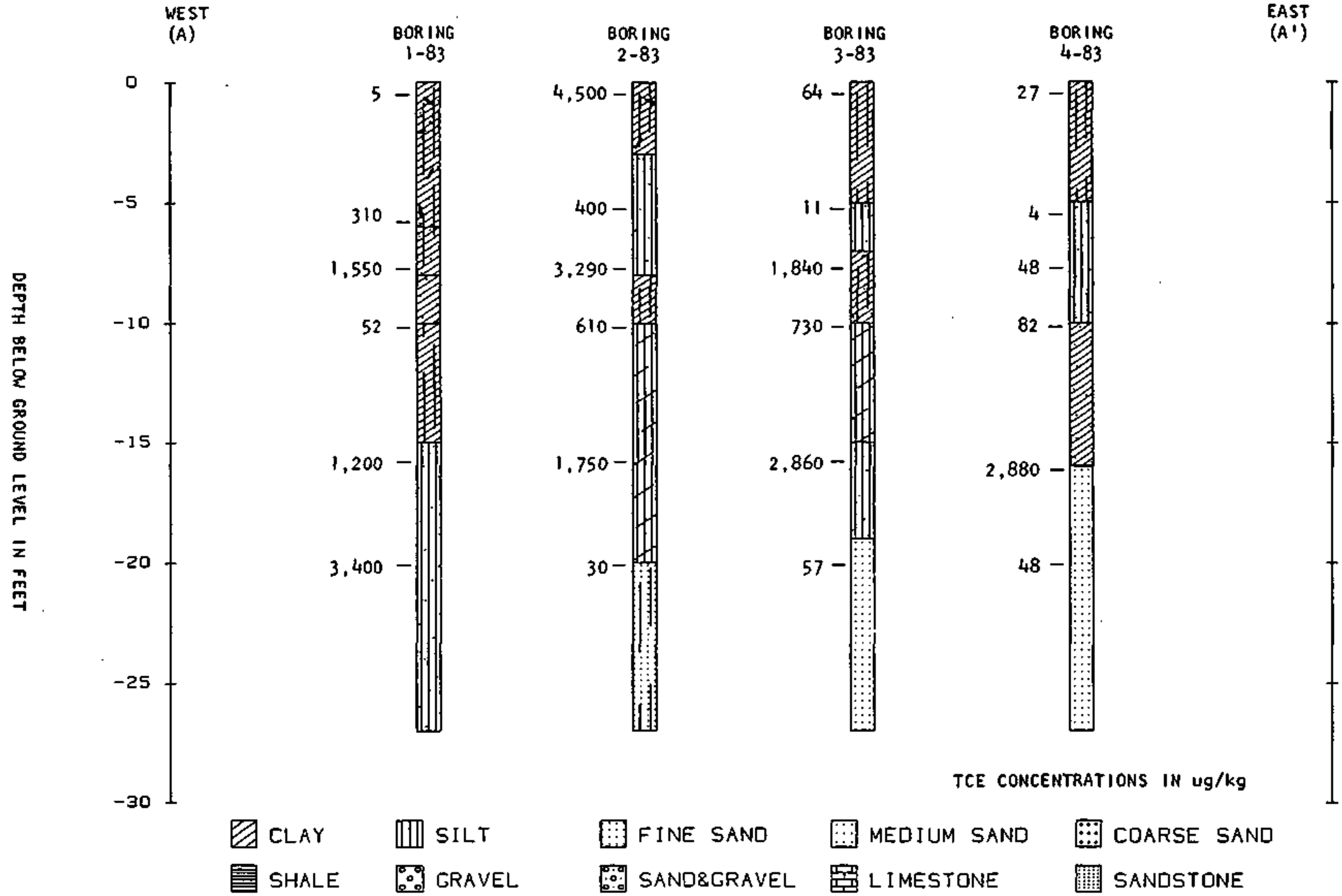
(Note: This figure is based on site maps provided by Groundwater Management, Inc. Groundwater Hydrogeologist from the Geophysical Survey, Groundwater Management, Inc. December 31, 1986.)

FIGURE 7. INFILTRATION FIELDS



(Note: This figure is based on site maps included in an attachment to the Second Five-Year Review.)

