FINAL
DNAPL FEASIBILITY STUDY
MONTROSE SUPERFUND SITE
20201 S. NORMANDIE AVENUE
LOS ANGELES, CALIFORNIA

September 27, 2013

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ACRONYMS AND ABBREVIATIONS

Abbreviation	**Term**
AQMD	Air Quality Management District
ARARs	Applicable or relevant and appropriate requirements
atm	Atmosphere
bgs	Below grade surface
BFS	Bellflower Sand
BHC	Benzene hexachloride
BTUs	British thermal unit
^{o}C	Degrees celsius
CAA	Clean Air Act
CCR	California Code of Regulations
CDWR	California Department of Water Resources
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CF	Chloroform
CFR	Code of Federal Regulations
cm/s	Centimeters per second
COCs	Contaminants of concern
cP	Centipoise
CPA	Central process area
CPVC	Chlorinated polyvinyl chloride
CWA	Clean Water Act
DCB	Dichlorobenzene
DCE	Dichloroethene
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DNAPL	Dense non-aqueous phase liquid
DOD	Department of Defense
DOE	Department of Energy
DTSC	Department of Toxic Substances Control
DUS	Dynamic underground stripping
dyn/cm	Dynes per centimeter
EPA	U.S. Environmental Protection Agency
ERH	Electrical resistance heating
ET-DSP^{TM}	Electro-Thermal Dynamic Stripping Process

ACRONYMS AND ABBREVIATIONS

Abbreviation	Term
Farmer Brothers	Farmer Brothers Coffee Company
FLUTe	Flexible Liner Underground Technologies™
FS	Feasibility Study
ft/ft	Feet per foot
FTO	Flameless thermal oxidizer
FWPCA	Federal Water Pollution Control Act
GAC	Granular activated carbon
g/cc	Grams per cubic centimeter
GHG	Greenhouse gas
gpd/ft	Gallons per day per foot
GRA	General response actions
GW	Groundwater
H+A	Hargis + Associates, Inc.
HD	Hydraulic displacement
ICs	Institutional controls
IGSM	Integrated global system model
ISCO	In-Situ chemical oxidation
ISGS	In-Situ groundwater standards
IPCC	Intergovernmental Panel on Climate Change
ISTD	In-Situ thermal destruction
ITRC	Interstate Technology & Regulatory Council
JCI	Jones Chemical Inc.
J.O.D.	Joint Outfall D
JP-4	Jet propellant fuel
Kv	Vertical hydraulic conductivity
Kw-hr	Kilowatt-hour
LACSD	Los Angeles County Sanitation District
LADWP	Los Angeles Department of Water and Power
LBA	Lower Bellflower Aquitard
LDA	Large Diameter Auger
LGAC	Liquid-phase granular activated carbon
LNAPL	Light non-aqueous phase liquid

ACRONYMS AND ABBREVIATIONS

Abbreviation	Term
MM	Million
MCB	Monochlorobenzene
MCF	Thousand cubic feet
MCLs	Maximum contaminant levels
µg/L	Micrograms per liter
mg/kg	Milligrams per kilogram
MGP	Manufactured gas plant
MIT	Massachusetts Institute of Technology
µmhos/cm	Micromhos per centimeter
m/L	Milligrams per liter
ml/min	Milliliter per minute
mmHg	Millimeters of mercury
MNA	Monitored natural attenuation
Montrose	Montrose Chemical Corporation of California
MSL	Mean sea level
NAPL	Non-aqueous phase liquids
NCP	National Oil and Hazardous Substances Contingency Plan
NPL	National Priorities List
NPV	Net present value
NRRB	National Remedy Review Board
OMB	Office of Management and Budget
OU	Operable unit
OVA	Organic vapor analyzer
PCE	Tetrachloroethene
pCBSA	Polychlorinated biphenols
PD	Playa Deposits
PDS	Passive diffusion bags
PEA	Preliminary Endangerment Assessment
PICS	Products of incomplete combustion
ppmv	Parts per million vapor
Lbs/hr	Pounds per hour
PPE	Personal protective equipment
PRB	Permeable Reactive Barrier
PRG	U.S. EPA Preliminary Remediation Goals
PVS	Palos Verdes Sands

ACRONYMS AND ABBREVIATIONS

Abbreviation	Term
RA	Remedial Alternatives
RAOs	Remedial Action Objectives
RD	Remedial Design
RI	Remedial Investigation
ROD	Record of Decision
ROI	Radius of influence
SCE	Southern California Edison
scfm	Standard cubic feet per minute
SEAR	Surfactant enhanced aquifer remediation
SEE	Steam enhanced extraction
Site	Montrose Superfund Site
SPH	Six phase heating
Stauffer	Stauffer Chemical Company
SREG	Smart Energy Resource Guide
SVE	Soil vapor extraction
T	Transmissivity
TASC	Technical Assistance Services for Communities
TBCs	To be considered
TCA	Trichloroethane
TCE	Trichloroethene
TCH	Thermal conductive heating
TEE	Thermal enhanced extraction
UBA	Upper Bellflower Aquitard
UN	United Nations
UNEP	United Nations Environmental Programme
UPRR	Union Pacific Railroad
UTCHEM	University of Texas Chemical Composition Simulator
VOC	Volatile Organic Compound
WBZ	Water bearing zone
WHO	World Health Organization
WRD	Water Replenishment District
ZVI	Zero Valent Iron

EXECUTIVE SUMMARY

This final dense non-aqueous phase liquid (DNAPL) Feasibility Study (FS) is part of the remedial evaluation process being conducted for the Montrose Chemical Corporation of California (Montrose) Superfund Site (Site) located at 20201 S. Normandie Avenue, Los Angeles, California (**Figure 1.1**). Montrose leased a 13-acre Property from Stauffer Chemical Company (Stauffer) in 1947 and manufactured technical grade dichlorodiphenyltrichloroethane (DDT) at the Property from 1947 until 1982. A DNAPL composed of DDT and monochlorobenzene (MCB), a raw material used in the manufacturing process, has been detected in certain areas beneath the Site. This FS identifies and evaluates alternatives for the remediation of DNAPL at the Site and has been prepared in accordance with the *Guidance for Conducting Remedial Investigations and Feasibility Studies under Comprehensive Environmental Response, Compensation, and Liability Act, Interim Final* (U.S. Environmental Protection Agency [EPA], 1988). Montrose conducted additional DNAPL-related testing at the Site during the period 2003 through 2009 and re-evaluated candidate remedial alternatives as documented in the draft DNAPL FS submitted to EPA on April 21, 2009 (Earth Tech, 2009a).

EPA commented on the draft FS in a letter dated January 27, 2010 (EPA, 2010a), and Montrose responded to EPA comments on April 27, 2010 (AECOM, 2010b; L&W, 2010). However, a number of technical and legal issues required resolution prior to revising the FS, and a series of reconciliation meetings and conference calls were held between September 2010 and February 2011 to address these issues. The majority of issues were satisfactorily reconciled as documented by the final meeting minutes submitted to EPA on April 21, 2011 (AECOM, 2011f). Although a small number of issues could not be reconciled, Montrose proceeded with revision of the DNAPL FS as requested by EPA in a letter dated July 22, 2011 (EPA, 2011b). A Revised DNAPL FS was submitted to EPA on December 7, 2011 (AECOM, 2011m).

The State of California Department of Toxic Substances Control (DTSC) commented on the Revised DNAPL FS in a memorandum dated August 21, 2012 (DTSC, 2012), and on behalf of EPA, CH2M Hill commented on the Revised FS in a memorandum dated January 30, 2013 (CH2M Hill, 2013). A National Remedy Review Board (NRRB) hearing was held on November 16, 2012, and NRRB commented in a letter dated February 1, 2013 (NRRB, 2013). EPA Region 9 subsequently responded to the NRRB comments in a letter dated March 22, 2013 (EPA, 2013).

A meeting was held on March 12, 2013, between EPA, DTSC, and Montrose to coordinate finalization of the DNAPL FS. The DNAPL FS was finalized in accordance with the consensus reached at that meeting regarding the process for addressing review comments. This final DNAPL FS supersedes the prior 1999, 2009, and 2011 versions and serves to evaluate candidate technologies and alternatives for the remediation of DNAPL at the Site.

This section provides an executive summary of the following DNAPL FS information:

- The nature and extent of DNAPL occurrence at the Montrose Site (refer to Section 2.0 for more details);
- DNAPL treatability and modeling studies (refer to Section 2.6 for more details);
- DNAPL remedial action objectives (refer to Section 3.1 for more details);
- Assembly of candidate DNAPL remedial alternatives (refer to Section 5.0 for more details);
- Detailed evaluation and comparison of candidate DNAPL remedial alternatives (refer to Sections 6.0 and 7.0 for more details).

Nature of DNAPL

DNAPLs composed of a VOC and a pesticide such that is found at the Montrose Site are not common, and the nature of the DNAPL is different from more common DNAPLs such as TCE and PCE. To illustrate this difference between the Montrose DNAPL and typical DNAPLs an evaluation was conducted by evaluating a number of case studies. Similar DNAPLs have only been reported at three other former DDT manufacturing facilities including:

- Velsicol Superfund Site in St. Louis, Michigan;
- Arkema, Inc. (formerly ATOFINA) Site in Portland, Oregon; and
- Syngenta Site in Houston, Texas.

Montrose evaluated six other former DDT manufacturing facilities in 2010 (AECOM, 2010e), but no DNAPL was reported at these sites. Due to the infrequent occurrence of this type of DNAPL, the behavior of this DNAPL under varying conditions is not well documented, and there is a limited basis from which to evaluate the success or failure of DNAPL remedial action at sites with these contaminants. Although it is recognized that there are other sites with complex stratigraphy and challenging contaminant properties, the remediation experience of DNAPLs at other former DDT manufacturing facilities is limited.

DNAPL Composition

Results of DNAPL sample analyses from 1998, 2008, and 2009 are provided in **Appendix A** and indicate that the Montrose DNAPL is typically composed of approximately 50% MCB by weight and 50% Total DDT by weight.

DNAPL Physical Properties

The physical properties of the Montrose DNAPL were evaluated during studies conducted in 1998 (H+A, 1999) and 2006 (H+A, 2006b; Davis, 2006) and are summarized as follows:

- The DNAPL co-boiling point (with water) is approximately 96°C at 1 atmosphere, which is relatively high compared with other VOC-based DNAPLs;
- MCB has a relatively high boiling point (132°C at 1 atmosphere) and a relatively low vapor pressure (12 millimeters of mercury at 20°C) as compared with other VOCs;
- The DNAPL is approximately 25% more dense than water (1.25 g/cc at 20°C);
- The DNAPL is approximately 2.5 times more viscous than water (2.5 centipoise at 20°C);
- The DNAPL interfacial tension (with water) is low to moderate in comparison with other common DNAPLs (13 to 15 dynes per centimeter).

Considering all physical properties, the Montrose DNAPL exhibits a moderate mobility as compared with other common DNAPLs.

Lateral Extent of DNAPL

The lateral extent of DNAPL occurs fully within the Technical Impracticability Waiver Zone established by the EPA as part of the Groundwater ROD (EPA, 1999). In the unsaturated zone, the definite extent of DNAPL is estimated to be approximately 57,000 square feet and encompasses the majority of the Central

Process Area (CPA) at the former Montrose plant. The possible extent of DNAPL in the unsaturated zone is estimated to be approximately 79,000 square feet.

DNAPL occurs over a larger area within the saturated zone than observed within the unsaturated zone. The definite presence of DNAPL in the saturated Upper Bellflower Aquitard (UBA) occurs over an area of approximately 150,000 square feet. DNAPL extends east of the former CPA, presumably due to DNAPL migration along the top of low permeability silt layers in the down-slope direction. The possible presence of DNAPL occurs over a larger area than the definite DNAPL and encompasses approximately 160,000 square feet.

Focused Treatment Area

Based on physical properties testing of one soil core, DNAPL saturations of 18.9% or more are required for the DNAPL to be mobile (in that soil type). This residual saturation is roughly equivalent to a DNAPL concentration of approximately 53,000 mg/kg. An area of approximately 26,000 square feet is estimated to contain DNAPL in concentrations which are potentially mobile at the Site. This area was defined based on DNAPL concentration data from numerous soil borings. For purposes of this FS, the area containing potentially mobile DNAPL is defined as the "Focused Treatment Area".

Residual DNAPL saturations are expected to vary at the Site, have not been measured with the exception of one soil core, and are uncertain. Therefore, some level of uncertainty is associated with the extent of mobile DNAPL at the Site. Additional DNAPL saturation and mobility testing will be required to verify the extent of mobile DNAPL for treatment. Consequently, the extent of the Focused Treatment Area may be revised in the future depending on the results of more extensive core and DNAPL saturation testing. Although the extent of mobile DNAPL is uncertain at this time, the assumptions were applied uniformly to the candidate alternatives and will not impact remedy evaluation in this FS.

The estimated extent of mobile DNAPL at the Site is also supported by field evidence. Through passive DNAPL accumulation and extraction testing, mobile DNAPL has been observed in seven wells, all of which occur within the estimated mobile DNAPL extent. Additionally, no mobile DNAPL has been observed at wells which occur outside the estimated extent of mobile DNAPL. The physical evidence at the Site corroborates the estimated extent of mobile DNAPL based on DNAPL concentrations and an assumed residual saturation.

Vertical Extent of DNAPL

DNAPL has been definitively detected from a minimum of 7 feet bgs in the unsaturated zone to a maximum of 101.5 feet bgs in the saturated UBA (H+A, 1999 and 2004b). The predominant DNAPL-impacted zone is the saturated portion of the UBA at depths ranging from approximately 75 to 95 bgs (H+A, 2004b). The majority of the observed DNAPL is perched on low permeability silt layers throughout the UBA.

The presence of DNAPL has not been confirmed in the Bellflower Sand (BFS) Aquifer underlying the UBA. Additional characterization activities were conducted in 2008 to investigate for the presence of DNAPL in the BFS at the Site (H+A, 2008b and 2008c). Increasing vertical concentration profiles were observed at well BF-9 and in discrete samples collected at boring BFSB-1, which could be indicative of DNAPL in the BFS. Concentrations at the base of the BFS at boring BFSB-1 were approximately 20% of the MCB solubility limit. Although EPA believes the concentration profile within the BFS is indicative of the presence of DNAPL at the base of the BFS (EPA, 2008b), the presence or absence of DNAPL in the BFS cannot be definitively determined based on the available data. Dissolved-phase concentrations greater than 1% of the solubility limit is just one of several possible indicators of DNAPL presence, and by itself, is not definitive of DNAPL occurrence. The presence of MCB in the BFS at concentrations

greater than 1% of the solubility limit can be attributed to vertically downward hydraulic groundwater gradients between the UBA and BFS. An unlined wastewater recycling pond was operated at the Site from 1947 to 1953, and the vertically downward hydraulic groundwater gradients would have been substantially enhanced during this period of the plant's operating history. Other than dissolved-phase concentrations exceeding 1% of the solubility limit, there is no direct evidence that DNAPL is present in the underlying BFS. No black or oily staining has been observed in the soil core, samples, or cuttings collected from the bottom of the BFS, and no elevated soil headspace concentrations has been observed, indicative of a DNAPL source in the BFS. Additionally, no DNAPL has been observed accumulating in any BFS wells. If there were significant DNAPL-phase MCB in the BFS, then multiple lines of evidence would have indicated the presence of DNAPL in the BFS during prior investigations. Given the limited evidence of DNAPL occurrence in the BFS, the mass of DNAPL potentially present in the BFS, if any, would be significantly less than the mass occurring within the overlying UBA, as indicated in Section 2.5.5.

Estimated DNAPL Mass in the Saturated Zone

Montrose and EPA both estimated the DNAPL mass in the saturated zone using valid but differing methodologies. Montrose estimated the DNAPL mass to be approximately 796,100 pounds using the liberal DNAPL thicknesses presented in Section 2.5.4, the DNAPL concentrations presented in Section 2.5.3, and the area of DNAPL-impacts presented in Section 2.5.1. The equivalent volume of DNAPL occurring within the saturated UBA was estimated as shown in **Appendix E** (H+A, 2008e).

EPA estimated the DNAPL mass to be approximately 900,000 pounds using the analytical results of soil samples collected during the DNAPL Reconnaissance Investigation (H+A, 2004b). Using physical properties results of soil samples collected from boring 2DSB-1 in February 2008, EPA estimated the thickness of MCB and mass integral (in grams per square foot) required to achieve the reported MCB concentration in the soil sample (CH2M Hill, 2010b and EPA, 2010b and 2010d). EPA averaged the mass integrals within each of the MCB concentration contours shown in **Figure 2.29** and multiplied by the area of the contours to obtain the estimated MCB mass. Consistent with the Montrose DNAPL composition, the mass of DNAPL (MCB and DDT) was determined by doubling the MCB mass estimate as shown in **Appendix E**.

Montrose and EPA DNAPL Mass Estimates

Treatment Area	DNAPL Mass (pounds)	
	Montrose Estimate	EPA Estimate
Entire DNAPL-Impacted Area	796,100	900,000
Focused Treatment Area	473,600	780,000
Mobile DNAPL	221,800	340,000

Given the uncertainty associated with the DNAPL characterization data, EPA considers the two above estimates roughly equivalent. The Montrose estimate does not account for a concentration profile within a DNAPL pool but does consider all of the characterization data in estimating the DNAPL mass. The EPA estimate does account for a vertical concentration profile within a DNAPL pool but only considers a small amount of the characterization data in estimating the DNAPL mass. There is inherently a high degree of uncertainty associated with the DNAPL mass estimates, and some interpretation of the data was required to estimate mass. However, the relative certainty of the data is considered adequate for the purposes of the FS and evaluation of candidate remedial technologies and alternatives.

Estimated MCB Mass in the Unsaturated Zone

The mass of MCB in the unsaturated zone was estimated as shown in **Appendix C** and summarized below:

- Playa Deposits (0 to 25 feet bgs): An estimated 237,000 pounds of MCB are present, including DNAPL-phase MCB.
- Palos Verdes Sand/unsaturated Upper Bellflower Aquitard (25 to 60 feet bgs): An estimated 261,000 pounds of MCB are present, including DNAPL-phase MCB.

Other VOCs occur in unsaturated soils in substantially lower concentrations and frequencies. Those VOCs are not components of DNAPL, they do not significantly contribute to the mass of VOCs at the Site, and they will not significantly impact remedial alternative analysis or the duration of necessary groundwater containment.

DNAPL Treatability and Modeling Studies

A series of studies, laboratory bench tests, and field pilot tests have been conducted to evaluate candidate DNAPL remedial technologies as described in Section 2.6 and summarized as follows:

- Mass Flux Evaluation: Hydraulic containment timeframes required under various assumed DNAPL mass reduction scenarios were estimated using numerical methods as described in Section 2.6.1 and **Appendix G**. Without any reduction in the DNAPL mass, hydraulic containment within the UBA will be required for nearly an estimated five millennia. Furthermore, the containment duration will not be meaningfully reduced even under various accelerated DNAPL mass reduction scenarios. EPA also evaluated hydraulic containment timeframes as documented in a memorandum dated September 29, 2010 (CH2M Hill, 2010b). Using the Falta Method referenced above and assuming primarily horizontal flow within the UBA, EPA estimated similar hydraulic containment timeframes. There is substantial uncertainty associated with these long-term containment timeframe estimates as EPA noted in their memorandum. Nonetheless, EPA acknowledged that hydraulic containment of the groundwater will be required for hundreds or thousands of years following a DNAPL remedy regardless of the remedy selected. Although the above evaluation establishes an approximate relationship between residual DNAPL mass and hydraulic containment timeframes, long-term hydraulic containment is an aspect of the remedy selected for groundwater (EPA, 1999) and is not subject to evaluation in this DNAPL FS. Furthermore, while residual DNAPL will continue to serve as a source for dissolved MCB in the long-term, it is immobile under gravitational forces and does not pose a risk to the groundwater remedy (refer to Section 3.1 for details).
- DNAPL Extraction Testing: Three separate DNAPL extraction field pilot tests were conducted at the Site from 1991 to 2008 as described in Section 2.6.3 (H+A, 1999 and 2007c). Mobile DNAPL was extracted from five different wells screened in the UBA at rates up to 11 gallons per day, including well UBE-5 located east of the CPA adjacent to soil boring SSB-12.
- Hydraulic Displacement Modeling: The performance of a hydraulic displacement DNAPL remedy in the UBA was modeled using the University of Texas Chemical Composition Simulator (UTCHEM), Version 9 (H+A, 2009b) as described in Section 2.6.4. The revised modeling approach predicted that DNAPL would be effectively mobilized for capture at well spacings up to 120 feet (i.e., 60-foot single well capture radius). In addition, the model predicted that DNAPL would not penetrate through the UBA and into the underlying BFS, even under conservative assumptions that maximized DNAPL accumulation over the basal silty sand layer in the UBA. However, there is some uncertainty associated with the continuity of the basal layer across the

Property and the pore entry pressures required to penetrate through the silty sands, if continuous. The basal silty sand would be expected to support DNAPL pool heights between 1.3 and 8 feet, if continuous, and depending on the pore entry pressure (see Section 2.6.4 for additional details).

- Soil Vapor Extraction (SVE) Field Pilot Test: A field pilot test to evaluate the feasibility of removing VOCs from unsaturated soils was conducted at the Property in 2003 (Earth Tech, 2009c) as described in Section 2.6.5. SVE was found to be a highly effective technology for removing MCB and other VOCs from permeable unsaturated soils within the Palos Verdes Sand (PVS) and unsaturated UBA. However, due to the low permeability of the shallow soils (primarily clayey silts) and vertical communication with the underlying PVS, SVE was found to be significantly less effective within the Playa Deposits (PD). However, higher permeability soils (silty sands) were identified in the PD at some boring locations within the DNAPL-impacted area, and therefore, SVE may be more effective within the PD at those locations.
- 2-Dimensional Steam Flushing Bench Study: A thermal technology bench-scale study was conducted by Dr. Brent Sleep with the University of Toronto to evaluate mobilization of the Montrose DNAPL under steam flushing. Runs 1 and 2 of the 2-dimensional steam flushing experiments were conducted in January and May, 2009 as described in Section 2.6.6. The volumes of DNAPL and steam condensate recovered from the test cell were carefully measured, and an extensive post-test sampling program documented the amount of MCB and Total DDT remaining in soil following steam flushing. The results of steam flushing Runs 1 and 2 are summarized as follows:
    - Between 57% and 63% of the initial DNAPL-phase MCB mass was removed after 3.4 to 5.2 pore volumes of steam flushing through the DNAPL Layer;
    - Between 6% and 20% of the initial DNAPL-phase DDT mass was removed after 3.4 to 5.2 pore volumes of steam flushing through the DNAPL Layer;
    - Significant concentrations of MCB (up to 20,000 mg/kg) and Total DDT (up to 44,700 mg/kg) remained in the soil following steam flushing;
    - Significant redistribution of MCB and Total DDT occurred during steam flushing including migration into and below the Capillary Barrier;
    - MCB concentrations up to 17,000 mg/kg and Total DDT concentrations up to 9,556 mg/kg were detected in soils below the Capillary Barrier and within the Base Layer following steam flushing;
    - Desaturation or partial desaturation of the thin silt layers were observed during steam flushing, reducing the effectiveness of these layers as capillary barriers to downward DNAPL migration.

Memorandums from Dr. Sleep summarizing the results of experiment Runs 1 and 2 were prepared and submitted to EPA in March and August, 2009 (Earth Tech, 2009a and Demaximis, 2009). A comprehensive summary report of all 2-D bench-scale testing activities was prepared and submitted to EPA in December 2011 (AECOM, 2011k). It should be noted that EPA does not agree with certain aspects of the 2-dimensional bench testing configuration or interpretation of results (CH2M Hill, 2013). Among other issues, EPA believes that steam could be injected into the Base Layer to serve as a "hot floor" and mitigate to some extent the potential for downward migration. Montrose contends that a steam injection hot floor may not be effective at mitigating downward DNAPL migration, and that there has been no true steam injection hot floor implemented at any DNAPL remediation site. Please refer to Section 4.6.3 for a more detailed discussion regarding this issue.

DNAPL Remedial Action Objectives (RAOs)

RAOs were established for the DNAPL program following a series of technical meetings with EPA in 2007 and 2008, with the final RAOs established at a September 11, 2008 meeting. Following a series of conference calls with EPA in 2010, RAO 4 was subsequently revised in December 2010 (AECOM, 2010g) to focus on reduction of mobile DNAPL mass at the Site, which is the principal threat to human health and the environment at the Site. The RAOs are presented in Section 3.1 and as follows:

1) Prevent human exposure to DNAPL constituents (via ingestion, inhalation, or dermal contact) that would pose an unacceptable health risk to on- or off-property receptors under industrial land uses of the Montrose plant property and adjacent properties;
2) To the extent practicable, limit uncontrolled lateral and vertical migration of mobile NAPL under industrial land use and hydraulic conditions in groundwater;
3) Increase the probability of achieving and maintaining containment of dissolved-phase contamination to the extent practicable, as required by the existing groundwater ROD, for the time period that such containment remains necessary;
4) Reduce mobile NAPL mass to the extent practicable;
5) To the extent practicable, reduce the potential for recontamination of aquifers that have been restored by the groundwater remedial actions, as required by the groundwater ROD, in the event containment should fail; and
6) To the extent practicable, reduce the dissolved-phase concentrations within the containment zone over time.

Principal Threat

DNAPL that is mobile in the environment, i.e., present at saturations above residual levels, is the principal threat at the Site. In the absence of remedial action, mobile DNAPL has the potential to migrate laterally outside the TI Waiver Zone or vertically downward to deeper aquifer units under gravitational forces. Mobile DNAPL migration in this manner would not be protective of human health and the environment. Mobile DNAPL migration as described above could threaten the remedy for groundwater by (a) decreasing the probability of achieving hydraulic containment of dissolved-phase MCB within the TI Waiver Zone, and (b) preventing the groundwater remedy from reducing dissolved-phase MCB concentrations outside the TI Waiver Zone to in-situ groundwater standards.

DNAPL that is immobile in the environment, i.e., present at or below residual saturations, is not a threat to the groundwater remedy at the Site. DNAPL at residual saturations is immobile under gravitational forces or natural hydraulic gradients. Although residual DNAPL will continue to serve as a source for dissolved MCB in the long-term, the groundwater remedy will effectively and hydraulically contain dissolved-phase MCB concentrations within the TI Waiver Zone.

Removal of all DNAPL at the Site, both mobile and residual, is not practicable or technically feasible at this time. For this reason, EPA established a TI Waiver Zone at the Site as indicated in the Groundwater ROD (EPA, 1999). However, a primary performance goal for the DNAPL remedy is to reduce DNAPL saturations in the subsurface to residual and immobile levels, either through mass removal or saturation depletion, without causing DNAPL to migrate outside of the TI Waiver Zone or into deeper aquifer units.

ARARs and TBCs

Identification of the applicable or relevant and appropriate requirements (ARARs) and criteria to-be-considered (TBCs) for DNAPL was accomplished by reviewing federal, state, and local laws, regulations, and policies. A determination of ARARs and TBCs was made based upon the terms of those statutes, regulations, and policies, consideration of EPA guidance, primarily the guidance entitled *CERCLA Compliance With Other Laws Manual: Interim Final (Parts I and II*), EPA/540/G-89/006 (August 1989b), and discussions with EPA. The ARARs and TBCs for DNAPL are presented in Section 3.3. Identification of the ARARs and TBCs in this FS is not determinative, and new or different ARARs may be identified by EPA in the ROD. Although TBCs are included in this analysis, there are, by definition, materials that are not legally enforceable but contain information that would be helpful to select, carry out, or determine the level of protectiveness of a selected remedy. However, EPA does not agree that the greenhouse gas materials listed in Section 3.3 constitute TBCs, on the basis that they do not contain performance standards or criteria that could be enforced if they were to be adopted as TBCs in the Record of Decision. In its letter of July 22, 2011 (EPA, 2011b), EPA explicitly instructed Montrose to remove the California and EPA global warming and green remediation documents from the list of TBCs, and EPA's position remains that these materials do not belong in the "To Be Considered" category.

Assembly of DNAPL Remedial Alternatives (RAs)

General Response Actions (GRAs) were identified in Section 3.2, and DNAPL remedial technologies and process options were preliminarily evaluated in Section 4. Following preliminary evaluation, retained DNAPL remedial technologies and process options were assembled into nine candidate RAs in Section 5 and described as follows:

Summary of Assembled Remedial Alternatives

Remedial Alternative	GRA Remedial Technologies/Process Options
Remedial Alternative 1	No Action
Remedial Alternative 2	Institutional Controls
Remedial Alternative 3	Institutional Controls SVE (unsaturated zone)
Remedial Alternative 4a	Institutional Controls SVE (unsaturated zone) Hydraulic Displacement, with untreated water injection
Remedial Alternative 4b	Institutional Controls SVE (unsaturated zone) Hydraulic Displacement, with treated water injection
Remedial Alternative 5a	Institutional Controls SVE (unsaturated zone) Steam Injection, focused treatment area
Remedial Alternative 5b	Institutional Controls SVE (unsaturated zone) Steam Injection, entire treatment area
Remedial Alternative 6a	Institutional Controls SVE (unsaturated zone) ERH, focused treatment area
Remedial Alternative 6b	Institutional Controls SVE (unsaturated zone) ERH, entire treatment area

The above nine candidate RAs are described in Section 5.1 and were evaluated in Section 5.2. In accordance with the DNAPL reconciliation discussions, none of the candidate RAs was eliminated from further consideration following the intermediate screening.

Detailed Evaluation and Comparison of Candidate DNAPL RAs

The candidate RAs were evaluated in Section 6 against the nine performance criteria defined by the National Contingency Plan (40 CFR 300.430 (e)(9)). The performance of the RAs relative to the nine criteria was then compared in Section 7 and is summarized below:

Overall Protection of Human Health and the Environment

Six of the nine candidate RAs are fully protective of human health and the environment as follows:

Protection of Human Health and the Environment Ranking

RA	Components	Protection of Human Health and Environment Rank
RA 1	No Action	Not Protective
RA 2	ICs	Not Protective
RA 3	ICs, SVE	Not Protective
RA 4a	ICs, SVE, HD with untreated water injection	Protective
RA 4b	ICs, SVE, HD with treated water injection	Protective
RA 5a	ICs, SVE Steam Injection over focused treatment area	Protective
RA 5b	ICs, SVE Steam Injection over entire treatment area	Protective
RA 6a	ICs, SVE, ERH over focused treatment area	Protective
RA 6b	ICs, SVE, ERH over entire treatment area	Protective

Notes:
ICs = Institutional controls
SVE = Soil vapor extraction
HD = Hydraulic displacement
ERH = Electrical resistance heating

RA 1 is not protective of human health because it does not include institutional controls. RA 1 is also not protective of the environment because mobile DNAPL mass would not be reduced in the unsaturated or saturated zones, and the potential for recontamination of the aquifers would remain.

RAs 2 and 3 are protective of human health but not the environment. The institutional controls component of this RA protects human health by restricting Site access and uses that may result in exposure to DNAPL-impacted soils. RA 3 also partially protects the environment by removing the source of VOCs and DNAPL in the permeable unsaturated zone overlying groundwater and by controlling VOC migration in soil gas in the short-term. However, these alternatives do not reduce the mobile DNAPL mass, the principal threat, or limit the potential for uncontrolled mobile DNAPL migration in the saturated zone.

RAs 4a through 6b are all protective of human health and the environment. RAs 4a and 4b protect the environment by removing mobile DNAPL mass from the saturated UBA by hydraulic displacement, reducing the risk of DNAPL migration either laterally within the UBA or downward into the BFS. RAs 4a and 4b will remove the majority of the mobile DNAPL mass from the UBA, and the mobility of the remaining DNAPL will be significantly reduced and unlikely to pose a significant threat to the

environment or risk of uncontrolled migration under normal hydrologic conditions. RAs 5a through 6b protect the environment by removing mobile and residual DNAPL mass from the saturated zone by steam injection or ERH. Although these thermal remediation RAs would remove more MCB mass than RAs 4a and 4b, they additionally present an increased risk of adverse consequences associated with remedy excursion, upset conditions, or uncontrolled contaminant migration.

RAs 4a through 6b all include some degree of risk associated with uncontrolled DNAPL migration during remedy implementation. Although RAs 4a and 4b do not include a hot floor, hydraulic displacement is a depleting technology which continuously reduces the DNAPL saturation and mobility. RAs 5a and 5b include a hot floor but can increase the DNAPL saturation and mobility at the steam front and can de-saturate thin capillary barriers (as demonstrated during 2-dimensional bench-scale testing), reducing their ability to support DNAPL pools and prevent downward migration. It is noted that EPA does not agree with the above characterization of mobilization risks during steam injection (CH2M Hill, 2013). RAs 6a and 6b have a reduced potential for uncontrolled migration but require that heated vapors be effectively recovered to prevent them from re-condensing in another portion of the saturated zone. ERH is a volatilization technology, not a displacement technology, and the higher number of wells required for ERH reduces the potential for uncontrolled DNAPL migration in the short-term.

Compliance with ARARs

All but two of the candidate RAs unconditionally complies with DNAPL ARARs as follows:

Compliance With ARARs Ranking

RA	Components	Compliance with ARARs Rank
RA 1	No Action	Does Not Comply
RA 2	ICs	Complies
RA 3	ICs, SVE	Complies
RA 4a	ICs, SVE, HD with untreated water injection	Does Not Comply (unless ARAR waived[1])
RA 4b	ICs, SVE, HD with treated water injection	Complies
RA 5a	ICs, SVE Steam Injection over focused treatment area	Complies
RA 5b	ICs, SVE Steam Injection over entire treatment area	Complies
RA 6a	ICs, SVE, ERH over focused treatment area	Complies
RA 6b	ICs, SVE, ERH over entire treatment area	Complies

Notes:
[1] A waiver to re-inject untreated groundwater would be required over the 5 year duration of the HD remedy for RA 4a.

The No Action RA (RA 1), which excludes institutional controls, may not comply with Land Use Covenant requirements established under CCR Title 22 and the California Civil Code, although these requirements may be met through the soil remedy. RA 1 would also not comply with DNAPL ARARs, unless institutional controls implemented through the soil remedy addressed DNAPL exposure pathways.

RA 4a includes re-injection of untreated water during hydraulic displacement and would not comply with EPA and State re-injection standards. A waiver of the re-injection standards would be required for the 5-year duration of the HD remedy, as previously approved by EPA and the State during field pilot testing of this technology. RA 4a would meet the requirements of 42 U.S.C. § 6939(b) by substantially reducing hazardous constituents prior to groundwater injection. Separation of the DNAPL from groundwater following total fluids extraction would initially remove up to 90% of the total contaminant mass before

re-injection. Additionally, the re-injection of groundwater under RA 4a would not trigger the State's anti-degradation policy because it would not negatively impact existing groundwater quality in the re-injection area, which occurs entirely on-Property and within the boundaries of the existing TI Water Zone. However, in accordance with EPA comments, RA 4a is ranked as not complying with ARARs unless the re-injection standards are temporarily waived in the short-term.

However, all other candidate RAs would unconditionally comply with ARARs. RAs 3 through 6b include SVE with ex-situ vapor treatment, and field pilot testing has already demonstrated the ability of activated carbon to comply with air emissions ARARs including the Clean Air Act and SCAQMD regulations. RAs 4b through 6b include treatment of the dissolved-phase concentrations in groundwater prior to re-injection and would also comply with Groundwater ROD in-situ groundwater standards.

Long-Term Effectiveness and Permanence

The long-term effectiveness of the candidate RAs is partially determined by their ability to reduce mobile DNAPL mass, the principal threat, in the short-term and reduce the potential for recontamination of the aquifers in the long-term. Mobile DNAPL mass left in place following implementation of the candidate RAs could migrate laterally or vertically in the future and may pose a risk to groundwater resources in the long-term. Although residual DNAPL mass left in place following implementation of the candidate RAs will serve as a continuing source to groundwater, it is immobile under gravitational forces and does not pose a risk to the groundwater remedy. Residual DNAPL mass left in place will slowly dissolve over time and be hydraulically contained by the groundwater remedy. The estimated hydraulic containment timeframes required to meet ARARs in the UBA were estimated as described in Section 2.6.1.

Long-Term Effectiveness and Permanence Ranking

RA	Components	Long-Term Effectiveness Rank
RA 1	No Action	Not Effective
RA 2	ICs	Not Effective
RA 3	ICs, SVE	Not Effective (Unsaturated Zone Only)
RA 4a	ICs, SVE, HD with untreated water injection	Moderately Effective
RA 4b	ICs, SVE, HD with treated water injection	Moderately Effective
RA 5a	ICs, SVE, Steam Injection over focused treatment area	Effective
RA 5b	ICs, SVE, Steam Injection over entire treatment area	Effective
RA 6a	ICs, SVE, ERH over focused treatment area	Effective
RA 6b	ICs, SVE, ERH over entire treatment area	Effective

Notes:
Estimated reduction in MCB mass shown in Section 7.4

RAs 1 through 3 are not effective in the long-term because they do not reduce the mobile DNAPL mass in the short-term. Although RA 3 reduces the DNAPL and MCB mass in the unsaturated zone, it also does not reduce the mobile DNAPL mass in the saturated zone.

RAs 4a and 4b remove mobile DNAPL mass from the saturated zone by hydraulic displacement. These RAs are expected to remove a substantial portion of the mobile DNAPL mass and significantly reduce the mobility of DNAPL remaining in the UBA. Any DNAPL not mobilized by the relatively dense well pattern and high horizontal gradients is unlikely to be particularly mobile under normal hydrologic conditions. However, RAs 4a and 4b are likely to remove less mobile DNAPL mass than RAs 5a and 6a, and any mobile DNAPL left in place following HD may pose a risk to groundwater resources in the long-term. Additionally, any DNAPL migrating vertically downward into the BFS would reduce the long-term effectiveness of this remedy. However, the basal layer of the UBA is expected to be capable of supporting DNAPL pool heights between 1.3 and 8 feet if continuous and depending on the capillary pressures required to penetrate the layer.

RAs 5a and 6a remove mobile and residual DNAPL mass over a focused treatment area in the saturated zone by steam injection and ERH, respectively. Where target temperatures are achieved and MCB is recovered by multi-phase extraction wells, RAs 5a and 6a are expected to be effective in reducing mobile DNAPL mass and the potential for recontamination of the aquifers. However, these thermal remediation technologies have not been pilot tested at the Site, and the effectiveness is uncertain. Steam injection was bench-scale tested, which demonstrated that between 57% and 64% of the MCB mass (and all of the mobile mass) could be removed under relatively ideal and controlled laboratory conditions. The highly layered and heterogeneous nature of the saturated UBA is not ideal conditions for steam injection (or hydraulic displacement), and there is a potential for steam injection to be less effective at field scale conditions. ERH is not permeability dependent and is less affected by the nature of the saturated UBA, although heated MCB vapors must still be effectively recovered in order to prevent cooling and re-condensing of the MCB in another part of the Site, potentially outside the DNAPL footprint.

RAs 5b and 6b remove mobile and residual DNAPL mass over the entire treatment area in the saturated zone by steam injection and ERH, respectively. These RAs have the same long-term effectiveness as RAs 5a and 6a, except that they would additionally remove residual DNAPL mass from outside of the focused treatment area where only 13% to 40% of the total DNAPL mass is estimated to occur. However, residual DNAPL is immobile under gravitational forces, does not pose a risk to the groundwater remedy, and will be hydraulically contained in the long-term. Despite implementing a large and full-scale thermal remedy over the entire treatment area at the Site, long-term hydraulic containment would still be required for hundreds or thousands of years as described in Section 2.6.1. None of the candidate RAs can remove sufficient DNAPL mass to meaningfully reduce the time required for long-term hydraulic containment, and these full-scale thermal RAs offer little advantage over the focused treatment area alternatives in terms of containment duration. Although RAs 5b and 6b have the potential to remove the most MCB mass, their ability to reduce the mobile DNAPL mass, limit uncontrolled migration, and reduce the potential for recontamination of the aquifers is identical to RAs 5a and 6a.

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents

In the long-term, all of the RAs slowly reduce the toxicity, volume, and mobility of the DNAPL in the saturated UBA via dissolution. In the short-term, DNAPL mass is reduced for the RAs as summarized below:

Estimated Volume Reduction in Short-Term

RA	Components	Reduction in Mobility or Toxicity	Reduction in Volume (gallons)			
			Unsaturated Zone MCB	Saturated Zone MCB	Total MCB	Saturated Zone Total DDT
RA 1	No Action	No	0	0	0	0
RA 2	ICs	No	0	0	0	0

RA 3	ICs, SVE	Unsaturated Zone Only	27,000-30,000	0 27,000-30,000		0
RA 4a	ICs, SVE, HD w/ untreated water injection	Some	27,000-30,000	9,000-13,000	36,000-43,000	9,000-13,000
RA 4b	ICs, SVE, HD w/ treated water injection	Some	27,000-30,000	9,000-13,000	36,000-43,000	9,000-13,000
RA 5a	ICs, SVE, Steam Injection over focused area	Yes	27,000-30,000	15,000-25,000	42,000-55,000	>0
RA 5b	ICs, SVE, Steam Injection over entire area	Yes	27,000-30,000	26,000-29,000	53,000-59,000	>0
RA 6a	ICs, SVE, ERH over focused area	Yes	27,000-30,000	15,000-25,000	42,000-55,000	0
RA 6b	ICs, SVE, ERH over entire area	Yes	27,000-30,000	26,000-29,000	53,000-59,000	0

RAs 1 and 2 do not reduce the toxicity, mobility, or volume of the DNAPL in the short-term. RAs 3 through 6b include reduction of VOC/DNAPL volume and mobility in the unsaturated zone by SVE. An estimated 27,000 to 30,000 gallons of MCB would be removed from the unsaturated zone by SVE depending on the removal efficiency within soils of varying permeability.

RAs 4a and 4b are expected to remove between 9,000 and 13,000 gallons of mobile MCB mass from the saturated zone by hydraulic displacement (upper end of performance range as described in Section 5.1.4). Although RAs 4a and 4b would not reduce MCB mass in the saturated zone as much as RAs 5a through 6b (which also remove residual DNAPL mass), it would remove a substantial portion of the mobile DNAPL mass (the principal threat) and significantly reduce the mobility of any DNAPL left in place within the focused treatment area. Any DNAPL not mobilized by a relatively high well density under high hydraulic gradients is not expected to be particularly mobile under normal hydrologic gradients, which would be 100 times lower or more. An equal volume of DNAPL-phase DDT, approximately 9,000 to 13,000 gallons, would also be removed by hydraulic displacement under RAs 4a and 4b, the majority of which would otherwise be left in-situ by the thermal remediation RAs. However, DDT is relatively insoluble in groundwater and is not expected to pose a significant environmental threat if left within the saturated UBA.

RAs 5a and 6a would remove an estimated 15,000 to 25,000 gallons of mobile and residual MCB from the saturated zone over a focused treatment area by steam injection and ERH respectively. Where target temperatures are achieved and MCB is recovered by multi-phase extraction, RAs 5a and 6a would be expected to reduce MCB saturations to residual levels and be relatively immobile in the environment. However, the saturated UBA is highly layered and heterogeneous, and steam will preferentially flow through the more permeable sand layers. Controlling the distribution of steam may be problematic, and heating of the less permeable silt layers will depend on heat conduction from the adjacent sands. The lithology of the UBA may also pose challenges for recovering heated MCB vapors, and if not effectively recovered, could re-condense in another part of the UBA, potentially outside the remediation footprint. Where inefficiencies occur and target temperatures are not achieved by the thermal remedy, higher and potentially mobile saturations may be left in the saturated zone.

RAs 5b and 6b would remove an estimated 26,000 to 29,000 gallons of mobile and residual MCB from the saturated zone over the entire treatment area by steam injection and ERH respectively. Although the

potential volume reduction from the full-scale thermal remediation RAs is the largest considered in this FS, it is only minimally larger than the potential volume reduction under the focused treatment area RAs (i.e., 15,000 to 25,000 gallons of MCB). Additionally, these full-scale RAs do not further reduce the mobility of DNAPL in the saturated UBA (i.e., the principal threat) over focused treatment area RAs 5a and 6a. Even under full-scale thermal remediation, some DNAPL will be left in place following steam injection or ERH and will serve as a long-term source to groundwater, requiring hydraulic containment for hundreds or thousands of years. The minimal increase in volume reduction offered by RAs 5b and 6b (with no further reduction in mobility) is off-set by negative impacts on other balancing criteria including cost, short-term effectiveness, and implementability.

Short-Term Effectiveness

Four of the nine candidate RAs are either effective or moderately effective in the short-term as indicated below. As described in Section 6.1.2, GHG emissions were incorporated as one of several factors under the short-term effectiveness criterion, allowing for a balancing of factors without trading cleanup objectives for other environmental objectives. GHG emissions are not being evaluated as a threshold criteria or being used to screen out or exclude remedial alternatives from consideration. However, there is a large disparity in GHG emissions between candidate alternatives, including some that exceed the federal reporting threshold of 25,000 metric tons per year and have carbon footprints greater than several California power plants.

Short-Term Effectiveness Ranking

RA	Components	Short-Term Effectiveness Rank	Estimated GHG Emissions (pounds of GHGs)
RA 1	No Action	Not Effective	0
RA 2	ICs	Not Effective	0
RA 3	ICs, SVE	Not Effective (Unsaturated Zone Only)	6,000,000
RA 4a	ICs, SVE, HD with untreated water injection	Effective	11,000,000
RA 4b	ICs, SVE, HD with treated water injection	Effective	26,000,000
RA 5a	ICs, SVE, Steam Injection over focused treatment area	Moderately Effective	51,000,000 – 106,000,000
RA 5b	ICs, SVE, Steam Injection over entire treatment area	Less Effective	189,000,000 – 412,000,000
RA 6a	ICs, SVE, ERH over focused treatment area	Effective	33,000,000 – 61,000,000
RA 6b	ICs, SVE, ERH over entire treatment area	Less Effective	143,000,000 – 227,000,000

RA 1 is not protective of human health and the environment in the short-term because institutional controls would not be required to prevent human exposure to DNAPL-impacted soils. RA 2 includes institutional controls for DNAPL but would not control migration of VOCs in soil gas or reduce mobile DNAPL mass in the short-term.

RA 3 additionally includes SVE and would protect human health and the environment in the short-term by reducing DNAPL mass in the unsaturated zone and controlling VOC migration in soil gas. Disposable carbon/resin is identified as the lowest cost treatment technology for this RA and was highly effective in

meeting air emission ARARs during SVE field pilot testing in 2003. However, in the short-term, RA 3 would not reduce the mass of mobile DNAPL in the saturated zone (principal threat) or limit the potential for uncontrolled DNAPL migration.

All of the candidate RAs which reduce DNAPL mass in the saturated zone (RA 4a through 6b) are expected to protect human health and the environment in the short-term (7 to 9 year remedy durations) but with varying amounts of risk. RA 4a requires the least amount of infrastructure (and least complex) and has the lowest risk of remedy excursions or upset conditions. The ex-situ system for RA 4a includes DNAPL separation and groundwater filtration, but no additional treatment of the groundwater is performed prior to re-injection. RA 4b has the same short-term effectiveness as RA 4a but includes treatment of groundwater by disposable LGAC and advanced oxidation (HiPOx™), both of which are processes that have been successfully pilot tested at the Site. Although RAs 4a and 4b do not include a hot floor in the BFS (like for steam injection), the risks of downward migration under hydraulic displacement are slightly lower than for steam injection. RAs 4a and 4b also have the lowest carbon footprints (11 to 26 million pounds of GHGs) of the candidate RAs which reduce DNAPL mass in the saturated zone in the short-term (i.e., RAs 4a through 6b).

The short-term effectiveness of RA 6a is comparable to that for RAs 4a and 4b. Although thermal remediation projects pose an increased potential for accidental release of heated vapors or contaminated steam to atmosphere as a fugitive emission, the risks under ERH are less than for steam injection due to lower operating pressures and a more gradual heating process. The heated vapors must also be effectively recovered in order to prevent contaminant migration in the subsurface, and the high density of ERH wells (relative to steam injection) reduces the risk associated with vapor migration and increases the potential for contaminant recovery. The risks of downward migration during drilling for ERH are less than for steam injection since installation of a hot floor into the BFS is not required by this RA. Additionally, a "bottom up" heating approach using ERH further reduces the risks of downward migration in the short-term. This alternative has a moderately large carbon footprint (33 to 61 million pounds of GHGs) and is the only candidate thermal remediation alternative not expected to approach or exceed the mandatory reporting threshold of 25,000 metric tons per year.

RA 5a would be effective in protecting human health and the environment in the short-term but would also have higher risks than for RAs 4a, 4b, and 6a. Under RA 5a, there is an increased potential for heated vapors or contaminated steam to be accidentally released to atmosphere as a fugitive emission due to increased operating pressures and rapid heating process. RA 5a would additionally include air emissions from the steam boilers and an increased mobilization risk associated with installation of the 36 hot floor wells into the underlying BFS. RAs 5a and 5b can also increase the mobility of the DNAPL in the short-term and concentrate it at the steam front. Additionally, steam injection has the potential to de-saturate thin capillary barriers in the short-term, thereby increasing their permeability and the potential for DNAPL to migrate through the barrier, even if continuous. RAs 5a and 5b include implementation of a hot floor in the BFS to abate DNAPL migrating through the UBA, if any, but 100% effectiveness is not assured. Steam injection hot floors are infrequently implemented, and there is an absence of experience at comparable sites to reliably predict the performance of a hot floor at the Montrose Site. It is noted that EPA does not agree with the above characterization of mobilization risks and hot floor effectiveness during steam injection (CH2M Hill, 2013). RA 5a has the largest carbon footprint (51 to 106 million pounds of GHGs) of the candidate focused treatment area RAs. It should also be noted that EPA does not concur with all aspects of the energy balance used to estimate the amount of energy required for a steam injection remedy and the associated carbon footprint (see Section 5.1.6 and Appendix I for details; CH2M Hill, 2013).

RAs 5b and 6b have the greatest potential of all RAs considered in this FS for remedy excursions, upset conditions, and migration risks due to the scale of the thermal remediation project. These RAs would

require the largest ex-situ vapor and groundwater treatment systems, which increases the level of required maintenance and the potential for upset conditions or fugitive emissions to occur in the short-term. RAs 5b and 6b also have the largest carbon footprints (143 to 412 million pounds of GHGs) of all candidate RAs considered in this FS. RA 5b would be expected to generate approximately 47,000 metric tons per year of GHGs, significantly exceeding the mandatory reporting threshold. The annual GHG emissions from RA 5b would exceed the carbon footprints reported for approximately 40% of the California power plants in 2007 (Environment Oregon Research & Policy Center, 2009).

Implementability

Six of the RAs are moderately to highly implementable, while three of the RAs would be difficult to implement as follows:

Implementability Ranking

RA	Components	Implementability Rank
RA 1	No Action	Highly Implementable
RA 2	ICs	Highly Implementable
RA 3	ICs, SVE	Highly Implementable
RA 4a	ICs, SVE, HD with untreated water injection	Difficult to Implement[1]
RA 4b	ICs, SVE, HD with treated water injection	Moderately Implementable
RA 5a	ICs, SVE, Steam Injection over focused treatment area	Moderately Implementable
RA 5b	ICs, SVE, Steam Injection over entire treatment area	Difficult to Implement
RA 6a	ICs, SVE, ERH over focused treatment area	Moderately Implementable
RA 6b	ICs, SVE, ERH over entire treatment area	Difficult to Implement

Notes:
[1] Although technically implementable, RA 4a may not be administratively implementable unless a waiver to re-inject untreated groundwater was granted over the 5 year duration of the HD remedy.

RAs 1 through 3 are highly implementable but are not protective of human health and the environment. SVE is a widely implemented technology, and disposable carbon/resin is readily available for ex-situ vapor treatment. Highly skilled operators are not required for RA 3, and there are a large number of contractors available to provide SVE remediation services.

The implementability of hydraulic displacement under RAs 4a and 4b has already been demonstrated through field pilot testing, with moderate DNAPL recovery rates observed in all wells within the mobile DNAPL footprint. The implementability of re-injecting groundwater into the UBA has also been successfully demonstrated during HD pilot testing (partially due to mounding in the unsaturated zone). However, under both HD alternatives, significant maintenance would be required to abate equipment and well fouling from DDT and mineral precipitates. Under RA 4a, treatment of the groundwater is not performed prior to re-injection, so the ex-situ equipment is the least complex and would require the least maintenance. However, administratively, RA 4a may be difficult to implement because a waiver of the re-injection standards would be required from EPA and the State over the 5-year duration of the remedy, although previously granted during field pilot testing of this technology. RA 4b would administratively comply with the groundwater re-injection standards but would require operation and maintenance of a robust ex-situ treatment train and be moderately implementable.

RAs 5a and 6a would also be moderately implementable. Thermal remediation projects require a large amount of infrastructure to heat the subsurface, recover contaminants, and treat or dispose of contaminants ex-situ. The difficulty of implementing these RAs is increased by the coordination required

between the DNAPL and groundwater remedies for disposal of the extracted groundwater. The operational demands of the soil heating technologies will increase the difficulty of implementing these RAs by requiring more maintenance, including boiler maintenance, water pre-conditioning, and brine disposal for RA 5a. RAs 5a and 6a would also require highly skilled field operators and specialized technology vendors. Also, due to the higher mass removal rates, RAs 5a and 6a would require use of either a steam-regenerable carbon/resin or thermal oxidation ex-situ vapor treatment system, which are more complex and require additional maintenance and management of additional waste streams not required by the other RAs.

RAs 5b and 6b are the least implementable of the candidate alternatives considered in this FS. If implemented, these RAs would be one of the largest and most complex thermal remedies ever conducted. A significant amount of wells and infrastructure would be required by these full-scale thermal RAs, increasing the difficulty of implementing the project. RA 6b would require installation of 729 ERH electrodes, multi-phase extraction wells, and temperature monitoring points, which would be a significant implementability and cost burden to the project. RA 5b would require installation of 77 hot floors wells through the DNAPL-impacted UBA and into the underlying BFS, increasing the difficulty of implementing this RA and the potential for downward migration to occur as a result of drilling. RAs 5b and 6b have all the implementability challenges of RAs 5a and 6a but also the increased implementability challenges associated with the substantially increased scale and size of the remedy.

Cost

Estimated costs for the nine RAs ranged from $0 to $84 MM NPV as follows:

Cost Ranking

RA	Components	Cost Rank	Estimated NPV Cost (million $)		Unit NPV Cost @4% ($/lb MCB removed)
			@7%	@4%	
RA 1	No Action	No Cost	$0 MM	$0 MM	NA
RA 2	ICs	Low	$0.2 MM	$0.2 MM	NA
RA 3	ICs, SVE	Low to Moderate	$4.4 MM	$4.8 MM	$17-$19/lb removed by SVE
RA 4a	ICs, SVE, HD with untreated water injection	Moderate	$11.0 MM	$12.2 MM	$54-$83/lb removed by HD
RA 4b	ICs, SVE, HD with treated water injection	High	$18.0 MM	$20.1 MM	$113-$172/lb removed by HD
RA 5a	ICs, SVE, Steam Injection over focused treatment area	High	$22.3-$29.8 MM	$24.0-$32.4 MM	$91-$211/lb removed by steam injection
RA 5b	ICs, SVE, Steam Injection over entire treatment area	Very High	$50.8-$71.7 MM	$56.3-$84.0 MM	$203-$345/lb removed by steam injection
RA 6a	ICs, SVE, ERH over focused treatment area	High	$18.6-$23.0 MM	$20.1-$25.0 MM	$74-$158/lb removed by ERH
RA 6b	ICs, SVE, ERH over entire treatment area	Very High	$46.2-$59.7 MM	$52.6-$69.5 MM	$189-$285/lb removed by ERH

Notes:
NA = not applicable; no mass reduction in short-term
Unit cost reflects NPV cost of remedial component (i.e., SVE, HD, steam, or ERH) divided by estimated MCB mass reduction in pounds (lb); HD, steam injection, and ERH unit costs do not reflect costs or mass reduction offered by SVE in the unsaturated zone.

RAs 1, 2, and 3 are the lowest cost RAs considered in this FS ($0 to $4.8 million NPV) but are not fully protective of human health and the environment. RA 3 includes SVE in the unsaturated zone, which is highly cost effective in removing MCB at a unit cost of approximately $17 to $19 per pound of MCB removed by SVE.

RA 4a is the lowest cost ($11.0 to $12.2 million NPV) of the focused treatment area RAs. This RA is cost effective in removing MCB at a unit cost of approximately $54 to $83 per pound of MCB removed by hydraulic displacement (excludes cost effectiveness of SVE). Re-injection of untreated groundwater reduces the cost of this focused treatment RA but would require waiving the groundwater re-injection standards within the hydraulic containment area and TI waiver zone (as previously done during field pilot testing).

RAs 4b, 5a, and 6a all have similar costs ($18.0 to $32.4 million NPV) to remove DNAPL mass over a focused treatment area. RA 4b includes ex-situ treatment of groundwater prior to re-injection, which increases the cost of a hydraulic displacement remedy at the Site by $7.0 to $7.9 million NPV but without increasing the DNAPL mass removal. Consequently, RA 4b is substantially less cost effective than RA 4a at approximately $113 to $172 per pound of MCB removed by hydraulic displacement.

RA 6a, ERH over a focused treatment area, is less costly ($18.6 to $25.0 million NPV) than the equivalent steam injection alternative, RA 5a ($22.3 to $32.4 million NPV). At the low end of the cost ranges, the cost effectiveness of these alternatives is similar to or slightly higher than RA 4a at $74 to $91 per pound of MCB removed by ERH and steam injection respectively. However, if additional energy and time is required to achieve the thermal performance objectives, these alternatives are significantly less cost effective at approximately $158 to $211 per pound of MCB removed by ERH and steam injection respectively.

RAs 5b and 6b are the highest cost RAs considered in this FS, between $46.2 and $84.0 million NPV, depending on the amount of energy required to achieve the thermal performance objectives. Although treating a significantly larger area, these full-scale alternatives are estimated to remove minimally more MCB (all at residual saturation) from the saturated zone than RAs 5a and 6a. Consequently, these full-scale RAs are not cost effective at $189 to $345 per pound of MCB removed by thermal remediation, even at the low end of the assumed range.

State Acceptance

This criterion cannot be evaluated until the State has commented on the revised DNAPL FS and Proposed Plan. Therefore, evaluation of this criterion is deferred and will be addressed by EPA in the ROD. However, the State issued an interim advisory on green remediation in December 2009 (DTSC, 2009), a TBC for this FS, and may have concerns regarding candidate DNAPL RAs with high carbon footprints.

RAs 5a, 5b, and 6b are expected to approach or exceed the 25,000 metric tons of GHGs per year reporting threshold and may not be acceptable to the State. The energy-based carbon footprint for RA 5b is expected to be larger than 40% of the carbon footprints reported for California power plants in 2007 (Environment Oregon Research & Policy Center, 2009) and may impede the State's ability to comply with the Global Warming Solutions Act of 2006, a TBC for this FS. RA 6a, ERH over a focused

treatment area, is the only candidate thermal remedy with an estimated carbon footprint below the 25,000 metric tons of GHGs per year reporting threshold.

The GHG emission estimates presented in this FS exclude procurement of carbon offsets, which, if available at the time of remedy implementation, may be one option for partially mitigating the carbon footprint of the selected DNAPL remedy. However, it should be noted that procurement of carbon offsets does not reduce the GHG emissions generated by a DNAPL remedy (emissions are offset on paper through emission credits). Furthermore, the carbon offsets market may continue to undergo significant changes as new GHG regulations come into effect, and it is unclear whether or not purchased offsets will have any value in the future.

Public Acceptance

This criterion cannot be evaluated until the public has commented on the revised DNAPL FS and Proposed Plan. Therefore, evaluation of this criterion is deferred and will be addressed by EPA in the ROD.

Summary

In summary, a total of nine candidate DNAPL RAs were evaluated against the NCP performance criteria. RAs 1 through 3 do not meet the required threshold criteria for protection of human health and the environment because they do not include mobile DNAPL mass reduction in the saturated zone, which is the principal threat at the Site. RA 4a would not comply with ARARs unless the re-injection standards were waived in the short-term over the 5-year duration of the HD remedy. However, RAs 4b through 6b all unconditionally meet the required threshold criteria and could be selected by EPA as the remedy for DNAPL. These five candidate RAs and RA 4a offer varying performance relative to the five balancing criteria as summarized below:

> **RAs 4a and 4b:** These RAs are effective in the long-term by reducing the mobile DNAPL mass by hydraulic displacement. These RAs would remove an estimated 36,000 to 43,000 gallons of MCB from the unsaturated and saturated zones combined and would significantly reduce the mobility of DNAPL remaining in the saturated zone. This reduction in DNAPL volume and mobility would limit the potential for uncontrolled migration and reduce the potential for recontamination of the aquifers. However, these HD RAs are likely to remove less mobile DNAPL mass than the thermal remediation RAs, and any mobile DNAPL mass left in place may reduce the long-term effectiveness of the remedy. Although there are vertical migration risks under these hydraulic displacement RAs, the risks are believed to be comparable to those of RA 6a and less than the risks posed by the steam injection and full-scale thermal RAs. These RAs have the highest ranking for short-term effectiveness due to reduced implementation risks (no thermal remedy) and relatively small carbon footprints. RA 4b would be moderately implementable with technical challenges associated with injection well fouling and ex-situ treatment of groundwater containing high dissolved-phase VOC concentrations. RA 4a has the lowest cost and is between 17% and 61% of the cost of other candidate RAs but may not be administratively implementable unless the re-injection standards are waived over the 5-year duration of the remedy. These RAs rank highly in some of the balancing criteria and pose reduced risks of uncontrolled DNAPL migration relative to steam injection.
>
> **RAs 5a and 6a:** These RAs are effective in the long-term by reducing the mobile and residual DNAPL mass over a focused treatment area by steam injection or ERH. RAs 5a and 6a would remove an estimated 42,000 to 55,000 gallons of MCB from the unsaturated and saturated zones combined and would significantly reduce the mobility of DNAPL remaining in the saturated

zone. Although these RAs would likely remove more MCB volume than RAs 4a and 4b, a portion of the volume reduction would be from residual DNAPL which is immobile in the environment and not a risk to the groundwater remedy. RA 6a is more highly ranked for short-term effectiveness than RA 5a because of reduced migration and implementation risks and a smaller carbon footprint. RA 6a is the only candidate thermal remediation alternative not expected to approach or exceed the mandatory reporting threshold of 25,000 metric tons per year. These RAs have a moderate ranking for implementability because thermal remediation systems require substantial infrastructure, highly skilled and trained operators, and a relatively high level of maintenance. RAs 5a and 6a have a relatively high cost and are between 70% and 170% higher than the cost of RA 4a. RAs 5a and 6a rank highly in long-term effectiveness and reduction of toxicity, mobility, and/or volume, and RA 6a is the highest ranked alternative in all categories except for cost (RA 4a is the lowest cost alternative).

However, these thermal remediation RAs also have an increased risk of uncontrolled contaminant migration, either laterally within the UBA or vertically downward into the BFS. For this reason, RA 5a includes a steam injection hot floor within the BFS, and RA 6 includes a bottom up heating approach for ERH. Although these approaches will reduce, to some extent, the risks associated with downward vertical migration, 100% effectiveness is not assured. The layered and heterogeneous UBA is not ideally suited for steam injection (or hydraulic displacement), and as a result, there are risks that steam injection may not achieve target temperatures uniformly throughout the treatment area. Of the two candidate thermal technologies, ERH is better suited to the lithology of the UBA and is not dependent on permeability for heating the soils (only dependent on permeability for recovering the MCB vapors). RA 6a has several advantages over RA 5a for application to the Montrose Site as indicated in Section 7 of the revised FS.

RAs 5b and 6b: These RAs are effective in the long-term by reducing the mobile and residual DNAPL mass over the entire treatment area by steam injection or ERH. These RAs would remove an estimated 53,000 to 59,000 gallons of MCB from the unsaturated and saturated zones combined. Although RAs 5b and 6b are the highest ranked in MCB volume reduction, they offer no advantages over RAs 5a and 6a in terms of mobility reduction or mobile DNAPL mass reduction, the principal threat. Residual DNAPL mass outside the focused treatment area is immobile under gravitational forces, poses no risk to the groundwater remedy, and will be hydraulically contained in the long-term. Despite implementing thermal remediation over a large area of approximately 160,000 square feet, these RAs would not meaningfully reduce the containment timeframes required for groundwater. Long-term hydraulic containment would still be required for hundreds or thousands of years following the DNAPL remedy. Furthermore, these RAs, if implemented, would be one of the largest and most complex thermal remedies ever conducted. RAs 5b and 6b are ranked the lowest in terms of short-term effectiveness, implementability, and cost. There are substantial risks associated with a thermal remedy of this size and complexity, and the carbon footprint of RA 5b is so significant as to exceed the GHG emissions reported for 40% of the power plants in California in 2007 (Environment Oregon Research & Policy Center, 2009). A thermal remedy of this size would be difficult to implement due to the number of wells, volumes of waste to be handled, level of maintenance required, and number of highly skilled and trained operators required. Finally, the cost of the full-scale thermal RAs would exceed $50 million NPV and would be cost prohibitive for Montrose, who does not possess the financial resources of the government agencies that implement large-scale thermal remedies at some sites. Although RAs 5b and 6b rank highly in volume reduction, they offer no benefit over RAs 5a and 6a in terms of mobility or mobile DNAPL mass reduction and are the lowest ranked alternatives for short-term effectiveness, implementability, and cost.

The performance and protectiveness of the selected remedy will be monitored closely and reviewed every 5 years. Although some DNAPL mass will be left in place following remediation, none of the candidate alternatives are capable of removing all of the DNAPL mass from the low permeability UBA. It is technically infeasible at this time to cost effectively remove all of the DNAPL mass from the Site. For this reason, EPA established a TI Waiver Zone at the Site in 1999. However, as treatment technologies for DNAPL source areas continue to advance, a cost effective method for removing all of the DNAPL mass may be developed and could be implemented at the Site in the future.

Section 1.0

Introduction

1.0 INTRODUCTION

This final dense non-aqueous phase liquid (DNAPL) Feasibility Study (FS) is part of the remedial evaluation process being conducted for the Montrose Chemical Corporation of California (Montrose) Superfund Site (Site) located at 20201 S. Normandie Avenue, Los Angeles, California (**Figure 1.1**). A DNAPL composed of monochlorobenzene (MCB) and dichlorodiphenyltrichloroethane (DDT) has been detected beneath the Site. This final FS identifies and evaluates alternatives for the remediation of DNAPL at the Site and has been prepared in accordance with the *Guidance for Conducting Remedial Investigations and Feasibility Studies under Comprehensive Environmental Response, Compensation, and Liability Act, Interim Final* (U.S. Environmental Protection Agency [EPA], 1988). In general, the FS process begins with a preliminary evaluation of remedial technologies to screen out those that are not, at a minimum, moderately effective and implementable. The retained technologies are then assembled into a series of remedial alternatives with each successive alternative potentially providing a greater degree of environmental restoration. These assembled alternatives are evaluated against a set of nine criteria and then compared, relative to their ability to meet the performance criteria. This final FS provides a mechanism by which EPA can evaluate the technologies and remedial alternatives for DNAPL at the Montrose Superfund Site.

Montrose submitted a prior version of the DNAPL FS to EPA in September 1999 (Hargis + Associates, Inc. [H+A], 1999). EPA subsequently requested that additional testing be conducted to further characterize the nature and extent of DNAPL at the Site and to evaluate candidate technologies through laboratory and field pilot studies. Montrose conducted additional DNAPL-related testing at the Site during the period 2003 through 2009 and re-evaluated candidate remedial alternatives as documented in the draft DNAPL FS submitted to EPA on April 21, 2009 (Earth Tech, 2009a).

EPA commented on the draft FS in a letter dated January 27, 2010 (EPA, 2010a), and Montrose responded to EPA comments on April 27, 2010 (AECOM, 2010b; L&W, 2010). However, a number of technical and legal issues required resolution prior to revising the FS, and a series of reconciliation meetings and conference calls were held between September 2010 and February 2011 to address these issues. The majority of issues were satisfactorily reconciled as documented by the final meeting minutes submitted to EPA on April 21, 2011 (AECOM, 2011f). Although a small number of issues could not be reconciled, Montrose proceeded with revision of the DNAPL FS as requested by EPA in a letter dated July 22, 2011 (EPA, 2011b). A Revised DNAPL FS was submitted to EPA on December 7, 2011 (AECOM, 2011m).

The State of California Department of Toxic Substances Control (DTSC) commented on the Revised DNAPL FS in a memorandum dated August 21, 2012 (DTSC, 2012), and the Water Replenishment District (WRD) of Southern California commented on the Revised FS in a memorandum dated August 20, 2012 (WRD, 2012). Montrose prepared and submitted preliminary responses to DTSC and WRD comments in a letter dated October 10, 2012 (AECOM, 2012). The Technical Assistance Services for Communities (TASC) also commented on the Revised FS in a memorandum dated September 2012 (TASC, 2012), and on behalf of EPA, CH2M Hill commented on the Revised FS in a memorandum dated January 30, 2013 (CH2M Hill, 2013).

A National Remedy Review Board (NRRB) hearing was held on November 16, 2012, and NRRB commented in a letter dated February 1, 2013 (NRRB, 2013). EPA Region 9 subsequently responded to the NRRB comments in a letter dated March 22, 2013 (EPA, 2013).

A meeting was held on March 12, 2013, between EPA, DTSC, and Montrose to coordinate finalization of the DNAPL FS. The DNAPL FS was finalized in accordance with the consensus reached at that meeting regarding the process for addressing review comments. This final DNAPL FS supersedes the prior 1999, 2009, and 2011 versions and serves to evaluate candidate technologies and alternatives for the remediation of DNAPL at the Site.

This section of the report defines terms for use in the FS and establishes the purpose and organization of the FS. This section additionally provides background information regarding the manufacturing history at the Site, current Property features, and a chronological summary of DNAPL characterization activities. Additionally, this section describes the geology and hydrogeology beneath the Site, both regionally and locally.

1.1 DEFINITION OF TERMS

For purposes of clarification, several terms are used in this DNAPL FS as defined below:

- The “Property” refers to the Montrose Property, not the entire Superfund Site, and encompasses the area within the fenced property located at 20201 South Normandie Avenue, Los Angeles, California.
- The “Site” refers to the entire Montrose Superfund Site, which includes the Montrose property and other areas.

- The term "Central Process Area" or CPA refers to an approximate 2-acre portion of the Montrose Property where most of the technical grade DDT manufacturing operations were historically conducted.

- The term “DNAPL” refers to a dense non-aqueous phase liquid; i.e., a liquid which is immiscible with and has a density greater than water. For this FS, the term DNAPL refers specifically to the Montrose DNAPL which is composed of MCB and DDT. The term DNAPL does not refer to MCB dissolved in groundwater.

- The term “NAPL” refers to any non-aqueous phase liquid, either a DNAPL or light non-aqueous phase liquid (LNAPL).

- The term “RI” refers to the Remedial Investigation Report (EPA, 1998).

- The term Total DDT refers to the sum of concentrations reported for 2,4’ and 4,4’ isomers of DDT, DDE (dichlorodiphenyldichloroethylene), and DDD (dichlorodiphenyldichloroethane).

- The term “DNAPL concentration” refers to the sum of concentrations reported for MCB and Total DDT in soil containing DNAPL. In soils not containing DNAPL, MCB and Total DDT may also occur but not in DNAPL-phase (and therefore not as a DNAPL concentration). Additional details regarding DNAPL characterization methods are provided in Section 2.5.

