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SUPPLEMENTAL FIELD SAMPLING PLAN

OMC PLANT 2
Waukegan, Illinois

Remedial Investigation/Feasibility Study
Pilot Testing

WA No. 018-RICO-0528/Contract No. EP-S5-06-01

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Abbreviations and Acronyms

ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
cis-1,2 DCE	cis-1,2-dichloroethene
CLP	Contract Laboratory Program
CSU	Colorado State University
DCE	dichloroethene
DNAPL	dense nonaqueous phase liquid
DO	dissolved oxygen
DPT	direct-push technology
DQO	data quality objective
EISB	enhanced in situ bioremediation
ELCR	excess lifetime cancer risk
EOS	edible oil substrate
FOP	Field Operating Procedure
FSP	Field Sampling Plan
ft^2	square foot
FTL	field team leader
HAS	hollow-stem auger
IDW	investigation-derived waste
IEPA	Illinois Environmental Protection Agency
MCL	Maximum Contaminant Levels
mg/L	milligrams per liter
MIP	membrane interface probe
mL	milliliter
mV	millivolt
NAPL	nonaqueous-phase liquid
NCP	National Contingency Plan
O&M	operations and maintenance
OMC	Outboard Marine Corporation
ORP	oxygen reduction potential
OU	operable unit
OVA	organic vapor analyzer
OVM	organic vapor meter
PCB	polychlorinated biphenyl
PPE	personal protective equipment
PRG	Preliminary Remediation Goal
PVC	polyvinyl chloride

QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
RI	remedial investigation
RSCC	Regional Sample Control Center
SDWA	Safe Drinking Water Act
SFSP	Supplemental Field Sampling Plan
SOW	statement of work
SVOC	semivolatile organic compound
TACO	State of Illinois Tier 1 Remediation Objective
TCE	trichloroethene
TCL	Target Compound List
TCLP	Toxicity Characteristic Leaching Procedure
TOC	total organic carbon
USEPA	United States Environmental Protection Agency
VFA	volatile fatty acid
VOC	volatile organic compound
ZVI	zero-valent iron

SECTION 1

Introduction

This *Supplemental Field Sampling Plan* (SFSP) defines the procedures that will be used to implement the groundwater pilot test at the Outboard Marine Corporation's (OMC's) Plant 2 site in Waukegan, Illinois. The effort is being conducted in accordance with the statement of work (SOW) for Work Assignment No. 018-RICO-0528.

CH2M HILL previously prepared a Field Sampling Plan (FSP) (dated November 2004) describing the remedial investigation (RI) that included the sampling of the building materials, soil and sediment, groundwater, and soil vapor. The investigation was designed to evaluate the impacts of OMC's historical operation and to evaluate the nature and extent of residual contamination in the different media. The site conceptual model, nature and extent of contamination, and the assessment of risk to human health and the environment are presented in the *Remedial Investigation Report* (CH2M HILL, 2006c).

Potential groundwater alternatives were developed and evaluated in the draft *Feasibility Study Report* (FS) (CH2M HILL, 2006a). Pilot-scale testing will be conducted in order to evaluate the overall effectiveness of the proposed groundwater remedial alternatives and to refine the conceptual designs and cost estimates. This supplemental plan describes the approach, data collection methods, and analytical program to be implemented during the pilot testing.

This plan was prepared to provide additional sampling details of pilot testing. It has been developed as a supplement to the FSP previously approved by the United States Environmental Protection Agency (USEPA) and discusses those elements that have been modified or are not included in the original FSP. This supplemental plan references the original FSP, where appropriate, and does not repeat information presented therein.

Consistent with the original FSP, this supplemental plan consists of the following:

- Section 1 briefly describes the site background and a general overview of the field activities.
- Section 2 describes the objectives and approach for the sampling program, including chemicals of concern and the analytical program.
- Section 3 presents the field investigation program, including the field tasks, sampling equipment, and sampling procedures.
- Section 4 provides the general technical guidelines and procedures to be used during the pilot test. This section also presents the sample identification and sample custody procedures, and quality assurance/quality control (QA/QC) requirements for sample collection, handling, and shipping.
- Section 5 provides the works cited in this document.

- Appendix A provides a copy of the proposed bench-scale testing to be performed by Colorado State University.
- Appendix B includes the Field Operating Procedures (FOPs) for installing the lysimeters and collecting pore water samples.
- Appendix C includes the *OMC Plant 2 (OU#4) Groundwater Treatment Pilot Study* technical memorandum

1.1 Project Background

This section provides a brief summary of the site description and project background. Detailed discussions of the site history, physical, and chemical characteristics are presented in the RI report (CH2M HILL, 2006c) and the draft FS report (CH2M HILL, 2006a).

The OMC Plant 2 site is at 100 East Seahorse Drive, Waukegan, Illinois, and is the fourth operable unit (OU) of the OMC National Priorities List site. The 65-acre site includes a 1,036,000 square foot (ft^2) former manufacturing plant building (i.e., Plant 2) and several parking lot areas to the north and south of the building complex (Figure 1-1). The site includes two polychlorinated biphenyl (PCB) containment cells in which PCB-contaminated sediment (dredged from the Waukegan Harbor in the early 1990s) and PCB-impacted soil are managed. The cells (the "East Containment Cell" and the "West Containment Cell") are located north of Plant 2. OMC performed the harbor dredging work under a 1988 Consent Decree with USEPA and the Illinois Environmental Protection Agency (IEPA) that also required the long-term operations and maintenance (O&M) of the containment cells.

OMC designed, manufactured, and sold outboard marine engines, parts, and accessories to a worldwide market for many years. OMC Plant 2 was a main manufacturing facility for OMC—the major production lines used PCB-containing hydraulic and lubricating/cutting oils, chlorinated solvent-containing degreasing equipment, and smaller amounts of hydrofluoric acid, mercury, chromic acid, and other similar chemical compounds.

OMC filed for bankruptcy protection on December 22, 2000, and later abandoned the property after completing a limited removal action under USEPA oversight. In November 2001, the bankruptcy trustee filed a motion to abandon OMC Plant 2. USEPA conducted a site discovery inspection in spring 2002 to document the presence of numerous chemical compounds in OMC Plant 2 and support the allegation of imminent and substantial endangerment. Based on the findings, USEPA and the State of Illinois filed a joint objection to the abandonment and alleged that the site posed an imminent and substantial endangerment to public health and welfare and the environment. The bankruptcy trustee negotiated an emergency removal action scope of work with USEPA and IEPA that was approved by the court on July 17, 2002. The waste removal activities for the OMC Trust were completed in November 2002 and the Trust abandoned the OMC Plant 2 property on December 10, 2002.

USEPA assumed control of building security and utilities on December 10, 2002, and planned further removal actions to clean up more of OMC Plant 2 in spring 2003. USEPA maintained electrical power to support O&M of the PCB containment cells until December 10, 2003, at which time, the state took over the O&M of the cells.

A field investigation was conducted at the OMC Plant 2 site between January and June 2005, and the following potential environmental problems were identified (CH2M HILL, 2006c):

- PCB-contaminated concrete floors, walls, and ceilings in the Old Die Cast, Parts Storage, and Metal Working Areas
- Chlorinated solvents in substantial quantities beneath the building
- A chlorinated solvent groundwater plume potentially migrating into Lake Michigan
- PCB-laden soils beneath the northern parking lot areas
- Pipe chases leading to the harbor and elsewhere containing oily residue laden with PCBs

Based on the data collected, potential alternatives were developed and evaluated in the draft FS report to address the contaminated building materials, soil and sediment, and groundwater (CH2M HILL, 2006a). USEPA will make the determination regarding final selection of the remedial alternative in the proposed plan.

1.2 Overview of the Pilot Test Activities

The draft FS report identified two in situ treatment technologies (chemical reduction in the DNAPL source areas and enhanced bioremediation in the groundwater source zone areas) as a viable response action to address the volatile organic compound (VOC)-contaminated source zones and the VOC groundwater plume at the OMC Plant 2 site. Based on the potential in situ remedial technologies identified for the source zones and groundwater plume, the overall objectives for the pilot test are as follows:

1) Evaluate the degree to which in situ treatment through substrate injection can reduce the concentrations of trichloroethene (TCE) and degradation products (cis-1,2-dichloroethene [cis-1,2 DCE] and vinyl chloride) in the target treatment source zone areas and downgradient monitoring locations
2) Determine the overall effectiveness of in situ treatment for achieving complete reduction of TCE to non-toxic degradation products (such as ethene or ethane)
3) Monitor the duration that the injected substrates can maintain enhanced, relative to background, reducing conditions for in situ treatment
4) Determine the radius of influence of the selected injection method
5) Evaluate the reduction of the mass of dense nonaqueous-phase liquid (DNAPL) and mass flux of dissolved-phase contamination from any remaining DNAPL achieved through shallow soil mixing of zero-valent iron (ZVI) and bentonite

An additional objective of the pilot test is to examine the effectiveness of two different amendments—a soluble substrate (e.g., sodium lactate) and an edible oil substrate (EOS™). Both amendments work to enhance the natural reductive dechlorination processes in the aquifer. The composition and historical performance for both amendments indicate that either could be effectively used in the enhanced in situ bioremediation (EISB) remedial alternative. The testing will help to determine which amendment is more effective, under

actual site conditions, in treating the site-related VOCs and should be recommended for use during the final remedy implementation.

Shallow soil mixing through the addition of ZVI and bentonite will be conducted in the DNAPL area. Prior to implementation, a bench-scale test will be conducted to evaluate the optimum dosage and source for the ZVI, potential amendments to control hydrogen gas production, and enhance post-mixing soil strength. The bench-scale testing will be performed by Colorado State University (CSU), the patent holder for this technology.

SECTION 2

Sample Network Rationale

2.1 Project Objective and Approach

The pilot test has been designed to collect the data needed to evaluate the overall effectiveness of the proposed in situ groundwater source zone and DNAPL area treatment alternatives and to refine the conceptual design and cost estimate. The approach for the pilot test, including treatment areas, types of amendments, and relative costs, was evaluated in the *OMC Plant 2 (OU#4) Groundwater Treatment Pilot Study* technical memorandum that is provided in Appendix C. Additional sampling has been identified to perform the following:

- Delineate the extent of the DNAPL encountered north of the trim building and east of the old die cast building, and collection of DNAPL, groundwater, and soil samples for bench-scale testing
- Verify baseline groundwater quality conditions
- Monitor the effectiveness of in situ treatment on enhancing reducing conditions to promote reductive dechlorination of TCE in the source zones and downgradient areas

2.2 Analytical Program

In developing the general chemical analytical program for the pilot test, the project objectives and the following elements were considered:

- Identification of target compounds with respect to historic operations, chemical usage, and the results of the previous investigations and risk evaluations
- Determining appropriate and acceptable analytical methodology that meets the data quality objectives (DQOs), including site-specific applicable or relevant and appropriate requirements (ARARs)
- Determining an effective analytical program with appropriate QA/QC requirements, such that sampling locations and frequency are optimized

2.2.1 Chemicals of Concern

Chemicals of concern are defined as those most likely to contribute a risk as a result of exposure. The results of the field investigation, conducted between January and June 2005, indicate that the groundwater contamination is mainly related to the use of chlorinated solvents, primarily TCE, in past manufacturing operations at OMC Plant 2. The presence of the TCE degradation compounds (cis-1,2-DCE and vinyl chloride) and results of the natural attenuation parameters indicate that TCE is being degraded by anaerobic reductive dechlorination.

Groundwater samples will also be analyzed to determine if the in situ treatment of the source zone areas have enhanced the natural reductive dechlorination processes occurring in the aquifer. The list of monitoring parameters and the rationale for the analysis are presented in Table 2-1.

TABLE 2-1
List of EISB Monitoring Parameters and Rationale

Parameter	Method	Reason for Monitoring
Water Level	Field measurement, taken using a water level indicator.	Provides quantitative indication that injection fluids are reaching the monitoring well. Also used to determine the well volume for well purging.
Turbidity	Field measurement	Typically used for well purge stabilization parameter.
Temperature	Field measurement.	Typically used for well purge stabilization parameter.
Specific Conductance	Field measurement	Typically used for well purge stabilization parameter.
Oxygen Reduction Potential (ORP)	Field measurement	To assess the degree to which the injection or mixing is enhancing the reducing conditions and whether groundwater conditions are optimal for biodegradation (ORP values less than -100 millivolts [mV]).
Dissolved Oxygen (DO)	Field measurement	To assess the degree to which the injection or mixing is enhancing the reducing conditions and whether groundwater conditions are optimal for biodegradation (DO values less than 0.5 mg/L).
pH	Field measurement	To assess the degree to which the injection or mixing is enhancing the reducing conditions. Ideal range for dechlorination bacteria is 5 to 9. Also, well purge stabilization parameter.
Alkalinity	SM 2320-B or EPA 300 Series	Indicator of biodegradation and the buffering capacity of the aquifer.
Nitrate/Nitrite	SW9056 or EPA 300 Series	Nitrate is an alternate electron acceptor for microbial respiration in the absence of oxygen. Nitrate levels less than 1.0 mg/L are desirable for anaerobic dechlorination.
VOCs	AOM01.1 (water samples) SOM01.1 (soil samples)	The chemicals of concern. A decrease in concentration of parent compounds will provide a direct indication that the biodegradation reactions are occurring.
Chloride	SW 846-9056 or EPA 300 Series	Chloride ions are produced by anaerobic dechlorination and may be used as a secondary indication of the occurrence of reactions.
Ferrous Iron	SW 846-6010B (water samples) Field measurement (soil samples)	Ferric iron is an alternate electron acceptor for microbial respiration in the absence of oxygen and nitrate; ferrous iron is produced by the reduction of ferric iron. This analysis provides information about the degree to which iron reduction processes are occurring in the aquifer. Soil samples will be analyzed using field measurements to confirm the target ratio of iron in the soil

TABLE 2-1
List of EISB Monitoring Parameters and Rationale

Parameter	Method	Reason for Monitoring
		mixing area.
Dissolved Manganese	SW846 6010B	Dissolved manganese (Mn^{2+}) is produced by the reduction of Mn^{4+} in a process similar to iron reduction. This analysis provides information about the degree to which manganese reduction processes are occurring in the aquifer.
Sulfate	EPA 300 Series	Sulfate is an alternate electron acceptor for microbial respiration in the absence of oxygen, nitrate, and ferric iron. Sulfate levels of less than 20 mg/L are desirable, but not required, for anaerobic dechlorination.
Sulfide	EPA 300 Series	Sulfide is produced during reduction of sulfate. Its presence indicates that sulfate reduction is occurring.
Methane/Ethane/ Ethene	RSK 175	Methane, ethane, and ethene are the final byproducts of reductive dechlorination of chlorinated solvents.
Volatile Fatty Acids (VFAs)	Ion chromatography	VFAs are produced as the microbial community ferments the EISB amendments, providing evidence of enhanced biological activity.
Total Organic Carbon (TOC)	SW 9060 or EPA 400 Series	Indicator of the natural organic carbon present at the site during baseline sampling and as an indicator of the substrate distribution during performance monitoring.

2.2.2 Analytical Objectives

The RI indicates that chlorinated VOCs are present in the groundwater at levels greater than the Safe Drinking Water Act (SDWA) federal Maximum Contaminant Levels (MCLs), USEPA Region 9's Preliminary Remediation Goals (PRGs), and the State of Illinois Tier 1 Remediation Objectives in 35 IAC Subtitle G, Chapter I, Subchapter f, Part 742, Appendix B ("TACO"). In the FS, the significantly lower USEPA Region 9 PRGs were selected as the remediation goal for groundwater so the cumulative risk from ingestion of groundwater does not exceed the 1×10^{-4} excess lifetime cancer risk (ELCR) value mandated by the National Contingency Plan (NCP). The data generated during the pilot test and associated analytical program will be used to achieve these remediation goals. The USEPA Region 9 PRGs and Tier 1 Remediation Goals for the VOCs in water are presented in Table 2-2.

2.2.3 Contract Laboratory Program Analysis

Analytical laboratories in USEPA's Contract Laboratory Program (CLP) will be utilized to the extent possible. The use of the CLP depends on the specific analyses and the required turnaround times. At this point, it is anticipated that Target Compound List (TCL) VOC analyses for the soil and groundwater samples will be conducted through the CLP. The specific required reporting limits for the CLP-laboratory analyses and the ability for the CLP to meet the specific media objectives will be discussed in the *Supplemental Quality Assurance Project Plan* governing the pilot test activities. The analytical methods will be selected such

that the quantitation limits for the chemicals of concern achieve the USEPA Region 9's PRGs.

TABLE 2-2
Analytical Objectives for Groundwater Samples
OMC Plant 2

Parameter – TCL VOCs (Method SOM01.1)	CAS No.	USEPA Region 9 PRG Tap Water (µg/L)	IEPA Tier 1 TACO Groundwater Class 1 (µg/L)	Contract Required Quantitation Limit (CRQL) (µg/L)
Acetone	67-64-1	5,475	700	5.0
Benzene	71-43-2	0.35	5.0	0.5
Bromodichloromethane	75-27-4	0.18	0.2	0.5
Bromoform (tribromomethane)	75-25-2	8.51	1	0.5
Bromomethane (Methyl bromide)	74-83-9	8.66	---	0.5
Bromochloromethane	74-97-5	---	---	0.5
2-Butanone (Methyl ethyl ketone)	78-93-3	6,968	---	5.0
Carbon disulfide	75-15-0	1,043	700	0.5
Carbon tetrachloride	56-23-5	0.17	5.0	0.5
Chlorobenzene	108-90-7	106	100	0.5
Chloroethane	75-00-3	4.64	---	0.5
Chloroform	67-66-3	0.17	0.2	0.5
Cyclohexane	110-82-7	10,342	---	0.5
Chloromethane (methyl chloride)	74-87-3	158	---	0.5
Dibromochloromethane	124-48-1	0.13	---	0.5
1,2-Dibromo-3-chloropropane (DBCP)	96-12-8	0.05	0.2	0.5
1,2-Dichlorobenzene	95-50-1	370	600	0.5
1,3-Dichlorobenzene	541-73-1	183	---	0.5
1,4-Dichlorobenzene	106-46-7	0.50	75	0.5
1,1-Dichloroethane	75-34-3	811	700	0.5
1,2-Dichloroethane (EDC)	107-06-2	0.12	5.0	0.5
1,2-Dibromoethane (EDB)	106-93-4	0.01	---	0.5
1,1-Dichloroethylene	75-35-4	339	7.0	0.5
1,2-Dichloroethylene (cis)	156-59-2	61	70	0.5
1,3-Dichloropropene (cis)	10061-01-5	---	---	0.5
1,2-Dichloroethylene (trans)	156-60-5	122	100	0.5
1,2-Dichloropropane	78-87-5	0.16	5.0	0.5
Ethylbenzene	100-41-4	1,340	700	0.5
2-hexanone	591-78-6	---	---	5.0
Methyl isobutyl ketone	108-10-1	1,993	---	5.0
Methylene chloride	75-09-2	4.28	5.0	0.5
Methylcyclohexane	108-87-2	5,217	---	0.5
Methyl tertbutyl ether (MTBE)	1634-04-4	11.00	---	0.5
Methyl acetate	79-20-9	6,083	---	0.5
Isopropylbenzene (Cumene)	98-82-8	658	---	0.5
1,1,2,2-Tetrachloroethane	79-34-5	0.06	---	0.5
1,1,2-trichloro-1,2,2-trifluoroethane (Freon 113)	76-13-1	59,180	---	0.5
Styrene	100-42-5	1641	---	0.5
Tetrachloroethylene (PCE)	127-18-4	0.10	5.0	0.5
Toluene	108-88-3	723	1,000	0.5
Trichlorofluoromethane	75-69-4	1,288	---	0.5

TABLE 2-2
Analytical Objectives for Groundwater Samples
OMC Plant 2

Parameter – TCL VOCs (Method SOM01.1)	CAS No.	USEPA Region 9 PRG Tap Water (µg/L)	IEPA Tier 1 TACO Groundwater Class 1 (µg/L)	Contract Required Quantitation Limit (CRQL) (µg/L)
1,2,4-Trichlorobenzene	120-82-1	7.16	70	0.5
1,2,3-Trichlorobenzene	87-61-6	---	---	0.5
1,1,1-Trichloroethane	71-55-6	3,172	200	0.5
1,1,2-Trichloroethane	79-00-5	0.20	5.0	0.5
Trichloroethylene (TCE)	79-01-6	0.03	5.0	0.5
Vinyl chloride (child/adult)+++	75-01-4	0.02	2.0	0.5
Xylenes	1330-20-7	206	10,000	0.5

"---" indicates no limit identified

Early in the week prior to the collection of samples requiring CLP analysis, USEPA's Regional Sample Control Center (RSCC) will be notified of the expected date of shipment and anticipated sampling duration, approximate number of samples to be collected, the sample matrices, the required analyses, and the analytical turnaround times. CH2M HILL will collect the soil and groundwater (and associated quality assurance/quality control [QA/QC] samples) samples as scheduled, and ship them to the CLP laboratories identified by RSCC. The RSCC personnel, as directed, will be notified of sample arrival on the day of shipment or at the start of the next business day.

2.2.4 Independent Laboratory Analysis

It is anticipated that some of the samples cannot be submitted to the CLP and will be analyzed by CT Laboratories, an independent laboratory procured by CH2M HILL, located in Baraboo, Wisconsin. These Special Analytical Services will likely include groundwater samples (and associated QA/QC samples) to be analyzed for TOC and the other natural attenuation parameters (e.g., alkalinity, nitrate, nitrite, chloride, ferrous iron, manganese, sulfate, sulfide, methane, ethane, and ethene) and volatile fatty acids.

Investigation-derived waste (IDW) soil samples will also be submitted to a non-CLP laboratory to be analyzed using the Toxicity Characteristic Leaching Procedure (TCLP) for VOCs to characterize the soils for offsite disposal. The specific media, numbers of samples, and the method requirements for the analyses conducted by these independent offsite laboratory(ies) will be discussed in the Quality Assurance Project Plan (QAPP).

2.3 Treatment Areas

2.3.1 Source Zone Areas

The results of the RI indicate that the groundwater contamination is likely related to the use of chlorinated solvents, primarily TCE, in past manufacturing operations at OMC Plant 2. The data indicate that the chlorinated "parent compound" in groundwater (TCE) was released to the subsurface during manufacturing operations and created "source zones." Source zones are portions of the aquifer that have particularly high dissolved-phase TCE

concentrations, and which may have residual DNAPL or high concentrations of adsorbed TCE that can continue to create and sustain dissolved-phase plumes.

Based on the findings of the membrane interface probe (MIP), soil, and groundwater investigations and the conceptual model of the site, five source zones were identified (Figure 2-1). Targeting these source zones for treatment will reduce the mass of "parent compound" (i.e., TCE) and result in a reduction of contaminant mass contributing to the downgradient groundwater plume. Two of the five source zone areas, Areas 2 and 4, were selected for treatment during this pilot testing (Figures 2-2 and 2-3, respectively).