ATTACHMENT B



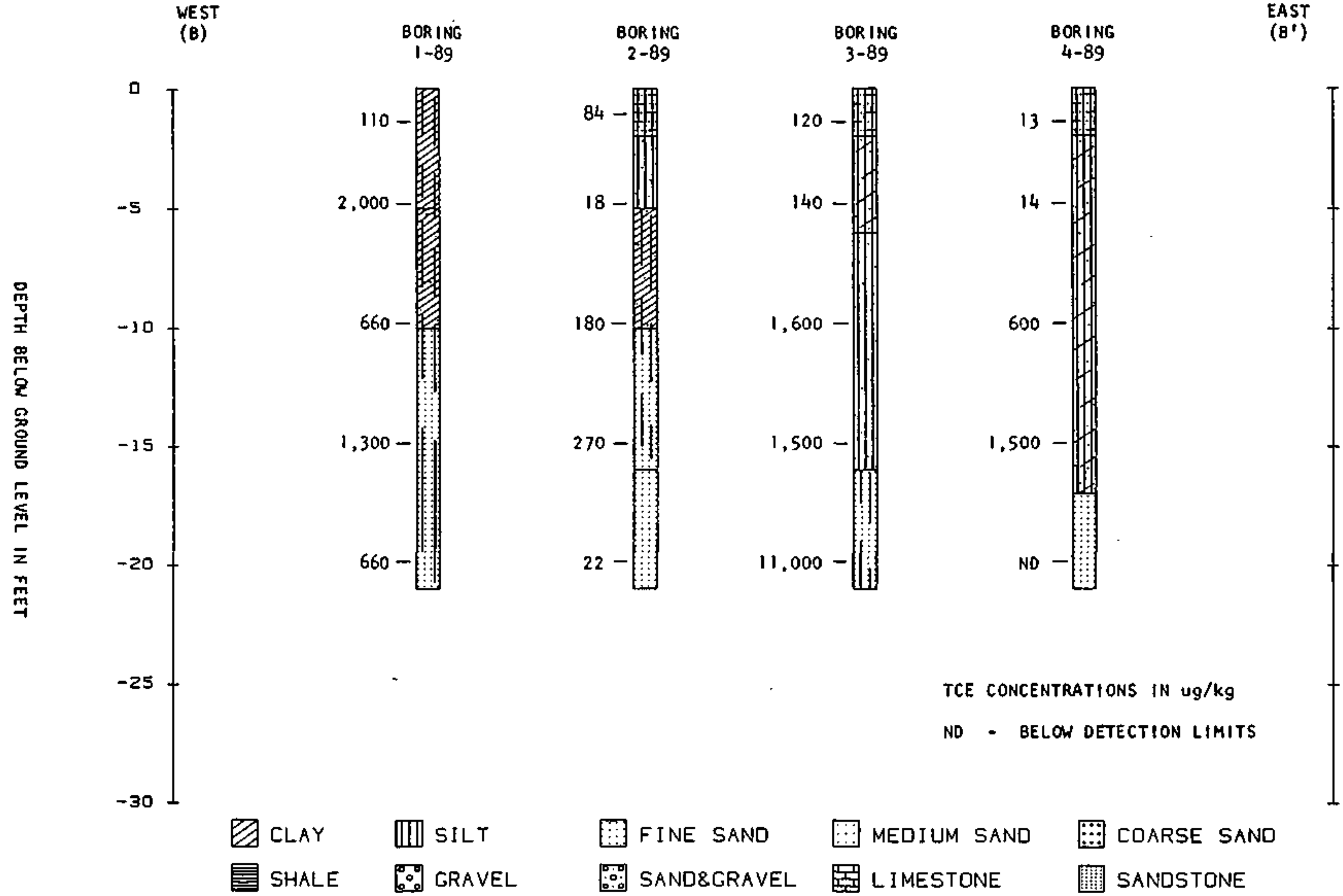
JOB: LIBERTY MISSOURI
JOB NO.: 39-0235
LOCATION: LIBERTY MISSOURI

CROSS SECTION A - A'

HYDROGEOLOGIST: DBK
DRAFTSMAN: WRS
DATE: 8-10-90

LAYNE GEOSCIENCES, INC.