- The term “mobile DNAPL” refers to DNAPL that occurs in sufficiently high saturations as to flow through soil pores under gravity or hydraulic displacement. As described in Section 2, DNAPL at saturations greater than 18.9% is considered mobile.

- The term “residual DNAPL” refers to DNAPL that occurs in low saturations, is bound in the soil pores by capillary forces, and is not mobile under gravity or hydraulic displacement. As described in Section 2, DNAPL at saturations less than 18.9% is not mobile. Given that the Site DNAPL is composed of 50% DDT and 50% MCB, a MCB saturation of less than 9.5% is considered immobile.

- The term “definite DNAPL” refers to the definitive occurrence of DNAPL at an investigation boring or sample. Additional details regarding the occurrence of DNAPL at the Site are provided in Section 2.5.

- The term “possible DNAPL” refers to the possible occurrence of DNAPL, which is not definitive, at an investigation boring or sample.

- The term “DNAPL-impacted area” refers to the area encompassing definite or possible DNAPL at the Property.

- The term “focused treatment area” refers to an area of approximately 26,000 square feet containing potentially mobile DNAPL as described in Section 2.5.3.

- The term “DNAPL architecture” refers to the spatial distribution and occurrence of DNAPL within porous media in the form of either ganglia or pools.

1.2 PROJECT BACKGROUND

This section briefly describes the location and manufacturing history of the Site. More detailed discussions of the Site location and historical Montrose operations at the Property are provided in the *Final Remedial Investigation Report for the Montrose Superfund Site* (EPA, 1998). The historical Site features described in this section are primarily limited to raw materials storage, specifically MCB, and manufacturing operations that ultimately were the source of DNAPL subsequently found in subsurface soils at the Property.

Site Location

The Montrose Property is located at 20201 South Normandie Avenue in the City of Los Angeles, California (**Figure 1.2**). The Site is located within a portion of the City of Los Angeles identified as the Harbor Gateway, which extends from Western Avenue to Normandie Avenue. The City of Torrance is located west of the Harbor Gateway, and unincorporated Los Angeles County is located east of the Harbor Gateway.

The Montrose Property occupies approximately 13 acres and is bounded by the Union Pacific Railroad (UPRR) right-of-way and Normandie Avenue to the east, the Jones Chemical Inc. (JCI) property and a right-of-way owned by the Los Angeles Department of Water and Power (LADWP) to the south, the former Boeing Realty Corporation property to the north, and Frito-Lay, Inc. to the west. The Farmer Brothers Coffee Company (Farmer Brothers) property is located to the south of the LADWP right-of-way.

The land use up to approximately one mile north and east of the Property, and approximately one half mile to the west, is zoned for industrial and commercial use. The area east of the Property is occupied by manufacturing and commercial facilities. The area to the west is occupied by manufacturing and an oil refinery. Land uses south and southeast of the Property are mixed manufacturing, commercial, and residential zoning. In a 2004 study conducted by EPA (EPA, 2004a), it was concluded that the most likely re-use scenario for the Montrose Property would be for industrial purposes, conforming with current zoning, surrounding property use, and the *Harbor Gateway Community General Plan* (City of Los Angeles, 1996).

Manufacturing History

Montrose leased the 13-acre Property from Stauffer Chemical Company (Stauffer) in 1947 and manufactured technical grade DDT at the Property from 1947 until 1982. Montrose manufactured DDT

by combining MCB and chloral in the presence of a powerful sulfuric acid catalyst (oleum). A number of processing steps then occurred to separate the DDT from the acid and residual raw materials; neutralize and purify the DDT; and crystallize the DDT to solid form. The solid DDT was then either bagged, or ground and bagged for sale. The Montrose plant produced as much as eighty million pounds of technical grade DDT annually. Montrose supplied technical grade DDT to, among others, the Department of Defense (DOD), United Nations (UN), and the World Health Organization (WHO).

Historical features associated with the Montrose DDT plant are shown in **Figure 1.3**. An aerial photograph of the plant from 1965 is shown in **Figure 1.4**. Most operations took place in the CPA. This portion of the Property is a rectangular area approximately 270 feet by 400 feet where the processing building, processing equipment, water recycling pond, electrical transformer station, filtration area, acid recovery plant, and several above- and below-ground tanks were located. The formulating and grinding plant, Warehouse No. 3, was built in 1964 directly south of the CPA and operated continuously from 1964 to 1982. Two 25,000-gallon, below-ground, redwood-lined, concrete tanks were installed in 1953 to store wastewater and were located near the southeastern corner of the CPA.

Raw materials consisting of MCB, chloral, and oleum were stored in aboveground tanks located in or near the CPA. Initially, raw material storage consisted of four 10,000-gallon tanks that contained (1) MCB, (2) oleum, (3) a mixture of MCB and chloral, and (4) spare oleum. All four tanks were located aboveground in the northeast quadrant of the CPA. An additional 10,000-gallon tank was added in 1950 to store a mixture of MCB and chloral. A 17,000-gallon tank was added in 1965 to store MCB. Both of these additional tanks were located aboveground in the northeast quadrant of the CPA. In 1968, the rail spur was modified; and two 50,000-gallon aboveground storage tanks were installed east of the formulating and grinding plant to allow transport of chloral and MCB via tank car. Dikes were constructed around these two tanks as a safety measure. In approximately January 1975, Montrose installed a 100,000-gallon aboveground fuel oil storage tank and related accessories west of the process building.

In addition to the Montrose operations, Stauffer operated a small benzene hexachloride (BHC) plant on the southeast corner of the Property from approximately 1954 until 1963 when the plant was dismantled and removed from the Site. Benzene was a feedstock in the production of BHC and was stored on the Property in a 5,000-gallon aboveground tank situated on a concrete pad. The benzene was trucked to the tank and then delivered from the tank to the plant through aboveground piping. Stauffer also operated a sulfuric acid manufacturing plant adjacent in the southwestern portion of the Site where JCI is currently located. The sulfuric acid plant was operated from the early 1940s until approximately 1952. The

sulfuric acid plant was dismantled after 1965. No DDT manufacturing operations occurred at the JCI property, and to date, no DNAPL has been detected in subsurface soils at that Property. Additional investigation of the JCI property has been conducted, including investigation for the presence of DNAPL (ARCADIS, 2011). In accordance with a letter dated August 15, 2011 (AECOM, 2011i) and although Montrose is not responsible for contaminants relating to JCI operations, the results of the recently completed DNAPL, soil, and soil gas investigations conducted at the JCI property are presented in Section 2 of the revised FS. Although VOCs related to former JCI operations were detected in soil and soil gas, no DNAPL was detected at the JCI property. The contaminants present in the unsaturated zone at the JCI property do not impact the candidate remedies for DNAPL at the Montrose Property and are therefore excluded from the remedy evaluation in this revised FS. JCI is responsible for the occurrence of VOCs related to their former operations at their property and will be evaluating candidate remedies separately. Furthermore, as detailed in a June 1, 2011 letter (L&W, 2011c), there are no technical advantages or cost efficiencies to be gained from combining unsaturated soil remedies between the two properties.

Montrose terminated its production process on or about July 2, 1982. By August 1982, Montrose had completely ceased operating the plant. The plant was fully dismantled and demolished by early 1983. EPA proposed the Site for the Superfund National Priorities List (NPL) in 1984, and the proposal was finalized in 1989.

1.3 PRESENT PROPERTY FEATURES

In 1985, the Montrose Property was re-graded and capped with asphalt to prevent exposure to underlying shallow soils impacted with DDT. Two large raised building pads were constructed at the Property as shown in **Figure 1.5**. Building Pad A is located in the eastern portion of the Property and is approximately 5 to 6 feet thick. Building Pad B is located in the central portion of the Property and is approximately 6 to 7 feet thick. Building Pad B is divided into two halves by a stormwater channel. The asphalt surface is sloped for stormwater drainage from an elevation of approximately 45 feet above mean sea level (MSL) in the northwest corner to approximately 40 feet MSL in the southeast corner of the Property.

During re-grading activities, concrete foundations and footings were either left in place, buried in debris pits and trenches, or crushed and used as aggregate beneath the asphalt cover. The types and locations of buried concrete debris at the Property were documented in a report entitled *Buried Concrete Debris Evaluation* (Earth Tech, 2003). The locations of buried concrete debris at the Property are shown in **Figure 1.6**.

A total of six temporary soil and debris containment cells are located in the western portion of the Property as shown in Figure 1.5. The cells were constructed by EPA to temporarily contain DDT-impacted soils and debris excavated from the historic stormwater pathway located along Kenwood Avenue, southeast of the Property. Five of the cells were constructed in 2001/2002, and one cell was constructed in 2008. The soils and debris contained in the cells will ultimately be incorporated into the soil remedial alternative selected for the Site. Until that time, the soil cells will remain in place and be inspected regularly to ensure effective containment of the soil and debris. EPA is maintaining the soil cells and the ultimate disposition of the stored soils is the responsibility of EPA (EPA, 2002). An aerial photograph from 2008, showing the present Property features, is provided as **Figure 1.7**.

Entrance to the Property is via South Normandie Avenue through a locking gate situated at the northeast corner of the Property (Figure 1.5). To prevent public access, chain link fencing with razor wire has been erected along the northern, western, and southern Property boundaries, and a wrought iron fence with razor wire bounds the east side of the Property. A former guard shack is located adjacent to the front gate in the northeast corner of the Property. Additionally, there is a storage container on-site for storage of field equipment and supplies. Water service is available through a metered line located at the northeast corner of the Property. Electrical and telephone services are not available at the Property. The Property remains vacant today.

Two sewer mains, the District 5 Interceptor and the Joint Outfall D (J.O.D.), run north to south beneath the eastern portion of the Property (Figure 1.5). The District 5 Interceptor is located approximately 50 feet west of the eastern Property boundary and is 62-inches in diameter. The J.O.D. is located approximately 30 feet west of the eastern Property boundary and is 57-inches in diameter. After 1953, Montrose discharged to the J.O.D sewer main through an 18-inch diameter sewer pipe (EPA, 1998). DDT-impacted sewer sediment was removed from the J.O.D. sewer main in 1996 and 1998 under EPA oversight (Earth Tech, 1999a). Prior to 1953, a 10-inch diameter sewer line ran from the former Montrose water recycling pond in the CPA to the East Torrance Extension Trunk located near the southwestern corner of the JCI property. Discharge to the 10-inch line was discontinued in 1953, and LACSD reported that the East Torrance Extension Trunk was abandoned in place in 1959 (LACSD, 1968).

1.4 REGIONAL HYDROGEOLOGIC FEATURES

A general description of the regional hydrogeologic features in the area surrounding the Site is provided below.

1.4.1 REGIONAL PHYSIOGRAPHY

The site is located on the Torrance Plain, which is a portion of the Los Angeles Coastal Plain (Coastal Plain) as shown in **Figure 1.8** (California Department of Water Resources [CDWR], 1961). The physiographic features of the Coastal Plain are the Torrance and Long Beach Plains, the El Segundo Sand Hills, the Dominguez and Alamitos Gaps, and portions of the Baldwin Hills, Rosecrans Hills, Dominguez Hill, Signal Hill, and the Palos Verdes Hills. The Baldwin Hills, Rosecrans Hills, Dominguez Hill, and Signal Hill are the surface expression of the Newport-Inglewood Uplift.

1.4.2 REGIONAL STRATIGRAPHY

The site is located within the West Coast Basin in the Torrance Plain. The basin is bounded on the north by the Ballona Escarpment, on the east by the Newport-Inglewood Uplift, on the southwest by the Palos Verdes Hills, and on the west by the Pacific Ocean (Figure 1.8). There are four major structural features in the vicinity of the site within the Torrance Plain. These features are the Charnock Fault, the Palos Verdes Fault, the Torrance Anticline, and the Gardena Syncline (CDWR, 1961).

The stratigraphy of the West Coast Basin includes Quaternary age continental and marine deposits and Tertiary age marine sediments overlying a basement complex of igneous and metamorphic rocks. The geologic units of hydrogeologic interest are, in order from oldest to youngest: the Pico Formation, the San Pedro Formation, the Lakewood Formation, older dune sand, alluvium, and active dune sand.

1.4.3 REGIONAL HYDROGEOLOGY

The Site is located in the groundwater basin known as the West Coast Basin (Figure 1.8). The West Coast Basin is located immediately west of the Newport-Inglewood Uplift. Pleistocene age and older formations have been downwarped forming the West Coast Basin. Groundwater in the West Coast Basin occurs in aquifers of varying water quality and usage. The principal aquifers at and in the vicinity of the Site are, in order from shallowest to deepest, the Gage aquifer, the Lynwood Aquifer, and the Silverado Aquifer (CDWR, 1961).

Regionally, the aquifers are primarily replenished with fresh water injected at two saltwater intrusion barrier projects located near the Pacific Ocean. The only significant source of natural replenishment comes from the Central Basin across the Newport-Inglewood Uplift. Injection barrier projects and pumpage primarily control water levels and flow directions within the basin. In the West Coast Basin, the base of the fresh water occurs at approximately 1,300 feet below MSL.

Hydrogeologic units in the West Coast Basin include aquitards and aquifers of varying compositions and water-yielding properties. These units, in order from first water encountered to deeper units, include the Bellflower aquitard (includes upper and lower aquitards, plus intermediate sand layer), the Gage aquifer, the Gage/Lynwood aquitard, the Lynwood aquifer, the Lynwood/Silverado aquitard, and the Silverado aquifer (**Figure 1.9**). Additional description of the site-specific stratigraphy is found in Section 1.5.1, and site-specific hydrogeology including groundwater flow direction, gradients, and hydraulic properties is provided in Section 1.5.2.

1.5 LOCAL HYDROGEOLOGIC FEATURES

A description of the hydrogeologic features beneath the Site is provided below, with an emphasis on the zones impacted by DNAPL. At the Site, DNAPL primarily occurs in the unsaturated zone and upper water-bearing zone, the Upper Bellflower Aquitard (UBA). Emphasis is placed on these stratigraphic units in this DNAPL FS. Stratigraphic units below the Bellflower Sand, such as the Gage and Lynwood Aquifers, are not impacted by DNAPL and are not discussed in detail in this FS.

1.5.1 STRATIGRAPHY

The stratigraphy of the Site is summarized below and is based on information provided in the 1998 Remedial Investigation (RI) Report (EPA, 1998) and subsequent characterization activities including the 2003/2004 DNAPL reconnaissance program (H+A, 2004b), the 2003 soil vapor extraction (SVE) pilot test (Earth Tech, 2004a), and the 2008 2-dimensional bench-scale studies (Earth Tech, 2008a). During the latter two characterization events, soil samples were specifically collected for physical properties analyses from stratigraphic units impacted with DNAPL. Physical properties results for unsaturated zone soils and the saturated UBA are provided in **Tables 1.1 and 1.2,** respectively. However, the physical properties data presented in these tables are based on a limited data set and do not account for potential variance throughout the Site.

A generalized stratigraphic column showing the various hydrologic units beneath the Property is provided as Figure 1.9. The nomenclature of the hydrologic units at the nearby Del Amo Superfund Site is slightly different and is additionally shown in this figure. However, the nomenclature used at the Del Amo Superfund Site will not be used for this FS. Because DNAPL occurs only at the Montrose Property and generally within the unsaturated zone and saturated UBA, use of this alternate nomenclature for deeper hydrologic units is not required in this FS. A cross-section location map and cross-sections illustrating the stratigraphy at the Site are provided in **Figures 1.10 through 1.13**. The information included in these

cross-sections is based primarily on detailed soil descriptions from continuous core logged during Site characterization activities.

Unsaturated Zone (0-60 feet bgs)

The unsaturated zone at the Property occurs from land surface to approximately 60 feet below grade surface (bgs). The upper 1 to 4 feet at the Property is generally composed of reworked or fill-type materials and debris. Below the surficial layer of reworked materials, the unsaturated zone is characterized as having three generalized soil layers identified, from upper to lower, as Playa Deposits (PD), Palos Verdes Sands (PVS), and the unsaturated UBA. Each of these layers is individually described below. The depth intervals indicated are generalized and vary across the Property to some degree.

Reworked Materials (0-4 feet bgs)

Reworked or fill-type material consisting of moderately to highly plastic dark brown clayey silt, silty clay, or clay is generally encountered from ground surface to between 1 and 4 feet bgs in most areas of the Property. The reworked material additionally contains some construction debris consisting of concrete, brick, gravel, and wood. The thickness of the reworked materials is thicker within the raised building pads, between approximately 5 and 7 feet. Within the buried concrete debris trenches and pits, reworked materials are present to approximately 15 feet bgs (Earth Tech, 2003).

Playa Deposits (4-25 feet bgs)

The PD occurs from approximately 4 to 25 feet bgs at the Property and is primarily composed of medium brown, moist, dense silts, with some sand and clay. In 2003, the physical properties of PD soils were measured during an SVE pilot test conducted within the CPA at EW-1 (**Figure 1.14**), and the average properties from three samples were reported as follows (Table 1.1):

- % sand = 22.7%
- % silt/clay = 77.3%
- Dry bulk density = 1.48 grams per cubic centimeter (g/cc)
- Moisture content = 18.4%
- Total porosity = 45.1%
- Effective porosity = 17.3%
- Horizontal permeability to air = 12 millidarcies or 1.1×10^{-05} centimeters per second (cm/s)

Soils in the PD exhibit a relatively low horizontal permeability to air and have a moderate moisture content. Soils in the PD are also characterized as having a relatively high total porosity but a substantially lower effective or interconnected porosity.

Palos Verdes Sand (25-45 feet bgs)

Soils in the PVS are primarily composed of light yellowish brown to light olive-brown, well sorted sand. At the Property, the PVS is generally encountered from approximately 25 to 45 feet bgs. Thin well-cemented fossiliferous sand is encountered at the base of the PVS. This cemented fossiliferous sand is thickest in the western portions of the Property (up to 8 feet) and appears to dip slightly and thins to less than 2 feet to the east (Figure 1.11). The average physical properties of PVS soils, as measured during the 2003 SVE pilot test from three samples, are summarized as follows (Table 1.1):

- % sand = 77.2%
- % silt/clay = 22.8%
- Dry bulk density = 1.43 g/cc
- Moisture content = 6.2%
- Total porosity = 45.9%
- Effective porosity = 31.2%
- Horizontal permeability to air = 2,437 millidarcies or 2.3×10^{-03} cm/s

Soils in the PVS are characterized as having a low moisture content and a relatively high effective porosity. Soils in the PVS also have a moderate to high permeability to air.

Unsaturated Upper Bellflower Aquitard (45-60 feet bgs)

The unsaturated portion of the UBA occurs from approximately 45 feet bgs to groundwater at approximately 60 feet bgs. Soils within the UBA are characterized as being heterogeneous with varying layers of sands and low permeability silts/clays. The upper 5 to 10 feet of the unsaturated UBA are typically characterized as being a sand layer, while the remaining 5 to 10 feet of the unsaturated UBA are typically characterized as being a silt/clay layer. The average physical properties of unsaturated UBA soils, as measured during the 2003 SVE pilot test from three samples, are summarized as follows (Table 1.1):

Unsaturated UBA, Sand Layer:

- % sand = 81.1%
- % silt/clay = 18.9%
- Dry bulk density = 1.29 g/cc
- Moisture content = 7.1%
- Total porosity = 51.6%

- Effective porosity = 39.9%
- Horizontal permeability to air = 3,458 millidarcies or 3.3×10^{-03} cm/s

Unsaturated UBA, Silt Layer:

- % sand = 23.8%
- % silt/clay = 76.2%
- Dry bulk density = 1.16 g/cc
- Moisture content = 37.2%
- Total porosity = 58.0%
- Effective porosity = 26.4%
- Horizontal permeability to air = 6 millidarcies or 5.5×10^{-06} cm/s

The upper portion of the unsaturated UBA has a high sand content, low moisture content, and exhibits a high effective porosity. The upper portion of the unsaturated UBA exhibits the highest permeability to air in the unsaturated zone. In contrast, the lower portion of the unsaturated UBA has a low sand content, a high moisture content, and a low effective porosity. The lower portion of the UBA exhibits a low horizontal permeability to air.

Saturated Upper Bellflower Aquitard (60-105 feet bgs)

Beneath the Property, the saturated UBA extends from groundwater, at 60 feet bgs, to a depth of approximately 105 feet bgs (Figure 1.11). The majority of the DNAPL detected at the Property is found within this lithologic unit as discussed further in Section 2.0. The saturated UBA is heterogeneous and interbedded with layers of fine-grained sand, silty sand, and silt, with lesser amounts of fine to medium sand and occasional clayey intervals. The upper portion of this interval tends to be composed of more sand layers, while the lower portion tends to be composed of more silt layers. These silt zones typically contain minimal sand, are firm to hard, and generally exhibit low or no plasticity. Sand layers within this portion of the UBA are generally well sorted. These interbedded layers vary in both thickness and continuity across the Property. The layers vary in thickness between a minimum of 0.1-foot and a maximum of approximately 4 to 5 feet. Overall, the sediments that comprise the lower portion of the UBA are interbedded, variable in thickness, and display varying degrees of lateral continuity (Figures 1.11 through 1.13). Individual intervals, comprised predominantly of either silt or sand beds, often correlate between adjacent borings even though they may vary in overall thickness or the number of beds comprising the interval.

The lowest portion of the UBA from about 95 feet bgs to the base of the unit at about 105 feet bgs consists primarily of silty sand (Figure 1.13). This silty sand interval, which ranges in thickness from about 8 to 23 feet, represents a transition from the overlying finer-grained silts to the underlying coarser-

grained BFS. This transition zone was observed in all 11 soil borings drilled to this depth at the Montrose Property, although there remains some uncertainty as to the lateral continuity of this zone at the Site (CH2M Hill, 2010b and AECOM, 2010d). The potential for DNAPL to penetrate this transition zone is further discussed in Section 2.6.4.

In 2008, the physical properties of saturated UBA soils were measured during 2-dimensional thermal remediation bench-scale testing conducted southwest of the CPA from boring 2DSB-1 (Figure 1.14), and the average properties from nine samples (six sand, three silt; Table 1.2) were reported as follows (Earth Tech, 2008b):

Saturated UBA, Sand Layers:

- % sand = 89.4%
- % silt/clay = 10.6%
- Dry bulk density = 1.54 g/cc
- Wet bulk density = 1.85 g/cc
- Total porosity = 42.4%
- Effective porosity = 29.0%
- Vertical permeability to water = 819 millidarcies or 7.1×10^{-04} cm/s

Saturated UBA, Silt Layers:

- % sand = 24.9%
- % silt/clay = 75.1%
- Dry bulk density = 1.45 g/cc
- Wet bulk density = 1.85 g/cc
- Total porosity = 46.4%
- Effective porosity = 15.3%
- Vertical permeability to water = 16 millidarcies or 1.4×10^{-05} cm/s

There are also some lithologic trends in the UBA that occur from west to east across the Montrose Property that are apparent in cross-section A-A' (Figure 1.11). In the western area, the lower portion of the UBA contains a greater percentage of sand intervals, whereas in the eastern area there is a higher percentage of silt and silty sand intervals. There is also a gradual easterly dip of approximately 2 degrees from horizontal to the strata that comprise the lower portion of the UBA. This dip is exhibited both by the top of silt layers and a fossiliferous zone encountered near the base of the UBA at depths of approximately 81 to 86 feet (Figures 1.11 through 1.13). If present in sufficient quantities, DNAPL can migrate along the top of dipping low permeability silt layers under gravitational forces in the down-dip direction. A geostatistical evaluation of the silt layers in the UBA indicated that the average down-dip direction was 8 degrees north of east as shown in **Figure 1.15** (H+A, 2008d). T he geostatistical evaluation also indicated that the silt layers were not laterally continuous over a distance of more than 50

feet. The significance of this issue is that DNAPL can migrate vertically downward by "stair stepping" off of the edge of discontinuous silt layers. When migrating DNAPL intercepts a discontinuity in a silt layer, the DNAPL can migrate down to an underlying layer either under gravity or as a result of a DNAPL remedial action.

Bellflower Sand (105-130 feet bgs)

The Bellflower Sand (BFS) underlies the UBA and occurs from approximately 105 to 130 feet bgs. The BFS comprises an interval of nearly continuous sand that coarsens with depth. The upper half of the unit typically consists of fine sand while the lower portion typically consists of fine to medium or fine- to coarse-grained sand. No DNAPL has been definitively identified in the BFS, although EPA believes that DNAPL is present in the BFS based on groundwater data collected in 2008 (H+A, 2008b and 2008c; EPA, 2008b). The base of the BFS is relatively flat beneath the Montrose Property as shown in **Figure 1.16** (AECOM, 2010f). East of the Montrose Property, the bed dip increases to approximately 2 degrees from horizontal and is generally oriented in an easterly direction. Although the basal elevation of the BFS is relatively certain at the Montrose Property (i.e., 17 control points at and immediately surrounding the Montrose Property), there is some uncertainty in the off-Property areas where there are fewer control points and some anomalous elevations (e.g., MWG004 located at the former Boeing Property to the north). The potential presence of DNAPL in the BFS is further discussed in Section 2.5.2.

Lower Bellflower Aquitard

The Lower Bellflower Aquitard (LBA) underlies the BFS and occurs to a depth of approximately 140 feet bgs. The LBA consists predominantly of brown silt, clayey silt, and silty sand.

Gage Aquifer /Unnamed Aquitard

The Gage aquifer, consisting primarily of fine-grained sand, is encountered beneath the LBA to a depth ranging from approximately 200 to 210 feet bgs. An unnamed aquitard underlying the Gage aquifer has been informally named the Gage-Lynwood aquitard. It consists of silt, sandy silt, and/or clayey silt interbedded with fine-grained silty sand and appears to be laterally continuous across the site.

Lynwood Aquifer /Unnamed Aquitard

The upper 20 feet of the Lynwood aquifer consists of dark gray fine- to medium-grained sand. This sand is underlain by as much as 8 feet of dark gray silt or clay of varying plasticity. Approximately 10 to 30 feet of gray, well-graded sand, gravelly sand, and sandy gravel with some silty sand interbeds underlie the top 20 to 30 feet of the Lynwood aquifer. The top of the Lynwood aquifer occurs approximately between

270 to 305 feet bgs across the site. The thickness of the Lynwood aquifer, based on borings drilled at the site, ranges from approximately 33 feet to greater than 108 feet. An unnamed aquitard, approximately 205 feet thick, separates the Lynwood aquifer and the underlying Silverado aquifer beneath and east of the site.

Silverado Aquifer

The Silverado aquifer consists of fine- to coarse-grained, blue-gray sands and gravels with discontinuous layers of silt and clay. The top of the Silverado aquifer was encountered at a depth of 490 feet bgs in the vicinity of the property. The Silverado aquifer reportedly attains a maximum thickness of about 500 feet.

1.5.2 HYDROGEOLOGY

The depth to the water table beneath the property is currently about 60 feet bgs. Historically, the water table has been considerably deeper, potentially on the order of 30 feet deeper than recent water levels, due to over-pumping from the groundwater basin (EPA, 1998). These data indicate that the water table may have been as deep as 90 feet bgs at the Montrose Property in the 1950's. Following adjudication of the groundwater basin in the 1960's, which limited groundwater pumping from the basin and operation of injection barriers along the coast, water levels throughout the basin have been gradually recovering. Groundwater levels may continue to rise in the future which may result in an increase in the saturated thickness of the UBA and a decrease in the portion of the UBA that comprises the unsaturated zone.

Horizontal Gradients

The groundwater flow direction in the UBA in October 2006 was to the south and southeast, but varied locally. Near the Property, the groundwater contours suggest that groundwater in the UBA flows from the northwest and northeast and converges in the area south of the Property. This may be due in part to a pinching out of the fine-grained sediments that comprise the UBA in the area southwest of the Montrose property. The horizontal hydraulic gradient in the UBA immediately downgradient of the Property ranges from 0.0004 to 0.0008 (**Figure 1.17**). The horizontal hydraulic gradient on the Property is somewhat steeper ranging from about 0.001 to 0.002. The regional direction of groundwater flow in the UBA has been about the same since 1988 (H+A, 2007a).

The groundwater flow direction in the BFS in the vicinity of the Site in October 2006 was to the southeast. The horizontal hydraulic gradient in the BFS ranges from approximately 0.0004 to 0.0007 (**Figure 1.18**). The horizontal hydraulic gradient within the BFS beneath the Montrose property is

somewhat steeper, averaging about 0.001. The regional direction of groundwater flow in the BFS has been about the same since 1987 (H+A, 2007a).

The groundwater flow direction in the Gage aquifer in October 2006 was to the southeast. The horizontal hydraulic gradient in the Gage aquifer is approximately 0.0007 within the vicinity of the Property. The hydraulic gradient to the southeast of the Property slightly increases to 0.001 (**Figure 1.19**). The regional direction of groundwater flow in the Gage aquifer has been about the same since 1987 (H+A, 2007a).

The groundwater flow direction in the Lynwood aquifer in October 2006 was to the east. The horizontal hydraulic gradient in the Lynwood aquifer is approximately 0.0002 (**Figure 1.20**). The direction of groundwater flow in October 2006 was about the same as the direction of groundwater flow observed in 2002 and 2004 (H+A, 2007a). In 1995, groundwater flow in this unit was to the southeast.

Vertical Gradients

Differences in water level elevations in adjacent hydrostratigraphic units provide an indication of the direction and magnitude of vertical hydraulic gradients across the aquitards that separate these units. The following is a summary of the differences in water level elevation between the UBA, BFS, Gage aquifer, and Lynwood aquifer observed in October 2006.

- UBA - BFS: Water level elevations in the BFS monitor wells were approximately 0.2 to 1.0 foot lower than water level elevations in adjacent UBA monitor wells. This indicates that there is currently a downward vertical gradient between the UBA and the BFS. The magnitude of the vertical gradient is greater in the area southeast of the Property and tends to decrease to the west. Within the CPA, the downward vertical gradient is approximately 0.014, which is 7 to 14 times higher than the corresponding horizontal gradient in this portion of the Property.
- BFS - Gage aquifer: Water level elevations in the Gage aquifer monitor wells were approximately 1.0 foot lower than water level elevations in adjacent BFS monitor wells. This indicates that there is a downward vertical gradient between the BFS and the Gage aquifer.
- Gage aquifer - Lynwood aquifer: Water level elevations in the Lynwood aquifer monitor wells were approximately 10 feet lower than water level elevations in adjacent Gage aquifer monitor wells. This indicates that there is a downward vertical gradient between the Gage aquifer and the Lynwood aquifer.

Hydraulic Properties - UBA

The horizontal hydraulic conductivity of the UBA is estimated to vary between 1 and 100 feet per day (ft/d) (between 3.5×10^{-04} and 3.5×10^{-02} cm/s) based on slug and constant rate discharge tests conducted prior to 1992 (EPA, 1998; Table 4.6 of the Final RI Report). The average hydraulic conductivity represented by these tests was 22 ft/d or 7.8×10^{-03} cm/s.

Additional hydraulic testing of the UBA was conducted in 2004-2005 during DNAPL extraction testing (H+A, 2008g). The transmissivity of the UBA was estimated to be 5,200 and 3,700 gallons per day per foot (gpd/ft) at UBE-1 and UBT-1 respectively based on constant rate tests. Assuming a vertical thickness of 30 feet (consistent with the screened intervals at these wells), the corresponding hydraulic conductivities are 23 and 17 ft/d respectively ($8.0x10^{-03}$ and $6.0x10^{-03}$ cm/s) which are similar to the average conductivity represented by the pre-1992 aquifer tests. However, as indicated by EPA (EPA, 2010a), the numerical solution used to estimate these transmissivities (Cooper-Jacobs straight-line method) does not account for leaky aquifer conditions or re-injection of groundwater into nearby wells UBI-1 and UBI-2.

The horizontal hydraulic conductivity of the UBA was also estimated at approximately 2 ft/d ($7.0x10^{-04}$ cm/s) by CH2M Hill in 2008, which is at the low end of the aquifer test results range (CH2M Hill, 2008). On behalf of EPA, CH2M Hill developed and calibrated a hydraulic flow model of the dual-site groundwater operable unit (i.e., Montrose and Del Amo Superfund Sites). However, the hydraulic model considered an area significantly larger than the Montrose Property (i.e., 5,400 acres) and represented the UBA by a single layer, which does not account for the multi-layered and heterogeneous nature of the UBA at the Montrose Property.

The vertical hydraulic conductivity of the UBA is estimated to vary between 0.00003 and 8 ft/d (between $1.1x10^{-08}$ and $2.9x10^{-03}$ cm/s) based on physical properties testing of 14 soil samples collected during remedial investigation activities (EPA, 1998; Table 4.7 of the Final RI Report). The lithology of the soil samples collected for analysis also varied significantly from clay to fine-grained sand. This large range of hydraulic conductivity indicates that the UBA is highly heterogeneous. The average vertical hydraulic conductivity represented by these tests was 0.006 ft/d or $2.2x10^{-06}$ cm/s.

As described in Section 1.5.1, additional physical properties testing of UBA soil samples was conducted in 2008. The vertical hydraulic conductivity of the samples ranged from 0.004 to 4 ft/d ($1.4x10^{-06}$ to $1.4x10^{-03}$ cm/s), which occurs within the range identified in the Final RI Report. Additionally, the calibrated hydraulic flow model (CH2M Hill, 2008) estimated a vertical hydraulic conductivity of approximately 0.01 ft/d ($3.5x10^{-06}$ cm/s) based on a horizontal to vertical permeability ratio of 200:1. Although the vertical gradient is roughly 10 times larger than the horizontal gradient, the vertical hydraulic conductivity is roughly 200 to 1,000 times smaller than the horizontal hydraulic conductivity on average. Therefore, the vertical groundwater flow in the UBA is estimated to be substantially lower than the horizontal groundwater flow.

Hydraulic Properties - BFS

A 12-hour aquifer test was performed at BFS monitoring well BF-9 during the RI. However, the drawdown data obtained from this test were superseded by results from longer-term testing at pilot test wells installed at the site. Results from the pilot testing program were simulated using the Remedial Design model as part of the design of the groundwater remedy for the Montrose site. Based on the model calibration simulations, the large-scale average hydraulic conductivity for the BFS in the vicinity of the CPA is approximately 250 feet per day (8.8 x 10^{-2} cm/s).

1.6 PREVIOUS INVESTIGATIONS

Various investigations have been conducted to characterize the nature and extent of DNAPL at the Property since it was first detected in November 1987. A chronologic summary of major DNAPL and volatile organic compound (VOC) characterization activities conducted at the Property since 1987 is provided below. This summary does not present all DNAPL-related activities due to the extensive characterization conducted at the Site over the past 21 years. A more complete summary of DNAPL-related activities conducted at the Property up to 1998 is provided in the RI Report (EPA, 1998).

1988/1989

- A focused field investigation was conducted to determine the chemical and physical characteristics of DNAPL and the rate of DNAPL accumulation in monitoring well MW-2 (H+A, 1999).
- Detailed lithologic logging and soil, groundwater, and DNAPL sampling and analyses was conducted at and in the vicinity of the CPA to depths of 130 feet bgs (H+A, 2004a).
- Design, construction, and testing of extraction well UBT-1 and observation wells UBT-2 and UBT-3 in the DNAPL-impacted area (H+A, 1999).
- Design, construction, and sampling of BFS monitoring well BF-9 adjacent to monitoring well MW-2 (EPA, 1998).

1991

- Design, construction, and testing of pilot extraction well UBE-1 for 28 days (H+A, 1992).

1998/1999

- Collection and analysis of DNAPL samples for physical properties and chemical composition to support evaluation of DNAPL remedial technologies and process options as part of the DNAPL FS (H+A, 1999).

2003/2004

- Drilled and sampled a total of 60 borings in the vicinity of the CPA as part of the DNAPL Reconnaissance Program to further define the extent and distribution of DNAPL on-Property (H+A, 2004b).
- Conducted short and long-term SVE pilot tests within the CPA and from all three unsaturated zone layers, including the PD, PVS, and UBA (Earth Tech, 2004a).
- Conducted a soil gas survey at the Property at 33 locations from three different depth intervals, including 5, 15, and 35 feet bgs (Earth Tech, 2004c).

2004/2005

- Design, construction, and extraction testing of groundwater/DNAPL at wells UBE-1, UBE-2, UBE-3, UBE-4, and UBT-1 over a 329 day period. (H+A, 2007c and 2008g).
- Drilling and sampling of soil from 152 borings as part of the Supplemental Soil Investigation in support of the Soil program. This work included 10 borings drilled to 90 feet bgs within the saturated UBA and logged for the presence of DNAPL (AECOM, 2011l, Earth Tech, 2005, and H+A, 2006a).

2006

- Completed measurements of the boiling point of the DNAPL, as detailed in an August 2006 report (H+A, 2006b).
- Completed measurements of physical properties of the DNAPL at temperatures ranging from 10 to 90 degrees Celsius (^{o}C) and conducted a bench-scale, one-dimensional steam column test as described in the August 2006 report summarizing the results of this work (Davis, 2006).

2007 to 2009

- Collected depth discrete groundwater samples and soil samples from the BFS to evaluate the possible presence of DNAPL (H+A, 2008b and 2008c).
- Conducted two-dimensional testing to evaluate the mobility of DNAPL during steam flushing, including physical properties testing of saturated UBA soils and DNAPL (Earth Tech, 2007c, 2007e, and 2008a). Physical properties testing of the DNAPL at temperatures between 20°C and 120°C was conducted in December 2008. The steam flushing experiments were conducted in 2008 and 2009, and results of experiment Runs 1 and 2 were provided to EPA in March and August 2009 (University of Toronto, 2009a and 2009b). A comprehensive summary report of the steam flushing experiments was submitted to EPA in December 2011 (AECOM, 2011k).

  Despite significant efforts, attempts to conduct two-dimensional electrical resistance heating experiments were terminated due to mechanical failure of the test cell under pressure. Additional details regarding the ERH two-dimensional testing was provided to EPA in March 2009 (Queen's University, 2009).
- Conducted computer modeling of hydraulic displacement alternatives for DNAPL as reported to EPA in January and April 2009 (H+A, 2009a and 2009b).
- Evaluated containment zone timeframes for DNAPL remedial alternatives (H+A, 2008e and 2009c). EPA commented on the containment timeframe memorandum in a letter dated December

23, 2008 (EPA, 2008g). A revised technical memorandum has been generated in response to EPA comments. A copy of the revised memo, responses to EPA comments and a copy of the EPA comment letter are provided in **Appendix G**.

- Evaluated candidate focused treatment areas for thermal DNAPL remedial alternatives (Earth Tech, 2008b).
- Installed one additional well, UBE-5, adjacent to soil boring SSB-12 and monitored for passive DNAPL accumulation (Earth Tech, 2008j). A short-term extraction test was conducted at UBE-5 in December 2008, confirming the presence of mobile DNAPL at this location. A summary of the extraction test results was provided to EPA in May 2009 (Earth Tech, 2009b).
- Continued to gauge and purge DNAPL, which has passively accumulated, from on-Property wells screened in the saturated UBA on a semi-annual basis; this activity has been on-going in varying frequencies since 1988.
- Montrose prepared detailed responses to a DNAPL remedial technology study conducted by CH2M Hill in November 2007 entitled "*Responses to EPA Focus Questions Pertaining to the Application of Thermal Treatment and Hydraulic Displacement at DNAPL Sites*". Montrose does not concur with the assessment of DNAPL remedial technologies in that study, and rebuttal discussions are provided for consideration in **Appendix K** of this FS.
- JCI conducted a DNAPL investigation at their property in August and September, 2010, including drilling of six deep soil borings to between 90 and 100 feet bgs. No DNAPL was detected in any of the soil borings or samples as reported in the *DNAPL Reconnaissance Investigation Data Report* (ARCADIS, 2011).
- A significant number of DNAPL reference and case study documents were consulted during development of this FS, not all of which are cited in Section 8 of the DNAPL FS. To capture the sum of information considered during evaluation of DNAPL remedial technologies, a compendium of the reference documents has been prepared and is provided in **Appendix L** of this FS.

1.7 TI WAIVER ZONE

This FS evaluates remedial alternatives for DNAPL associated with the Montrose Site. A similar evaluation process was completed for groundwater contamination associated with the Montrose site. Ultimately, EPA issued a Record of Decision (ROD) which "presents the selected remedial action for (1) groundwater contamination, and (2) isolation and containment of non-aqueous phase liquids (NAPL) (EPA, 1999)." The groundwater ROD indicates that although options are being evaluated for removing some of the DNAPL "it will not be practicable to remove enough (virtually all) DNAPL so as to attain drinking water standards in the immediate vicinity of the DNAPL (EPA, 1999)." In light of this, EPA issued a waiver of the requirement to attain cleanup levels to a region of groundwater in the vicinity of the DNAPL.

As it relates to the TI Waiver zone, the groundwater ROD discusses DNAPL associated with the Montrose site and light non-aqueous phase liquid (LNAPL) associated with the Del Amo Superfund Site.

Because of overlap between the areas affected by Montrose DNAPL and Del Amo LNAPL, a single TI Waiver zone was established for the Joint Site (**Figure 1.21**). Details regarding the TI Waiver zone are provided in the groundwater ROD (EPA, 1999). The lateral and vertical extents of the TI Waiver zone for the MCB plume associated with the DNAPL at the Montrose site are summarized below.

1.7.1 LATERAL EXTENT

The lateral extent of the TI Waiver Zone was selected to be as small as possible without causing adverse migration due to containment pumping (EPA, 1999). Since the groundwater ROD requires a containment zone downgradient of the DNAPL-impacted area to contain MCB-impacted groundwater, the TI Waiver zone must be sufficiently large to ensure that DNAPL would not be mobilized by containment pumping. Thus, the TI Waiver zone is larger than the known extent of the DNAPL (Figure 1.21). All DNAPL remedial alternatives considered by this FS would be conducted within the lateral extents of the TI Waiver Zone. The lateral extent varies depending on the hydrogeologic unit; it is generally most expansive in the shallowest unit, the water table zone, and smallest in size in the deepest unit, the Gage aquifer.

1.7.2 VERTICAL EXTENT

As indicated in the GW ROD (EPA, 1999), the TI Waiver zone at the Montrose site includes the UBA, the BFS, and the Gage aquifer (Figure 1.21). All DNAPL-impacted saturated zones occur within the TI Waiver Zone. As with the lateral extent, the vertical extent of the TI Waiver Zone is larger than the known extent of DNAPL.

1.8 INTERRELATIONSHIP OF DNAPL, SOIL, AND GROUNDWATER REMEDIES

The remedies for soil, groundwater, and DNAPL at the Site are interrelated. DNAPL is present in soils beneath the Property and serves as a source of MCB to groundwater. The combined remedies for soil, DNAPL, and groundwater individually and collectively serve to protect human health and the environment. Additionally, the relationship and timing of the remedies must be considered in order to implement them effectively. As such, the evaluations completed as part of this DNAPL FS have been conducted with consideration to the interrelationship between the potential DNAPL, soil, and groundwater remedial programs.

A groundwater pump and treat remedy was selected for the Site in 1999 as specified in the ROD (EPA, 1999). The ROD establishes requirements for groundwater within the area of DNAPL occurrence, and contains provisions for limiting adverse migration of DNAPL during the groundwater remedy.

Additionally, the ROD requires provisions for containment of dissolved-phase MCB surrounding DNAPL sources both during and following the groundwater remedy. The pump and treat remedy will include a series of groundwater extraction and injection wells and an on-Property aboveground treatment system located as shown in **Figure 1.22**. The duration of the active extraction pump and treat remedy is expected to be between 35 and 50 years based on the most recent modeling results (EPA, 2008c), while pumping and treatment for containment is expected to last much longer (H+A, 2008e and 2009c; Appendix G).

A soil remedy has not yet been selected for the Site, and candidate soil remedial alternatives are currently being evaluated as part of a revised Soil FS being prepared concurrently by Geosyntec. A prior version of the Soil FS was submitted to EPA in 1999 (Earth Tech, 1999b) and considered six different remedial alternatives for soil including SVE, capping, and excavation with on-Property treatment. This revised DNAPL FS evaluates SVE as a remedial technology for VOCs and DNAPL in the unsaturated zone; therefore, the Soil FS will only address VOCs in near surface soils between approximately 0 and 10 feet bgs, while the DNAPL FS will address VOCs in deeper unsaturated zone soils from approximately 10 to 60 feet bgs.

Although remedies for soil and DNAPL have not yet been selected, Montrose conducted a preliminary evaluation of interrelationship issues in 2007 (H+A, 2007b). EPA commented on the Montrose evaluation and conducted its own evaluation (*Interconnections Analysis*, EPA, 2007). Although there were differences in assumptions between the two evaluations, both demonstrated that the interrelationship issues could be reasonably managed so that the various remedies did not significantly interfere with each other.

Because the soil, DNAPL, and groundwater aspects of the site are interrelated, so are the potential remedial programs associated with each are interrelated as well. Therefore, the evaluation of remedial alternatives completed as part of this DNAPL FS was conducted to ensure that the effects on the soil and groundwater programs are fully considered.

1.9 PURPOSE AND ORGANIZATION OF REPORT

The primary objectives of this FS are to develop, screen, and evaluate potential remedial alternatives for DNAPL to the extent necessary to select an appropriate remedy. Data generated during the RI and subsequent DNAPL characterization activities have been used to evaluate remedial options. The FS is a process that includes:

- Identification of Remedial Action Objectives (RAOs) and potential remedial technologies;
- Screening of remedial technologies for their ability to meet requirements of technical feasibility, implementability, and cost-effectiveness requirements;
- Evaluation of whether the assembled screened alternatives can be implemented in a reasonable time frame, and allowing for elimination of less practical alternatives from further evaluation; and
- Completion of the detailed analysis of the retained alternatives with respect to nine established National Oil and Hazardous Substances Contingency Plan (NCP) criteria, which address:
  - Overall protection of human health and the environment;
  - Compliance with applicable or relevant and appropriate requirements (ARARs);
  - Long-term effectiveness and permanence;
  - Short-term effectiveness;
  - Reduction of toxicity, mobility, or volume through treatment;
  - Implementability;
  - Cost effectiveness;
  - Regulatory acceptance;
  - Public acceptance.

The remaining portions of this FS report have been organized into the following sections:

- Section 2.0 – Provides a description of the nature and extent of DNAPL and its constituents in soils underlying the Property.
- Section 3.0 - Describes Remedial Action Objectives (RAOs) and ARARs for DNAPL. General Response Actions (GRAs) for DNAPL are additionally identified for subsequent preliminary screening in Section 4.0.
- Section 4.0 – Provides a description and preliminary screening of the remedial technologies and process options identified as GRAs in Section 3.0.
- Section 5.0 - Provides an assembly of remedial alternatives based on the preliminary screening of remedial technologies and process options conducted in Section 4.0. The assembled remedial alternatives are then initially screened in advance of detailed analysis.
- Section 6.0 - Provides a detailed analysis of the remedial alternatives, retained from the initial screening in Section 5.0, in accordance with NCP criteria (40 CFR 30.430(e)(9)).
- Section 7.0 – Provides a comparative analysis of the remedial alternatives evaluated in Section 6.0.
- Section 8.0 – Provides a list of references used during development of the DNAPL FS.

TABLES

Table 1.1
Physical Properties Analytical Results for the Unsaturated Zone (0 to 60 feet bgs)
Montrose Superfund Site

Lithologic Layer	Sample ID	Depth (ft bgs)	Moisture Content (ASTM D2216) (% wt)	Bulk Density (API RP40) (%)	Total Porosity (API RP40) (%)	Effective Porosity (ASTM D425M) (%)	Vertical Permeability to Air (API RP40) (millidarcy)	Horizontal Permeability to Air (API RP40) (millidarcy)	Atterberg Limits (ASTM D4318)			USCS Classification	Particle Size Summary (ASTM D422/D4464M) (% wt)							
									Liquid Limit	Plastic Limit	Plasticity Index		Gravel	Coarse Sand	Medium Sand	Fine Sand	Total Sand	Silt	Clay	Silt & Clay
Playa Deposits	EW-1-10	10	11.7	1.56	42.3	18.9	141	32.6	26.3	14.2	12.1	ML – Sandy Silt	0	0	0.04	34.8	34.9	46.8	18.4	65.1
	EW-1-15	15	23.1	1.45	45.8	13.7	12.7	1.82	28.3	15.8	22.5	ML – Silt with Sand	0	0	0.04	16.6	16.6	54.2	29.2	83.4
	EW-1-20	20	20.4	1.43	47.2	19.2	7.58	1.96	37.5	16.3	21.2	ML - Silt with Sand	0	0	0.01	16.5	16.6	53.4	30.1	83.5
	Average		**18.4**	**1.48**	**45.1**	**17.3**	**53.8**	**12.1**	**Average (%)**				0	0	0.03	22.6	**22.7**	51.4	25.9	**77.3**
Palos Verdes Sand	EW-1-30	30	5.8	1.43	46.3	32.9	1,679	2,168	non-plastic			SP-SM –Poorly Graded Sand with Silt	0	0	0	72.8	72.8	19.5	7.7	27.2
	EW-1-35	35	8.3	1.43	46.1	30.1	1,506	2,341	non-plastic			SP-SM –Poorly Graded Sand with Silt	0	0	0	73.3	73.3	18.0	8.8	26.7
	EW-1-40	40	4.5	1.45	45.3	30.7	3,105	2,803	non-plastic			SM - Silty Sand	0	3.2	32.1	50.4	85.7	[a]	[a]	14.4
	Average		**6.2**	**1.44**	**45.9**	**31.2**	**2,097**	**2,437**	**Average (%)**				0	1.1	10.7	65.5	**77.2**	18.7	8.2	**22.8**
UBA Sand	EW-1-50	50	**7.1**	**1.29**	**51.6**	**39.9**	**2,416**	**3,458**	non-plastic			SM - Silty Sand	0	0	6.35	74.72	**81.1**	15.1	3.8	**18.9**
UBA Silt	EW-1-55	55	41.4	1.07	61.6	17.9	3.66	0.886	66.8	26.8	40	ML – Silt	0	0	0.12	20.10	20.2	63.8	16.0	79.8
	EW-1-60	60	33	1.25	54.4	34.8	8.21	10.4	non-plastic			ML – Sandy Silt	0	0	0.04	27.38	27.4	64.8	7.8	72.6
	Average		**37.2**	**1.16**	**58.0**	**26.4**	**5.9**	**5.6**	**Average (%)**				0	0	0.1	23.7	**23.8**	64.3	11.9	**76.2**

Notes:
Extraction well EW-1 was drilled on June 4, 2003 as part of SVE Pilot Test activities.
(a) Silt and clay were not differentiated in this mechanically-sieved, coarse-grained sample.
% Percent
% wt Percent by weight
API American Petroleum Institute
ASTM American Society for Testing and Materials
ft bgs feet below ground surface
g/cc grams per cubic centimeter
UBA Upper Bellflower Aquitard
USCS Unified Soil Classification System

Table 1.2
Physical Properties Analytical Results for the Saturated UBA (60 to 105 feet bgs)
Montrose Superfund Site

Lithologic Layer	Sample ID	Depth, ft bgs.	Moisture Content, % weight	Dry Bulk Density (API RP40) (g/cc)	Wet Bulk Density (API RP40) (g/cc)	Total Porosity (API RP40) (%)	Effective Porosity (ASTM D425M) (%)	Effective Vertical Permeability to Water (API RP40) (millidarcy)	USCS Classification	Particle Size Distribution, % wt.							Silt & Clay
										Gravel	Coarse Sand	Medium Sand	Fine Sand	Total Sand	Silt	Clay	
Saturated UBA Sand	2DSB-1-65	65	26.2	1.39	1.75	48.25	35.1	1,350	SP	0	0	13.3	77.1	90.4	7.1	2.6	9.6
	2DSB-1-72	72	18.7	1.61	1.91	40.07	27.2	885	SP-SM	0	0	38.0	49.7	87.7	10.1	2.1	12.3
	2DSB-1-75	75	18.9	1.58	1.88	41.22	30.5	1,052	SP	0	0	51.9	44.5	96.4	2.7	0.9	3.6
	2DSB-1-79	79	17.1	1.66	1.95	37.41	26.3	549	SP-SM	2.8	7.0	25.9	53.2	88.9	(2)	(2)	11.1
	2DSB-1-88	88	21.1	1.51	1.82	43.32	25.2	568	SM-Silty Sand	0	0	0	77.7	77.7	15.3	7.0	22.3
	2DSB-1-98	98	19.7	1.50	1.80	43.89	29.6	512	SW	18.3	9.2	6.1	62.0	95.5	(2)	(2)	4.5
	Average		**20.3**	**1.54**	**1.85**	**42.36**	**29.0**	**819**	**Average (%)**	3.5	2.7	22.5	60.7	**89.4**	8.8	3.2	**10.6**
Saturated UBA Silt	2DSB-1-76	76	26.6	1.44	1.83	47.36	32.3	22.1	ML- Silt with Sand	0	0	0	22.7	22.7	66.5	10.8	77.3
	2DSB-1-82	82	35.2	1.32	1.78	51.77	6.2	1.4	ML- Silt	0	0	0	12.6	12.6	67.9	19.5	87.4
	2DSB-1-90	90	19.7	1.60	1.94	40.01	7.4	24.8	ML-Sandy Silt	0	0	0	39.3	39.3	37.5	23.1	60.7
	Average		**27.2**	**1.45**	**1.85**	**46.38**	**15.3**	**16.1**	**Average (%)**	0	0	0	47.1	**24.9**	67.9	19.5	**75.1**

Notes:
Soil samples from boring 2DSB-1 were collected on February 27, 2008 as part of the 2-Dimensional Bench Scale Testing.

%	percent
% wt	percent by weight
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
ft bgs	feet below ground surface
g/cc	grams per cubic centimeter
UBA	Upper Bellflower Aquitard
USCS	United Soil Classification System

FIGURES

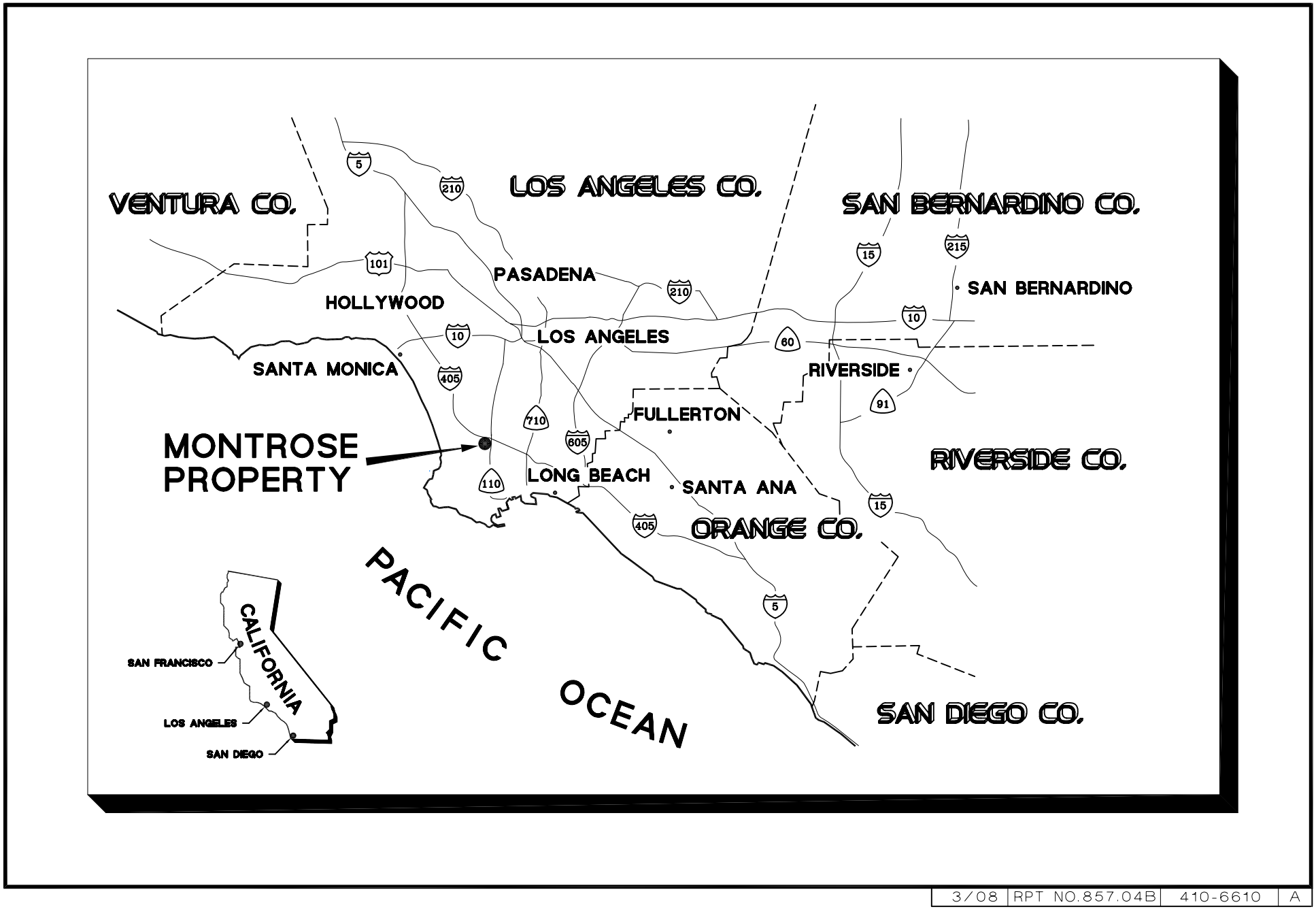

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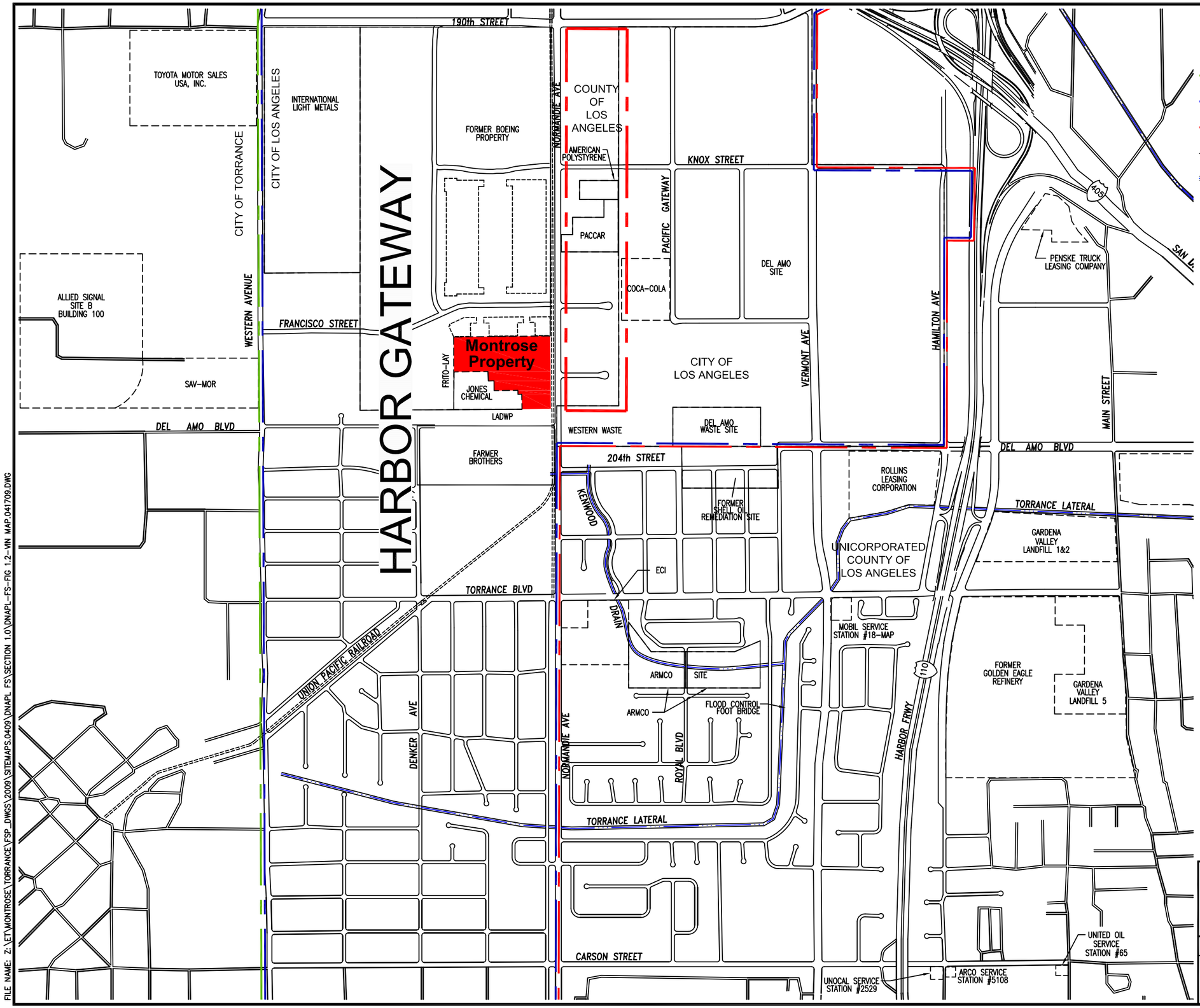
FIGURE 1.1 SITE LOCATION MAP



Legend:

- Location of Current Montrose Property Boundary (Surveyed August, 2001)
- City of Torrance from LADPW, 2004
- City of Los Angeles/Harbor Gateway
- Unincorporated Los Angeles County
- Selected Industrial Areas
- Flood Control / Storm Water Channel

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, On-line GIS database, copyright 2006. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors. Montrose Chemical Corp. and Hargis + Associates, map dated September, 2004.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004. TerraServer Georeferenced Imagery, June 2003.
3. Not a Surveyed Map, Site Features, Streets and Boundary locations are approximate.

NORTH

0 500 1,000 FEET

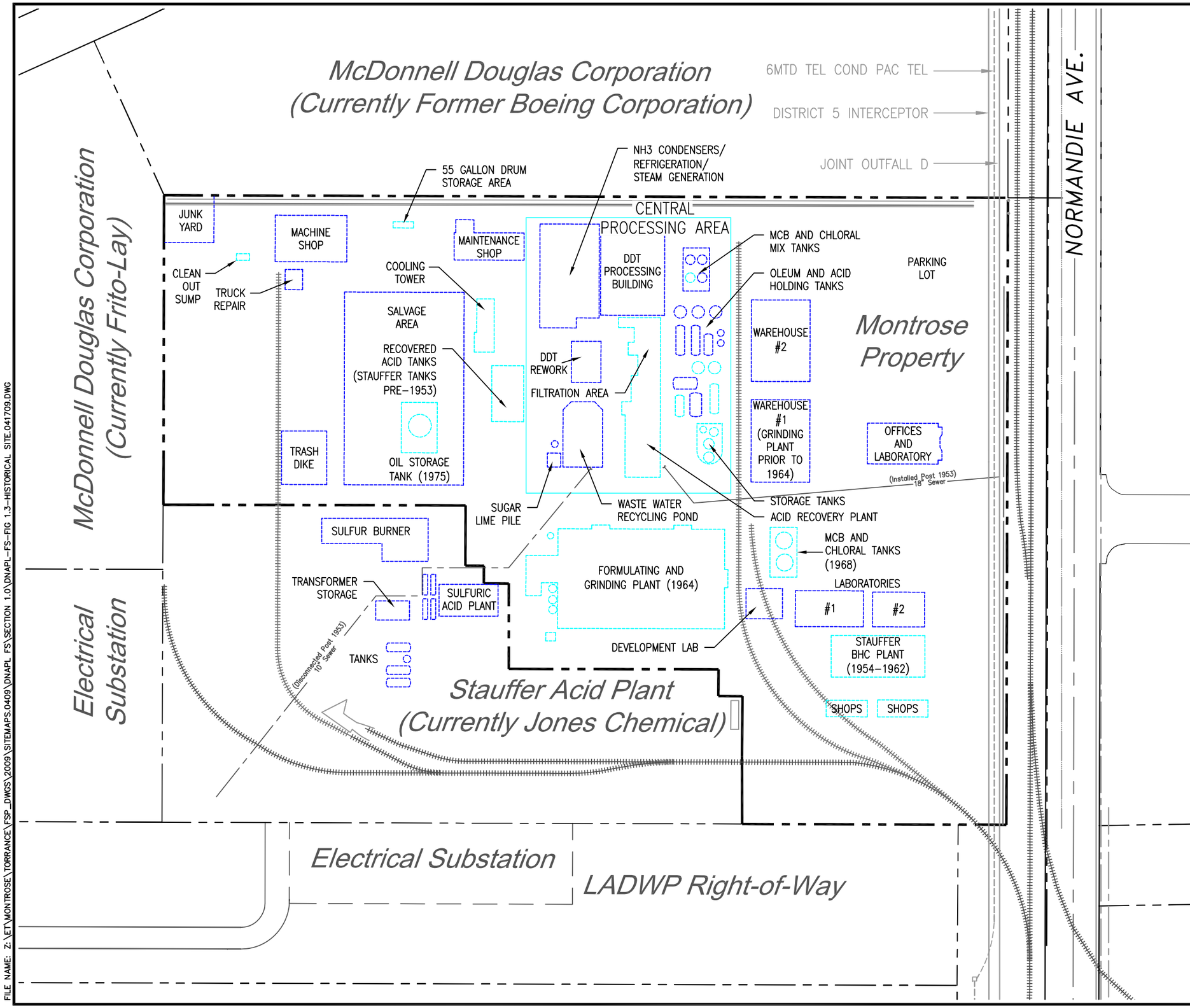
SCALE: 1"= 1,000'

Montrose Chemical Corporation

Vicinity Map

Date: 04-09	Montrose Superfund Site	Figure
Project No. 103649	EARTH TECH | AECOM	1.2

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2009\SITEMAPS.0409\DNAPL FS\SECTION 1.0\DNAPL-FS-FIG 1.2-VIN MAP.041709.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Railroad Tracks
- Built Post-1953 Building
- Existing in 1953 Building
- LADWP — Los Angeles Department of Water and Power
- NH3 — Ammonia

Note: Not All Historical Features Shown.

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, On-line ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference:
   Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
   Continental Aerial, circa 1962.
   TerraServer Georeferenced Imagery, 2003.
3. Former Plant Site features based from historic Above Referenced Aerial Photos.
4. Final Remediation Investigation Report EPA Figure 5.20, May 1998.