2.3.2 DNAPL Area

It should be noted that while in situ bioremediation methods have been found to be effective for reducing dissolved-phase contamination, they have not yet been shown to be highly effective for directly remediating nonaqueous phase liquid (NAPL). The presence of DNAPL outside the building in the eastern portion of Area 2 requires more active remedial technologies than EISB. In situ soil mixing using a chemical reducing agent was selected to target this DNAPL area (Figure 2-2). The results of testing the soil mixing technology will be used to evaluate if soil mixing would provide effective treatment of the DNAPL and whether it should be implemented if other DNAPL areas are found during the building demolition or subsequent site remediation.

2.4 DNAPL Delineation

To optimize the treatment of the DNAPL, the extent and thickness of the DNAPL in Area 2 must be accurately defined prior to the start of soil mixing activities. A limited subsurface investigation will be conducted using direct-push technology (DPT) methods (e.g., Geoprobe®) to delineate the extent of the DNAPL area identified during the RI. This focused investigation will include the collection of groundwater grab samples from the base of the aquifer (about 30 feet below ground surface [bgs]) at an estimated 24 boring locations. Initially, grab samples will be collected from eight borings located at a 25-foot radius from the soil boring (SO-057) where DNAPL was encountered during the RI (Figure 2-2). Discreet groundwater samples and soil samples will be collected, field screened (total organic vapor measurements), and examined for visual and olfactory evidence of mobile and/or residual DNAPL. Samples will not be sent for laboratory analysis. Subsequent sets of eight borings will be stepped out or moved in at 10-foot increments, based on the presence/absence of DNAPL in the soil/groundwater samples. The extent of the DNAPL area will be marked for pilot testing.

Based on the estimated extent of the DNAPL, three additional monitoring well nests will be installed using hollow-stem auger techniques to monitor the effectiveness of the in situ soil mixing. Each well nest will consist of a shallow well installed at the water table (well depth of about 15 feet) and a deep well installed to the top of the till (well depth of about 30 feet). The monitoring wells will be sampled using the low-flow sampling methods prior to and after mixing to monitor any changes in groundwater conditions resulting from the soil mixing. The new monitoring wells will be included in the overall baseline groundwater sampling event and with the EISB post-injection performance monitoring program.

2.5 Bench Testing

A bench test will be conducted to optimize the effectiveness of the in situ soil mixing. The objectives of the bench test are to collect site-specific information on the optimum dosage and source of the zero-valent iron (ZVI), and potential amendments to control hydrogen gas production and enhance post-mixing soil strength. The amendment mixing technology patent holder,.Colorado State University (CSU), will perform the bench-scale treatability test. Approximately 200 pounds of soil, 1 gallon of groundwater, and 80 milliliters (mL) of DNAPL will be collected using DPT methods during the DNAPL delineation activities and sent to CSU for use in the bench testing.

The proposed bench test will consist of the following:

- Soil will be visually logged and monitored by organic vapor analyzer (OVA). Samples with elevated OVA readings will be screened for the presence of DNAPL using Sudan IV and an ultraviolet light. After logging, the soil samples will be combined into a single composite sample.
- The composite soil sample will be mixed with site water, spiked with DNAPL, and homogenized prior to filling the study columns.
- A grout mixture with predetermined amounts of reactive media (granular iron), stabilizing agents (bentonite), and other ingredients (sodium bicarbonate or fly ash) will be mixed with the spiked site soil in each column.
- Soil samples will be collected immediately after mixing; subsequent samples will be collected after approximate reaction times of 3, 7, 28, and 56 days and analyzed for water content and chloride concentration. During the experiment, the volume of gas produced in each column will also be monitored.
- At the end of the experiment (approximately 56 days), a portion of three select columns will be measured for compressive strength (American Society for Testing and Materials D4219-02).

The description of CSU's proposed ZVI-clay treatability study is provided in Appendix A.

2.6 EISB

The enhanced anaerobic biodegradation pilot test will involve the injection of the selected amendment (i.e., EOS and sodium lactate) into the shallow and deep intervals of the aquifer in two areas. An aqueous solution of the amendment will be prepared onsite and injected into a series of closely spaced, 2-inch-diameter injection wells. Permanent injection wells, rather than direct-push locations, will be installed to allow for future injections. Spacing for the installation of the injection wells is a function of the amendment being added (particle size, viscosity) and achievable injection rate. Injection parameters for each of the amendments are presented in Table 2-3.

TABLE 2-3

Summary of Injection Implementation

Amendment	Treatment Area[a]	Depth[b]	Well Spacing (ft)	Number of Wells Per Barrier	Barrier Spacing (ft)	Number of Barriers	Total Number of Wells[c]	Amendment Amount per Injection (lb)	Injection Volume Per Well (gal)	Number of Injection Events
EOS	Area 2	Shallow	30	3-7	93	3	13/5	5,989	2,247	1
		Deep	25	7-9	59	3	23/5	46,322	3,121	1
Lactate	Area 4	Shallow	20	4-6	95	2	10/3	627	2,247	4
		Deep	30	4-6	64	2	9/3	1,671	1,997	4

[a] Treatment areas for Areas 2 and 4 are shown on Figures 2-2 and 2-3, respectively.
[b] Depths refer to:
Shallow = injection wells installed to a depth of 15 feet.
Deep = injection wells installed to the base of the aquifer about 30 feet.
[c] Total Number of Wells = New Injection Wells/Monitoring Wells.

TABLE 2-4
Summary of Existing Monitoring Well Locations
OMC Plant 2

Well ID	Ground Elevation (ft amsl)	Top of Casing Elevation (ft amsl)	Surface Completion	Well Diameter	Date Installed	Total Depth (ft bgs)	Total Depth (ft btoc)	Screened Interval (ft bgs)	May 2005 Water Level (ft btoc)
Along East Access Road									
W-13	584.43	586.71	Stick-up	2" S.S.	NA	NA	12.48	NA	5.76
MW-14S	583.44	583.06	Flush Mount	2" SCH 40 PVC	NA	NA	11.33	NA	2.35
MW-14D	583.47	583.19	Flush Mount	2" SCH 40 PVC	NA	NA	29.78	25.75–30.75	2.49
MW-100	585.45	585.04	Flush Mount	2" SCH 40 PVC	NA	NA	12.39	NA	3.20
MW-101	585.16	585.04	Flush Mount	2" SCH 40 PVC	NA	NA	12.47	NA	4.11
MW-102	585.97	585.57	Flush Mount	2" SCH 40 PVC	NA	NA	12.47	NA	4.72
MW-508S	584.93	584.67	Flush Mount	2" SCH 40 PVC	3/22/2005	7.0	6.23	1.5–6.5	3.69
MW-508D	584.96	584.68	Flush Mount	2" SCH 40 PVC	3/22/2005	29.5	29.46	24.0–29.0	3.70
East and West Containment Cells or Along North Ditch									
W-5	584.90	588.39	Stick-up	2" S.S.	NA	NA	35.21	NA	7.36
W-6	584.80	588.27	Stick-up	2" S.S.	NA	NA	32.10	NA	6.30
W-7	583.83	586.49	Stick-up	2" S.S.	NA	NA	30.84	NA	4.41
W-8	583.39	586.20	Stick-up	2" S.S.	NA	NA	34.23	NA	5.67
W-9	584.83	587.36	Stick-up	2" S.S.	NA	NA	27.37	NA	5.00
W-10	584.04	587.12	Stick-up	2" S.S.	NA	NA	25.05	NA	4.19
W-11	587.03	588.83	Stick-up	2" S.S.	NA	NA	21.72	NA	5.82
W-12	584.20	586.78	Stick-up	2" S.S.	NA	NA	29.10	NA	4.55
MW-500S	583.71	586.18	Stick-up	2" SCH 40 PVC	3/28/2005	7.0	9.07	1.5–6.5	4.03
MW-500D	583.65	586.19	Stick-up	2" SCH 40 PVC	3/28/2005	26.0	27.12	20.5–25.5	4.02
MW-501S	583.36	585.83	Stick-up	2" SCH 40 PVC	4/4/2005	7.0	10.22	1.5–6.5	5.23
MW-501D	583.29	585.76	Stick-up	2" SCH 40 PVC	38446	28.5	31.27	23.0–28.0	5.21
Outside of Chip Dock Area									
MW-502S	584.93	587.44	Stick-up	2" SCH 40 PVC	3/17/2005	7.5	9.87	2.0–7.0	4.79
MW-502D	584.84	587.33	Stick-up	2" SCH 40 PVC	3/16/2005	23.5	25.84	18.0–23.0	4.70
Outside of Chip Room									
MW-503S	584.91	584.66	Flush Mount	2" SCH 40 PVC	3/16/2005	7.5	7.33	2.0–7.0	2.41
MW-503D	584.86	584.63	Flush Mount	2" SCH 40 PVC	3/16/2005	25.5	23.89	20.0–25.0	2.40
Parking Lot between Old Die Cast Area and New Die Cast Area									
MW-507S	583.88	586.32	Stick-up	2" SCH 40 PVC	3/15/2005	7.5	9.64	2.0–7.0	4.50
MW-507D	583.93	586.34	Stick-up	2" SCH 40 PVC	3/15/2005	25.5	26.08	20.0–25.0	4.53
Within the Plant 2 Building									
MW-504S	588.42	588.23	Flush Mount	2" SCH 40 PVC	3/18/2005	9.5	9.41	4.0–9.0	6.22
MW-504D	588.42	588.16	Flush Mount	2" SCH 40 PVC	3/18/2005	29.5	28.50	24.0–29.0	6.16
MW-505S	588.36	588.13	Flush Mount	2" SCH 40 PVC	3/18/2005	9.5	8.78	4.0–9.0	5.68
MW-505D	588.36	587.97	Flush Mount	2" SCH 40 PVC	3/25/2005	27.5	25.42	22.0–27.0	5.52
MW-506S	588.42	588.18	Flush Mount	2" SCH 40 PVC	3/18/2005	9.5	9.23	4.0–9.0	5.97

TABLE 2-4
Summary of Existing Monitoring Well Locations
OMC Plant 2

Well ID	Ground Elevation (ft amsl)	Top of Casing Elevation (ft amsl)	Surface Completion	Well Diameter	Date Installed	Total Depth (ft bgs)	Total Depth (ft btoc)	Screened Interval (ft bgs)	May 2005 Water Level (ft btoc)
MW-506D	588.42	588.19	Flush Mount	2" SCH 40 PVC	3/25/2005	28.5	27.53	23.0–28.0	5.99
MW-510S	588.33	588.05	Flush Mount	2" SCH 40 PVC	3/18/2005	9.5	9.23	4.0–9.0	5.97
MW-510D	588.33	588.07	Flush Mount	2" SCH 40 PVC	4/4/2005	27.5	27.28	22.0–27.0	5.95
MW-511S	588.41	588.15	Flush Mount	2" SCH 40 PVC	3/18/2005	9.5	9.27	4.0–9.0	6.46
MW-511D	588.41	588.22	Flush Mount	2" SCH 40 PVC	3/25/2005	28.5	28.51	23.0–28.0	6.51
Chemical Storage Area									
MW-509S	584.42	584.22	Flush Mount	2" SCH 40 PVC	3/22/2005	7.5	6.46	2.0–7.0	1.21
MW-509D	584.41	584.19	Flush Mount	2" SCH 40 PVC	3/22/2005	20.0	19.38	14.5–19.5	1.99
MW-517S	584.18	586.64	Stick-up	2" SCH 40 PVC	4/1/2005	8.0	9.75	2.5–7.5	4.26
MW-517D	584.19	586.64	Stick-up	2" SCH 40 PVC	4/1/2005	20.5	22.53	15.0–20.0	4.21
Near Corporate Offices and Parking Lot Area South of the Plant									
MW-15S	584.61	584.46	Flush Mount	2" SCH 40 PVC	NA	NA	11.84	NA	3.02
MW-15D	584.78	584.54	Flush Mount	2" SCH 40 PVC	NA	NA	28.62	24.18–28.84	3.11
MW-512S	584.83	584.56	Flush Mount	2" SCH 40 PVC	3/31/2005	8.0	7.34	2.5–7.5	3.06
MW-512D	584.86	584.60	Flush Mount	2" SCH 40 PVC	3/31/2005	25.5	25.53	20.0–25.0	3.09
MW-513S	585.44	585.23	Flush Mount	2" SCH 40 PVC	3/30/2005	8.0	7.21	2.5–7.5	3.60
MW-513D	585.54	585.29	Flush Mount	2" SCH 40 PVC	3/30/2005	25.5	23.31	20.0–25.0	3.65
MW-514S	584.70	584.70	Flush Mount	2" SCH 40 PVC	3/30/2005	8.0	6.93	2.5–7.5	3.45
MW-514D	584.92	584.70	Flush Mount	2" SCH 40 PVC	3/30/2005	25.5	24.90	20.0–25.0	3.45
MW-515S	583.97	583.71	Flush Mount	2" SCH 40 PVC	3/31/2005	8.5	7.90	3.0–8.0	2.47
MW-515D	583.88	583.90	Flush Mount	2" SCH 40 PVC	3/31/2005	26.5	26.23	21.0–26.0	2.34
Larsen Marine Service Property–South of Seahorse Drive									
W-3	583.80	585.70	Stick-up	2" S.S.	NA	NA	24.20	NA	4.05
W-4	582.92	582.60	Flush Mount	2" S.S.	NA	NA	23.64	NA	2.14
MW-3S	584.60	587.48	Stick-up	2" SCH 40 PVC	NA	NA	14.89	NA	6.29
MW-3D	584.88	587.41	Stick-up	2" SCH 40 PVC	NA	NA	30.81	22.8–27.8	6.28
MW-11S	584.44	587.19	Stick-up	2" SCH 40 PVC	NA	NA	14.22	NA	6.15
MW-11D	584.33	587.12	Stick-up	2" SCH 40 PVC	NA	NA	30.71	22.73–27.41	6.05
MW-516S	584.08	583.80	Flush Mount	2" SCH 40 PVC	3/29/2005	8.5	8.23	3.0–8.0	3.75
MW-516D	584.04	583.78	Flush Mount	2" SCH 40 PVC	3/29/2005	25.5	25.41	20.0–25.0	3.77

Notes:
ft amsl = feet above sea leavel
ft bgs = feet below ground surface.
ft btoc = feet below top of casing
NA = not available
"S" suffix for well ID indicates shallow monitoring well
"D" suffix for well ID indicates deep monitoring well

The proposed EISB pilot test will consist of the following field activities:

1) Injection well and monitoring well installation
2) Baseline sampling and analysis
3) Injection of amendment
4) Post-injection performance monitoring (secondary and primary)
5) Follow-up injections, as needed

2.6.1 Injection Well and Monitoring Well Installation

EISB testing will be implemented at VOC groundwater source zone Areas 2 and 4 (Figure 2-2 and 2-3, respectively) identified during RI activities. Area 2 is located at the northeast corner of the metal working area and Area 4 is located just east of the corporate building. A total of 55 injection wells and 16 additional monitoring wells (8 monitoring well nests) will be installed in the two EISB treatment areas.

Permanent injection wells will be installed in a barrier configuration to use natural advective transport as the mechanism to bring dissolved contaminants into contact with the amendments and be reductively dechlorinated. The injection wells will be placed in a line perpendicular to the groundwater flow for each area. It is expected that only a portion of the contaminant mass will be treated within the injection area and that treatment will continue as the contaminant mass is transported beyond the injection area through the treatment area. The spacing between lines of injection wells was based on an estimated travel time of 2 years for the shallow wells and 3 years for the deep wells. Because of the slower groundwater velocity and higher concentrations of contaminants observed in the deep zone, more injection wells will be installed in the deep zone compared with the shallow zone. The proposed number of permanent injection wells to be installed within each of the target areas are presented in Table 2-3. Monitoring wells will also be installed within the target areas to allow performance monitoring of the EISB pilot study. The approximate locations for injection wells, shallow/deep monitoring well nests, and existing locations to be used for monitoring during the pilot test for the Areas 2 and 4 are shown in Figures 2-2 and 2-3, respectively.

2.6.2 Baseline Groundwater Sampling

After installation and development of the additional monitoring wells, water level measurements and groundwater samples will be collected from the 16 new and 58 existing monitoring wells (Figure 2-4). The data collected will be used to establish baseline groundwater flow and water quality conditions (including extent of DNAPL) prior to the start of the treatability study.

In addition to the 16 wells installed to monitor the effectiveness of the in situ soil mixing and EISB monitoring, 58 of the existing monitoring wells will be included in the baseline sampling event (Table 2-4). The locations of the existing monitoring wells are shown in Figure 2-4, and well construction information is presented in Table 2-5. Groundwater samples will be collected using low-flow methods and analyzed for the parameters presented in Table 2-1.

TABLE 2-5
Summary of Groundwater Monitoring Events and Sampling Locations
OMC Plant 2

Monitoring Event	Area	Number of New Wells	Number of Existing Wells	Total Number of Wells
Baseline Sampling	Site-wide	16	58	74
Post-injection Monitoring	Area 2	10	2 (MW504S and D)	12
	Area 4	6	2 (MW514S and D)	8
Annual Sampling	Site-wide	16	58[b]	74
In Situ Soil Mixing[a]	Area 2	6 (plus 3 Suction Lysimeters)	0	6 (plus 3 Suction Lysimeters)

[a]Sampling will be included in the EISB post-injection performance monitoring.
[b]Actual number of existing wells to be sampled in the annual monitoring may be reduced based on the results of the baseline sampling

2.6.3 Amendment Injection

The target amounts of the EISB amendment to be injected were developed using site-specific groundwater VOC concentrations along with hydrogeologic, geochemical, and subsurface biological data. The target EISB amendment concentrations are designed to achieve and sustain reducing conditions favorable to bioremediation of the chlorinated VOCs. A summary of the injection implementation parameters is presented in Table 2-3.

The selected EISB amendment (i.e., EOS and sodium lactate) will be combined with water to form a solution that will be injected directly into the injection wells using a pump and manifold system. The solution (or emulsion, in the case of EOS) will be pumped into a manifold capable of injecting into as many as eight injection locations simultaneously.

EISB amendments will be delivered to the subsurface by injection to an estimated 36 wells in Area 2 and approximately 19 wells in Area 4. EISB injection volumes will be 100,000 gallons per event for Area 2 and 40,000 gallons per event for Area 4. Injections of lactate will be repeated every 90 days, for a total of four injection events within the 18-month duration of this pilot test. Because EOS differs in composition from lactate, the persistence of EOS is reported as 3 years or more. Based on the manufacturer's data regarding the persistence of EOS, only one injection event of EOS will be performed as part of the pilot test.

2.6.4 Post-injection Monitoring

Following the initial injection, groundwater sampling events will be conducted at designated intervals to quantify changes in groundwater geochemistry and contaminant concentrations.

The post-injection monitoring will consist of primary and secondary performance monitoring events that will begin 30 days post-injection (Table 2-6). For the primary and secondary post-injection monitoring, groundwater samples will be collected from 20 monitoring wells (Table 2-5). Secondary monitoring will be performed every 30 days and will include pH, temperature, turbidity, ORP, specific conductance, DO, and TOC. Primary monitoring events will be performed every 90 days post-injection, and will include the parameters listed in Table 2-1. Performance monitoring will continue for approximately 18 months, resulting in six secondary and four primary monitoring events. The timeline for sampling is estimated, and may be modified based on the results of prior sampling events or field observations.

TABLE 2-6
Approximate Sampling Schedule for Post-injection Performance Monitoring

Sampling Event	Number of Days Post-injection
Injection	0
Secondary Monitoring	30
Secondary Monitoring	60
Primary Monitoring	90
Injection	0
Secondary Monitoring	30
Secondary Monitoring	60
Primary Monitoring	90

Groundwater samples will be collected using low-flow purge techniques. Secondary performance monitoring, with the exception of TOC, will include analyses for field parameters (ORP, pH, DO, temperature, turbidity, and conductivity) that will be collected during well purging using field instruments. Visual indications (color) of substrate migration will also be noted.

2.6.5 Annual Monitoring

An annual monitoring event will be conducted to evaluate overall temporal trends in the groundwater quality. Groundwater samples will be collected using low-flow purge techniques from the 16 new and a maximum of 58 existing monitoring wells and analyzed for the parameters listed in Table 2-1. The actual number of monitoring wells sampled during the annual monitoring event may be revised based on the results of the baseline groundwater sampling.

2.7 In situ Soil Mixing

In situ soil mixing pilot testing will be conducted in a portion of Area 2 known to contain TCE DNAPL and located outside the building to treat an area of DNAPL identified during the RI. In situ soil mixing uses a large-diameter (typically 3- to 12-foot-diameter) auger with mixing paddles and grout ports to "drill" into the ground as a fluid grout is pumped through the shaft. The fluid acts as an aid to drilling and is mixed into the drilled soil column. In hazardous waste treatment applications, conventional soil mixing equipment is used to mix reactive media (e.g., ZVI) and stabilizing agents (e.g., clay) with contaminated soil. Through mixing, heterogeneous subsurface source zones are transformed into uniform bodies of soils, contaminants, reactive media, and stabilizing agents. Within the treated interval, reactive media will drive contaminant degradation, while stabilizing agents will reduce the hydraulic conductivity. The combination of soil-mixing with amendments achieves both containment and source depletion.

2.7.1 Soil Mixing Implementation

During the pilot test, the soils in the refined DNAPL area will be mixed in situ with a combination of ZVI and bentonite clay. ZVI will be incorporated at an estimated concentration of 2 percent by soil mass to provide chemical reduction of the TCE DNAPL. Bentonite will be incorporated to reduce groundwater flow through the treated area and the mass flux of dissolved phase contaminants. A soil-strengthening agent such as Portland cement may be added to increase the post-mixing soil strength. An estimated 2,800 cubic yards of soil will be mixed over a period of 4 weeks.

2.7.2 Performance Sampling

During and following the completion of mixing activities, soil and groundwater data will be collected to evaluate amendment distribution throughout the mixing zone, concentrations of the amendment in the mixing zone, changes in groundwater geochemistry, and changes in contaminant concentrations. The results of the test will be used to evaluate the effectiveness of this technology for in situ treatment of DNAPL areas.

Ten soil samples will be collected during and after soil mixing from within the mixing zone and around the perimeter. Soil samples from within the mixing zone will be analyzed in the field for iron to confirm that the final ZVI concentrations meet design parameters (i.e., the target iron ratio). Soil samples will also be analyzed for VOCs to monitor the effect of the mixing and serve as a baseline for comparison of soil sample results at intervals following treatment.

In addition, three suction lysimeters will be placed in the soil mixing area to sample soil moisture for VOCs immediately following soil mixing and at intervals following treatment. Groundwater samples will also be collected using low-flow purge techniques from the three monitoring wells near the mixing zone and analyzed for parameters listed in Table 2-7. Post-treatment sampling will be designed to monitor for increasing dissolved phase concentrations or changes in groundwater conditions resulting from disturbance of the DNAPL. Two rounds of groundwater sampling will be conducted concurrent with the EISB post-injection monitoring.