FIGURE: 1-5



JOB: LIBERTY MISSOURI
JOB NO.: 39-0235
LOCATION: LIBERTY MISSOURI

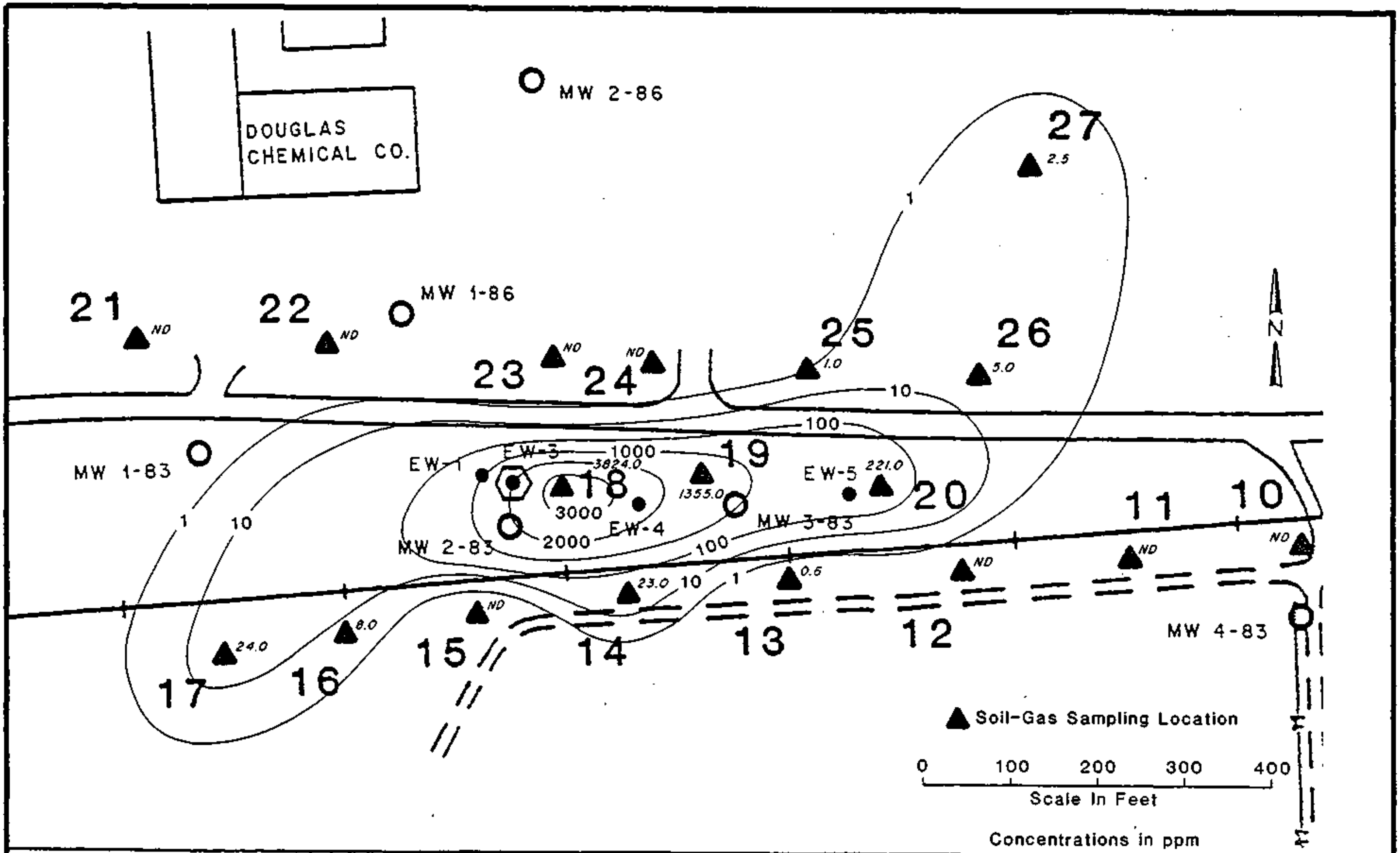
CROSS SECTION B - B'

HYDROGEOLOGIST: DBK
DRAFTSMAN: WRS
DATE: 8-10-90

LAYNE GEOSCIENCES, INC.