NORTH

0 60 120 FEET

SCALE: 1"= 120'

Montrose Chemical Corporation

Historical Site Features
(Combined Pre and Post 1953)

Date: 04-09	Montrose Superfund Site	Figure
Project No. 103649	EARTH TECH | AECOM	1.3

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2009\SITEMAPS.0409\DNAPL FS\SECTION 1.0\DNAPL-FS-FIG 1.3-HISTORICAL SITE.041709.DWG

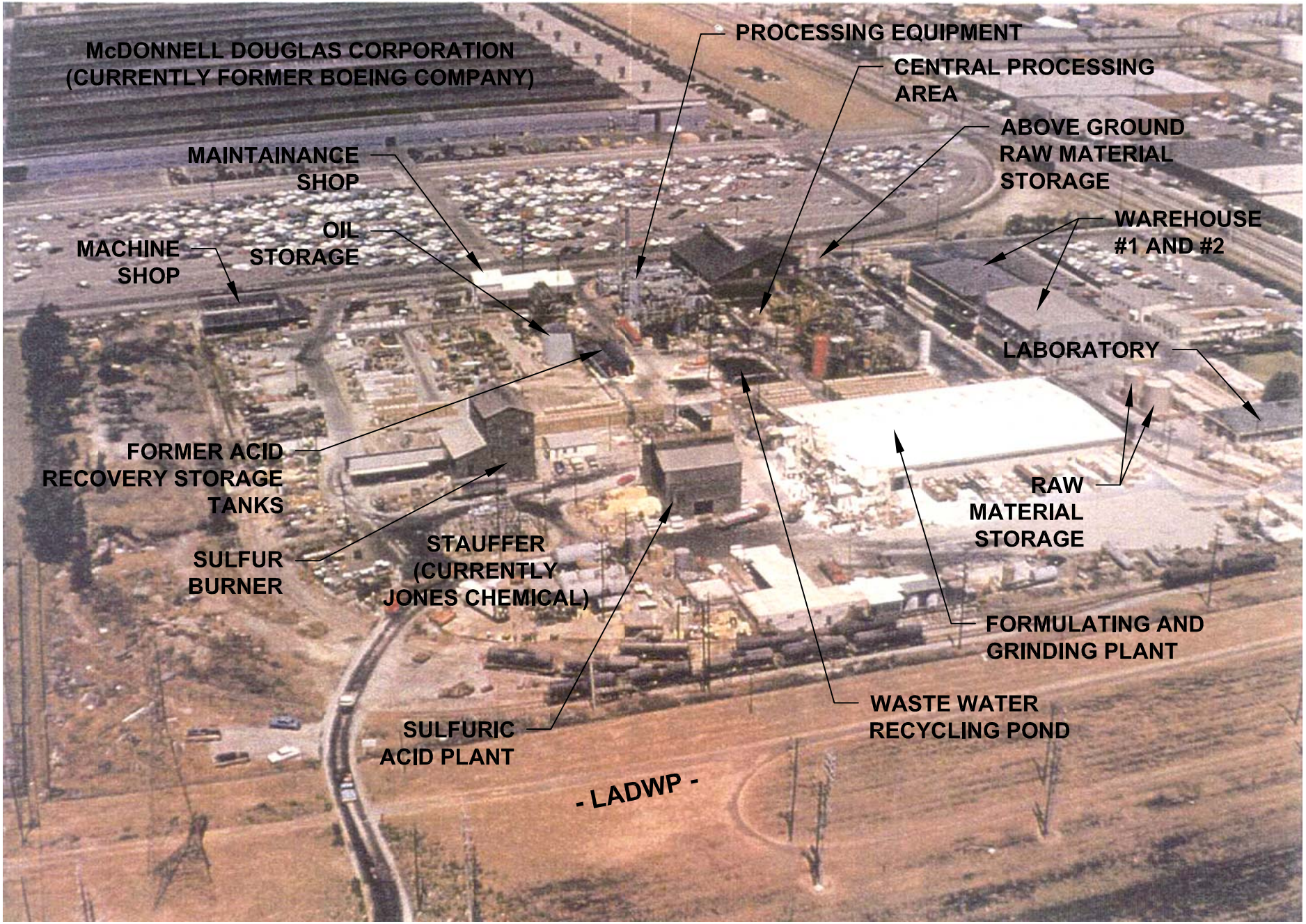
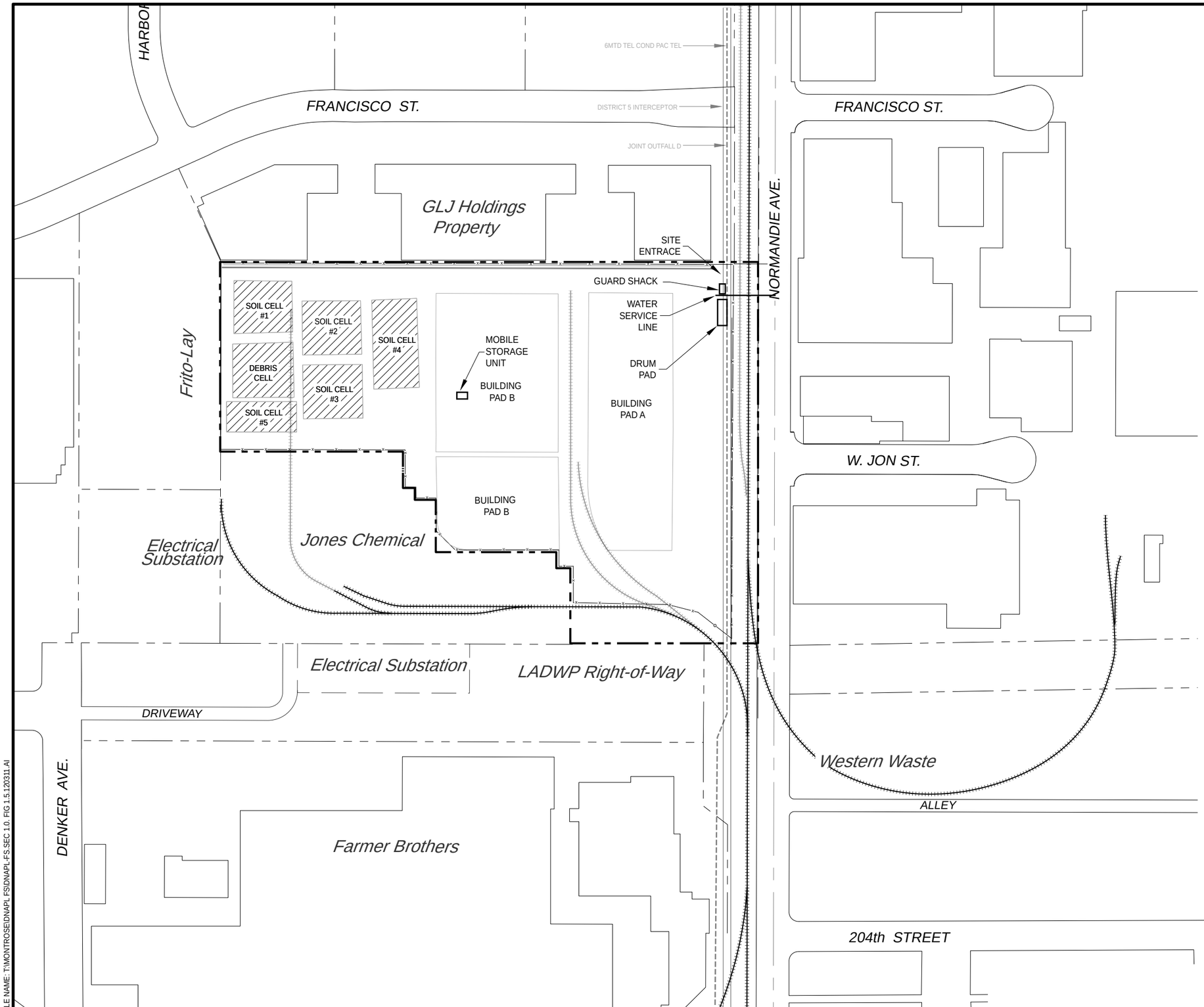


FIGURE 1.4 AERIAL PHOTO, MONTROSE SUPERFUND SITE, MID 1960'S



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- Utility Trench

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference:
   Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
   TerraServer Georefernced Imagery, 2003

NORTH

0 100 200 FEET

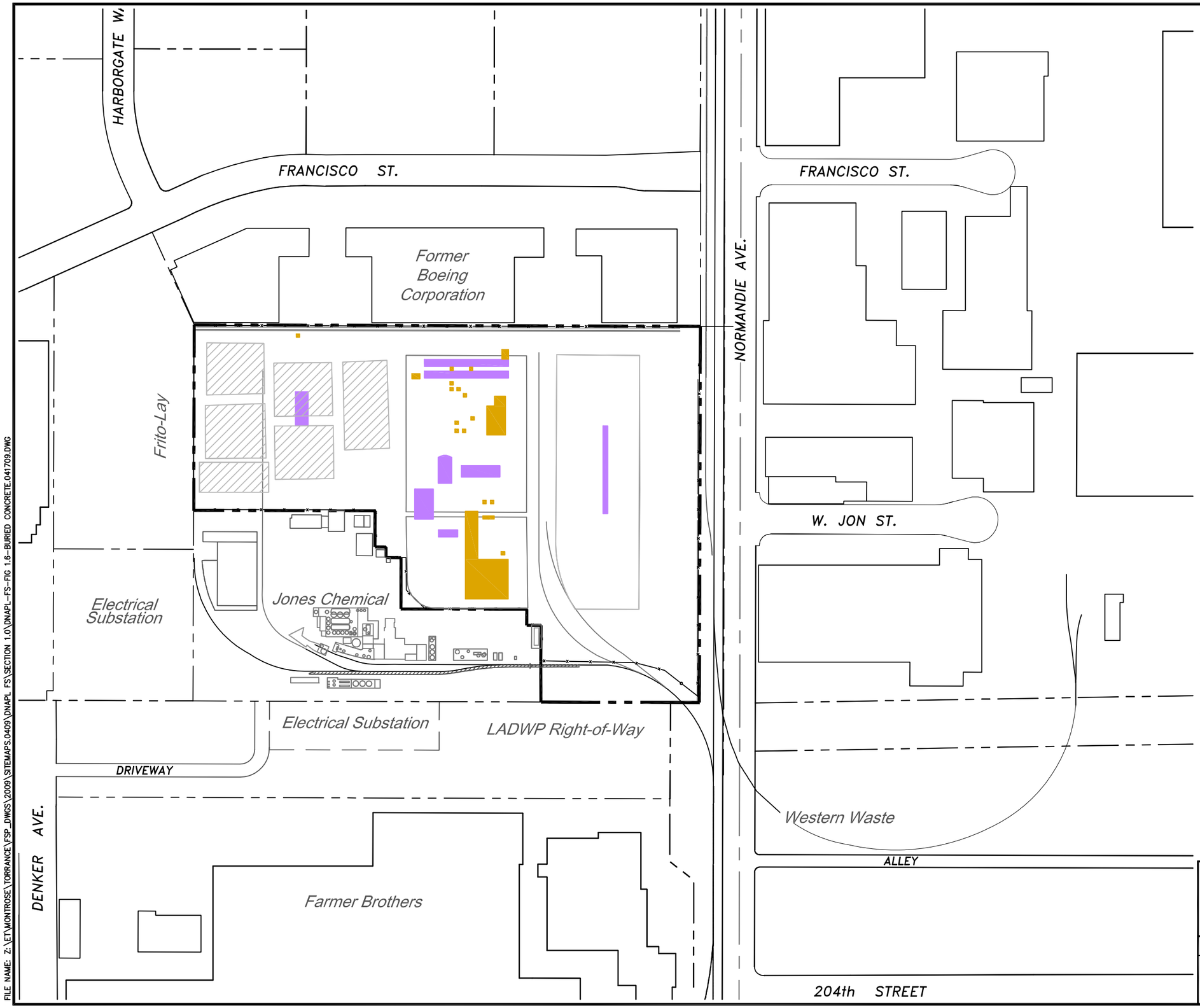
SCALE: 1"= 200'

Montrose Chemical Corporation

Present Property Features

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	1.5

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 1.0. FIG 1.5.120311.AI



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- Soil Cells
- Raised Buildings Pads
- LADWP — Los Angeles Department of Water and Power
- Concrete Debris Pits and Trenches
- Concrete Slabs and Footings Left in Place

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, On-line ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference:
   Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Former Plant Site features based from historic Above Referenced Aerial Photos.
4. Source: EarthTech, 2003

NORTH

0 100 200 FEET

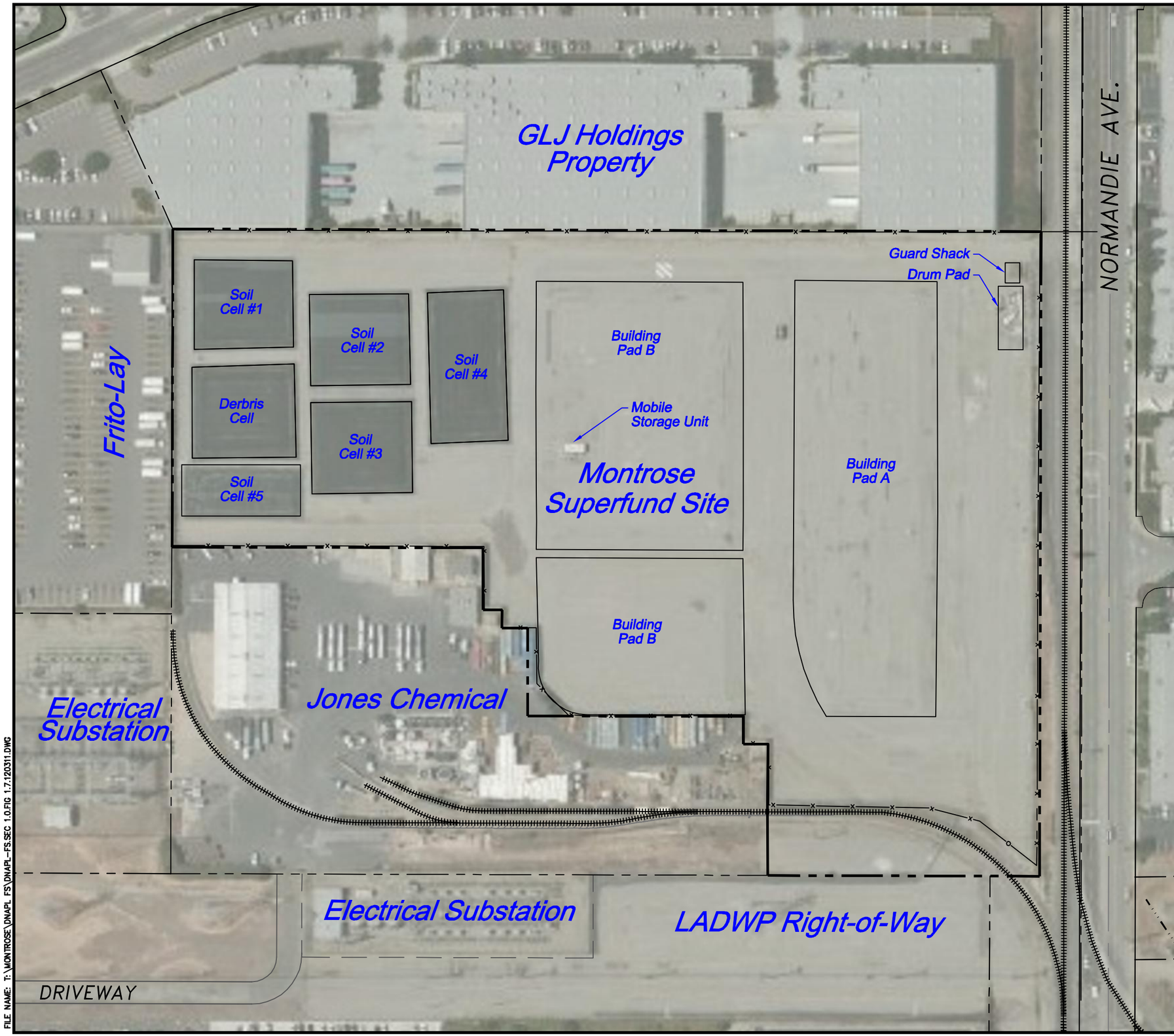
SCALE: 1"= 200'

Montrose Chemical Corporation

Buried Concrete Debris Locations

Date: 04-09	Montrose Superfund Site	Figure
Project No. 103960	EARTH TECH | AECOM	1.6

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2009\SITEMAPS.0409\DNAPL FS\SECTION 1.0\DNAPL-FS-FIG 1.6-BURIED CONCRETE.041709.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, On-line GIS data set, Copyright 2006. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004. Bing Maps Image of 20201 S. Normandie Ave., Torrance, California 90502 http://www.bing.com/maps accessed: December 4, 2011

NORTH

0 60 120 FEET

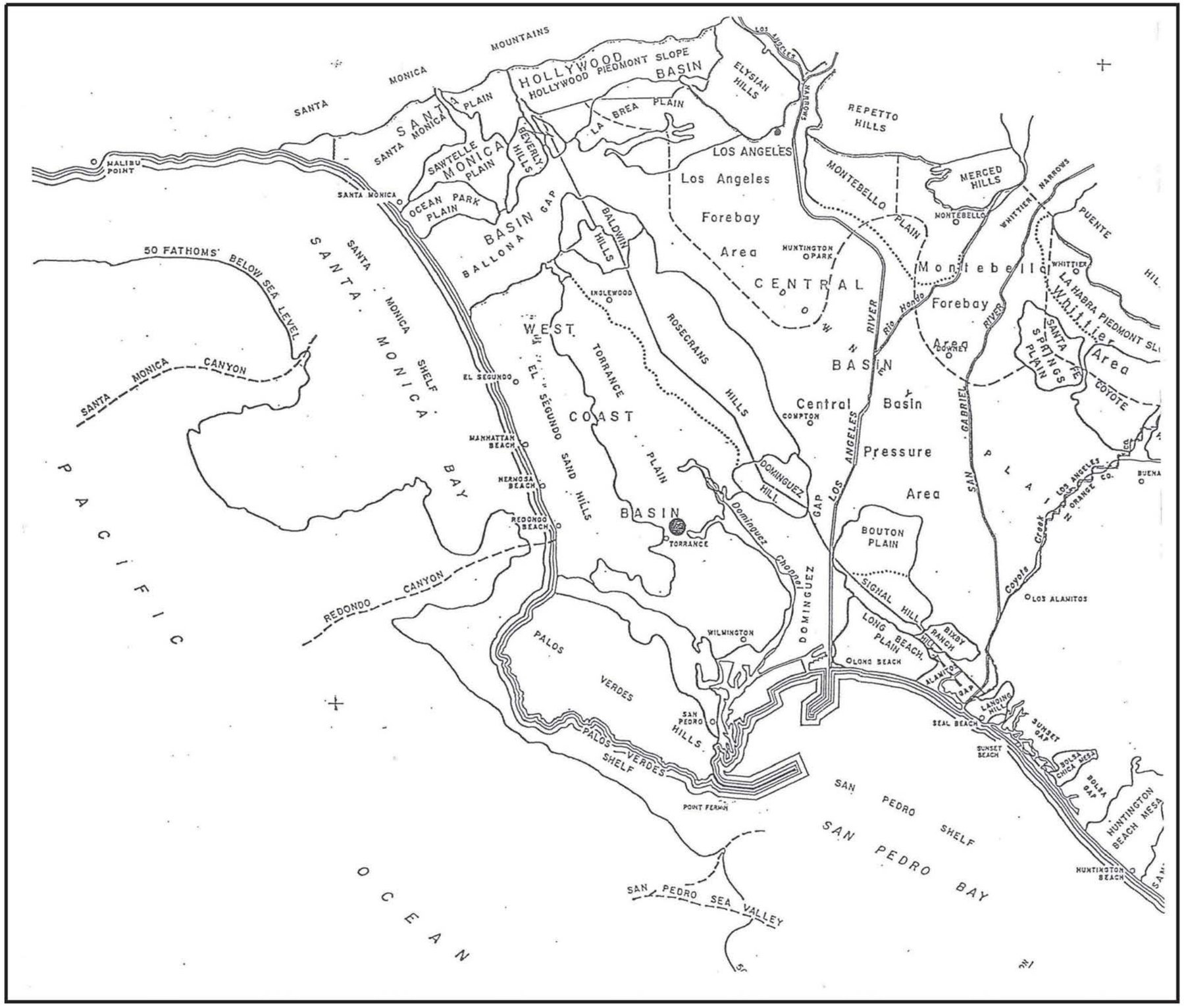
SCALE: 1"= 120'

Montrose Chemical Corporation

Aerial Photo
Montrose Superfund Site
2010

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	1.7

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 1.0.FIG 1.7.120311.DWG



EXPLANATION

- MONTROSE PROPERTY
- BOUNDARY BETWEEN PHYSIOGRAPHIC FEATURES (DOTTED WHERE APPROXIMATE OR POORLY DEFINED)
- BOUNDARY OF GROUNDWATER BASIN
- BOUNDARY OF FOREBAY AND WHITTIER AREA
- AXIS OF SUBMARINE CANYON

SOURCE: CDWR, 1961

0 4 8
MILES

MONTROSE CHEMICAL CORPORATION
TORRANCE, CALIFORNIA

REGIONAL HYDROGEOLOGIC FEATURES

3/08

FIGURE 1.8

RPT NO. 857.04B | 410-5815 | A

MONTROSE RI (2)				DEL AMO STUDY AREA RI (3)
HYDROGEOLOGIC UNIT		AVERAGE THICKNESS (ft)	BASE ELEV. RANGE (ft/msl)	HYDROSTRATIGRAPHIC UNIT
UPPER PLEISTOCENE (1) LAKEWOOD FORMATION	UNSATURATED	60 ▼	-12 TO -20	UPPER BELLFLOWER AQUITARD
	UPPER BELLFLOWER AQUITARD	40	-20 TO -90	MIDDLE BELLFLOWER AQUITARD: B-SAND / MUD
	BELLFLOWER SAND	45	-70 TO -110	MIDDLE BELLFLOWER AQUITARD: C-SAND
	LOWER BELLFLOWER AQUITARD	30	-85 TO -140	LOWER BELLFLOWER AQUITARD
	GAGE AQUIFER	60	-155 TO -190	GAGE AQUIFER
LOWER PLEISTOCENE (1) SAN PEDRO FORMATION	GAGE/ LYNWOOD AQUITARD	20	-170 TO -230	GAGE/ LYNWOOD AQUITARD
	LYNWOOD AQUIFER	36	-240	
	LYNWOOD SILVERADO AQUITARD	208	-440	
	SILVERADO AQUIFER	>240	NOT REACHED	

EXPLANATION

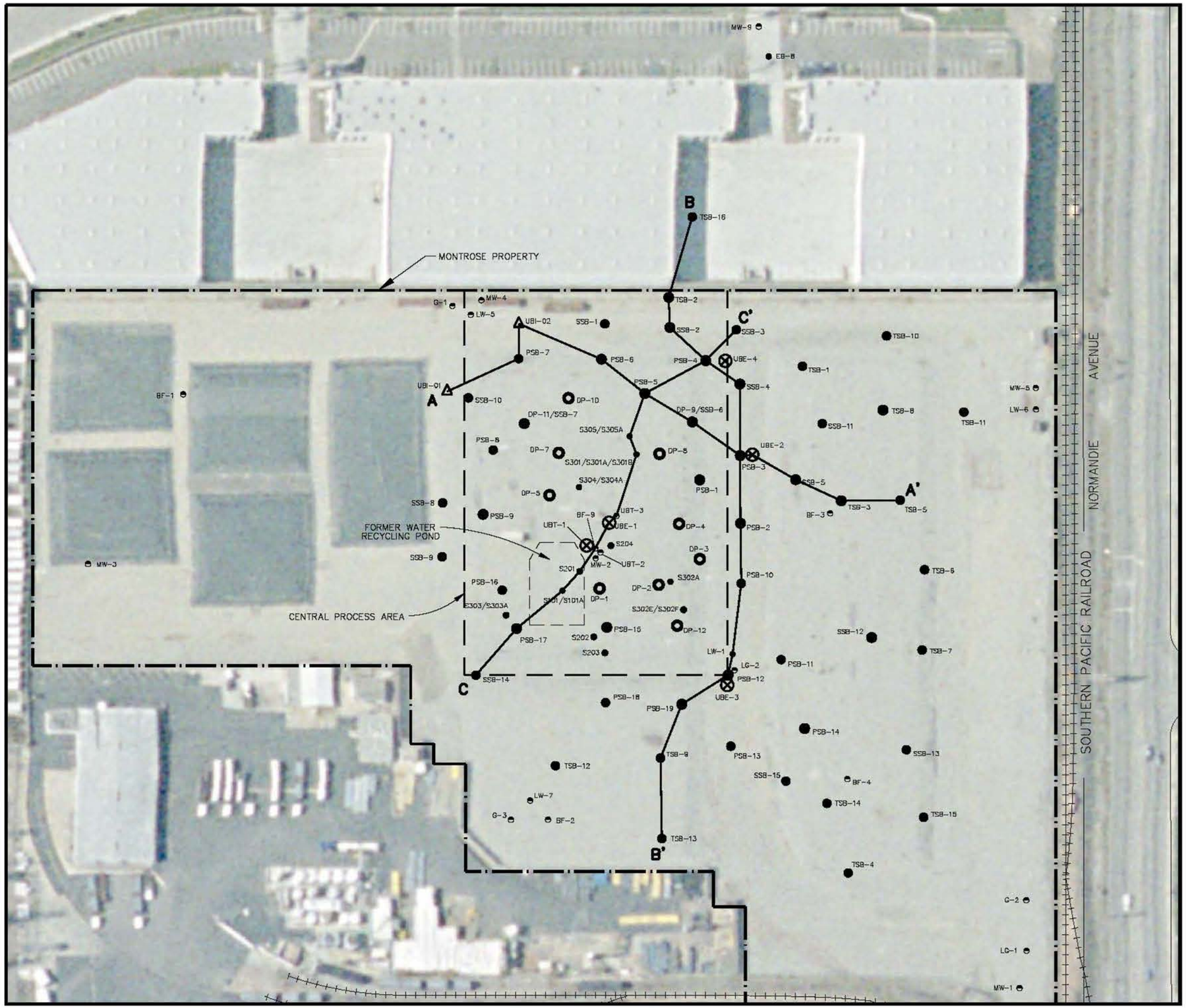
ft = FEET
msl = MEAN SEA LEVEL
▼ = WATER TABLE

SOURCES:

(1) CDWR BULLETIN 104, 1961 AND POLAND ET AL, 1959
(2) ENVIRONMENTAL PROTECTION AGENCY, 1998
(3) DAMES & MOORE, 1998

3/08	RPT NO.857.04B	640-0136	B

FIGURE 1.9 STRATIGRAPHIC COLUMN



EXPLANATION

S305/S305A — SOIL BORING

MW-2 — MONITOR WELL

PSB-7 — SONIC BORING

DP-10 — DIRECT PUSH BORING

UBE-2 — EXTRACTION WELL

UBI-01 — INJECTION WELL

PROPERTY BOUNDARY

A — A' CROSS SECTION LOCATION

SOURCE: HARGIS + ASSOCIATES, 2004b

0 100 200
FEET

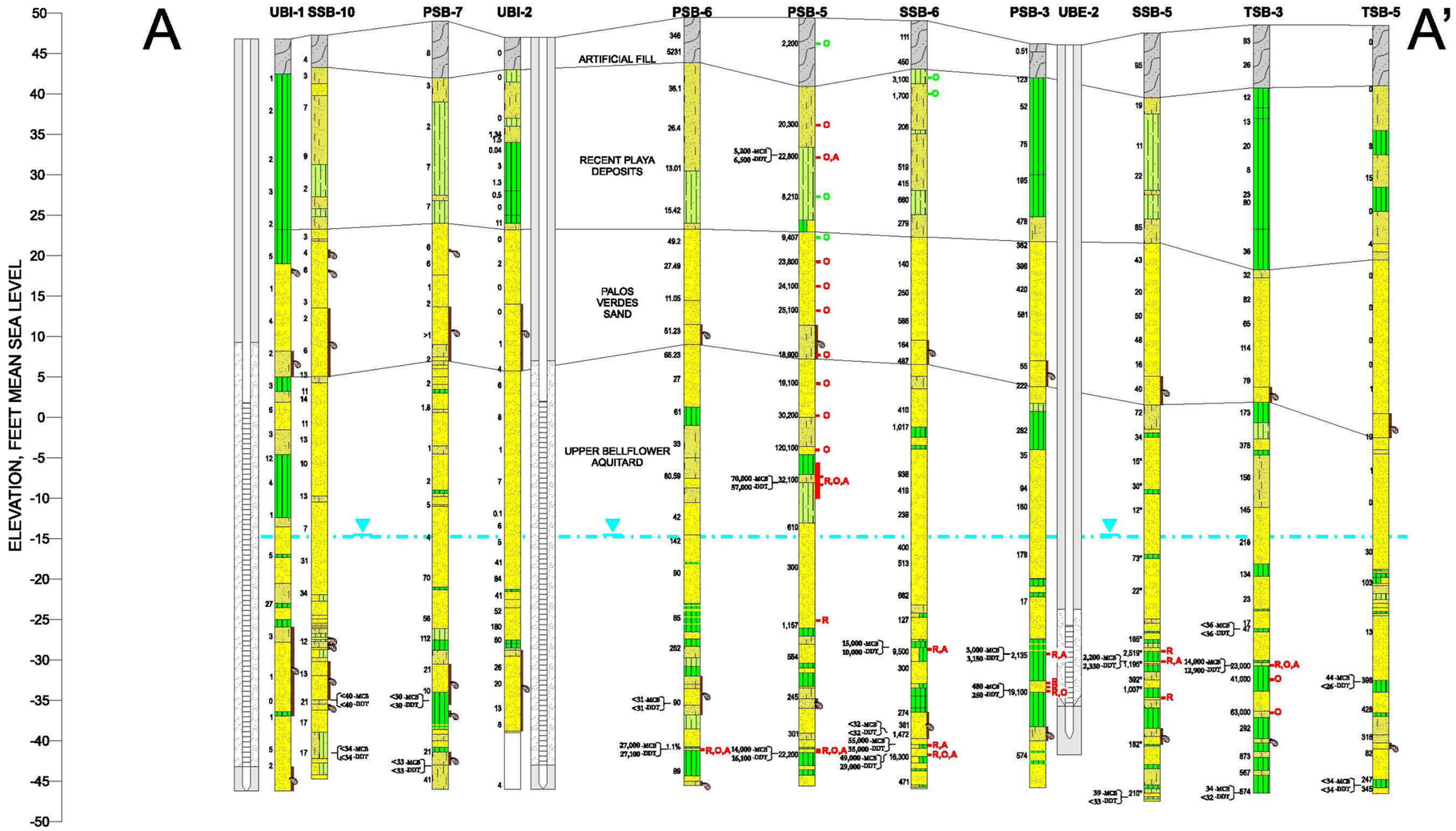
MONTROSE CHEMICAL CORPORATION OF CALIFORNIA
TORRANCE, CALIFORNIA

CROSS SECTION LOCATION MAP

HARGIS + ASSOCIATES, INC. 3/08

FIGURE 1.10

RPT NO.857.04B | 410-6614 | A



EXPLANATION

- FILL
- SAND
- SILTY SAND
- CLAYEY SAND
- SANDY SILT
- SILT
- CLAY
- SHELLS
- 3,145 — OVA READING IN PPM
- <40 -MCB, <40 -DDT — CONCENTRATION OF CHLOROBENZENE AND DDT IN MG/KG
- DNAPL PRESENT
- DNAPL POSSIBLY PRESENT
- V,R,O,A — BASIS OF DETERMINATION OF DNAPL PRESENCE
  - VISUAL
  - RIBBON TEST
  - OVA READING
  - LABORATORY ANALYSIS
- APPROXIMATE GROUNDWATER SURFACE (-14.75 FEET MSL) BASED ON JANUARY 2004 MEASUREMENTS

VERTICAL SCALE (feet): 0, 5, 10

4 TO 1 VERTICAL EXAGGERATION

HORIZONTAL SCALE (feet): 0, 20, 40

CASING
SEAL
WELL SCREEN
FILTER PACK
SUMP
GROUT BASKET

NOTES

DDT = DICHLORODIPHENYLTRICHLOROETHANE
DNAPL = DENSE NONAQUEOUS PHASE LIQUID
MCB = CHLOROBENZENE
MG/KG = MILLIGRAMS PER KILOGRAM
MSL = MEAN SEA LEVEL
OVA = ORGANIC VAPOR ANALYZER
PPM = PARTS PER MILLION
RIBBON = HYDROPHOBIC DYE-IMPREGNATED FABRIC

SOURCE: HARGIS + ASSOCIATES, 2004b

MONTROSE CHEMICAL CORPORATION OF CALIFORNIA
TORRANCE, CALIFORNIA

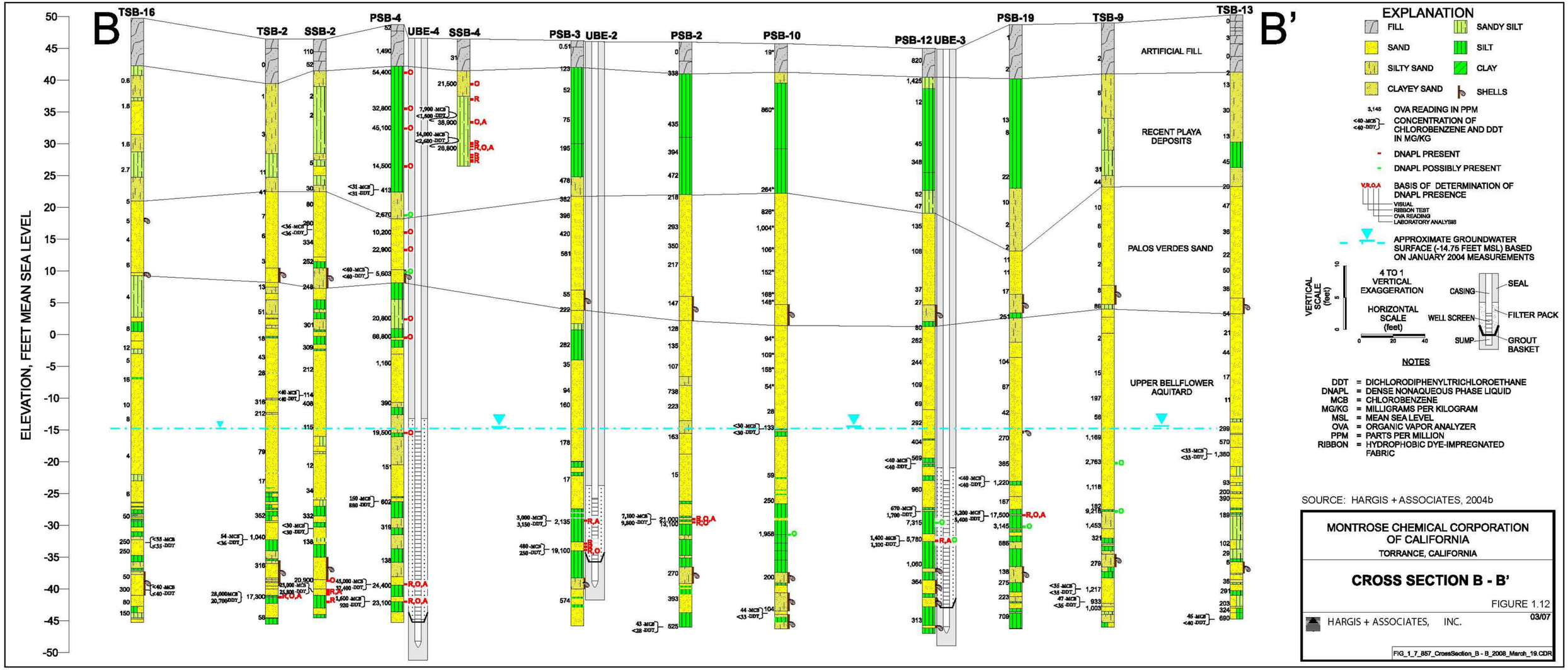
CROSS SECTION A - A'

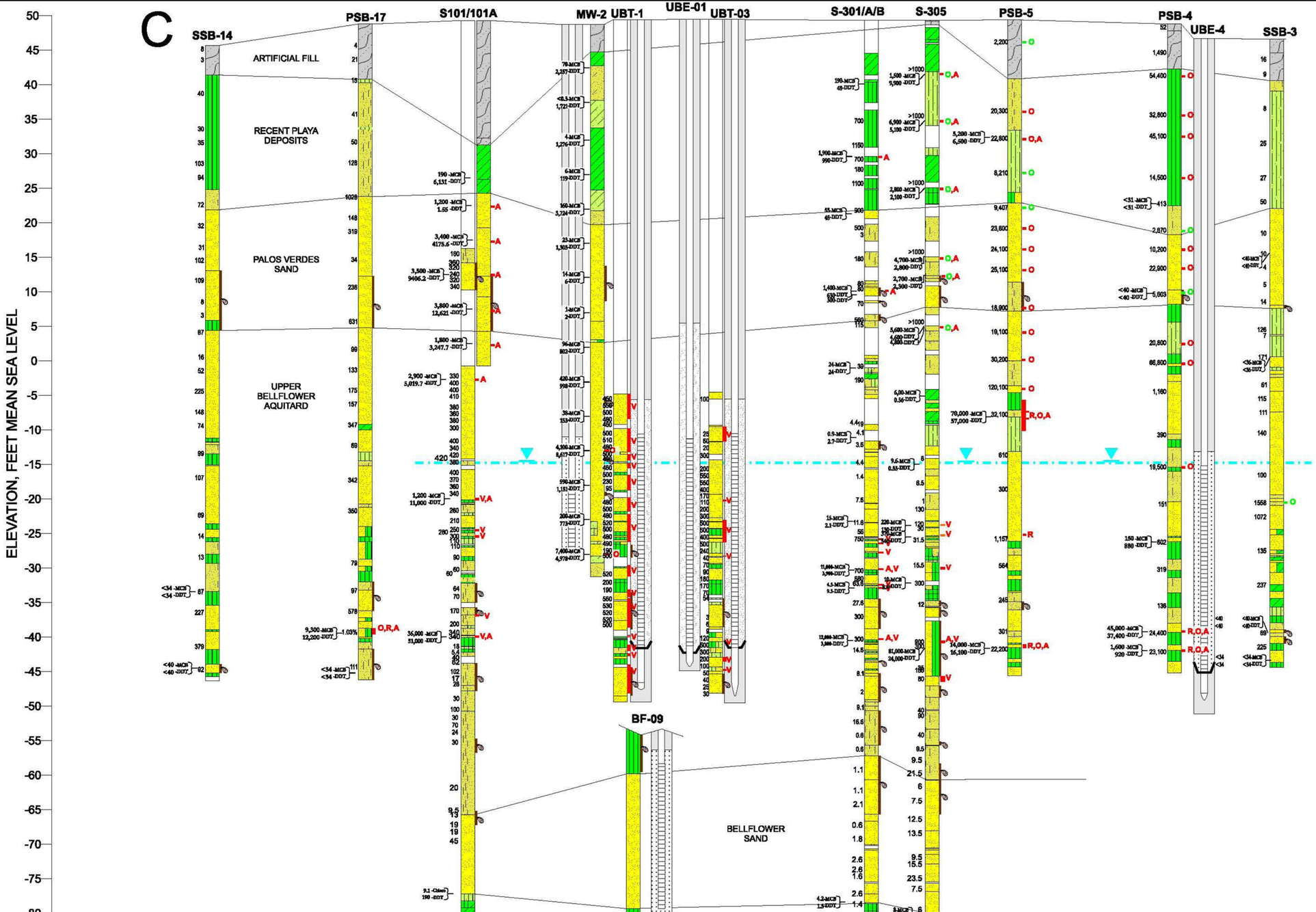
FIGURE 1.11

HARGIS + ASSOCIATES, INC.

03/07

FIG_1_6_857_CrossSection_A - A_2008_March_19.CDR


B
B'
TSB-16
TSB-2
SSB-2
PSB-4
UBE-4
SSB-4
PSB-3
UBE-2
PSB-2
PSB-10
PSB-12
UBE-3
PSB-19
TSB-9
TSB-13
ELEVATION, FEET MEAN SEA LEVEL
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
ARTIFICIAL FILL
RECENT PLAYA DEPOSITS
PALOS VERDES SAND
UPPER BELLFLOWER AQUITARD
EXPLANATION
FILL
SAND
SILTY SAND
CLAYEY SAND
SANDY SILT
SILT
CLAY
SHELLS
3,145 OVA READING IN PPM
<40 -MCB <40 -DDT CONCENTRATION OF CHLOROBENZENE AND DDT IN MG/KG
DNAPL PRESENT
DNAPL POSSIBLY PRESENT
V,R,O,A BASIS OF DETERMINATION OF DNAPL PRESENCE
VISUAL
RIBBON TEST
OVA READING
LABORATORY ANALYSIS
APPROXIMATE GROUNDWATER SURFACE (-14.75 FEET MSL) BASED ON JANUARY 2004 MEASUREMENTS
VERTICAL SCALE (feet)
0
5
10
4 TO 1 VERTICAL EXAGGERATION
HORIZONTAL SCALE (feet)
0
20
40
CASING
SEAL
WELL SCREEN
FILTER PACK
SUMP
GROUT BASKET
NOTES
DDT = DICHLORODIPHENYLTRICHLOROETHANE
DNAPL = DENSE NONAQUEOUS PHASE LIQUID
MCB = CHLOROBENZENE
MG/KG = MILLIGRAMS PER KILOGRAM
MSL = MEAN SEA LEVEL
OVA = ORGANIC VAPOR ANALYZER
PPM = PARTS PER MILLION
RIBBON = HYDROPHOBIC DYE-IMPREGNATED FABRIC
SOURCE: HARGIS + ASSOCIATES, 2004b
MONTROSE CHEMICAL CORPORATION OF CALIFORNIA
TORRANCE, CALIFORNIA
CROSS SECTION B - B'
FIGURE 1.12
03/07
HARGIS + ASSOCIATES, INC.
FIG_1_7_857_CrossSection_B - B_2008_March_19.CDR



EXPLANATION

- FILL
- SANDY SILT
- SAND
- SILT
- SILTY SAND
- CLAY
- CLAYEY SAND
- SHELLS

3,145 — OVA READING IN PPM

<40 -MCB / <40 -DDT — CONCENTRATION OF CHLOROBENZENE AND DDT IN MG/KG

DNAPL PRESENT

DNAPL POSSIBLY PRESENT

V,R,O,A — BASIS OF DETERMINATION OF DNAPL PRESENCE
- VISUAL
- RIBBON TEST
- OVA READING
- LABORATORY ANALYSIS

APPROXIMATE GROUNDWATER SURFACE (-14.75 FEET MSL) BASED ON JANUARY 2004 MEASUREMENTS

VERTICAL SCALE (feet): 0, 5, 10

3 TO 1 VERTICAL EXAGGERATION

HORIZONTAL SCALE (feet): 0, 15, 30

CASING — SEAL — WELL SCREEN — FILTER PACK — SUMP — GROUT BASKET

NOTES

DDT = DICHLORODIPHENYLTRICHLOROETHANE
DNAPL = DENSE NONAQUEOUS PHASE LIQUID
MCB = CHLOROBENZENE
MG/KG = MILLIGRAMS PER KILOGRAM
MSL = MEAN SEA LEVEL
OVA = ORGANIC VAPOR ANALYZER
PPM = PARTS PER MILLION
RIBBON = HYDROPHOBIC DYE-IMPREGNATED FABRIC

SOURCE: HARGIS + ASSOCIATES, 2004b

MONTROSE CHEMICAL CORPORATION OF CALIFORNIA
TORRANCE, CALIFORNIA

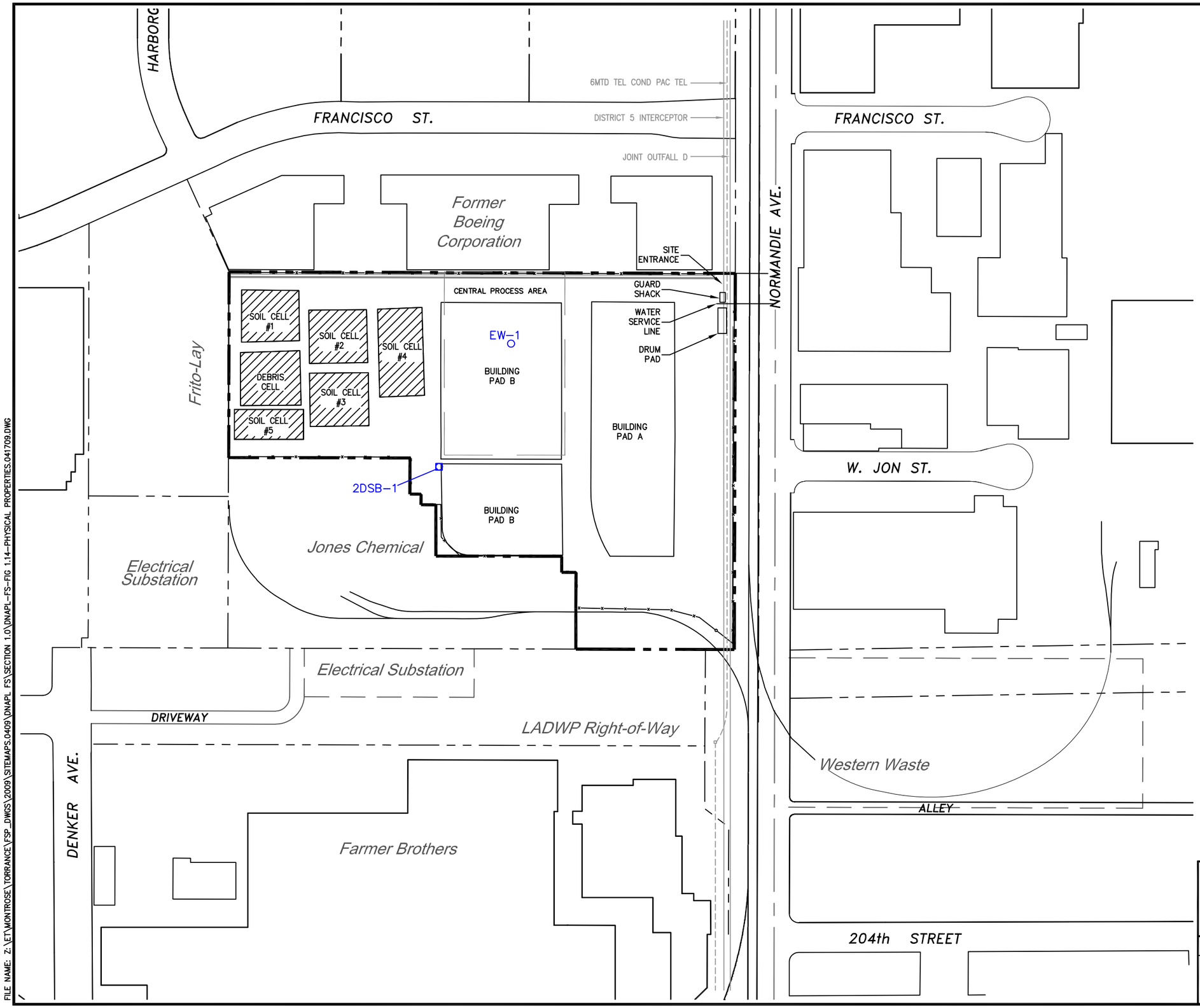
CROSS SECTION C - C'

FIGURE 1.13

HARGIS + ASSOCIATES, INC.

03/07

FIG_1_8_857_CrossSection_C - C_2008_March_19.CDR



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- Utility Trench
- EW-1 — SVE Pilot Test Extraction Well, Vadose Zone Samples
- 2DSB-1 — 2-Dimensional Bench Scale Test Soil Boring, Saturated Upper Bellflower Aquitard

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, On-line ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference:
   Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
   TerraServer Georeferenced Imagery, 2003.

NORTH

0 100 200 FEET

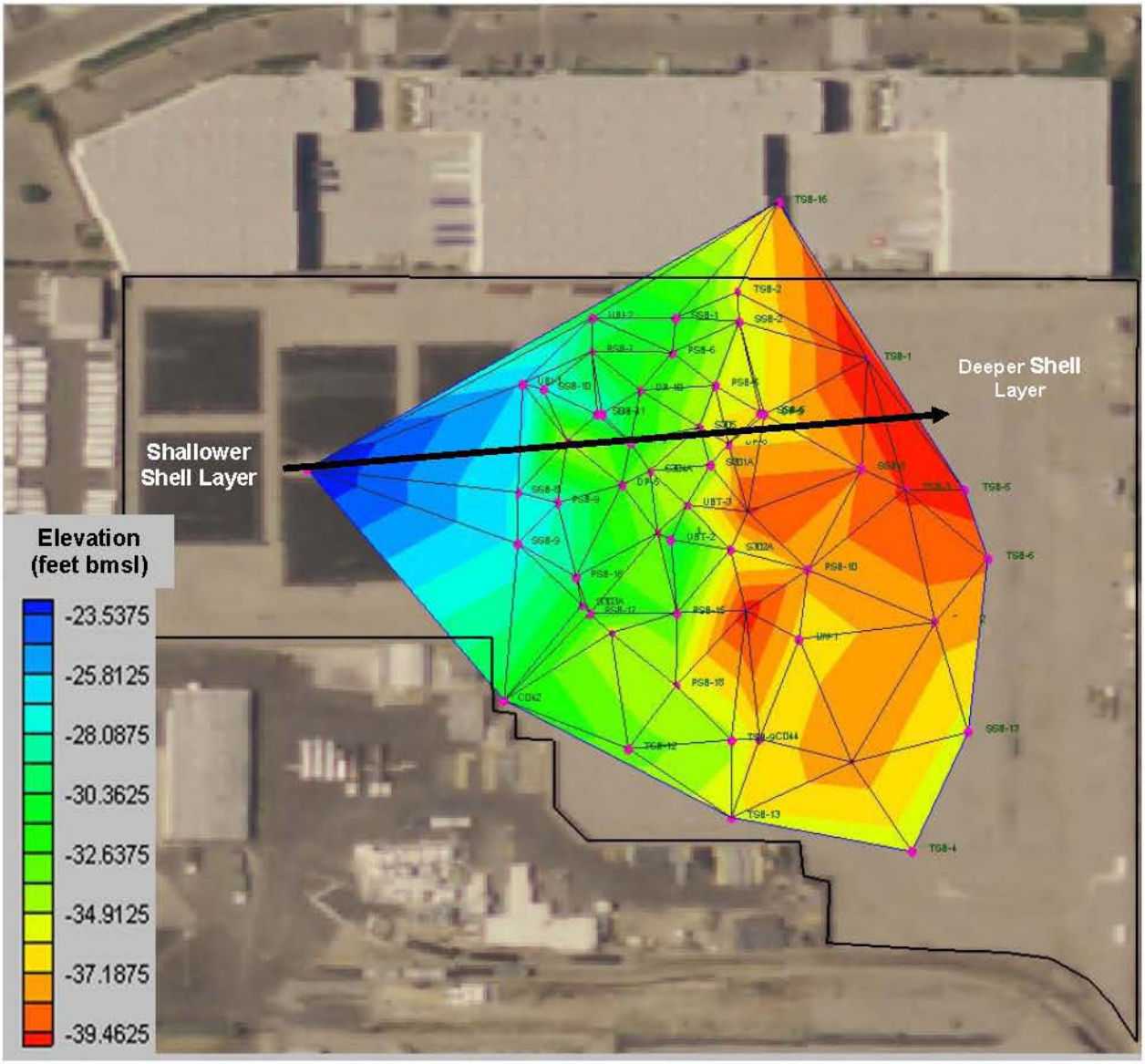
SCALE: 1"= 200'

Montrose Chemical Corporation

Physical Properties
Soil Sampling Locations

Date: 04-09	Montrose Superfund Site	Figure
Project No. 103649	EARTH TECH | AECOM	1.14

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2009\SITEMAPS.0409\DNAPL FS\SECTION 1.0\DNAPL-FS-FIG 1.14-PHYSICAL PROPERTIES.041709.DWG



SOURCE: HARGIS + ASSOCIATES, 2008d

NOTE:

ARROW DEMONSTRATES GRADUAL DOWN DIP IN UPPER BELLFLOWER AQUITARD, WITH AN AVERAGE DIRECTION 8 DEGREES NORTH OF EAST.

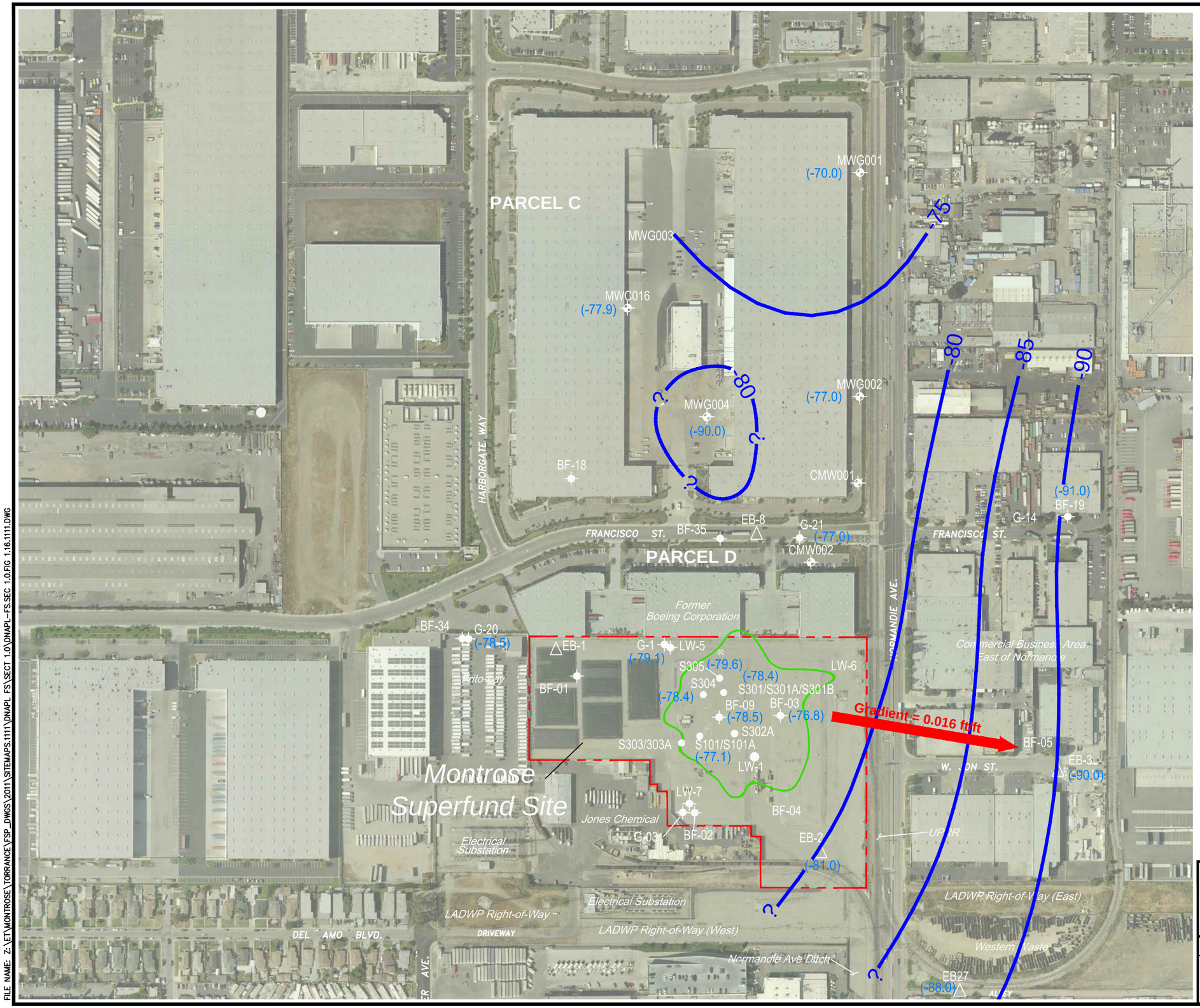
MONTROSE CHEMICAL CORPORATION
TORRANCE, CALIFORNIA

STRATIGRAPHIC BED ORIENTATION SATURATED UPPER BELLFLOWER AQUITARD

HARGIS + ASSOCIATES, INC. 3/08

FIGURE 1.15

RPT NO. _____ A



Legend:

- Location of Current Montrose Property Boundary
- LADWP — Los Angeles Department of Water and Power
- Entire DNAPL Impacted Area
- EB-1 △ — Exploratory Boring
- S301 ● — Soil Boring
- BF-01 — Monitoring Well
- MWG001 — Monitoring Well Owned by Boeing
- (-70.0) — Basal Elevation of the Bellflower Sand
- -90 — Basal Elevation Contour Line

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, On-line GIS data set, Copyright 2010. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas U.S.G.S Orthorectified Image, Dated July 29, 2009.
3. Source: EPA, 1998. Final Remedial Investigation Report for the Montrose Superfund Site, Los Angeles, California. May 18, 1998. H+A, 2004b. Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, California, Revision 1.0. October 22, 2004. Haley & Aldrich, 2001. Former C-6 Facility Groundwater Assessment Report, Los Angeles, California. Haley & Aldrich, 2006a. Well Completion Report, Site-Wide Groundwater Monitoring Wells, Boeing Reality Corporation, Former C-6 Facility, Los Angeles, California. March 7, 2006. Haley & Aldrich, 2006b. Well Completion Report, MWG001, MWG002, MWG0003, MWG004 and MWC009, Boeing Reality Corporation, Former C-6 Facility, Los Angeles, California. March 31, 2006.

NORTH

0 150 300 FEET

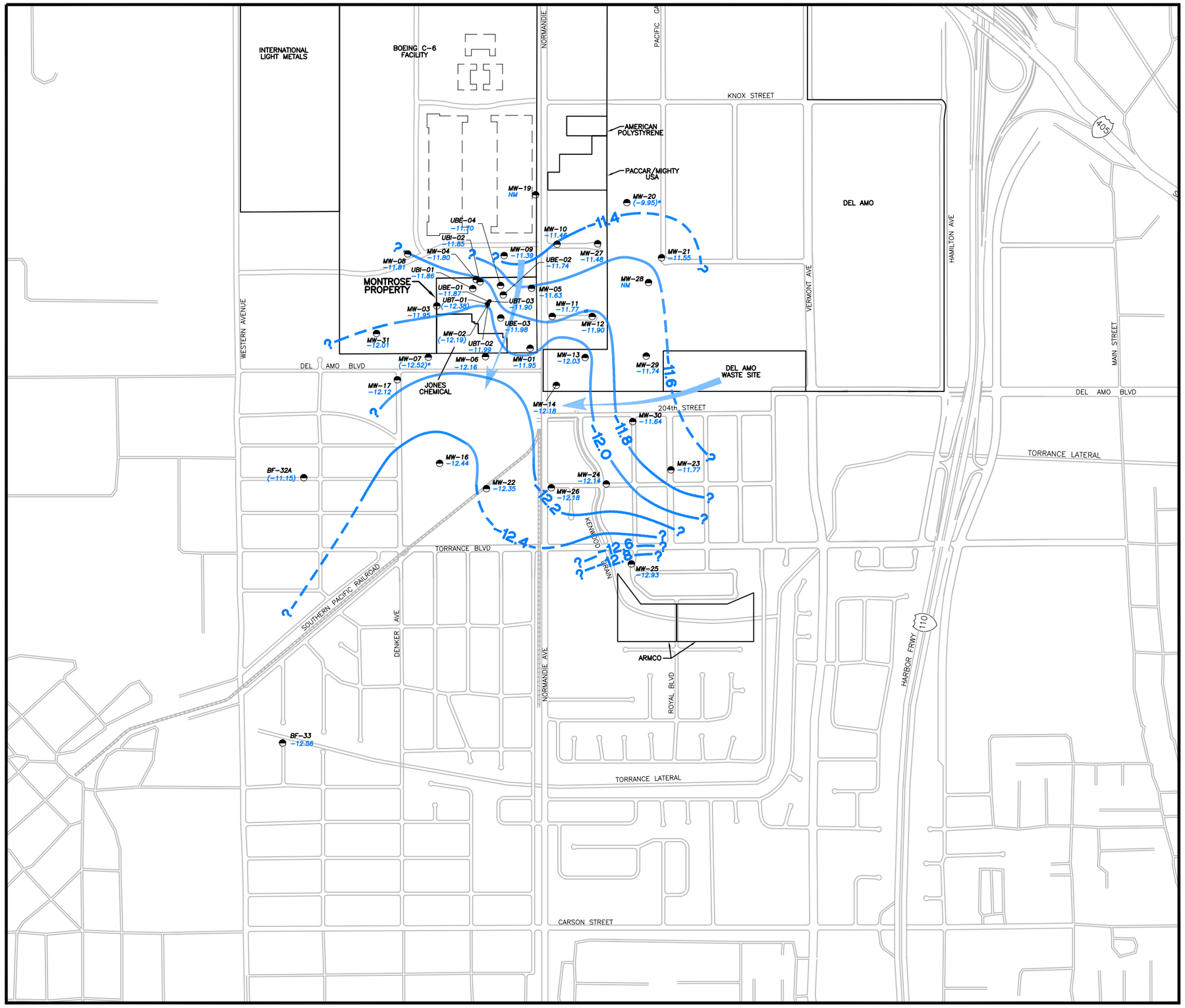
SCALE: 1"= 300'

Montrose Chemical Corporation

BFS Basal Elevation Map

Date: 11-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	1.16

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1111\DNAPL FS\SECT 1.0\DNAPL-FS.SECT 1.0.FIG 1.16.1111.DWG



EXPLANATION

MW-31	UPPER BELLFLOWER AQUITARD MONITOR WELL
-12.01	WATER LEVEL ELEVATION FEET MEAN SEA LEVEL
NM	NOT MEASURED
( )	NOT CONTOURED
*	WATER LEVEL POTENTIALLY EFFECTED BY FLOATING FREE PRODUCT

? —— -12 — — — — ?

CONTOUR LINE OF EQUAL WATER LEVEL ELEVATION IN FEET BELOW MEAN SEA LEVEL; DASHED WHERE APPROXIMATE, QUERIED WHERE INFERRED.

DIRECTION OF GROUNDWATER FLOW

SOURCE: HARGIS + ASSOCIATES, 2007a

0 1,000 2,000

FEET

MONTROSE CHEMICAL CORPORATION

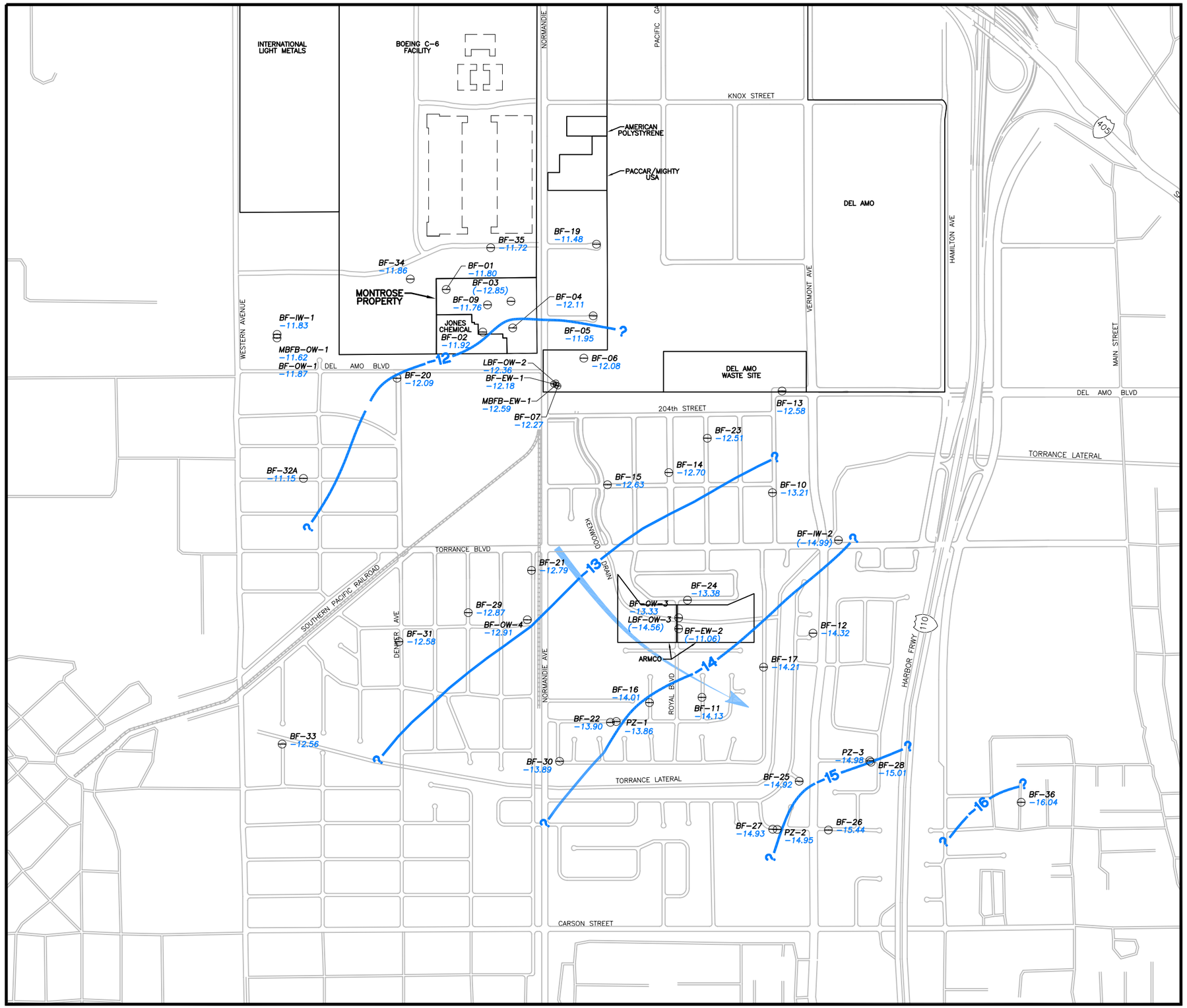
TORRANCE, CALIFORNIA

GROUNDWATER ELEVATION MAP
UPPER BELLFLOWER AQUITARD
OCTOBER 2006

HARGIS + ASSOCIATES, INC. 3/08

FIGURE 1.17

RPT NO. 857.04B | 220-1909 | A



EXPLANATION

BF-12 — BELLFLOWER SAND MONITOR WELL

-14.32 — WATER LEVEL ELEVATION FEET MEAN SEA LEVEL

NM — NOT MEASURED

( ) — NOT CONTOURED

? —— -12 —— ? — CONTOUR LINE OF EQUAL WATER LEVEL ELEVATION IN FEET BELOW MEAN SEA LEVEL; DASHED WHERE APPROXIMATE, QUERIED WHERE INFERRED.

DIRECTION OF GROUNDWATER FLOW

SOURCE: HARGIS + ASSOCIATES, 2007a

0 1,000 2,000

FEET

MONTROSE CHEMICAL CORPORATION

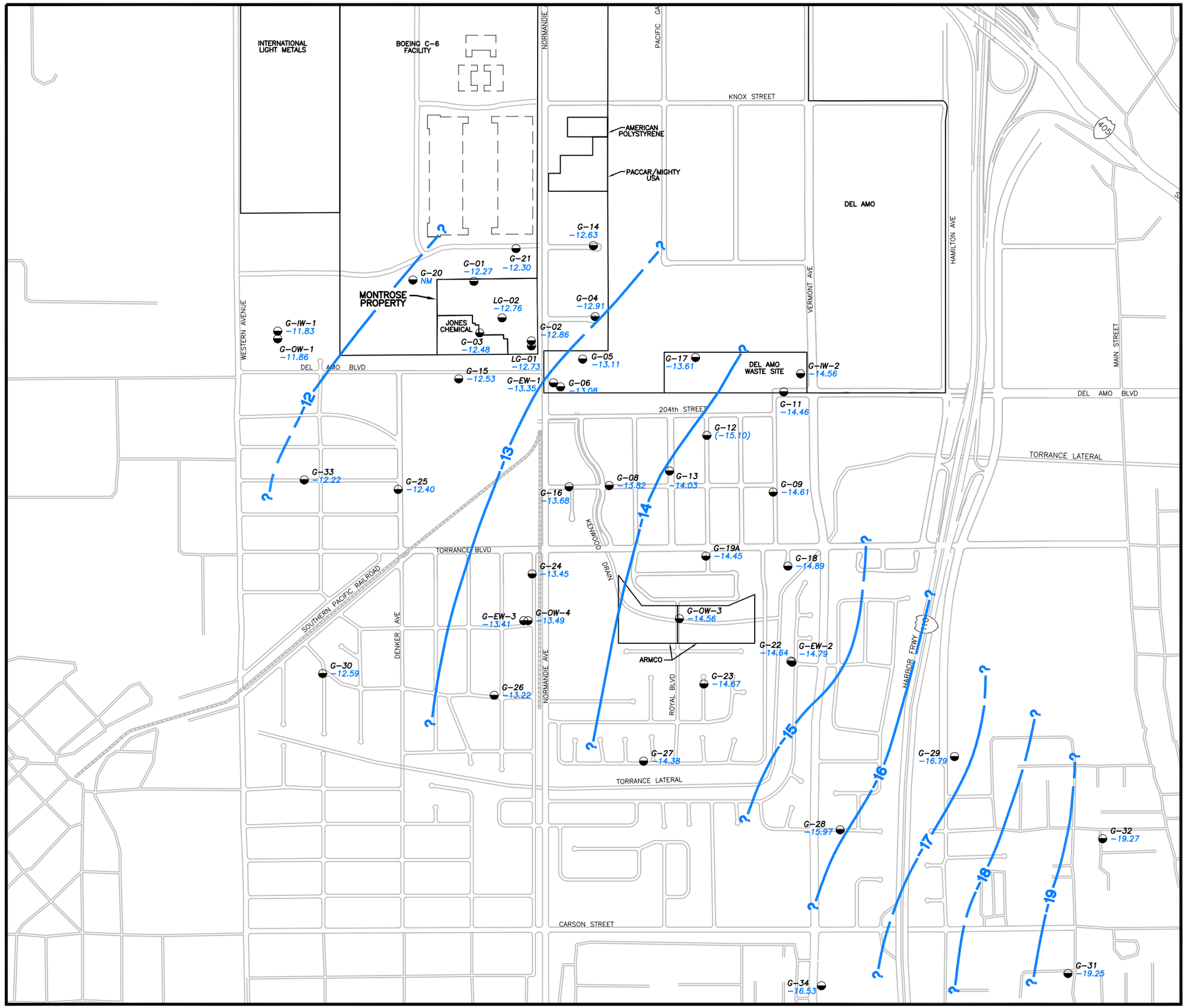
TORRANCE, CALIFORNIA

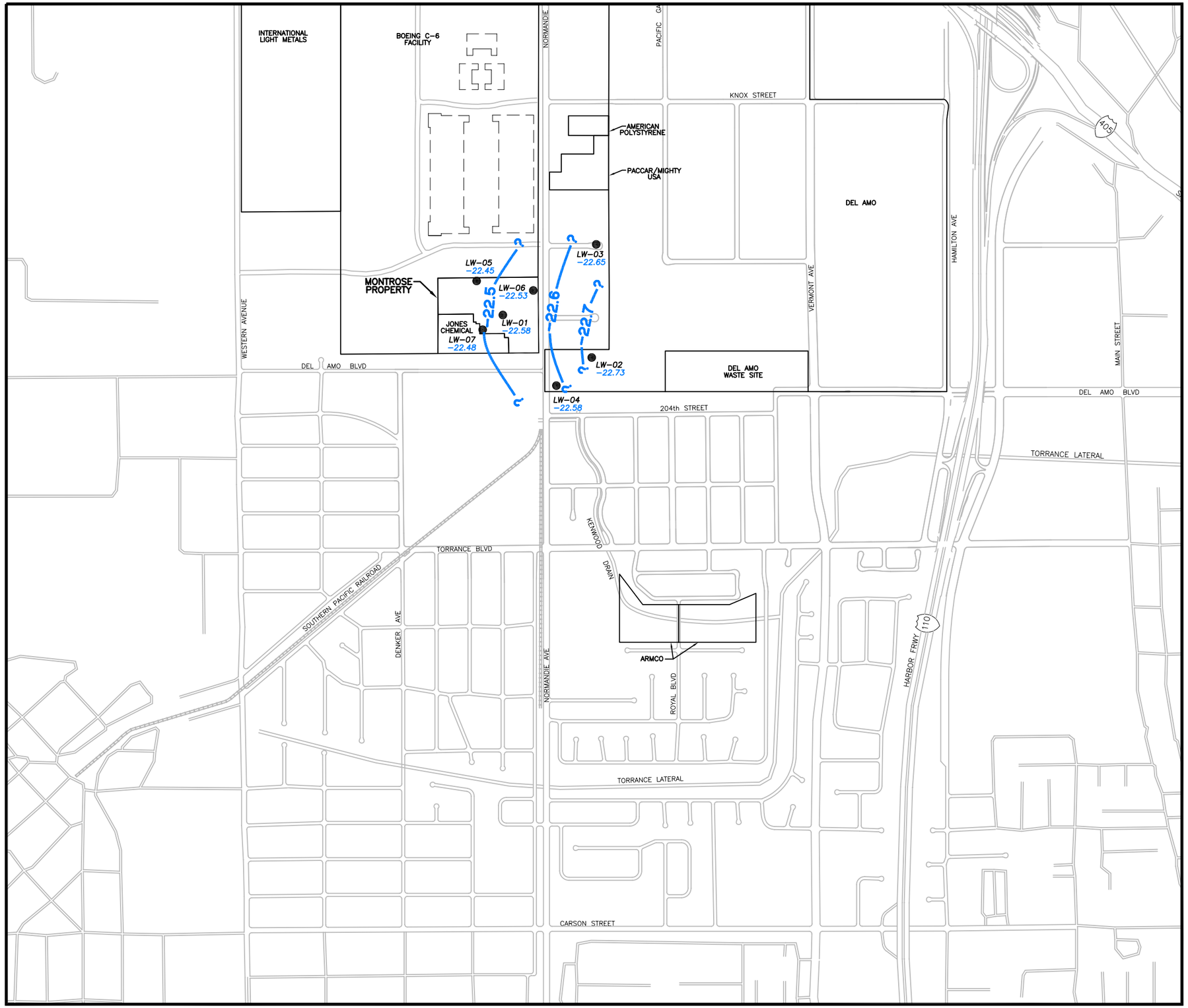
GROUNDWATER ELEVATION MAP
BELLFLOWER SAND
OCTOBER 2006

HARGIS + ASSOCIATES, INC. 3/08

FIGURE 1.18

RPT NO. 857.04B | 220-1910 | A


INTERNATIONAL LIGHT METALS
BOEING C-6 FACILITY
NORMANDIE
PACIFIC GAS
KNOX STREET
AMERICAN POLYSTYRENE
PACCAR/MIGHTY USA
DEL AMO
HAMILTON AVE
405
MONTROSE PROPERTY
JONES CHEMICAL
WESTERN AVENUE
VERMONT AVE
MAIN STREET
DEL AMO BLVD
DEL AMO WASTE SITE
204th STREET
TORRANCE LATERAL
TORRANCE BLVD
SOUTHERN PACIFIC RAILROAD
DENKER AVE
KENWOOD DRAIN
ARMCO
ROYAL BLVD
HARBOR FRWY
CARSON STREET
G-05 GAGE AQUIFER MONITOR WELL
-13.11 WATER LEVEL ELEVATION FEET MEAN SEA LEVEL
NM NOT MEASURED
( ) NOT CONTOURED
? —— -12 —— ? CONTOUR LINE OF EQUAL WATER LEVEL ELEVATION IN FEET BELOW MEAN SEA LEVEL; DASHED WHERE APPROXIMATE, QUERIED WHERE INFERRED.
DIRECTION OF GROUNDWATER FLOW
SOURCE: HARGIS + ASSOCIATES, 2007a
0 1,000 2,000
FEET
MONTROSE CHEMICAL CORPORATION
TORRANCE, CALIFORNIA
GROUNDWATER ELEVATION MAP
GAGE AQUIFER
OCTOBER 2006
HARGIS + ASSOCIATES, INC.
3/08
FIGURE 1.19
RPT NO. 857.04B
220-1911
A



EXPLANATION

LW-01 ● LYNWOOD AQUIFER MONITOR WELL

-22.60 WATER LEVEL ELEVATION FEET MEAN SEA LEVEL

( ) NOT CONTOURED

? —— -12 — — — — ?

CONTOUR LINE OF EQUAL WATER LEVEL ELEVATION IN FEET BELOW MEAN SEA LEVEL; DASHED WHERE APPROXIMATE, QUERIED WHERE INFERRED.