TABLE 2-7
List of Soil Mixing Performance Sampling and Monitoring Parameters

Parameter	Method	Rationale for Monitoring
Water Level	Field measurement, taken using a water level indicator	Provides quantitative indication that injection fluids are reaching the monitoring well. Also used to determine the well volume for well purging.
Turbidity	Field measurement	Typically used for well purge stabilization parameter.
Temperature	Field measurement.	Typically used for well purge stabilization parameter.
Specific Conductance	Field measurement	Typically used for well purge stabilization parameter.
ORP	Field measurement	To assess the degree to which the mixing is enhancing the reducing conditions and whether groundwater conditions are optimal for biodegradation (ORP values less than -100 mV).
DO	Field measurement	To assess the degree to which the mixing is enhancing the reducing conditions and whether groundwater conditions are optimal for biodegradation (DO values less than 0.5 mg/L).
pH	Field measurement	To assess the degree to which the mixing is enhancing the reducing conditions. Ideal range for dechlorination bacteria is 5 to 9. Also well purge stabilization parameter.
VOCs	SOM01.1 (water samples) SOM01.1 (soil samples)	The chemicals of concern. A decrease in concentration of parent compounds will provide a direct indication that the reduction reactions are being effective.
Chloride	SW 846-9056 or EPA 300 Series	Chloride ions are produced by anaerobic dechlorination and may be used as secondary indication of the occurrence of reactions.
Total Iron	Field measurement	Soil samples will be collected to confirm the target ratio of iron.

SECTION 3

Pilot Test Program

The testing program was developed based on pilot test objectives, current site conditions, available information on past activities and suspected source areas, available physical and chemical data, and knowledge of the proposed remedial alternatives (based on the draft FS and the pilot test memorandum [CH2M HILL, 2006a and 2006b, respectively]). The field activities include delineating the DNAPL area, installing additional monitoring wells, collecting groundwater, DNAPL, and soil samples, and injecting or mixing amendments to promote degradation of the VOC source zone areas.

Pilot testing will be performed to evaluate the effectiveness of the two in situ technologies. EISB will include the injection of soluble amendments into two potential groundwater VOC source zone areas (Figure 2-2 and 2-3) through injection wells. In situ soil mixing will use a patented amendment mixture of ZVI and bentonite to treat an identified DNAPL area. The information from these tests will be used to determine if these in situ treatment technologies can be implemented as a major component of the groundwater remedy.

The general tasks and field operations and procedures that have been previously described in the USEPA-approved FSP (CH2M HILL, 2004a) for the RI are not repeated herein. The modified or supplemental activities are described in the following sections

3.1 Tasks

The following tasks will be implemented during the pilot test:

- **Mobilization**—This task consists of constructing support facilities, mobilizing the equipment to the site prior to the field activities, and establishing the field office.
- **DNAPL Delineation**—This task includes soil and groundwater sampling, using direct-push technology, to delineate the lateral extent of the DNAPL area to be treated.
- **Bench Testing**—Data generated during this task will help define the design parameters for the in situ soil mixing pilot test.
- **Enhanced In situ Biodegradation**—This task consists of the installation of monitoring wells and injection wells, baseline groundwater sampling, injection of selected amendments into the shallow and deep portions of the aquifer, and post-injection performance monitoring. The data generated will determine the effectiveness of the amendment injections to reduce chlorinated VOC concentrations in the source zone areas and downgradient monitoring locations.
- **In situ Soil Mixing**—Treatment of the DNAPL area using large-diameter augers to incorporate bentonite and ZVI into the subsurface is included in this task. Soil samples will be collected during and after the mixing to monitor the effectiveness of the technology. Water samples from lysimeters and monitoring wells will also be collected to monitor for changes in groundwater conditions because of the mixing.

- **Surveying**—Coordinates for the sample locations, elevations of the new monitoring wells, and the soil mixing treatment area will be established during this task.
- **Dispose of Investigation-Derived Waste**—This task includes characterizing and disposing of IDW in accordance with local, state, and federal regulations.
- **Demobilization**—At the completion of fieldwork, personnel, equipment, and supplies will be demobilized from the site.

3.2 Field Operations and Procedures

This section provides an overview of the equipment, operations, and procedures that will be performed during the pilot test.

3.2.1 Mobilization

The following mobilization tasks will be completed prior to the start of the pilot test:

- Mobilize and set up support facilities (electricity, water, portable facilities, security [if necessary]), and field office equipment and supplies (computer, water cooler).
- Identify and set up the temporary IDW storage area.
- Locate and inspect existing onsite and offsite monitoring wells. The well inspections will include visual observations of well condition, well construction (e.g., depth of well, casing material), and groundwater level measurements. All observations and measurements will be documented in the field notebook.
- Locate approximate locations for initial DNAPL delineation borings, monitoring wells, and injection wells. Locations will be inspected to determine if modifications are necessary based on structural limitations (low-overhead clearances or building support columns) or other potential hazards (underground utilities, etc.). Any modifications necessary will be recorded along with the reason for the modification.
- Identify and contact utility companies to get underground utility clearance for the sampling locations.
- Post signs that provide appropriate contacts for information and for reporting suspected criminal activities.
- Obtain and transport the identified field supplies (e.g., personal protective equipment [PPE], sample containers, preservatives, sample forms and other related items), and field monitoring equipment to the site.
- Mobilize DPT (e.g., Geoprobe®) and drilling contractor and supplies and materials.
- Confirm that analyses are scheduled through the USEPA CLP and the independent laboratories.
- Confirm that field equipment is in proper working order and has received the appropriate quality control checks.

During mobilization activities, the field team leader (FTL) will perform walk-through inspection of the site and inspect and generate field sampling maps. The level of health and safety protection to be used during the mobilization activities will be Level D.

3.2.2 DNAPL Delineation

3.2.2.1 Soil and Groundwater Sampling

A limited subsurface investigation will be conducted using DPT (e.g., Geoprobe) to delineate the extent of the DNAPL area. Soil and groundwater grab samples will be collected from an estimated 24 borings completed to the base of the aquifer (i.e., a depth of approximately 30 feet bgs). The initial eight soil borings will be installed 25 feet from the soil boring (SO-057) where DNAPL was detected during the RI. Additional boring locations will be offset based on the presence/absence of DNAPL in the soil/groundwater samples.

Soil samples will be collected continuously using DPT methods from the ground surface to the top of the till (estimated to be 30 feet bgs). The soil samples will be logged, field screened using an organic vapor meter (OVM) and examined for visual indications of mobile and/or residual DNAPL. A groundwater grab sample will also be collected at each boring from the base of the aquifer and visually examined for the presence of DNAPL. Samples will not be collected for laboratory analysis. The sampling procedures and equipment applicable to these activities will be in accordance with the Field Operating Procedures included in the November 2004 FSP (CH2M HILL, 2004a).

3.2.2.2 Monitoring Well Installation and Sampling

Groundwater monitoring well nests will be installed at an estimated three locations to monitor changes in groundwater quality because of the soil mixing activities. Each well nest will consist of a shallow well installed at the water table (well depth of 15 feet) and a deep well installed at the top of the till (well depth of about 30 feet). The 2-inch monitoring wells will be installed using hollow-stem auger (HSA) techniques, constructed of polyvinyl chloride (PVC) casing and well screens, and developed following the same procedures as for the RI monitoring wells. The monitoring wells will be sampled using the low-flow sampling methods prior to and after mixing and will be analyzed for VOCs, TOC, volatile fatty acids, and natural attenuation parameters (see Table 2-1). These new monitoring wells will be included in the overall baseline groundwater sampling event and with the EISB post-injection performance monitoring program.

3.2.3 Bench Testing

Soil, groundwater, and DNAPL samples for in situ soil mixing bench testing will be collected using DPT methods during DNAPL delineation activities. Approximately 200 pounds of soil, 1 gallon of groundwater, and 80 mL of DNAPL will be collected and sent to CSU for use in the bench testing. Sampling will be conducted in accordance with the procedures presented in the FSP (CH2M HILL, 2004a).

3.2.4 EISB

The enhanced anaerobic biodegradation pilot test involves the injection of the selected amendment (i.e., EOS and sodium lactate) into the shallow and deep intervals of the aquifer in two areas. The prepared amendment solution will be injected into a series of closely

spaced, 2-inch-diameter injection wells. The design EISB pilot test has been designed to achieve and sustain reducing conditions that will enhance the bioremediation of the chlorinated VOCs.

3.2.4.1 Injection Well and Monitoring Well Installation

Monitoring and injection wells constructed for the pilot test will be installed using HSA drilling methods. The number and depths of the injection wells and monitoring wells to be installed in two areas are presented in Table 2-3. The injection wells will be constructed using flush-thread, 2-inch-diameter PVC risers with stainless-steel, continuous wire-wrapped screens. Monitoring wells will be constructed using 2-inch-diameter PVC risers and screens. The newly installed wells will be developed prior to the injection. Wells will be developed by alternately surging and purging with a surge block and/or submersible pump. Injection wells and monitoring wells will be installed, constructed, and developed in accordance with procedures presented in the November 2004 FSP (CH2M HILL, 2004a).

3.2.4.2 Baseline Groundwater Sampling

Groundwater samples will be collected from the 16 new monitoring wells and the 58 previously installed monitoring wells to establish baseline groundwater conditions prior to the start of the treatability study. Groundwater samples will be collected using low-flow methods and analyzed for the parameters presented in Table 2-1.

Prior to sampling, groundwater levels will be measured with an electronic water-level indicator. In addition, an oil-water interface probe will be lowered to the bottom of the well to check for the presence or absence of NAPL in monitoring wells and to measure the total depth of the well. The well depth will be used to calculate the required purge volumes and assess the amount of solids collecting in the well.

Specific equipment and procedures for low-flow sampling and measuring water levels are presented in the November 2004 FSP (CH2M HILL, 2004a).

3.2.4.3 Amendment Injection

The EISB amendments (i.e., EOS and sodium lactate) will be purchased from a material vendor. The selected EISB amendment will be combined with water from a local potable water source (e.g., a hydrant) in a 2,500-gallon poly tank to form a solution (or emulsion, in the case of EOS) that will be pumped into a manifold capable of injecting into eight injection locations simultaneously.

A pump and manifold injection system will be developed that includes a positive-displacement pump capable of delivering 10 gallons per minute per well to eight injection wells. Valves, flow meters, and related appurtenances will be used for equally distributing the volume of substrate to each injection well. A portable poly tank may be used to transport the amendment solution from the mixing area to the injection area if the injection area is not in a secure location.

EISB amendments will be delivered to the subsurface by injection to an estimated 36 wells in Area 2 and approximately 19 wells in Area 4. EISB injection volumes will be 122,000 gallons per event for Area 2 and 66,000 gallons per event for Area 4. Injections of lactate will be

repeated every 90 days for a total of four injection events. Because EOS differs in composition from lactate, the persistence of EOS is reported as 3 years or more. Based on the manufacturer's data regarding the persistence of EOS, only one injection event of EOS will be performed as part of the pilot test.

3.2.4.4 Post-injection Monitoring

Primary and secondary performance groundwater monitoring will be conducted after the injections to quantify changes in groundwater geochemistry and contaminant concentrations. Groundwater samples from 20 monitoring wells will be collected using low-flow purge techniques (see Table 2-5). Performance monitoring will continue for approximately 18 months, resulting in six secondary and four primary monitoring events.

The groundwater samples for primary performance monitoring events will include analyses of all parameters listed in Table 2-1. The secondary performance monitoring events will only include analyses for field parameters (ORP, pH, DO, temperature, turbidity, and conductivity) and TOC. Field parameters will be collected during well purging using field instruments. Visual indications (color) of substrate migration will also be noted. Specific equipment and procedures for low-flow sampling and measuring water levels are presented in the November 2004 FSP (CH2M HILL, 2004a).

3.2.4.5 Annual Monitoring

An annual monitoring event will be conducted to evaluate overall temporal trends in the groundwater quality. Groundwater samples will be collected using low-flow purge techniques from the 74 new and existing monitoring wells and analyzed for the parameters listed in Table 2-1. Specific equipment and procedures for low-flow sampling and measuring water levels are presented in the November 2004 FSP (CH2M HILL, 2004a).

3.2.5 In situ Soil Mixing

3.2.5.1 Soil Mixing Implementation

Upon completion of the DNAPL area investigation and the bench testing, the soil mixing design will be refined and the soil mixing equipment will be mobilized to the portion of Area 2 known to contain TCE DNAPL and located outside the building. The soil mixing equipment will include a crane, large-diameter augers, support equipment, batch mixing equipment, and an injection pump. The soil mixing will be performed in a pattern resembling a series of overlapping vertical columns. The large-diameter auger will be advanced to the base of the aquifer, during which a combination of ZVI and bentonite clay will be injected through nozzles on the auger blades. ZVI will be incorporated at an estimated concentration of 2 percent by soil mass. Near ground surface, approximately 3 percent concrete would be added to the mixture to provide a stable ground surface. An estimated 2,800 cubic yards of soil will be mixed in situ with a combination of ZVI and bentonite clay over a 4-week period.

The high VOC concentrations anticipated in the aquifer may produce vapors during soil mixing. In addition, hydrogen gas may be produced from the rapid reaction between the ZVI and the VOCs. Air monitoring will be performed during implementation, and should VOC vapors become a concern, engineering methods (e.g., large-diameter fans and/or a

fume hood installed on the mixing auger) will be implemented to control the vapors in the work area.

3.2.5.2 Performance Monitoring

During and after the soil mixing, soil samples will be collected from the mixing zone and around the perimeter to quantify homogeneous amendment distribution throughout the mixing zone, concentrations of the amendment in the mixing zone, changes in groundwater geochemistry, and changes in contaminant concentrations. An estimated 10 soil samples from within the mixing zone will be analyzed in the field for iron to confirm that the final ZVI concentrations meet design parameters (i.e., the target iron ratio). Soil samples will also be analyzed for VOCs to monitor the effect of the mixing and serve as a baseline for comparison of soil sample results at intervals following treatment.

Suction lysimeters will be installed at three locations within the mixing zone to collect groundwater samples immediately following the mixing and at intervals following treatment. Two rounds of groundwater samples will be conducted concurrent with the EISB post-injection monitoring and analyzed for VOCs. The procedures for the installation and sampling of the suction lysimeters are provided in *FOP-22 Suction Lysimeter Installation and Pore Water Sample Collection Procedure* in Appendix B.

Groundwater samples will also be collected using low-flow purge techniques from the monitoring wells in the vicinity of the mixing zone. Post-treatment sampling has been designed to monitor for any increasing dissolved-phase concentrations or changes in groundwater conditions resulting from the disturbance of the DNAPL. Table 2-7 presents a summary of the performance confirmation sampling parameters.

3.2.6 Surveying

A licensed surveyor will survey the DPT boring, monitoring and injection well locations, the elevation of the monitoring well casings, and extent of the soil mixing treatment area. The horizontal position of the various sampling/monitoring locations will be established to within 0.1 foot using latitude and longitude in decimal degrees and Universal Transverse Mercator North American Datum 83 coordinates. Elevations will be established within 0.01 foot based on the North American Vertical Datum.

3.2.7 IDW Sampling and Disposal

Materials that may become IDW requiring proper treatment, storage, and disposal are as follows:

- Personal Protective Equipment (PPE)—This includes disposable coveralls, gloves, booties, respirator canisters, etc.
- Disposable equipment—This includes plastic ground and equipment covers, aluminum foil, Teflon® tubing, broken or unused sample containers, sample container boxes, tape, etc.
- Soil cuttings from the DPT borings and well installation
- Groundwater obtained through well development or well purging

- Decontamination water

The solid and liquid IDW generated during the fieldwork will be containerized, sampled, characterized, and disposed of following the completion of pilot test activities. CH2M HILL assumes that all solid wastes generated will be disposed of at a licensed municipal landfill and all liquid wastes will be disposed of without treatment to the North Shore Sanitary District.

PPE, after decontamination, will be treated as debris and placed in a dumpster. PPE that is not decontaminated will be stored in 55-gallon drums. This waste will be disposed of in accordance with the procedures presented in the *Waste Transportation and Disposal Plan* (CH2M HILL, 2004b).

3.2.8 Demobilization

Upon conclusion of the field activities, all support facilities and equipment from the site will be demobilized. All equipment and tools will be properly decontaminated before they are demobilized from the area. No site restoration activities are anticipated other than those required at sampling locations.

SECTION 4

General Field Operations

See Section 4 of the original FSP.

SECTION 5

Works Cited

CH2M HILL. 2004a. *Field Sampling Plan, OMC Plant 2, Waukegan, Illinois*. November.

CH2M HILL. 2004b. *Site Management Plan, OMC Plant 2 (Operable Unit 4), Waukegan, Illinois*. September.

CH2M HILL. 2006a. *Draft Feasibility Study Report, OMC Plant 2, Waukegan, Illinois*. May.

CH2M HILL. 2006c. *Remedial Investigation Report, OMC Plant 2, Waukegan, Illinois*. April.

Figures

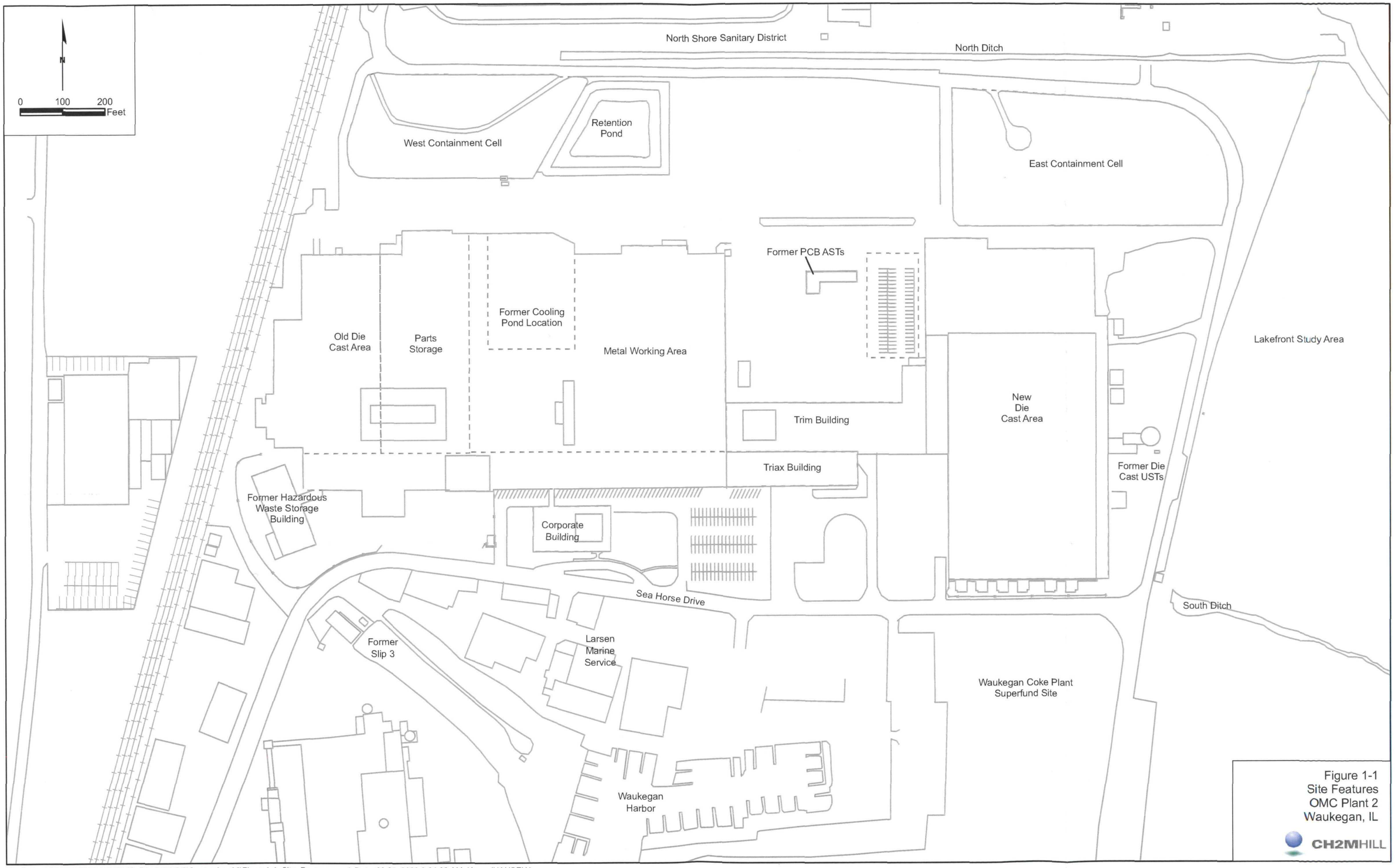

Figure 1-1
Site Features
OMC Plant 2
Waukegan, IL

CH2MHILL

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Figure 2-1
Source Zones
OMC Plant 2

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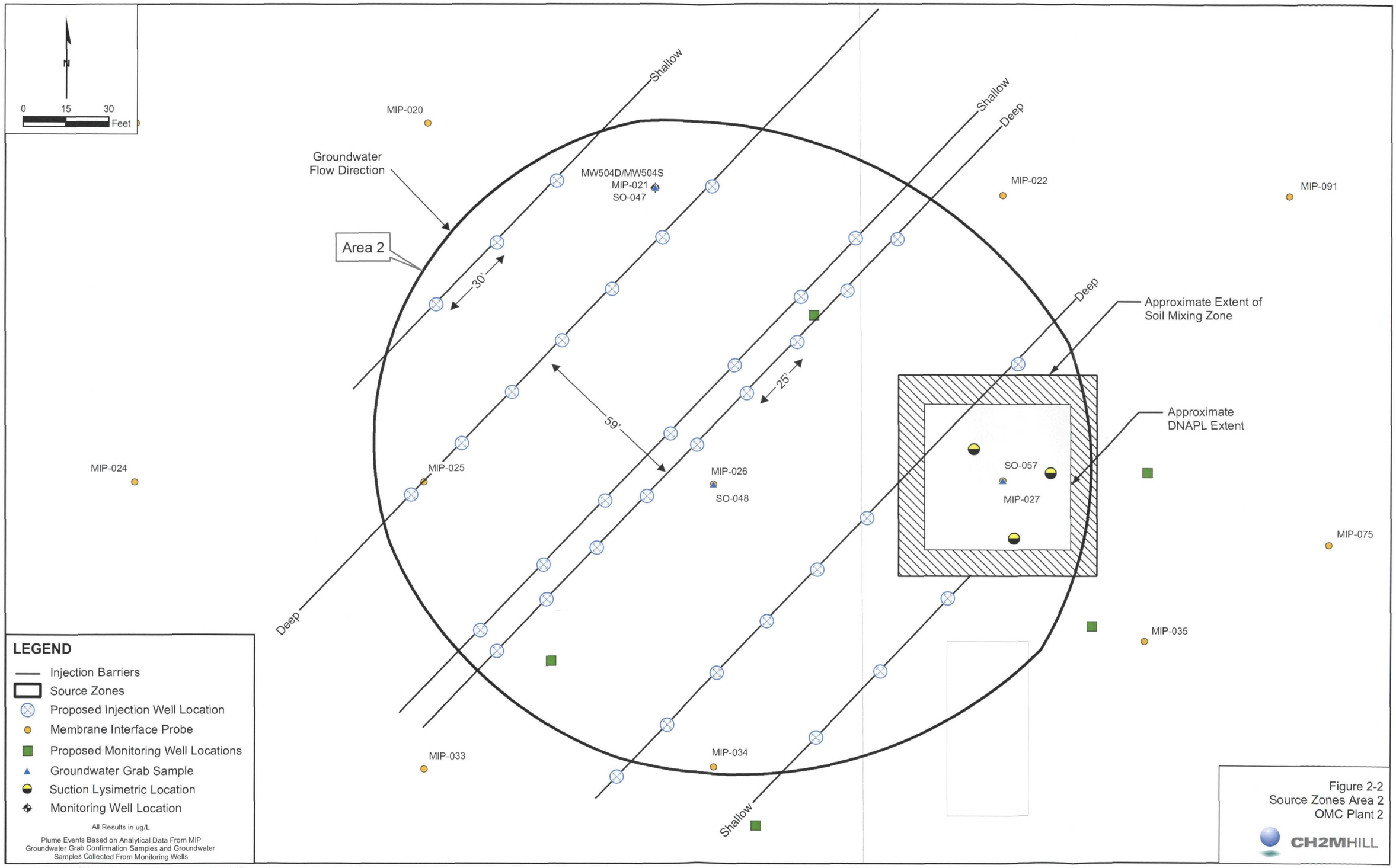