FIGURE: 1-6

ATTACHMENT C



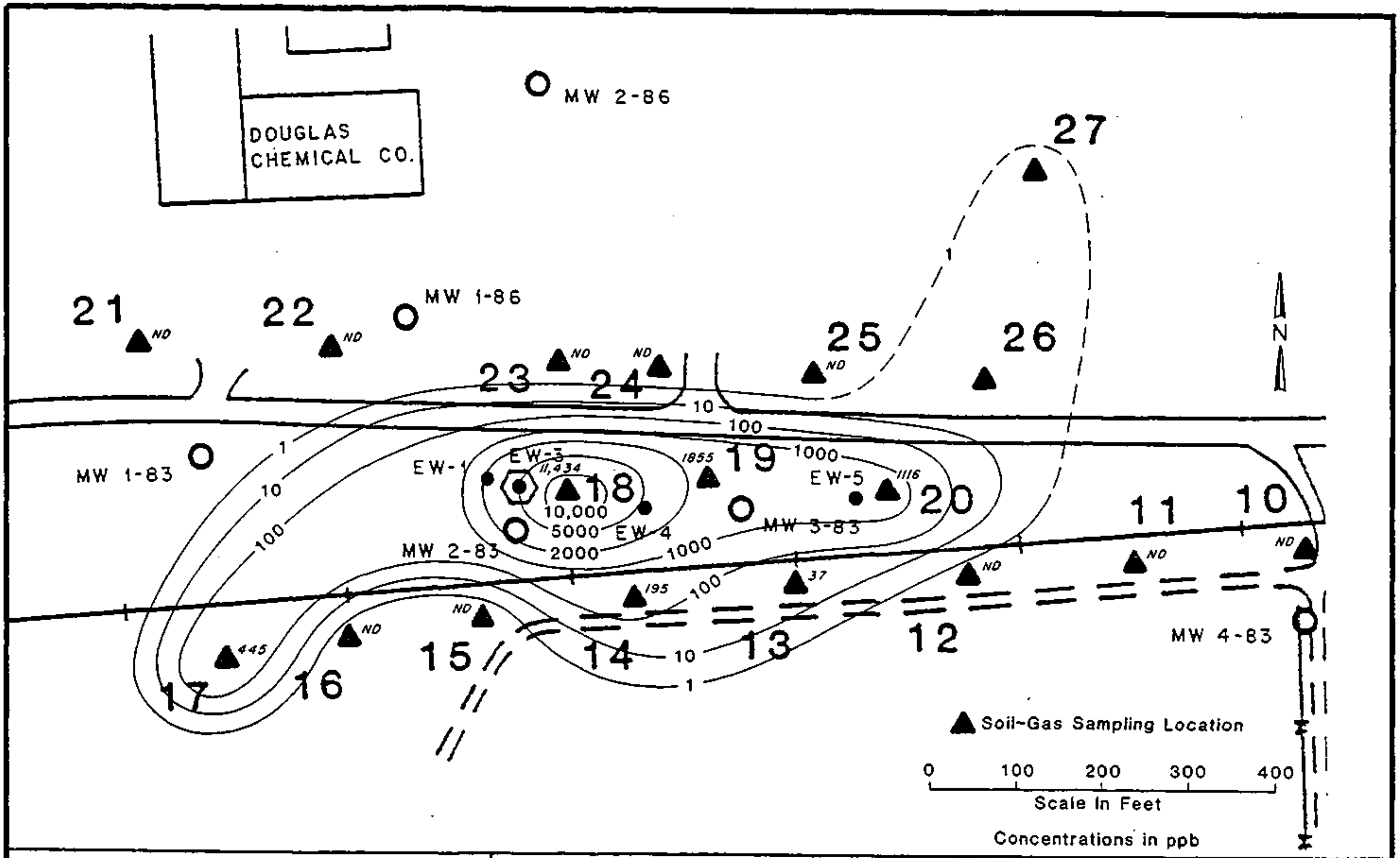
JOB: LIBERTY MISSOURI
JOB NO.: 39-0235
LOCATION: LIBERTY MISSOURI

TCE CONCENTRATIONS
FROM SOIL GAS ANALYSIS

ENGINEER: MK
DRAFTSMAN: WRS
DATE: 12-14-89

LAYNE GEOSCIENCES, INC.