DIRECTION OF GROUNDWATER FLOW

SOURCE: HARGIS + ASSOCIATES, 2007a

N

0 1,000 2,000

FEET

MONTROSE CHEMICAL CORPORATION

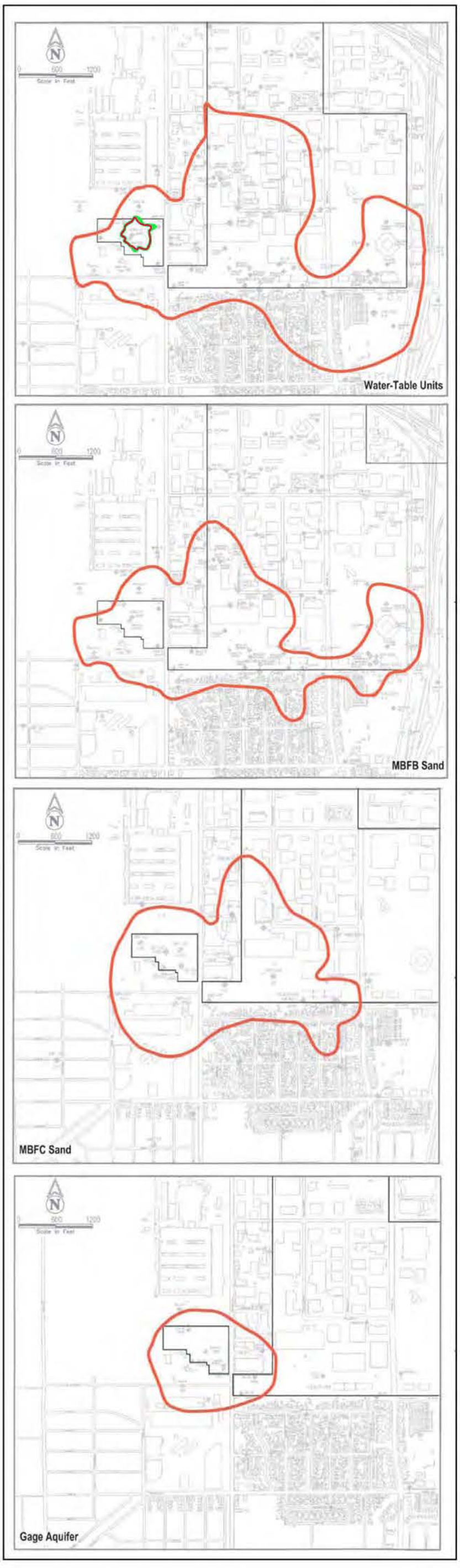
TORRANCE, CALIFORNIA

GROUNDWATER ELEVATION MAP
LYNWOOD AQUIFER
OCTOBER 2006

HARGIS + ASSOCIATES, INC. 3/08

FIGURE 1.20

RPT NO. 857.04B | 220-1912 | A



EXPLANATION

MONTROSE PROPERTY

TI WAIVER ZONE EXTENT

EXTENT OF CONFIRMED DNAPL PRESENCE IN THE SATURATED UBA

EXTENT OF POSSIBLE DNAPL PRESENCE IN THE SATURATED UBA

MBFB = MIDDLE BELLFLOWER B-SAND

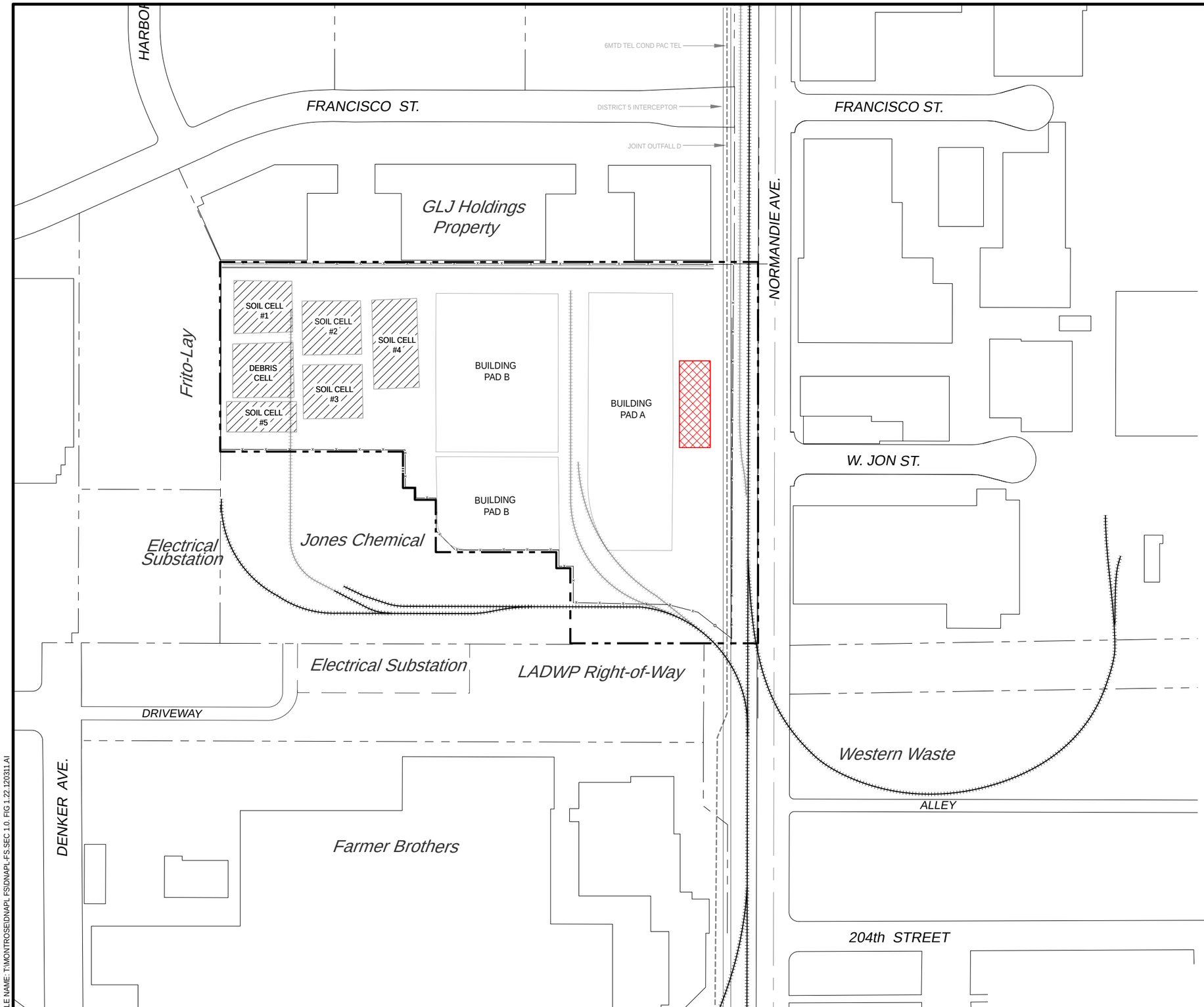
MBFC = MIDDLE BELLFLOWER C-SAND

NOTE:
THE TI WAIVER ZONE IS FOR THE JOINT SITE. THE ROD (EPA, 1999) DOES NOT PROVIDE A PRECISE DEMARCATION BETWEEN THE MONTROSE AND DEL AMO PORTIONS OF THE TI WAIVER ZONE.

SOURCE: ENVIRONMENTAL PROTECTION AGENCY, 1999

3/08	RPT NO. 857.04b	410-6644	A

FIGURE 1.21
TI WAIVER ZONE EXTENT



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- Utility Trench
- Proposed Treatement Plant Location

References:

1. Parcel Boundary Information from Los Angeles,CA, Department of Public Works, Online ArcInfoGIS data set, 2004. Montrose Chemical CorporationBoundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference:
   Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
   TerraServer Georefernced Imagery, 2003.
3. GeoSyntec, 2011. *Montrose Chemical Corporation of California, Dual Site Groundwater Operable Unit, Montrose Chemical and Del Amo Superfund Site, Torrance, California, Intermediate Design Drawings.* June 30.

NORTH

0 100 200 FEET

SCALE: 1"= 200'

Montrose Chemical Corporation

Planned
Groundwater Treatment Plant
Location Map

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	1.22

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 1.0. FIG 1.22.120311.AI

Section 2.0

Nature and Extent of DNAPL Contamination

2.0 NATURE AND EXTENT OF DNAPL CONTAMINATION

This section presents the nature and extent of DNAPL at the Site as determined by the characterization activities listed in Section 1.6. The extent of DNAPL contamination at the Site is presented for each of the stratigraphic units including the unsaturated zone, saturated UBA, and the BFS. Since the stratigraphic units below the BFS are not related to the occurrence of DNAPL at the Site, they are not discussed in this section. The characterization data presented in this section is organized as follows:

- Section 2.1 – Presents the chemical and physical properties of the DNAPL;
- Section 2.2 – Presents the nature and extent of contamination in the unsaturated zone;
- Section 2.3 – Presents the nature and extent of contamination in the saturated UBA;
- Section 2.4 – Presents the nature and extent of contamination in the BFS;
- Section 2.5 – Presents the extent of DNAPL at the Site;
- Section 2.6 – Presents a summary of DNAPL treatability and modeling studies.

Because the Montrose DNAPL is an unusual mixture comprised of MCB and DDT, the following sections, besides providing basic information on the character of this material, also provide comparisons of the material to other more common DNAPLs found at other sites.

2.1 NATURE OF DNAPL

DNAPLs composed of a VOC and a pesticide such that is found at the Montrose Site are not common, and the nature of the DNAPL is different from more common DNAPLs such as TCE and PCE. To illustrate this difference between the Montrose DNAPL and typical DNAPLs an evaluation was conducted by evaluating a number of case studies. Similar DNAPLs have only been reported at three other former DDT manufacturing facilities including:

- Velsicol Superfund Site in St. Louis, Michigan;
- Arkema, Inc. (formerly ATOFINA) Site in Portland, Oregon; and
- Syngenta Site in Houston, Texas.

The DNAPL remedies implemented to date at these three sites include hydraulic containment and/or extraction of mobile DNAPL. However, the hydraulic containment system at the Velsicol Site was unsuccessful in preventing DNAPL seepage into the adjacent Pine River, and alternative DNAPL remedies are currently under FS evaluation for that site. Montrose evaluated six other former DDT manufacturing facilities in 2010 (AECOM, 2010e), but no DNAPL was reported at these sites.

Additionally, only four other sites have been identified where MCB (without DDT) was a primary component of the DNAPL including:

1) SMC Route 44 site in Taunton, Massachusetts;
2) Silresim site in Lowell, Massachusetts;
3) GATX Annex Terminal in San Pedro, California; and
4) Standard Chlorine of Delaware site in New Castle County, Delaware.

Four additional sites were suspected of containing MCB as a minor site contaminant (CH2M Hill, 2007 and EPA,2010a) including: the Loring Quarry site, Hill Air Force Base, Kelly Air Force Base, and the Eastland Woolen Mill site. However, a detailed review of those sites revealed that MCB was not a significant contaminant of concern as indicated in **Appendix K**.

Due to the infrequent occurrence of this type of DNAPL, the behavior of this DNAPL under varying conditions is not well documented, and there is a limited basis from which to evaluate the success or failure of DNAPL remedial action at sites with these contaminants. The Montrose DNAPL and Site conditions are not common, and there is limited experience at other sites with comparable conditions on which to evaluate candidate DNAPL remedial alternatives. Although it is recognized that there are other sites with complex stratigraphy and challenging contaminant properties, the remediation experience of DNAPLs at other former DDT manufacturing facilities is limited.

DDT is a solid at standard temperature and pressure, but is highly soluble in MCB. The Montrose DNAPL is saturated with DDT, and any decrease in the percentage of MCB in the DNAPL will result in precipitation of DDT. This effect has been observed at the Property during DNAPL purging, sampling, and extraction testing. DDT readily precipitates out of solution, forming a light-colored precipitate which adheres strongly to solid materials, including Teflon™, and can result in equipment fouling. DDT fouling of equipment and the associated impact on remedy performance is further discussed in subsequent sections where appropriate.

The chemical composition and physical properties of the Montrose DNAPL were evaluated during studies conducted in 1998, 2005, 2006, and 2008. In 1998, a study was conducted to characterize the chemical composition of the DNAPL and to obtain data regarding the physical properties of the DNAPL at standard temperature (20°C) and pressure (1 atmosphere). Non-standard and Site-specific laboratory methods were developed to identify the chemical composition of the Montrose DNAPL (H+A, 1999). Additional studies were conducted in 2005 to evaluate the boiling point of the DNAPL (H+A, 2006b). In 2006, EPA conducted studies of the DNAPL to evaluate density, viscosity, and interfacial tension at

varying temperatures up to 90°C (Davis, 2006). Finally, additional testing of the DNAPL composition was conducted in 2008 in coordination with 2-dimensional bench-scale testing (AECOM, 2011k).

2.1.1 CHEMICAL COMPOSITION

Five DNAPL samples were collected from individual wells in 1998 and analyzed for chemical composition (H+A, 1999). The DNAPL samples were collected from MW-2, UBT-1 through UBT-3, and UBE-1 (**Figure 2.1**). Results indicated that the DNAPL was composed of approximately 50% MCB by weight (a VOC) and 50% DDT by weight (a non-volatile pesticide). Less than 1% by weight was composed of other VOCs including methyl ethyl ketone (0.5% by weight in one sample), chloroform (0.1 to 0.4% by weight in four samples), 1,4-dichlorobenzene (0.1 to 0.2% by weight in five samples), and pCBSA (0.07 to 0.14% by weight in five samples).

Additional DNAPL samples were collected in 2008 for chemical analysis in advance of 2-dimensional bench-scale testing (Earth Tech, 2007a). Two composite DNAPL samples were collected on March 7, 2008 by combining DNAPL purged from wells UBE-1 and UBE-4. The samples consisted of one primary and one duplicate sample and were analyzed for MCB and Total DDT by EPA Method 8270C modified. Analytical results for both samples were identical, indicating 64% MCB by weight and 36% DDT by weight. No DDD or DDE isomers were detected in the samples. Analytical results of DNAPL samples from 1998 and 2008 are provided in **Appendix A**.

Both results are considered valid and within the range of required analytical precision, since DNAPL from well UBE-4 was not tested in 1998 (the well had not yet been installed). However, the DDT component of the DNAPL has a tendency to precipitate in the sample jar prior to analysis which could result in a reduced concentration of DDT in the DNAPL. Although laboratory procedures established for analysis of the Montrose DNAPL by modified EPA 8270C are intended to minimize the effects of DDT precipitation, Montrose conducted additional analyses of a DNAPL sample from UBE-4 in March 2009 to resolve the DNAPL composition at this well (**Appendix A**). Results indicated that the DNAPL was composed of 51% MCB and 49% Total DDT by weight, which is consistent with the 1998 results. The 2008 and 2009 DNAPL analytical results will be reported to EPA as part of on-going bench-scale treatability studies, as described in Section 2.6.6. For the purpose of this FS, it is assumed that the Montrose DNAPL is composed of 50% by weight MCB and 50% by weight DDT.

2.1.2 PHYSICAL PROPERTIES

Physical properties of the DNAPL were evaluated during studies conducted in 1998 (H+A, 1999) and 2006 (H+A, 2006b; Davis, 2006). In 1998, the density, viscosity, and interfacial tension of the DNAPL were measured at a temperature of 22 °C. In 2006, boiling point experiments were conducted for both DNAPL and a DNAPL/groundwater mixture. A dditionally, EPA conducted experiments in 2006 measuring DNAPL density, viscosity, and interfacial tension at temperatures between 10 and 90°C. The results of the DNAPL physical testing were relatively consistent showing little variability in the physical properties from one well location to another. The results of the physical properties analyses are summarized below:

Physical Properties of Montrose DNAPL

Physical Property	Test Temperature	Result	Year of Test
Density	10 °C	1.228 to 1.239 g/cc	2006 – Davis
	22 °C	1.241 to 1.252 g/cc	1998 – H+A
	90 °C	1.155 to 1.157 g/cc	2006 – Davis
Viscosity	10 °C	3.4 to 3.5 cP	2006 – Davis
	22 °C	2.5 to 2.8 cP	1998 – H+A
	60 °C	1.8 to 2.0 cP	2006 – Davis
Interfacial Tension, DNAPL-Groundwater	10 °C	11.1 to 11.5 dyn/cm	2006 – Davis
	22 °C	13.0 to 15.0 dyn/cm	1998 – H+A
	90 °C	10.6 to 11.8 dyn/cm	2006 – Davis
Boiling Point – DNAPL only[1]	Various	Initial: 128 °C Final: 359 °C	2006 – H+A
Co-Boiling Point – DNAPL/GW mixture[2]	Various	Initial: 96 °C Final: 115 °C	2006 – H+A

1. The boiling point increases as the MCB component of the DNAPL boils off, eventually reaching a maximum temperature when the DNAPL was likely composed solely of DDT.
2. Initially, the DNAPL boiled off more rapidly than the water. After capture of approximately half of the DNAPL, when the MCB component boiled off, the water began to boil off more rapidly than the DNAPL, steadily increasing to a maximum temperature.
g/cc = grams per cubic centimeter
cP = centipoise
dyn/cm = dynes per centimeter

Density

Density is the measure of weight per unit volume for a material and is often compared to water. Contaminants that are immiscible with water and have densities greater than 1.0 g/cc are referred to as

DNAPLs. Contaminants that are immiscible with water and have densities less than 1.0 g/cc are referred to as light non-aqueous phase liquids (LNAPLs). The Montrose DNAPL density, 1.25 g/cc at 20°C, is approximately 25% more dense than water. In the saturated zone, the DNAPL will experience a net downward gravitational force, causing it to flow downward through permeable soil layers and to accumulate above low permeability silts or clays (also called capillary barriers).

The Montrose DNAPL density at ambient conditions is considered a moderate density. Compared with other common DNAPLs, the Montrose DNAPL is heavier than creosote (approximately 1.1 g/cc) but is lighter than trichloroethene (TCE; approximately 1.46 g/cc) or tetrachloroethene (PCE; approximately 1.62 g/cc).

Viscosity

Viscosity is a measure of a fluid's resistance to flow. Contaminants with viscosities greater than 1 cP are more viscous than water, while contaminants with viscosities less than 1 cP are less viscous than water. The Montrose DNAPL viscosity, approximately 2.5 cP at 20°C, is therefore 2.5 times more viscous than water. Although the viscosity of MCB (0.8 cP) is less than that of water, the large percentage of DDT in the Montrose DNAPL results in a viscosity well above that of water.

The significance of this physical property is that the flow of Montrose DNAPL through saturated soils will be 2.5 times slower than the flow of water under equivalent hydraulic conditions and saturations. The Montrose DNAPL is considered to have a moderate viscosity in comparison to other common DNAPLs. For example, DNAPLs such as TCE and PCE have viscosities under 1.0 cP, while creosote has a high viscosity of approximately 20 cP (greater than 10 cP in most cases).

Interfacial Tension

Interfacial tension is a measure of the attractive forces at the interface between two immiscible fluids, which, in this case, are DNAPL and groundwater. The interfacial tension results in capillary forces that must be overcome in order to mobilize a fluid through a soil matrix. Low interfacial tensions lead to low capillary forces and indicate that fluids will require less energy to displace from soil pores as compared with high interfacial tensions.

The interfacial tension of the Montrose DNAPL/water of 13 to 15 dyn /cm is low to moderate in comparison with other common DNAPLs. The interfacial tensions of TCE/water, PCE/water, and creosote/water mixtures encountered at sites typically range from approximately 20 to 30 dyn/cm.

Considering all physical properties (i.e., moderate density, moderate viscosity, and low to moderate interfacial tension), the Montrose DNAPL exhibits a moderate mobility as compared with other common DNAPLs.

Boiling Point

The boiling point of a liquid is the temperature at which the vapor pressure above a liquid equals the ambient pressure; at this point a liquid begins to boil. The boiling point of pure MCB at 1 atmosphere is 132°C, which is well above the boiling point of pure water (100°C). However, in the presence of groundwater at atmospheric pressure, the boiling point of an MCB/water mixture is 92°C at 1 atmosphere, which is below the boiling point of pure water and pure MCB. This phenomenon is known as the co-boiling point, where the boiling point at the interface of two fluids is lower than the boiling point of either fluid (i.e. based on Dalton's Law). This principle is fundamental to thermal remediation projects and allows boiling of the DNAPL, at the interface, in advance of groundwater boiling. The co-boiling points for the Montrose DNAPL and other common VOC NAPLs (USACE, 2009 and ITRC, 2004) are shown below:

Co-Boiling Point of VOC NAPL/Water Mixtures

NAPL	Co-Boiling Point with Water at 1 atm
Benzene	69°C
TCE	73°C
PCE	88°C
MCB	92°C
Montrose DNAPL	96°C

Notes:
atm = atmosphere

The co-boiling point for the Montrose DNAPL is relatively high compared with other VOCs. For example, saturated soils contaminated with Montrose DNAPL would require an additional 19°C of heating in order to initiate co-boiling as compared to a DNAPL composed of TCE. A comparison of boiling points and vapor pressures (vapor pressure, is the pressure of a vapor in equilibrium with its non-vapor phases) for MCB and other common VOCs (USACE, 2002 and 2009) is provided below:

Boiling Point and Vapor Pressure of VOCs

VOC	Boiling Point at 1 atm (°C)	Vapor Pressure at 20 °C (mm Hg)	
Benzene	80	81	More Volatile
TCE	87	73	↓
PCE	121	19	
MCB	132	12	Less Volatile

Notes:
mm Hg = millimeters of mercury

Because of the higher boiling point (132°C at 1 atmosphere) and lower vapor pressure (12 mm Hg at 20°C) of MCB, thermal remediation technologies that rely primarily on contaminant volatilization will be less effective for the Montrose DNAPL than for most other VOCs. However, the boiling point and vapor pressure of MCB are not significantly different from those for PCE, and depending on the site conditions, thermal remediation performance at sites with PCE DNAPLs may provide some data for the Montrose Site.

Creosote is not listed in the above tables because it is not a VOC. Creosote has a high boiling point of more than 200°C and a low vapor pressure of approximately 0.5 mm Hg at 20°C (Koppers Industries, 2001). C onsequently, thermal remediation of creosote DNAPLs rely primarily on displacement mechanisms (i.e., reduction of viscosity) and, to a much lesser extent, volatilization (since temperatures will not be high enough to boil creosote). However, for the Montrose DNAPL, volatilization of the MCB component will be the primary removal mechanism during thermal remediation (both direct and via steam stripping), although some liquid-phase DNAPL may also be removed by displacement during steam injection.

DNAPL-Water Capillary Pressure Curve

DNAPL-water capillary pressure curves provide a measure of DNAPL saturation at varying capillary pressures and provide an indication of DNAPL mobility in the saturated zone. Drainage and imbibition capillary pressure curves for the Montrose DNAPL were measured for a core sample collected from the saturated UBA as part of the 2-dimensional thermal remediation bench-scale testing (Earth Tech, 2008a). DNAPL, soil, and groundwater collected from the Site were used to conduct the capillary pressure measurements.

The capillary pressure measurements were conducted by PTS Laboratories in Santa Fe Springs, California, and a copy of their laboratory report is provided in **Appendix B**. For the drainage curve, DNAPL displaces water in a saturated core at increasing capillary pressures. The drainage curve ended with a maximum DNAPL saturation of 50.7%. For the imbibition curve, water displaces DNAPL at varying capillary pressures, and the curve ended with a minimum DNAPL saturation of 18.9%.

The significance of this value is that the lowest achievable residual DNAPL saturation from this soil type through hydraulic displacement would be 18.9%, provided that the pore space was initially saturated to at least 50.7%. This data point is representative of conditions in this particular soil sample, but residual saturations at the Property will vary with soil conditions. This sample was identified as a fine-grained sand consisting of 89% sand and 11% silt and clay, with an effective porosity of 26% and a vertical permeability to water of 5×10^{-4} cm/s.

While this soil type is reasonably representative of the sand layers within the saturated UBA, soil samples with smaller pore throats, such as present in silts and clays, will generally exhibit higher residual DNAPL saturations. The above core sample result is specific to that particular soil type and is not representative of all DNAPL-impacted soil types at the Site. Additional core testing will be required in the future to establish residual DNAPL saturations for soil types subject to remediation. Please refer to Section 2.5.3 for additional details regarding use of this core testing result.

2.2 SOIL CONTAMINATION IN THE UNSATURATED ZONE

Contamination, sorbed-phase and DNAPL-phase, occurs at the Site in both the unsaturated zone and saturated zone. This section summarizes the occurrence and distribution of contaminants in the unsaturated zone between land surface and groundwater (60 feet bgs). Contamination in shallow unsaturated soils (i.e., surface to approximately 10 feet bgs) is being addressed by the Soil FS, currently under preparation by Geosyntec. Contamination in deeper unsaturated soils (i.e., 10 to 60 feet bgs) is being addressed by this DNAPL FS. The nature and extent of impact to groundwater in the UBA is discussed in Section 2.3, and impact to groundwater in the BFS is discussed in Section 2.4. The nature and extent of DNAPL at the Property is presented in Section 2.5.

Contaminants discussed in this section include MCB and DDT, which are related to the occurrence of DNAPL at the Property, and other VOCs, which can impact DNAPL remedial technologies and process options considered in this FS. Although the unsaturated zone was additionally characterized for metals, concentrations approaching EPA PRGs were infrequently detected and primarily occurred in near-surface

soils. Metals in unsaturated soils will not impact DNAPL remedial technologies or process options evaluated in this FS, and therefore, are not presented in this section (but will be addressed in the Soil FS).

The occurrence and distribution of contaminants is based on (i) soil investigation activities conducted during the Remedial Investigation at the Site (EPA, 1998), (ii) a SVE pilot test conducted in 2003 (Earth Tech, 2004a), (iii) a soil gas survey conducted in 2003 and in 2010 (Earth Tech, 2004c, AECOM 2011j), (iv) a DNAPL Reconnaissance Program conducted by Montrose in 2003/2004 (H+A, 2004b), (v) supplemental soil investigation activities conducted in 2005 and 2008 (Earth Tech, 2007b and AECOM, 2011l), and (vi) soil, soil gas and DNAPL investigations conducted in 2010 by Jones Chemical (ARCADIS, 2010 and 2011).

2.2.1 MCB

MCB is the predominant VOC detected in unsaturated soils at the Property, and the distribution of MCB in the unsaturated zone is shown in **Figure 2.2**. The highest MCB concentration detected at each soil boring is mapped in this figure (i.e. one peak concentration per location). The highest concentrations of MCB, up to 70,000 mg/kg (at boring PSB-5), occur within the CPA. Relatively high MCB concentrations in soil extend from boring S-101 at the former wastewater pond to boring SSB-4 in the northeast corner of the CPA, where raw materials storage tanks were located. DNAPL-impacted soil samples were collected from the unsaturated zone at borings PSB-5 and SSB-4, and MCB was detected in concentrations of 70,000 (at 57.5 feet bgs) and 14,000 mg/kg (at 17 feet bgs) in these two samples respectively. Relatively high MCB concentrations in soil were additionally detected at borings 24D, S302F, and C33 located near the southeastern corner of the CPA. Outside of these source area locations, only low to moderate concentrations of MCB were detected in soil. MCB concentrations in the PD and PVS/unsaturated UBA are mapped in **Figures 2.3a and 2.3b** respectively

<u>MCB in Soil Gas</u>

In 2003, MCB concentrations in soil gas were measured at depths of 5 and 15 feet bgs in the PD and at 35 feet bgs in the PVS, from up to 33 locations (Earth Tech, 2004c). MCB concentrations in soil gas were also tested at depths of 5 and 15 feet bgs in the PD from six locations along the northern Property boundary in 2010 (AECOM, 2011j). MCB concentrations in soil gas are mapped at each of these depths in **Figures 2.4a through 2.4c** and summarized as follows:

<u>MCB at 5-feet bgs in the PD</u>

- MCB concentrations in soil gas ranged from <0.5 to 450 ug/L.

- The maximum MCB concentration detected in soil gas was 450 ug/L at SG14, located east of the CPA at Building Pad A.

MCB at 15-feet bgs in the PD

- MCB concentrations in soil gas ranged from <0.5 to 4,400 ug/L.
- The maximum MCB concentration detected in soil gas was 4,400 ug/L at SG16A, located within the CPA and former water recycling pond.

MCB at 35-feet bgs in the PVS

- MCB concentrations in soil gas ranged from <1 to 8,800 ug/L.
- The maximum MCB concentration detected in soil gas was 8,800 ug/L at SG21, located in the southeast corner of the CPA.
- MCB concentrations in soil gas greater than 1,000 ug/L were observed at SG08, SG16A, SG17, SG21, SG25, and SG29, extending from the CPA over an area extending both east and southeast of the CPA.
- MCB was typically not detected at the JCI property and was only detected in one sample (J-SG-84) at a concentration of 210 ug/L (ARCADIS, 2010).

2.2.2 ESTIMATED MASS OF MCB IN THE UNSATURATED ZONE

To support evaluation of remedial technologies and process options, the mass of MCB in the unsaturated zone was estimated as shown in **Appendix C**. The average MCB concentration within the impacted areas shown in **Figures 2.3a and 2.3b** were used to estimate the MCB mass. Because soils in the PD exhibit low permeability to air, the mass of MCB was estimated for two depth intervals corresponding to the PD (0-25 feet bgs) and the PVS/unsaturated UBA (25-60 feet bgs) as follows:

- PD (0 to 25 feet bgs): An estimated 237,000 pounds of MCB are present, including DNAPL-phase MCB detected at 17 feet bgs in SSB-4.
- PVS/unsaturated UBA (25 to 60 feet bgs): An estimated 261,000 pounds of MCB are present, including DNAPL-phase MCB detected at 57.5 feet bgs in PSB-5.

Other VOCs occur in unsaturated soils in substantially lower concentrations and frequencies. Those VOCs are not components of DNAPL, they do not significantly contribute to the mass of VOCs at the Site, and they will not significantly impact remedial alternative analysis or containment timeframes. For these reasons, the mass of VOCs other than MCB are not presented in this FS. Although DNAPL-phase DDT in the saturated zone is considered by this FS (as presented in Section 2.5.5), sorbed-phase Total DDT (a solid) in the unsaturated zone is not considered by this FS. Shallow soils in the unsaturated zone (i.e., 0 to 10 feet bgs) that are impacted with Total DDT will be addressed by the Soil FS (currently in progress). More than 500,000 pounds of sorbed-phase Total DDT are estimated to be present in the unsaturated soils at the Site (see Soil FS for further details).

2.2.3 OTHER VOCS

Although MCB is the predominant VOC detected in soils and soil gas at the Property, a small number of other VOCs were detected in excess of their respective industrial PRGs (EPA, 2008e), including chloroform, 1,4-DCB, PCE, benzene, and carbon tetrachloride. These VOCs occur in substantially lower concentrations in the unsaturated zone, are not a component of the Montrose DNAPL, and do not significantly contribute to the mass of VOCs in the subsurface. Nonetheless, some of these VOCs may affect DNAPL remedy evaluation, and therefore, the occurrence of these VOCs in the unsaturated zone is summarized below. Specifically, chloroform was the second highest vapor-phase contaminant detected in soil vapors extracted during an SVE pilot test conducted at the Site in 2003 and will need to be considered during selection of an off-gas treatment technology.

Chloroform

- In unsaturated soils, chloroform was detected in concentrations up to 160 mg/kg as shown in **Figure 2.5**. The highest chloroform concentrations occur over a limited area in the northeast corner of the CPA at borings 14D, C15, and C9. The highest chloroform concentrations in this area occur within the low permeability PD soils, with up to 160 mg/kg at 10 feet bgs and up to 130 mg/kg at 20 feet bgs. Outside the CPA, the highest concentrations of chloroform, up to 11 mg/kg, occur to the southeast at borings C45 and C50. Chloroform concentrations in the PD and PVS/unsaturated UBA are mapped separately in **Figures 2.6a and 2.6b**.
- In soil gas, chloroform was detected in concentrations up to 220 ug/L at 5-feet bgs (SG36B), 440 ug/L at 15-feet bgs (SG16A), and 11,000 ug/L at 35-feet bgs (SG08). The highest concentrations of chloroform in soil gas occur at 35 feet bgs in SG08, located in the northeast corner of the CPA, and in SG29, located southeast of the CPA. Maps of chloroform in soil gas are provided as **Figures 2.7a through 2.7c**. At the JCI property, chloroform was detected at concentrations up to 4,400 ug/L at J-SG-96 (ARCADIS, 2010).

1,4-Dichlorobenzene

- In unsaturated soils, 1,4-DCB was detected in concentrations up to 260 mg/kg as shown in **Figure 2.8**. The highest 1,4-DCB concentrations occur over a limited area in the CPA at borings 24D, C15, and C33. The highest 1,4-DCB concentrations in this area occur within the low permeability PD soils, with up to 240 mg/kg at 7 feet bgs, up to 260 mg/kg at 10 feet, and up to 190 mg/kg at 20 feet bgs. Outside the CPA, the highest concentrations of 1,4-DCB, up to 44 mg/kg, occur in the southeast corner of the Property at boring C64. 1,4-DCB concentrations in the PD and PVS/unsaturated UBA are mapped separately in **Figures 2.9a and 2.9b**.
- Only very low concentrations of 1,4-DCB were detected in soil gas; this contaminant has a low vapor pressure under 2 mm Hg at 20°C. In soil gas, 1,4-DCB was detected in concentrations up to 2 ug/L at 5-feet bgs (SG27), 25 ug/L at 15-feet bgs (SG16A), and 7 ug/L at 35-feet bgs (SG31). Maps of 1,4-DCB in soil gas are provided as **Figures 2.10a through 2.10c**. The soil gas at the JCI property was not analyzed for 1,4-DCB (ARCADIS, 2010).

PCE

- In unsaturated soils, PCE was detected in concentrations up to 34 mg/kg as shown in **Figure 2.11**. The highest PCE concentrations occur in isolated areas at the Property in borings C14, C33, and C55. Nearly all of these PCE concentrations occur within the low permeability PD soils. PCE concentrations in the PD and PVS/unsaturated UBA are mapped separately in **Figures 2.12a and 2.12b**. At the JCI property, PCE was detected at concentrations up to 6,120 mg/kg (ARCADIS, 2010).
- In soil gas, PCE was detected in concentrations up to 59 ug/L at 5-feet bgs (SG48B), 410 ug/L at 15-feet bgs (SG25), and 5,700 ug/L at 35-feet bgs (SG28). Maps of PCE in soil gas are provided as **Figures 2.13a through 2.13c**. The PCE in soil gas originates from the JCI Property, with the highest concentrations occurring along the Montrose/JCI property boundary. PCE is a known contaminant of concern in soil and soil gas at the JCI property (Levine-Fricke, 1995). At the JCI property, PCE was detected in soil gas at concentrations up to 22,000 ug/L at J-SG-105 (ARCADIS, 2010).

Benzene

- In unsaturated soils, benzene was found to exceed the 2008 EPA Industrial PRG in only two samples collected from boring S204, located in the CPA (**Figure 2.14**). Benzene concentrations of 10 and 20 mg/kg were detected in samples collected at 26 and 26.5 feet bgs in this boring. No other unsaturated soil samples exhibited benzene concentrations in excess of the 2008 EPA Industrial PRG.
- In soil gas, benzene was detected in concentrations up to 6 ug/L at 5-feet bgs (SG14), 7 ug/L at 15-feet bgs (SG25), and 370 ug/L at 35-feet bgs (SG29). Maps of benzene in soil gas are provided as **Figures 2.15a through 2.15c**. At the JCI property, benzene was detected at concentrations up to 190 ug/L at J-SG-112 (ARCADIS, 2010).

Carbon Tetrachloride

- In unsaturated soils, carbon tetrachloride was found to exceed the 2008 EPA Industrial PRG in only two samples collected from boring C15, located in the CPA (**Figure 2.16**). Carbon tetrachloride concentrations of 2.8 and 3.2 mg/kg were detected in samples collected at 10 and 20 feet bgs in this boring. No other unsaturated soil samples contained carbon tetrachloride concentrations in excess of the 2008 EPA Industrial PRG.
- In soil gas, carbon tetrachloride was detected in concentrations up to 5 ug/L at 5-feet bgs (SG25), 9 ug/L at 15-feet bgs (SG37), and 250 ug/L at 35-feet bgs (SG28). The carbon tetrachloride in soil gas originates from the JCI Property, with the highest concentrations occurring along the Montrose/JCI property boundary. Carbon tetrachloride is a known contaminant of concern in soil and soil gas at the JCI property (Levine-Fricke, 1995). Maps of carbon tetrachloride in soil gas are provided as **Figures 2.17a through 2.17c**. At the JCI property, carbon tetrachloride was detected at concentrations up to 290 ug/L at J-SG-96 (ARCADIS, 2010).

2.2.4 TOTAL DDT

Maximum Total DDT concentrations in the unsaturated zone between 0 and 5 feet bgs are mapped in **Figure 2.18**. Relatively high concentrations of Total DDT, up to 23,620 mg/kg (at boring C2), were

detected in soils over the majority of the Montrose property. The highest concentrations of Total DDT occur within the raised building pads and subsurface soils within the CPA and the northwest corner of the Property (EPA, 1998 and AECOM, 2011l). Total DDT concentrations up to 36,620 mg/kg were detected in shallow soils at the JCI property.

DDT is relatively insoluble in water, adsorbs strongly to soil grains, and is not volatile. Because of these properties, DDT will tend to accumulate in shallow, near-surface soils. However, as demonstrated by the DNAPL, DDT can migrate vertically downward as a component of a MCB/DDT liquid mixture. Therefore, relatively high concentrations of DDT at depth suggest the possible presence of DNAPL, either currently or historically (i.e., the MCB component of the DNAPL may have volatilized/weathered over time). Maximum Total DDT concentrations in the unsaturated zone between 10 and 60 feet bgs are mapped in **Figure 2.19** and summarized below; this map excludes Total DDT in the upper 10 feet of the unsaturated zone. The DDT that is present from 0 to 10 feet bgs will be addressed as part of the pending Soil FS.

<u>Total DDT (10 to 60 feet bgs)</u>

- Relatively high concentrations of Total DDT occur throughout the CPA, including:
  - Up to 57,000 mg/kg at PSB-5 in the northeast corner of the CPA,
  - Up to 9,406 mg/kg at S-101/101A within the former water recycling pond and southwestern portion of the CPA,
  - Up to 13,000 mg/kg at PSB-15 located in the southern portion of the CPA, and
  - Up to 1,498 mg/kg at C33 located at the eastern edge of the CPA.
- Relatively low concentrations of Total DDT occur outside the CPA source areas within the 10-60 foot interval of the unsaturated zone. The highest Total DDT concentration outside the CPA source areas over this interval is 30 mg/kg at C50, located southeast of the CPA.
- The maximum Total DDT concentration detected at the JCI property between 10 and 60 feet was 16 mg/kg at C181, located in the northeastern portion of the property along a former surface water drainage pathway.

2.3 GROUNDWATER CONTAMINATION IN THE UPPER BELLFLOWER AQUITARD

Because the distribution of dissolved DNAPL components can be used to infer the extent and distribution of DNAPL, an overview of groundwater contamination in the UBA is presented in this section. For a detailed discussion of regional groundwater contamination at the Site, the reader is referred to the RI Report and subsequent monitoring reports (EPA, 1998; H+A, 2004c, 2007a, and 2009d; Avocet, 2010).

2.3.1 MCB

The lateral extent of the MCB plume in the UBA is depicted in **Figure 2.20** and is based on groundwater samples collected in October 2006 and April 2009, as well as the most recent historical results (i.e., for wells not sampled in October 2006 or April 2009). On-Property the highest concentrations of MCB on-Property (up to 380,000 ug/L at well MW-2) occur within the CPA. The highest concentration approaches the solubility limit for MCB (from DNAPL) in water, which is approximately 410,000 ug/L as indicated in the Final RI Report (EPA, 1998). A MCB plume, i.e. greater than 10,000 ug/L, extends from the property towards the southeast, with a concentration of 150,000 ug/L being detected at monitoring well MW-1 in the southeast corner of the Property. The small lateral extent of MCB in the UBA, approximately 1,500 to 2,000 feet downgradient from the DNAPL source areas, is attributed to low hydraulic conductivity, and consequently low horizontal groundwater flow velocity within the UBA.

2.3.2 OTHER VOCS

Other VOCs detected in groundwater samples collected from on-Property wells screened in the UBA during the Montrose October 2006 and April 2009 monitoring events include:

- Benzene at 3,300 ug/L (MW-1),
- Chloroform from 6.1 ug/L to 18,000 ug/L (MW-1, MW-3, and MW-4),
- Carbon Tetrachloride at 2.6 ug/L (MW-3),
- 1,4-DCB at 190J ug/L (MW-1),
- PCE from 30 ug/L to 2,400 ug/L (MW-1, MW-3 and MW-4),
- TCE from 110 ug/L to 380J ug/L (MW-1, MW-3 and MW-4), and
- 1,1-DCE at 6.1 ug/L (MW-3).

The VOCs detected during the October 2006 and April 2009 monitoring events are generally consistent with historical detections in the UBA. Further information regarding other VOCs detected during the October 2006 and April 2009 sampling events can be found in their respective monitoring reports (H+A, 2007a and 2009d).

2.3.3 DDT

DDT is hydrophobic and relatively insoluble in groundwater. Without MCB as a co-solvent, DDT will adsorb strongly to soil grains and be relatively immobile in groundwater. DDT has been infrequently

detected in groundwater within the UBA despite having been mobilized to the saturated zone by MCB. The concentration of DDT in groundwater in the UBA is mapped in **Figure 2.21**.

2.3.4 pCBSA

pCBSA is an organic salt and is highly soluble in groundwater, up to approximately 150,000 mg/L. pCBSA is stable in groundwater and migrates readily with groundwater flow and through dissolution. pCBSA is only a trace constituent in DNAPL, and the occurrence of this contaminant in groundwater is not related to DNAPL. However, the presence of pCBSA in groundwater will affect DNAPL remedial technologies and process options considered in this FS. pCBSA concentrations in the UBA are mapped in **Figure 2.22**. The highest concentrations of pCBSA of 470,000 ug/l were detected at well MW-2, within the CPA, and well MW-1, at the southeast corner of the site.

2.3.5 INORGANICS

High concentrations of inorganics in groundwater can result in mineral fouling of equipment during DNAPL remediation, primarily from formation of calcium carbon scale. For this reason, the following inorganic concentrations are presented below, and additional details regarding inorganic concentrations are available in the RI Report (EPA, 1998). Although metals have been detected in groundwater, none of their concentrations are high enough to impact DNAPL remedial technologies or process options, other than possibly arsenic. The concentration ranges of specific inorganics detected in on-Property wells, located within or near DNAPL-impacted areas, are summarized below:

- Total Dissolved Solids (TDS) concentrations in on-Property UBA wells ranged from 860 mg/L (MW-3) to 14,000 mg/L (MW-2) and were generally highest in wells located within the CPA.
- Calcium concentrations in on-Property UBA wells ranged from 162 mg/L (MW-3) to 770 mg/L (MW-1) and did not significantly vary across the Property.
- Bicarbonate concentrations in on-Property UBA wells ranged from 420 mg/L (MW-4) to 830 mg/L (MW-1) and did not significantly vary across the Property.
- Relatively neutral acidic conditions, pH values ranging from 6.5 to 7.1 units, have been reported in on-Property UBA wells.
- Arsenic concentrations in on-Property UBA wells ranged from <0.002 mg/L (MW-5) to 0.16 mg/L (MW-2). The arsenic concentration reported at MW-2 (0.014 mg/L) exceeds the Federal maximum contaminant level of 0.01 mg/L.

The potential for calcium carbonate scaling is evaluated by estimating the Langelier Saturation Index (LSI). Based on the inorganic concentrations in the UBA, an LSI of approximately 0.2 is estimated, indicating a slight potential for calcium carbonate scaling (Lenntech, 2011). LSI values greater than 0.5 would be indicative of a high scaling potential.

2.4 GROUNDWATER CONTAMINATION IN THE BELLFLOWER SAND

Some technologies being considered for remediation of the DNAPL-impacted soils may include components that extend into the BFS. Therefore, discussion of the water quality in this zone is presented to provide background for assessing those remedial alternatives. For a detailed discussion of regional groundwater contamination at the Site, the reader is referred to the RI and subsequent monitoring reports (EPA, 1998; H+A, 2004c, 2007a, and 2009d).

2.4.1 MCB

The lateral extent of the MCB plume in the BFS is mapped in **Figure 2.23** and is based on the most recent groundwater samples collected in October 2006 and April 2009. The highest concentration of MCB detected in the BFS at the Property was 87,000 ug/L at well BF-2 located at the southern Property boundary. Within the CPA, MCB was detected at 19,000 ug/L in well BF-9. Concentrations of MCB exceeding the California MCL in the BFS extend several thousand feet downgradient of the source area, and the large lateral extent is attributed to high hydraulic conductivity and a high horizontal groundwater flow velocity within the BFS beneath the Site.

2.4.2 OTHER VOCS

Other VOCs detected on-Property in groundwater samples collected from the BFS during the 2006 and 2009 monitoring events include:

- TCE was detected at 1,200 ug/L in well BF-3 located east of the CPA.
- Chloroform was detected at 970 ug/L in well BF-2 located at the southern Property boundary.

2.4.3 DDT

The concentration of DDT in groundwater in the BFS is shown in **Figure 2.24** and is based on data collected in 2004. Only trace level concentrations of DDT were detected in the BFS, including 4.4 ug/L in monitoring well BF-9 located within the CPA. DDT was also detected at concentrations ranging from 1 to 3 ug/L in monitoring wells located immediately upgradient and downgradient of the CPA.

2.4.4 PCBSA

The lateral extent of the pCBSA plume in the BFS is mapped in **Figure 2.25** and is based on the October 2006 monitoring event and data collected in December 2008 (H+A, 2009d). The highest concentration of pCBSA detected in the BFS at the Property was 76,000 ug/L at well BF-9 located within the CPA.

2.5 EXTENT OF DNAPL

Field investigations have been conducted to assess the vertical and lateral extent of DNAPL beneath the Site. Soil borings drilled prior to 2003 were evaluated for evidence of DNAPL by visual inspection and laboratory analysis. Soil borings drilled after 2003 as part of the DNAPL Reconnaissance Investigation Program were evaluated for evidence of DNAPL using not only visual inspection of core but also staining on a hydrophobic dye-impregnated fabric (Flexible Liner Underground Technologies [FLUTe] ribbon), laboratory analysis of discrete soil samples, and organic vapor analyzer (OVA) field soil headspace measurements (H+A, 2004b). These lines of evidence provide information related to the definite and possible presence of DNAPL in the subsurface. The following guidelines were used in evaluating the various lines of evidence for assessing DNAPL occurrence at the Site:

DNAPL Occurrence Guidelines

Method	**DNAPL Not Present**	**DNAPL Possibly Present**	**DNAPL Definitely Present**
Primary			
Visual	Not Visible	Not Visible	Oily Sheen
FLUTe Ribbon	No Staining	No Staining	Ribbon Staining
Secondary			
Laboratory Results[1]	<180 mg/kg MCB or <60 mg/kg Total DDT	180 to 1,000 mg/kg MCB or 60 to 1,000 mg/kg Total DDT	>1,000 mg/kg MCB or >1,000 mg/kg Total DDT
OVA readings[1]	<1,500 ppmv	1,500 to 10,000 ppmv	>10,000 ppmv

Notes:
[1] The rationale for the criteria for laboratory results and OVA readings maybe found in H+A, 2004b.
mg/kg = milligrams per kilogram
ppmv = parts per million vapor
FLUTe = Flexible Liner Underground Technologies

2.5.1 ESTIMATED LATERAL EXTENT OF DNAPL

The lateral extent of DNAPL varies between the unsaturated and saturated zones, as described below. Based on recent and historic investigations, the area directly beneath the CPA has the most DNAPL in both the unsaturated zone and the saturated UBA. The lateral extent of DNAPL occurs fully within the Technical Impracticability Waiver Zone established by the EPA as part of the ROD (EPA, 1999). A summary of DNAPL characterization results is provided in **Appendix D**. Additional information regarding the extent of DNAPL in the unsaturated zone is provided in the report summarizing the results of the DNAPL reconnaissance investigation (H+A, 2004b).

Unsaturated Zone (0 to 60 feet bgs)

The majority of the DNAPL in the unsaturated zone occurs in the CPA as shown in **Figure 2.26**. This figure depicts both the definite and possible extents of DNAPL in the unsaturated zone. The definite extent of DNAPL is estimated to be approximately 57,000 square feet and encompasses the majority of the CPA including the former water recycling pond and raw materials storage area. The area is bounded by borings PSB-15, S302F, and PSB-10 to the south and by borings SSB-7, PSB-5, PSB-4, and SSB-4 to the north. DNAPL was visually observed at 57 feet bgs in boring PSB-5 and at 17 feet bgs in boring SSB-4.

The possible extent of DNAPL is estimated to be approximately 79,000 square feet and encompasses areas surrounding by borings PSB-6 to the north, PSB-16 to the west, and several borings to the south. Additionally, two isolated small areas at C59 and C64 located in the unsaturated zone at the southeastern corner of the Property were found to have MCB/Total DDT concentrations meeting the criteria for possible DNAPL, although it is unlikely that DNAPL is present at these locations. Some of the DNAPL characterization criteria, specifically soil analytical results and field headspace concentrations, are not as reliable in characterizing DNAPL in the unsaturated zone. The presence of DDT and MCB in shallow unsaturated soils does not uniquely distinguish DNAPL, as those contaminants could have been released individually. High concentrations of DDT, well above the DNAPL characterization criteria, are present in shallow soils (0-10 feet bgs) over the majority of the Property. DDT is a solid at atmospheric conditions, and in the absence of a co-solvent, has limited potential for migration in the subsurface. Additionally, VOCs in unsaturated soils will volatilize into soil gas in accordance with their physical properties (i.e. partial pressures) and can migrate or diffuse in soil gas over larger areas. For this reason, field headspace concentrations are not as a reliable a method for distinguishing DNAPL in the unsaturated zone (as other methods, i.e., visual staining or FLUTe ribbon).

Saturated UBA (60 to 105 feet bgs)

DNAPL occurs over a larger area within the saturated zone than observed within the unsaturated zone. The definite presence of DNAPL in the saturated UBA occurs over an area of approximately 150,000 square feet as shown in **Figure 2.27**. This area encompasses the majority of the former CPA, including the water recycling pond and raw materials storage areas. As shown in this figure, DNAPL extends east of the former CPA, presumably due to DNAPL migration along the top of low permeability silt layers in the down-slope direction. The extent of definite DNAPL within the saturated UBA is described as follows:

- The most significant DNAPL impacts within the saturated UBA occur at wells UBT-1 through UBT-3, located in the CPA near the former water recycling pond.
- Definite DNAPL occurs up to approximately 180 feet east of the former CPA and adjacent railroad tracks at borings TSB-3, TSB-8, and SSB-12.
- Definite DNAPL does not extend significantly west of the former water recycling pond at borings PSB-9 and PSB-17.
- Definite DNAPL extends to the northern Property boundary at borings TSB-2 and SSB-2; DNAPL is estimated to extend approximately 30 feet north of the Property boundary (i.e. onto the adjacent former Boeing property) based on the definite occurrence of DNAPL at TSB-2.
- Definite DNAPL extends southeast of the former CPA at borings C44, PSB-18, and PSB-14.

The possible presence of DNAPL occurs over a larger area than the definite DNAPL and encompasses approximately 160,000 square feet as shown in **Figure 2.27**. The possible presence of DNAPL occurs to the east at SSB-3 and TSB-11 and to the south at TSB-9.

2.5.2 ESTIMATED VERTICAL EXTENT OF DNAPL

DNAPL has been definitively detected from a minimum of 7 feet bgs in the unsaturated zone to a maximum of 101.5 feet bgs in the saturated UBA (H+A, 1999 and 2004b). The predominant DNAPL-impacted zone is the saturated portion of the UBA at depths ranging from approximately 75 to 95 bgs (H+A, 2004b). Cross-sections have been constructed showing the heterogeneous interbedded nature of the UBA and the distribution of DNAPL within the unsaturated zone and saturated UBA (Figures 1.11 through 1.13). The majority of the observed DNAPL is perched on low permeability silt layers throughout the UBA.

<u>BFS</u>

In 1988, six soil borings were drilled to the base of the BFS within the CPA. The data obtained during the 1988 program were presented in a technical memorandum to EPA (H+A, 2004a) and are summarized as follows:

- DNAPL was not visually observed within the BFS in core samples from the 6 deep soil borings advanced in the CPA beneath the area known to contain DNAPL in the UBA.
- The maximum concentration of MCB detected in BFS soil was 51 mg/kg in a soil sample collected at 125.3 feet bgs.
- The maximum concentration of DDT detected in BFS soil was 130 mg/kg in a soil sample collected at 126.5 feet bgs.

When the data collected in 1988 were re-evaluated in connection with the DNAPL characterization criteria established in 2003/2004 for the Reconnaissance Program, the DDT result of 130 mg/kg in a soil

sample collected at 126.5 feet bgs would be interpreted as indicating the possible presence of DNAPL at that location. The RI Report provides some discussion of the possible presence of DNAPL in the BFS. The report states that *"DNAPL was not directly observed in the underlying BFS, however, its likely presence could be inferred from groundwater concentrations (EPA, 1998)."* The report goes on to indicate that *"the occurrence of DDT at these concentrations* (in a soil sample at 130 mg/kg) *may be related to the past or present occurrence of DNAPL, or may be a remnant of having drilled through high concentrations in the overlying DNAPL impacted zone (EPA, 1998)."* To further assess the presence of DNAPL in the BFS, additional field investigations were conducted in 2008.

2008 Field Investigation for Presence of DNAPL in BFS

In March 2008, passive diffusion bags (PDBs) were placed in BFS monitoring wells BF-2, BF-4, and BF-9 (Figure 2.1) to determine the vertical profile of dissolved contaminants within the BFS. These wells were selected because they are either beneath the known footprint of DNAPL in the UBA (BF-9) or downgradient of the extent of DNAPL in the UBA (BF-2 and BF-4). After 2 weeks, the passive diffusion bags were removed from the wells and analyzed for the presence of VOCs by EPA 8260B. Results are summarized as follows:

2008 Passive Diffusion Bag Results in BFS

BFS Monitoring Well	Passive Diffusion Bag Sample Depth (feet bgs)	MCB Concentration (ug/L)
BF-2	114-115.5	52,000
	118.25-119.75	33,000
	122.5-124	53,000
BF-4	112-113.5	13,000
	116.25-117.75	21,000
	120.5-122	19,000
BF-9	107-108.5	28,000
	112-113.5	64,000
	117.5-119	79,000
	126-127.5	78,000

A strongly increasing concentration trend, from top to bottom of the aquifer unit, may be indicative of DNAPL presence. No increasing concentration trend was evident at BF-2, and although the MCB concentration increased in the middle of the BFS at BF-4, the concentration at the bottom of the aquifer was not higher than the middle. However, the concentrations of MCB did increase with depth in the samples collected from shallow to deeper depths in BF-9.

Based on the results of the PDB samples, two soil borings were drilled immediately outside the known extent of DNAPL in the UBA at the locations shown in **Figure 2.28** (H+A, 2008c). Boring BFSB-1 was drilled south of the CPA and between monitoring wells BF-2 and BF-9. Boring BFSB-2 was drilled southeast of the CPA and near monitoring well BF-4. Rotosonic drilling methods were used to continuously core the soils during drilling to a total depth of 125 feet bgs. The core was logged and tested for the presence of DNAPL in accordance with the methods established during the DNAPL Reconnaissance Program. Depth discrete groundwater samples were collected between 98 and 125 feet using SimulProbe® sampling device. The samples were analyzed for the presence of VOCs by EPA 8260B, pesticides by EPA 8081A, and pCBSA by EPA 314.0 modified. Results are presented in **Table 2.1** and summarized as follows:

<u>BFSB-1</u>

- No DNAPL was visually observed or detected by the FLUTe ribbon.
- All soil sample headspace concentrations were relatively low, with a maximum concentration of 118 ppmv.
- At the base of the UBA, the MCB concentration was 150,000 ug/L at 98.5 feet and 19,000 ug/L at 109.5 feet bgs. Within the BFS, between 109.5 and 125 feet bgs, MCB concentrations then consistently increased to a maximum value of 100,000 ug/L at 125 feet.
- pCBSA concentrations at the base of the UBA were 720,000 ug/L at 98.5 feet and 33,000 ug/L at 109.5 feet. Within the BFS, between 109.5 and 125 feet, pCBSA concentrations consistently increased to a maximum value of 320,000 ug/L at 125 feet.
- Total DDT was detected in low concentrations between 0.15 ug/L at 109.5 feet and 8.84 ug/L at 120 feet bgs.

<u>BFSB-2</u>

- No DNAPL was visually observed or detected by the FLUTe ribbon.
- All soil sample headspace concentrations were relatively low, with a maximum concentration of 81 ppmv.
- The MCB concentration at the base of the UBA was 13,000 ug/L at 100 feet bgs. Within the BFS, from 110 to 124.5 feet bgs, MCB concentrations ranged between 20,000 ug/L and 45,000 ug/L.
- The pCBSA concentration at the base of the UBA was 63,000 ug/L at 100 feet bgs. Within the BFS, from 110 to 124.5 feet bgs, pCBSA concentrations ranged between 47,000 ug/L and 130,000 ug/L.
- Total DDT was detected in low concentrations between 0.36 ug/L at 100 feet and 7.5 ug/L at 120 feet bgs.

No definite DNAPL was detected within the UBA or BFS during drilling of BFSB-1 and BFSB-2. However, an increasing vertical concentration profile was observed at BFSB-1, which can be indicative of

DNAPL in the BFS, and the concentrations at the base of the BFS were approximately 20% of the MCB solubility limit. Although EPA believes the concentration profile within the BFS is indicative of the presence of DNAPL at the base of the BFS (EPA, 2008b), the presence or absence of DNAPL in the BFS cannot be definitively determined based on the available data. Dissolved-phase concentrations greater than 1% of the solubility limit is just one of several possible indicators of DNAPL presence, and by itself, is not definitive of DNAPL occurrence. This rule of thumb indicates that a DNAPL source may be present at the Site, such as at an upgradient location (EPA Publication 9355.4-07FS, 1992). Technical guidance documents generally recommend that multiple lines of evidence should be used to determine DNAPL presence in the subsurface, not just dissolved concentrations, such as follows:

- Estimating Potential for Occurrence of DNAPL at Superfund Sites, EPA, 9355.4-07FS, January 1992.

  "*Conditions that indicate potential for DNAPL at site based on laboratory data:*

  Condition 1 of 4: "*Concentrations of DNAPL-related chemicals in ground water are >1% of pure phase solubility or effective solubility*".

- An Introduction to Characterizing Sites Contaminated with DNAPLs, ITRC, September 2003.

  "*This technique is subjective and must be used very carefully. It should be considered only part of the process used to determine if DNAPL is present, not a method by itself that will indicate the presence/absence of DNAPL*"…"*The best method used in DNAPL source area determination may be to use the "propensity of data" from site characterization efforts. There is no one particular method available to clearly delineate presence/absence of DNAPL.*"

- Strategies for Monitoring the Performance of DNAPL Source Zone Remedies, ITRC, August 2004.

  "*Because of uncertainties inherent with using any one analytical method for detecting DNAPLs, the distribution of DNAPL is best defined by the use of "converging lines of evidence," rather than just a single measurement or observation.*"

The presence of MCB in the BFS at concentrations greater than 1% of the solubility limit can be attributed to vertically downward hydraulic groundwater gradients between the UBA and BFS. An unlined wastewater recycling pond was operated at the Site from 1947 to 1953, and the vertically downward hydraulic groundwater gradients would have been substantially enhanced during this period of the plant's operating history.

Other than dissolved-phase concentrations exceeding 1% of the solubility limit, there is no direct evidence that DNAPL is present in the underlying BFS. No black or oily staining has been observed in the soil core, samples, or cuttings collected from the bottom of the BFS, and no elevated soil headspace concentrations have been observed, indicative of a DNAPL source in the BFS. Additionally, no DNAPL has been observed accumulating in any BFS wells. If there were significant DNAPL-phase MCB in the BFS, then multiple lines of evidence would have indicated the presence of DNAPL in the BFS during

prior investigations. Given the limited evidence of DNAPL occurrence in the BFS, the mass of DNAPL potentially present in the BFS, if any, would be significantly less than the mass occurring within the overlying UBA, as indicated in Section 2.5.5.In comments dated January 27, 2010 (EPA, 2010a), EPA suggested that dissolved MCB concentrations observed north and upgradient of the Property at wells BF-35, CMW001, and CMW002 may be indicative of DNAPL migration within the BFS. Montrose addressed this issue during conference calls held in October and November 2010 (AECOM, 2010d through 2010f). Although dissolved MCB concentrations exceeding 1% of the solubility limit extend several hundred feet north of the Montrose Property, the data does not definitively indicate the presence of DNAPL in the BFS. Wells CMW001 and CMW002 have been sampled regularly since installation in 2003. The MCB concentration in well CMW001 has remained relatively stable over time, varying between 5,000 and 10,000 ug/L (approximately 1% to 2% of the solubility limit). The MCB concentration in well CMW002 was relatively stable through September 2010, but subsequently, increased from 11,000 to 32,000 ug/L by November 2012 (approximately 2% to 8% of the solubility limit).

EPA has indicated that the presence of DNAPL in the vicinity of this well is one possible explanation for the MCB concentration increase. Consequently, Montrose tested this well for the presence of DNAPL in November 2012, but none was detected. Furthermore, the groundwater was not discolored, which, based on years of DNAPL purging and monitoring data, is typically indicative of a nearby DNAPL source at the Site. Finally, as shown in Figure 1.16, the base of the BFS dips primarily to the east, and not to the north. A more likely explanation is that vertical communication with a shallow source in the UBA is causing the MCB concentration at CMW002 to increase. In 2002, grab groundwater samples were collected using SimulProbe® at 90 and 130 feet bgs from boring DDS-2-29 located adjacent to CMW002. The 90-foot sample was collected from the base of the UBA and found to contain 100,000 ug/L MCB. The 130-foot sample was collected from the base of the BFS and found to contain 5,700 ug/L MCB. Based on this data, it is unlikely that the elevated concentration of MCB detected at well CMW002 is a result of DNAPL migrating laterally along the base of the BFS. Until such time as there are multiple lines of evidence of DNAPL occurrence at CMW002, no conclusions can be drawn regarding the potential presence of DNAPL in the BFS at this location. The MCB concentration at well CMW002 will continue to be monitored closely, and the well re-tested for the presence of DNAPL as needed in the future. MCB concentrations within the BFS will be monitored as part of performance monitoring for this remedy

2.5.3 DNAPL CONCENTRATION

During the Reconnaissance Investigation Program (H+A, 2004b), a number of DNAPL-impacted soil samples were collected for laboratory analysis of MCB and Total DDT by EPA Method 8270C modified. During supplemental soil investigation activities in 2005 (Earth Tech, 2007b), a small number of additional soil samples from the saturated UBA were characterized for the presence of MCB by EPA 8260B and for Total DDT by EPA 8081A. For the purposes of this FS, the sum of the MCB and Total DDT concentrations in saturated soils, where liquid-phase DNAPL occurs, is referred to as the "DNAPL concentration". DNAPL concentrations detected in the saturated UBA are provided in **Table 2.2**, mapped in **Figure 2.29**, and summarized as follows:

- The highest DNAPL concentrations, greater than 50,000 mg/kg, occur within the CPA between boring S-101/101A in the water recycling pond and SSB-4 located in the northeast corner of the CPA.
- One high DNAPL concentration (103,000 mg/kg) was reported at SSB-12 located southeast of the CPA.
- Moderate DNAPL concentrations, greater than 10,000 mg/kg, occur over the southern portion of the CPA at borings C30 and PSB-15, 18, and 19. Moderate DNAPL concentrations additionally occur east of the CPA at PSB-2, 11, and 14 and TSB-3 and 8.
- Low DNAPL concentrations, below 1,000 mg/kg, were reported at DP-1, 2, 4, and 8, located immediately east wells UBT-1 through UBT-3. It is uncertain whether the low concentrations reported at these borings are accurate or whether the limited analytical program or direct-push drilling methods have resulted in conservatively low concentrations. The rotosonic drilling methods used at all other DNAPL investigation borings (identified with prefix PSB, SSB, TSB, and C) were found to provide more reliable and representative results.
- The areas represented by possible DNAPL all have low DNAPL concentrations below 1,000 mg/kg.

Characterization of DNAPL concentration in subsurface soils was not an objective of the Reconnaissance Investigation Program. The primary objective of that program was to characterize the presence of the DNAPL, not quantify the thickness or concentration of the DNAPL. As a result, only a limited number of DNAPL-impacted soil samples were collected for laboratory analysis, only one sample per boring in many cases. Given the limited analytical data available for DNAPL-impacted soil samples, there is a greater uncertainty related to the distribution of DNAPL concentrations within the saturated UBA.

Focused Treatment Area

Based on physical properties testing of one soil core collected from boring 2DSB-1 (**Appendix B**), DNAPL saturations of 18.9% or more are required for the DNAPL to be mobile (in that soil type). Using a wet bulk density of 1.85 g/cc, this residual saturation is equivalent to a DNAPL concentration of

approximately 53,000 mg/kg. Therefore, DNAPL is potentially mobile in areas with DNAPL concentrations exceeding 53,000 mg/kg. As shown in Figure 2.29, an area of approximately 26,000 square feet is estimated to contain DNAPL in concentrations which are potentially mobile at the Site. This area was defined based on DNAPL concentration data from numerous soil borings. For purposes of this FS, the area containing potentially mobile DNAPL is defined as the "Focused Treatment Area".

Assessment of Uncertainties

Residual DNAPL saturations are expected to vary at the Site, have not been measured with the exception of one soil core, and are uncertain. Therefore, some level of uncertainty is associated with the extent and estimated mass of mobile DNAPL at the Site. If the true average residual DNAPL saturation at the Site is above 18.9%, then the extent and mass of mobile DNAPL presented in this FS will be over-estimated. Similarly, if the true average residual DNAPL saturation at the Site is below 18.9%, then the extent and mass of mobile DNAPL at the Site would be higher than estimated in this FS.

The estimated extent of mobile DNAPL at the Site is also supported by field evidence. Through passive DNAPL accumulation and extraction testing, mobile DNAPL has been observed in seven wells, all of which occur within the estimated mobile DNAPL extent. Additionally, no mobile DNAPL has been observed at wells UBE-2 and UBE-3, which occur outside the estimated extent of mobile DNAPL. The physical evidence at the Site corroborates the estimated extent of mobile DNAPL based on DNAPL concentrations and an assumed residual saturation. Nonetheless, additional DNAPL saturation and mobility testing will be required to verify the extent of mobile DNAPL for treatment. Consequently, the extent of the Focused Treatment Area may be revised in the future depending on the results of more extensive core and DNAPL saturation testing. Although the extent of mobile DNAPL is uncertain at this time, the assumptions were applied uniformly to the candidate alternatives and will not impact remedy evaluation in this FS.

2.5.4 DNAPL THICKNESS

While the vertical extent of DNAPL-impacts at the Site is from 7 to 101.5 feet bgs (as described in Section 2.5.2), DNAPL does not fully occupy pore spaces throughout the soil column. Instead, DNAPL occurs in the form of ganglia and pools over relatively thin intervals that make up only a fraction of the total soil column. In order to estimate the mass of DNAPL at the Site, it is necessary to estimate the DNAPL thickness, defined as being the sum of DNAPL-impacted soil intervals within the soil column.

Where DNAPL was visibly observed in soil cores or detected using the FLUTe ribbon, the thickness is reasonably certain, although some level of uncertainty remains. The FLUTe ribbon may not detect DNAPL since it only contacts a portion of the soil core. In the saturated zone, soil headspace can be used to determine the presence of VOCs or DNAPL, but it does not provide any information regarding thickness. Similarly, soil analytical data can determine the presence of DNAPL, but the available sample volume is very small and does not provide information regarding DNAPL thickness. Therefore, while the extent of DNAPL is reasonably well defined by the reconnaissance borings, estimates of thickness are less certain in some cases. The estimates of DNAPL thickness has to be guided to some extent by professional judgment.

DNAPL thickness was estimated by H+A using two different approaches, one conservative and one liberal, to provide a range of candidate thicknesses. However, in comments made by EPA in December 2008 (EPA, 2008g), EPA believes that the conservative approach resulted in an underestimate of the DNAPL thickness. Therefore, in accordance with EPA comments, only the liberal approach for estimating DNAPL thickness is presented in the FS as follows:

Liberal Evaluation of Thicknesses

For the liberal scenario, the following was assumed for DNAPL thickness:

- Visual observation = observed thickness
- FLUTe ribbon = thickness of stain
- DNAPL observed at base of sand layer = 0.1 feet for thin layers and up to 1.5 feet for thicker layers (approximately 50% of the layer thickness)
- DNAPL observed throughout layer = thickness of entire layer
- Alternating evidence of DNAPL in a layer = thickness equal to half the distance between non-DNAPL depths

Professional judgment was used to assign thickness values for the liberal estimate (conservatively high estimate, if anything). In some cases, the liberal thickness estimate was greater than the DNAPL thickness observed in a soil core or on the FLUTe ribbon. Additionally, DNAPL thickness greater than a minimum value of 0.1-feet was assigned to soils exhibiting high headspace concentrations or laboratory results. The liberal thickness of DNAPL estimated to occur in each boring (cumulative observed thickness) is provided in **Table 2.3** and mapped in **Figure 2.30**. Thickness varied from 0.25 to 14.15 feet (H+A, 2008e and 2008f). The thickest DNAPL occurred within the CPA, near the former wastewater pond at UBT-1 through UBT-3, at PSB-9 located west of the former wastewater pond, and at the former

raw materials storage area near PSB-5. DNAPL thickness to the east of the CPA was less than or equal to 2 feet.

EPA used an alternate approach to estimate DNAPL thickness as documented in a memorandum dated March 11, 2010 (CH2M Hill, 2010b). Instead of using the interpreted extent of DNAPL thickness, CH2M Hill estimated the vertical thickness based on the reported concentration of DNAPL in soil samples and the capillary properties of the soil. A total of 9 soil samples collected from boring 2DSB-1 in February 2008 were analyzed for air/water capillary pressures (**Appendix B**). The reported van Genuchten parameters were used to estimate the vertical height of DNAPL required to produce the reported concentrations of DNAPL in soil. EPA estimates of DNAPL thickness are shown adjacent to the Montrose estimates in **Table 2.3**.

Although the EPA approach accounts for a DNAPL saturation profile within a given DNAPL pool, there is still substantial uncertainty associated with the estimate of DNAPL thickness. This approach assumes that the soil sample was collected at the base of the DNAPL pool, which is not the case as there was no protocol employed during the DNAPL investigation to only collect samples from the base of DNAPL occurrences. Samples were collected at varying depths, both where DNAPL was suspected and where DNAPL was absent. Additionally, this approach assumes that the physical properties are constant throughout the soil column, which is not true. In some cases, the thickness of DNAPL estimated by EPA exceeds the total thickness of the sand layer in which DNAPL was reported to occur. Additionally, EPA's estimate only considered the concentration of MCB in soil, even though Total DDT concentrations were reported coincidentally with MCB. Finally, EPA's estimate of thickness assumes only one occurrence of DNAPL in each boring, although DNAPL occurred at up to seven different depths within a single boring.

There is a relatively high degree of uncertainty associated the estimates of DNAPL thickness at the Site. For this reason, both methods used to estimate DNAPL thickness are considered valid and are presented in the FS.

2.5.5 ESTIMATED DNAPL MASS

Based on the extent, concentration, and estimate of DNAPL thickness, the mass of DNAPL was estimated as described in this section. DNAPL mass in the saturated UBA was estimated by both Montrose and EPA using two different methods, and both estimates are presented in this section.