Figure 2-2
Source Zones Area 2
OMC Plant 2

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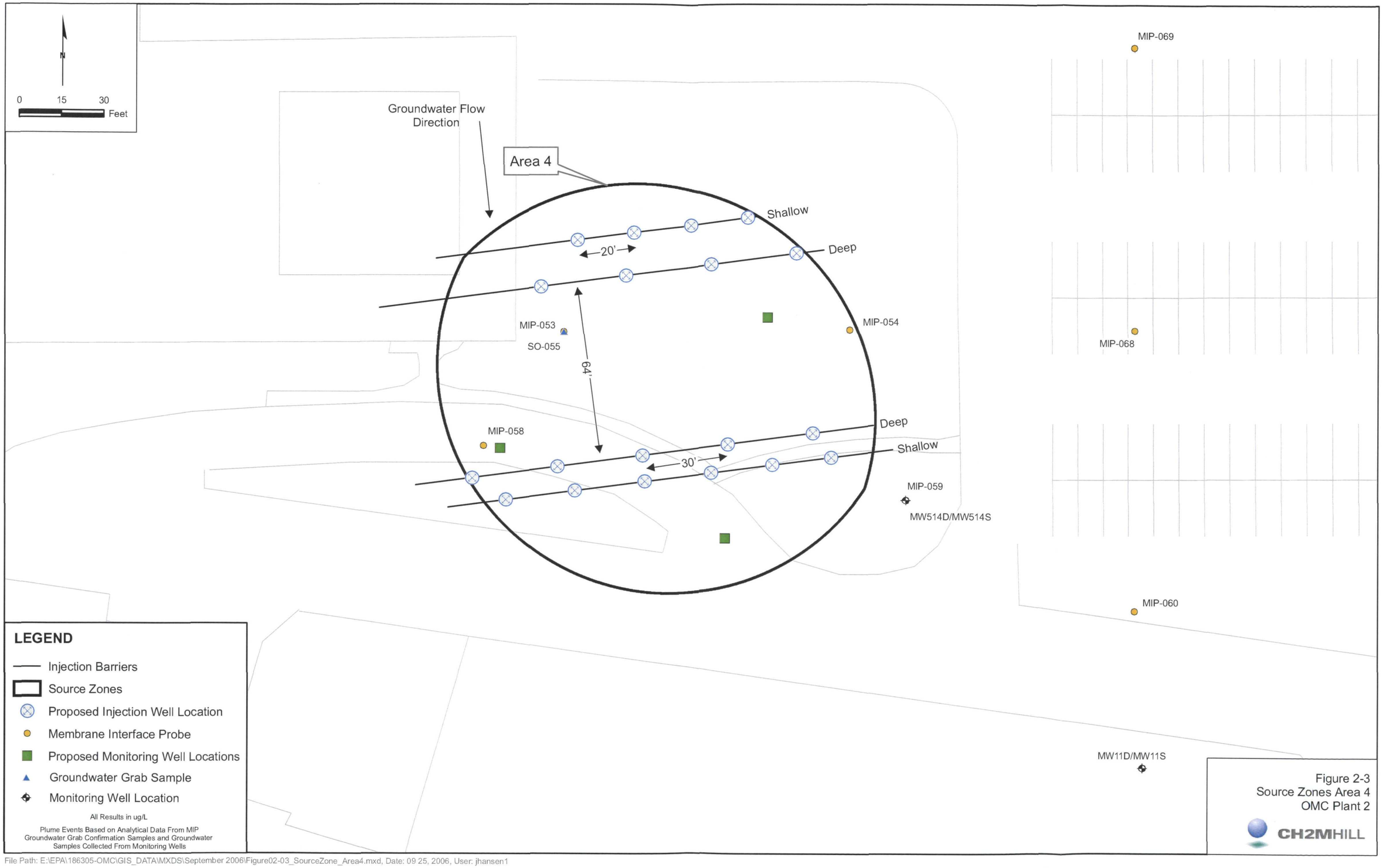

Figure 2-3
Source Zones Area 4
OMC Plant 2

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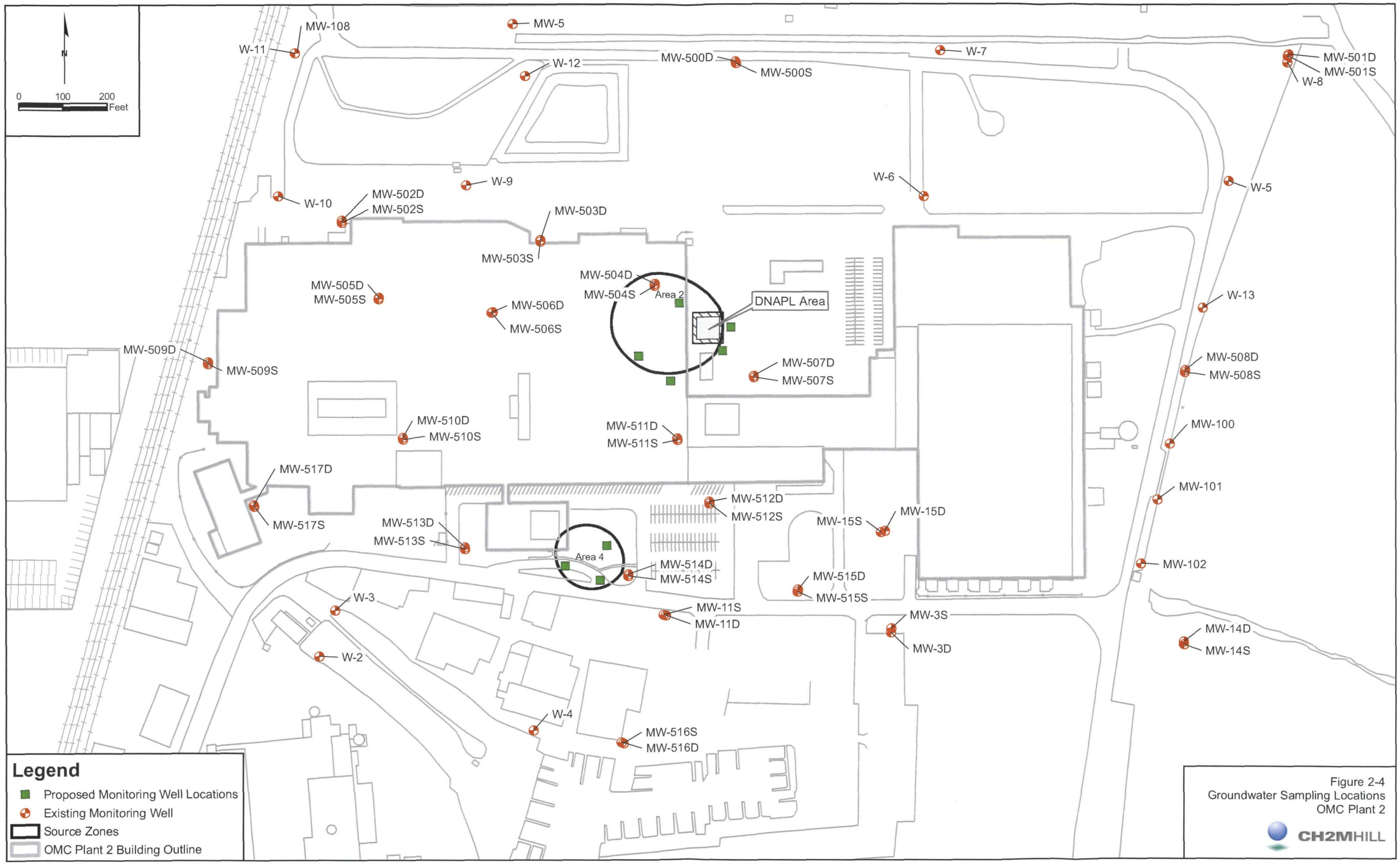


Figure 2-4
Groundwater Sampling Locations
OMC Plant 2

File Path: E:\EPA\186305-OMC\GIS_DATA\MXDS\September 06\Figure02-04_GW_Sampling Locations.mxd, Date: 09 25, 2006 9:23:27 AM, User: JHANSEN1

Appendix A

CSU's Proposal for ZVI-Clay Treatability Study

Proposal for ZVI-Clay Treatability Study

OMC Plant 2
Waukegan, Illinois

Developed by

Colorado State University
Civil and Environmental Engineering
CCH
Center for Contaminant Hydrology

For

CH2M HILL, Inc.

August 22, 2006

1.0 Introduction

The following proposal has been developed per the request of Jewelle Keiser, Phil Smith, and Paul Rohde of CH2M HILL. The described work will support an evaluation of ZVI-Clay technology for treatment of contaminated soils at OMC Plant 2 in Waukegan, Illinois. Contents of this proposal include background information, scope of work, budget, schedule, and project team. Objectives of the work include the following:

1. Demonstrating the effectiveness of ZVI-Clay to degrade trichloroethylene (TCE), 1,1,1-trichloroethane (1,1,1-TCA), and related degradation products in site soils

2. Resolving the relative effectiveness of Peerless, GMA, and QMP iron at application rates of 1 and 3 percent by dry weight soil

3. Investigating the effectiveness of sodium bicarbonate and fly ash to control low pH condition that could drive excess generation of hydrogen gas

4. Evaluating the use of fly ash to improve post treatment soil strength

Questions and/or comments regarding this proposal should be directed to Mitch Olson (970-491-8720) or Tom Sale (970-491-8413) at the Colorado State University (CSU) Center for Contaminant Hydrology.

2.0 Background Information

The following provides background information regarding ZVI-Clay technology and the site.

2.1 Technology Description

ZVI-Clay is an *in situ* source remediation technology that involves admixing reactive media (zero valent iron), stabilizing agents (clay) and soils containing chlorinated compounds using conventional soil mixing equipment (Figure 1). Reactive media and stabilizing agents are delivered into the subsurface via a grout that is injected concurrently with soil mixing. Through this process, chlorinated compounds in treated zones are depleted and hydraulic conductivity of the targeted zone is decreased. The net benefit is a dramatic reduction in future releases of contaminants from the treated interval.

DuPont pioneered this technology through research conducted between 1996 and 2002. In 2003, DuPont donated patents covering ZVI-Clay technology to CSU. CSU's current focus with the technology is further development and commercialization.

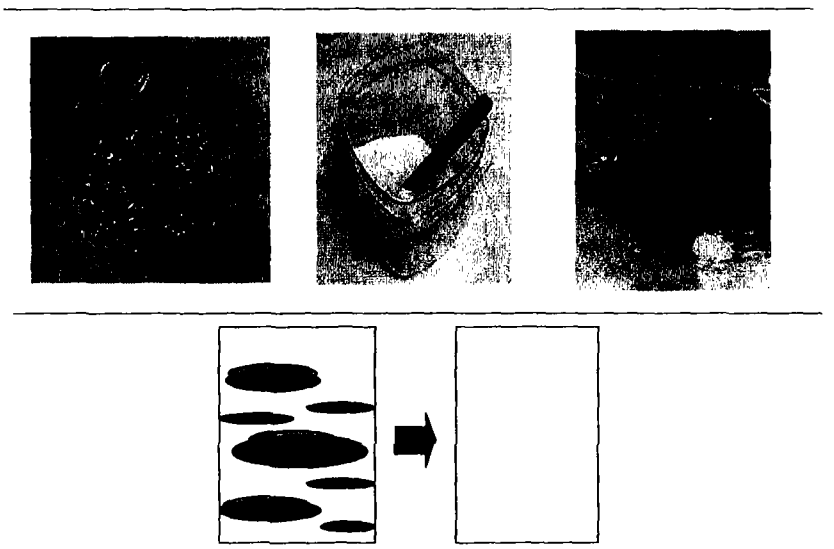


Figure 1. Admixing reactive media, stabilizing agents, and contaminated soils using conventional soil mixing techniques.

2.2 Relevant Site Attributes

Target sediments at the Site include layers of fill, sand, and till. The fill extends from 2 to 12 feet, consisting of "silty or clayey sand and/or gravel deposits with wood fragments, bricks, and other debris." Beneath the fill, a sand/gravel layer extends to a depth of 25 to 30 feet. At greater depths, a till layer is encountered, comprising mostly clay interspersed with sand and gravel. In the absence of other obstacles such as boulders/cobbles, utilities, or buildings, this type of media is likely to be amenable to soil mixing.

DNAPL was noted at depths of 26.5 to 30.5 feet. It is assumed that the surface of the till layer marks the limit of downward contaminant migration. The DNAPL comprised mainly TCE. Other contaminants noted include 1,1,1 TCA and TCE daughter products (1,1-DCE, 1,2-DCE, and VC). Work conducted to date suggests that these compounds are amenable to ZVI-mediated degradation.

3.0 Scope of Work

Bench-scale studies will be conducted to achieve the objectives identified in Section 1.0. Activities include the following:

Task 1: Batch Reactor Construction
Task 2: Receipt and Preparation of Site Soils
Task 3: Column Mixing
Task 4: Sampling and Analysis
Task 5: Documentation and Reporting

These tasks are described in detail in the following text.

Task 1: Batch reactor construction

This task consists of constructing columns that will be used for the batch reactor study. The columns are 40 centimeters in height and constructed of 4-inch schedule 40 transparent PVC. Sampling ports are located at 10 cm intervals along the wall of the column. The top of each column is sealed using a Cherne Monitor-Well plug. The bottom of the column is cemented into a PVC flange; this flange will be bolted onto an acrylic sheet to seal the column.

Task 2: Receipt and preparation of site soil samples

Approximately 220 pounds of site soils are requested (assuming 14 columns). It is assumed that CH2M HILL will collect soils in acetate sleeves. One gallon of site water and 80 mL of site DNAPL are also requested. The DNAPL volume of 80 mL is based on an assumed target soil concentration of 1,000 mg/kg. A summary of site materials and quantities requested by CSU is shown in Table 1.

Table 1
Site Materials Requested

Material	Amount Requested	Use
Soil	220 lbs.	Column mixing plus contingency; 50 lb. stored as archive
Water	1 gal.	Soil saturation
DNAPL	80 mL	Spiking soil to elevated contaminant level

Upon receipt, each soil sleeve will be weighed and cut open; soil contents will be visually logged and monitored via organic vapor analyzer (OVA). Samples with elevated OVA readings will be screened for the presence of DNAPL using Sudan IV and a UV light. Sudan IV is an organic-soluble dye used as a DNAPL indicator. UV light causes many NAPLs to fluoresce. After logging, all soil samples will be combined into a single composite sample.

To the extent practical, care will be taken to minimize volatilization losses of target contaminants. As such, soil samples will be stored at approximately 4°C until treatment. A portion of the composite sample will be removed and stored as an archive sample.

The composite soil sample will be spiked and homogenized prior to filling the study columns. DNAPL provided from the Site will be added to spike soil contaminants levels to approximately 10 times those found in the field. In previous soil-mixing field projects, post-mixing soil contaminant levels were much higher than predicted, likely due to the difficulty of finding and quantifying *in situ* DNAPL. Use of exaggerated contaminant levels in the laboratory provides a

safety factor and enhances that probability that better performance will be achieved in the field. Following the addition of Site water and DNAPL, the soil will be homogenized using a standard drill-driven paint mixer. The columns will be loaded with the homogenized soil sample prior to mixing.

Task 3: Column Mixing

The experimental design is illustrated in Figure 2. *Figure 2a* shows control columns that will be prepared without iron. *Figure 2b* shows columns that will be prepared with variable iron amounts and sources. *Figure 2c* shows columns that will be prepared to evaluate the use of sodium bicarbonate (as pH control) or fly ash. Except for one of the controls (as indicated in Figure 2a), all columns include 1% bentonite clay per dry weight soil.

Immediately prior to mixing, a grout mixture will be prepared with pre-determined amounts of reactive media (granular iron), stabilizing agents (bentonite), and other ingredients (sodium bicarbonate or fly ash). The grout mixture will be admixed with the spiked site soil in each column using the apparatus shown in Figure 3. The mixing apparatus advances a soil-mixing auger through the columns with fixed vertical velocity, rate of rotation, and rate of grout injection. The apparatus is designed to achieve repeatable mixing results in a laboratory setting.

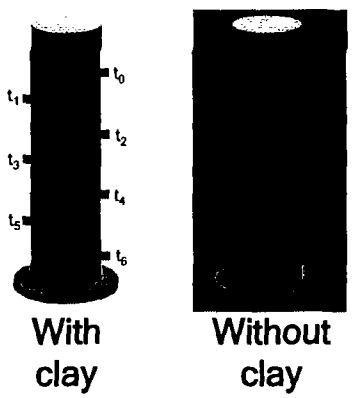


Figure 2a: Control columns (no iron added).

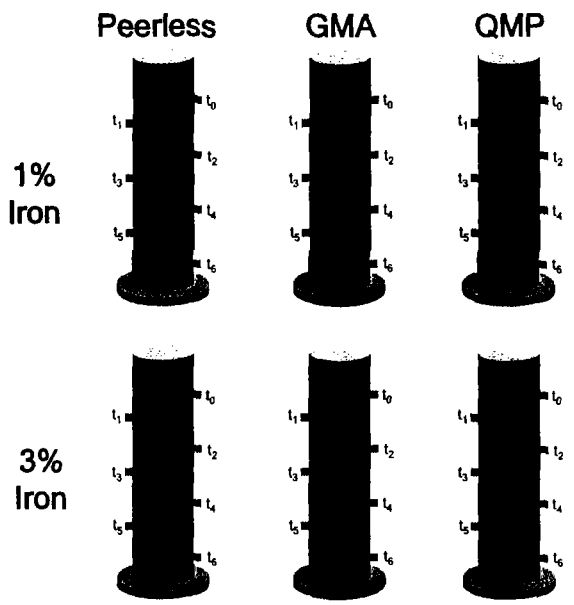


Figure 2b: Variable iron source and amount.

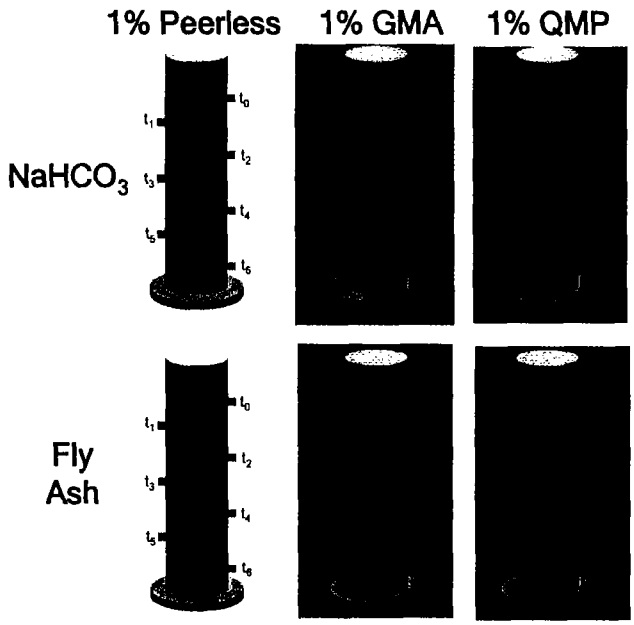


Figure 2c: pH control / enhanced soil strength.

Figure 2 - Experimental design (a total of 14 columns are proposed; optional columns are highlighted).

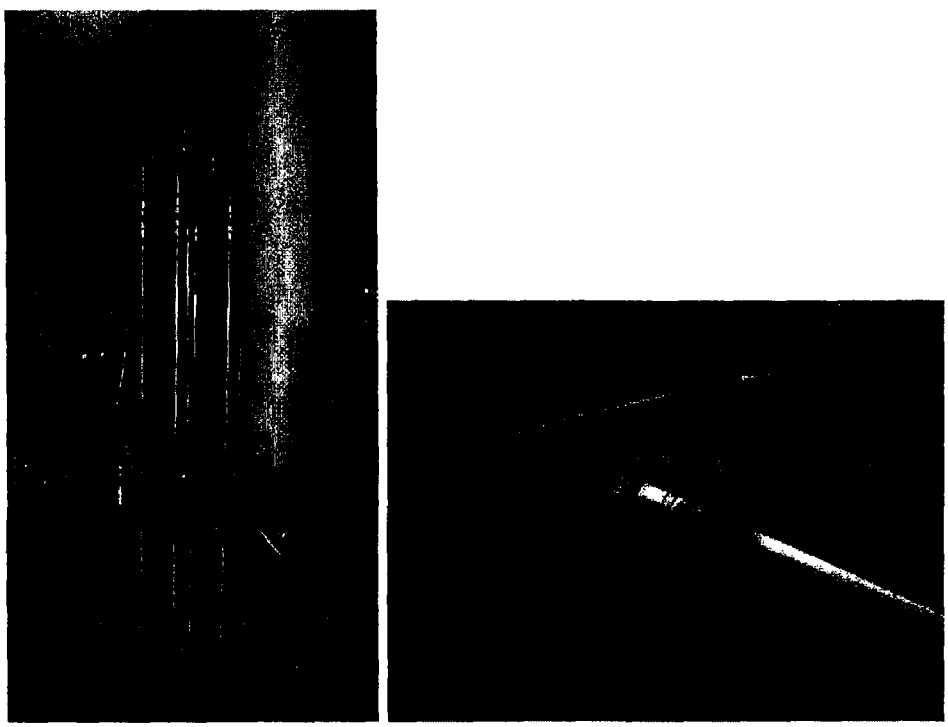


Figure 3 - Apparatus for admixing reactive media and stabilizing agents with spiked site soils—platform (left) and soil-mixing auger (right).

Task 4: Sampling and Analysis

Initial soil samples will be collected immediately after mixing; subsequent samples will be collected after approximate reaction times of 3, 7, 28, and 56 days (actual sample times subject to change based on results of previous samples). Techniques employed in collecting samples are illustrated in Figure 4. Soil samples will be extracted into methyl tertiary butyl ether (MTBE) for analysis. Analysis for chlorinated organic compounds will be conducted on a Hewlett Packard 5890 Series II gas chromatograph (GC) with an Agilent DB-624 column and electron capture detector (ECD). Duplicate and blank samples will be collected at an approximate frequency of 10%.