FIGURE: 17



JOB: LIBERTY MISSOURI
JOB NO.: 39-0235
LOCATION: LIBERTY MISSOURI

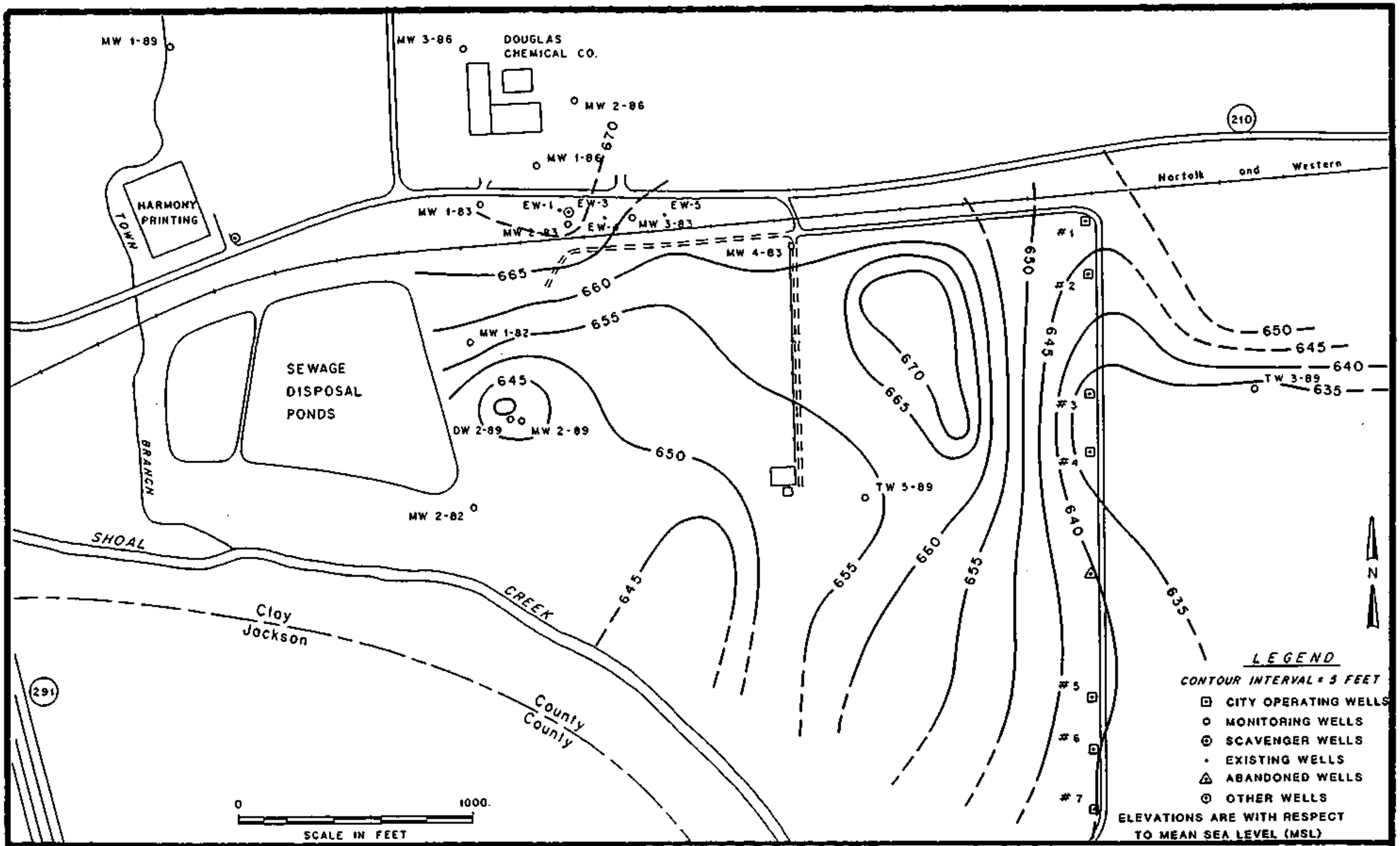
TCA CONCENTRATIONS
FROM SOIL GAS ANALYSIS

ENGINEER: MK
DRAFTSMAN: WRS
DATE: 12-14-89

LAYNE GEOSCIENCES, INC.