Unsaturated Zone

The mass of MCB in the unsaturated zone was estimated as reported in Section 2.2. MCB concentrations detected in DNAPL-impacted soil samples at PSB-5 and SSB-4 were included in that estimate and are not duplicated here as a separate DNAPL mass estimate.

Saturated UBA (60 to 105 feet bgs)

Without information regarding the amount of contaminant mass released at a site, it can be difficult to reliably estimate the total mass of contaminant in the subsurface. However, the amount of DNAPL mass (i.e., MCB and DDT) in the saturated UBA was estimated using the area of DNAPL-impacts to soil, DNAPL thicknesses, DNAPL concentrations, and soil bulk density, as described below.

Montrose DNAPL Mass Estimate

Montrose estimated the mass of DNAPL in the saturated UBA using the following equation:

Mass = Area x Thickness x Concentration x Wet Bulk Density

The DNAPL mass was estimated to be approximately 796,100 pounds as shown in **Appendix E** (H+A, 2008e). This mass estimate is based on the liberal DNAPL thicknesses presented in Section 2.5.4, the DNAPL concentrations presented in Section 2.5.3, the area of DNAPL-impacts presented in Section 2.5.1, and the average wet bulk density of the sand layers presented in Table 1.2. Using the measured density of the Montrose DNAPL at 22°C (1.25 g/cc), the equivalent volume of DNAPL occurring within the saturated UBA is estimated at 76,000 gallons.

EPA DNAPL Mass Estimate

EPA estimated DNAPL-phase MCB mass based on the analytical results of soil samples collected during the DNAPL Reconnaissance Investigation (H+A, 2004b). Using physical properties results of soil samples collected from boring 2DSB-1 in February 2008, EPA estimated the thickness of MCB and mass integral (in grams per square foot) required to achieve the reported MCB concentration in the soil sample (CH2M Hill, 2010b and EPA, 2010b and 2010d). EPA averaged the mass integrals within each of the concentration contours shown in Figure 2.29 and multiplied by the area of the contours to obtain the estimated MCB mass. Consistent with the Montrose DNAPL composition, the mass of DNAPL (MCB and DDT) was determined by doubling the MCB mass estimate. The EPA estimate of DNAPL mass at the Site is 900,000 pounds as shown in **Appendix E** (CH2M Hill, 2010b). Using the measured density of the

Montrose DNAPL at 22°C (1.25 g/cc), the equivalent volume of DNAPL occurring within the saturated UBA is estimated at 86,000 gallons.

In addition to total DNAPL mass (residual and mobile), both Montrose and EPA estimated the mass of mobile DNAPL by assuming a residual DNAPL saturation of 18.9%, consistent with the results of physical properties testing. The estimates of DNAPL mass for the various treatment scenarios are summarized below:

Montrose and EPA DNAPL Mass Estimates

Treatment Area	DNAPL Mass (pounds)	
	Montrose Estimate	EPA Estimate
Entire DNAPL-Impacted Area	796,100	900,000
Focused Treatment Area	473,600	780,000
Mobile DNAPL	221,800	340,000

Given the uncertainty associated with the DNAPL characterization data, EPA considers the two above estimates roughly equivalent and requested that both estimates be presented in the FS. The Montrose estimate does not account for a concentration profile within a DNAPL pool but does consider all of the characterization data in estimating the DNAPL mass. The EPA estimate does account for a vertical concentration profile within a DNAPL pool but only considers a small amount of the characterization data in estimating the DNAPL mass. Approximately 87% of the EPA DNAPL mass estimate is based on the concentrations from eight soil samples. Additionally, the EPA estimate of DNAPL mass in the Focused Treatment Area assumes an area of approximately 30,500 square feet, which is slightly higher than the area of 26,000 square feet defined by the assumed 18.9% residual DNAPL saturation. There is inherently a high degree of uncertainty associated with the DNAPL mass estimates, and some interpretation of the data was required to estimate mass. However, the relative certainty of the data is considered adequate for the purposes of the FS and evaluation of candidate remedial technologies and alternatives.

2.6 DNAPL TREATABILITY AND MODELING STUDIES

The nature and extent of DNAPL occurrence at the Montrose Site was presented in Sections 2.1 through 2.5. This section summarizes the treatability and modeling studies conducted to evaluate candidate DNAPL remedial technologies at the Site. These studies provide valuable information for evaluating remedial technologies identified in Section 3 and preliminarily screened in Section 4. Additionally, some

of these studies provide evidence of mobile DNAPL occurrence at the Site, specifically passive DNAPL accumulation (Section 2.6.2) and hydraulic displacement field pilot testing (Section 2.6.3).

In some cases, preliminary screening, such as discussions with technology vendors or literature research, provides sufficient information to evaluate the implementability and potential effectiveness of DNAPL remedial technologies. However, for other remedial technologies, preliminary screening techniques were not sufficient to fully understand the strengths and limitations of the technology as applied to the Montrose Site. In these cases, theoretical modeling, bench-scale testing, and/or field-scale pilot testing was conducted to better assess the implementability, effectiveness, and costs related to the DNAPL remedial technologies. The following sections summarize the results of treatability and modeling studies conducted to evaluate DNAPL remedial technologies in support of this FS.

2.6.1 MASS FLUX EVALUATION

Long-term hydraulic containment of dissolved-phase MCB within the TI Waiver Zone is required by the groundwater ROD. As groundwater flows through the DNAPL-impacted area, the MCB component of the DNAPL will solubilize into groundwater. Hydraulic containment of the dissolved-phase MCB is required in the long-term to prevent migration of dissolved-phase MCB outside the TI Waiver Zone and into areas treated by the groundwater remedy. Groundwater flow at the Site was assumed to occur primarily in the horizontal direction since the vertical groundwater velocity between the UBA and BFS is estimated to be small compared with the horizontal velocity.

To support remedy evaluation, the duration of containment within the saturated zone that will be required following a DNAPL remedy was estimated using a numerical method (H+A, 2008e). The Falta Method (Falta et.al., 2005) was used to estimate containment zone timeframes assuming a Power Function with a first order decay (i.e., exponential decline of the contaminant mass flux over time). The duration required for hydraulic containment is dependent on the mass of the DNAPL-phase MCB within the saturated zone, and containment zone timeframes were estimated assuming varying amounts of MCB mass reduction in the UBA in the short-term. Three different treatment scenarios were considered including hydraulic displacement (which removes mobile DNAPL mass), thermal remediation within a focused treatment area (same footprint as for hydraulic displacement, which is the estimated extent of mobile DNAPL), and thermal remediation over the entire DNAPL-impacted area.

The containment timeframes estimated in the September 4, 2008 version of the H+A memorandum were originally based on the average DNAPL mass in the saturated UBA (average of conservative and liberal). As explained in Section 2.5.4 and based on EPA comments, only the liberal DNAPL mass is presented in

this FS. Therefore, the containment timeframes were re-estimated using only the liberal DNAPL mass estimate as the basis, and a revised H+A memorandum is provided as **Appendix G** in this FS (H+A, 2009c). In this revised memorandum, three different MCB mass reduction percentages were assumed (60%, 80%, and 90%) for each of the three treatment scenarios. These mass reduction assumptions apply to the DNAPL-phase MCB and exclude dissolved-phase MCB nor any impact associated with MCB in the unsaturated zone. The revised estimates for hydraulic containment timeframes using only the liberal DNAPL mass, the 60% to 90% mass reduction assumptions, and assuming primarily horizontal groundwater flow in the UBA are summarized as follows:

Montrose Hydraulic Containment Timeframe Estimates

	Assumed MCB Mass Reduction*		**Containment Timeframe (years)**
	(pounds)	**(%)**	
Containment Only	0	0%	4,900
Hydraulic Displacement (equivalent to 60, 80, and 90% of mobile DNAPL mass or 110,900 pounds; MCB component only)	66,550	17%	4,700
	88,700	22%	4,700
	99,800	25%	4,700
Thermal Remediation, over Focused Treatment Area (equivalent to 60, 80, and 90% of MCB mass in focused treatment area or 236,800 pounds)	142,100	36%	4,500
	189,500	48%	4,400
	213,150	54%	4,300
Thermal Remediation, Entire DNAPL-Impacted Area (MCB mass of 398,000 pounds)	238,800	60%	4,200
	318,400	80%	3,600
	358,200	90%	3,100

Notes:
* Based on estimated MCB mass (DNAPL-phase) in saturated UBA; 50% of 796,100 pounds or 398,000 pounds
See Section 5.1.1 and Appendix G for further details

Without any reduction in the DNAPL mass, containment within the UBA will be required for approximately 4,900 years. Under a hydraulic displacement remedy, containment zone timeframes are reduced to approximately 4,700 years. Under a thermal remedy within a focused treatment area equivalent to the mobile DNAPL footprint, containment zone timeframes are reduced to between approximately 4,300 and 4,500 years. Under a thermal remedy over the entire DNAPL-impacted area, containment zone timeframes are reduced to between approximately 3,100 and 4,200 years (or longer, if thermal remediation is unable to achieve the assumed mass reductions). Given the complexities of the Site lithology, area and depth of the DNAPL impacts to soil, and the unique nature of the Montrose DNAPL, there is some uncertainty at this time in any thermal remedy performance estimate. Removal of even 80% to 90% of the DNAPL mass by thermal remediation is considered an optimistic, high-end assumption for mass removal at the Site.

It will not be technically feasible to remove a sufficient amount of DNAPL to meaningfully reduce the duration of the containment system operation. Although some level of uncertainty exists in the selected input parameter values, the sensitivity analysis that H+A conducted bounds the probable range of values, and selected values generally provide low-end estimates of timeframe (H+A, 2009c; Appendix G). Additionally, fine-grained low permeability layers can store significant amounts of dissolved-phase mass which is released very slowly over time (i.e., back diffusion), even after DNAPL in the source zone has been removed. Although the methods used to estimate containment timeframes do not consider back diffusion, the containment timeframes are not expected to be significantly under-estimated since DNAPL dissolution over thousands of years is a more significant driving factor than back diffusion.

EPA also evaluated hydraulic containment timeframes as documented in a memorandum dated September 29, 2010 (CH2M Hill, 2010b). U sing the Falta Method referenced above and assuming primarily horizontal flow within the UBA, EPA estimated hydraulic containment timeframes as shown below.

EPA Hydraulic Containment Timeframe Estimates

DNAPL Remedy	**Assumed MCB Mass Reduction**	**Containment Timeframe (years)**
Containment Only	0%	5,840
Hydraulic Displacement	38%	5,430
Thermal Remediation, over Focused Treatment Area	Residual Saturation = 4% Residual Saturation = 0.5%	4,930 4.220
Thermal Remediation, Entire DNAPL-Impacted Area	Residual Saturation = 4% Residual Saturation = 0.5%	4,870 3,320

There is substantial uncertainty associated with these long-term containment timeframe estimates as EPA noted in their memorandum. Using a different method or assuming a primarily vertical flow within the UBA would result in different hydraulic containment timeframes. Nonetheless, EPA acknowledged that hydraulic containment of the groundwater will be required for hundreds or thousands of years following a DNAPL remedy regardless of the remedy selected.

The above evaluation was important in establishing an approximate relationship between residual DNAPL mass and hydraulic containment timeframes. However, long-term hydraulic containment is an aspect of the remedy selected for groundwater (EPA, 1999), and therefore, is not subject to evaluation in this DNAPL FS. Furthermore, while residual DNAPL will continue to serve as a source for dissolved MCB in the long-term, it is immobile under gravitational forces and does not pose a risk to the

groundwater remedy. Please refer to Section 3.1 for a description of the principal threat and Remedial Action Objectives.

2.6.2 PASSIVE DNAPL ACCUMULATION AND RECOVERY

Wells screened within the DNAPL-impacted portion of the UBA are routinely gauged and purged to remove DNAPL which has passively accumulated in the well sumps. Passive DNAPL recovery in the UBA wells within the CPA has been on-going since 1988 and is summarized in **Appendix F** and presented below:

Passive DNAPL Recovery Since 1988

Well	2010 Passive DNAPL Recovery (gallons)	Cumulative Passive DNAPL Recovery To Date (1988-2010) (gallons)
MW-2	0.0	7.7
UBT-1	1.3	75.0
UBT-2	0.3	19.4
UBT-3	0.0	29.3
UBE-1	1.0	38.3
UBE-2	0.0	0.7
UBE-3	0.0	0.0
UBE-4	16.8	133.1
UBE-5	4.5	9.7
Total	23.9	313.2

The highest rate and volume of passive DNAPL recovery has occurred within the CPA at the source area wells. Wells UBE-2 and UBE-3 located east of the source areas in the CPA have exhibited either minimal or no passive DNAPL recovery. Passive DNAPL accumulation rates have historically been between approximately 0.001 and 0.02 gallons per day. The passive DNAPL accumulation rate at UBE-4 in 2010 was approximately 0.06 gallons per day.

Routine passive recovery of DNAPL at a UBA well provides definitive proof of DNAPL presence, because only mobile DNAPL would passively accumulate on a repeated basis. However, the absence of passive DNAPL accumulation is not conclusive evidence that mobile DNAPL is not present; it merely proves that the well has not intercepted mobile DNAPL. In sum, the lack of passive accumulation does not disprove the presence of mobile DNAPL, it only provides information related to DNAPL mobility within near-wellbore conditions.

Mobile DNAPL Occurrence at Well UBE-5

DNAPL characterization data collected in 2003/2004 suggested the presence of mobile DNAPL at boring SSB-12 located southeast of the CPA. A high DNAPL concentration, 105,000 mg/kg, was detected in a soil sample collected at 82.5 feet bgs in boring SSB-12. However, at this eastern location, no mobile DNAPL was expected based on the lack of mobile DNAPL at wells UBE-2 and UBE-3 in the same vicinity and the lack of historical DNAPL sources in this area of the Property. Additionally, the soil samples collected for laboratory analysis in 2004 during the DNAPL Reconnaissance Program were very small in size, only 5 grams. The small discrete sample at boring SSB-12 is an isolated occurrence and the location is remote from known DNAPL source areas. Therefore, to verify the occurrence of mobile DNAPL at this location, well UBE-5 was installed in September 2008 within 5 feet of soil boring SSB-12 as shown in Figure 2.1. Well UBE-5 was screened to coincide with the occurrence of DNAPL in that boring (Earth Tech, 2008j).

No mobile DNAPL was found at well UBE-5 after 6 weeks of monitoring for passive accumulation as of mid-October 2008. The well was purged on October 15, 2008 using a bladder pump, confirming that no DNAPL had passively accumulated in the well sump to that point. A short-term extraction test was subsequently conducted at this well in December 2008, during which approximately 1.4 gallons of DNAPL were recovered. A description of the test results is provided in Section 2.6.3.

2.6.3 HYDRAULIC DISPLACEMENT FIELD PILOT TESTING

The mobility of DNAPL in the subsurface is a function of its saturation. DNAPL is most mobile at high saturations and its mobility decreases non-linearly as its saturation decreases. If DNAPL is hydraulically displaced from a porous media, a quantity of DNAPL, referred to here as “residual saturation”, will remain in the pore spaces as ganglia that have been disconnected from any continuous pool of DNAPL. At residual saturation, the DNAPL is essentially immobile, although its dissolution will remain a source of groundwater contamination over the long-term, thus effectively requiring indefinite containment.

DNAPL has been observed in UBA monitoring and extraction wells located within the CPA. Additionally, since 1988, passive DNAPL accumulation in these wells has been routinely gauged and purged as described in Section 2.5.1. Based on the passive recoverability of the DNAPL, three field-scale hydraulic displacement pilot tests were conducted at the Property in 1991, 2004/2005, and 2008.

The first of these tests was conducted in 1991 at UBA extraction well UBE-1 (Figure 2.1; H+A, 1992). A total of 298 gallons of DNAPL was recovered during the 28-day extraction test conducted at this well.

The test evaluated only primary pumping mechanisms. While a substantial volume of DNAPL was recovered during the 1991 pilot test, uncertainties remained regarding the potential effectiveness of a hydraulic displacement remedy for DNAPL including: 1) the 28-day test was not conducted for a sufficient period to determine how quickly the DNAPL accumulation rate would decay, and 2) it was unknown if the results obtained at extraction well UBE-1 were typical of what could be expected for overall DNAPL accumulation, or if it represents an unusually productive well.

A second testing program was conducted in 2004 and 2005 to address these uncertainties (H+A, 2007c). Groundwater and DNAPL pumping at extraction well UBE-1 was conducted for a longer duration than the 1991 test in order to assess the amount of time required for the rate of DNAPL accumulation to decay. Additionally, short-duration tests were conducted at four additional wells to determine the variability in DNAPL recovery characteristics across the Property, and water level monitoring was conducted to assess the hydraulic radius of influence at each of the extraction wells. DNAPL recovery observed during the 2004/2005 field pilot test is presented in **Table 2.4** and summarized as follows:

- 398 gallons of DNAPL were recovered from UBE-1 over 109 operating days,
- 45 gallons of DNAPL were recovered from UBT-1 over 18 operating days,
- 11 gallons of DNAPL were recovered from UBE-4 over 19 operating days,
- 0.7 gallons of DNAPL were recovered from UBE-2 over 16 operating days, and
- No DNAPL was recovered from UBE-3 over 14 operating days.

The 2004/2005 testing program provided sufficient data to make the following general conclusions:

1. Timeframes for DNAPL recovery are expected to be considerably shorter at extraction wells located in areas with lower DNAPL saturations, typically near the margin of the CPA. Additionally, no DNAPL recovery is expected in areas where saturations are below the residual saturation.
2. DNAPL recovery varies substantially within the DNAPL-impacted area. DNAPL recovery is tied to the DNAPL saturation in the vicinity of the extraction well.
3. DNAPL recovery is enhanced by creating a groundwater gradient around the extraction well. Overall, the data obtained during the tests indicates that DNAPL recovery rates generally increased as groundwater extraction rates increased.
4. Equipment fouling by DDT and inorganic precipitates will need to be addressed through maintenance during a hydraulic displacement remedy.

A third short-term test was conducted in December 2008 at well UBE-5 located east/southeast of the CPA (Earth Tech, in process). Well UBE-5 was located adjacent to soil boring SSB-12, where a high concentration of DNAPL was measured in soil at one depth of approximately 82.5 feet bgs. The DNAPL

concentration observed at this location (103,000 mg/kg) is representative of mobile DNAPL saturations, and therefore, a short-term test was conducted to determine if mobile DNAPL was present within the vicinity of this boring and well. Groundwater was extracted at a rate of approximately 1.0 to 1.75 gpm from UBE, screened from 75 to 85 feet bgs, for a period of approximately 5 days. A total of 8,318 gallons of groundwater was extracted from UBE-5 during this period. During the 4.5 days of extraction, a total of 0.3 gallons of DNAPL were recovered under a drawdown of approximately 15 feet in UBE-5. The pump was lowered into the well screen on the last day, increasing the drawdown to approximately 25 feet, and another 1.2 gallons of DNAPL was recovered in a 5.5-hour period (0.22 gallons per hour or 5.2 gallons per day). A total of approximately 1.5 gallons of DNAPL was recovered from UBE-5 during the short-term test.

To further evaluate hydraulic displacement as a candidate remedial technology for the Site, modeling was conducted, as described in Section 2.6.4, to provide a better estimate of the DNAPL radial distances of capture and the potential for downward migration.

2.6.4 MODELING OF HYDRAULIC DISPLACEMENT ON DNAPL MOBILITY

The performance of a hydraulic displacement DNAPL remedy in the UBA was modeled using the University of Texas Chemical Composition Simulator (UTCHEM), Version 9 (H+A, 2009a and 2009b). DNAPL remediation by hydraulic displacement in the UBA was initially modeled to evaluate both well spacing and timeframes to deplete a DNAPL pool using a hysteresis routine and the van Genuchten capillary pressure-saturation relationship (fit to data that was measured as part of baseline soils analysis for 2-dimensional thermal remediation bench testing; see Section 2.6.5). A simplified model setup was assumed, including one DNAPL-impacted sand layer overlying one low permeability silt layer with one extraction well. Ten simulation runs were conducted by varying five parameters including the hydraulic conductivity of the sand layer, DNAPL pool location, DNAPL pool length, DNAPL saturations, and groundwater drawdown. However, the initial model results predicted spontaneous DNAPL migration laterally within the sand layer under static (non-pumping) conditions due to a lack of heterogeneity within the sand and were therefore considered unreliable. The reason for the spontaneous migration was the use of the van Genuchten capillary pressure-saturation relationship, which does not account for entry pressure.

An alternate modeling approach was used which replaced the van Genuchten capillary pressure-saturation relationship with the Brooks-Corey empirical relationship. The Brooks-Corey relationship accounts for entry pressure but cannot be used with hysteresis in the model. Although this alternate approach does not allow evaluation of pumping durations, it was successfully used to evaluate well spacing and DNAPL

capture radius. In lieu of the planned 10 modeling runs, only the most conservative model inputs were assumed to identify the smallest DNAPL capture radius (i.e., use of other model input assumptions would result in larger capture radii). The revised modeling approach, using conservative assumptions, predicted that DNAPL would be effectively mobilized for capture at a well spacing up to 120 feet (i.e., 60-foot single well capture radius). The capture radius evaluation was based on an assumed initial DNAPL saturation of 30% and a residual DNAPL saturation of 19%. This model-predicted well spacing (120 feet) was larger than initially expected (less than 50 feet) and suggests that hydraulic displacement may be a more effective DNAPL remedial technology than originally considered by EPA. The initial results of the hydraulic displacement modeling were submitted to EPA in a technical memorandum dated January 15, 2009 (H+A, 2009a). A summary HD modeling report was prepared and submitted to EPA on April 6, 2009 (H+A, 2009b).

A secondary objective of the hydraulic displacement modeling was to evaluate the potential for downward vertical migration into the BFS. Because the silt layers at the Property are laterally discontinuous, DNAPL has the potential to migrate vertically downward to underlying layers as a result of hydraulic displacement. For this reason, a second model setup consisting of five soil layers was assumed to evaluate the potential for downward migration of DNAPL during a hydraulic displacement remedy. Conservative assumptions were used that maximized the amount of DNAPL accumulation over the basal silty sand layer in the UBA, DNAPL pool heights up to 8 feet, thus increasing the potential for DNAPL to overcome the pore entry pressure of that layer and migrate vertically downward. Even under these conservative assumptions, the model predicted that DNAPL would not penetrate through the basal silty sand layer of the UBA and into the underlying BFS. The potential for DNAPL downward migration into the underlying BFS as a result of hydraulic displacement appears to be minimal, if any, based on these modeling results.

However, there is some uncertainty associated with the assumptions used in the model as identified by CH2M Hill in a memorandum dated January 18, 2011 (CH2M Hill, 2011). The model assumed that the basal silty sand layer is continuous across the DNAPL-impacted area. Although the basal layer was present in all 11 soil borings drilled to this depth, there remains the possibility that a discontinuity in the basal layer may exist at the Property. Additionally, the pore entry pressure of the basal silty sand layer has not been previously measured and was scaled from the assumed layer permeability to be approximately 6,100 Pascals, which EPA believes is high. The definition of silty sands under the Unified Soil Classification System (USCS) encompasses a wide range of particle sizes (15% to 50% silt). Accordingly, the permeabilities and pore entry pressures of the basal silty sand layer could vary significantly over this range of particle sizes. Assuming pore entry pressures between approximately

1,400 and 3,400 Pascals, the basal silty sand layer could support DNAPL pool heights between 1.9 and 4.6 feet if continuous at the Property (CH2M Hill, 2011 and AECOM, 2011d). A lthough the HD modeling indicated that the risk of vertical migration during HD was minimal under specific assumptions, there is uncertainty associated with the continuity of the basal layer across the Property and the pore entry pressures required to penetrate through the silty sands if continuous.

2.6.5 SOIL VAPOR EXTRACTION FIELD PILOT TEST

A field pilot test to evaluate the feasibility of removing VOCs from unsaturated soils was conducted at the Property in 2003 (Earth Tech, 2009c). A single SVE well, EW-1, was installed within the CPA between soil borings 14D and S-305/305A, where high concentrations of VOCs were previously reported in soil. The well was constructed with three separate 10-foot screened intervals positioned to coincide with the three unsaturated soil layers at the Property (10-20 feet bgs in the PD, 30-40 feet bgs in the PVS, and 50-60 feet bgs in the unsaturated UBA). Six soil vapor monitoring points, VMP-1 through VMP-6, were installed in varying directions and distances from the extraction well in order to monitor vacuum influence in the subsurface. Short and long-term pilot tests were conducted based on the permeability of the soil matrix (longer tests for low permeability soils). The SVE pilot test provided performance data relative to soil vapor flow rates, soil vapor contaminant concentrations, vacuum or radial influence, and contaminant recovery rates. A summary of SVE field pilot test results is provided below by unsaturated soil layer.

<u>PD</u>

- A vacuum of 18 inches of mercury was required to induce soil vapor flow within the PD, and the flow rate gradually increased over time. Eventually, a soil vapor flow rate of 68 scfm was achieved, although significant vacuum influence within the underlying PVS was observed, indicating that at least a portion of the soil vapor flow was originating from the PVS.
- A relatively low radius of influence of 48 feet was observed during pilot testing.
- MCB concentrations in extracted soil vapors declined from 5,300 to 2,400 ppmv during pilot testing. Chloroform concentrations declined from 1,600 to 1,300 ppmv during pilot testing.
- Based on the pilot test results, an initial VOC mass removal rate of 173 pounds per day was estimated for a well screened in the PD at this location, although a portion of the VOC mass may be originating from the underlying PVS.

<u>PVS</u>

- A relatively high soil vapor flow rate of 111 standard cubic feet per minute (scfm) was observed during pilot testing at an applied well vacuum of 5 inches of mercury.
- A relatively high radius of influence of 123 feet was observed during pilot testing.

- MCB concentrations in extracted soil vapors increased from 4,300 to 5,600 ppmv during pilot testing. Chloroform concentrations increased from 2,100 to 2,200 ppmv.
- Based on the pilot test results, an initial VOC mass removal rate of 472 pounds per day was estimated for a well screened in the PVS at this location.

Unsaturated UBA

- A moderate soil vapor flow rate of 50 scfm was observed during pilot testing at an applied well vacuum of 14 inches of mercury.
- A moderate vacuum radius of influence of 64 feet was observed during pilot testing.
- MCB concentrations in extracted soil vapors declined from 20,000 to 6,800 ppmv during pilot testing. Chloroform concentrations declined from 3,500 to 2,100 ppmv during pilot testing.
- Based on the pilot test results, an initial VOC mass removal rate of 223 pounds per day was estimated for a well screened in the unsaturated UBA at this location.

Granular activated carbon (GAC) was used during the pilot test to treat the extracted soil vapors. The GAC was found to be highly effective in treating the vapor-phase contaminants exhibiting an adsorption capacity of approximately 25% by weight. SVE was found to be a highly effective technology for removing MCB and other VOCs from permeable unsaturated soils within the PVS and unsaturated UBA. However, due to the low permeability of the soils and vertical communication with the underlying PVS, SVE was found to be significantly less effective within the PD. The PD soils at the vapor extraction well were classified as a clayey silt with approximately 10% very fine-grained sand. However, the PD soils were classified as silty sands at 13 boring locations within the DNAPL-impacted area, and therefore, SVE may be more effective within the PD at those locations.

2.6.6 2-DIMENSIONAL THERMAL TECHNOLOGY BENCH-SCALE STUDIES

Two separate thermal technology bench-scale studies were initiated in March 2008 (Earth Tech, 2008a). The objective of the studies was to evaluate mobilization of the Montrose DNAPL under both steam injection/flushing and electrical resistance heating (ERH). Both studies employed a thin 2-dimensional test cell to simulate in-situ conditions, with approximate dimensions of 3 feet long by 2 feet tall by 6 inches in depth. Soil, groundwater, and DNAPL from the Site were collected to support the studies. To support mass balance calculations, relatively contaminant-free soil and groundwater were collected from boring 2DSB-1 and well MW-3 respectively. The soil core was segregated into three different generalized soil types in order to simulate the layered stratigraphy of the saturated UBA. DNAPL was collected from wells UBE-1 and UBE-4 and was placed into the packed test cell to simulate accumulation above a thin, low permeability capillary barrier. Adequate supplies of all three Site materials were shipped to two different universities for bench-scale testing. The ERH study was conducted by Dr.

Bernie Kueper with Queen's University, while the steam injection study was conducted by Dr. Brent Sleep with the University of Toronto. Both university professors are recognized experts in the application of thermal remediation technologies.

Numerous problems were encountered with the ERH test cell when operated under pressure as required by the study workplan, and as a result, efforts to complete the 2-dimensional ERH bench study have been terminated. A summary of this work was submitted to EPA in March 2009 (Queen's University, 2009). Dr. Kueper indicated that the Montrose ERH bench study was "the most challenging laboratory program" he had ever encountered in 20 years of experience conducting laboratory experiments. Problems encountered that might be transferrable to application of ERH at the Montrose Site include:

- Downward leakage of pooled DNAPL along the ERH electrodes or well casings. Given the relatively high electrode and well density typically used during ERH remedies, the potential to intercept pooled DNAPL at the Montrose Site is substantial and would likely pose an increased risk of downward migration;
- Evaluation of materials compatibility for exposure to the Montrose DNAPL. The Viton® gaskets used in the test cell were chemically degraded during the attempted ERH bench study;
- Evaluation of DNAPL wettability against well casings and other materials. Although the Montrose DNAPL was non-wetting to Teflon®, Dr. Kueper found the DNAPL to be slightly wetting to Viton®.

However, 2-dimensional testing using the steam injection cell was successful, and experiment Runs 1 and 2 were conducted on January 8 and May 6, 2009, respectively. The experiment runs and results are described below:

2-Dimensional Steam Flushing Runs 1 and 2

Thin and discontinuous capillary barriers pose a risk for DNAPL vertical migration during steam flushing, evaluation of which was a fundamental objective of the 2-D study. Although silt layers up to 4 feet in thickness occur at the Montrose Site, the scale of the 2-D cell cannot accommodate testing of thick soil layers. Therefore, two configurations representing the thinnest occurrences of capillary barriers observed at the Site were tested in Runs 1 and 2 as follows:

- **Run 1:** Steam flushing Run 1 was conducted on January 8, 2009. Run 1 simulated a DNAPL pool within a high permeability DNAPL Layer and overlying a 4 cm high Capillary Barrier

composed of low permeability silt. DNAPL was observed at the outlet condenser within the first hour of steam flushing, and visible DNAPL recovery continued through the first 6.5 hours of steam flushing. The initial recovered DNAPL was black in color, similar to the source material, but the recovered DNAPL became progressively lighter in color as the test continued. The DNAPL Layer was heated to temperatures greater than 100°C after 3 hours of steam flushing and reached peak temperatures between 120°C and 132°C after approximately 6 hours. Run 1 was terminated after approximately 11 hours and 3.4 pore volumes of steam flushing through the DNAPL Layer.

- **Run 2:** Steam flushing Run 2 was conducted on May 6, 2009. Run 2 simulated a DNAPL pool within a high permeability DNAPL Layer and overlying a 8 cm high Capillary Barrier composed of moderately low permeability sandy silt. DNAPL was observed at the outlet condenser after approximately 1.25 hours of steam flushing, but unlike Run 1, the majority of the DNAPL recovery occurred in the latter portions of the test. Visible DNAPL recovery continued through the first 8.5 hours of steam flushing. The DNAPL Layer was heated to temperatures greater than 116°C after 5 hours of steam flushing and remained between 116°C and 132°C for the duration of the test. Run 2 was terminated after approximately 9 hours and 5.2 pore volumes of steam flushing through the DNAPL Layer.

Run 1 and 2 Results

The volumes of DNAPL and steam condensate recovered from the test cell were carefully measured, and an extensive post-test sampling program documented the amount of MCB and Total DDT remaining in soil following steam flushing. The results of steam flushing Runs 1 and 2 are summarized as follows:

- Between 57% and 63% of the initial DNAPL-phase MCB mass was removed after 3.4 to 5.2 pore volumes of steam flushing through the DNAPL Layer;
- Between 6% and 20% of the initial DNAPL-phase DDT mass was removed after 3.4 to 5.2 pore volumes of steam flushing through the DNAPL Layer;
- Significant concentrations of MCB (up to 20,000 mg/kg) and Total DDT (up to 44,700 mg/kg) remained in the soil following steam flushing;
- Significant redistribution of MCB and Total DDT occurred during steam flushing including migration into and below the Capillary Barrier;

- MCB concentrations up to 17,000 mg/kg and Total DDT concentrations up to 9,556 mg/kg were detected in soils below the Capillary Barrier and within the Base Layer following steam flushing;
- Desaturation or partial desaturation of the thin silt layers were observed during steam flushing, reducing the effectiveness of these layers as capillary barriers to downward DNAPL migration.

The 2-D bench-scale studies conducted by the University of Toronto in 2009 evaluated the movement and remobilization of Montrose DNAPL during steam flushing under simulated Site conditions. Although between 57% and 63% of the initial DNAPL-phase MCB mass was removed after 3.4 to 5.2 pore volumes of steam flushing, a substantial amount of the initial MCB mass remained in the test cell and significant remobilization of the MCB and Total DDT was observed, including vertical migration through and below the capillary barrier as summarized below.

Run 1 and 2 Steam Flushing Results

	Run 1		**Run 2**	
Description	**MCB**	**Total DDT**	**MCB**	**Total DDT**
Percent of Initial Mass Removed from Test Cell				
DNAPL	60%	20%	54%	6%
Condensate	3%	<1%	3%	<1%
Percent of Initial Mass Remaining in Test Cell				
DNAPL Layer	20%	57%	12%	80%
Capillary Barrier	1%	7%	14%	6%
Base Layer	8%	25%	24%	7%
Mass Balance Evaluation				
Mass Balance	-8%	+9%	+7%	-1%

Memorandums from Dr. Sleep summarizing the results of experiment Runs 1 and 2 were prepared and submitted to EPA in March and August, 2009 (de maximis, 2009a and 2009b). A comprehensive summary report of all 2-D bench-scale testing activities was prepared and submitted to EPA in December 2011 (AECOM, 2011k).

It should be noted that EPA does not agree with certain aspects of the 2-dimensional bench testing configuration or interpretation of results (CH2M Hill, 2013). Among other issues, EPA believes that steam could be injected into the Base Layer to serve as a “hot floor” and mitigate to some extent the potential for downward migration. Montrose contends that a steam injection hot floor may not be effective at mitigating downward DNAPL migration, and that there has been no true steam injection hot

floor implemented at any DNAPL remediation site. Please refer to Section 4.6.3 for a more detailed discussion regarding this issue.

1-Dimensional Steam Flushing Experiments

Dr. Eva Davis of EPA conducted a series of one-dimensional steam flushing column experiments in 2004/2005 using materials collected from the Site in 2003 (Davis, 2006). Soils from four different soil borings (PSB-4, PSB-15, SSB-2, and SSB-6) were used to pack a small one-dimensional test column with dimensions of 2-inches diameter by 6-inches long (i.e., a tubular test cell). Steam was injected in one end of the test column at a temperature of approximately 150°C and a flow rate of approximately 75 ml per hour for a total duration of approximately 5 to 5.5 hours per column. This duration is roughly equivalent to 4 pore volumes of steam flushing. EPA measured the quantity and concentration of total fluids exiting the column, and EPA measured the concentration of contaminants remaining in the steam flushed soil column following treatment. EPA issued a report on the one-dimensional steam flushing column experiments in August 2006 (Davis, 2006).

It is important to be careful in drawing conclusions for full-scale system performance based on one-dimensional column experiments as they do not represent the full range of fluid flow and thermodynamic processes that occur at full-scale. In particular, field-scale thermal technology performance is limited by uneven heat propagation, fluid flow, chemical distribution, and all of these are constrained for optimal performance in one-dimensional column tests. In general, one-dimensional column tests arguably produce better performance results than those achieved at the field-scale for similar operating conditions. Such tests are often good indicators of infeasibility (i.e., identifying conditions that are likely to be unsuccessful), but care must be taken in making any feasibility inferences.

TABLES

Table 2.1
2008 Field Investigation Results for Presence of DNAPL in BFS Aquifer
Montrose Superfund Site

Sample Identifier	Sample Date	Sample Collection Depth (bgs)	Hydrogeologic Unit	GROUNDWATER SAMPLE RESULTS (micrograms per liter)									FIELD SCREENING RESULTS (a,b)				
				MCB	pCBSA	2,4'-DDD	2,4'-DDE	2,4'-DDT	4,4'-DDD	4,4'-DDE	4,4'-DDT	Total DDT	FLUTEe Ribbon Staining (yes / no)	Visual Evidence	PID (ppm)	FID (ppm)	DNAPL Occurrence
Soil Boring BFSB-1																	
BFSB1-GW-98.5	4/29/2008	98.5	UBA	150,000	720,000	<0.094	<0.094	0.23 (c)	0.11 (c)	0.13	0.33	0.8	no	no	28	34	None
BFSB1-GW-109.5	5/6/2008	109.5	UBA	19,000	33,000	<0.094	<0.094	<0.094	<0.094	<0.094	0.15	0.15	no	no	32	34	None
BFSB1-GW-115	5/6/2008	115	BFS	71,000	87,000	3.4	<0.094	<0.094	3.5	<0.094	0.12	7.02	no	no	21	18	None
BFSB1-GW-120	5/6/2008	120	BFS	90,000	230,000	3.4	<0.094	0.11 (c)	4.9	0.11	0.32	8.84	no	no	59	57	None
BFSB1-GW-125	5/7/2008	125	BFS	96,000	320,000	0.6	<0.094	<0.094	0.54	<0.094	<0.094	1.14	no	no	118	67	None
BFSB100-GW-125 (e)	5/7/2008	125	BFS	100,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	None
Soil Boring BFSB-2																	
BFSB2-GW-100	4/17/2008	100	UBA	13,000	63,000	0.098 (c)	<0.094	<0.094	0.12	<0.094	0.14	0.36	no	no	81	18	None
BFSB2- GW-110	5/1/2008	110	BFS	25,000	52,000	<0.094	<0.094	0.11	0.12	<0.094	0.22	0.45	no	no	4	1	None
BFSB2-GW-114.5	5/2/2008	114.5	BFS	20,000	47,000	<0.094	<0.094	0.13	0.095	0.12 (d)	0.38	0.73	no	no	22	4	None
BFSB2-GW-120	5/2/2008	120	BFS	32,000	97,000	2.8	0.10 (c)	0.28	4.2	<0.094	0.12	7.5	no	no	20.2	0	None
BFSB2-124.5	5/2/2008	124.5	BFS	45,000	130,000	2.3	<0.094	0.28	1.4	0.15	0.5	4.6	no	no	63	69	None

Acronyms/Abbreviations:
bgs = below ground surface
UBA = Upper Bellflower aquitard
BFS = Bellflower sand
MCB = Chlorobenzene
2,4'-DDD = 2,4'-Dichlorodiphenyldichloroethane
2,4'-DDE = 2,4'-Dichlorodiphenyldichloroethylene
2,4'-DDT = 2,4'-Dichlorodiphenyltrichloroethane
4,4'-DDD = 4,4'-Dichlorodiphenyldichloroethane
4,4'-DDE = 4,4'-Dichlorodiphenyldichloroethylene
4,4'-DDT = 4,4'-Dichlorodiphenyltrichloroethane
pCBSA = para-Chlorobenzene sulfonic acid
FLUTe = Flexible Liner Underground Technologies
PID = Photoionization Detector
FID = Flame Ionization Detector
ppm = parts per million
DNAPL = dense non-aqueous phase liquid
(<) = Less than; the numerical value is the Limit of Detection for that compound
NA = Not analyzed

Source : Hargis + Associates, Results of Field Investigation into the Possible Presence of DNAPL in the Bellflower Sand, June 24, 2008.

Footnotes
(a) Results of field screening within the groundwater sampling interval are reported in this table. Refer to lithologic logs (Figures 2 through 4 of above reference) for a complete report of soil screening results in the core intervals.
(b) FID and PID results are provided for the nearest field measurement, if not exactly at the groundwater sample collection depth.
(c) The Relative Percent Difference between the primary and confirmatory analysis exceeded 40%. Per the analytical method, the lower value was reported.
(d) The Relative Percent Difference between the primary and confirmatory analysis exceeded 40%. Per the analytical method, the higher value was reported.
(e) Duplicate sample.

Table 2.2
DNAPL Concentrations in the Saturated UBA (60-105 feet bgs)
Montrose Superfund Site

Soil Boring Identifier	Sample Depth (feet bgs)	Sample Date	Concentrations in milligram per kilogram								
			MCB	2,4'-DDD	2,4'-DDE	2,4'-DDT	4,4'-DDD	4,4'-DDE	4,4'-DDT	Total DDT	Total DNAPL
DP-1	79	5/6/2003	**310**	<51	<51	<51	<51	<51	**110**	**110**	**420**
DP-1	85	5/6/2003	**480**	<71	<71	<71	<71	<71	**170**	**170**	**650**
DP-2	78	5/6/2003	**210**	<27	<27	<27	<27	<27	**42**	**42**	**252**
DP-2	89	5/7/2003	**130**	<29	<29	<29	<29	<29	**110**	**110**	**240**
DP-3	71.5	5/7/2003	<28	<28	<28	<28	<28	<28	<28	<28	0
DP-3	78.8	5/7/2003	**13,000**	<3,700	<3,700	<3,700	<3,700	<3,700	**8,300**	**8,300**	**21,300**
DP-4	76.7	5/8/2003	**30**	<28	<28	<28	<28	<28	<28	<28	**30**
DP-4	86.7	5/8/2003	**45**	<28	<28	<28	<28	<28	<28	<28	**45**
DP-5	72.7	5/8/2003	**95**	<34	<34	<34	<34	**43**	**85**	**128**	**223**
DP-5	89.6	5/8/2003	**3,400**	<1,400	<1,400	<1,400	<1,400	<1,400	**2,400**	**2,400**	**5,800**
DP-7	71.9	5/9/2003	<31	<31	<31	<31	<31	<31	<31	<31	0
DP-7	89.5	5/9/2003	**16,000**	<3,900	<3,900	<3,900	<3,900	<3,900	**12,000**	**12,000**	**28,000**
DP-7	94.9	5/9/2003	**95**	<23	<23	<23	<23	<23	**42**	**42**	**137**
DP-8	79.9	5/12/2003	**100**	<24	<24	<24	<24	<24	<24	<24	**100**
DP-8	89.1	5/12/2003	<27	<27	<27	<27	<27	<27	<27	<27	0
DP-9	75.3	5/13/2003	<22	<22	<22	<22	<22	<22	<22	<22	0
DP-9	85.6	5/13/2003	<30	<30	<30	<30	<30	<30	<30	<30	0
DP-10	72.9	5/13/2003	<30	<30	<30	<30	<30	<30	<30	<30	0
DP-10	85.6	5/13/2003	<26	<26	<26	<26	<26	<26	<26	<26	0
DP-11	76.4	5/14/2003	<28	<28	<28	<28	<28	<28	<28	<28	0
DP-11	81.3	5/14/2003	<27	<27	<27	<27	<27	<27	<27	<27	0
DP-12	72	5/14/2003	**40**	<24	<24	<24	<24	<24	<24	<24	**40**
DP-12	80.4	5/14/2003	**550**	<130	<130	130	<130 J	<130	**420**	**550**	**1,100**
PSB-1	76.5	10/7/2003	**1,700**	<510	<510	<510	<510	<510	**1,900**	**1,900**	**3,600**
PSB-1	81	10/7/2003	**2,400**	<580	<580	620	<580	<580	**2,500**	**3,120**	**5,520**
PSB-2	75	10/8/2003	**7,100**	<1,500	<1,500	2,100	<1,500	<1,500	**7,700**	**9,800**	**16,900**
PSB-2	92	10/8/2003	**43**	<28	<28	<28	<28	<28	<28	<28	**43**
PSB-3	75.5	10/9/2003	**3,000**	<630	<630	650	<630	<630	**2,500**	**3,150**	**6,150**
PSB-3	80	10/9/2003	**480**	<120	<120	<120	<120	<120	**250**	**250**	**730**
PSB-4	75	10/10/2003	**150**	<140	<140	**200**	<140	<140	**680**	**880**	**1,030**
PSB-4	88	10/10/2003	**45,000**	<7,000 J	<7,000 J	9,400 J	<7,000 J	<7,000 J	28,000 J	28,000 J	**45,000**
PSB-4	90.7	10/10/2003	**1,600**	<500	<500	<500	<500	<500	**920**	**920**	**2,520**
PSB-5	91	10/13/2003	**14,000**	<2,900	<2,900	**4,100**	<2,900	<2,900	**12,000**	**16,100**	**30,100**
PSB-6	84.8	10/14/2003	<31	<31	<31	<31	<31	<31	<31	<31	0
PSB-6	90.4	10/14/2003	**27,000**	<6,800	<6,800	**8,100**	<6,800	<6,800	**19,000**	**27,100**	**54,100**
PSB-7	84	10/15/2003	<30 J	<30 J	<30 J	<30 J	<30 J	<30 J	<30 J	<30 J	0
PSB-7	92	10/15/2003	<33 J	<33 J	<33 J	<33 J	<33 J	<33 J	<33 J	<33 J	0
PSB-8	84.5	10/16/2003	<30	<30	<30	<30	<30	<30	<30	<30	0
PSB-9	85.5	10/17/2003	<34	<34	<34	<34	<34	<34	<34	<34	0
PSB-9	92.2	10/17/2003	**2,000**	<280	<280	390	<280	<280	**1,400**	**1,790**	**3,790**
PSB-10	60.5	10/28/2003	<30	<30	<30	<30	<30	<30	<30	<30	0
PSB-10	89.5	10/28/2003	**44**	<33	<33	<33	<33	<33	<33	<33	**44**
PSB-11	74.5	10/29/2003	3,200 J	<2,000 J	<2,000 J	2,300 J	<2,000 J	<2,000 J	6,400 J	6,400 J	0
PSB-11	81.6	10/29/2003	47 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	0

Table 2.2
DNAPL Concentrations in the Saturated UBA (60-105 feet bgs)
Montrose Superfund Site

Soil Boring Identifier	Sample Depth (feet bgs)	Sample Date	Concentrations in milligram per kilogram								
			MCB	2,4'-DDD	2,4'-DDE	2,4'-DDT	4,4'-DDD	4,4'-DDE	4,4'-DDT	Total DDT	Total DNAPL
PSB-12	65.2	10/30/2003	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	0
PSB-12	72.8	10/30/2003	670 J	<630 J	<630 J	<630 J	<630 J	<630 J	1,700 J	1,700 J	0
PSB-12	77.4	10/30/2003	1,400 J	<400 J	<400 J	<400 J	<400 J	<400 J	1,100 J	1,100 J	0
PSB-13	68.8	10/31/2003	<51 J	<51 J	<51 J	<51 J	<51 J	<51 J	<51 J	<51 J	0
PSB-13	90	10/31/2003	<47 J	<47 J	<47 J	<47 J	<47 J	<47 J	<47 J	<47 J	0
PSB-14	78.5	11/4/2003	**8,600**	<3,500	<3,500	<3,500	<3,500	<3,500	**9,900**	**9,900**	**18,500**
PSB-14	93.5	11/4/2003	<40	<40	<40	<40	<40	<40	<40	<40	0
PSB-15	75	11/5/2003	9000 J	<2,000 J	<2,000 J	2,600 J	<2,000 J	<2,000 J	8,600 J	8600 J	0
PSB-15	79.75	11/5/2003	**13,000**	<3,300	<3,300	<3,300	<3,300	<3,300	**11,000**	**11,000**	**24,000**
PSB-16	85.25	11/7/2003	<36	<36	<36	<36	<36	<36	<36	<36	0
PSB-16	89.5	11/7/2003	**49**	<35	<35	<35	<35	<35	<35	<35	**49**
PSB-17	88.25	11/10/2003	**9,300**	<2,000	<2,000	2,200	<2,000	<2,000	**10,000**	**10,000**	**19,300**
PSB-17	94	11/10/2003	<34	<34	<34	<34	<34	<34	<34	<34	0
PSB-18	69	11/22/2003	**400**	<400 J	<400 J	510 J	<400 J	<400 J	1,500 J	1,500 J	**400**
PSB-18	88.5	11/22/2003	**5,700**	<1,800 J	<1,800 J	<1,800 J	<1,800 J	<1,800 J	5,900 J	5,900 J	**5,700**
PSB-19	71.8	11/23/2003	<40	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	0
PSB-19	77.2	11/23/2003	**5,200**	<1,500 J	<1,500 J	1,500 J	<1,500 J	<1,500 J	3, 900 J	**3, 900 J**	**5,200**
SSB-1	83	10/20/2003	NA	NA	NA	NA	NA	NA	NA	NA	NA
SSB-1	90.5	10/20/2003	<21	<21	<21	<21	<21	<21	<21	<21	0
SSB-2	56	10/21/2003	<40	<40	<40	<40	<40	<40	<40	<40	0
SSB-2	77	10/21/2003	<30	<30 J	<30 J	<30 J	<30 J	<30 J	<30 J	<30 J	0
SSB-2	87	10/21/2003	**23,000**	<2,900	<2,900	**6,800**	<2,900	<2,900	**19,000**	**25,800**	**48,800**
SSB-3	86	10/22/2003	<40	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	0
SSB-3	90	10/22/2003	<34	<34	<34	<34	<34	<34	<34	<34	0
SSB-5	77.75	10/24/2003	**2,200**	<340	<340	530	<340	<340	1,800	2,330	**4,530**
SSB-5	94.5	10/24/2003	**39**	<33	<33	<33	<33	<33	<33	<33	**39**
SSB-6	77.5	11/6/2003	**15,000**	<3,100	<3,100	<3,100	<3,100	<3,100	**10,000**	**10,000**	**25,000**
SSB-6	88	11/6/2003	<32	<32	<32	<32	<32	<32	<32	<32	0
SSB-6	89.5	11/6/2003	**55,000**	<30,000	<30,000	<30,000	<30,000	<30,000	**35,000**	**35,000**	**90,000**
SSB-6	90.75	11/6/2003	**49,000**	<28,000	<28,000	<28,000	<28,000	<28,000	**29,000**	**29,000**	**78,000**
SSB-7	89.5	11/11/2003	<2,000	<2,000	<2,000	<2,000	<2,000	<2,000	**6,200**	**6,200**	**6,200**
SSB-7	94	11/11/2003	<40	<40	<40	<40	<40	<40	<40	<40	0
SSB-8	82.5	11/12/2003	<40	<40	<40	<40	<40	<40	<40	<40	0
SSB-8	91	11/12/2003	<40	<40	<40	<40	<40	<40	<40	<40	0
SSB-9	72.5	11/14/2003	<45	<45	<45	<45	<45	<45	<45	<45	0
SSB-9	92	11/14/2003	<40	<40	<40	<40	<40	<40	<40	<40	0
SSB-10	82.25	11/18/2003	<40	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	0
SSB-10	88.75	11/18/2003	<34	<34 J	<34 J	<34 J	<34 J	<34 J	<34 J	<34 J	0
SSB-11	78	11/19/2003	**990**	<350 J	<350 J	<350 J	<350 J	<350 J	1,400 J	1,400 J	**990**
SSB-11	92	11/19/2003	**40**	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	**40**
SSB-12	64.9	11/20/2003	<40	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	0
SSB-12	82.5	11/20/2003	**50,000**	<20,000 J	<20,000 J	<20,000 J	<20,000 J	<20,000 J	53,000 J	53,000 J	**50,000**
SSB-13	69.2	11/21/2003	<40	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	0
SSB-13	92	11/21/2003	<40	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	<40 J	0

Table 2.2
DNAPL Concentrations in the Saturated UBA (60-105 feet bgs)
Montrose Superfund Site

Soil Boring Identifier	Sample Depth (feet bgs)	Sample Date	Concentrations in milligram per kilogram								
			MCB	2,4'-DDD	2,4'-DDE	2,4'-DDT	4,4'-DDD	4,4'-DDE	4,4'-DDT	Total DDT	Total DNAPL
SSB-14	79	11/24/2003	<34	<34	<34	<34	<34	<34	<34	<34	0
SSB-14	90.3	11/24/2003	<40	<40	<40	<40	<40	<40	<40	<40	0
SSB-15	78	12/2/2003	<31	<31	<31	<31	<31	<31	<31	<31	0
SSB-15	88	12/2/2003	<34	<34	<34	<34	<34	<34	<34	<34	0
TSB-1	60	11/13/2003	<50	<50	<50	<50	<50	<50	<50	<50	0
TSB-1	71	11/13/2003	<35	<35	<35	<35	<35	<35	<35	<35	0
TSB-2	78.75	11/17/2003	**54**	<36	<36	<36	<36	<36	<36	<36	**54**
TSB-2	87.75	11/17/2003	**28,000**	<4,000	<4,000	**4,700**	<4,000	<4,000	**16,000**	**20,700**	**48,700**
TSB-3	74.7	11/25/2003	<36	<36	<36	<36	<36	<36	<36	<36	0
TSB-3	79.3	11/25/2003	**14,000**	<2,000	<2,000	3,000	<2,000	<2,000	**9,900**	**12,900**	**26,900**
TSB-3	95	11/25/2003	**34**	<32	<32	<32	<32	<32	<32	<32	**34**
TSB-4	72	12/4/2003	<30	<30	<30	<30	<30	<30	<30	<30	0
TSB-4	81.7	12/4/2003	<28	<28	<28	<28	<28	<28	<28	<28	0
TSB-5	81	1/19/2004	**44**	<26	<26	<26	<26	<26	<26	<26	**44**
TSB-5	94.5	1/19/2004	<34	<34	<34	<34	<34	<34	<34	<34	0
TSB-6	80.25	1/20/2004	<36	<36	<36	<36	<36	<36	<36	<36	0
TSB-6	93.75	1/20/2004	<36	<36	<36	<36	<36	<36	<36	<36	0
TSB-7	83.5	1/21/2004	<33	<33	<33	<33	<33	<33	<33	<33	0
TSB-7	91.5	1/21/2004	<34	<34	<34	<34	<34	<34	<34	<34	0
TSB-8	87	1/22/2004	**700**	<200	<200	<200	<200	<200	**460**	**460**	**1,160**
TSB-8	87.1	1/22/2004	**5,100**	<1,700	<1,700	<1,700	<1,700	<1,700	**3,200**	**3,200**	**8,300**
TSB-8	91	1/22/2004	**13,000**	<3,500	<3,500	<3,500	<3,500	<3,500	**8,000**	**8,000**	**21,000**
TSB-9	89	1/23/2004	<35	<35	<35	<35	<35	<35	<35	<35	0
TSB-9	91	1/23/2004	**47**	<35	<35	<35	<35	<35	<35	<35	**47**
TSB-10	77.25	1/26/2004	<31	<31	<31	<31	<31	<31	<31	<31	0
TSB-10	84.5	1/26/2004	**46**	<34	<34	<34	<34	<34	<34	<34	**46**
TSB-11	81	1/27/2004	<34	<34	<34	<34	<34	<34	<34	<34	0
TSB-11	82.5	1/27/2004	**280**	<66	<66	<66	<66	<66	**100**	**100**	**380**
TSB-11	91	1/27/2004	<50	<50	<50	<50	<50	<50	<50	<50	0
TSB-12	85.5	1/28/2004	<40	<40	<40	<40	<40	<40	<40	<40	0
TSB-12	94.75	1/28/2004	<40	<40	<40	<40	<40	<40	<40	<40	0
TSB-13	69	1/29/2004	<33	<33	<33	<33	<33	<33	<33	<33	0
TSB-13	95	1/29/2004	**45**	<40	<40	<40	<40	<40	<40	<40	**45**
TSB-14	88	2/2/2004	**35**	<35	<35	<35	<35	<35	<35	<35	**35**
TSB-14	92.5	2/2/2004	**40**	<30	<30	<30	<30	<30	<30	<30	**40**
TSB-15	82	2/4/2004	<34	<34	<34	<34	<34	<34	<34	<34	0
TSB-15	88	2/4/2004	<35	<35	<35	<35	<35	<35	<35	<35	0
TSB-15	92	2/4/2004	<35	<35	<35	<35	<35	<35	<35	<35	0
TSB-16	83	8/29/2004	<35	<35	<35	<35	<35	<35	<35	<35	0
TSB-16	90	8/29/2004	<40	<40	<40	<40	<40	<40	<40	<40	0
C59-67	67	5/16/2005	<40	<40	<40	<40	<40	<40	<40	<40	0
C59-84	84	5/16/2005	**66**	<30	<30	<30	<30	<30	<30	<30	**66**
C42-81	81	5/17/2008	<35	<35	<35	<35	<35	<35	<35	<35	0
C42-88	88	5/17/2008	<23	<23	<23	<23	<23	<23	<23	<23	0

Table 2.2
DNAPL Concentrations in the Saturated UBA (60-105 feet bgs)
Montrose Superfund Site

Soil Boring Identifier	Sample Depth (feet bgs)	Sample Date	Concentrations in milligram per kilogram								
			MCB	2,4'-DDD	2,4'-DDE	2,4'-DDT	4,4'-DDD	4,4'-DDE	4,4'-DDT	Total DDT	Total DNAPL
C13-77	77	5/18/2005	<30	<30	<30	<30	<30	<30	<30	<30	0
C13-86	86	5/18/2005	<29	<29	<29	<29	<29	<29	<29	<29	0
C44-76.7	76.7	5/19/2005	**62**	<32	<32	<32	<32	<32	<32	<32	**62**
C44-81	81	5/19/2005	**4,100**	<760	<760	**960**	<760	<760	**2,900**	**3,860**	**7,960**
C30-66.5	66.5	5/20/2005	**8,300**	<1,600	<1,600	**1,600**	<1,600	<1,600	**5,000**	**6,600**	**14,900**
C30-85	85	5/20/2005	**120**	<110	<110	**150**	<110	<110	**650**	**800**	**920**

Footnotes:

bgs = Below ground surface

J = Estimated value

2,4'-DDD = 2,4'-Dichlorodiphenyldichloroethane

2,4'-DDE = 2,4'-Dichlorodiphenyldichloroethylene

2,4'-DDT = 2,4'-Dichlorodiphenyltrichloroethane

4,4'-DDD = 4,4'-Dichlorodiphenyldichloroethane

4,4'-DDE = 4,4'-Dichlorodiphenyldichloroethylene

4,4'-DDT = 4,4'-Dichlorodiphenyltrichloroethane

(<) = Less than the Laboratory Reporting Limit

MCB = Monochlorobenzene

Total DDT = Sum of 2,4' and 4,4' isomers of DDT, DDD, DDE

Total DNAPL= Sum of MCB and Total DDT

Source:

Hargis + Associates, Results of DNAPL Reconnaissance Investigation, October 22, 2004.

Table 2.3
DNAPL Thickness in Saturated UBA (60-105 feet bgs)
Montrose Superfund Site

Boring ID	Saturated UBA			
	Maximum MCB Concentration (mg/kg)	Maximum Total DDT Concentration (mg/kg)	Maximum DNAPL Concentration (mg/kg)	Liberal DNAPL Thickness (feet)
DP- 1	480	170	650	0.50
DP- 2	210	110	320	0.00
DP- 3	13,000	8,300	21,300	0.50
DP- 4	45	<28	45	0.00
DP- 5	3,400	2,400	5,800	0.30
DP- 7	16,000	12,000	28,000	1.00
DP- 8	100	<24	100	0.00
DP- 9	<30	<30	<60	0.00
DP- 10	<30	<30	<60	0.00
DP- 11	<28	<28	<56	0.00
DP- 12	550	550	1,100	1.25
PSB- 1	2,400	3,120	5,520	2.50
PSB- 2	7,100	9,800	16,900	0.85
PSB- 3	3,000	3,150	6,150	1.75
PSB- 4	45,000	37,400	82,400	2.95
PSB- 5	14,000	16,100	30,100	2.50
PSB- 6	27,000	27,100	54,100	0.35
PSB- 7	<33	<33	<66	0.00
PSB- 8	<30	<30	<60	0.00
PSB- 9	2,000	1,790	3,790	4.00
PSB- 10	44	<33	44	0.00
PSB- 11	3,200	8,700	11,900	2.00
PSB- 12	1,400	1,100	2,500	1.55
PSB- 13	<51	<51	<102	0.00
PSB- 14	8,600	9,900	18,500	1.00
PSB- 15	13,000	11,000	24,000	1.75
PSB- 16	49	<35	49	0.00
PSB- 17	9,300	12,200	21,500	1.00
PSB- 18	5,700	5,900	11,600	1.75
PSB- 19	5,200	5,400	10,600	0.25
SSB- 1	<21	<21	<42	0.00
SSB- 2	23,000	25,800	48,800	2.35
SSB- 3	<40	<40	<80	0.00
SSB- 4	N/A	N/A	N/A	0.00

Table 2.3
DNAPL Thickness in Saturated UBA (60-105 feet bgs)
Montrose Superfund Site

Boring ID	Saturated UBA			
	Maximum MCB Concentration (mg/kg)	Maximum Total DDT Concentration (mg/kg)	Maximum DNAPL Concentration (mg/kg)	Liberal DNAPL Thickness (feet)
SSB- 5	2,200	2,330	4,530	0.95
SSB- 6	55,000	35,000	90,000	2.50
SSB- 7	<2,000	6,200	6,200	1.50
SSB- 8	<40	<40	<80	0.00
SSB- 9	<45	<45	<90	0.00
SSB- 10	<40	<40	<80	0.00
SSB- 11	990	1,400	2,390	0.70
SSB- 12	50,000	53,000	103,000	1.00
SSB- 13	<40	<40	<80	0.00
SSB- 14	<40	<40	<80	0.00
SSB- 15	<34	<34	<68	0.00
TSB- 1	<50	<50	<100	0.00
TSB- 2	28,000	20,700	48,700	0.30
TSB- 3	14,000	12,900	26,900	1.60
TSB- 4	<30	<30	<60	0.00
TSB- 5	44	<34	44	0.00
TSB- 6	<36	<36	<72	0.00
TSB- 7	<34	<34	<68	0.00
TSB- 8	13,000	8,000	21,000	0.95
TSB- 9	47	<35	47	0.00
TSB- 10	46	<34	46	0.00
TSB- 11	280	100	380	0.00
TSB- 12	<40	<40	<80	0.00
TSB- 13	45	<40	45	0.00
TSB- 14	40	<35	40	0.00
TSB- 15	<35	<35	<70	0.00
TSB- 16	<40	<40	<80	0.00
C- 13	<30	<30	<60	0.00
C- 30	8,300	6,600	14,900	2.00
C- 42	<35	<35	<70	0.00
C- 44	4,100	3,860	7,960	1.00
C- 59	66	<40	66	0.00
S- 101/101A	36,000	51,000	87,000	1.05
S- 201	N/A	N/A	N/A	N/A

Table 2.3
DNAPL Thickness in Saturated UBA (60-105 feet bgs)
Montrose Superfund Site

Boring ID	Saturated UBA			
	Maximum MCB Concentration (mg/kg)	Maximum Total DDT Concentration (mg/kg)	Maximum DNAPL Concentration (mg/kg)	Liberal DNAPL Thickness (feet)
S- 202	N/A	N/A	N/A	N/A
S- 203	N/A	N/A	N/A	N/A
S- 204	N/A	N/A	N/A	N/A
S- 301/301A	12,000	3,800	15,800	1.20
S- 302A	54	88	142	1.45
S-302E/302F	N/A	N/A	N/A	1.45
S- 303/303A	1	8	9	0.00
S- 304/304A	4,900	69,000	73,900	1.00
S- 305/305A	81,000	24,000	105,000	2.20
MW- 2	7,400	4,980	12,380	N/A
UBT- 1	N/A	N/A	N/A	14.15
UBT- 2	N/A	N/A	N/A	7.55
UBT- 3	N/A	N/A	N/A	4.50
LW- 1	N/A	N/A	N/A	1.30

Notes:

DNAPL = Dense Non Aqueous Phase Liquid

MCB = Monochlorobenzene

UBA = Upper Bellflower Aquitard

DDT= Dichlorodiphenyltrichloroethane

Total DDT = Sum of 2,4' and 4,4' isomers of DDT, DDD, DDE

mg/kg= milligrams per kilogram

bgs = Below ground surface

N/A = Not Available

Sources:

Earth Tech, DNAPL Focused Treatment Area Evaluation, Saturated UBA, June 5, 2008.