Each soil sample will also be analyzed for water content and chloride concentration. Water content is necessary to calculate contaminant concentrations on a dry soil basis. Chloride concentration provides an independent means of evaluating treatment (reductive dechlorination) that is not biased by potential contaminant losses through volatilization. Chloride analysis will be performed using an ion-specific electrode (ISE). In addition, select samples will be analyzed for iron content. Magnetic separation will be used for iron content analysis.

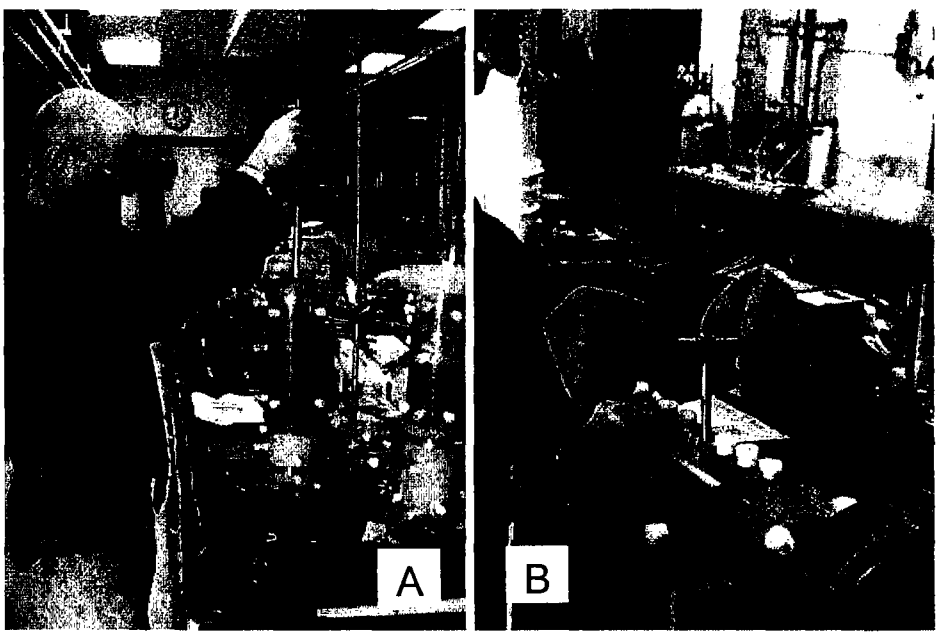


Figure 4 - A) composite soil sample along axis of a column and B) discrete sub samples from points along a column.

At the end of the experiment (~56 days) a portion of three select columns will be sacrificed for measurement of compressive strength (ASTM D4219-02). The three columns will be selected based on experimental results, and will likely consist of (1) a control column, (2) a column containing clay and fly ash, and (3) a column containing clay and no fly ash.

During the experiment, the volume of gas produced in each column will be monitored. To accomplish this, a gas collection apparatus will be attached to the top of each column shortly after soil mixing is complete. The apparatus consists of a 1-liter glass flask that is initially filled with water. The apparatus is configured such that gas evolution in the column will displace water from the flask. The volume of gas produced over time will be estimated from the volume of water remaining in the flask.

Task 5: Documentation and Reporting

Following standard reporting procedures, CSU will produce draft and final reports describing methods and results. The reports will include detailed description of methods and results.

4.0 Schedule

A project schedule is shown in Figure 5. A draft report will be provided to CH2M HILL 70 days after receipt of the soils samples. A final report will be issued 1 week after receiving final comments from CH2M HILL.

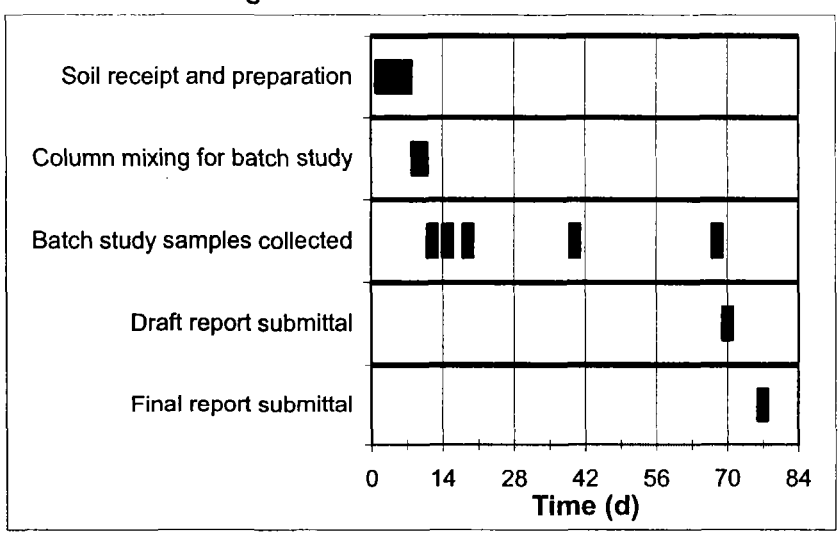


Figure 5: Project schedule.

5.0 Project Team

The primary members of the project team are Mitch Olson and Dr. Tom Sale. Mitch Olson is a full-time Research Associate in CSU's Center for Contaminant Hydrology. Through his recently completed MS degree research at CSU, Mitch pioneered development of the ZVI-Clay treatability study method described herein. Dr. Sale is the director of the Center for Contaminant Hydrology and is leading CSU development of the ZVI-Clay technology. Undergraduate research assistants at CSU, who are fully familiar with related procedures, will assist Mitch and Tom in carrying out the above tasks.

Appendix B

Field Operating Procedures

FIELD OPERATING PROCEDURE FOP-22

Suction Lysimeter Installation and Pore Water Sample Collection Procedure

Purpose

The purpose of this FOP is to provide a general guideline for the installation of suction lysimeters and to provide guidance for the collection of soil pore water samples from the lysimeters.

Scope

The methods described for the lysimeter installation and pore water sample collection are typically utilized to monitor the unsaturated zone or pore water within fine-grained materials.

Equipment and Materials

- Suction lysimeters
- Polyethylene purge tubing
- Clamping rings and/or valves
- Pressure/vacuum hand pump
- Silica flour
- 1-inch ID PVC pipe
- Stainless-steel coupler for lysimeter to PVC pipe
- 1-inch PVC caps
- Clean latex or surgical gloves as specified in the Health and Safety Plan
- Precleaned sample containers, coolers, and other sampling supplies as referred to in the Field Sampling Plan
- Decontamination supplies including 10 percent methanol rinse, nonphosphate soap, and distilled water, paper towels, and plastic sheeting
- Field notebook, sample data sheets, chain-of-custody forms, and custody seals
- Concrete forms
- Concrete

- Ice
- Appropriate personal protective equipment as specified in the health and safety plan
- Tool box
- 55-gallon drum or 5-gallon buckets, with covers, to contain soil and purge water

Procedures and Guidelines

Lysimeter Installation

1. Check that sampling tubes and other downhole equipment and sampling equipment are decontaminated in accordance with FOP-17, *Decontamination of Drilling Rigs and Equipment*.
2. Wear appropriate personal protective equipment, as required by the Health and Safety Plan. Change gloves between sampling locations.
3. Confirm that all underground utility clearances have been obtained and maps of private utilities have been consulted.
4. Connect vacuum tubing and pressure tubing to the lysimeter verifying that tubing will extend at least 2.5 feet above the ground surface after the lysimeter is installed to the desired depth.
5. Test vacuum and pressure lines for leaks using hand pump and a mild soap solution. If leaks are detected, repair and re-test.
6. Run tubing from the lysimeter through stainless-steel connecter and 1-inch diameter PVC piping.
7. Thread stainless-steel connector onto the lysimeter and PVC pipe onto stainless-steel connector.
8. Drill a 3-inch diameter borehole to the target installation depth.
9. Prepare a slurry of the silica flour and pour a small volume of slurry down the borehole to cover the porous cup portion of the lysimeter.
10. Lower the lysimeter assembly into the borehole and push it all the way to the bottom of the borehole to ensure good contact with the native soil.
11. After placing the lysimeter at the appropriate depth, pour the remaining slurry into the access hole so that the slurry covers at least the porous steel as well as above and below it. Check that the PVC pipe extends at least 2.5 feet above ground surface.
12. Place bentonite chips, pellets, or grout to a depth of approximately 1 foot below ground surface.
13. Install sonotube form over the top of the 1-inch PVC pipe to a depth of at least 2 feet. Excavate soil from inside the sonotube, if necessary.

14. Mix concrete and place inside the sonotube to construct surface seal. Concrete should slope down from the well pipe to direct surface water away from the well.
15. Attach the PVC pipe cap loosely and label the well cap with the lysimeter location ID.
16. Discard unused soil according to the guidelines for investigation-derived waste.
17. Decontaminate all nondedicated downhole equipment in accordance with FOP-17, *Decontamination of Drilling Rigs and Equipment.*
18. Additional sampling may be required at the location. The location should be secured and clearly marked to prevent slip/trip/fall injuries.

Lysimeter Sampling

1. Check that non-dedicated sampling equipment is decontaminated in accordance with FOP-17, *Decontamination of Drilling Rigs and Equipment.*
2. Wear appropriate personal protective equipment, as required by the Health and Safety Plan. Change gloves between sampling locations.
3. Close the valve or clamp on the tubing going to the collection bottle and open the clamp on the tubing to the overflow bottle.
4. Connect the vacuum pump and begin to pump with the vacuum, pulling water into the porous part of the lysimeter. Water will collect in the chamber. The pumping time required to fill the chamber depends on the soil moisture and can be up to 1 hour.
5. When a sufficient volume of water has been collected, the hand pump will be disconnected and the valve or clamp on the tubing to the collection bottle will be opened.
6. Connect the hand pump to the vacuum/pressure tubing. Apply pressure and the water will begin to flow into the sample bottle.
7. Label, handle, and store the sample according to procedures outlined in the Field Sampling Plan. Record sampling data such as depth, time, and date as specified in the Field Sampling Plan. Discard unused sample according to the guidelines for investigation-derived waste.
8. Decontaminate all nondedicated equipment in accordance with FOP-17, *Decontamination of Drilling Rigs and Equipment.*
9. Additional sampling may be required at the location. The location should be secured and clearly marked to prevent slip/trip/fall injuries.

Attachments

None.

Reference

None.

Key Checks and Items

1. Prior to field installation, pressure techniques should be used to check all lysimeters for leaks.
2. Proper installation of silica flour is required to prevent intake clogging with fine soil particles.
3. Care should be taken to avoid pulling water into the sampling pump.
4. Collect rinse water investigation-derived waste and containerize with well development and purge water.
5. The concrete pad should be at least 2 feet in diameter and extend 2 feet below ground surface.

Appendix C

Pilot Study Technical Memorandum

OMC Plant 2 (OU #4) Groundwater Treatment Pilot Study

PREPARED FOR: Mr. Kevin Adler/USEPA

PREPARED BY: Ms. Keli McKenna/CH2M HILL
Mr. Paul Rohde/CH2M HILL

COPIES: Ms. Jewelle Keiser/CH2M HILL

DATE: May 18, 2006

PROJECT NUMBER: 186305

Introduction

This Pilot Study Work Plan describes the evaluation and recommended approach for a pilot test of in situ treatment technology for the contaminated groundwater at the Outboard Marine Corporation (OMC) Plant 2 (Operable Unit 4) site in Waukegan, Illinois. The results of the pilot test will be used to determine if the technology can be used as the major component of the final groundwater remedy selected for the site.

The feasibility of in situ treatment technologies to address the contaminated groundwater was identified during the technology screening and alternative development task. The source zone in situ treatment alternative developed in the feasibility study includes both in situ chemical reduction and enhanced reductive dechlorination as potential technologies. The overall objective of this work plan is to develop a pilot test that will evaluate whether the addition of an insoluble chemical amendment or soluble substrate can effectively enhance the naturally occurring anaerobic reductive dechlorination of parent product (trichlorothene [TCE]) to its transformation products (cis-1,2-dichloroethene [1,2-DCE] and vinyl chloride [VC]).

The objectives of this planning effort are to:

- Identify the target areas/zones for the pilot test
- Evaluate and select the in situ treatment amendment(s) for the pilot test. Possible amendments include soluble substrates (lactate, whey, molasses, and corn syrup), Edible Oil Substrate (EOS™), zero-valent iron (ZVI), EHC™ (patented combination of controlled-release carbon and ZVI particles by Adventus America)
- Evaluate and develop a preliminary design of the selected amendment delivery method(s)
- Develop the performance monitoring program
- Develop a preliminary cost for the pilot test

Site Description and Background

The OMC Plant 2 site is located at 100 East Seahorse Drive, Waukegan, Illinois. The 65-acre site includes a 1,036,000-square-foot (ft^2) former manufacturing plant building (i.e., Plant 2) and several parking lot areas to the north and south of the building complex. The site includes two polychlorinated biphenyl (PCB) containment cells in which PCB-contaminated sediment (dredged from Waukegan Harbor in the early 1990s) and PCB-impacted soil are managed.

OMC designed, manufactured, and sold outboard marine engines, parts, and accessories to a worldwide market for many years. OMC Plant 2 was a main manufacturing facility for OMC—the major production lines used PCB-containing hydraulic and lubricating/cutting oils, chlorinated solvent-containing degreasing equipment, and smaller amounts of hydrofluoric acid, mercury, chromic acid, and other similar chemical compounds.

Plant records indicate that chlorinated solvent handling occurred throughout the history of the plant and that up to 17 solvent degreasers were used in 1979. In addition to the degreaser units, the facility had a distiller for the purpose of reclaiming solvents and a 5,500-gallon trichloroethylene (TCE) tank housed in a semigrade vault.

Physical Characteristics

The subsurface materials encountered include near-surface fill materials above a naturally occurring sand unit that overlies clay till. The fill deposit extends from 2 to 12 feet below ground surface (bgs). Underlying the fill is a poorly graded sand or silty sand to a depth of about 25 to 30 feet. This relatively permeable sand unit comprises an unconfined aquifer with a geometric mean hydraulic conductivity of about 2.0×10^{-2} centimeters per second (cm/sec) and an average porosity of about 30 percent. Beneath the sand unit is 70 to 80 feet of hard gray clay that forms the lower boundary of the unconfined aquifer.

Groundwater is shallow and was encountered at depths ranging between 2 and 7 feet, depending on the ground surface elevation. Groundwater flow is generally west to east across the northern portion of the site (toward Lake Michigan) and, in the southern portion of the site, groundwater flows toward the south (toward Waukegan Harbor). The horizontal gradient is flat beneath the building and increases toward the south. The overall average site gradient is estimated to be 0.002 foot per foot (ft/ft). The calculated groundwater velocities ranged from about 70 to 150 feet/year in the shallow zone and 6 to 30 feet/year in the deeper zone of the aquifer. The overall site average groundwater velocity is estimated to be about 70 feet/year. Vertical gradients between the shallow and the deeper portions of the aquifer are almost non-existent.

Nature of Contamination

A field investigation was conducted at the OMC Plant 2 site between January and June 2005. The following provides a summary of the data collected and extent of contamination.

- A membrane interface probe (MIP) investigation was performed to delineate the extent of volatile organic compounds (VOCs) in the subsurface. The MIP investigation identified five source areas of chlorinated VOC (CVOC) contamination, as shown in

Figure 1, based on elevated readings (> 7.5×10^5 µV) from the photoionization detector (PID) and an electron capture device (ECD).

- Subsurface soil samples were collected to define the nature and extent of contamination within the footprint of the building and surrounding areas. Soil samples for VOC analysis were collected from 0 to 0.5 bgs and greater than 0.5 foot bgs. The total CVOCs for soil samples collected below the water table are presented in Figure 2.
- Monitoring well installation and groundwater sampling were performed to assess groundwater quality, including data to determine if conditions are conducive for natural attenuation. The TCE concentrations for the groundwater samples collected in the shallow and deep zone are shown in Figures 3 and 4, respectively.
- An investigation was performed to determine the extent of the dense nonaqueous phase liquid (DNAPL) encountered at one location (SO-057) (see Figure 1). The extent of the DNAPL was investigated with the MIPs and not found at locations 50 feet around the MIP-027/SO-057 location. A saturated soil sample collected from SO-081 had concentrations of TCE at 1,302 mg/kg, which is indicative of the presence of residual DNAPL (see Figure 2).

Development of Pilot Test Components

The results of the field investigation indicate that the groundwater contamination is likely related to the use of chlorinated solvents, primarily TCE, in past manufacturing operations at OMC Plant 2. The data collected indicate that the chlorinated "parent compound" in groundwater (TCE) was released to the subsurface during manufacturing operations. These releases created what are typically referred to as "source zones." Source zones are portions of the aquifer that have particularly high dissolved phase TCE concentrations, and which may have residual DNAPL or high concentrations of adsorbed TCE which can continue to create and sustain dissolved phase plumes.

Based on the findings of the MIP, soil, and groundwater investigations and the conceptual model of the site, five source zones have been identified as shown in Figure 5. These five source zones will be the target treatment zones (TTZs) for the pilot test. Targeting the source zones for treatment will reduce the mass of "parent" (e.g., TCE) contaminant and result in a reduction of contaminant mass contributing to the downgradient groundwater plume.

Investigation data also indicate that TCE is being degraded by naturally occurring bacteria (via reductive dechlorination) to transformation products (1,2-DCE and vinyl chloride). Because of the degree to which TCE is being naturally degraded, a technology that further stimulates the natural processes should effectively treat the concentrations of dissolved-phase contaminants in the TTZs. The existing subsurface geology, geochemical conditions, contaminants, and the magnitude of concentrations detected in the onsite groundwater make in situ treatment an effective groundwater alternative. The naturally occurring process can be further enhanced using enhanced in situ biodegradation (EISB) or in situ chemical reduction (ISCR). Amendments were evaluated to identify substrate(s) to be used in the pilot test that would enhance the existing reducing and microbiological conditions.

It should be noted that while in situ biodegradation methods have been found to be effective for reducing dissolved phase contamination, they have not yet been shown to be highly effective for directly remediating NAPL. Recent research has demonstrated that when in situ biodegradation methods are optimally applied to a DNAPL source zone, these methods reduce the dissolved phase concentrations and indirectly reduce the longevity of NAPL source zones by accelerating the dissolution of the NAPL into the groundwater. More active alternatives such as extraction, in situ thermal treatment, and soil mixing, are more effective for direct remediation of NAPL.

The presence of DNAPL outside the building in the eastern portion of TTZ 2 requires more active remedial alternatives than EISB or ISCR. To optimize the mass of contaminants treated, active DNAPL remediation technologies were screened to retain those with low operation and maintenance costs in addition to low infrastructure (electricity, capital equipment) requirements, while providing effective treatment of the DNAPL. Based on the alternative screening, in situ soil mixing using a chemical reducing agent was selected to target the DNAPL in TTZ 2.

Based on the TTZs and the recommended remedial technologies, the objectives for the pilot test are to:

1) Evaluate the degree to which in situ treatment can reduce the concentrations of TCE and daughter products (cis-1,2 DCE and VC) in the target treatment areas and downgradient monitoring locations

2) Determine the overall effectiveness of in situ treatment for achieving complete reduction of TCE to non-toxic degradation products (such as ethane or ethane)

3) Monitor the duration that the injected substrates can maintain enhanced, relative to background, reducing conditions for in situ treatment

4) Determine the radius of influence of the selected injection method

5) Reduce the mass of DNAPL, to the extent practicable, and mass flux of dissolved phase contamination from any remaining DNAPL

Description of Amendments Evaluated

Groundwater conditions including, but not limited to, dissolved oxygen and oxygen-reduction potential (ORP) are indicative of and favorable for anaerobic biodegradation; therefore, alternatives that would enhance the existing conditions were evaluated. The following sections provide a brief description of the pilot test alternatives, general approach, and procedures to be employed for achieving in situ treatment in the TTZ(s).

Soluble Substrate

For anaerobic biodegradation to be successful, adequate quantities of electron donor, bioavailable carbon, and nutrients must be in contact with the active microbial consortia and the target contaminants. The dechlorination process involves the replacement of chlorine atoms from the contaminant with hydrogen atoms. In natural anaerobic systems, hydrogen is the most common electron donor, released by the anaerobic fermentation of the organic carbon. Anaerobic processes can be enhanced by the addition of chemicals that stimulate

release of hydrogen gas to the microbial consortia in the TTZ. The injection of soluble substrates stimulates the enhanced reductive dechlorination process as the substrate ferments; it releases hydrogen gas, which is used as the electron donor by the microbes.

A number of soluble substrates are available including lactate, whey, molasses and corn syrup. These substrates are nearly 100 percent soluble when dissolved in water. The resulting solution can be delivered to the subsurface by injection using permanent injection wells. The solution can be distributed over a large radius because there are no insoluble particles to become "clogged" in the well screen filter pack, and/or pore spaces as there would be with an insoluble material such as ZVI. The "clogging" of aquifer pore spaces reduces the effective porosity of the aquifer and may alter the groundwater flow in the treatment area. The injection of lactate as a soluble substrate for EISB has been successful at multiple sites; therefore, lactate was used to develop injection parameters and costs for this evaluation.

Edible Oil Substrate (EOS™)

Another electron donor similar to the soluble substrates is EOS™. EOS™ is a patented emulsified oil product that consists primarily of emulsified soybean oil with lesser amounts of lactate and micronutrients. Following injection, the vegetable oil dissolves into groundwater over time, biodegrades to volatile fatty acids, and releases hydrogen to support biological reductive dechlorination of the CVOCs.

EHC™

EHC™ is a patented combination of controlled-release carbon and ZVI used for stimulating reductive dechlorination of CVOC in groundwater by a combination of EISB and ISCR. EHC is a solid material that can be injected as a slurry into the saturated zones of contaminated aquifers. The ZVI causes a decrease in the ORP and results in chemical reduction of the CVOCs. In addition, the indigenous bacteria ferment the carbon and release a variety of fatty acids which serve as electron donors for fermentative bacteria.

Because it contains ZVI, EHC is most frequently injected using pneumatic fracturing or other delivery methods, rather than being injected in a liquid form. The need for an alternate delivery method or a greater number of injection wells for EHC results in a considerably greater cost to create a similar treatment zone as soluble substrates or emulsified vegetable oils (EVO).

Zero Valent Iron

ZVI or elemental iron (Fe_0) is a strong reducing agent that is capable of abiotically dehalogenating several common chlorinated solvents (e.g., TCE) by ISCR. Granular ZVI has been used in permeable reactive barriers for groundwater treatment for many years. The granular ZVI used in permeable barrier applications typically consists of iron particles in the size range of −8+50 mesh, which makes the ZVI barrier more permeable than the surrounding aquifer.

An emerging technology based on ZVI is the use of nanoscale or micronscale zero-valent iron for source zone, rather than plume treatment. The finer particles are much more reactive than granular ZVI and have the potential to quickly treat the higher concentrations

of CVOC present in source zones. The finer ZVI particle size is similar to the pore size of the soil allowing the ZVI to be emplaced by injection.