FIGURE: 18

ATTACHMENT D



JOB: LIBERTY MISSOURI
JOB NO.: 39-0235
LOCATION: LIBERTY MISSOURI

BEDROCK CONFIGURATION MAP

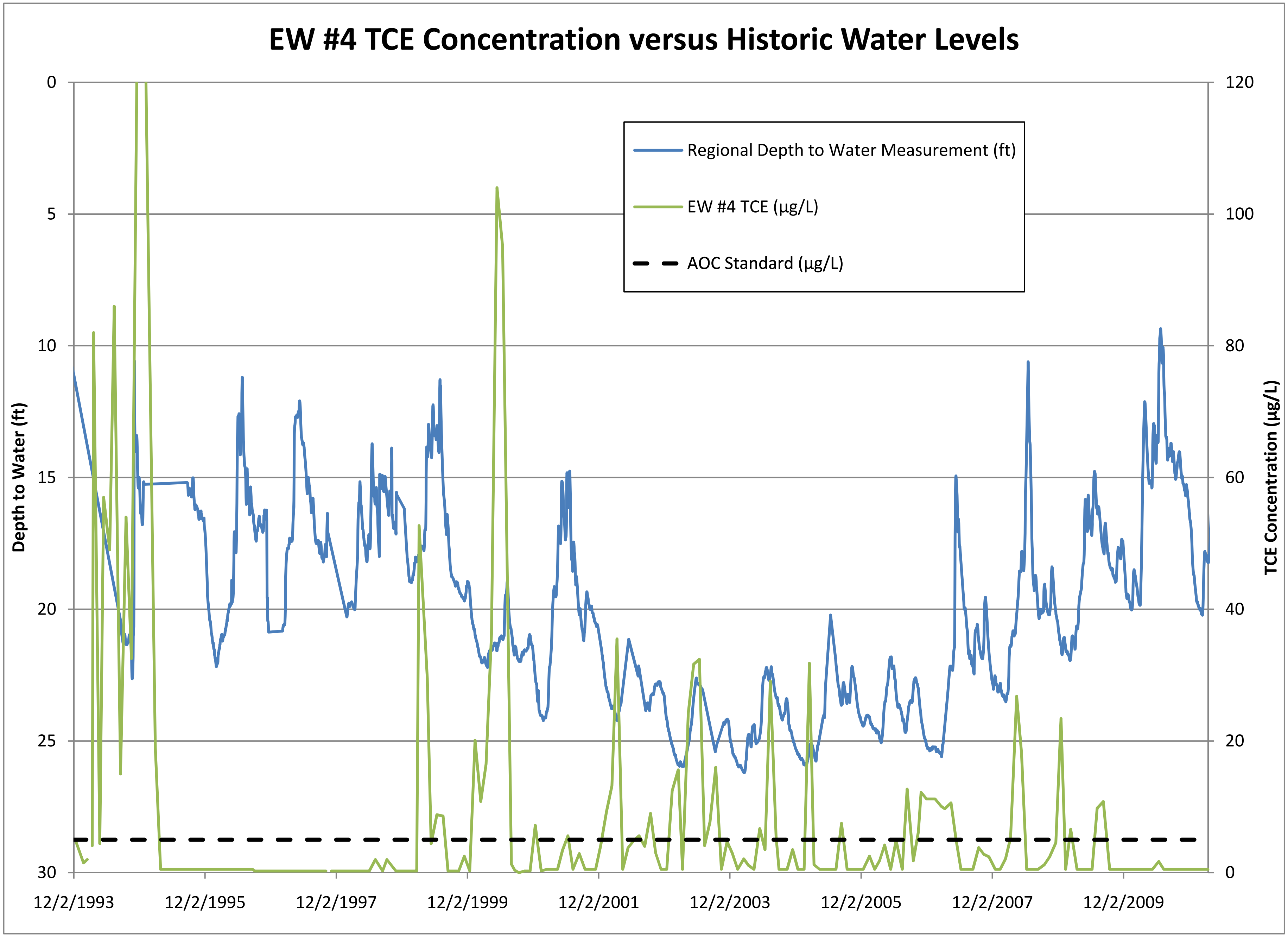
HYDROGEOLOGIST: DBK
DRAFTSMAN: WRS
DATE: 8-10-90