Hargis + Associates, Evaluation of Containment Zone Timeframes Following a DNAPL Remedy at the Montrose Site, September 4, 2008

Table 2.4
Hydraulic Displacement Field Pilot Test Results
Montrose Superfund Site

EXTRACTION WELL	CUMMULATIVE GW EXTRACTION RATE (gpm)	GW DRAWDOWN (feet)	DNAPL RECOVERED (liters)	DNAPL RECOVERED (gallons)	TOTAL DURATION[1]			OPERATING DURATION[1]		
					DURATION (hours)	DNAPL RECOVERY RATE (gph)	DNAPL SPECIFIC CAPACITY (gph/ft)	DURATION (hours)	DNAPL RECOVERY RATE (gph)	DNAPL SPECIFIC CAPACITY (gph/ft)
Active groundwater extraction in the indicated well:										
1991 28-day Test										
UBE-1	7.0	10.0	1,084.9	286.4	672	0.43	0.04	671	0.43	0.04
2004/2005 Tests										
UBE-1	2.4	1.3	40.8	10.8	667	0.02	0.01	484	0.02	0.02
	5.2	2.9	259.7	68.6	1,199	0.06	0.02	483	0.14	0.05
	8.5	5.0	671.2	177.2	2,856	0.06	0.01	1,289	0.14	0.03
	11.8	7.4	536.5	141.6	456	0.31	0.04	371	0.38	0.05
	Subtotals		**1,508.2**	**398.2**	**5,178**			**2,627**		
UBE-2	1.9	4.7	2.5	0.7	308	.002 (intermittent)	4.0×10^{-4}	136	0.005 (intermittent)	0.001
	2.6	7.1	0.0	0.0	218	no recovery	no recovery	240	no recovery	no recovery
	Subtotals		**2.5**	**0.7**	**526**			**376**		
UBE-3	4.1	7.2	0.0	0.0	211	no recovery	no recovery	182	no recovery	no recovery
	8.0	16.6	0.0	0.0	263	no recovery	no recovery	160	no recovery	no recovery
	Subtotals		0.0	0.0	**474**			**342**		
UBE-4	7.5	5.9	0.0	0.0	58	no recovery	no recovery	51	no recovery	no recovery
	9.9	7.9	5.0	1.3	95	0.01	0.002	55	0.02	0.003
	11.2	9.0	38.0	10.0	479	0.02	0.002	347	0.03	0.003
	Subtotals		**43**	**11.4**	**632**			**453**		
UBT-1	6.0	7.4	2.1	0.6	49	0.01	0.002	24	0.02	0.003
	8.1	11.9	112.7	29.8	314	0.09	0.008	290	0.10	0.009
	9.6	16.3	56.2	14.8	194	0.08	0.005	112	0.13	0.008
	Subtotals		**171**	**45.1**	**557**			**426**		
2008 Test										
UBE-5	1.4[2]	15.2	1.25	0.3	143	0.002	0.0002	128.0	0.003	0.0002
	1.5[3]	25.5	4.5	1.2	5.5	0.2	0.009	5.5	0.2	0.008
	Subtotals		**5.8**	**1.5**	**148.5**			**133.5**		

Notes:

1. "Total Duration" represents the entire period associated with a particular rate step even if the pumps were not operating.
   "Operating Duration" represents only the cummulative operating time associated with a particular rate step.
2. Grundfos Pump set above screen at 74' bgs
3. Grundfos Pump set in middle of the screen at 85' bgs

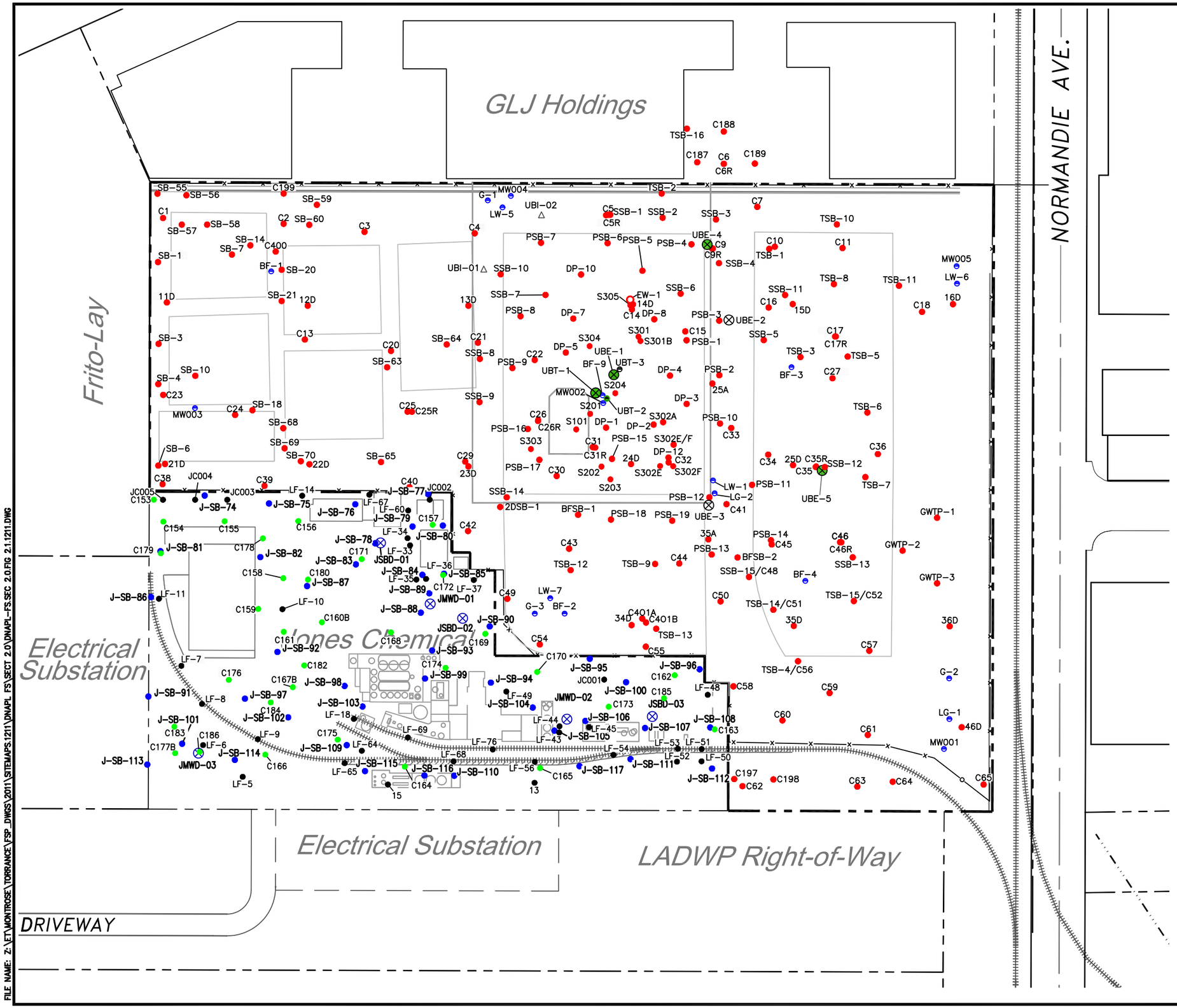
Abbreviations:

DNAPL = Dense non-aqueous phase liquid
GW = Groundwater
gpm = Gallons per minute
gph = Gallons per hour
gph/ft = Gallons per hour per foot of groundwater drawdown

Source:

Hargis + Associates, DNAPL Extraction Test Summary Report, June 4, 2008.
Earth Tech, Technical Memorandum Re: DNAPL Extraction Test at UBE-5, In Process

FIGURES



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Extraction Well
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- 46D — JCI Historical Soil Boring Location
- C172 — Supplemental Soil Investigation–Jones Chemical Boring Location

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
4. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

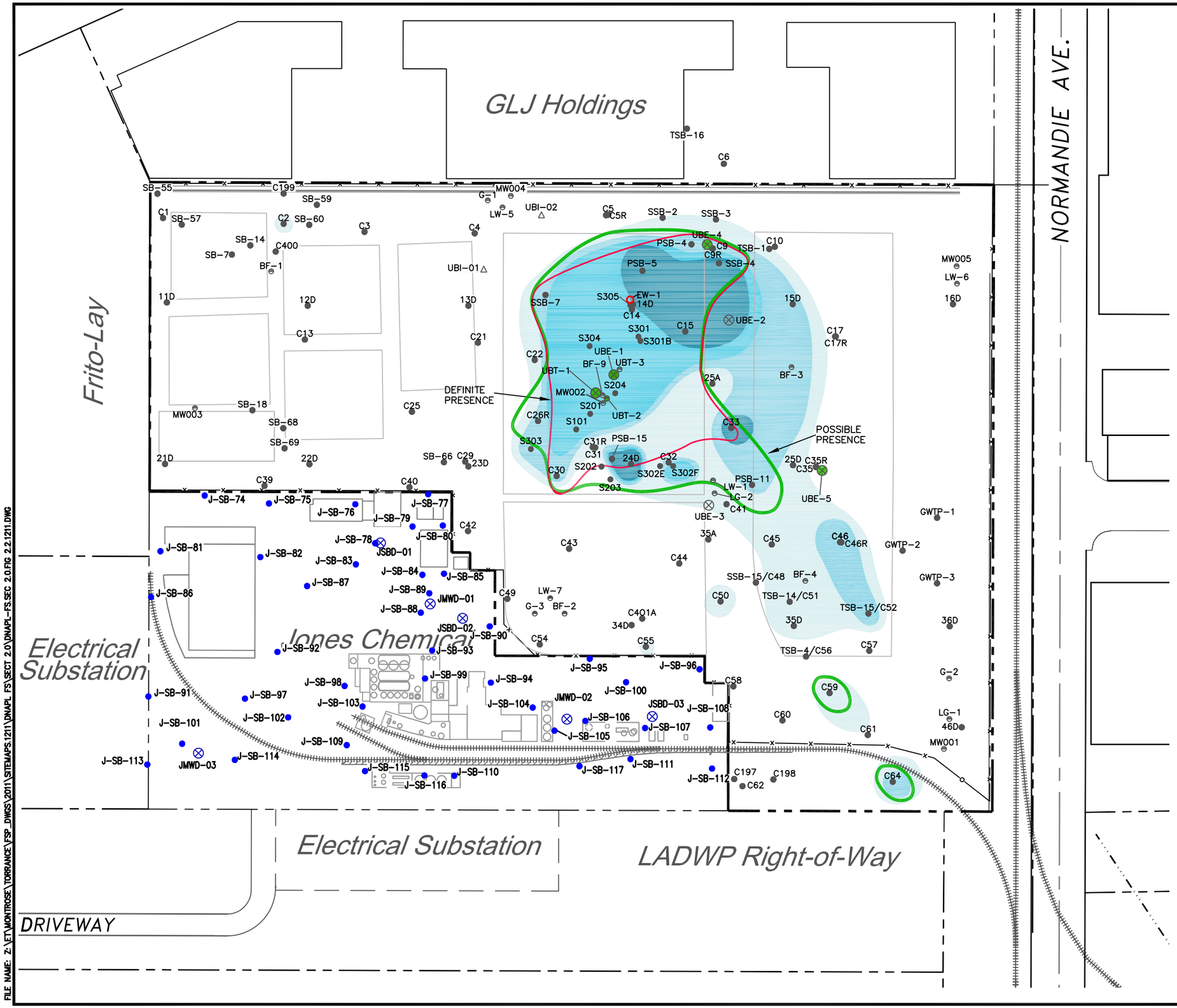
SCALE: 1"= 120'

Montrose Chemical Corporation

On Site Soil Boring/ Well Location Map

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.1

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.1.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
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- Surveyed Fence Line
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- LADWP — Los Angeles Department of Water and Power
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- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum MCB Isoconcentration in Soil Contour Interval 10–100 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 100–1000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 1000–10,000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval >10,000 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

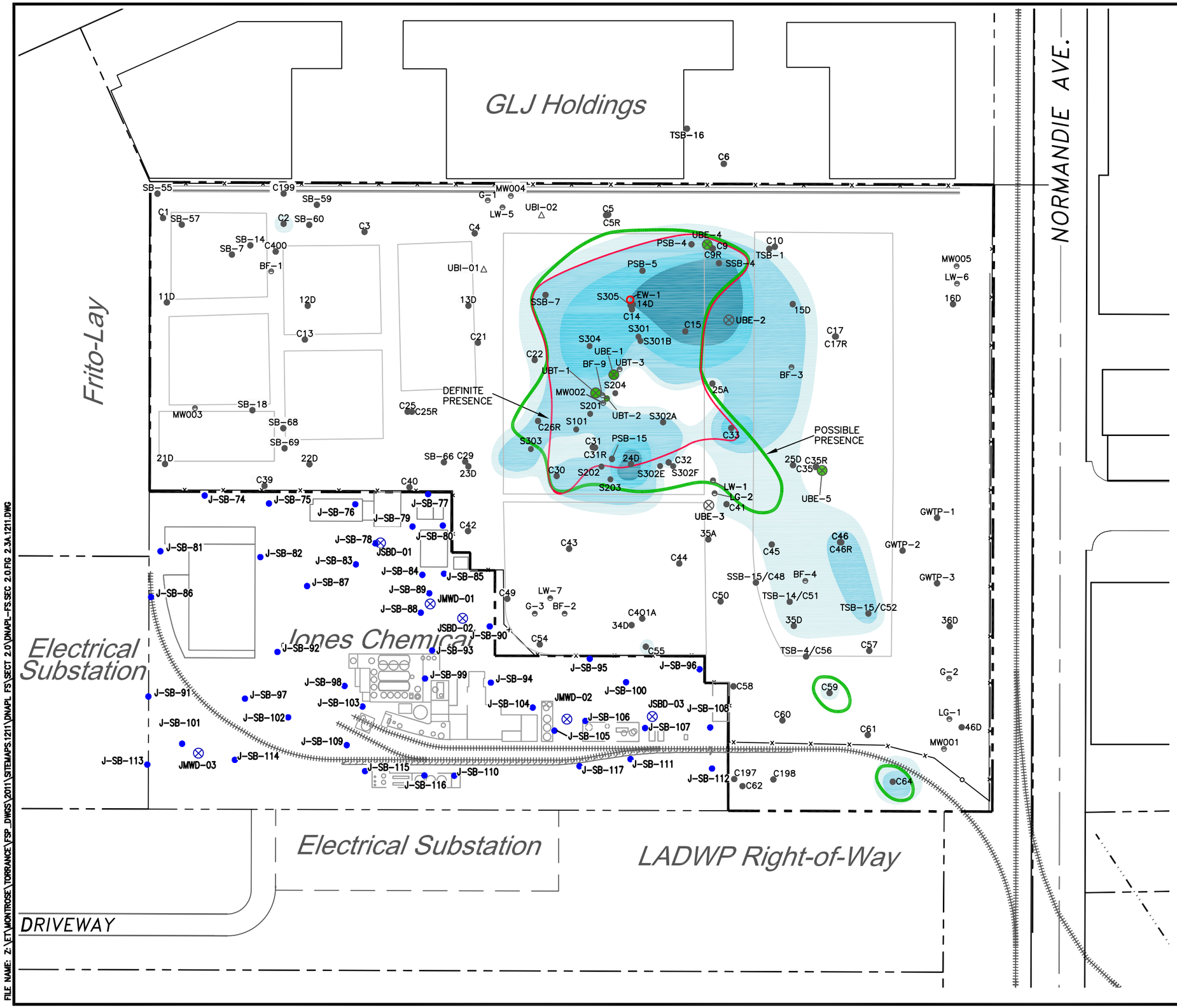
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum MCB Concentration in the Unsaturated Zone (0-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.2

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS\1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.2.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum MCB Isoconcentration in Soil Contour Interval 10–100 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 100–1000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 1000–10,000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval >10,000 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

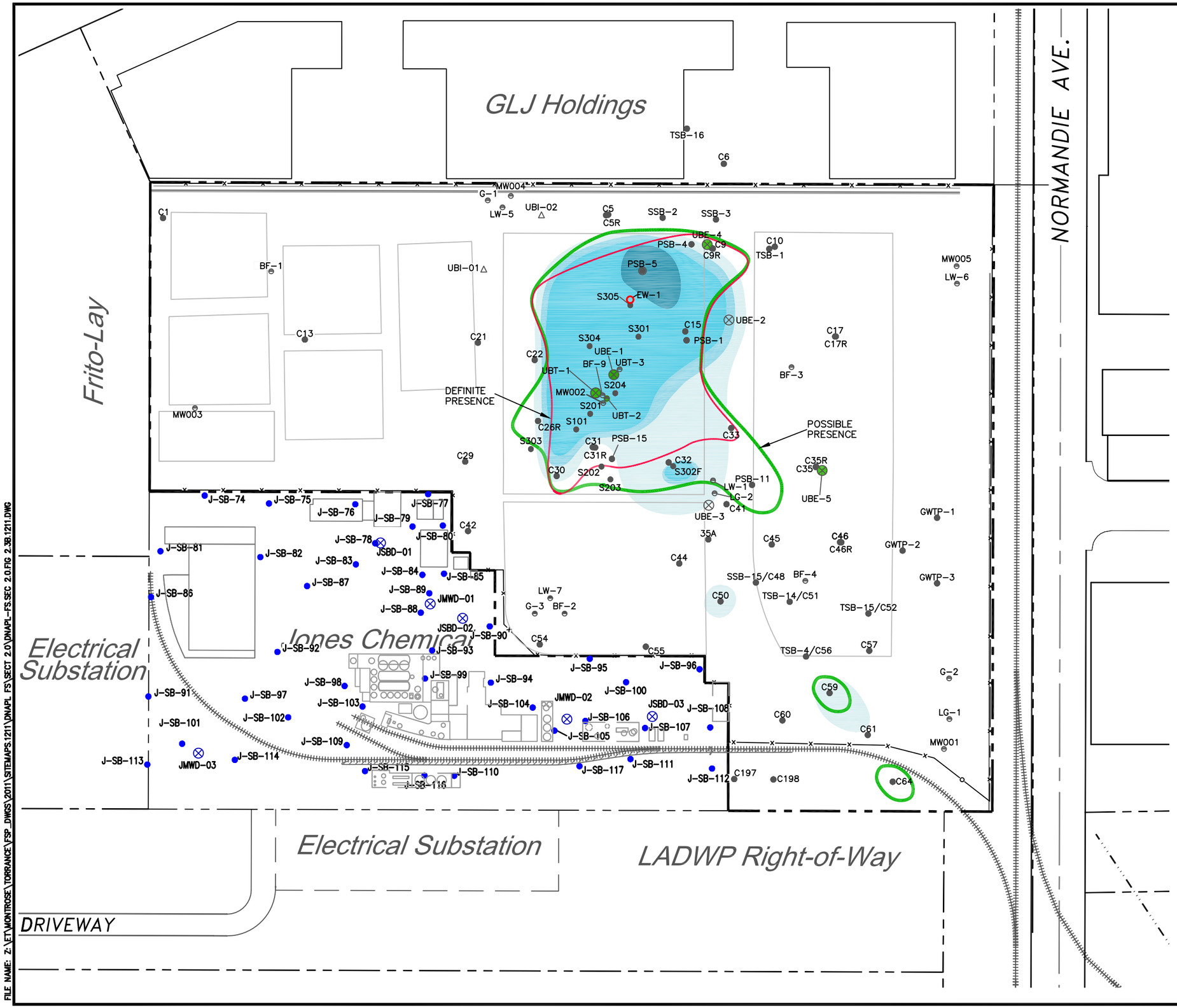
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum MCB Concentration in the Unsaturated Zone (0-25 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.3a

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS\1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.3A.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum MCB Isoconcentration in Soil Contour Interval 10–100 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 100–1000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 1000–10,000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval >10,000 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

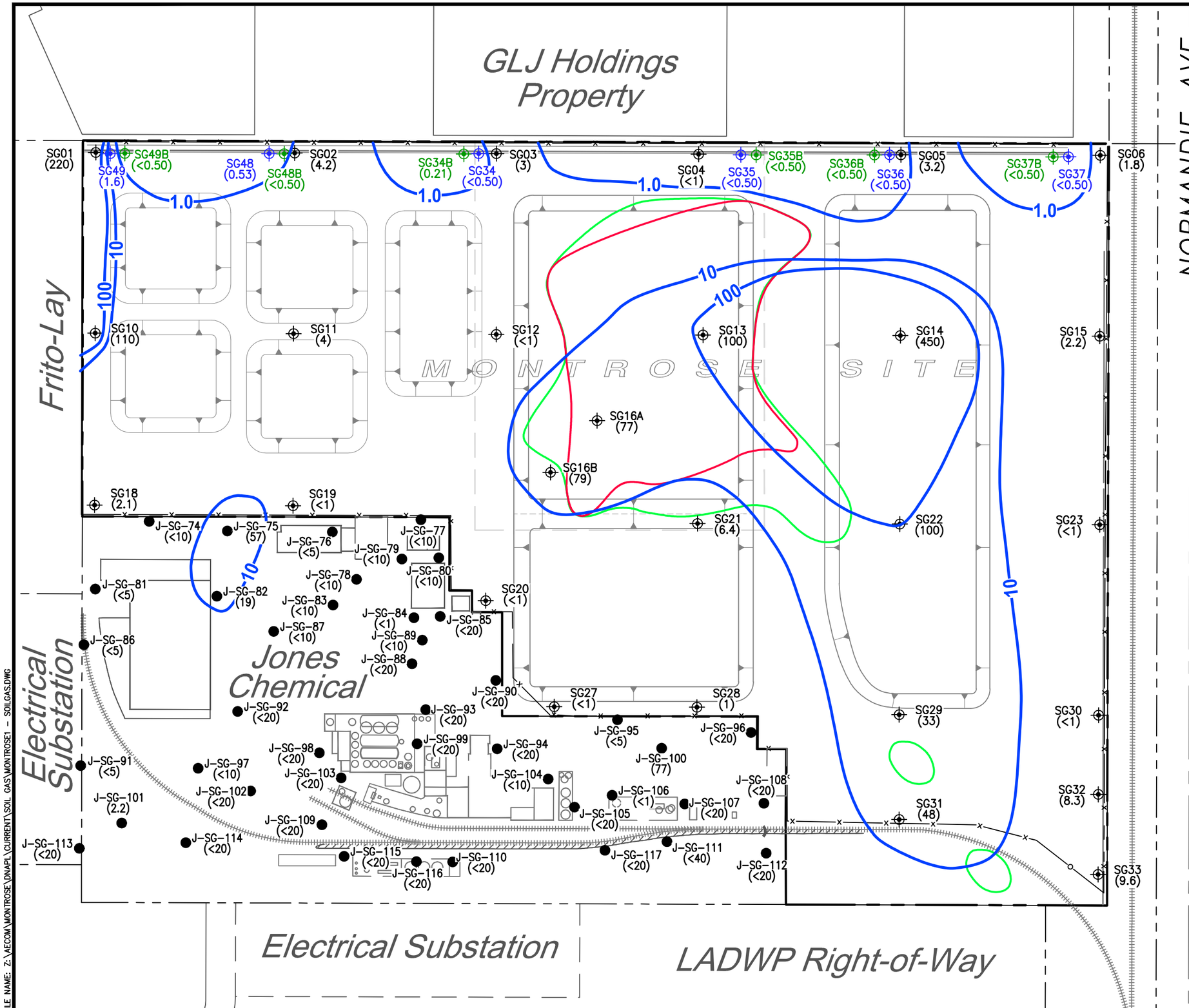
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum MCB Concentration in the Unsaturated Zone (25-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.3b

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.3B.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 100 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — MCB Concentrations Reported in µg/L at 5-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- SG49B — 2010 Single-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

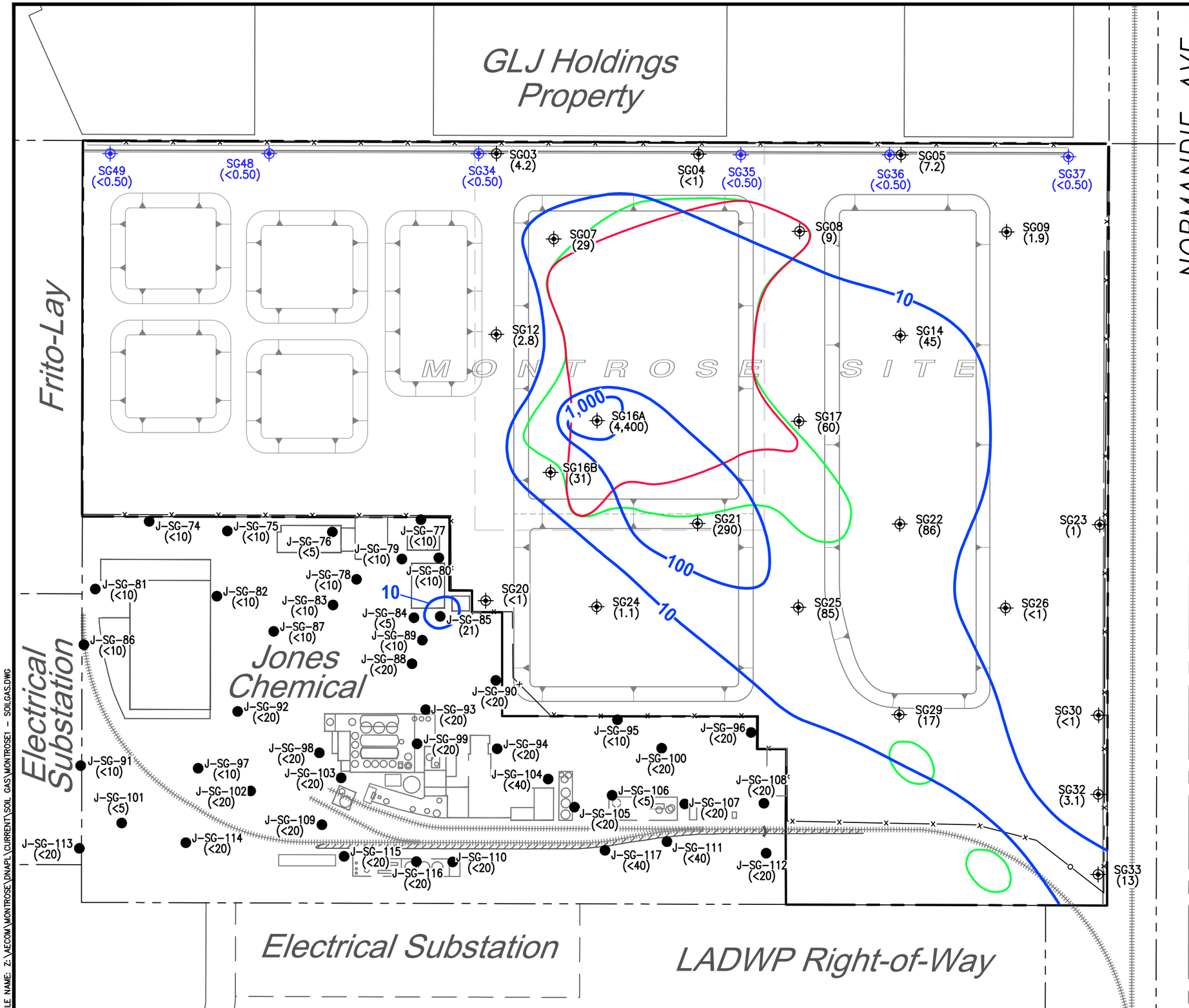
0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

MCB in Soil Gas (5 feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.4a

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — MCB Concentrations Reported in $\mu g/L$ at 15-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

MCB in Soil Gas (15 feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.4b

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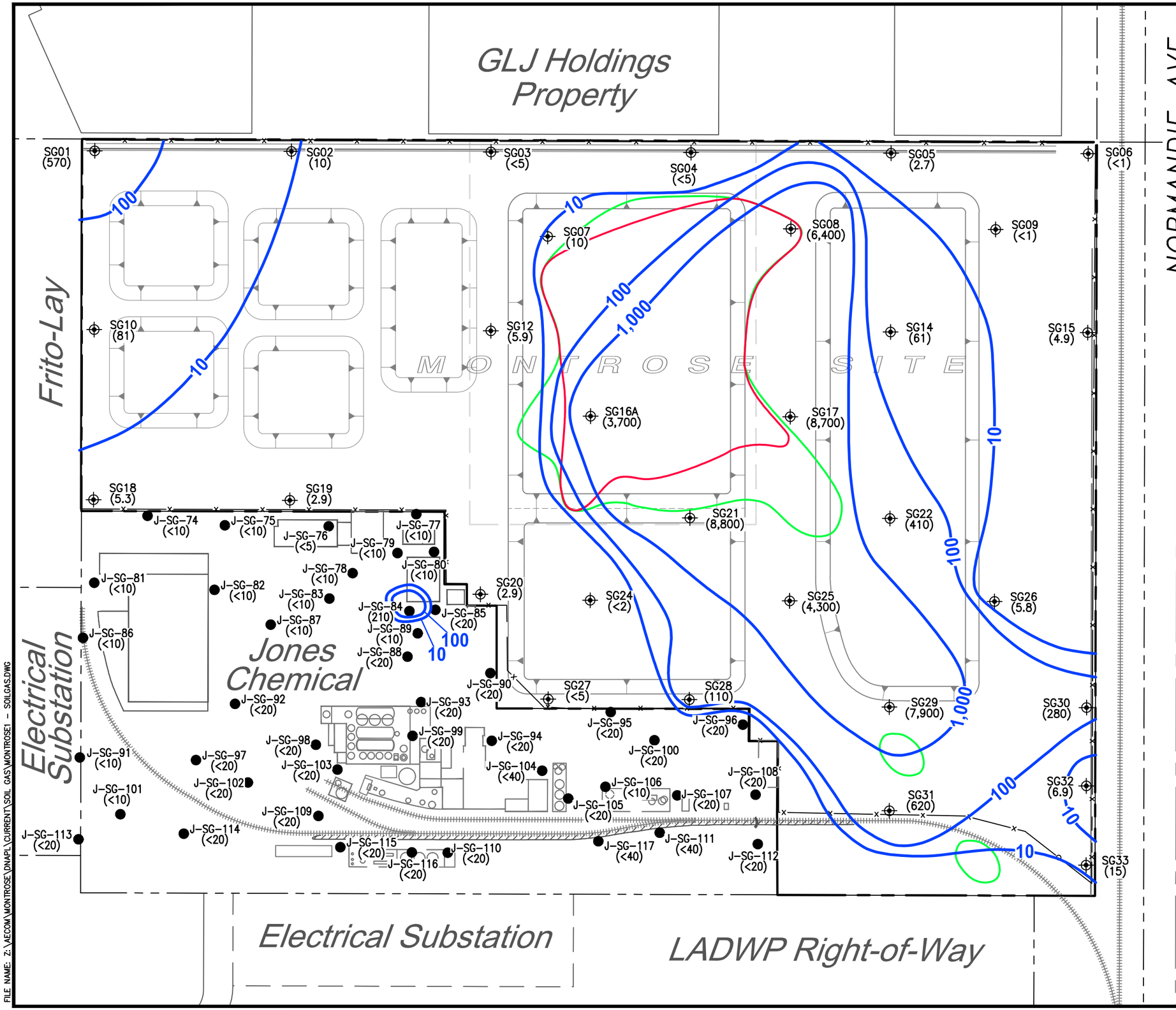

Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- —1,000— Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) MCB Concentrations Reported in $\mu g/L$ at 35-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

MCB in Soil Gas (35 feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.4c

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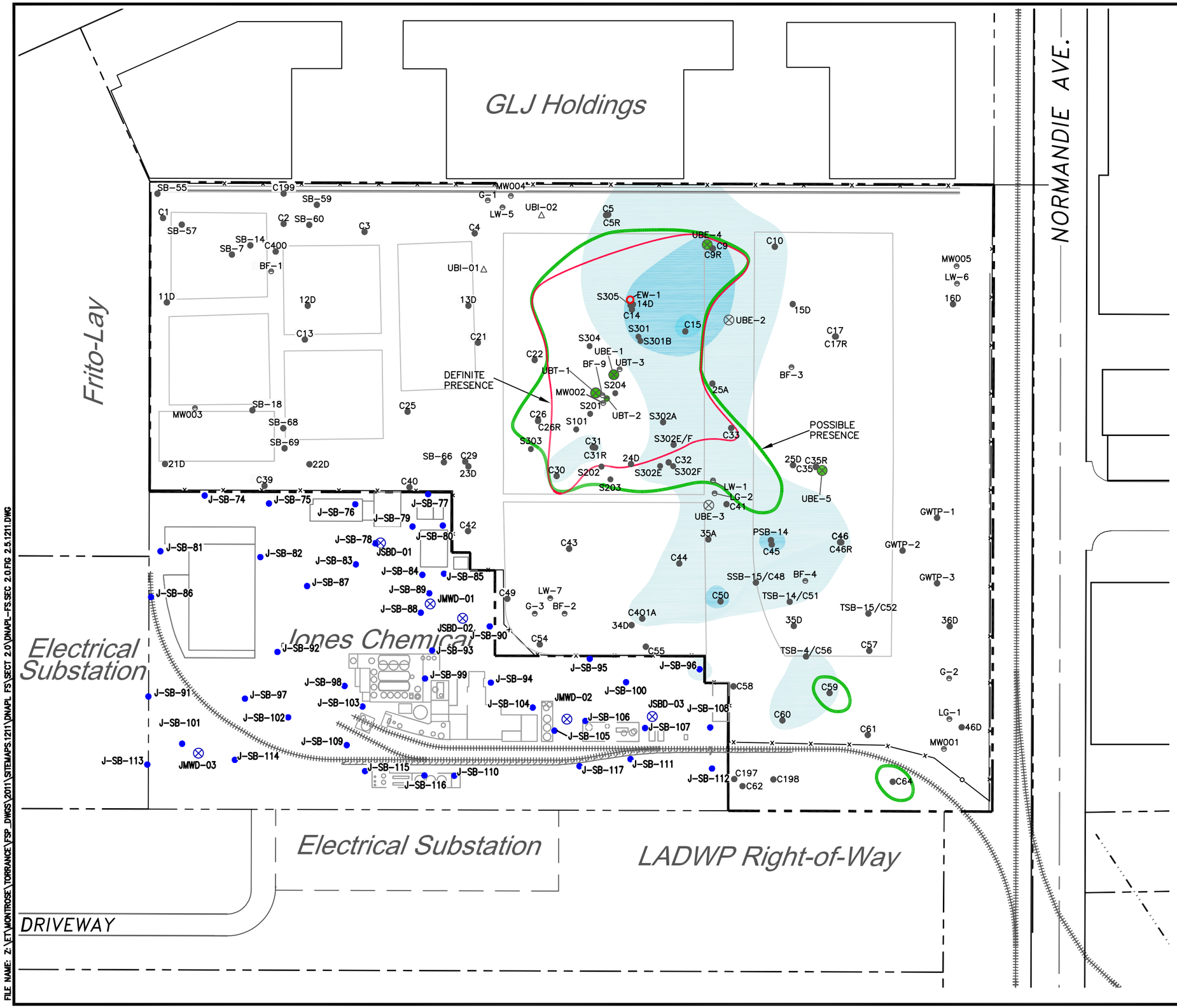


Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum Chloroform Isoconcentration in Soil Contour Interval 1–10 mg/kg
- Maximum Chloroform Isoconcentration in Soil Contour Interval 10–100 mg/kg
- Maximum Chloroform Isoconcentration in Soil Contour Interval 100–1,000 mg/kg

2008 EPA Industrial PRG = 1.5 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

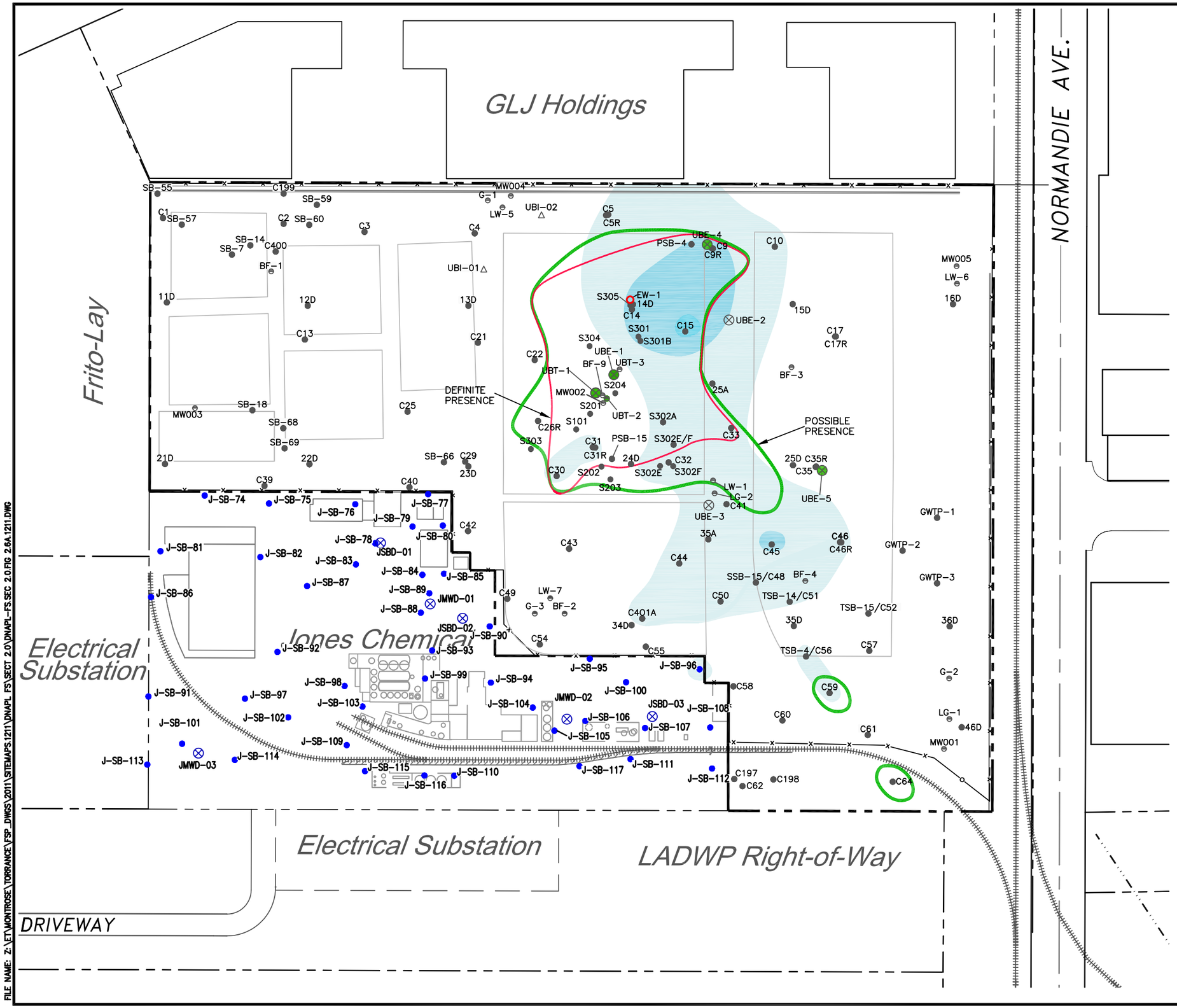
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum Chloroform Concentration in the Unsaturated Zone (0-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.5

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.5.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum Chloroform Isoconcentration in Soil Contour Interval 1–10 mg/kg
- Maximum Chloroform Isoconcentration in Soil Contour Interval 10–100 mg/kg
- Maximum Chloroform Isoconcentration in Soil Contour Interval 100–1,000 mg/kg

2008 EPA Industrial PRG = 1.5 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

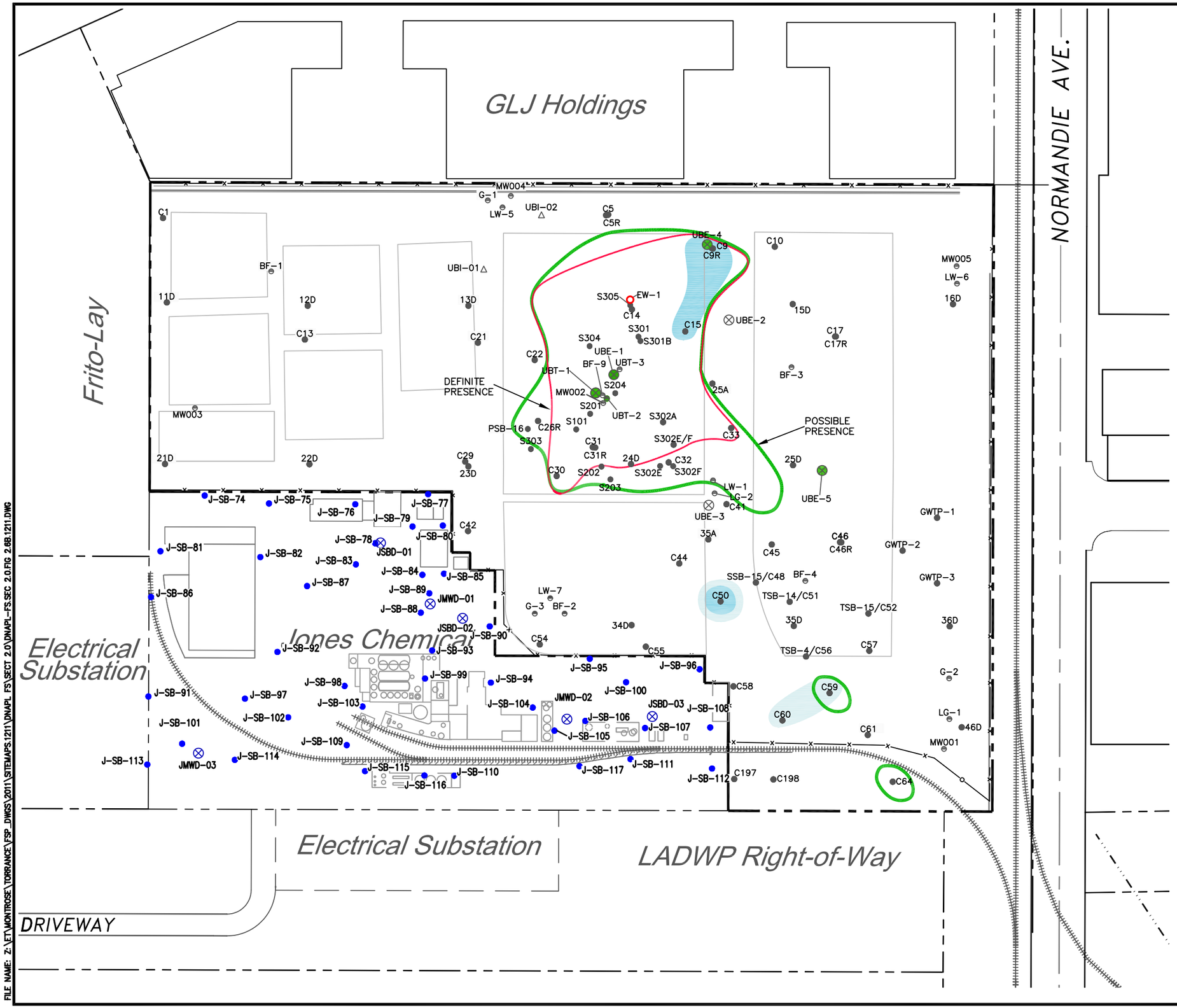
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum Chloroform Concentration in the Unsaturated Zone (0-25 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.6a

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.6A.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum Chloroform Isoconcentration in Soil Contour Interval 1–10 mg/kg
- Maximum Chloroform Isoconcentration in Soil Contour Interval 10–100 mg/kg

2008 EPA Industrial PRG = 1.5 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

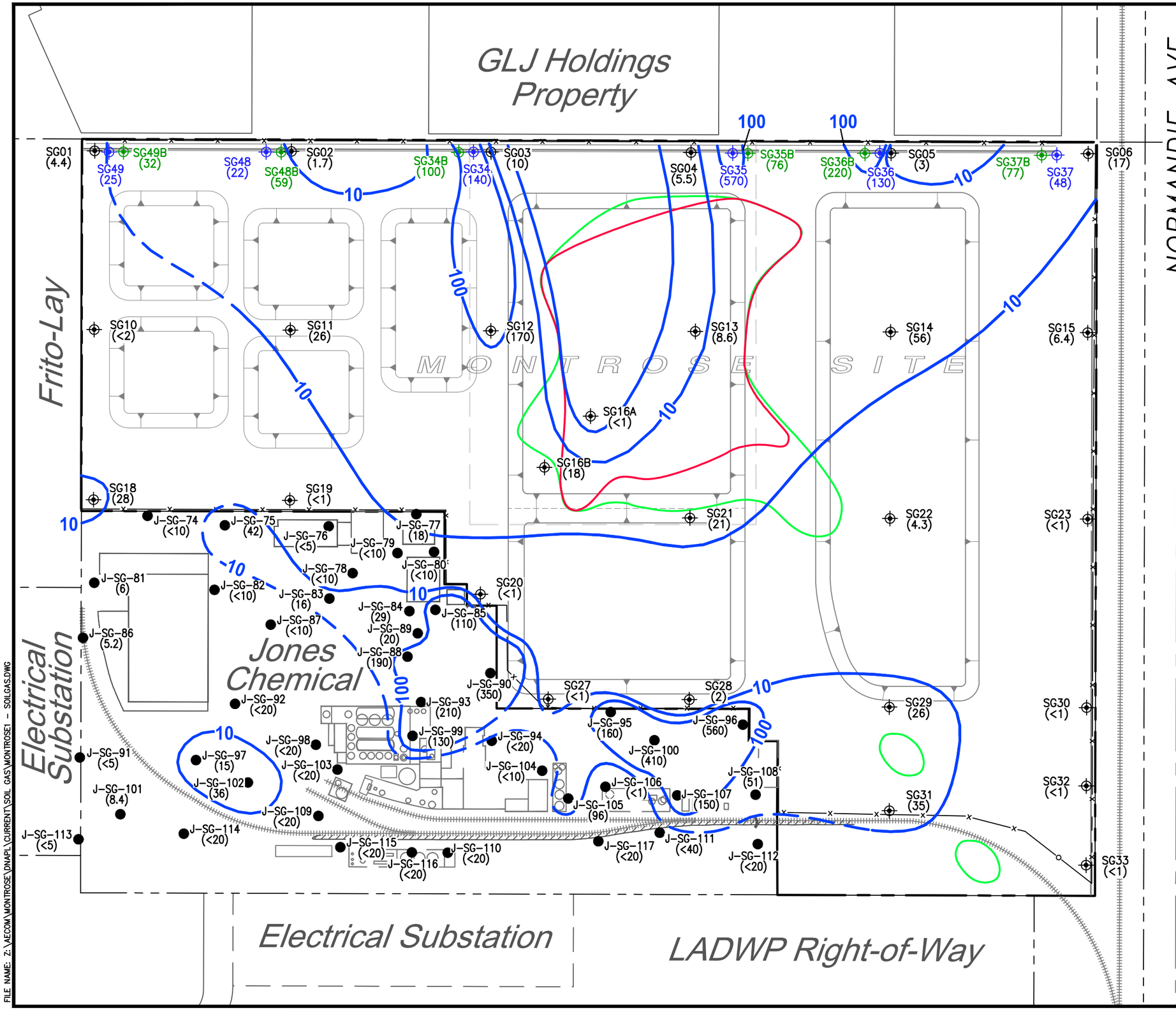
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum Chloroform Concentration in the Unsaturated Zone (25-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.6b

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.6B.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — Chloroform Concentrations Reported in µg/L at 5-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- SG49B — 2010 Single-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

References:

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   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

Chloroform in Soil Gas (5 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.7a

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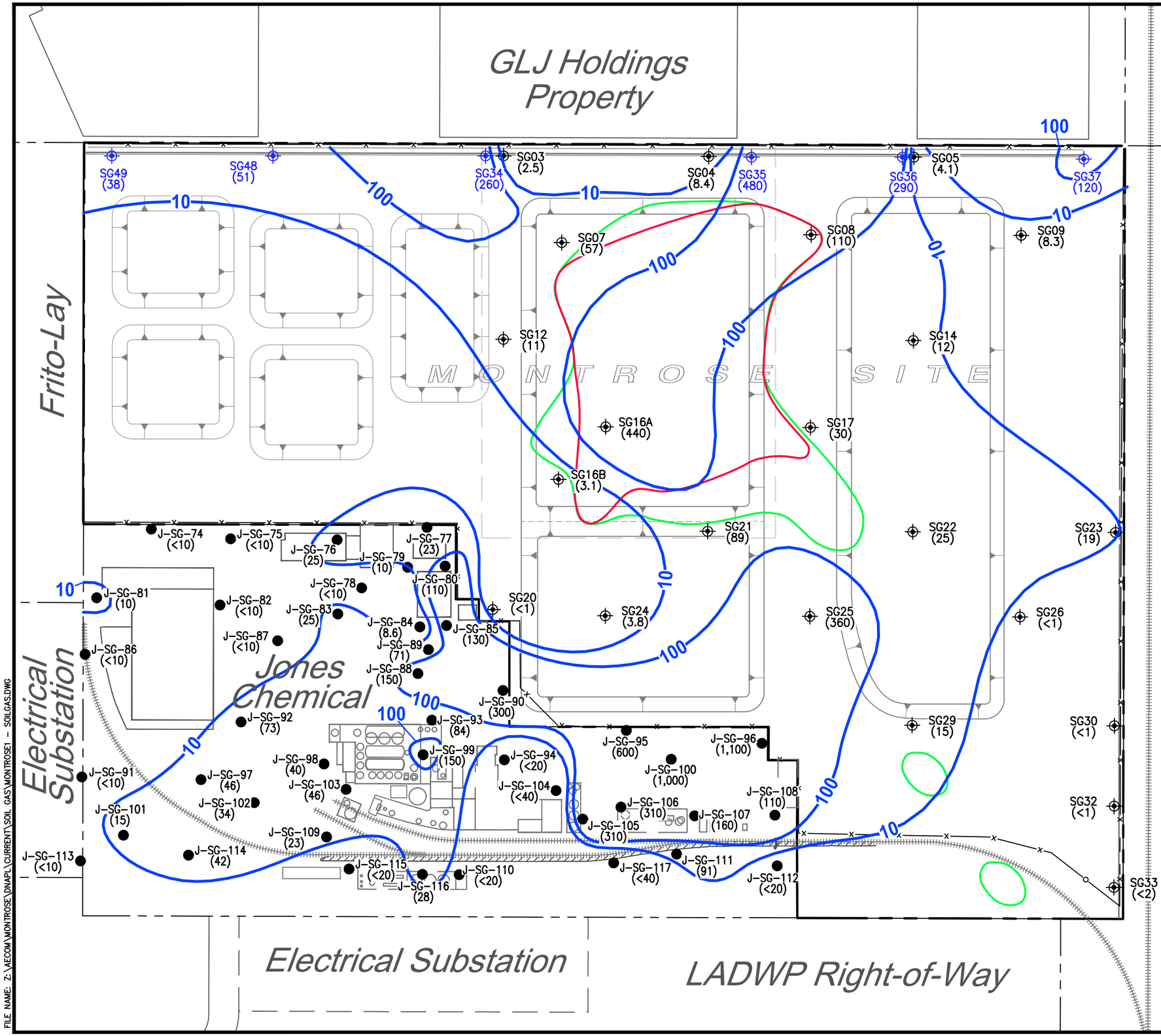

Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — Chloroform Concentrations Reported in µg/L at 15-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

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3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

Chloroform in Soil Gas (15 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.7b

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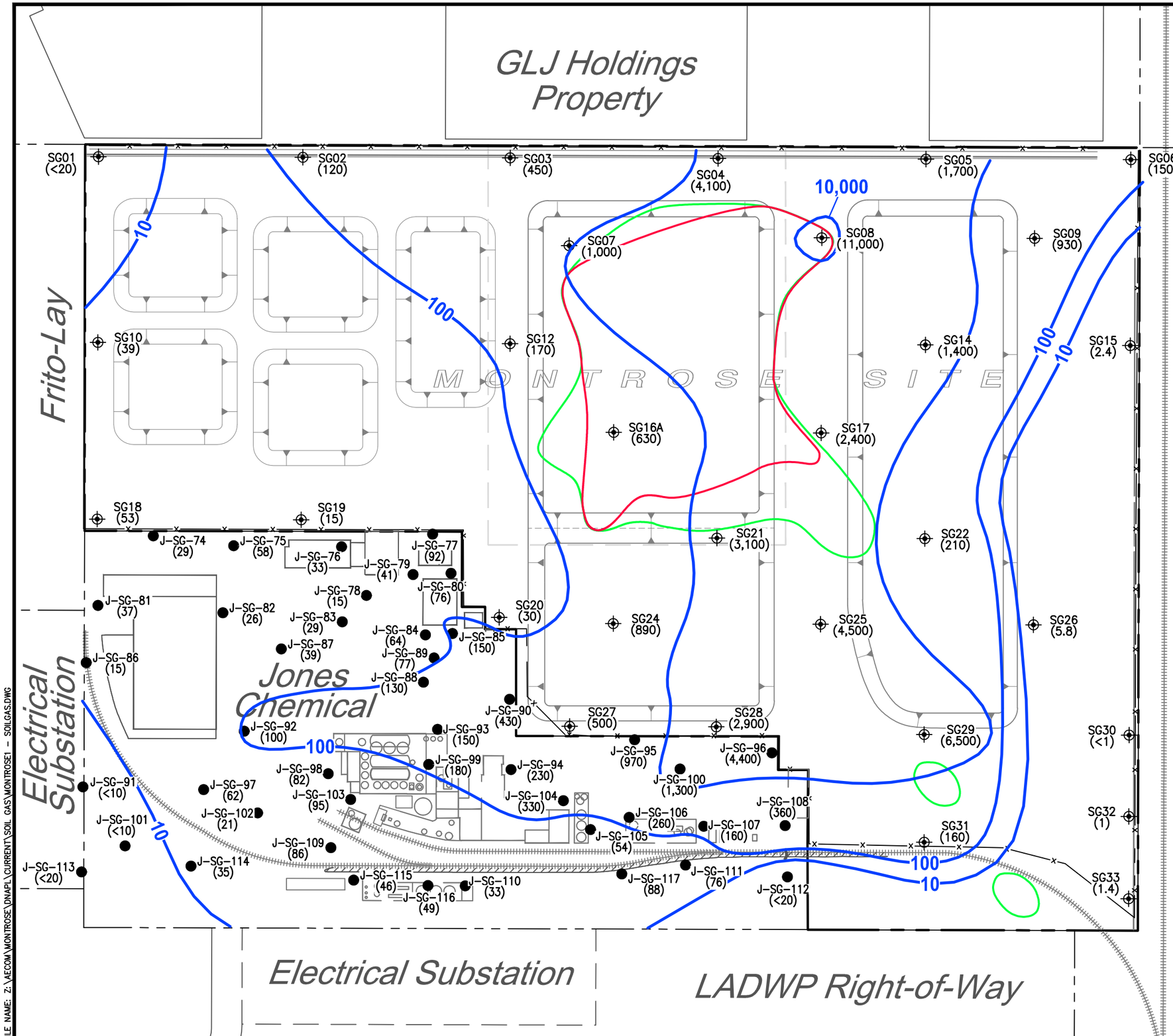

Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — Chloroform Concentrations Reported in µg/L at 55-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

Chloroform in Soil Gas (35 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.7c

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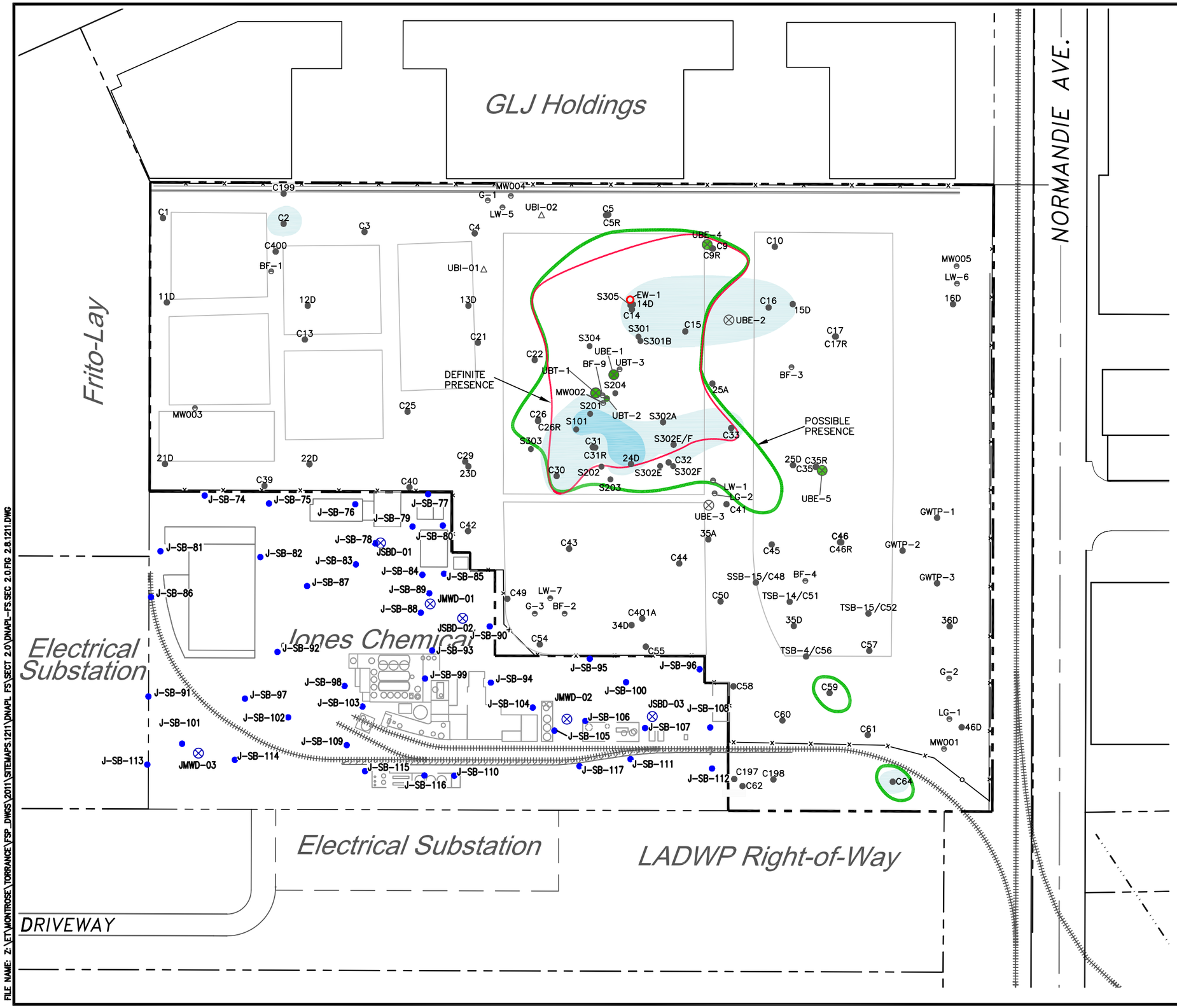


Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum 1,4-DCB Isoconcentration in Soil Contour Interval 10-100 mg/kg
- Maximum 1,4-DCB Isoconcentration in Soil Contour Interval 100-1,000 mg/kg

2008 EPA Industrial PRG = 13 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a;EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

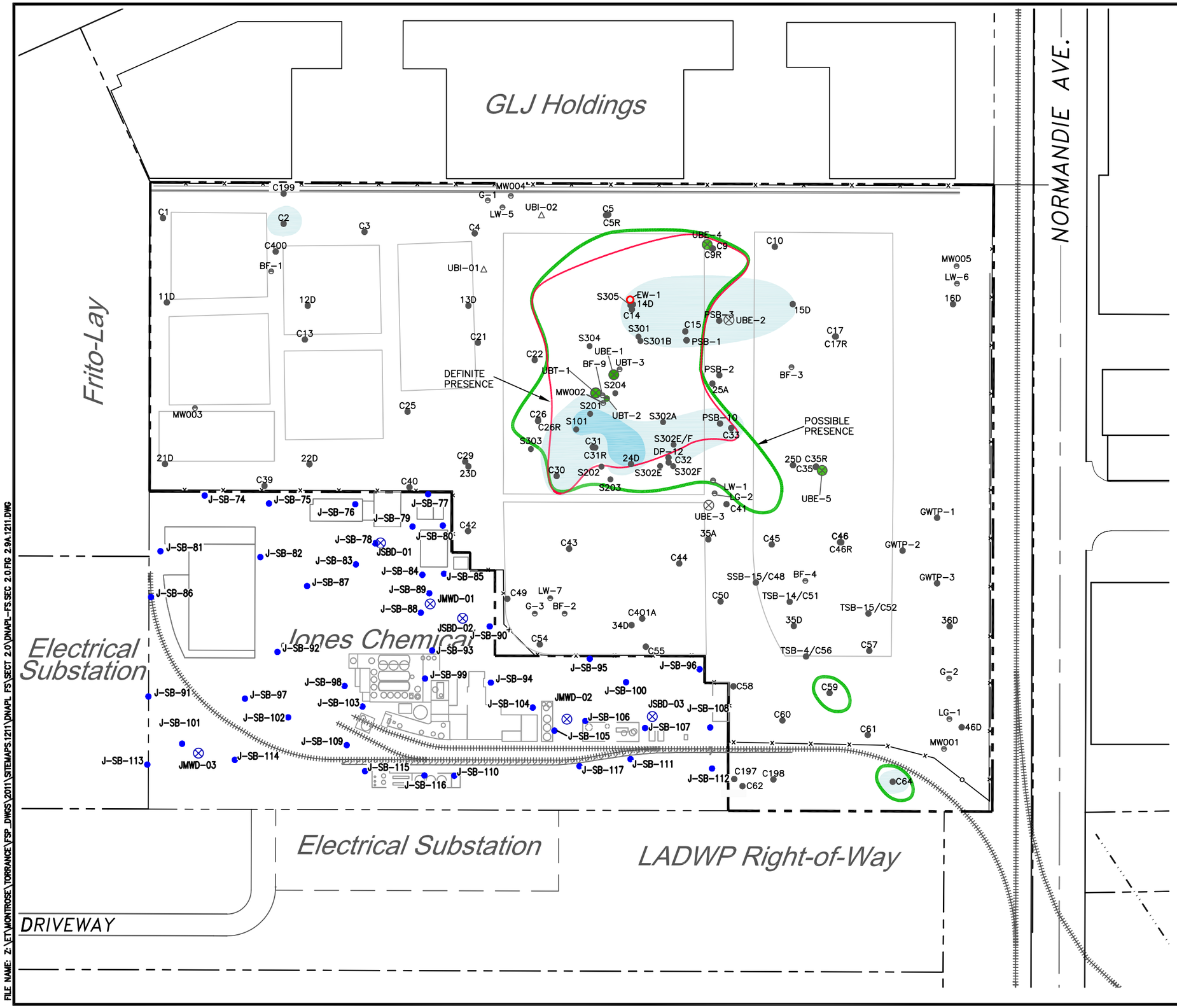
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum 1,4-DCB Concentration in the Unsaturated Zone (0-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.8

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS\1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.8.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum 1,4-DCB Isoconcentration in Soil Contour Interval 10-100 mg/kg
- Maximum 1,4-DCB Isoconcentration in Soil Contour Interval 100-1,000 mg/kg

2008 EPA Industrial PRG = 13 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

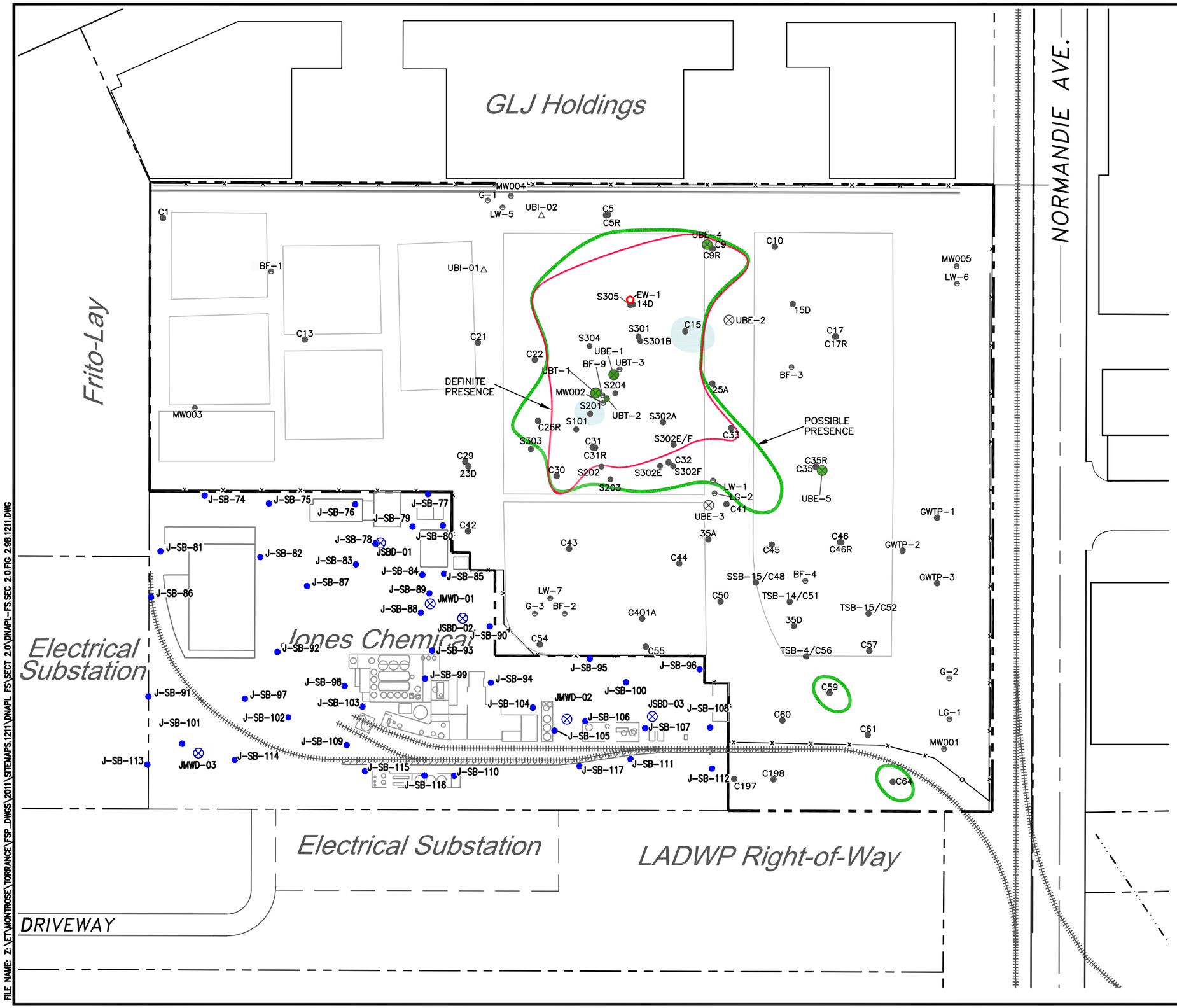
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum 1,4-DCB Concentration in the Unsaturated Zone (0-25 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.9a

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.9A.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Average Maximum 1,4-DCB Isoconcentration in Soil Contour Interval 10-100 mg/kg

2008 EPA Industrial PRG = 13 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
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4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

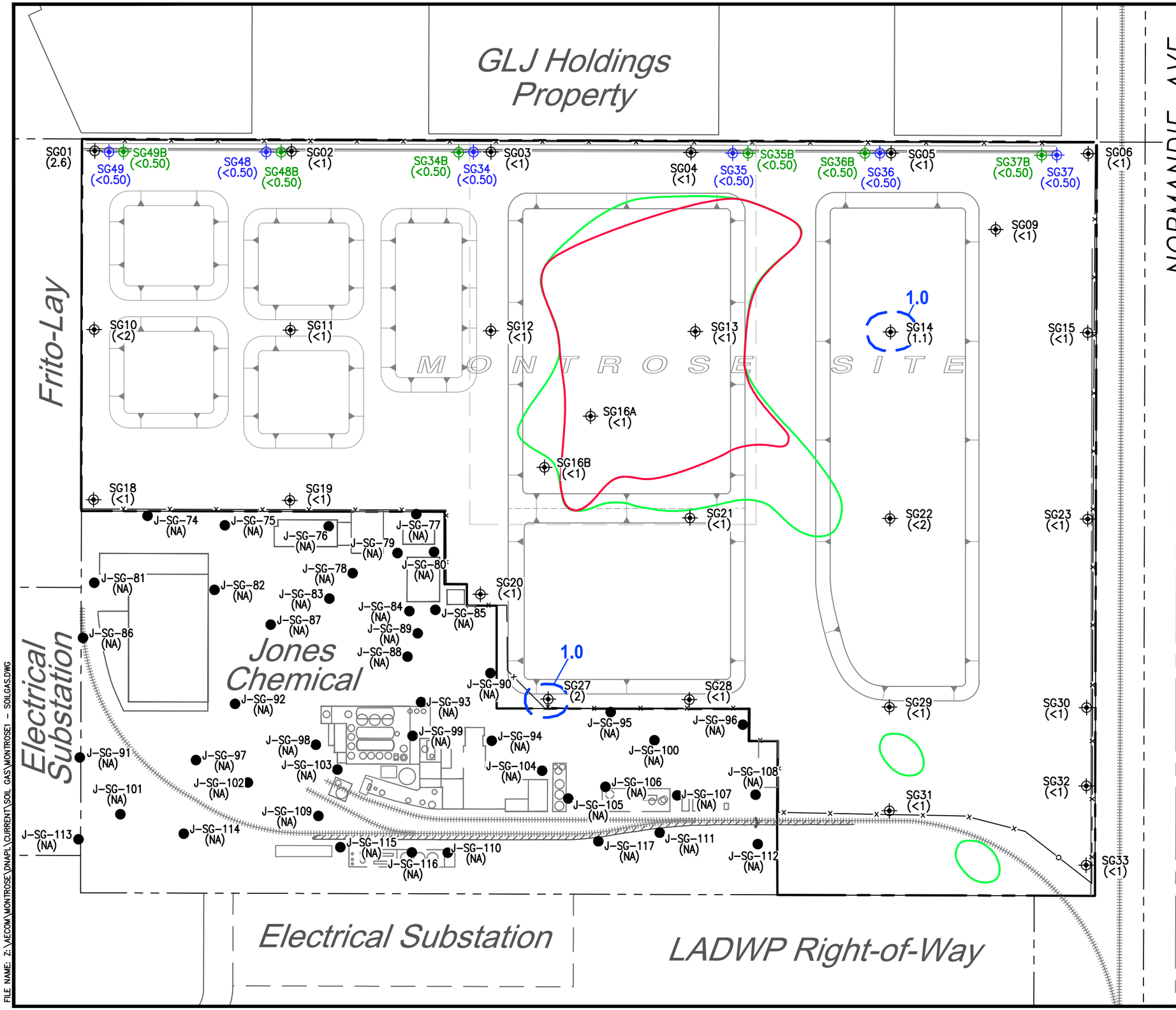
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum 1,4-DCB Concentration in the Unsaturated Zone (25-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.9b

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS\1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.9B.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 1.0 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — 1,4-DCB Concentrations Reported in µg/L at 5-Feet Below Grade Surface (BGS) 1,4-DCB Not Analyzed by EPA Method 8260B during the 2010 JCI Soil Gas Sampling Event
- (NA) — Not Analyzed
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- SG49B — 2010 Single-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100

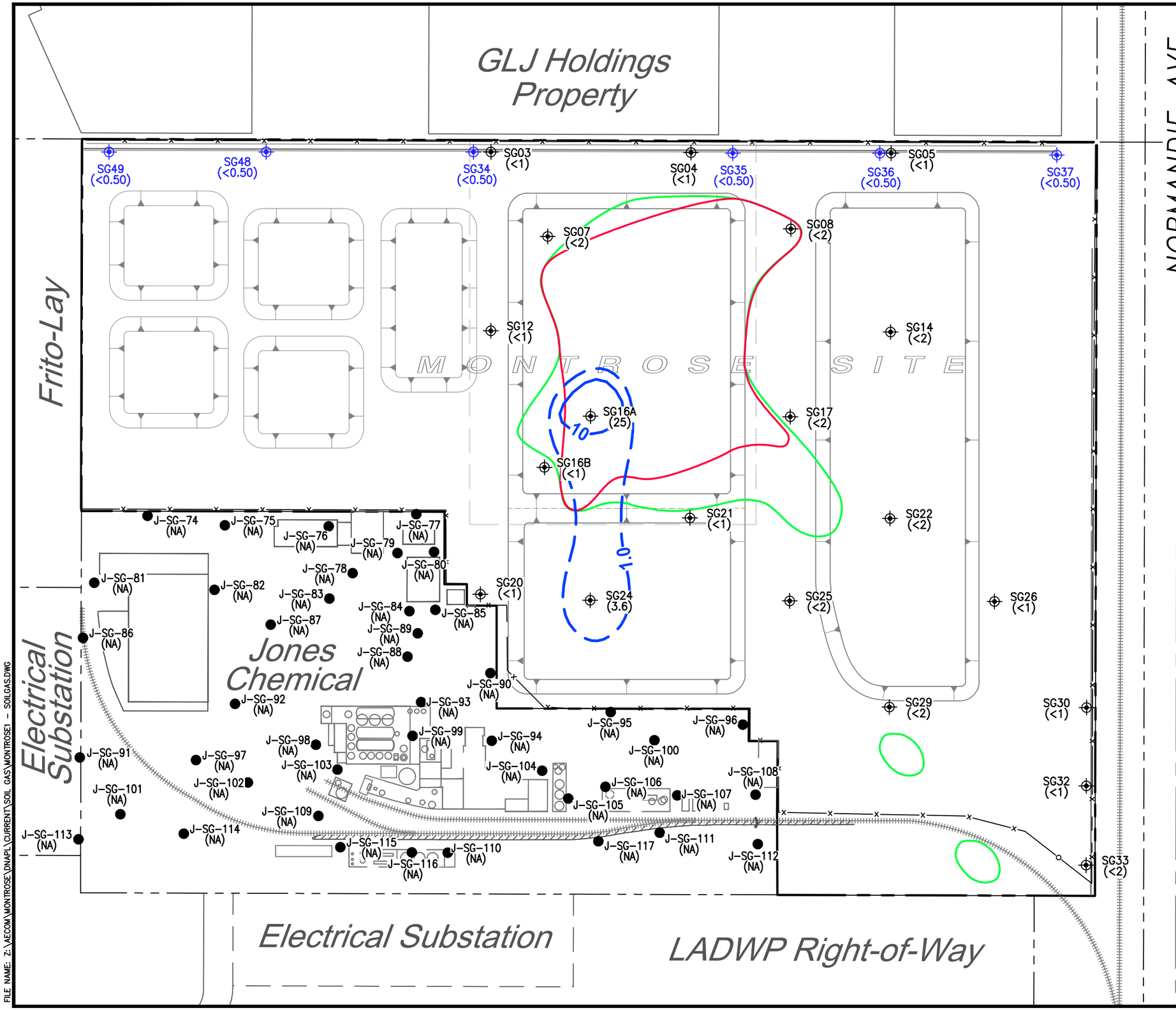
SCALE: 1"= 100'

Montrose Chemical Corporation

1,4-DCB in Soil Gas (5 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.10a

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — 1,4-DCB Concentrations Reported in µg/L at 15-Feet Below Grade Surface (BGS) 1,4-DCB Not Analyzed by EPA Method 8260B during the 2010 JCI Soil Gas Sampling Event
- (NA) — Not Analyzed
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

1,4-DCB in Soil Gas (15 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.10b

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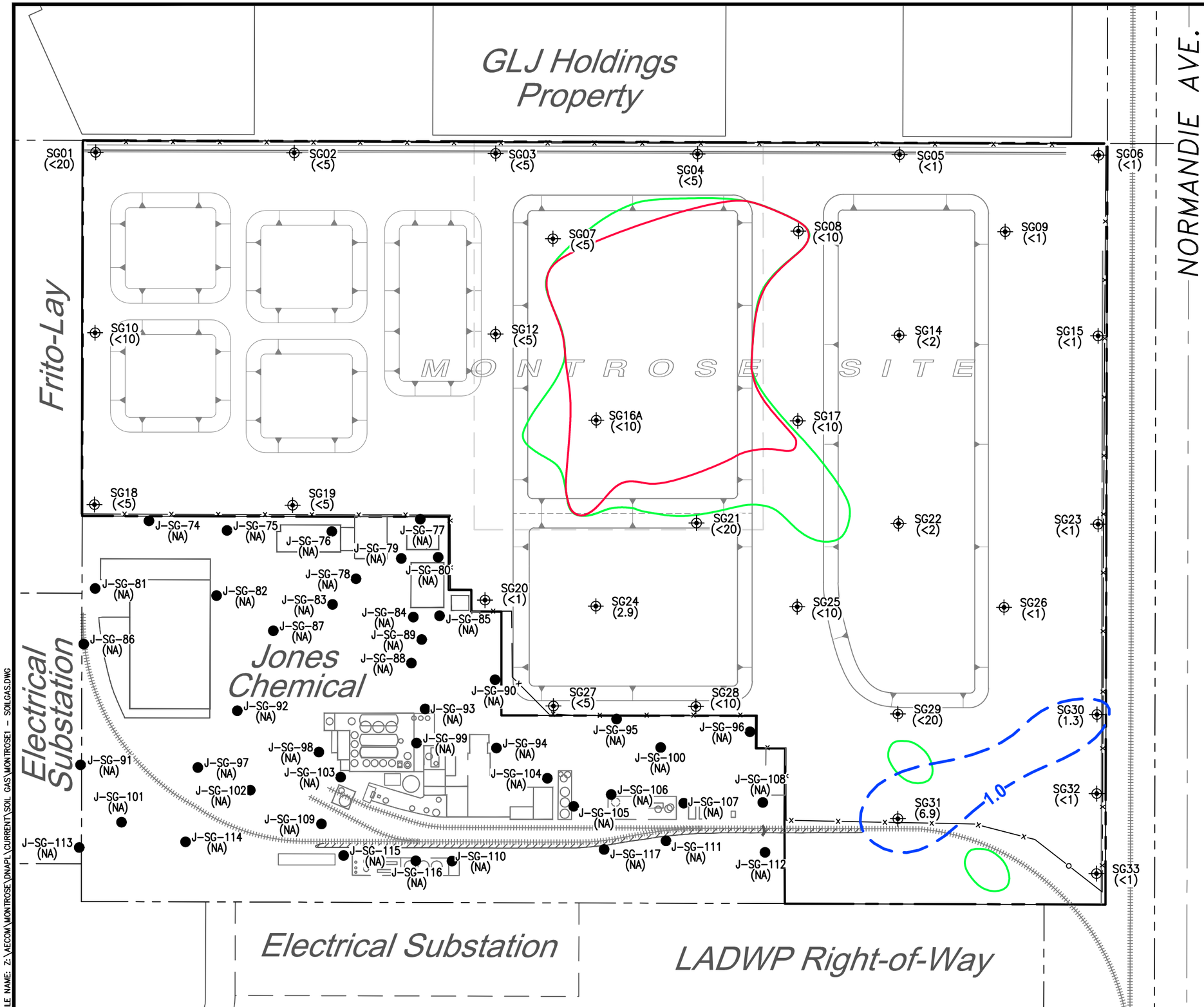

Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 1.0 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — 1,4-DCB Concentrations Reported in µg/L at 35-Feet Below Grade Surface (BGS) 1,4-DCB Not Analyzed by EPA Method 8260B during the 2010 JCI Soil Gas Sampling Event
- (NA) — Not Analyzed
- SG01 — 2003 Temporary Soil Gas Sampling Point
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
   Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100

SCALE: 1"= 100'

Montrose Chemical Corporation

1,4-DCB in Soil Gas (35 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.10c

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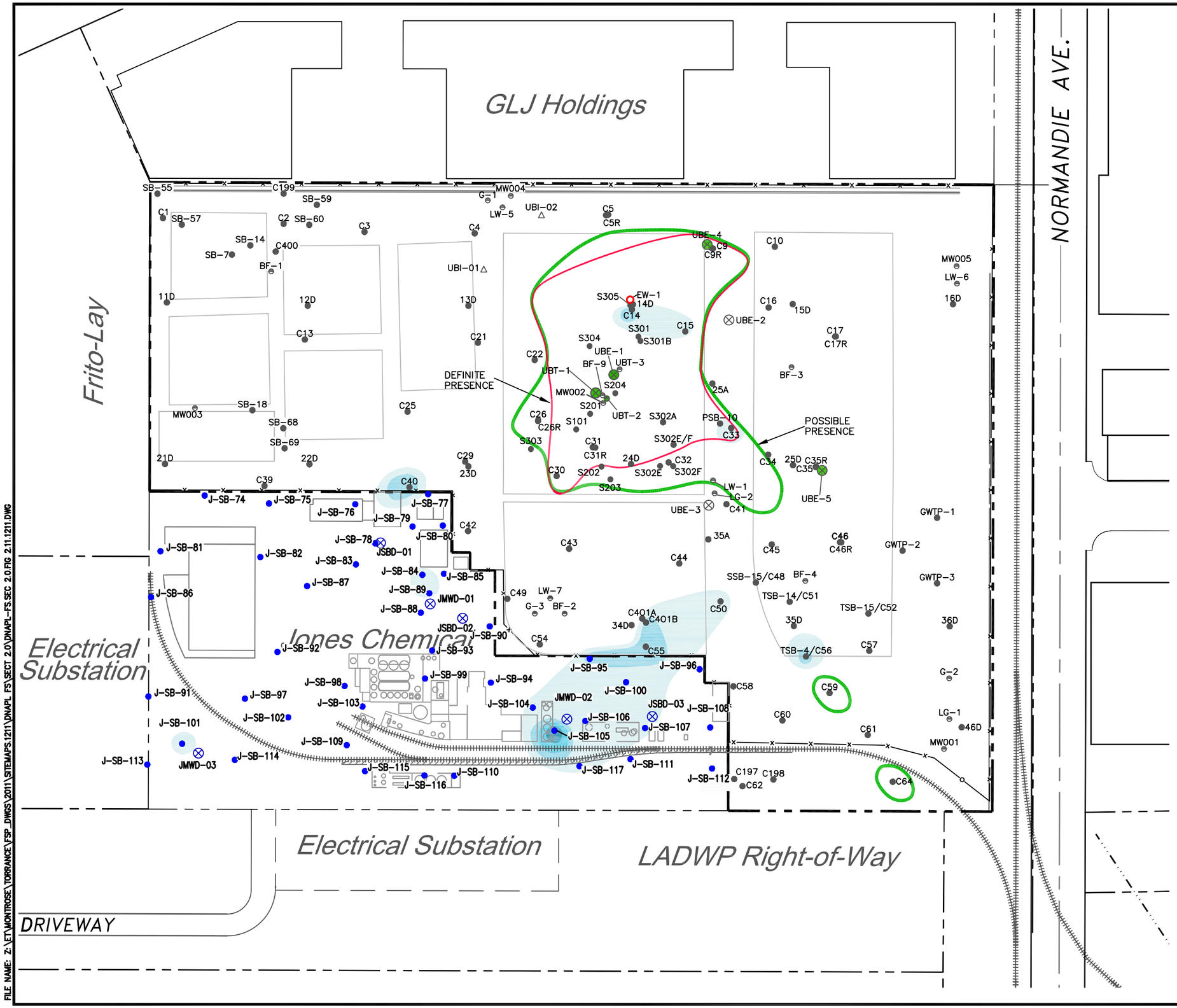


Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum PCE Isoconcentration in Soil Contour Interval 1–10 mg/kg
- Maximum PCE Isoconcentration in Soil Contour Interval 10–100 mg/kg
- Maximum PCE Isoconcentration in Soil Contour Interval 100–1,000 mg/kg
- Maximum PCE Isoconcentration in Soil Contour Interval 1,000–10,000 mg/kg

2008 EPA Industrial PRG = 2.7 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

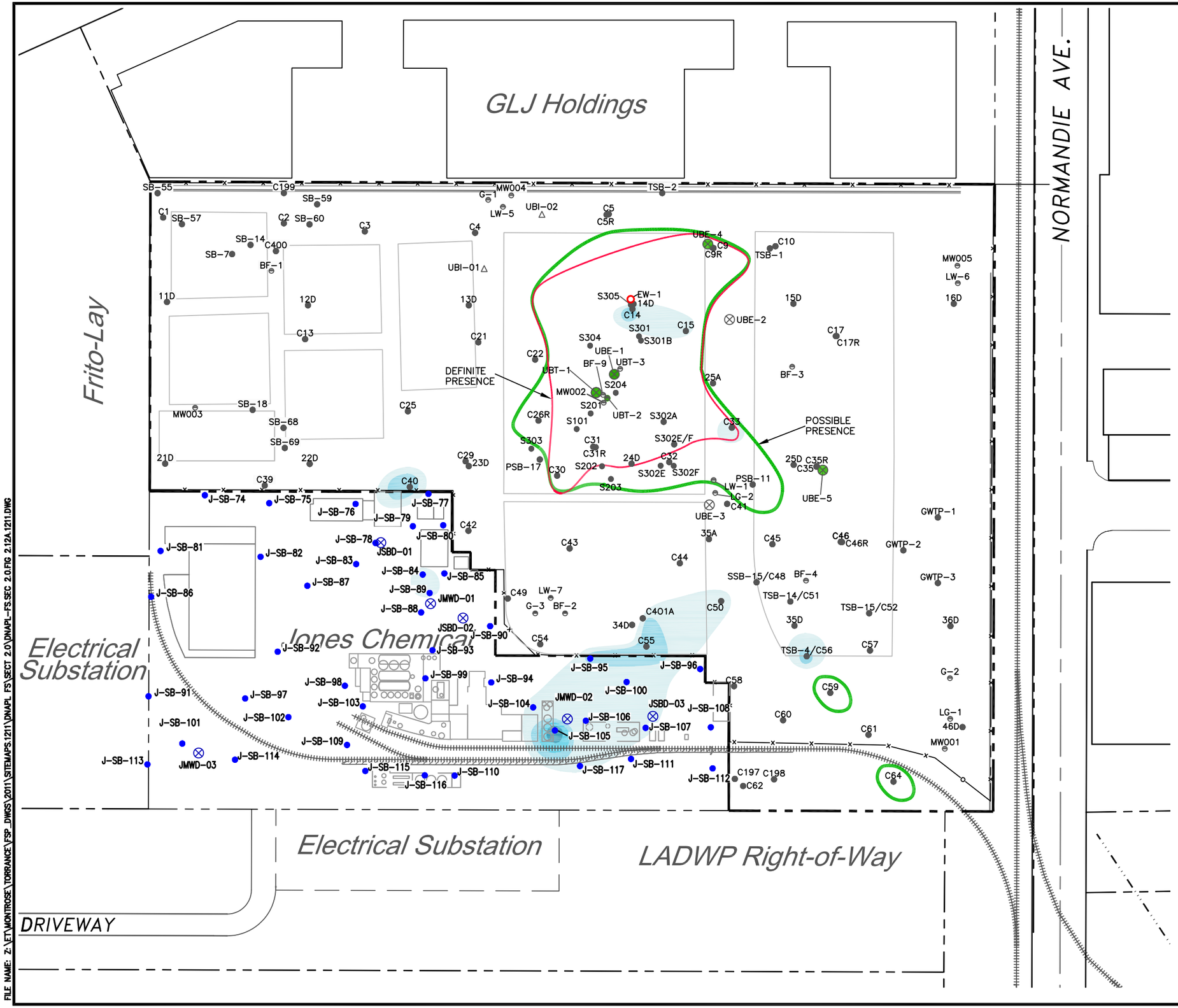
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum PCE Concentration in the Unsaturated Zone (0-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.11

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.11.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
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- Existing Site Features
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- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum PCE Isoconcentration in Soil Contour Interval 1–10 mg/kg
- Maximum PCE Isoconcentration in Soil Contour Interval 10–100 mg/kg
- Maximum PCE Isoconcentration in Soil Contour Interval 100–1,000 mg/kg
- Maximum PCE Isoconcentration in Soil Contour Interval 1,000–10,000 mg/kg

2008 EPA Industrial PRG = 2.7 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
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5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

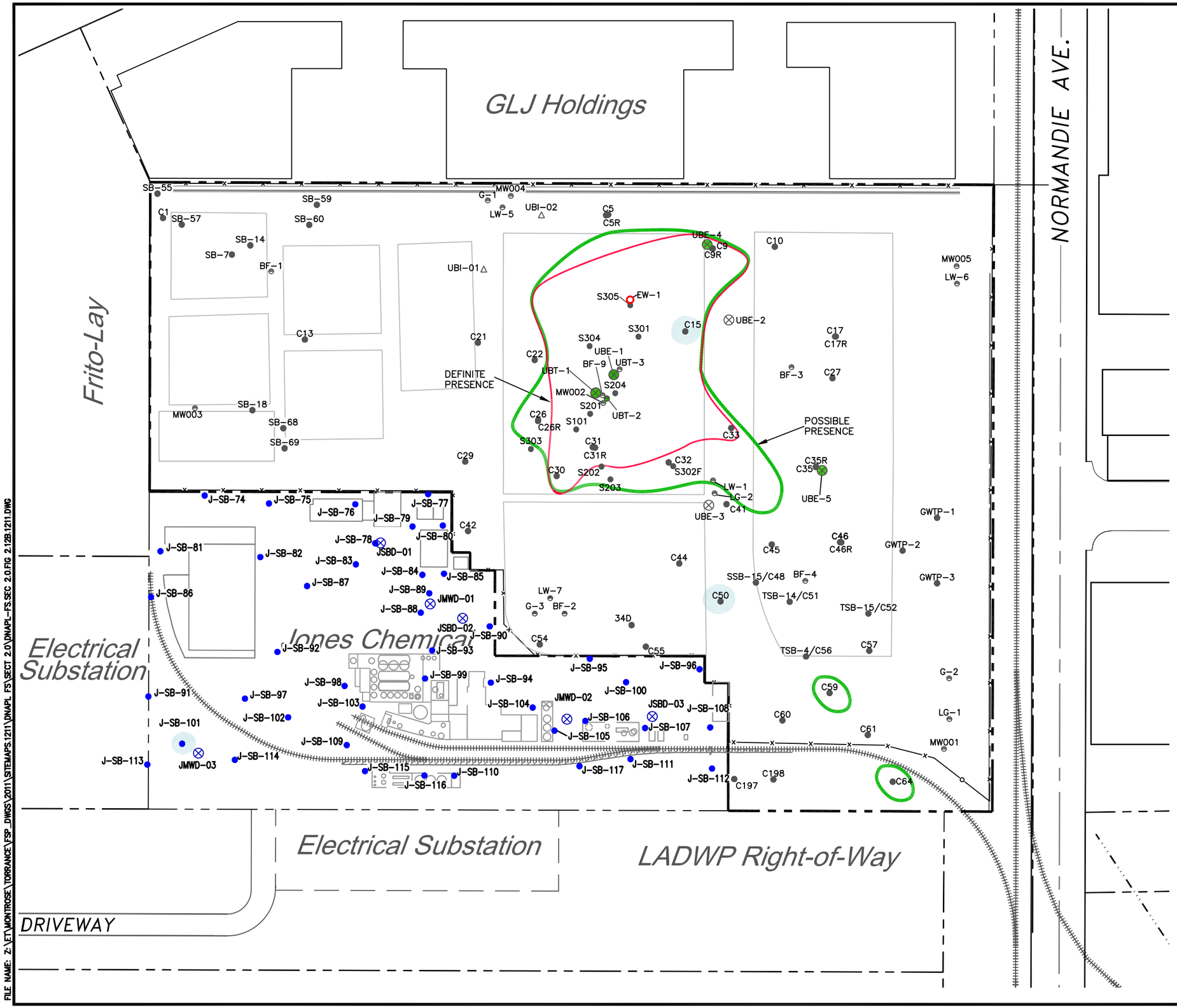
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum PCE Concentration in the Unsaturated Zone (0-25 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.12a

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.12A.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
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- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum PCE Isoconcentration in Soil Contour Interval 1–10 mg/kg

2008 EPA Industrial PRG = 2.7 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
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3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

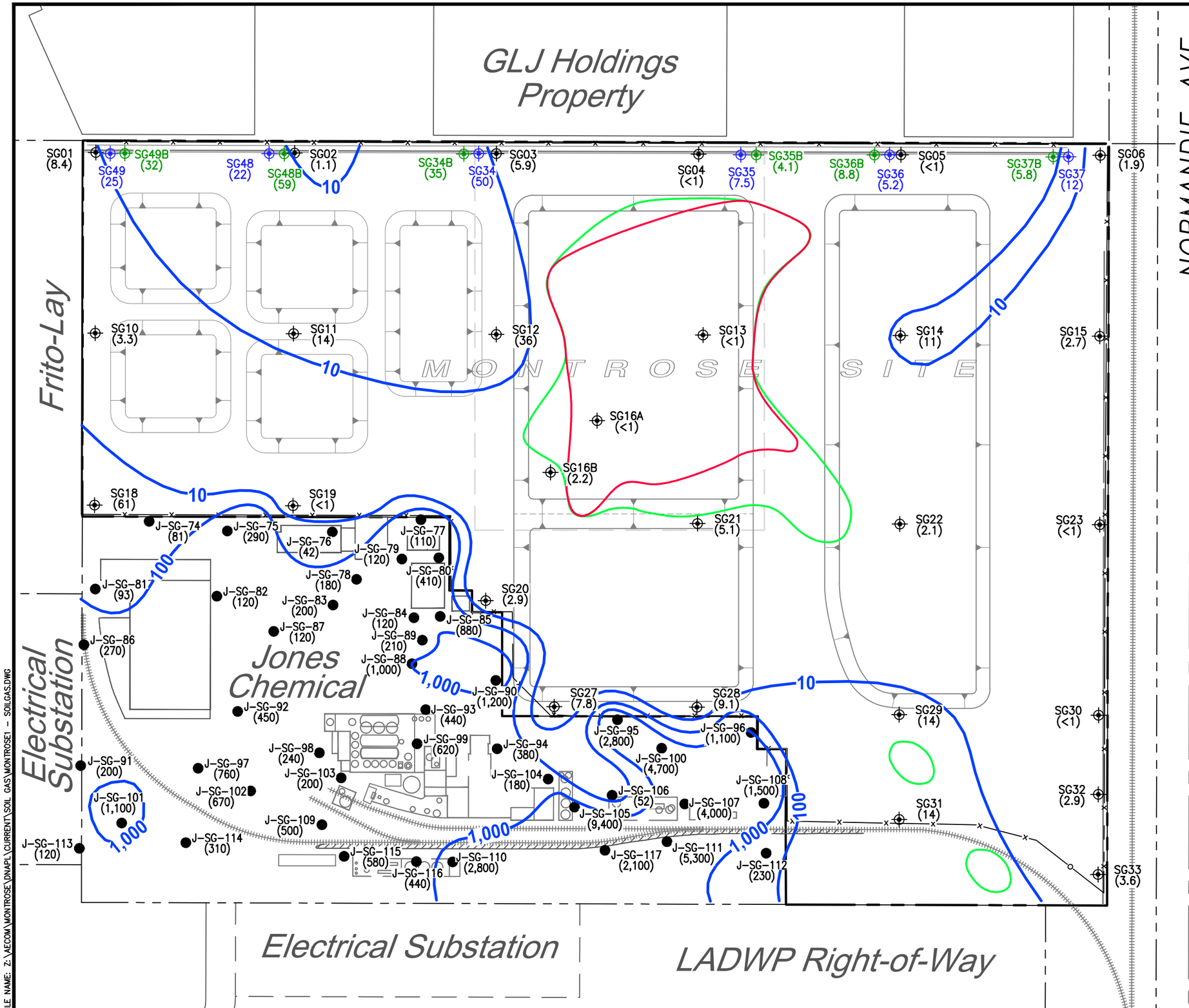
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum PCE Concentration in the Unsaturated Zone (25-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.12b

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS\1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.12B.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — PCE Concentrations Reported in µg/L at 5-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- SG49B — 2010 Single-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

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4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

PCE in Soil Gas (5 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.13a

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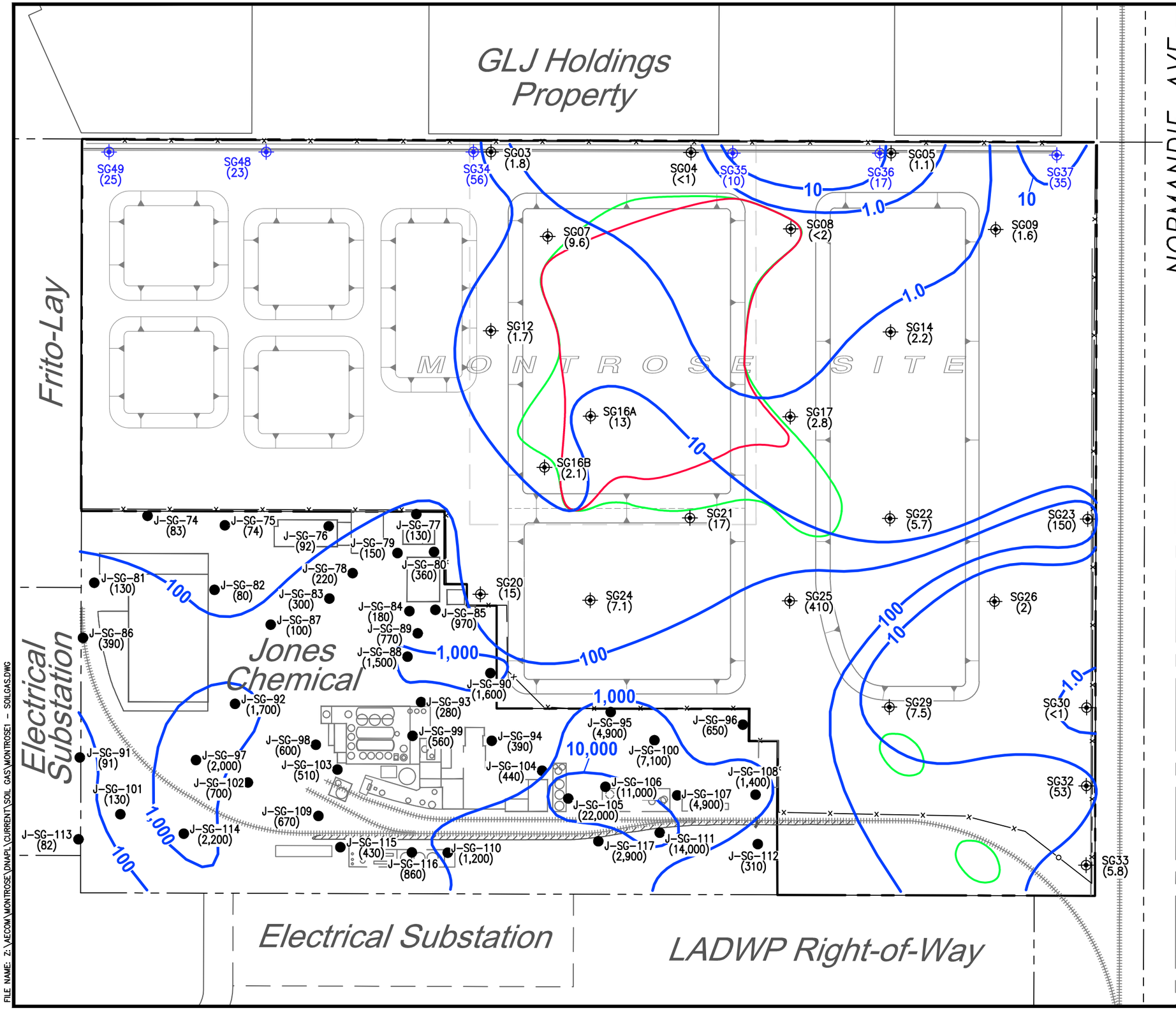

Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — PCE Concentrations Reported in µg/L at 15-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
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   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

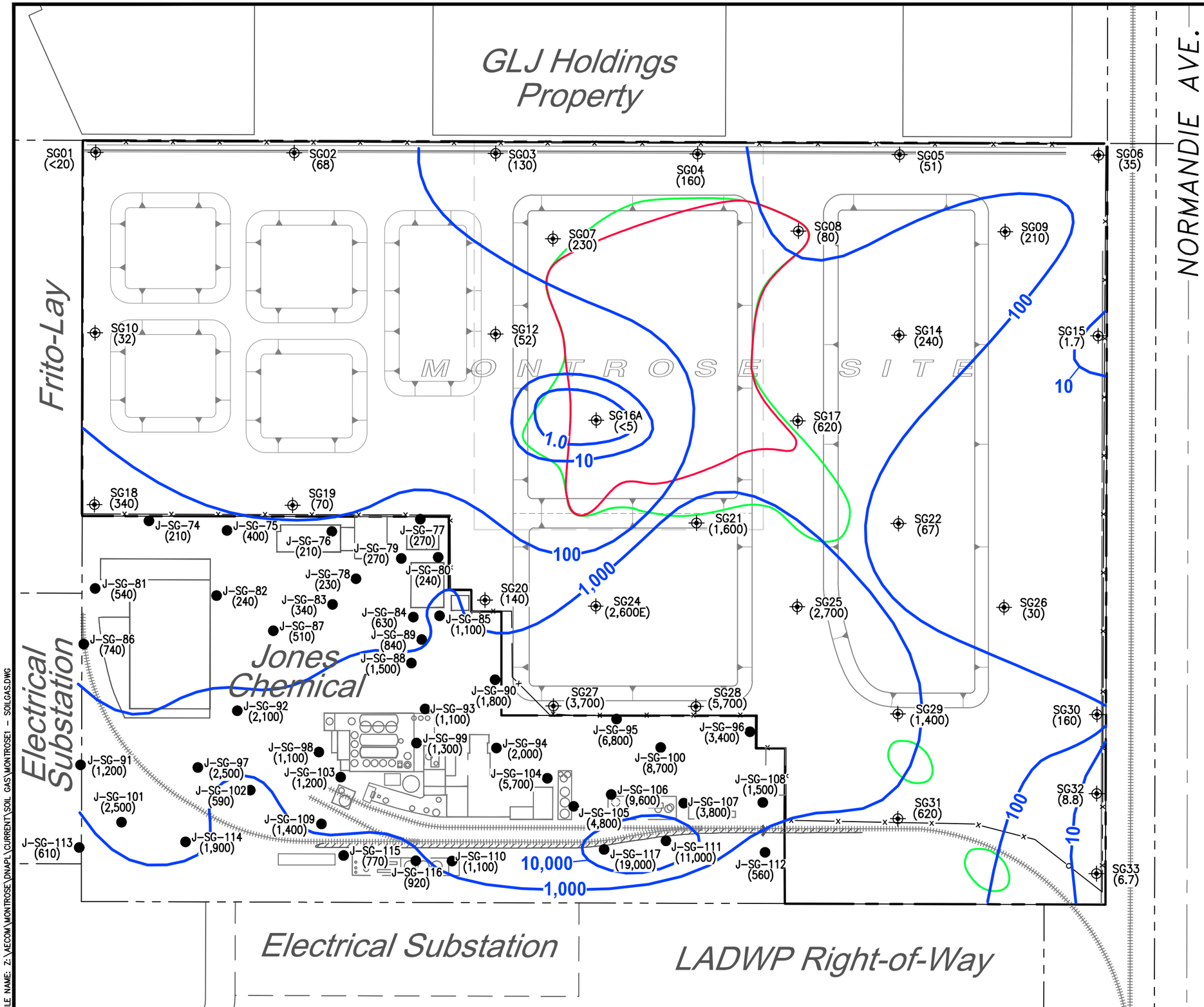
0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

PCE in Soil Gas (15 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.13b

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 100 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — PCE Concentrations Reported in µg/L at 35-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

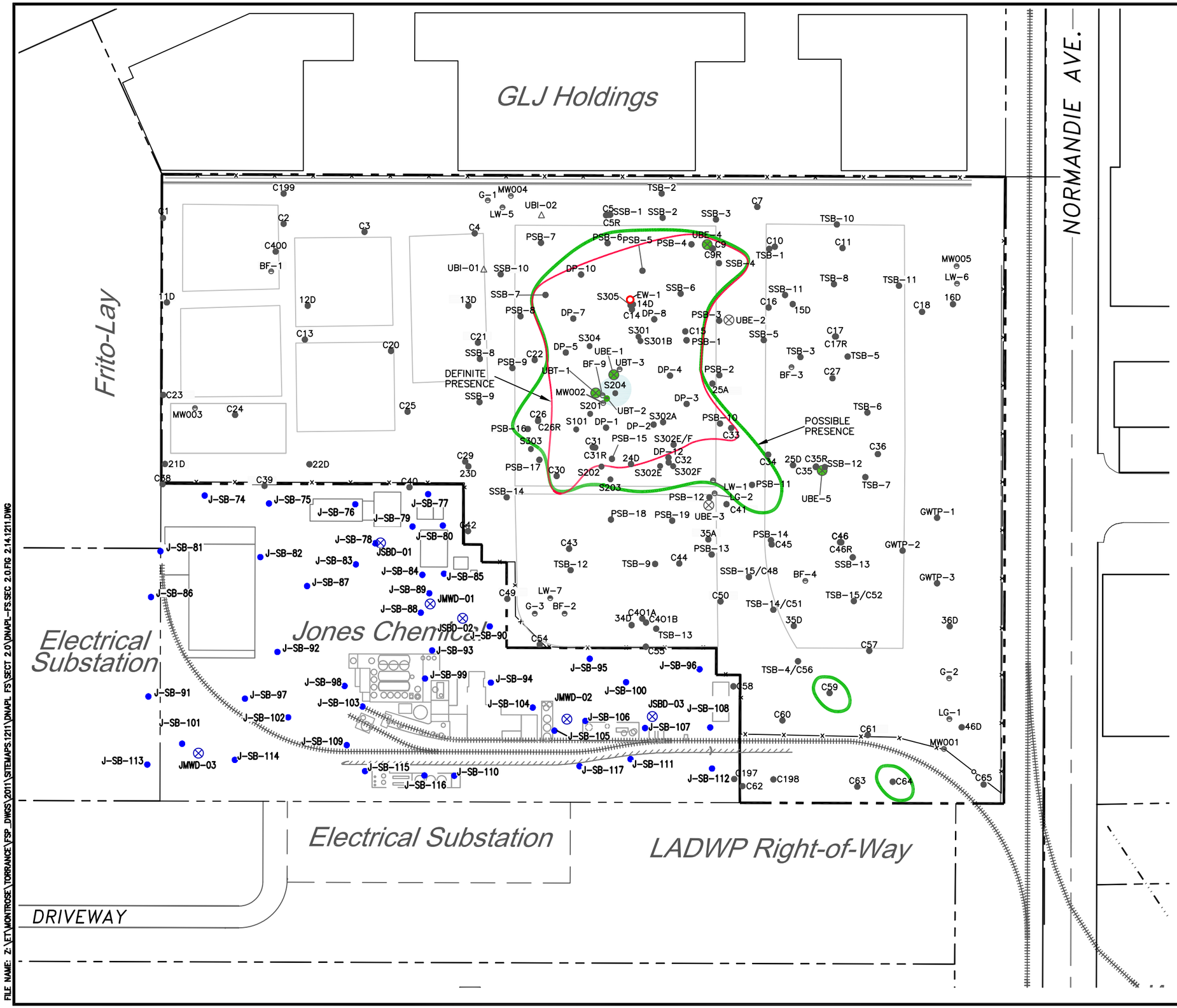
0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

PCE in Soil Gas (35 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.13c

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum Benzene Isoconcentration in Soil Contour Interval 10–100 mg/kg

2008 EPA Industrial PRG = 5.6 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

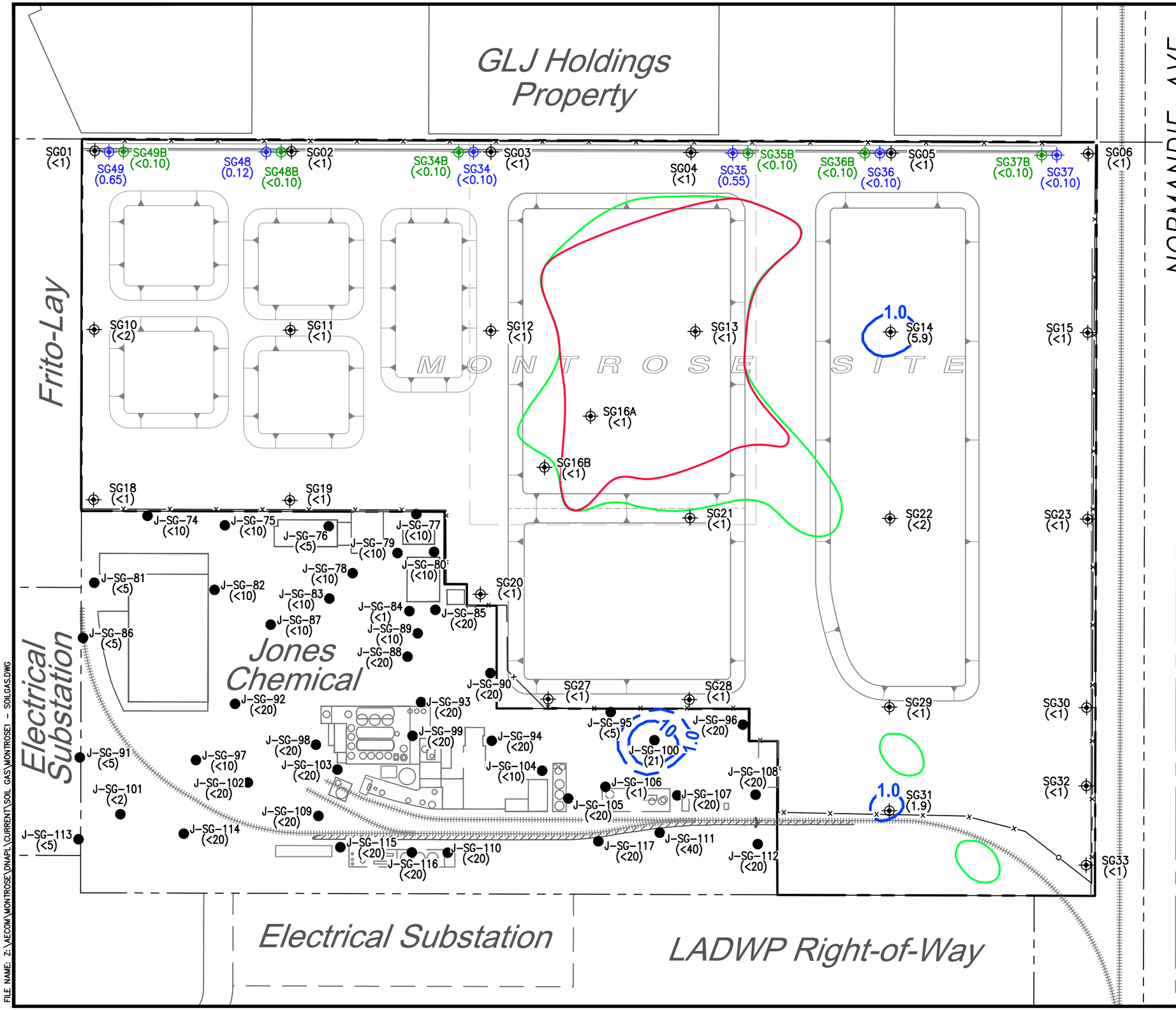
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum Benzene Concentration in the Unsaturated Zone (0-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.14

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.14.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- SG49B — 2010 Single-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
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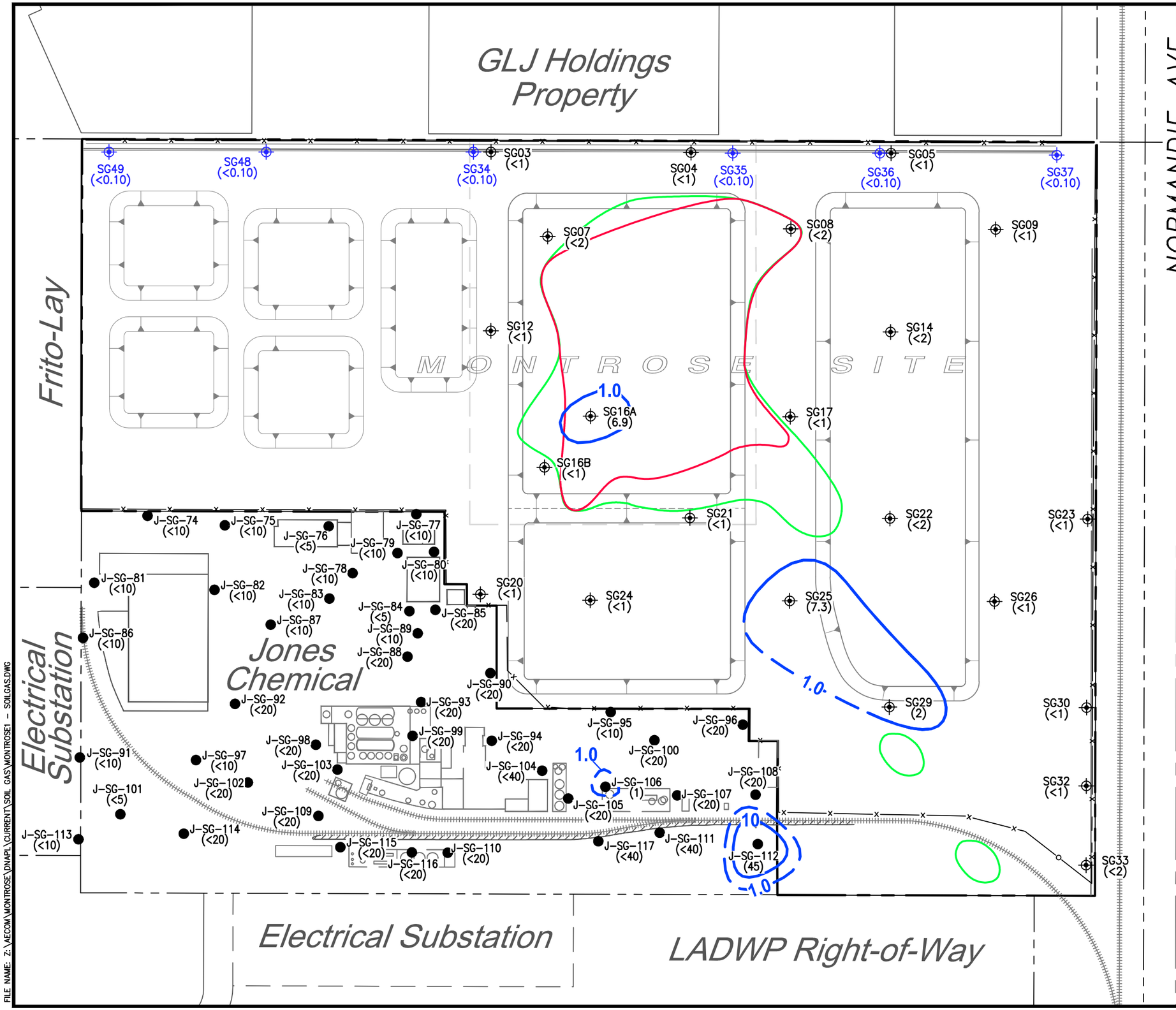
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

Montrose Chemical Corporation

Benzene in Soil Gas (5 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.15a

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — Benzene Concentrations Reported in µg/L at 15-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100

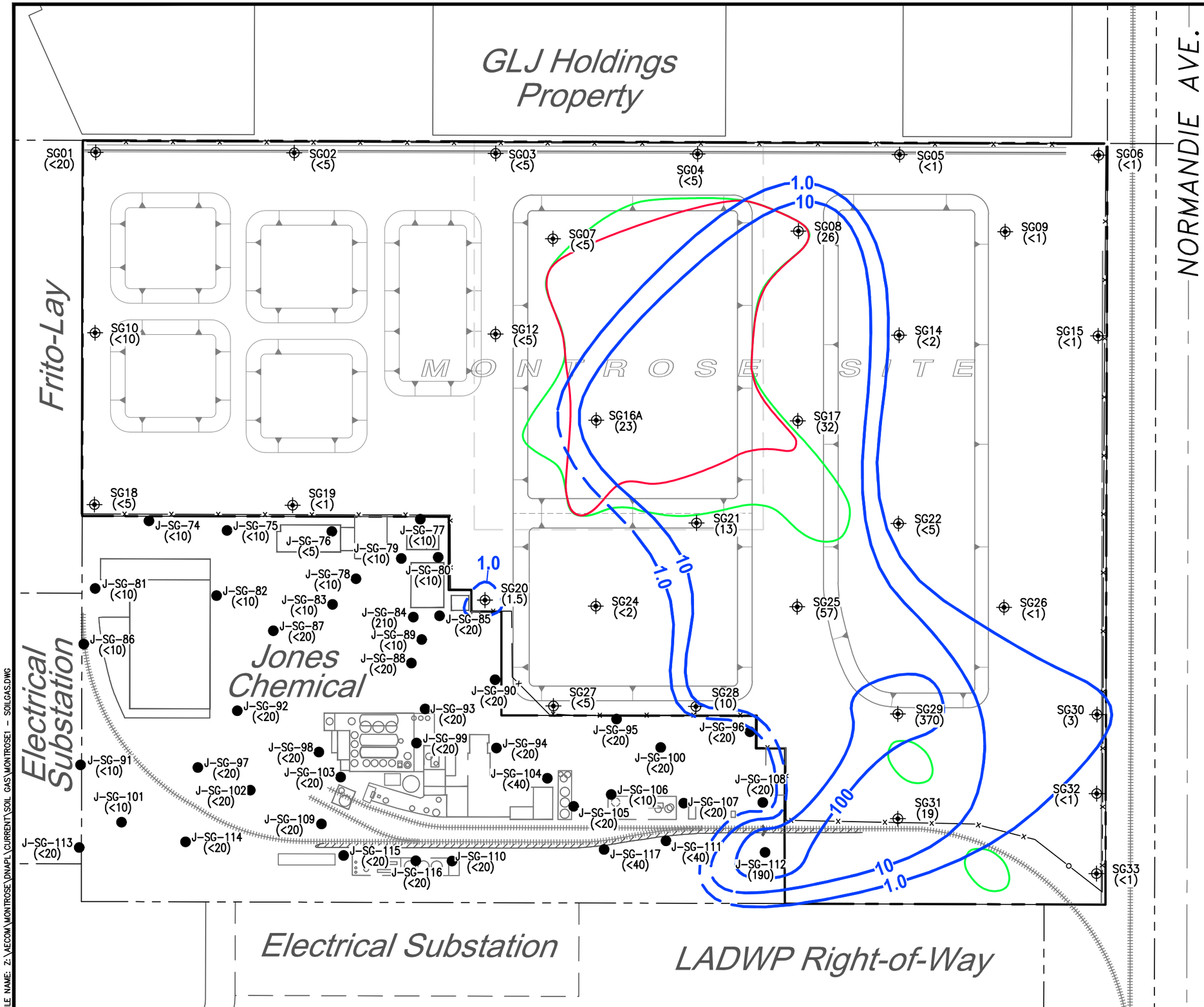
SCALE: 1"= 100'

Montrose Chemical Corporation

Benzene in Soil Gas (15 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.15b

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 100 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — Benzene Concentrations Reported in µg/L at 35-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

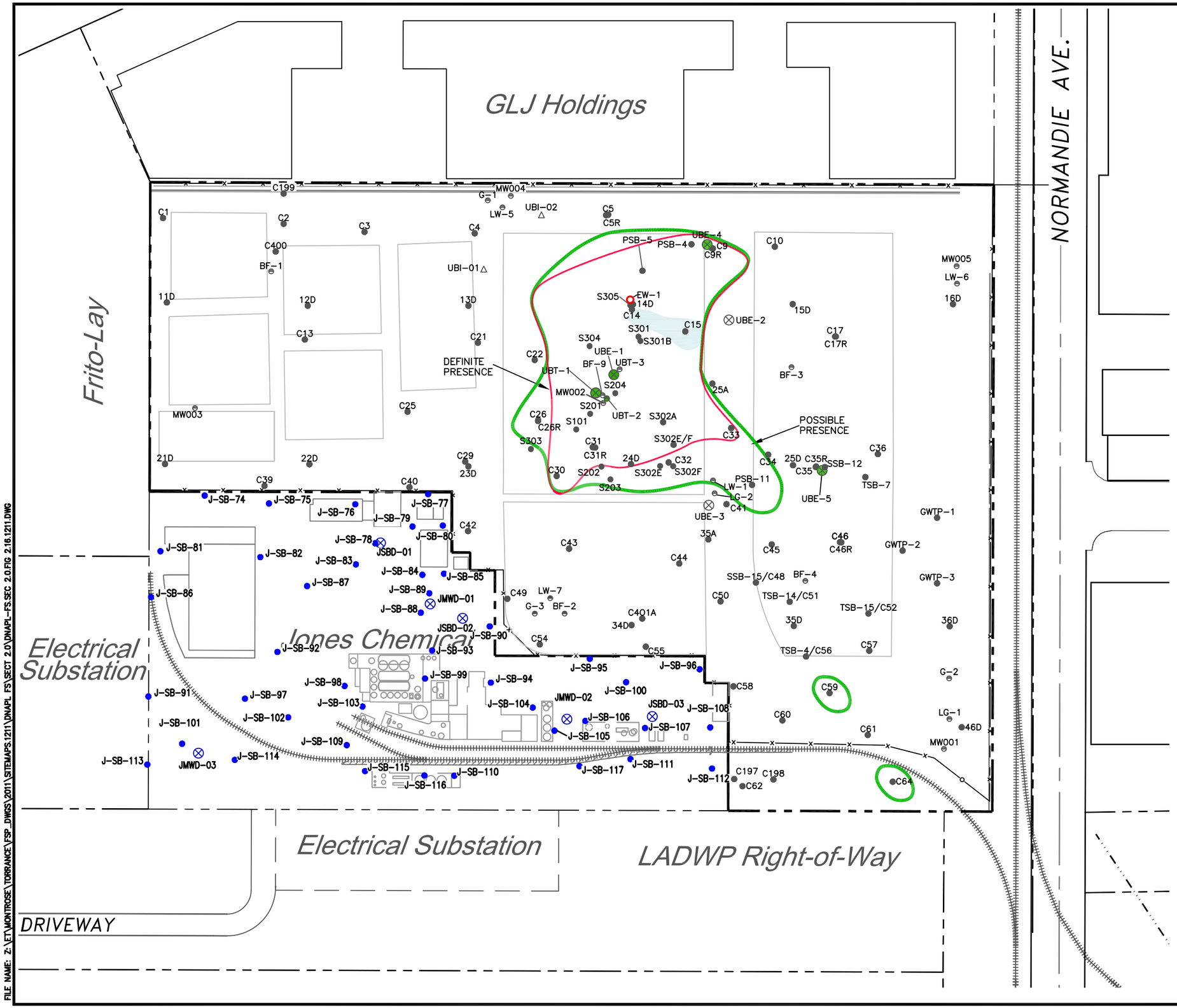
0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

Benzene in Soil Gas (35 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.15c

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- EW-1 — SVE Pilot Test Well Location
- JS-B-117 — JCI Soil Boring Location
- JMWD-03 — JCI DNAPL Investigation Soil Boring
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- Maximum Carbon Tetrachloride Isoconcentration in Soil Contour Interval 1–10 mg/kg

2008 EPA Industrial PRG = 1.3 mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Contours from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b
5. Acardis, 2001. DNAPL Reconnaissance Investigation Data Report, JCI Jones Chemicals, Inc., 1401 W. Del Amo Bvd., Torrance, California. January 26.

NORTH

0 60 120 FEET

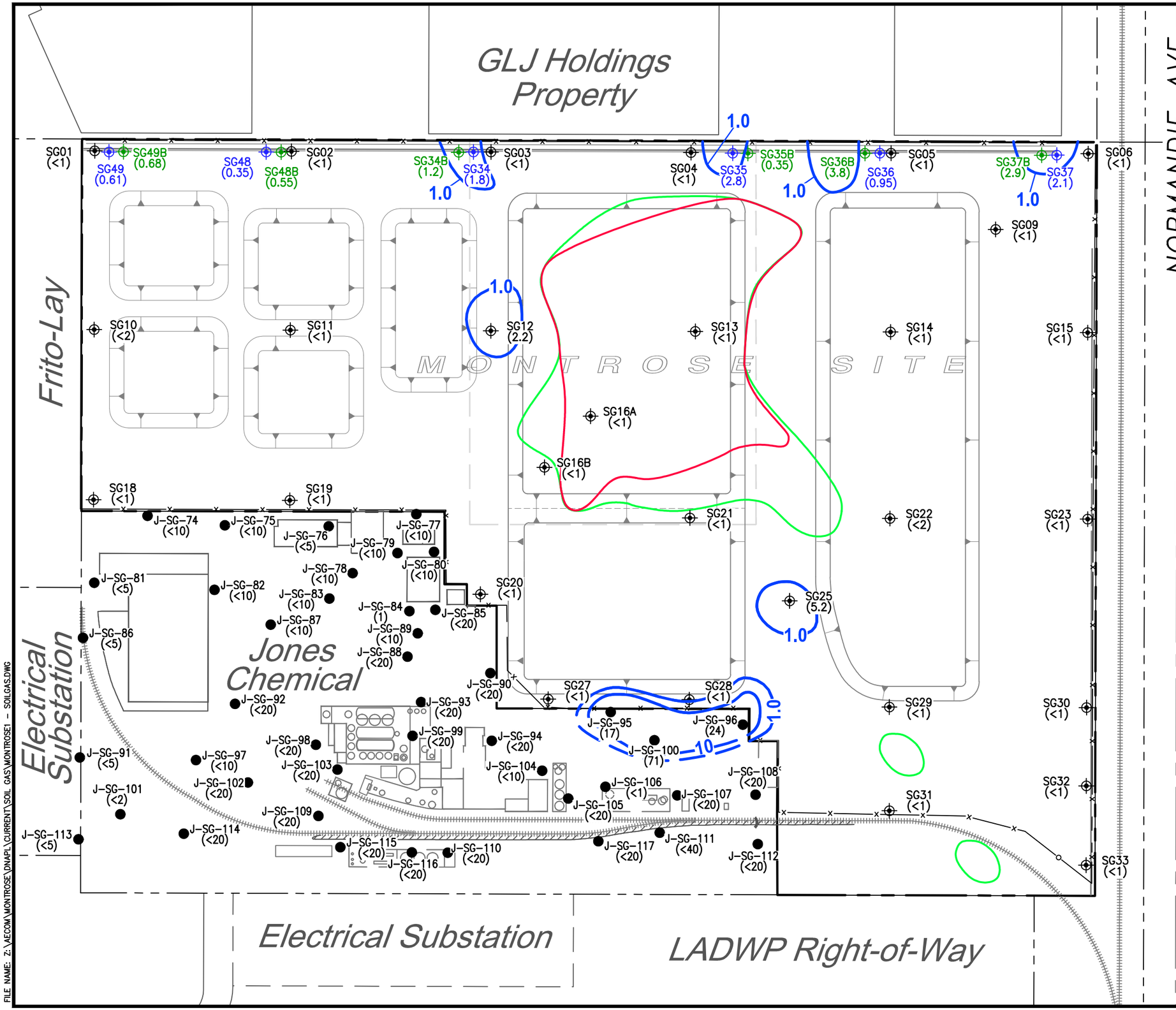
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum Carbon Tetrachloride Concentration in the Unsaturated Zone (0-60 Feet bgs)

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.16

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.16.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — Carbon Tetrachloride Concentrations Reported in $\mu g/L$ at 5-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- SG49B — 2010 Single-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

0 50 100

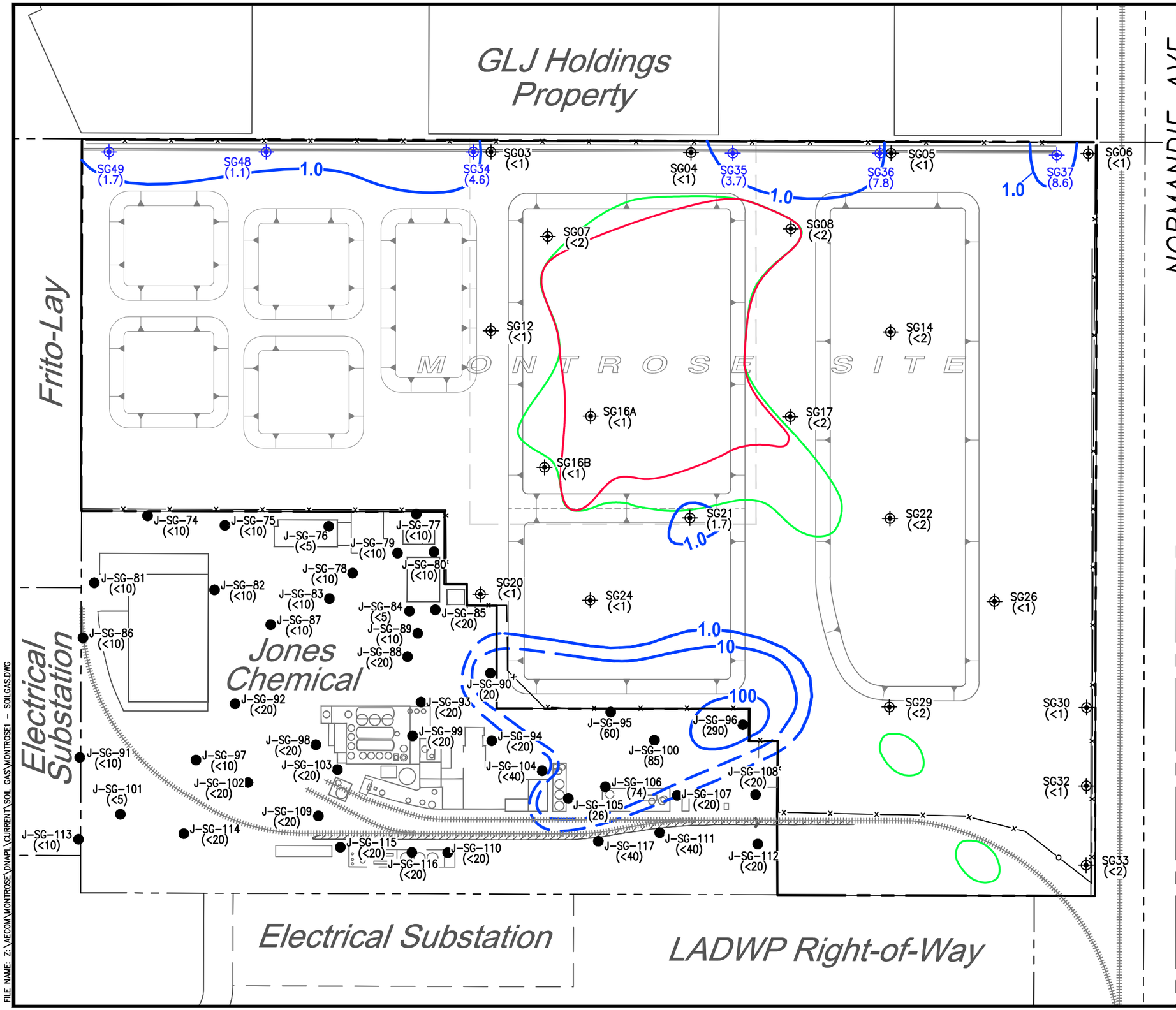
SCALE: 1"= 100'

Montrose Chemical Corporation

Carbon Tetrachloride in Soil Gas (5 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.17a

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — Carbon Tetrachloride Concentrations Reported in µg/L at 15-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- SG49 — 2010 Multi-depth Soil Gas Probe
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

Notes:

1. 2010 GLJ Property Soil Gas data is reported in the Revised Soil Gas Survey Report Addendum, Montrose Superfund Site, noted in Reference #3 below

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
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   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

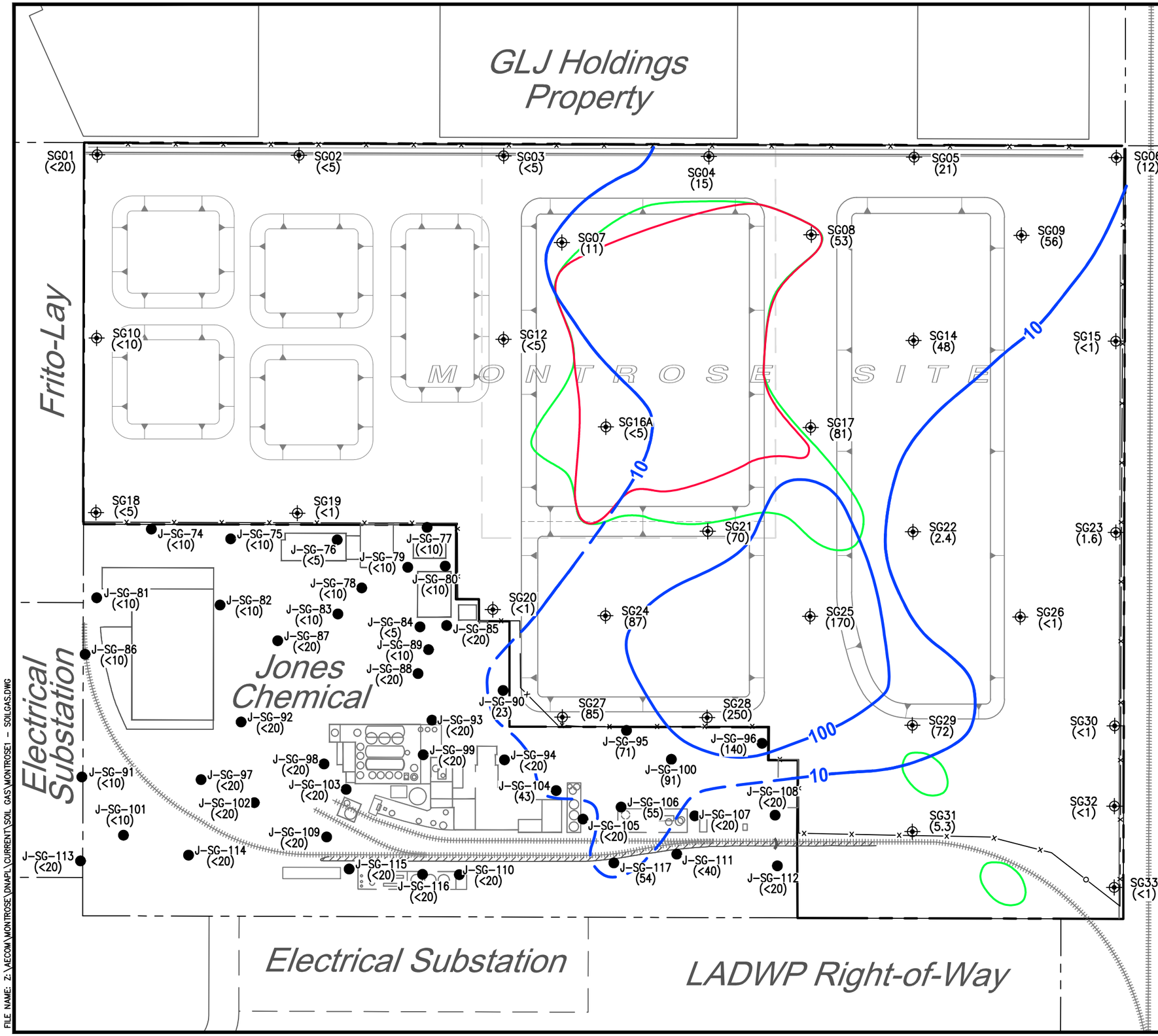
0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

Carbon Tetrachloride in Soil Gas (15 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.17b

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- DNAPL — Dense Nonaqueous Phase Liquid
- Definite DNAPL extent in unsaturated UBA
- Possible DNAPL extent in unsaturated UBA
- 10 — Isoconcentration Contour (Approximate) (Dashed where Inferred) Contours are Truncated at Property Boundary
- (<1.05) — Carbon Tetrachloride Concentrations Reported in µg/L at 35-Feet Below Grade Surface (BGS)
- SG01 — 2003 Temporary Soil Gas Sampling Point
- J-SG-96 — 2010 JCI Soil Gas Sampling Point

References:

1. Post-1953 Plant Layout: Continuous Batch Process, Final Remedial Investigation Report for the Montrose Superfund Site. Prepared by Montrose Chemical Corporation of America; Revised by USEPA Region IX, May 1998 and Earth Tech, February 2004.
2. Satellite/Aerial Photos Reference:
   Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
   Continental Aerial, circa 1962.
   Continental Aerial, circa 1981.
   TerraServer Georeferenced Imagery, 2003.
3. Earth Tech, 2004. Revised Soil Gas Survey Report, Montrose Superfund Site. October 13.
   AECOM, 2011. Revised Soil Gas Survey Addendum, Montrose Superfund Site. September 7.
4. Acardis, 2010. Draft Soil and Soil Gas Data Report, JCI Jones Chemical Inc., 1401 W. Del Amo Blvd, Torrance, California. August 19.

NORTH

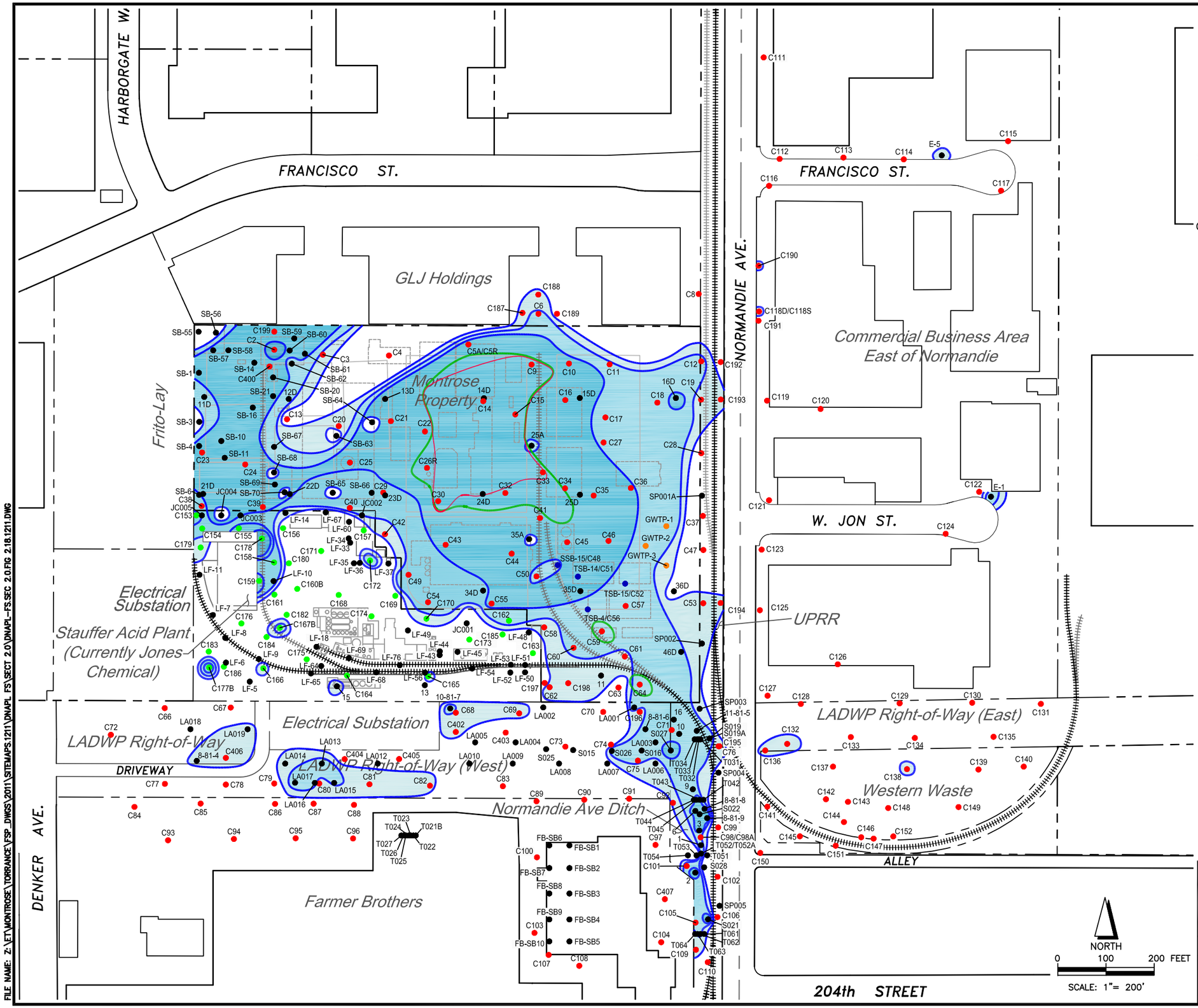
0 50 100
SCALE: 1"= 100'

Montrose Chemical Corporation

Carbon Tetrachloride in Soil Gas (35 Feet BGS)

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.17c

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\SOIL GAS\MONTROSE1 - SOILGAS.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Existing Railroad Tracks
- Historical Railroad Tracks
- Current-Day Building Locations
- Historical Site Feature
- LADWP — Los Angeles Department of Water and Power
- SSB-15 — DNAPL Reconnaissance Boring Location
- C196 — Supplemental Soil Investigation Boring Location 2005 – 2008
- 46D — Historical Soil Boring Location
- GWTP-3 — Groundwater Treatment Plant Geotechnical Boring Location – 2008
- C172 — Supplemental Soil Investigation–Jones Chemical Boring Location
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- DDT Isoconcentration Contour Line
- Total DDT Concentration in Soil = 10–100 mg/kg
- Total DDT Concentration in Soil = 100–1,000 mg/kg
- Total DDT Concentration in Soil = 1,000–10,000 mg/kg
- Total DDT Concentration in Soil = >10,000 mg/kg

References:

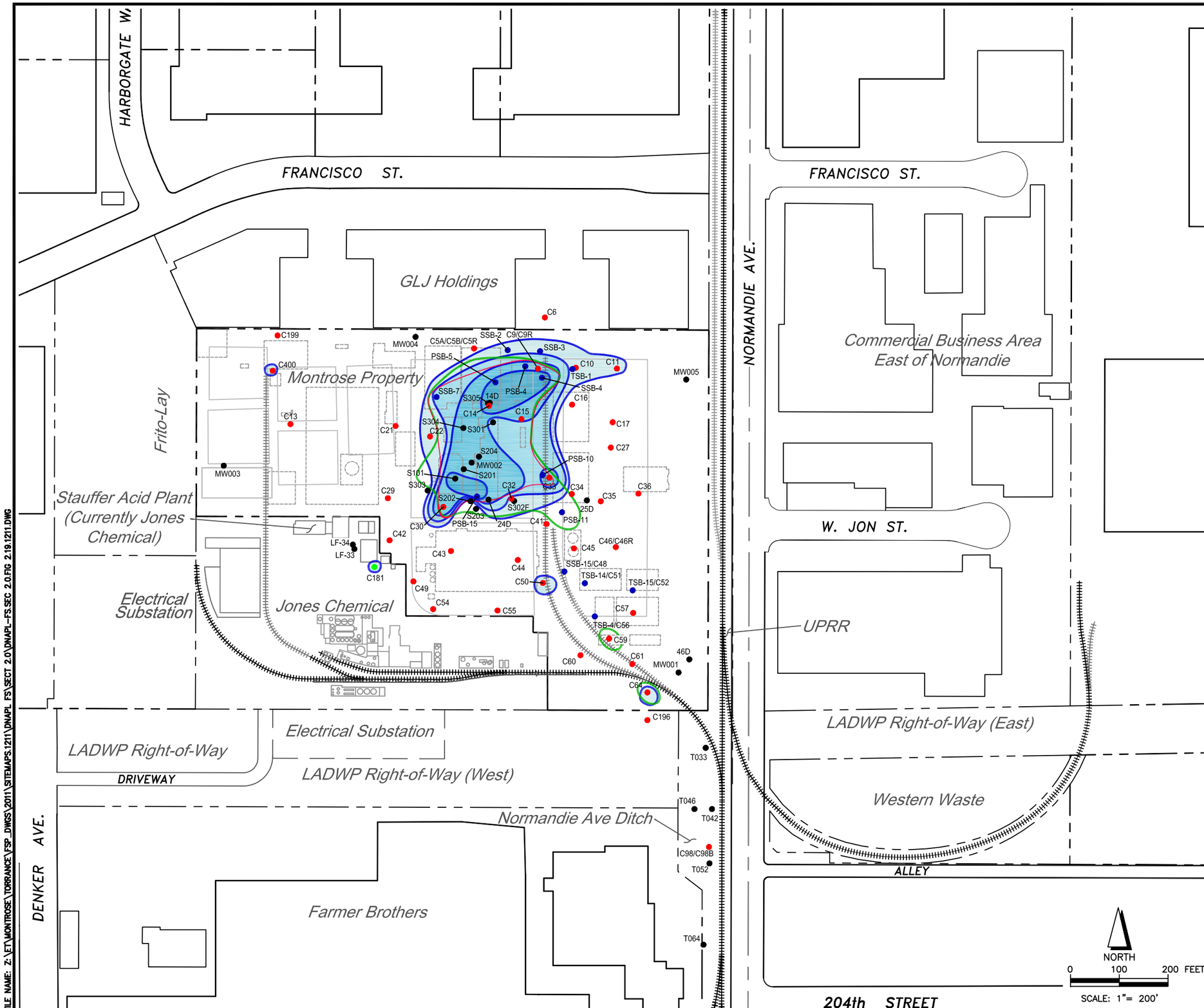
1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online GIS data set, ©2009. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin & Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Georeferenced Satellite Image from U.S. Geological Survey, July 31, 2007. Google Earth Pro ©2009. Historical Continental Aerial, circa 1962. Historical Continental Aerial, circa 1981.
3. Former Plant Site features based on historical above-referenced aerial photos.
4. Source: Final Remedial Investigation Report for the Montrose Superfund Site, Los Angeles, California (EPA, 1998); Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, California, Revision 1.0. (H+A, 2004); Technical Memorandum to Susan Keydel, US EPA, DNAPL Reconnaissance Borings in Support of Earth Tech Soil Sampling Program, Montrose Site, Torrance, California (H+A, 2006); Geotechnical and Chemical Evaluation, Groundwater Treatment Plant Site Soils, Montrose Superfund Site (Earth Tech, 2008). Levine-Fricke, 1995. Preliminary Endangerment Assessment (PEA), Jones Chemical Facility, Torrance, California. Volumes I and II. (Levine-Fricke, 1995 and Levine-Fricke, 2008). Draft Remedial Investigation Workplan, JCI Jones Chemical, Inc., Torrance, California. (Levine-Fricke, 2008). Supplemental Soil Investigation Report, Jones Chemical Property (Earth Tech, 2009a).

Montrose Chemical Corporation

Maximum Total DDT in the Unsaturated Zone 0-5 Feet bgs

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.18

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.18.1211.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Existing Railroad Tracks
- Historical Railroad Tracks
- Current-Day Building Locations
- Historical Site Feature
- LADWP — Los Angeles Department of Water and Power
- SSB-15 — DNAPL Reconnaissance Boring Location
- C196 — Supplemental Soil Investigation Boring Location 2005 – 2008
- 46D — Historical Soil Boring Location
- C181 — Supplemental Soil Investigation-Jones Chemical Boring Location
- Extent of Definite DNAPL in Unsaturated Zone
- Possible DNAPL Extent in Unsaturated Zone
- DDT Isoconcentration Contour Line
- Total DDT Concentration in Soil = 10-100 mg/kg
- Total DDT Concentration in Soil = 100-1,000 mg/kg
- Total DDT Concentration in Soil = 1,000-10,000 mg/kg
- Total DDT Concentration in Soil = >10,000 mg/kg

References:

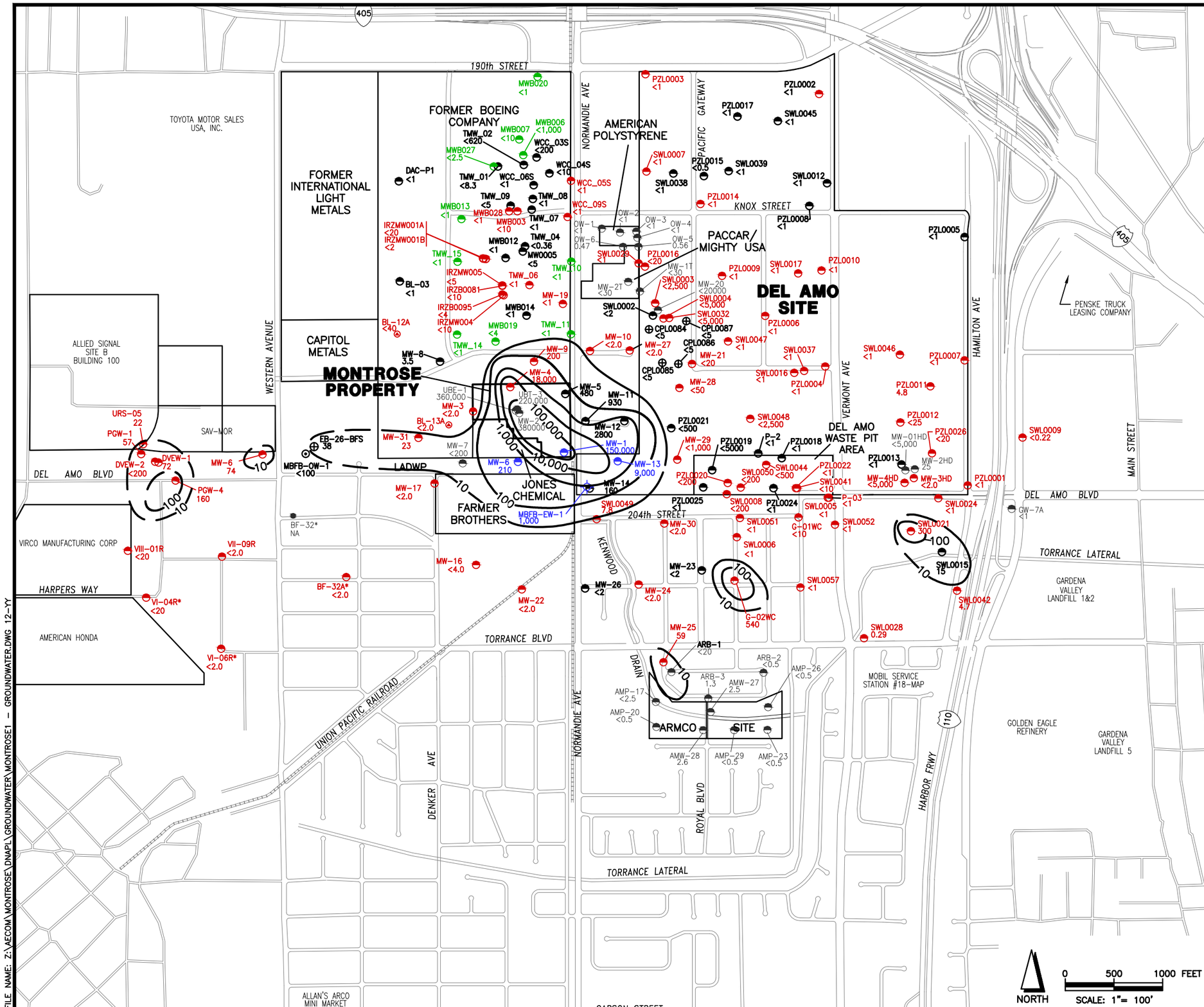
1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online GIS data set, ©2009. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin & Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Georeferenced Satellite Image from U.S. Geological Survey, July 31, 2007. Google Earth Pro ©2009. Historical Continental Aerial, circa 1962. Historical Continental Aerial, circa 1981.
3. Former Plant Site features based on historical above-referenced aerial photos.
4. Source: Final Remedial Investigation Report for the Montrose Superfund Site, Los Angeles, California (EPA, 1998); Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, California, Revision 1.0. (H+A, 2004); Technical Memorandum to Susan Keydel, US EPA, DNAPL Reconnaissance Borings in Support of Earth Tech Soil Sampling Program, Montrose Site, Torrance, California (H+A, 2006); Geotechnical and Chemical Evaluation, Groundwater Treatment Plant Site Soils, Montrose Superfund Site (Earth Tech, 2008). Levine-Fricke, 1995. Preliminary Endangerment Assessment (PEA), Jones Chemical Facility, Torrance, California. Volumes I and II. (Levine-Fricke, 1995 and Levine-Fricke, 2008). Draft Remedial Investigation Workplan, JCI Jones Chemical, Inc., Torrance, California. (Levine-Fricke, 2008). Supplemental Soil Investigation Report, Jones Chemical Property (Earth Tech, 2009a).