As noted with EHC, injection methods for ZVI may be significantly different and more expensive than for soluble substrates or EVO, due to the need for alternate delivery methods or a greater number of injection points. The alternative delivery methods and close spacing required for delivery of EHC and/or ZVI make ISCR implementation cost prohibitive for this pilot test; however, ISCR will be evaluated as a full-scale remedial alternative in the feasibility study.

EISB Implementation

The enhanced anaerobic biodegradation pilot test implementation will involve the injection of the selected amendment into the shallow and deep intervals of the aquifer. Each material presented would require an aqueous solution be prepared onsite and injected into a series of closely spaced, 2-inch-diameter injection wells. Permanent injection wells, rather than direct push locations, will be installed to allow for future injections. Spacing for the installation of the injection wells is a function of the amendment being added (particle size, viscosity) and achievable injection rate. Injection parameters for each of the amendments were developed and are presented in Tables 1 through 3.

The proposed pilot test will consist of the following field activities:

1) Injection well and monitoring well installation (including baseline sampling and analysis)
2) Injection of amendment
3) Post-injection performance monitoring
4) *Follow-up injections, as needed*

Injection Well and Monitoring Well Installation

Permanent injection wells will be installed in a barrier configuration to use natural advective transport as the mechanism to bring dissolved contaminants into contact with the amendments and be reductively dechlorinated. The injection wells will be placed in a line perpendicular to the groundwater flow for each TTZ. It is expected that only a portion of the contaminant mass will be treated within the injection area and that treatment will continue as the contaminant mass is transported beyond the injection area through the TTZ. The spacing between lines of injection wells was based on an estimated travel time of 2 years for the shallow wells and 3 years for the deep wells. Because of the slower groundwater velocity and higher concentrations of contaminants observed in the deep zone, more injection wells will be installed in the deep zone compared with the shallow zone. The proposed permanent injection wells to be installed within each of the five TTZs are described in Tables 1 through 4. Monitoring wells will also be installed in the TTZs to allow performance monitoring of the EISB pilot study. The approximate locations for injection wells, shallow/deep monitoring well nests, and existing locations to be used for monitoring during the pilot test for each TTZ are shown in Figures 6 through 10.

TABLE 1
Summary of Lactate Injection Parameters and Cost
OMC Plant 2

Area	Treatment Depth[a]	Injection Well Spacing (ft)	Number of Injection Wells Per Barrier	Barrier Spacing (ft)	Number of Barriers	Total Number of Wells	Substrate Per Injection Event (lbs)	Injection Volume Per Well (gal)	Number of Re-Injection Events[b]	Cost	Total Cost
Area 1	Deep	20	5	30	6	30	2,089	1,997	13	$ 145,871	$ 183,051
	Shallow	27.5	4	90	2	8	527	1,888	20	$ 37,180	
Area 2	Deep	17.5	12	30	7	84	4,478	1,529	13	$ 362,827	$ 474,307
	Shallow	27.5	8	90	3	24	1,580	1,888	20	$ 111,480	
Area 3	Deep	20	11	30	5	55	3,829	1,997	13	$ 266,674	$ 340,994
	Shallow	27.5	8	90	2	16	1,053	1,888	20	$ 74,320	
Area 4	Deep	20	6	30	4	24	1,671	1,997	13	$ 117,157	$ 156,965
	Shallow	30	4	95	2	8	627	2,247	18	$ 39,808	
Area 5	Deep	22.5	8	30	6	48	4,230	2,528	13	$ 261,588	$ 322,812
	Shallow	30	6	90	2	12	940	2,247	18	$ 61,224	

[a]Depths refer to:
Shallow = injection wells installed to a depth of about 15 feet
Deep = injection wells installed to a depth of about 30 feet
[b]Number of injection events to achieve remedial action objectives

TABLE 2
Summary of EOS Injection Parameters and Cost
OMC Plant 2

Area	Treatment Depth[a]	Injection Well Spacing (ft)	Number of Injection Wells Per Barrier	Barrier Spacing (ft)	Number of Barriers	Total Number of Wells	Substrate Per Injection Event (lbs)	Injection Volume Per Well (gal)		Cost[b]	Total Cost
Area 1	Deep	27.5	4	61	3	11	16,938	3,776	$	135,702	$ 156,373
	Shallow	20	5	283	1	5	2,156	999	$	20,671	
Area 2	Deep	25	9	59	4	34	46,322	3,121	$	380,145	$ 428,048
	Shallow	30	7	293	1	7	5,989	2,247	$	47,903	
Area 3	Deep	27.5	8	61	3	24	35,869	3,776	$	289,554	$ 338,062
	Shallow	20	11	283	1	11	5,369	999	$	48,508	
Area 4	Deep	30	4	64	2	8	17,355	4,494	$	129,945	$ 170,299
	Shallow	20	6	283	1	6	3,396	999	$	40,354	
Area 5	Deep	22.5	8	56	3	24	26,558	2,528	$	229,548	$ 274,900
	Shallow	22.5	8	286	1	8	4,396	1,264	$	45,352	

[a]Depths refer to:
Shallow = injection wells installed to a depth of about 15 feet
Deep = injection wells installed to a depth of about 30 feet
[b]Cost revised to reflect 3 injections of EOS. Cost calculated using 3x substrate and injection costs plus injection well installation cost.

TABLE 3
Summary of EHC Injection Parameters and Cost
OMC Plant 2

Area	Area (ft^2)	Volume[a] (ft^3)	Volume (cy)	Bulk Density[b] (lb/ft3)	Percentage of EHC by Soil Mass	Mass of EHC Required (lb)	Total Injection Volume (gal)	Cost of EHC[c]
Area 1	18,649	559,479	20,721	90	0.4%	201,412	57,546	$ 362,542
Area 2	44,536	1,336,068	49,484	91	0.1%	121,582	34,738	$ 218,848
Area 3	34,784	1,043,522	38,649	102	0.4%	425,757	121,645	$ 766,362
Area 4	17,532	525,954	19,480	118	0.4%	248,250	70,929	$ 446,850
Area 5	31,182	935,473	34,647	91	0.2%	170,256	48,645	$ 306,461

[a]Based on an assumed target thickness of 30' ft
[b]Based on maximum observed in area
[c]Based on an estimated cost of $1.80/lb. Does not include delivery.

Area	Well Spacing (ft)	Number of Wells Per Barrier	Barrier Spacing (ft)	Number of Barriers	Total Number of Wells[a]	Injection Volume Per Well (gal)	Water Volume (gal)	Total Cost[b]
Area 1	20	5	20	9	45	1,279	44,850	$ 524,652
Area 2	20	11	20	11	121	287	27,074	$ 649,353
Area 3	10	22	50	3	66	1,843	94,807	$ 1,005,797
Area 4	10	12	50	3	36	1,970	55,280	$ 577,656
Area 5	10	18	50	4	72	676	37,912	$ 563,886

[a]Assumed that half the wells will be installed in the shallow zone and half in the deeper zone
[b]Based on the following assumptions:
Pumping rate of 10 gpm/well
Capacity to pump 8 well at a time
$1,725/day for labor and expenses for a 8 hr work day for two people

Monitoring and injection wells constructed for the pilot test will be installed using hollow-stem auger drilling methods. The construction details for the shallow and deep locations are shown in Figure 11 and 12, respectively. The wells will be constructed using flush-thread, 2-inch-diameter PVC risers with stainless-steel, continuous wire-wrapped screens. All newly installed wells will be developed prior to the injection. Wells will be developed by alternately surging and purging with a surge block and/or submersible pump. Injection wells and monitoring wells will be developed in accordance with development procedures presented in the Field Sampling Plan (CH2M HILL, 2004).

Prior to pilot study implementation, groundwater samples will be collected from the existing monitoring wells at the site, in addition to the new monitoring wells installed as part of the pilot study, to establish baseline groundwater conditions. Groundwater samples will be analyzed for the same parameters selected to monitor the performance of the EISB pilot study.

Amendment Injection

Target EISB amendment injection concentrations were developed using site-specific groundwater VOC concentrations along with hydrogeologic data, geochemical data, and subsurface biological data. The target EISB amendment concentrations are designed to achieve and sustain conditions favorable to EISB.

The selected EISB amendment will be combined with water to form a solution that will be injected directly into the injection wells using a pump and manifold system. The solution (or emulsion in the case of EOS) will be pumped into a manifold capable of injecting into as many as eight injection locations simultaneously.

Post-Injection Monitoring

Following the initial injection, groundwater sampling events will be conducted to quantify changes in groundwater geochemistry and contaminant concentrations. Groundwater samples will be collected using low-flow purge techniques and on the approximate schedule shown in Table 4. The timeline for sampling is estimated and may be modified based on the results of prior sampling events or field observations.

The primary performance monitoring events shown in Table 4 will include analyses of all parameters listed in Table 5. The secondary performance monitoring events will only include analyses for field parameters (ORP, pH, dissolved oxygen, temperature, turbidity, and conductivity) and total organic carbon. Field parameters will be collected during well purging using field instruments. Visual indications of substrate migration (color) will also be noted. The rationale for selection of each parameters selected is also presented in Table 5.

TABLE 4
Approximate Sampling Schedule for Post-Injection Performance Monitoring

Sampling Event	Number of Days Post-Injection
Injection	0
Secondary Monitoring	30
Secondary Monitoring	60
Primary Monitoring	90
Secondary Monitoring	120
Secondary Monitoring	150
Primary Monitoring	180

TABLE 5
List of EISB Post-Injection Sampling and Monitoring Parameters

Parameter	Method	Reason for Monitoring
Water Level	Field measurement, taken using a water level indicator.	Provides quantitative indication that injection fluids are reaching the monitoring well. Also used to determine the well volume for well purging.
Turbidity	Field Measurement	Typically used for well purge stabilization parameter.
Temperature	Field measurement.	Typically used for well purge stabilization parameter.
Specific Conductance	Field Measurement	Typically used for well purge stabilization parameter.
Oxygen Reduction Potential	Field Measurement	To assess the degree to which the injection is enhancing the reducing conditions and whether groundwater conditions are optimal for biodegradation (ORP values less than -100 mV).
Dissolved Oxygen	Field Measurement	To assess the degree to which the injection is enhancing the reducing conditions and whether groundwater conditions are optimal for biodegradation (DO values less than 0.5 mg/L).
pH	Field Measurement	To assess the degree to which the injection is enhancing the reducing conditions. Ideal range for dechlorination bacteria is 5 to 9. Also, well purge stabilization parameter.
Alkalinity	SM 2320-B or EPA 300 Series	Indicator of biodegradation and the buffering capacity of the aquifer.
Nitrate	SW9056 or EPA 300 Series	Nitrate is an alternate electron acceptor for microbial respiration in the absence of oxygen. Nitrate levels less than 1.0 mg/L are desirable for anaerobic dechlorination.
VOCs	SW 846-8260B	The chemicals of concern. A decrease in concentration of parent compounds will provide a direct indication that the oxidation reactions are being effective.
Chloride	SW 846-9056	Chloride ions are produced by anaerobic dechlorination and may be used as a secondary indication of the occurrence of reactions.
Ferrous Iron	Field measurement	Ferric iron is an alternate electron acceptor for microbial respiration in the absence of oxygen and nitrate; ferrous iron is produced by the reduction of ferric iron. This analysis provides information about the degree to which iron reduction processes are occurring in the aquifer.
Dissolved manganese	SW846 6010B	Dissolved manganese (Mn2+) is produced by the reduction of Mn4+ in a process similar to iron reduction. This analysis provides information about the degree to which manganese reduction processes are occurring in the aquifer.
Sulfate	EPA 300 Series	Sulfate is an alternate electron acceptor for microbial respiration in the absence of oxygen, nitrate, and ferric iron. Sulfate levels less than 20 mg/L are desirable, but not required, for anaerobic

TABLE 5
List of EISB Post-Injection Sampling and Monitoring Parameters

Parameter	Method	Reason for Monitoring
		dechlorination.
Sulfide	EPA 300 Series	Sulfide is produced during reduction of sulfate, Its presence indicates that sulfate reduction is occurring.
Methane/Ethane/ Ethene	RSK 175	Methane, ethane, and ethene are the final byproducts of reductive dechlorination of chlorinated solvents.
Volatile Fatty Acids (VFAs)	Ion chromatography	VFAs are produced as the microbial community ferments the EISB amendments, providing evidence of enhanced biological activity.
Total Organic Carbon (TOC)	SW 9060 or EPA 400 Series	Indicator of the natural organic carbon present at the site during baseline sampling and as an indicator of the substrate distribution during performance monitoring.

Evaluation and Recommendation

In order to evaluate the potential costs for injecting the EISB amendment and materials that could be used for the pilot test, CH2M HILL prepared order of magnitude cost estimates for several different scenarios.

Cost estimates were prepared using unit costs from remedial investigation (RI) activities for drilling and labor and from material vendors for injection material and ancillary equipment (pumps, piping, etc). The level of effort (LOE) necessary to implement the pilot study was estimated based on the LOE utilized during the RI investigation and the preliminary pilot study design. Material quantities, injection volumes, injection rates, and injection design are based on the site conceptual model developed as part of the RI. For the EISB injection, amendment volumes, injection well spacing, re-injection frequency, and injection concentration were evaluated to determine the lowest-cost design alternative while optimizing the treatment to achieve 95 percent (or greater) contaminant mass reduction in each source zone.

The estimated costs prepared using this approach are considered order-of-magnitude (+50, -25%) and are considered suitable for comparing alternatives. Actual cost to implement any particular technology will, however, vary somewhat from the estimated costs, depending on actual site conditions, actual bids received for the work from subcontractors, and a variety of other factors.

A summary of the estimated EISB costs is presented in Table 6. Based on the assumptions used in the estimating process, injection of EOS and/or lactate provide the

TABLE 6
Summary of EISB Cost Alternatives
OMC Plant 2

Area	Lactate	EOS	EHC
Area 1	$ 183,051	$ 156,373	$ 524,652
Area 2	$ 474,307	$ 428,048	$ 649,353
Area 3	$ 340,994	$ 338,062	$ 1,005,797
Area 4	$ 156,965	$ 170,299	$ 577,656
Area 5	$ 322,812	$ 274,900	$ 563,886

[a] Costs do not include installation of additional monitoring wells.

most cost-effective alternative(s) for the groundwater remediation pilot test; however, EISB effectiveness for treatment of residual DNAPL is limited. Based on site-specific data and EISB experience, CH2M HILL recommends the use of both lactate and EOS as the EISB amendment at OMC Plant 2 to determine the most effective amendment. A more active remediation technology is, however, recommended to address the DNAPL in TTZ 2.

Soil Mixing

In situ soil mixing (SSM) uses a large-diameter (typically 3- to 12-foot-diameter) auger with mixing paddles and grout ports to "drill" into the ground as a fluid grout is pumped through the shaft. The fluid acts as an aid to drilling and is mixed into the drilled soil column. Initial SSM applications generated a soil-cement mass to create structural elements for foundations and retaining walls, and soil improvement. More recently, SSM has been used with specialized cementing and chemical reagents for hazardous waste treatment, solidification/stabilization, and for constructing underground vertical barriers for groundwater containment.

In hazardous waste treatment applications, conventional soil mixing equipment is used to mix reactive media (e.g., zero valent iron) and stabilizing agents (e.g., clay) with contaminated soil. Through mixing, heterogeneous subsurface source zones are transformed into uniform bodies of soils, contaminants, reactive media, and stabilizing agents. Within the treated interval, reactive media drives contaminant degradation while stabilizing agents reduce the hydraulic conductivity. The combination of soil-mixing with amendments achieves both containment and source depletion.

Soil Mixing Implementation

A soil mixing alternative was developed for a portion of area 2 known to contain TCE DNAPL and located outside the building. The in situ soils would be mixed with a combination of ZVI and bentonite clay. This mixture provides chemical reduction of the TCE DNAPL via the ZVI, while the bentonite component reduces groundwater flow through the treated area and reduces the mass flux of dissolved phase contaminants. Near ground surface, approximately 3 percent concrete would be added to the mixture to provide a stable ground surface.

The soil mixing will be performed in a pattern resembling a series of overlapping vertical columns. The large-diameter auger will be advanced to the base of the aquifer, at which time injection of the selected amendment through nozzles on the auger blades will begin. To focus on DNAPL treatment, the amendments will be added primarily to the soil in the bottom 10 feet of the aquifer.

To optimize the treatment of the DNAPL in TTZ 2, the DNAPL extent must be accurately defined.

DNAPL Area Investigation

Prior to the start of soil mixing activities, a focused investigation would be performed to delineate the extent and thickness of the DNAPL in area 2. This investigation will include the collection of groundwater grab samples from the base of the aquifer. The grab samples would be collected from 8 points at a 25-foot radius from the soil boring location (SO-057)

where DNAPL was detected during the RI. The samples will be examined for visual indications of DNAPL; no samples will be sent for laboratory analysis. Soil samples will also be collected following the layout for groundwater grab samples. Soil samples will be examined for visual evidence of residual DNAPL. Based on the visual evidence found at a 25-foot radius, the radius of subsequent sets of 8 groundwater grab samples will be increased or decreased at 10-foot increments.

Soil Mixing

After determining the extent of the DNAPL, the area will be marked and, based on the extent of the DNAPL, additional monitoring wells may be installed. The additional monitoring wells will be sampled to determine pretreatment groundwater conditions, and will be sampled after mixing to monitor any changes in groundwater conditions resulting from the soil mixing. After monitoring well installation and sampling is completed, the soil mixing equipment will be mobilized to the site. The soil mixing equipment will include a crane, large-diameter augers, support equipment, batch mixing equipment, and an injection pump.

Post-Soil Mixing Performance Monitoring

During and following the completion of mixing activities, confirmation sampling will be conducted to quantify homogeneous amendment distribution throughout the mixing zone, concentrations of the amendment in the mixing zone, changes in groundwater geochemistry, and changes in contaminant concentrations. Soil samples will be collected from within the mixing zone and around the perimeter. Groundwater samples will be collected using low-flow purge techniques from the existing and/or newly installed monitoring wells in the vicinity of the mixing zone. Post-treatment sampling will be designed to monitor for any increasing dissolved phase concentrations or changes in groundwater conditions resulting from disturbance of the DNAPL. Table 7 presents a summary of the performance confirmation sampling parameters.

TABLE 7
List of Soil Mixing Performance Sampling and Monitoring Parameters

Parameter	Method	Reason for Monitoring
Water Level	Field measurement, taken using a water level indicator.	Provides quantitative indication that injection fluids are reaching the monitoring well. Also used to determine the well volume for well purging.
Turbidity	Field measurement	Typically used for well purge stabilization parameter.
Temperature	Field measurement.	Typically used for well purge stabilization parameter.
Specific Conductance	Field measurement	Typically used for well purge stabilization parameter.
Oxygen Reduction Potential	Field measurement	To assess the degree to which the mixing is enhancing the reducing conditions and whether groundwater conditions are optimal for biodegradation (ORP values less than -100 mV).
Dissolved Oxygen	Field measurement	To assess the degree to which the mixing is enhancing the reducing conditions and whether groundwater conditions are optimal for biodegradation (DO values less than 0.5 mg/L).

TABLE 7
List of Soil Mixing Performance Sampling and Monitoring Parameters

Parameter	Method	Reason for Monitoring
pH	Field measurement	To assess the degree to which the mixing is enhancing the reducing conditions. Ideal range for dechlorination bacteria is 5 to 9. Also well purge stabilization parameter.
VOCs	SW 846-8260B	The chemicals of concern. A decrease in concentration of parent compounds will provide a direct indication that the oxidation reactions are being effective.
Chloride	SW 846-9056	Chloride ions are produced by anaerobic dechlorination and may be used as secondary indication of the occurrence of reactions.
Total Iron	Field measurement	Soil samples will be collected to confirm the target ratio of iron.

Soil Mixing Recommendation

Soil mixing is an effective technology for treatment of mobile DNAPL in area 2. Soil mixing is not a cost effective or feasible alternative for areas 1, 3, 4, or 5 because of relatively low (dissolved phase) concentrations of contaminants and/or access to the areas is restricted by the building. An estimated cost summary to perform soil mixing for a portion of area 2 is presented in Table 8.

TABLE 8
Summary of In situ Soil Mixing with ZVI Parameters and Cost
OMC Plant 2

Area	Area (ft^2)	Volume[a] (ft^3)	Volume (cy)	Bulk Density[b] (lb/ft^3)	Amount of Iron Required[c] (ton)	Cost of Fine Grain Iron[d]	In Situ Soil Mixing[e]	Total Cost
Area 2 (outside bldg)	2,500	75,000	2,778	91	34	$ 25,594	$ 180,556	$ 206,149

Costs to install a potable water line to the DNAPL are to support mixing of zvi/clay is not included.
[a]Based on an assumed target thickness of 30 ft.
[b]Based on maximum observed in area
[c]Based on a final iron percentage of 1% by soil mass
[d]Based on an estimated cost of $750/ton.
[e]Based on an estimated cost of $65/cy. Does not include site preparation and restoration, permitting, and license fee

Work Cited

CH2M HILL. 2004. *Field Sampling Plan. OMC Plant 2, Waukegan, Illinois. Remedial Investigation/Feasibility Study.* November.

TABLE 1
Summary of Lactate Injection Parameters and Cost
OMC Plant 2

Area	Treatment Depth[a]	Injection Well Spacing (ft)	Number of Injection Wells Per Barrier	Barrier Spacing (ft)	Number of Barriers	Total Number of Wells	Substrate Per Injection Event (lbs)	Injection Volume Per Well (gal)	Number of Re-Injection Events[b]	Cost	Total Cost
Area 1	Deep	20	5	30	6	30	2,089	1,997	13	$ 145,871	$ 183,051
	Shallow	27.5	4	90	2	8	527	1,888	20	$ 37,180	
Area 2	Deep	17.5	12	30	7	84	4,478	1,529	13	$ 362,827	$ 474,307
	Shallow	27.5	8	90	3	24	1,580	1,888	20	$ 111,480	
Area 3	Deep	20	11	30	5	55	3,829	1,997	13	$ 266,674	$ 340,994
	Shallow	27.5	8	90	2	16	1,053	1,888	20	$ 74,320	
Area 4	Deep	20	6	30	4	24	1,671	1,997	13	$ 117,157	$ 156,965
	Shallow	30	4	95	2	8	627	2,247	18	$ 39,808	
Area 5	Deep	22.5	8	30	6	48	4,230	2,528	13	$ 261,588	$ 322,812
	Shallow	30	6	90	2	12	940	2,247	18	$ 61,224	

[a]Depths refer to:
Shallow = injection wells installed to a depth of about 15 feet
Deep = injection wells installed to a depth of about 30 feet
[b]Number of injection events to achieve remedial action objectives

TABLE 2
Summary of EOS Injection Parameters and Cost
OMC Plant 2

Area	Treatment Depth[a]	Injection Well Spacing (ft)	Number of Injection Wells Per Barrier	Barrier Spacing (ft)	Number of Barriers	Total Number of Wells	Substrate Per Injection Event (lbs)	Injection Volume Per Well (gal)	Cost[b]	Total Cost
Area 1	Deep	27.5	4	61	3	11	16,938	3,776	$ 135,702	$ 156,373
	Shallow	20	5	283	1	5	2,156	999	$ 20,671	
Area 2	Deep	25	9	59	4	34	46,322	3,121	$ 380,145	$ 428,048
	Shallow	30	7	293	1	7	5,989	2,247	$ 47,903	
Area 3	Deep	27.5	8	61	3	24	35,869	3,776	$ 289,554	$ 338,062
	Shallow	20	11	283	1	11	5,369	999	$ 48,508	
Area 4	Deep	30	4	64	2	8	17,355	4,494	$ 129,945	$ 170,299
	Shallow	20	6	283	1	6	3,396	999	$ 40,354	
Area 5	Deep	22.5	8	56	3	24	26,558	2,528	$ 229,548	$ 274,900
	Shallow	22.5	8	286	1	8	4,396	1,264	$ 45,352	

[a]Depths refer to:
Shallow = injection wells installed to a depth of about 15 feet
Deep = injection wells installed to a depth of about 30 feet
[b]Cost revised to reflect 3 injections of EOS. Cost calculated using 3x substrate and injection costs plus injection well installation cost.