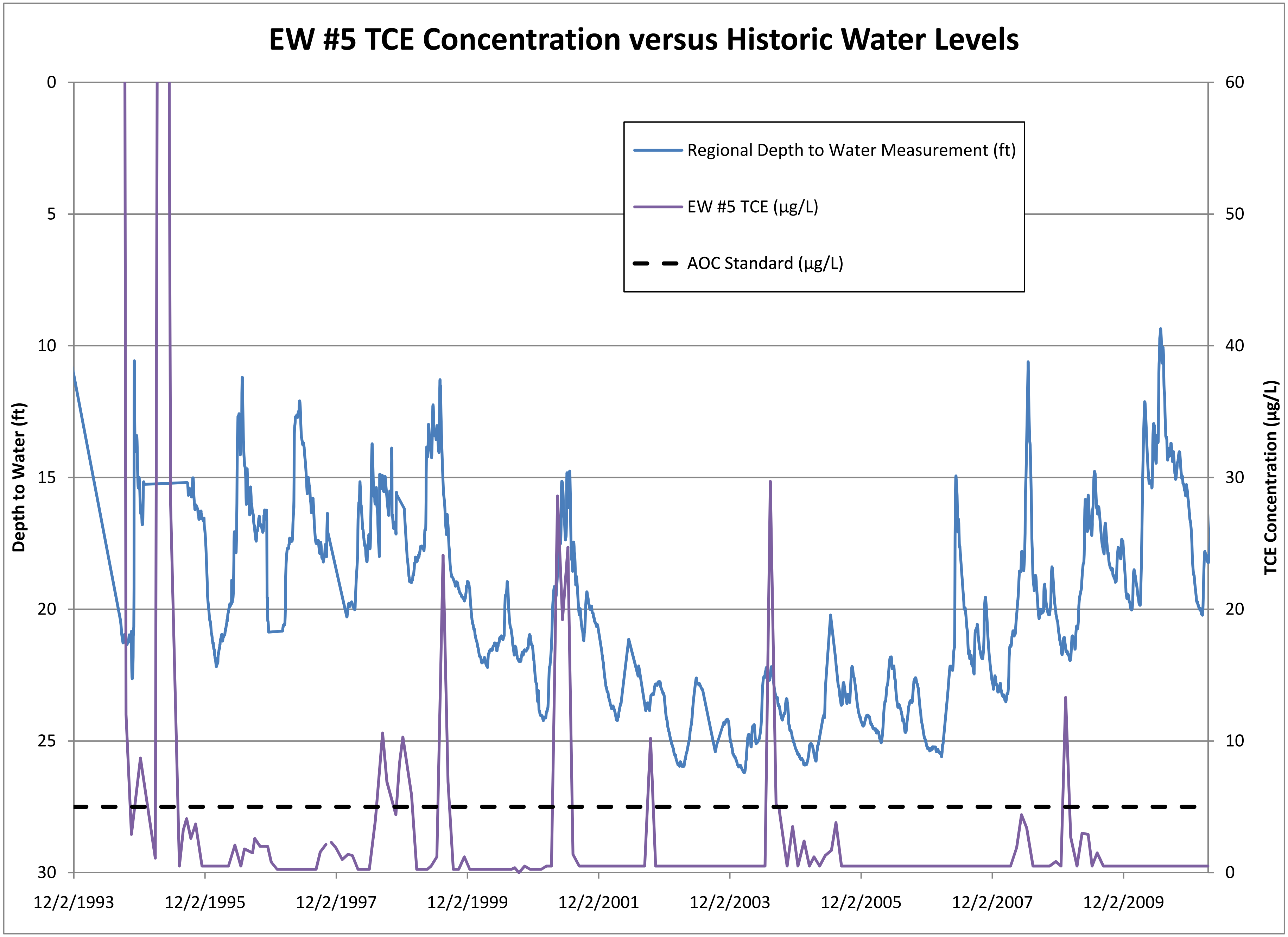
LAYNE GEOSCIENCES, INC.

FIGURE: 1-15

ATTACHMENT E


-
e


EW #4 TCE Concentration versus Historic Water Levels
Depth to Water (ft)
0
5
10
15
20
25
30
TCE Concentration (µg/L)
120
100
80
60
40
20
0
12/2/1993
12/2/1995
12/2/1997
12/2/1999
12/2/2001
12/2/2003
12/2/2005
12/2/2007
12/2/2009
Regional Depth to Water Measurement (ft)
EW #4 TCE (µg/L)
AOC Standard (µg/L)


EW #5 TCE Concentration versus Historic Water Levels
Depth to Water (ft)
0
5
10
15
20
25
30
TCE Concentration (µg/L)
60
50
40
30
20
10
0
12/2/1993
12/2/1995
12/2/1997
12/2/1999
12/2/2001
12/2/2003
12/2/2005
12/2/2007
12/2/2009
Regional Depth to Water Measurement (ft)
EW #5 TCE (µg/L)
AOC Standard (µg/L)