TABLE 3
Summary of EHC Injection Parameters and Cost
OMC Plant 2

Area	Area (ft2)	Volume[a] (ft3)	Volume (cy)	Bulk Density[b] (lb/ft3)	Percentage of EHC by Soil Mass	Mass of EHC Required (lb)	Total Injection Volume (gal)	Cost of EHC[c]
Area 1	18,649	559,479	20,721	90	0.4%	201,412	57,546	$ 362,542
Area 2	44,536	1,336,068	49,484	91	0.1%	121,582	34,738	$ 218,848
Area 3	34,784	1,043,522	38,649	102	0.4%	425,757	121,645	$ 766,362
Area 4	17,532	525,954	19,480	118	0.4%	248,250	70,929	$ 446,850
Area 5	31,182	935,473	34,647	91	0.2%	170,256	48,645	$ 306,461

[a]Based on an assumed target thickness of 30' ft
[b]Based on maximum observed in area
[c]Based on an estimated cost of $1.80/lb. Does not include delivery.

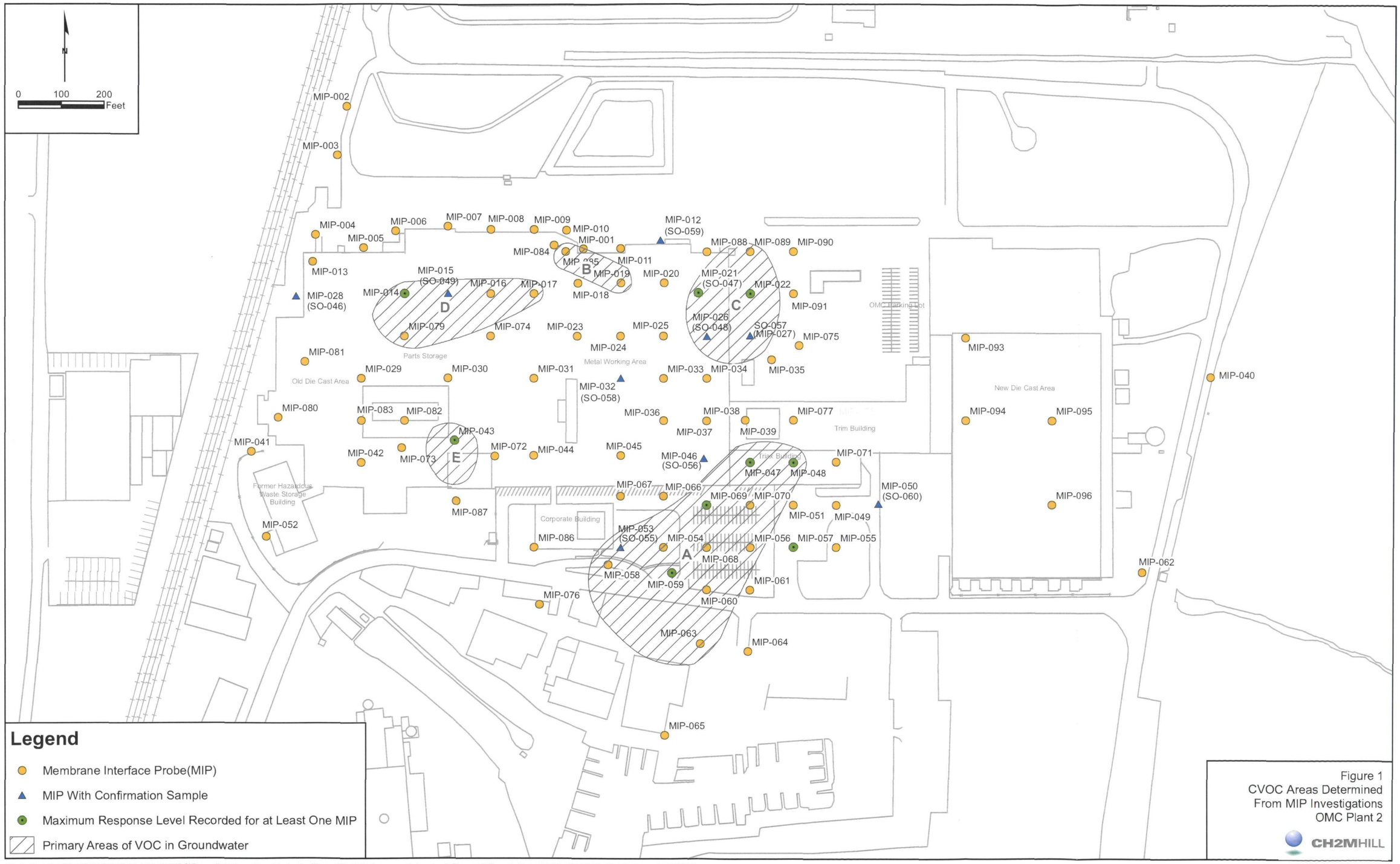
Area	Well Spacing (ft)	Number of Wells Per Barrier	Barrier Spacing (ft)	Number of Barriers	Total Number of Wells[a]	Injection Volume Per Well (gal)	Water Volume (gal)	Total Cost[b]
Area 1	20	5	20	9	45	1,279	44,850	$ 524,652
Area 2	20	11	20	11	121	287	27,074	$ 649,353
Area 3	10	22	50	3	66	1,843	94,807	$ 1,005,797
Area 4	10	12	50	3	36	1,970	55,280	$ 577,656
Area 5	10	18	50	4	72	676	37,912	$ 563,886

[a]Assumed that half the wells will be installed in the shallow zone and half in the deeper zone
[b]Based on the following assumptions:
Pumping rate of 10 gpm/well
Capacity to pump 8 well at a time
$1725/day for labor and expenses for a 8 hr work day for two people

TABLE 8
Summary of Insitu Soil Mixing with ZVI Parameters and Cost
OMC Plant 2

Area	Area (ft2)	Volume[a] (ft3)	Volume (cy)	Bulk Density[b] (lb/ft3)	Amount of Iron Required[c] (ton)	Cost of Fine Grain Iron[d]	In Situ Soil Mixing[e]	Total Cost
Area 2 (outside bldg)	2,500	75,000	2,778	91	34	$ 25,594	$ 180,556	$ 206,149

Costs to install a potable water line to the DNAPL are to support mixing of zvi/clay is not included.
[a]Based on an assumed target thickness of 30 ft.
[b]Based on maximum observed in area
[c]Based on a final iron percentage of 1% by soil mass
[d]Based on an estimated cost of $750/ton.
[e]Based on an estimated cost of $65/cy. Does not include site preparation and restoration, permitting, and license fee



Legend

- Membrane Interface Probe(MIP)
- MIP With Confirmation Sample
- Maximum Response Level Recorded for at Least One MIP
- Primary Areas of VOC in Groundwater

Figure 1
CVOC Areas Determined
From MIP Investigations
OMC Plant 2

CH2MHILL

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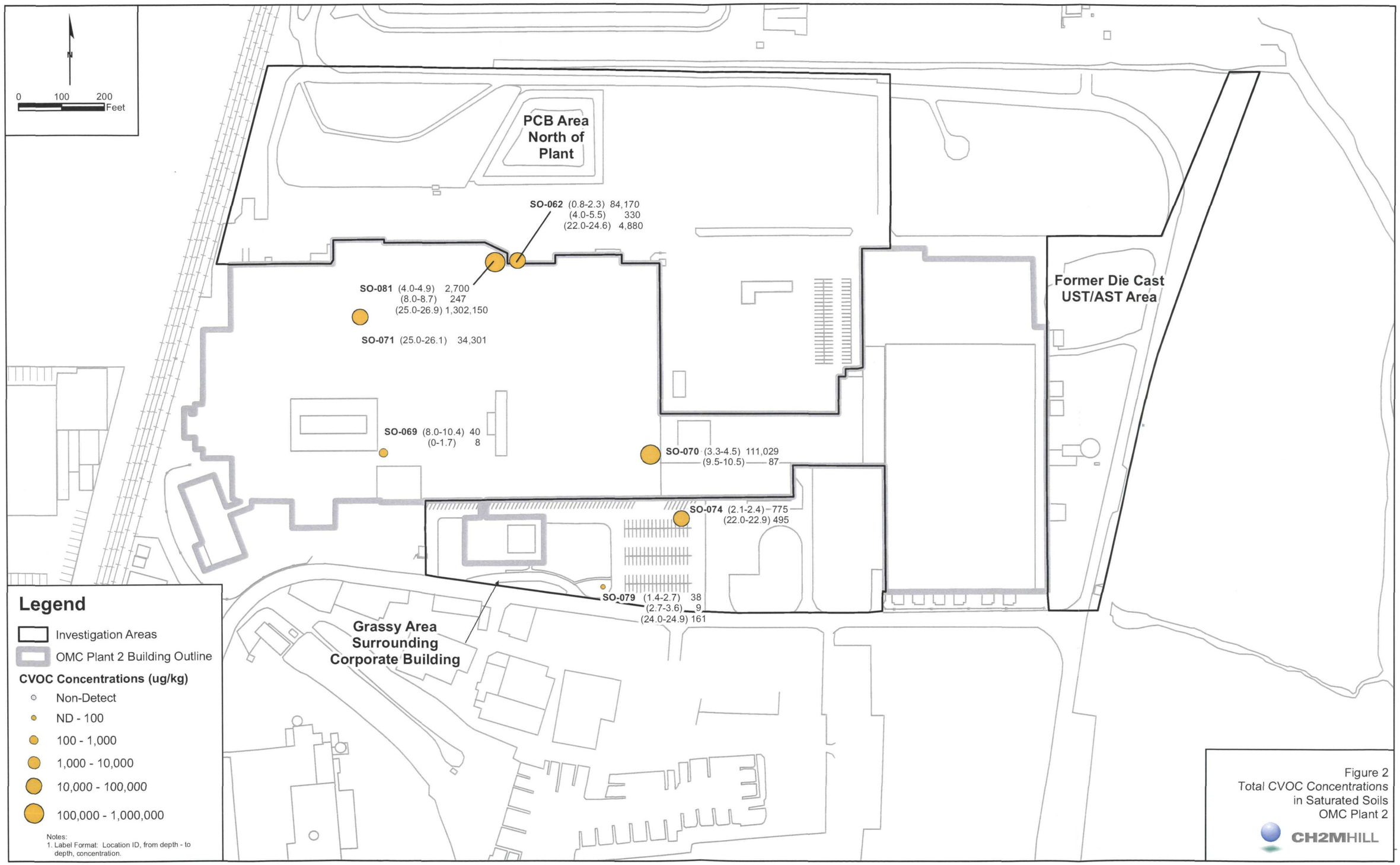

Figure 2
Total CVOC Concentrations in Saturated Soils
OMC Plant 2

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Figure 3
Shallow Groundwater TCE Concentrations
OMC Plant 2

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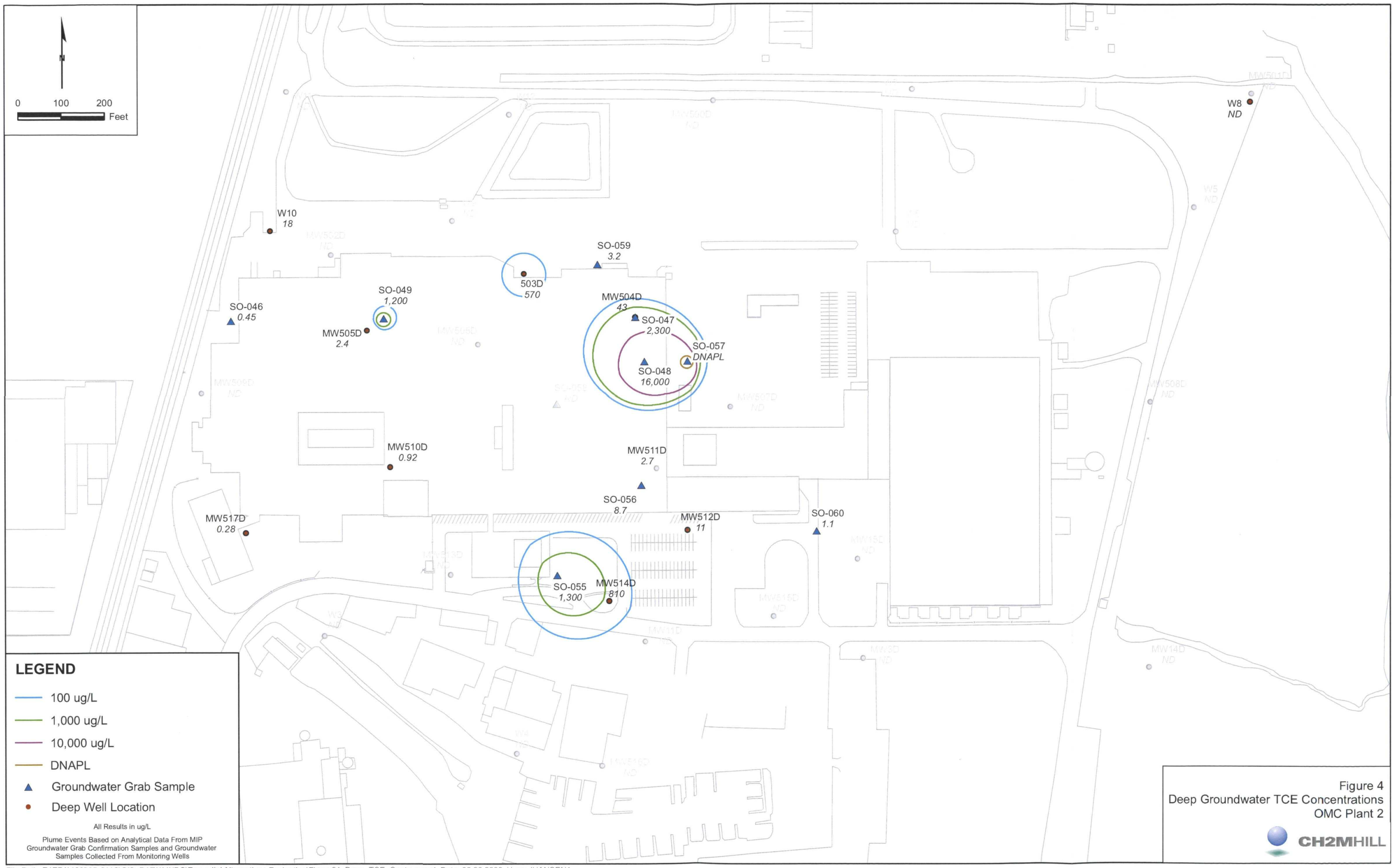

Figure 4
Deep Groundwater TCE Concentrations
OMC Plant 2

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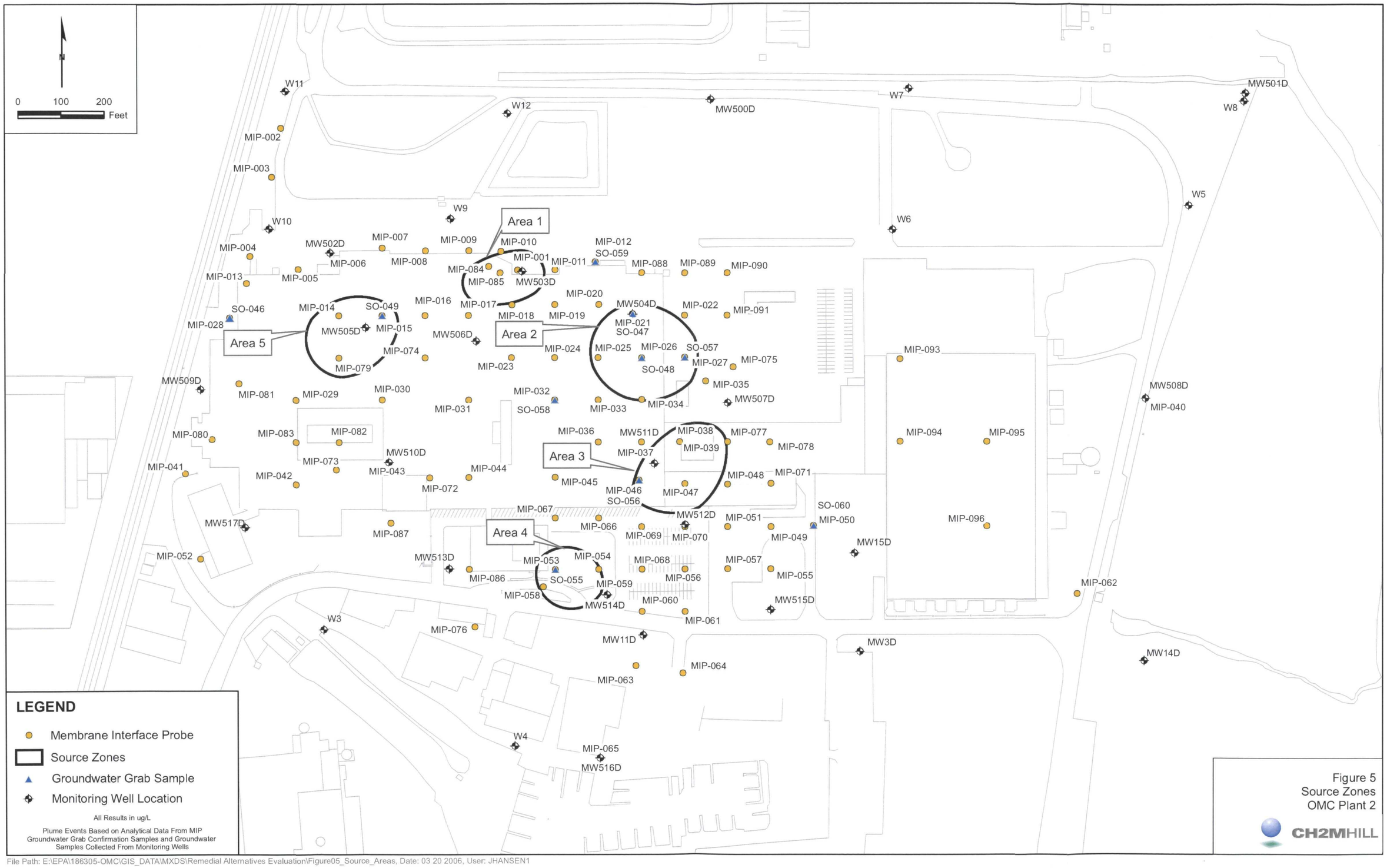

Figure 5
Source Zones
OMC Plant 2

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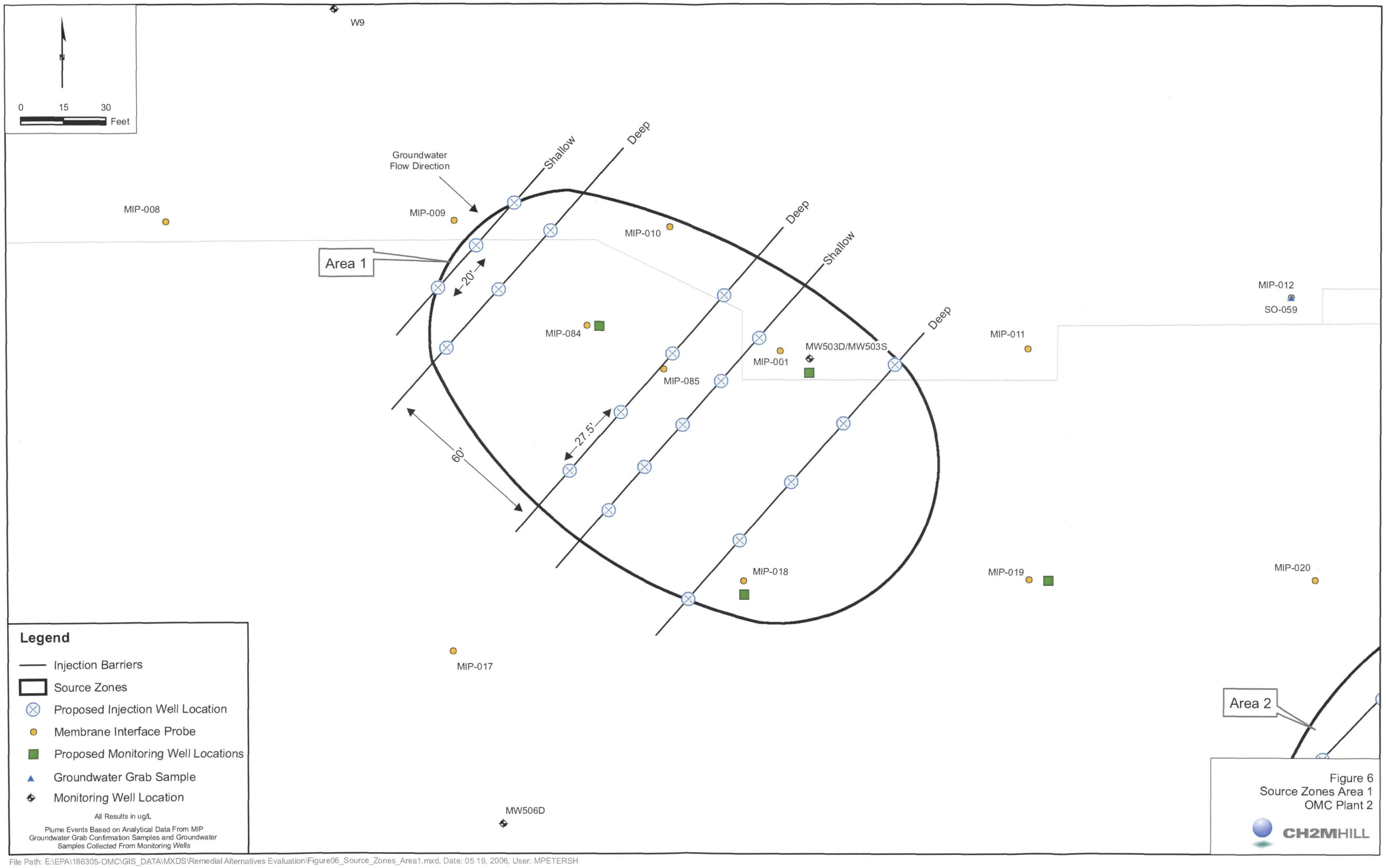