ATTACHMENT F

Power Sources and Global Emissions Factors for Electricity Provided by

Table 5 Missouri State Electricity Pofile www.eia.gov

Type	% Used*	Water (gal/kWh)		CO2e (lbs/kWh)		NOx (lbs/kWh)		SOx (lbs/kWh)		PM (lbs/kWh)		HAPs (lbs/kWh)		Lead (lbs/kWh)		Mercury (lbs/kWh)		Dioxins (lbs/kWh)	
		Full Load	Adjusted	Full Load	Adjusted	Full Load	Adjusted	Full Load	Adjusted	Full Load	Adjusted	Full Load	Adjusted	Full Load	Adjusted	Full Load	Adjusted	Full Load	Adjusted
Biomass	0%	168	0	0	0	0.0015	0	0.00060	0	0.000084	0	0	0	0	0	0	0	0	0
Coal	81%	0.94	0.76234	2.4	1.9464	0.0067	0.0054337	0.015	0.012165	0.0017	0.0013787	0.0007	0.0005677	0.00000024	1.9464E-07	0.000000042	3.4062E-08	3.8E-13	2.8969E-13
Geothermal	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	2%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	4%	0.79	0.03081	1.4	0.0546	0.0012	0.0000468	0.012	0.000468	0.000088	3.432E-06	0.000193	7.527E-06	1.31E-08	5.109E-10	2.9E-09	1.131E-10	0	0
Nuclear	12%	0.72	0.08352	0.024	0.002784	0.000056	0.0000065	0.000131	1.5196E-05	0.0000126	1.4616E-06	0.0000053	6.148E-07	5.2E-09	6.032E-10	4.6E-10	5.336E-11	2.9E-15	2.4221E-16
Oil	0%	3.52	0	1.9	0	0.0036	0.0000000	0.0041	0	0.00029	0	0.0000902	0	0.00000129	0	1.01E-08	0	1.04E-12	0
Solar	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wind	0%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	1%	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total based on kWh at plant	**100%**		**0.9**		**2**		**0.00549**		**0.0126**		**0.001384**		**0.0005758**		**0.0000002**		**3.4E-08**		**2.9E-13**
Total based on kWh at point of use (0.12 kWh/kWh lost in transmission)			**1**		**2.24**		**0.00615**		**0.0141**		**0.00155**		**0.000645**		**0.00000022**		**3.8E-08**		**3.2E-13**

** Based on the following:*

Obtain "generation mix" or "fuel blend" from the local utility provider and enter the percentages of each type of electrcity generation method into the "% Used" column of the above table. Percentages should add to 100%.*

The above table provides the conversion factors to convert each kWh of electricity from each generation type into each of the environmental parameters.

"Adjusted" refers to adjusting the footprint value by the percentage of electricity from that particular generation type (e.g., the adjusted value for CO2e emitted by nuclear is 10% of the full-load value if the % of electricity generated by nuclear is 10%).

Notes:

- *Water consumption for thermoelectric power plants in U.S. - 0.47 gallons per kWh**
- *Water consumption for hydroelectric power assumed to be 0 gallons per kWh (i.e., considers evaporation from reservoir as non-additive)*
- *Water consumption for coal resource extraction and fuel processing - 0.16 cubic meters per GJ of extracted energy, and 33% thermal energy conversion to electricity***
- *Water consumption for uranium resource extraction and fuel processing - 0.086 cubic meters per GJ of extracted energy and 33% thermal energy conversion to electricity***
- *Water consumption for natural gas resource extraction and fuel processing - 0.11 cubic meters per GJ of extracted energy and 33% thermal energy conversion to electricity***
- *Water consumption for oil resource extraction and fuel processing - 1.06 cubic meters per GJ of extracted energy and 33% thermal energy conversion to electricity***
- *Water consumption for biomass based on 55 cubic meters per GJ of extracted energy and 33% thermal energy conversion to electricity****
- *CO2e, Nox, SOx, and PM emissions from NREL LCI for each fuel type *****

** Consumptive Water Use for U.S. Power Production, December 2003 • NREL/TP-550-33905*

*** Gleick PH. Water and energy. Annu. Rev. Energy Environ. Vol 19, 1994. p 267-99.*

**** The Water Footprint of Energy Consumption : an Assessment of Water Requirements of Primary Energy Carriers, Winnie Gerbens-Leenes, Arjen Hoekstra, Theo an der Meer, ISESCO Science and Technology Vision, Volume 4 - Number 5, May 2008*

***** "NREL LCI" refers to the U.S. Dept. of Energy, National Renewable Energy Laboratory (NREL), Life-Cycle Inventory Database (www.nrel.gov/lci) maintained by the Alliance for Sustainable Energy, LLC.*