Figure 6
Source Zones Area 1
OMC Plant 2

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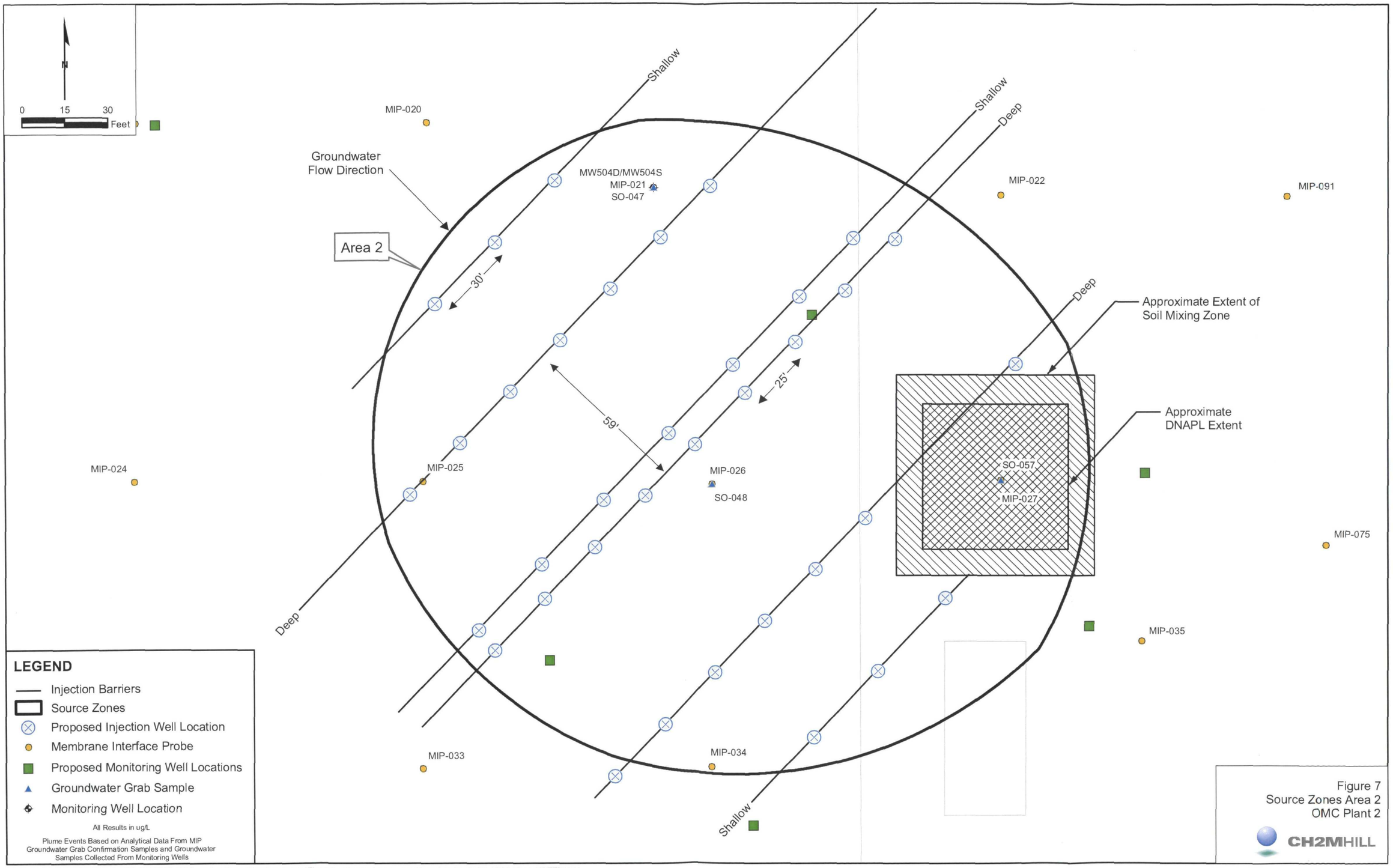

Figure 7
Source Zones Area 2
OMC Plant 2

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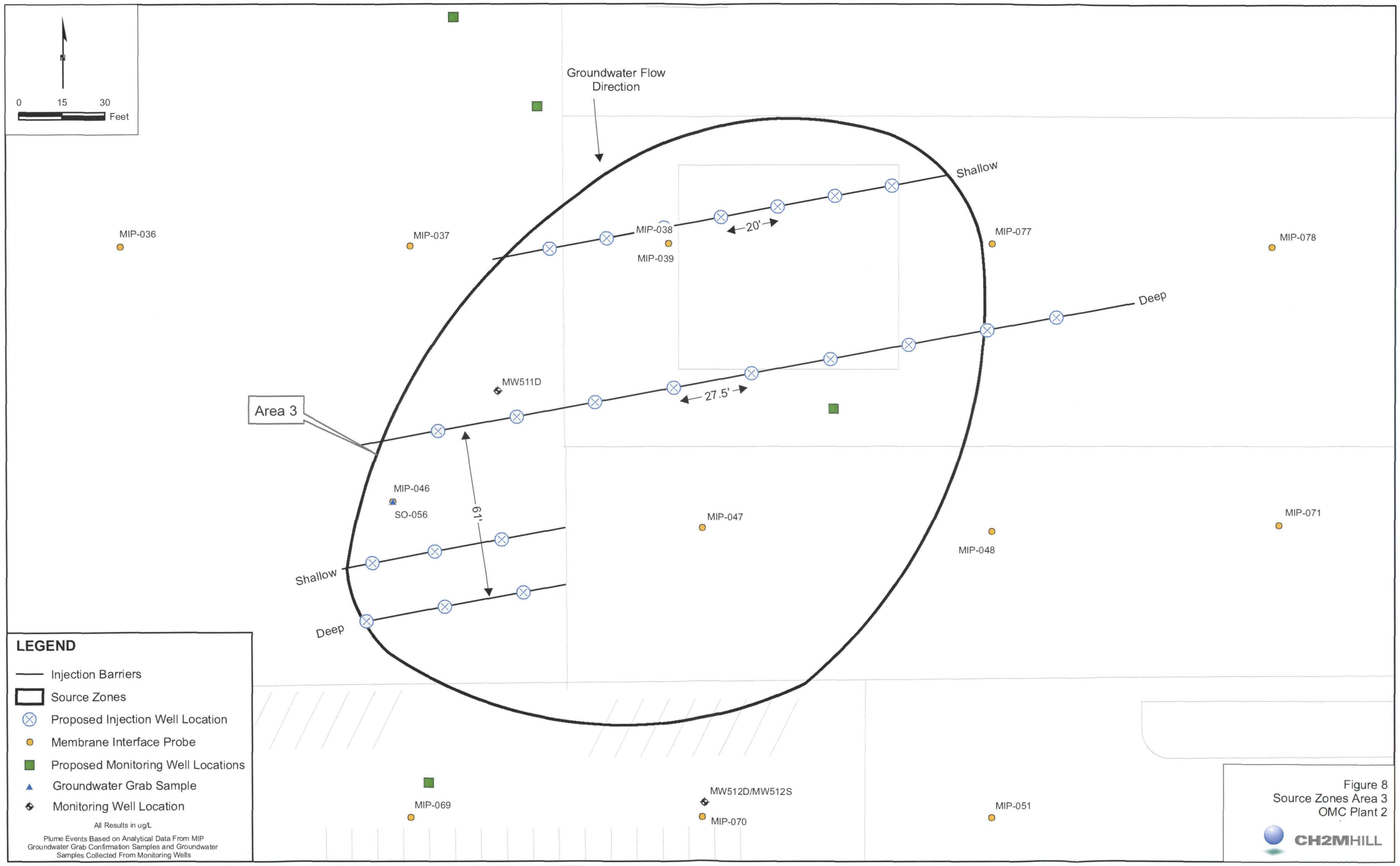

Figure 8
Source Zones Area 3
OMC Plant 2

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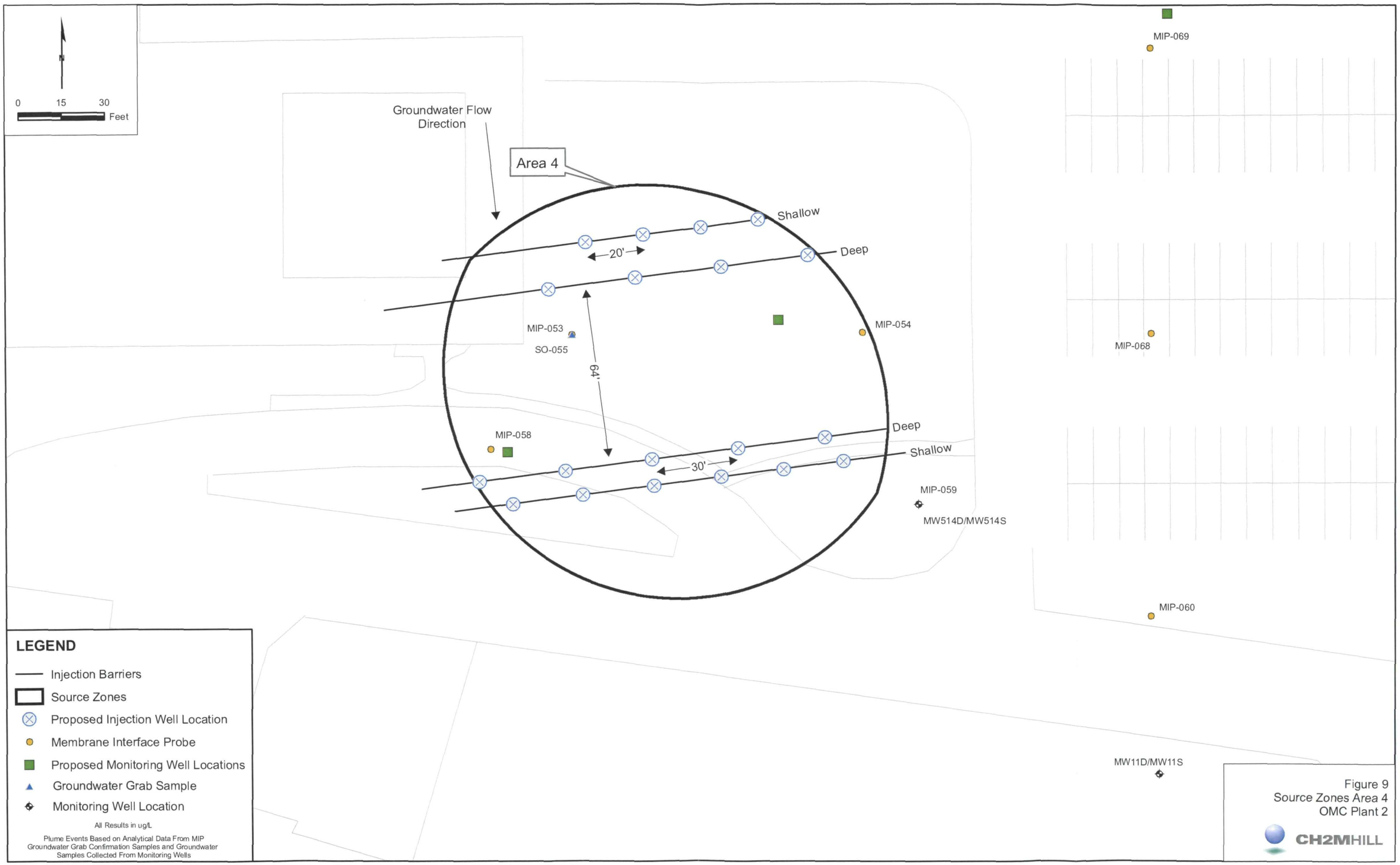

Figure 9
Source Zones Area 4
OMC Plant 2

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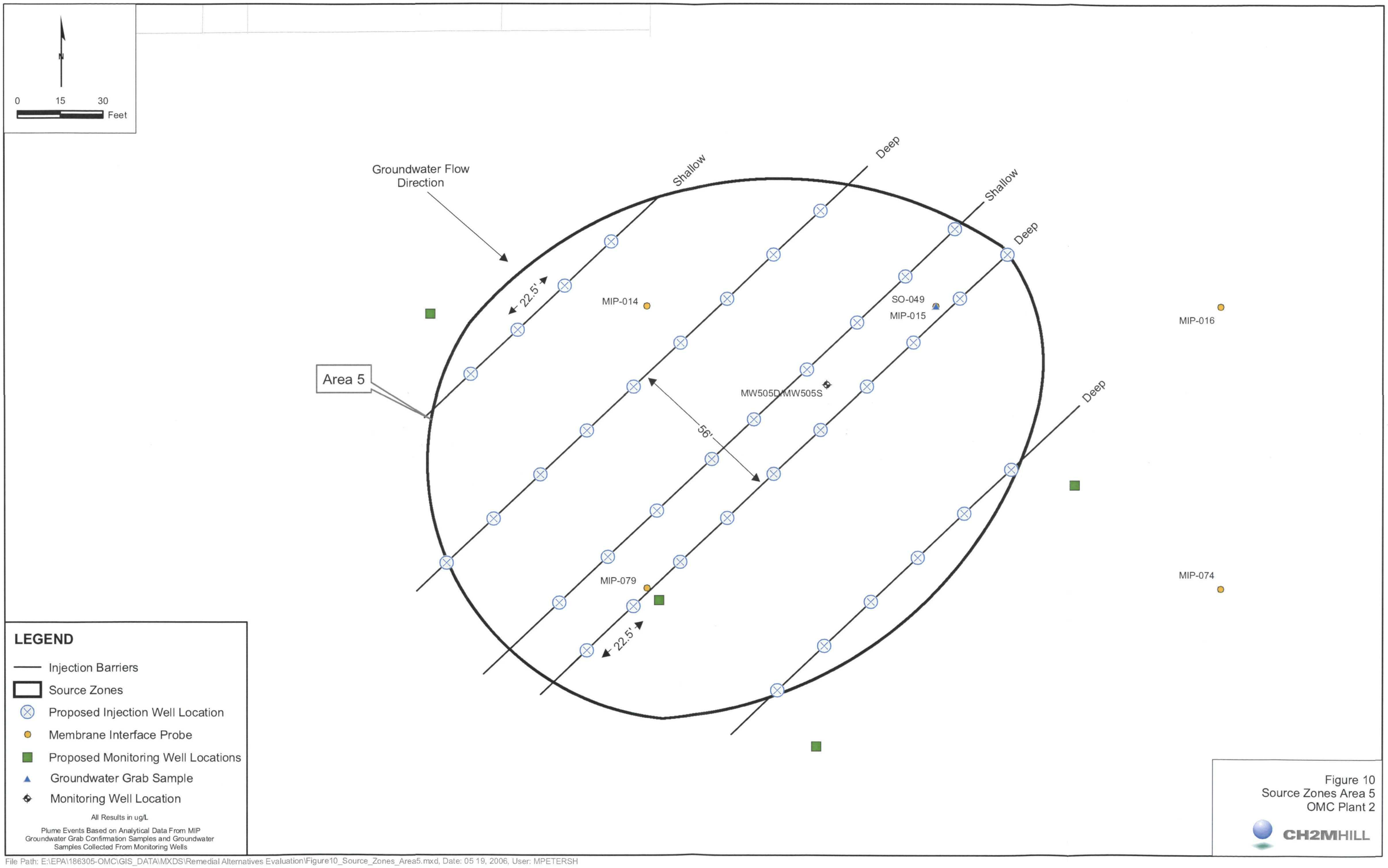

Figure 10
Source Zones Area 5
OMC Plant 2

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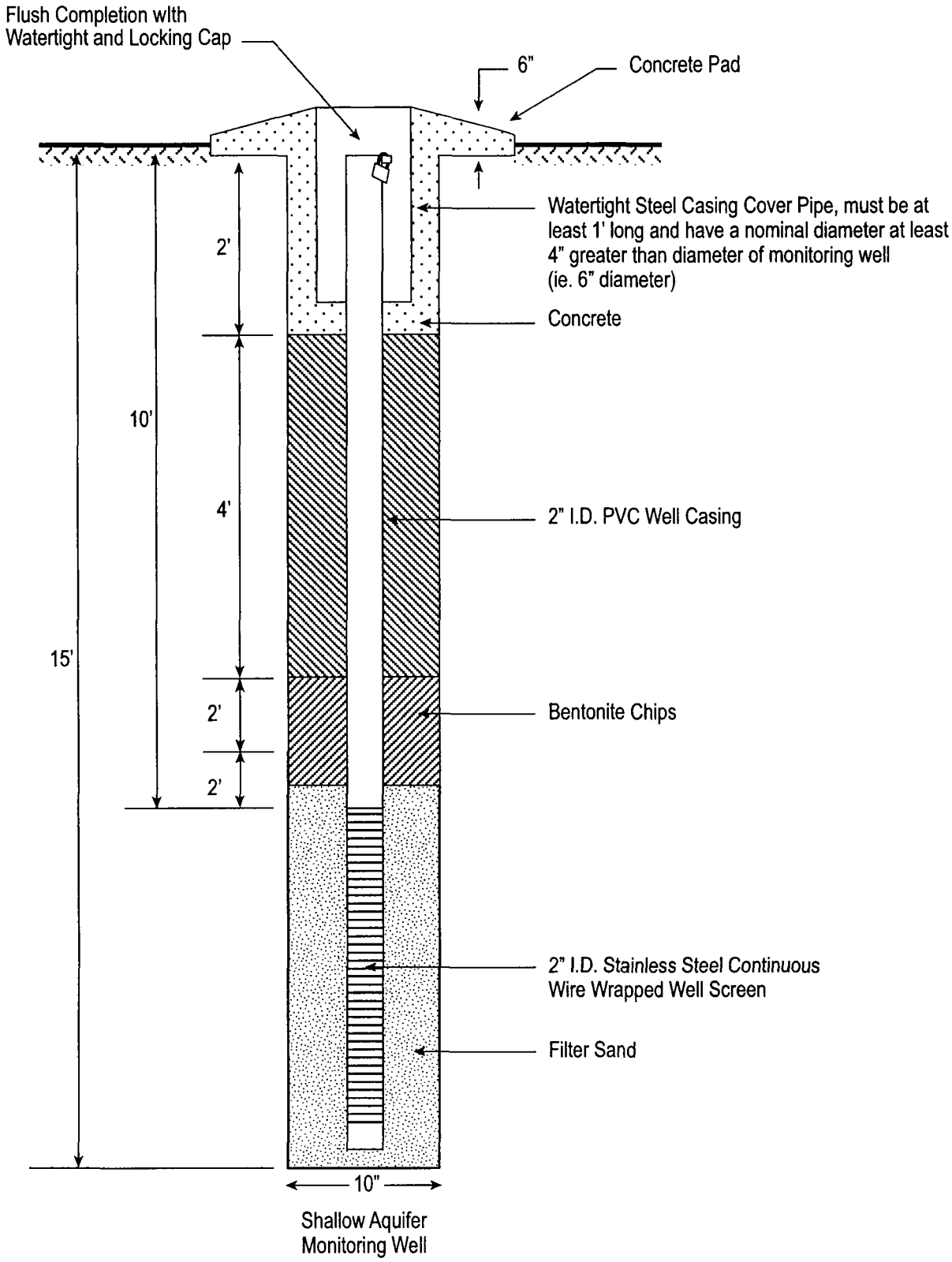

FIGURE 11
Shallow Zone Well Diagram
OMC Plant 2 Pilot Study

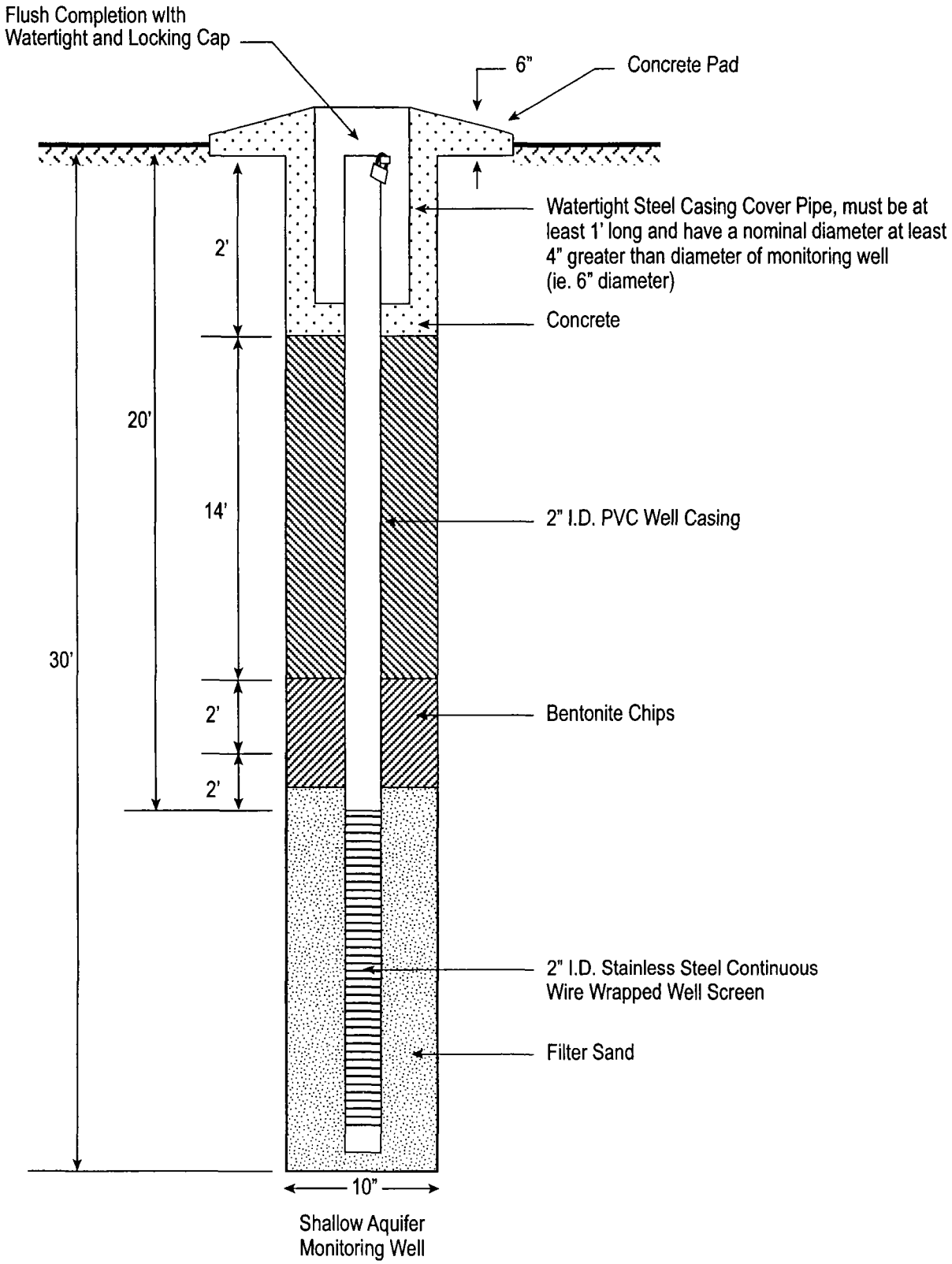

FIGURE 12
Deep Zone Well Diagram
OMC Plant 2 Pilot Study