Montrose Chemical Corporation

Maximum Total DDT in Unsaturated Zone 10-60 Feet bgs

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	2.19

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1211\DNAPL FS\SECT 2.0\DNAPL-FS.SEC 2.0.FIG 2.19.1211.DWG



Legend:

BL-12A	Cluster Well
MW-2	Upper Bellflower Aquitard Monitor Well Collected prior to 2004
MW-5	Upper Bellflower Aquitard Monitor Well Collected 2004 – September 2006
MW-4	Upper Bellflower Aquitard Monitor Well Sampled between September and November 2008
MW-6	Upper Bellflower Aquitard Monitor Well Sampled April 2009
MWB007	Upper Bellflower Aquitard Monitor Well Sampled between April and September 2010
EB-26-BFS	Exploratory Boring and Temporary Upper Bellflower Aquitard Observation Well
BF-32	Destroyed Monitor Well
MBFB-EW-1	Middle Bellflower 'B' Extraction Well
MBFB-OW-1	Middle Bellflower 'B' Observation Well
NA	Not Analyzed
<1	Less than; Numerical value is the limit of detection for this analysis.
*	Well screened from the water table zone into the Middle Bellflower 'C' sand.
0.1	Total MCB concentration in micrograms per liter
MCB	Monochlorobenzene
100	Contour line of equal concentration of MCB in micrograms per liter dashed where approximate, queried where inferred based on most recent sampling results.

Well Identifier Notes:

MW = Montrose Monitor Wells
G, GW, SWL, PZL, GW, P, MW-2T, MW-xHD = Del Amo Monitor Wells
OW = American Polystyrene Monitor Wells
AMW, AMP, ARB = Armco Monitor Wells
DAC, TMW, WCC, MWB = Boeing Monitor Wells
BL = Industrial Light Metals Monitor Wells
IRZB, IRZMW = Boeing Bioremediation Wells

References:

1. Avocet Environmental, 2010. Annual Groundwater Monitoring Report, Boeing Former C-6 Facility, 19503 South Normandie Avenue, Los Angeles, California. May 27.
2. H+A, 2009. Supplemental Groundwater Sampling and Analysis Results, April 2009, Montrose Superfund Site, Los Angeles, California. July 13.
3. H+A, 2007a. 2006 Groundwater Monitoring Results Report, Montrose Site, Torrance, California. February 28.

Notes:

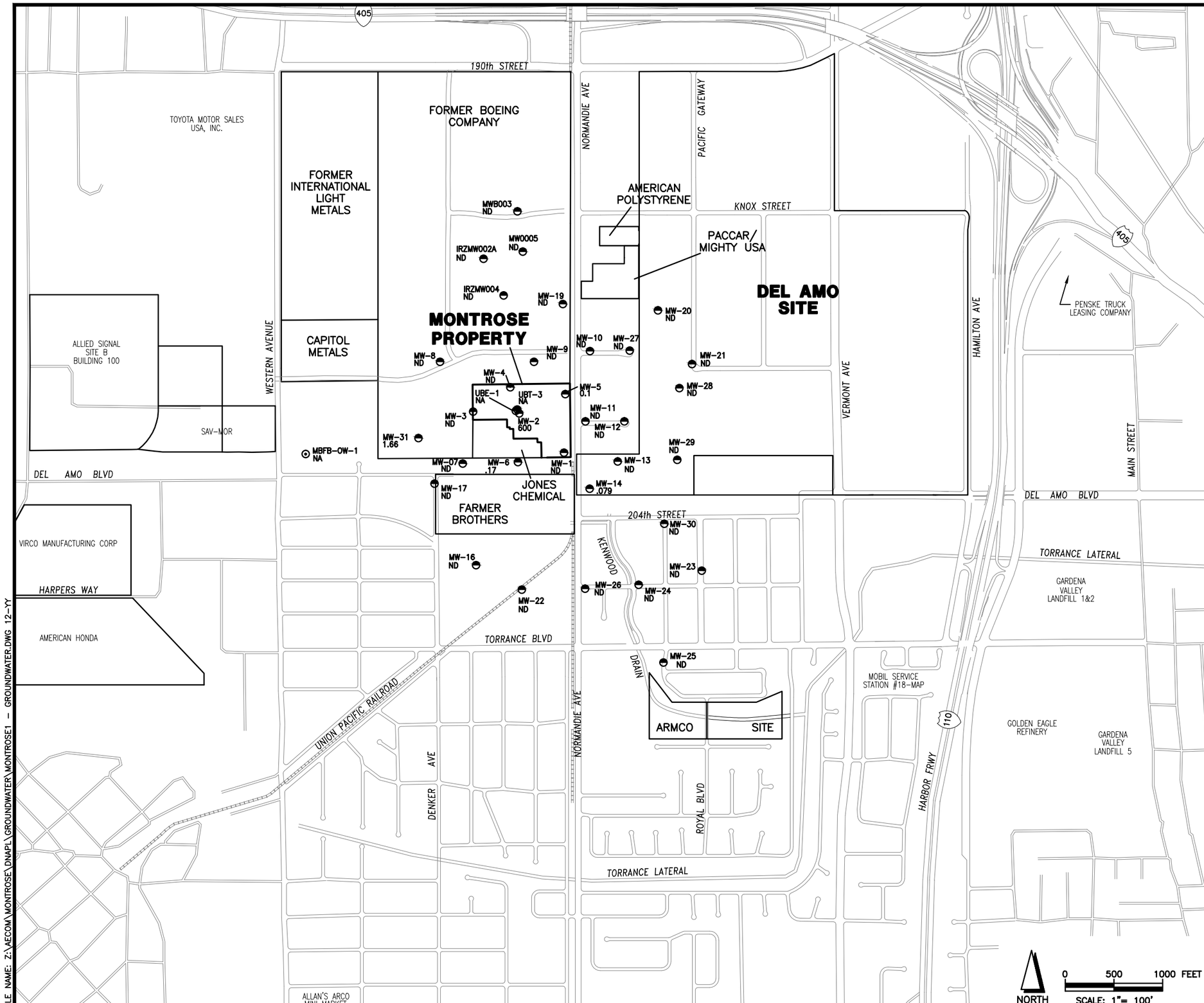
1. In the area West of Western Avenue, not all historical data are shown. Details are provided in: H+A Technical Memorandum Results of West of Western Avenue Groundwater Assessment Montrose Site Torrance, California, April 24, 2009

Montrose Chemical Corporation

Total MCB in Groundwater
Upper Bellflower Aquitard

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.20

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\GROUNDWATER\MONTROSE1 – GROUNDWATER.DWG 12-YY



Legend:

MW-5	Upper Bellflower Aquitard Monitor Well
MBFB-OW-1	Upper Bellflower Aquitard Observation Well
NA	Not Analyzed
ND	None of the component compounds detected in the sample
0.1	Total DDT concentration in micrograms per liter based on sum of component compounds. Results shown are for samples collected between 1990 and 2010. The most recent result is shown for each well sample.
DDT	Dichlorodiphenyltrichloroethane

References:

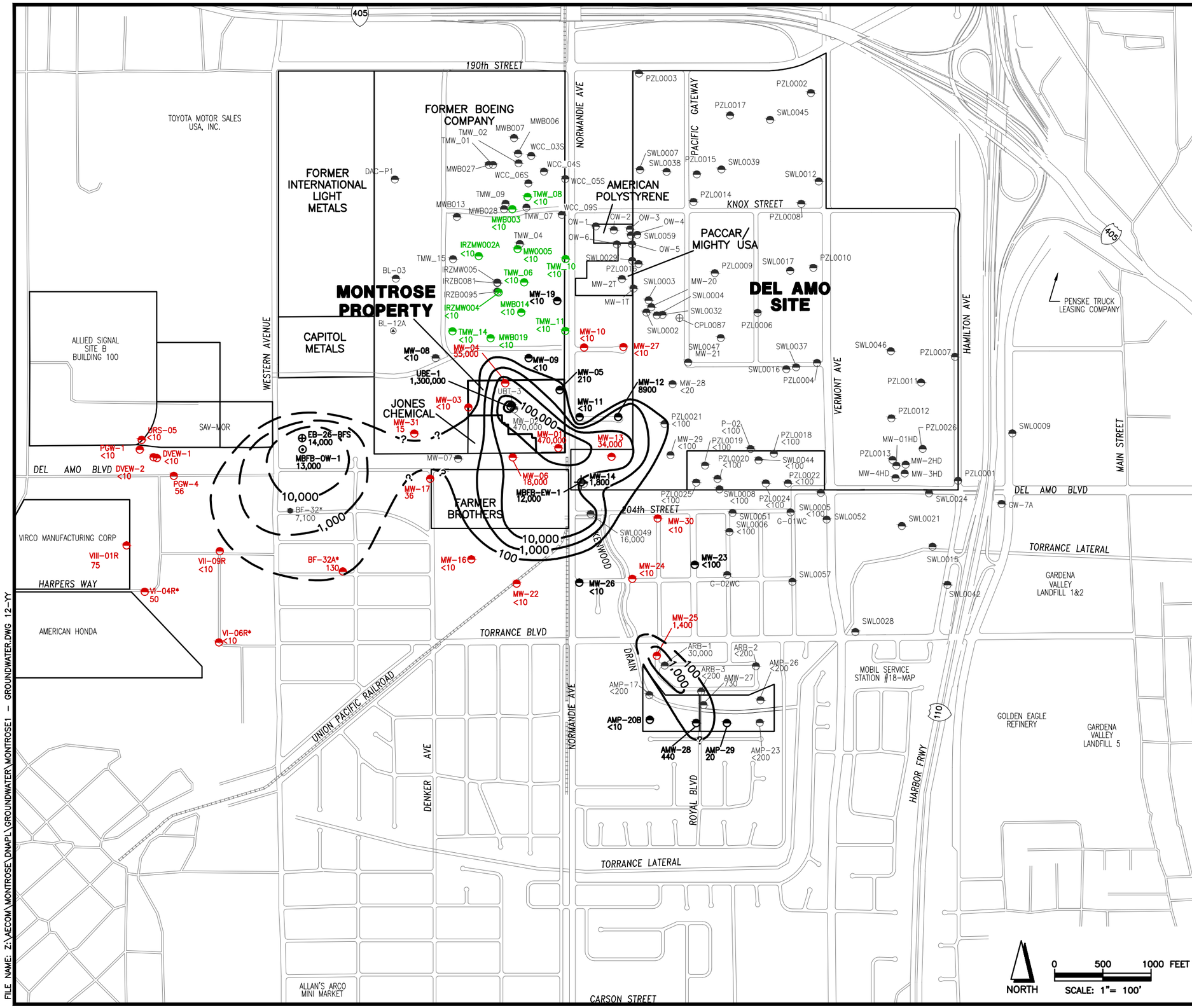
1. Avocet Environmental, 2010. Annual Groundwater Monitoring Report, Boeing Former C-6 Facility, 19503 South Normandie Avenue, Los Angeles, California. May 27.
2. H+A, 2009. Supplemental Groundwater Sampling and Analysis Results, April 2009, Montrose Superfund Site, Los Angeles, California. July 13.
3. H+A, 2007a. 2006 Groundwater Monitoring Results Report, Montrose Site, Torrance, California. February 28.

Montrose Chemical Corporation

Total DDT in Groundwater
Upper Bellflower Aquitard

Date: 11-11	Montrose Superfund Site	Figure 2.21
Project No. 103649	AECOM	

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\GROUNDWATER\MONTROSE1 - GROUNDWATER.DWG 12-YY



Legend:

BL-12A	Cluster Well
MW-2	Upper Bellflower Aquitard Monitor Well Collected prior to 2004
MW-5	Upper Bellflower Aquitard Monitor Well Collected 2004 – October 2006
MW-4	Upper Bellflower Aquitard Monitor Well Sampled between October 2006 and December 2008
MWB007	Upper Bellflower Aquitard Monitor Well Sampled between April and September 2010
EB-26-BFS	Exploratory Boring and Temporary Upper Bellflower Aquitard Observation Well
BF-32	Destroyed Monitor Well
MBFB-EW-1	Middle Bellflower 'B' Extraction Well
MBFB-OW-1	Middle Bellflower 'B' Observation Well
NA	Not Analyzed
<1	Less than; Numerical value is the limit of detection for this analysis.
0.1	Total pCBSa concentration in micrograms per liter
*	Well screened from the water table zone into the Middle Bellflower 'C' sand.
pCBSA	para-Chlorobenzene sulfonic acid
100	Contour line of equal concentration of pCBSA in micrograms per liter dashed where approximate, queried where inferred based on most recent sampling results.

Well Identifier Notes:

MW = Montrose Monitor Wells
MBFB = Montrose Observation Wells
G, GW, SWL, PZL, P, MW-2T, MW-xHD = Del Amo Monitor Wells
OW = American Polystyrene Monitor Wells
AMW, AMP, ARB = Armco Monitor Wells
DAC, TMW, WCC, MWB = Boeing Monitor Wells
BL = Industrial Light Metals Monitor Wells
IRZB, IRZMW = Boeing Bioremediation Wells

References:

1. Avocet Environmental, 2010. Annual Groundwater Monitoring Report, Boeing Former C-6 Facility, 19503 South Normandie Avenue, Los Angeles, California. May 27.
2. H+A, 2009. Supplemental Groundwater Sampling and Analysis Results, April 2009, Montrose Superfund Site, Los Angeles, California. July 13.
3. H+A, 2007a. 2006 Groundwater Monitoring Results Report, Montrose Site, Torrance, California. February 28.

Notes:

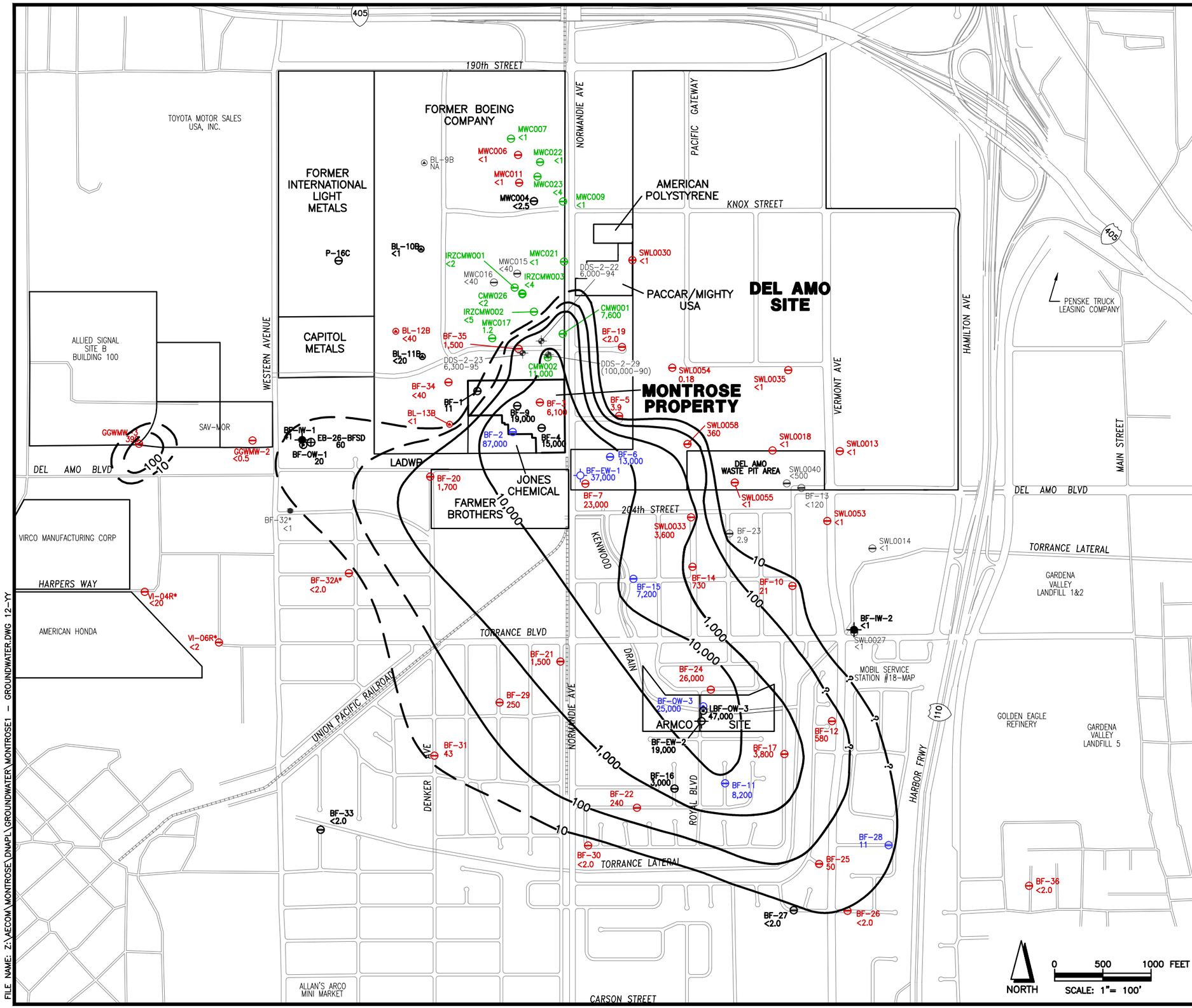
1. In the area West of Western Avenue, not all historical data are shown. Details are provided in: H+A Technical Memorandum Results of West of Western Avenue Groundwater Assessment Montrose Site Torrance, California, April 24, 2009

Montrose Chemical Corporation

Total pCBSA in Groundwater
Upper Bellflower Aquitard

Date: 11-11	Montrose Superfund Site	Figure 2.22
Project No. 103649	AECOM	

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\GROUNDWATER\MONTROSE1 – GROUNDWATER.DWG 12-YY



Legend:

BL-11B	Cluster Well
BF-1	Bellflower Sand Monitor Well Collected prior to 2004
BF-1	Bellflower Sand Monitor Well Collected 2004 – September 2006
BF-3	Bellflower Sand Monitor Well Sampled between September and November 2008
BF-2	Bellflower Sand Monitor Well Sampled April 2009
MWC007	Bellflower Sand Monitor Well Sampled between April and September 2010
EB-26-BFSD	Exploratory Boring and Temporary Bellflower Sand Observation Well
DDS-2-22 6,000-94	Boeing Hydropunch sample location Concentration – Collection Depth Sampled prior to September 2006
BF-32	Destroyed Monitor Well
BF-EW-2	Bellflower 'B' Extraction Well
BF-IW-2	Bellflower 'B' Injection Well
BF-OW-1	Middle Bellflower 'B' Observation Well
NA	Not Analyzed
<1	Less than; Numerical value is the limit of detection for this analysis.
0.1	Total MCB concentration in micrograms per liter
*	Well screened from the water table zone into the Middle Bellflower 'C' sand.
MCB	Monochlorobenzene
(100,000)	Concentration not contoured
100	Contour line of equal concentration of MCB in micrograms per liter dashed where pproximate, queried where inferred based on most recent sampling results.

Well Identifier Notes:

BF = Montrose Monitor Wells
SWL = Del Amo Monitor Wells
WCC, MWC, CMW = Boeing Monitor Wells
BL = Industrial Light Metals Monitor Wells
IRZCMW = Boeing Bioremediation Wells

References:

1. Avocet Environmental, 2010. Annual Groundwater Monitoring Report, Boeing Former C-6 Facility, 19503 South Normandie Avenue, Los Angeles, California. May 27.
2. H+A, 2009. Supplemental Groundwater Sampling and Analysis Results, April 2009, Montrose Superfund Site, Los Angeles, California. July 13.
3. H+A, 2007a. 2006 Groundwater Monitoring Results Report, Montrose Site, Torrance, California. February 28.

Notes:

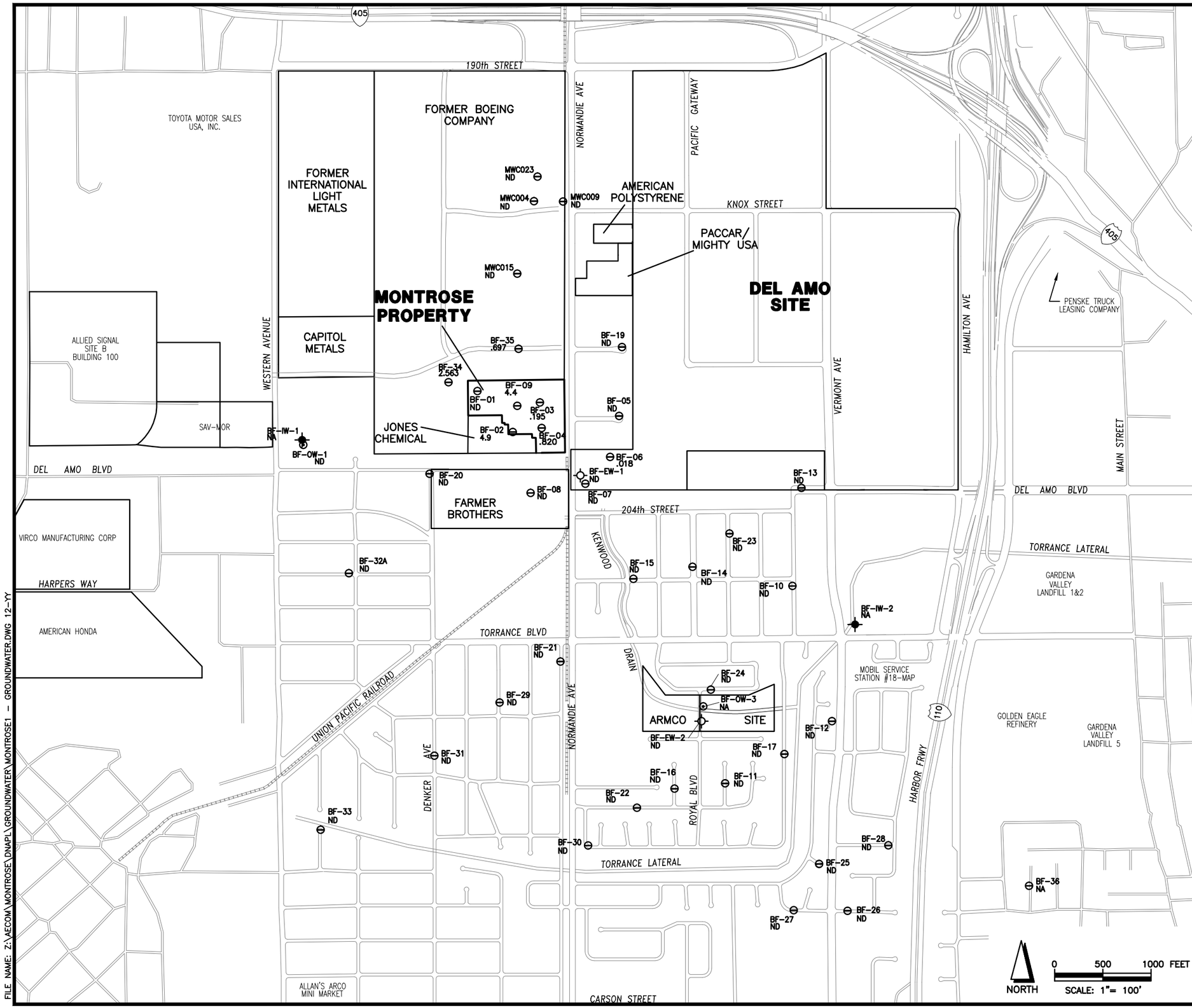
1. In the area West of Western Avenue, not all historical data are shown. Details are provided in: H+A Technical Memorandum Results of West of Western Avenue Groundwater Assessment Montrose Site Torrance, California, April 24, 2009

Montrose Chemical Corporation

Total MCB in Groundwater Bellflower Sand

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.23

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\GROUNDWATER\MONTROSE1 – GROUNDWATER.DWG 12-YY



Legend:

BF-05	Bellflower Sand Monitor Well
MBFB-OW-1	Bellflower Sand Observation Well
BF-EW-1	Bellflower Sand Extraction Well
BF-IW-1	Bellflower Sand Injection Well
NA	Not Analyzed
ND	None of the component compounds detected in the sample
0.1	Total DDT concentration in micrograms per liter based on sum of component compounds. Results shown are for samples collected between 1990 and 2010. The most recent result is shown for each well sample.
DDT	Dichlorodiphenyltrichloroethane

References:

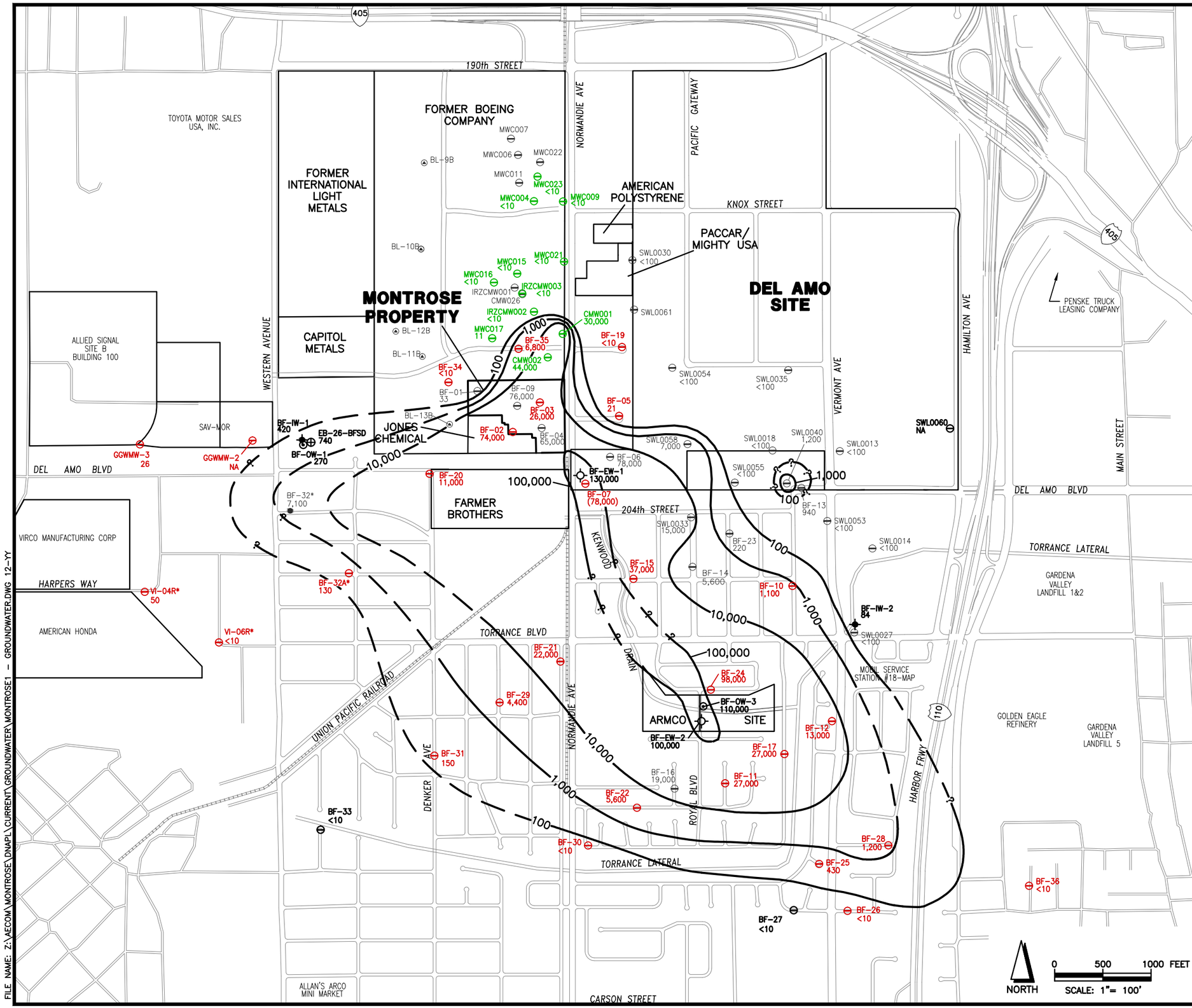
1. Avocet Environmental, 2010. Annual Groundwater Monitoring Report, Boeing Former C-6 Facility, 19503 South Normandie Avenue, Los Angeles, California. May 27.
2. H+A, 2009. Supplemental Groundwater Sampling and Analysis Results, April 2009, Montrose Superfund Site, Los Angeles, California. July 13.
3. H+A, 2007a. 2006 Groundwater Monitoring Results Report, Montrose Site, Torrance, California. February 28.

Montrose Chemical Corporation

Total DDT in Groundwater
Bellflower Sand

Date: 11-11	Montrose Superfund Site	Figure 2.24
Project No. 103649	AECOM	

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\GROUNDWATER\MONTROSE1 - GROUNDWATER.DWG 12-YY



Legend:

BL-11B	Cluster Well
BF-1	Bellflower Sand Monitor Well Collected prior to 2004
BF-1	Bellflower Sand Monitor Well Collected 2004 – October 2006
BF-3	Bellflower Sand Monitor Well Sampled between October 2006 and December 2008
MWC007	Bellflower Sand Monitor Well Sampled between April and September 2010
BF-32	Destroyed Monitor Well
BF-EW-2	Bellflower 'B' Extraction Well
BF-IW-2	Bellflower 'B' Injection Well
BF-OW-1	Middle Bellflower 'B' Observation Well
NA	Not Analyzed
<1	Less than; Numerical value is the limit of detection for this analysis.
0.1	Total pCBSa concentration in micrograms per liter
*	Well screened from the water table zone into the Middle Bellflower 'C' sand.
pCBSA	para–Chlorobenzene sulfonic acid
(100,000)	Concentration not contoured
100	Contour line of equal concentration of pCBSa in micrograms per liter dashed where approximate, queried where inferred based on most recent sampling results.

Well Identifier Notes:

BF = Montrose Monitor Wells
SWL = Del Amo Monitor Wells
WCC, MWC, CMW = Boeing Monitor Wells
BL = Industrial Light Metals Monitor Wells
IRZCMW = Boeing Bioremediation Wells

References:

1. Avocet Environmental, 2010. Annual Groundwater Monitoring Report, Boeing Former C–6 Facility, 19503 South Normandie Avenue, Los Angeles, California. May 27.
2. H+A, 2009. Supplemental Groundwater Sampling and Analysis Results, April 2009, Montrose Superfund Site, Los Angeles, California. July 13.
3. H+A, 2007a. 2006 Groundwater Monitoring Results Report, Montrose Site, Torrance, California. February 28.

Notes:

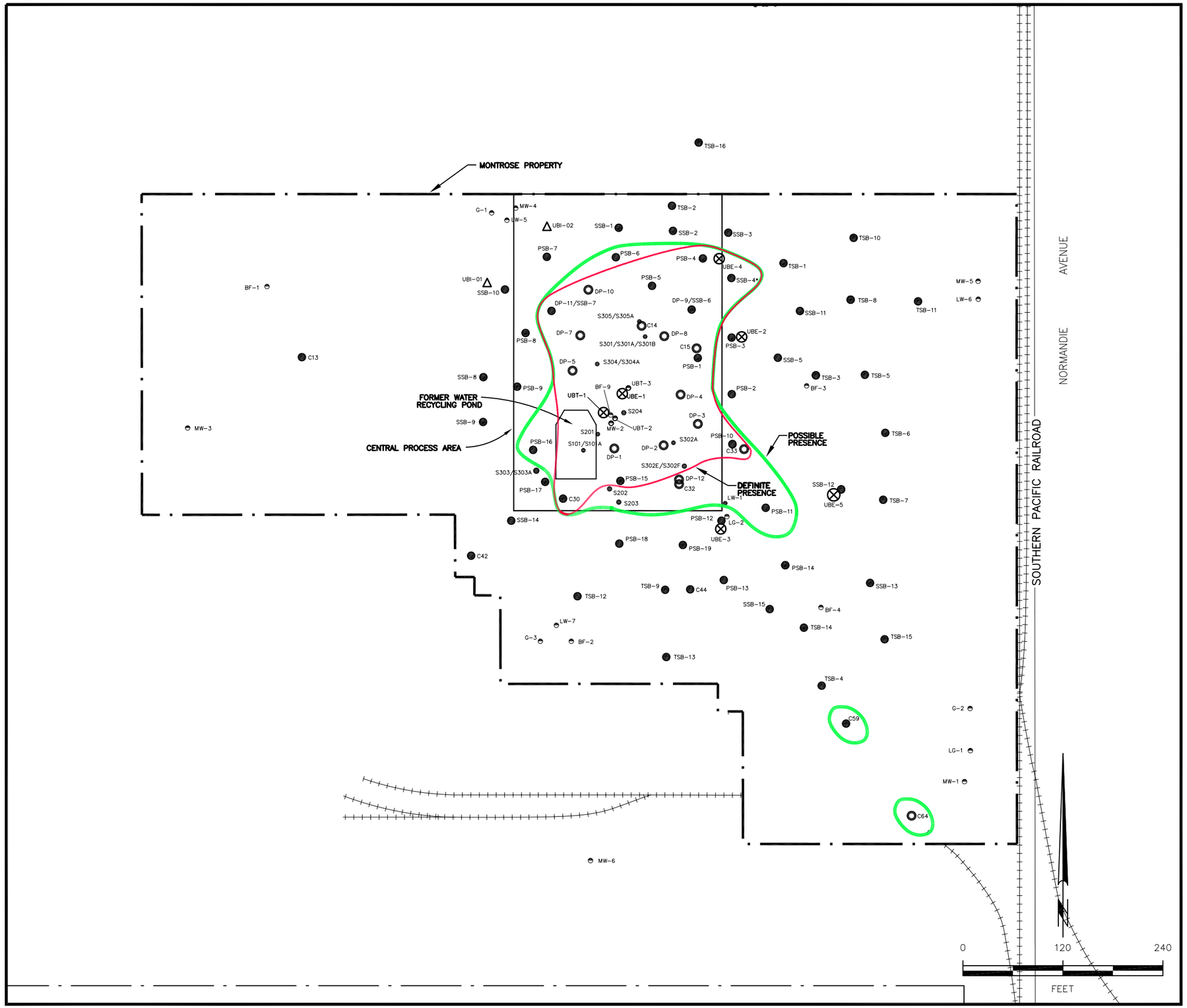
1. In the area West of Western Avenue, not all historical data are shown. Details are provided in: H+A Technical Memorandum Results of West of Western Avenue Groundwater Assessment Montrose Site Torrance, California, April 24, 2009

Montrose Chemical Corporation

Total pCBSA in Groundwater Bellflower Sand

Date: 11-11	Montrose Superfund Site	Figure
Project No. 103649	AECOM	2.25

FILE NAME: Z:\AECOM\MONTROSE\DNAPL\CURRENT\GROUNDWATER\MONTROSE1 – GROUNDWATER.DWG 12-YY



EXPLANATION

- MUD ROTARY BORING DRILLED TO 2003
- DIRECT PUSH BORING DRILLED 2003
- SONIC BORING DRILLED 2003–2005
- MONITOR WELL
- EXTRACTION WELL
- INJECTION WELL
- DEFINITE DNAPL EXTENT IN UNSATURATED UBA
- POSSIBLE EXTENT IN UNSATURATED UBA

SOURCE: HARGIS + ASSOCIATES, 2006a

MONTROSE CHEMICAL CORPORATION
TORRANCE, CALIFORNIA

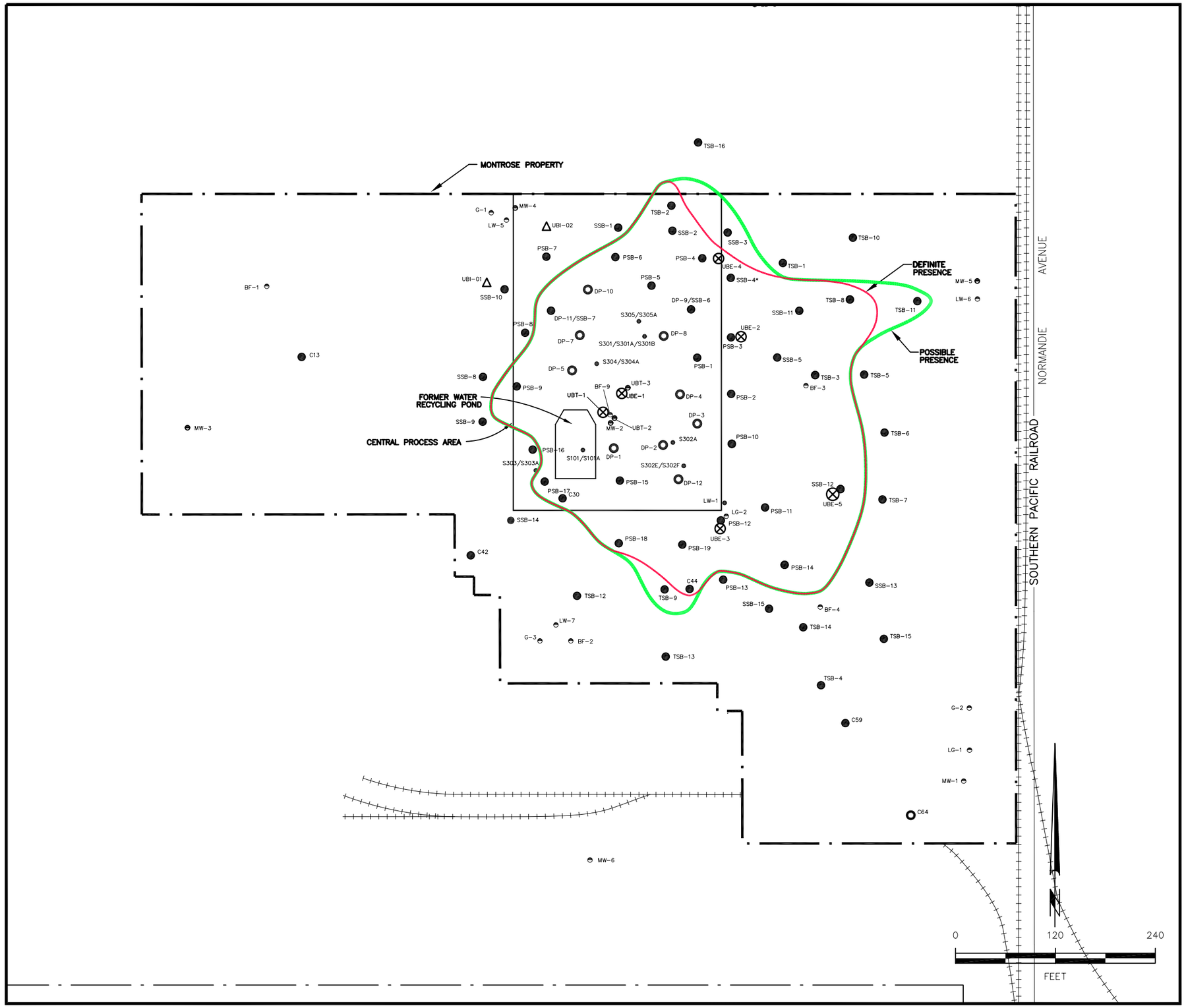
DNAPL EXTENT IN THE UNSATURATED UBA (0-60 FEET bgs)

HARGIS + ASSOCIATES, INC.
Hydrogeology/Engineering

11-11

FIGURE 2.26

RPT NO. 857.04b | 410-6615 | A



EXPLANATION

- MUD ROTARY BORING DRILLED PRIOR TO 2003
- DIRECT PUSH BORING DRILLED 2003
- SONIC BORING DRILLED 2003–2005
- MONITOR WELL
- EXTRACTION WELL
- INJECTION WELL
- DEFINITE DNAPL EXTENT IN SATURATED UBA
- POSSIBLE DNAPL EXTENT IN THE SATURATED UBA

SOURCE: HARGIS + ASSOCIATES, 2006a

MONTROSE CHEMICAL CORPORATION
TORRANCE, CALIFORNIA

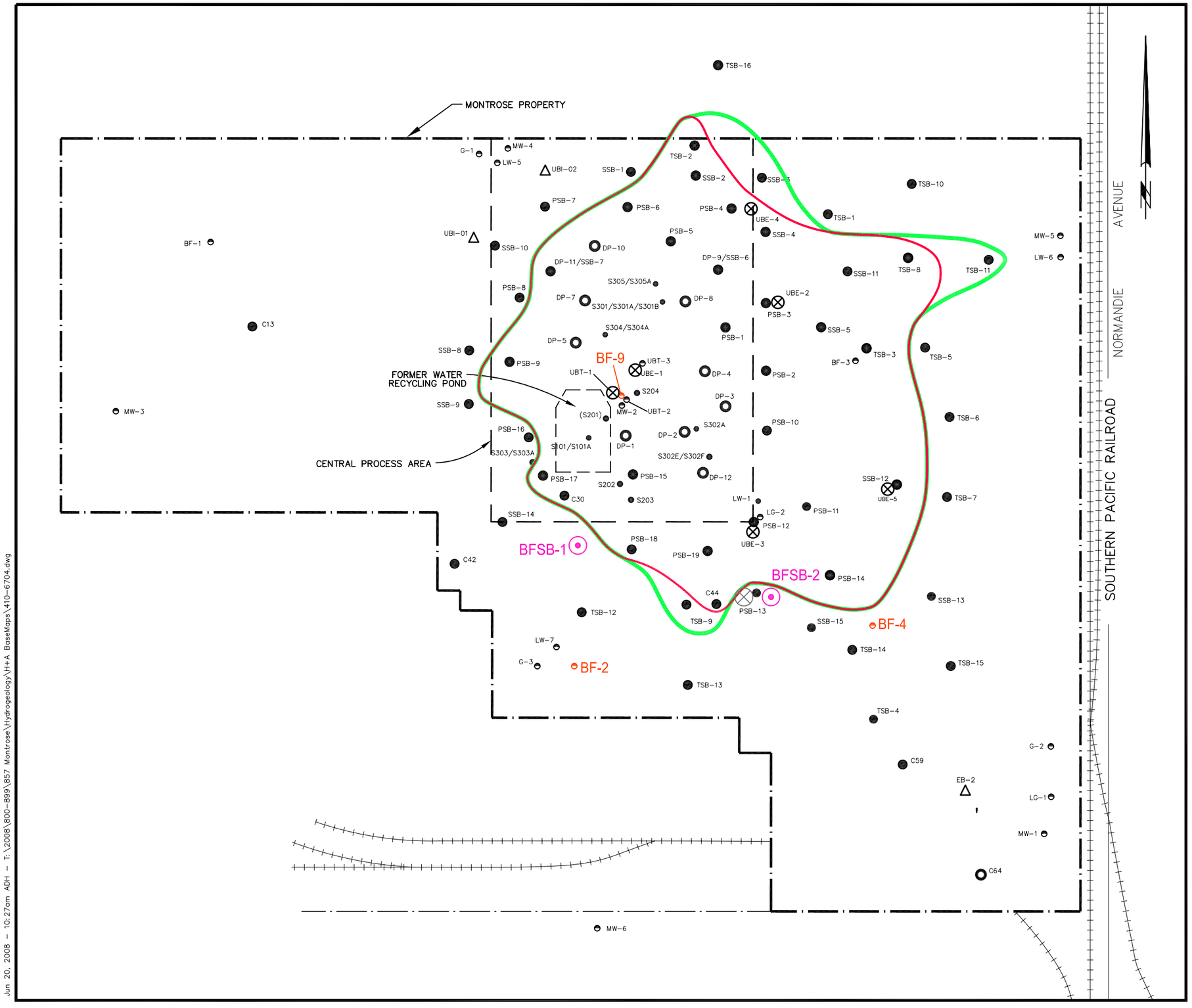
DNAPL EXTENT IN THE SATURATED UBA (60-105 FEET bgs)

HARGIS + ASSOCIATES, INC.
Hydrogeology/Engineering

11-11

FIGURE 2.27

RPT NO. 857.04b | 410-6616 | A



EXPLANATION

BFSB-1	BELLFLOWER SAND DNAPL RECONNAISSANCE BORING AND DEPTH DISCRETE GROUNDWATER SAMPLE LOCATION, APRIL–MAY 200o
⊗	INITIAL LOCATION OF BORING BFSB–2, ABANDONED AND RELOCATED AS SHOWN
BF-2	DEPTH DISCRETE GROUNDWATER SAMPLE LOCATION, MARCH 2008
S305/S305A	SOIL BORING
MW–2	MONITOR WELL
PSB–7	SONIC BORING
DP–10	DIRECT PUSH BORING
UBE–2	EXTRACTION WELL
UBI–01	INJECTION WELL
	PROPERTY BOUNDARY
	DEFINITE DNAPL EXTENT IN SATURATED UBA
	POSSIBLE DNAPL EXTENT IN THE SATURATED UBA

SOURCE: HARGIS + ASSOCIATES, 2008c

BFS = BELLFLOWER SAND

NOTE FIGURE ORIGINALLY PRODUCED AS PART OF THE RESULTS OF THE DNAPL RECONNAISSANCE INVESTIGATION: HARGIS + ASSOCIATES, INC., 2004. RESULTS OF DNAPL RECONNAISSANCE INVESTIGATION, MONTROSE SITE, TORRANCE, CALIFORNIA, JUNE 19, 2004. FIGURE SUBSEQUENTLY MODIFIED BASED ON DATA COLLECTED AS PART OF THE SUPPLEMENTAL SOILS INVESTIGATION IN TECHNICAL MEMORANDUMS TITLED: DNAPL RECONNAISSANCE BORINGS IN SUPPORT OF EARTH TECH SOIL SAMPLING PROGRAM. MONTROSE SITE, TORRANCE, CALIFORNIA. JANUARY 19, 2006; AND, ADDENDUM 2 TO THE RESULTS OF DNAPL RECONNAISSANCE INVESTIGATION, MONTROSE SITE, TORRANCE, CALIFORNIA, FEBRUARY 20, 2008.

0 100 200
FEET

MONTROSE CHEMICAL CORPORATION OF CALIFORNIA
TORRANCE, CALIFORNIA

2008 DNAPL INVESTIGATION BORINGS, BFS

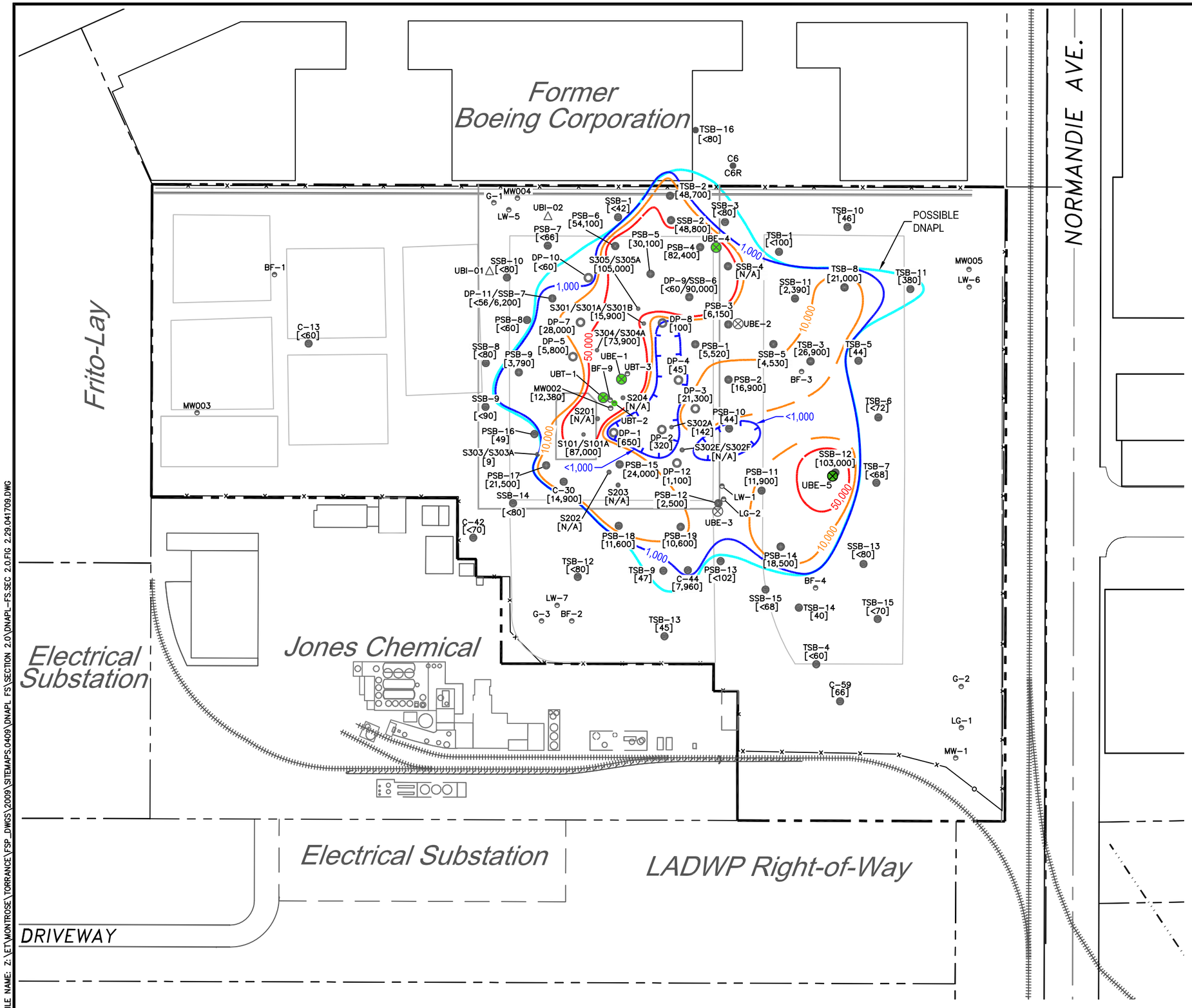
HARGIS + ASSOCIATES, INC.
Hydrogeology/Engineering

11-11

FIGURE 2.28

RPT NO. 857.04G | 410-6704 | C

Jun 20, 2008 – 10:27am ADH – T:\2008\800-899\857 Montrose\Hydrogeology\H+A BaseMaps\410-6704.dwg



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- PSB-7 — Sonic Boring Location
- DP-10 — Direct Push Boring Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire Possible DNAPL Impacted Area
- 1,000 — 1,000 mg/kg DNAPL Concentration (MCB + Total DDT)
- 10,000 — 10,000 mg/kg DNAPL Concentration (MCB + Total DDT)
- 50,000 — 50,000 mg/kg DNAPL Concentration (MCB + Total DDT)
- [21,000] — MCB + Total DDT mg/kg

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, On-line ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. Source: Earth Tech, 2008b

NORTH

0 60 120 FEET

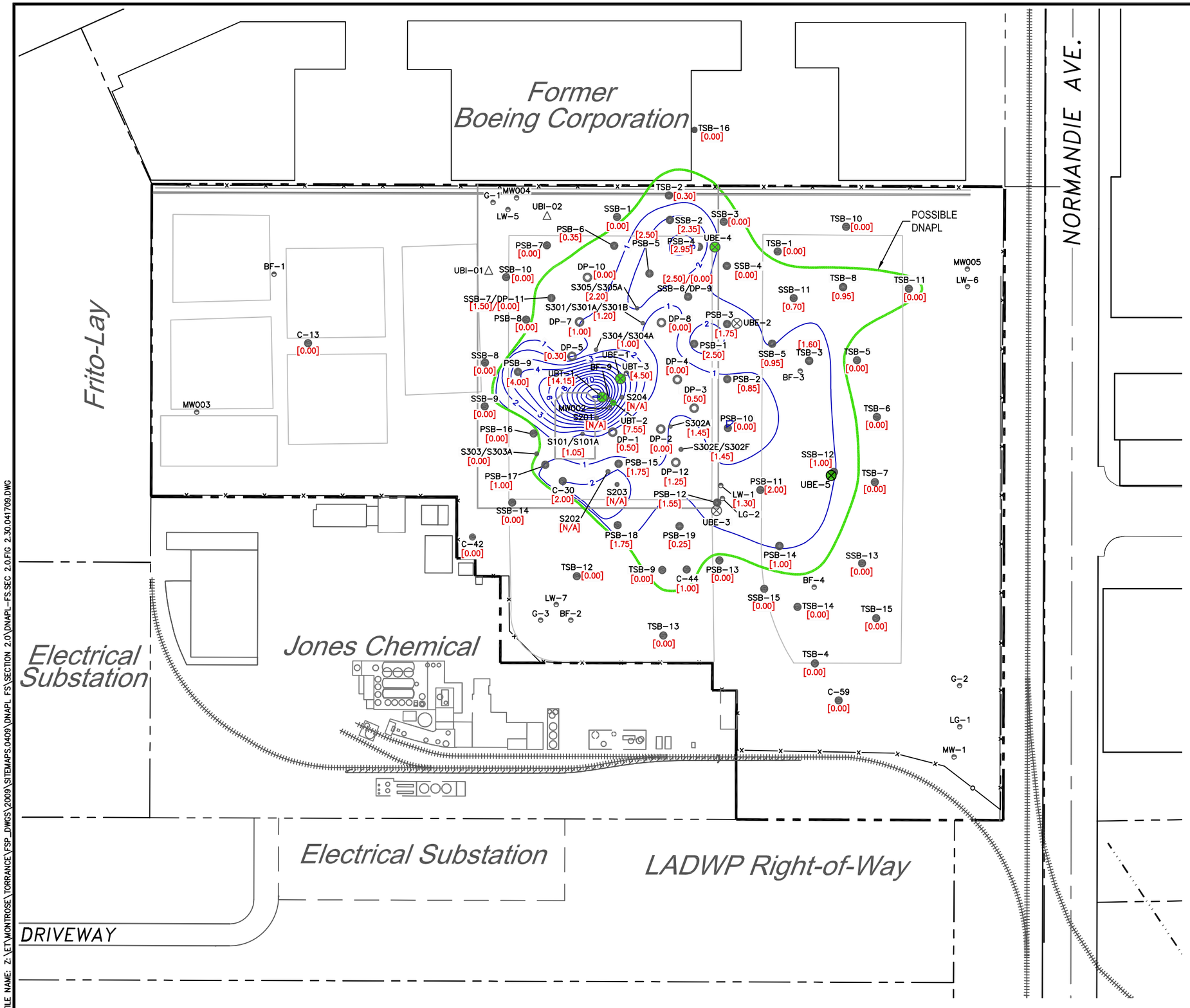
SCALE: 1"= 120'

Montrose Chemical Corporation

Maximum DNAPL Concentration, Saturated UBA

Date: 04-09	Montrose Superfund Site	Figure
Project No. 103649	EARTH TECH | AECOM	2.29

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2009\SITEMAPS.0409\DNAPL FS\SECTION 2.0\DNAPL-FS.SEC 2.0.FIG 2.29.041709.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- PSB-7 — Sonic Boring Location
- DP-10 — Direct Push Boring Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire Possible DNAPL Impacted Area
- 1 — DNAPL Definite Thickness in Feet
- [1.60] — DNAPL Thickness in Feet

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, On-line ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. Source: H+A, 2008a

NORTH

0 60 120 FEET

SCALE: 1"= 120'

Montrose Chemical Corporation

Liberal DNAPL Thickness, Saturated UBA

Date: 04-09	Montrose Superfund Site	Figure
Project No. 103649	EARTH TECH | AECOM	2.30

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2009\SITEMAPS.0409\DNAPL FS\SECTION 2.0\DNAPL-FS.SEC 2.0.FIG 2.30.041709.DWG

Section 3.0

Remedial Action Objectives, General Response Actions and ARARS

3.0 REMEDIAL ACTION OBJECTIVES, GENERAL RESPONSE ACTIONS, and ARARS

This section identifies the objectives and regulatory requirements for the remedial alternatives considered by this DNAPL FS. The first step is to identify RAOs for protecting human health and the environment, which will be used throughout the screening process. Following development of RAOs for the Site, GRAs are defined which are actions that may achieve the RAOs. During the screening process (Section 4.0), remedial technologies, process options, and alternatives that are not capable of meeting the RAOs will be eliminated. Compliance with ARARs must also be considered throughout the screening process; thus an overview of ARARs developed for the Site is presented. Together, the development of RAOs, GRAs, and ARARs will provide a basis for the selection of applicable treatment technologies and remedial action alternatives to be evaluated during the screening process.

3.1 REMEDIAL ACTION OBJECTIVES

Remedial alternatives must satisfy the fundamental goal of being protective of human health and the environment. RAOs have been developed for DNAPL that will satisfy this goal and incorporate the contaminants of concern (COCs), potential receptors, potential exposure routes, and acceptable exposure levels. EPA found that it is technically impracticable to reduce contaminant concentrations within the DNAPL-impacted zone to pre-defined Maximum Contaminant Levels (MCLs) or risk-based cleanup levels (as defined in the Groundwater ROD, EPA, 1999). For this reason, a TI Waiver Zone was established in the Groundwater ROD throughout the DNAPL-impacted soils, and long-term hydraulic containment of contaminants within the TI Waiver Zone are required by that ROD. Therefore, the generalized objectives for remediation within the DNAPL-impacted zone are to remove mobile DNAPL mass to the extent practicable, to reduce the mobility of DNAPL in the subsurface, and to decrease the uncertainty associated with the groundwater remedy and containment requirements. As a result, RAOs for DNAPL are more appropriately specified in terms of contaminant mobility and mass reduction than they would be in terms of contaminant concentrations. Accordingly, the RAOs for DNAPL at the Site are as follows:

1) Prevent human exposure to DNAPL constituents (via ingestion, inhalation, or dermal contact) that would pose an unacceptable health risk to on- or off-property receptors under industrial land uses of the Montrose plant property and adjacent properties;
2) To the extent practicable, limit uncontrolled lateral and vertical migration of mobile NAPL under industrial land use and hydraulic conditions in groundwater;
3) Increase the probability of achieving and maintaining containment of dissolved-phase contamination to the extent practicable, as required by the existing groundwater ROD, for the time period that such containment remains necessary;

4) Reduce mobile NAPL mass to the extent practicable;
5) To the extent practicable, reduce the potential for recontamination of aquifers that have been restored by the groundwater remedial actions, as required by the groundwater ROD, in the event containment should fail; and
6) To the extent practicable, reduce the dissolved-phase concentrations within the containment zone over time.

The RAOs were established for the DNAPL program in September 2008 following a series of technical meetings with EPA in 2007 and 2008. Following a series of conference calls with EPA in 2010, RAO 4 was subsequently revised in December 2010 (AECOM, 2010g) to focus on reduction of mobile DNAPL mass at the Site, which is the principal threat to human health and the environment at the Site as described below.

Principal Threat

DNAPL that is mobile in the environment, i.e., present at saturations above residual levels, is the principal threat at the Site. In the absence of remedial action, mobile DNAPL has the potential to migrate laterally outside the TI Waiver Zone or vertically downward to deeper aquifer units under gravitational forces. Mobile DNAPL migration in this manner would not be protective of human health and the environment. Mobile DNAPL migration as described above could threaten the remedy for groundwater by (a) decreasing the probability of achieving hydraulic containment of dissolved-phase MCB within the TI Waiver Zone, and (b) preventing the groundwater remedy from reducing dissolved-phase MCB concentrations outside the TI Waiver Zone to in-situ groundwater standards.

DNAPL that is immobile in the environment, i.e., present at or below residual saturations, is not a threat to the groundwater remedy at the Site. DNAPL at residual saturations is immobile under gravitational forces or natural hydraulic gradients. Although residual DNAPL will continue to serve as a source for dissolved MCB in the long-term, the groundwater remedy will effectively and hydraulically contain dissolved-phase MCB concentrations within the TI Waiver Zone.

Removal of all DNAPL at the Site, both mobile and residual, is not practicable or technically feasible at this time. For this reason, EPA established a TI Waiver Zone at the Site as indicated in the Groundwater ROD (EPA, 1999). However, a primary performance goal for the DNAPL remedy is to reduce DNAPL saturations in the subsurface to residual and immobile levels, either through mass removal or saturation depletion, without causing DNAPL to migrate outside of the TI Waiver Zone or into deeper aquifer units.

3.2 GENERAL RESPONSE ACTIONS

GRAs are remedial technologies and associated process options that may achieve the RAOs for protecting human health and the environment. Protectiveness can be achieved by reducing exposure or exposure routes, such as restricting access to DNAPL-impacted soils. Protectiveness can also be achieved by reducing the mass or mobility of DNAPL in the subsurface. The GRAs for DNAPL at the Site are identified according to the following seven general categories:

- No action
- Institutional controls
- Containment
- Collection/Extraction
- In-Situ Treatment
- Ex-Situ Treatment
- Disposal

A brief description of each GRA category is provided as follows:

- **No Action:** Under this GRA, no further action would be taken at the Site to remediate DNAPL beyond what is otherwise required for containment under the Groundwater ROD. The use of a no action alternative serves to establish a baseline by which the protectiveness of other remedies can be measured.

- **Institutional Controls:** Under this GRA, institutional controls include implementation of administrative procedures and access restrictions to prevent human exposure to DNAPL-impacted soils. Two examples of institutional controls are deed restrictions and fencing.

- **Containment:** Under this GRA, human health and the environment are protected by controlling the DNAPL exposure pathways. Hydraulic containment of DNAPL impacts to groundwater is required by the Groundwater ROD, and therefore, is excluded from evaluation in this DNAPL FS. However, containment of separate-phase DNAPL can also be accomplished via barrier walls.

- **Collection/Extraction:** This GRA includes methods for extracting DNAPL from contaminated media for ex-situ treatment or disposal. Primary collection methods for DNAPL include soil vapor extraction (for VOC component present above the water table), passive extraction (i.e. extraction of DNAPL into wells), and active extraction (i.e. hydraulic displacement). Enhanced collection methods for DNAPL include injection of a surfactant/polymer, to enhance DNAPL mobility, and flooding with a co-solvent, such as an alcohol. Excavation of DNAPL-impacted soils, either by conventional methods or large diameter auger, is another collection method.

- **In-Situ Treatment:** This GRA involves treating contaminated media in-situ by changing the physical or chemical state of the contaminant. In-situ treatment methods for DNAPL include biological degradation, chemical oxidation or reduction, and thermal remediation, the latter of which can result in contaminant volatilization, oxidation, or flushing. Application of zero valent iron is an

example of in-situ chemical reduction. Under this GRA, the need for ex-situ treatment or disposal of contaminants may be reduced or eliminated. Deep soil mixing or stabilization is another form of in-situ treatment that changes the contaminant physical state by mixing it with a binding agent such as cement.

- **Ex-Situ Treatment:** This GRA includes ex-situ technologies for treatment of contaminants from a collection process. Ex-situ treatment technologies for soil vapors include thermal oxidation and adsorption, using either disposable or steam-regenerable carbon or resin. The ex-situ treatment technologies for groundwater, as identified by the Groundwater ROD, include liquid-phase granular activated carbon (LGAC) and advanced oxidation. The only ex-situ treatment technology considered for DNAPL is separation (from groundwater), and disposal of the separated DNAPL off-Site.

- **Disposal:** This GRA includes disposal options for contaminants from a collection process. Disposal options for groundwater include re-injection into the DNAPL-impacted zone (saturated UBA) or into the BFS and Gage Aquifer in coordination with the groundwater remedy. In accordance with the groundwater ROD, only treated groundwater can be re-injected into the BFS and Gage Aquifer. However, for the DNAPL-impacted UBA, re-injection of both treated and untreated groundwater is considered in this FS at the recommendation of EPA. The only disposal option for collected DNAPL is off-Site incineration as there is no commercial vendor which offers recycling of recovered DNAPL containing MCB and DDT.

The above GRAs are further discussed and preliminarily evaluated against three performance criteria in Section 4.0. The extent of DNAPL (area and volume) for which these GRAs are being evaluated is presented in Section 2.0. Additional details regarding treatment areas, volumes, and flow rates are provided in Section 5.0 for GRAs retained following the preliminary evaluation and assembled into remedial alternatives.

3.3 ARARS

The Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986, promulgated cleanup standards at Superfund sites, 42 USC §9610-9675. CERCLA requires that remedial actions meet federal standards that are determined to be applicable or relevant and appropriate (42 USC §9621(d), CERCLA §121(d)). The terms "*Applicable*" and "*Relevant and Appropriate*" are defined in the Code of Federal Regulations (CFR), Title 40, Part 300. An "*Applicable*" requirement refers to those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances at a CERCLA site. A "*Relevant and Appropriate*" requirement refers to cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law. Non-promulgated advisories or guidance issued by Federal or State government that are not legally binding and do not have the status of

potential ARARs can additionally be considered for remedial action, and these criteria are conventionally referred to as "*To Be Considered*" (TBCs). Applicable standards are those that apply directly to site circumstances or condition and require little judgment in determining suitability. If the requirement is not applicable, it may nonetheless be relevant and appropriate if, based on best professional judgment, the circumstances or conditions at the CERCLA site are sufficiently similar to the conditions addressed by the requirement.

ARARs are subdivided into three categories as follows:

- Chemical-Specific ARARs: Requirements that set health- or risk-based concentration limits or discharge limitations on specific chemicals released into the environment.
- Action-Specific ARARs: Requirements that govern performance, design, or other similar criteria related to particular remedial actions (e.g. air emission requirements).
- Location-Specific ARARs: Requirements that place restrictions on activities due to their particular locations (e.g. floodplains, faults, wetlands).

Additionally, only the substantive portions of state and federal environmental laws and regulations are ARARs for remedial actions at the Property. Under CERCLA, "administrative requirements", such as administration of permits, are not considered ARARs, although in practice, general requirements on a local level are typically followed.

Identification of the ARARs and TBCs for DNAPL was accomplished by reviewing federal, state, and local laws, regulations, and policies. A determination of ARARs and TBCs was made based upon the terms of those statutes, regulations, and policies, consideration of EPA guidance, primarily the guidance entitled *CERCLA Compliance With Other Laws Manual: Interim Final (Parts I and II*), EPA/540/G-89/006 (EPA, 1989b), and discussions with EPA. The ARARs and TBCs identified for DNAPL are listed below and summarized in **Table 3.1.** The applicability and relevance of these ARARs is not discussed in this section but is provided in Table 3.1. Identification of the ARARs and TBCs in this FS is not determinative, and new or different ARARs may be identified by EPA in the ROD.

The ARARs and TBCs for the DNAPL FS were previously identified in the April 2009 Draft FS (Earth Tech, 2009a). EPA commented on the draft ARARs and TBCs in January 2010 (EPA, 2010a), and on behalf of Montrose, Latham & Watkins responded to the comments in April 2010 (L&W, 2010). Efforts to reconcile the ARARs and TBCs continued into 2011, and an additional letter addressing candidate TBCs was submitted to EPA in May, 2011 (L&W, 2011b). The candidate ARARs and TBCs presented in this FS reflect the outcome of these efforts to identify requirements that are applicable, relevant and appropriate, or to be considered in addressing DNAPL at the Site.

Chemical-Specific ARARs

- Porter-Cologne Water Quality Control Act, California Water Code (§13140-13147, 13172, 13240, 13260, 13263, 13267, 13304, 13360) (27 CCR §20200-20230)
- South Coast Air Quality Management District, Permit Screening Emission Level for Chloroform (Package "L", Table 1A, September 10, 2010)

Location-Specific ARARs

- Migratory Bird Treaty Act (16 USC §703-712)
- Endangered Species Act of 1973 (16 USC §1531-1536) (50 CFR Part 17, 402)

Action-Specific ARARs

- State Water Resources Control Board Resolutions 68-16 and 92-49 III.G
- Identification and Characterization of Hazardous Waste (40 CFR Part 261 et seq.) (22 CCR §66261 et seq.)
- Solid Waste Disposal Act and Resource Conservation and Recovery Act (RCRA), Generators of Hazardous Waste (40 CFR Part 262 et seq.) (22 CCR §66262 et seq.)
- Resource Conservation and Recovery Act (RCRA), Interim Control of Hazardous Waste Injection (42 U.S.C. §6939b(b))
- Land Disposal Restrictions (40 CFR Part 268 et seq.) (22 CCR §66268 et seq.)
- Waste Management and Classification (27 CCR §20200-20220)
- California Hazardous Waste Control Act, California Health & Safety Code (§25100, et seq.)
- Requirements for the Underground Injection Control Program (40 CFR Part 144-148)
- Clean Air Act (CAA) (42 USC §7401-7462) (40 CFR Part 60-69)
- South Coast Air Quality Management District (Rule 201, 201.1, 401-405, 408, 409, 466, 474, 476, 1001, 1146, 1166, 1176, 1301, 1401, and 1470)
- Land Use Covenant (22 CCR §67391.1)
- Environmental Covenant, California Civil Code (§1471)
- EPA Mandatory Greenhouse Gas Reporting (40 CFR Part 98)

The following four potential ARARs relating to drinking water standards were excluded from the above list:

- Federal Primary Drinking Water Standards (40 CFR Part 141)
- California Primary Drinking Water Standards (22 CCR §64431 and 64444)
- California Secondary Drinking Water Standards (22 CCR §64449)
- California Department of Health Applied Action Levels

The Groundwater ROD for the Site (EPA, 1999) established a TI Waiver Zone in which the requirements associated with these ARARs are waived due to technical impracticability. Since the DNAPL occurs fully within the TI Waiver Zone as described in Section 1.7, then the requirements associated with the above drinking water standards are not applicable and are therefore excluded from this FS. However, if groundwater generated by a DNAPL remedy is re-injected outside of the TI Waiver Zone boundaries, these ARARs would be applicable as would the In-Situ Groundwater Standards (ISGS) established in the Groundwater ROD. In a letter dated January 27, 2010 (EPA, 2010a), EPA disagreed with the above interpretation regarding the applicability of groundwater standards to re-injection within the TI Waiver Zone, indicating that it was technically feasible to treat the hazardous substances found in groundwater to state and federal maximum contaminant limits. However, as indicated by Latham & Watkins in a letter dated April 28, 2010 (L&W, 2010), the Groundwater ROD only considered re-injection along the boundaries of the dissolved VOC plume and outside the TI Waiver Zone. While treatment of groundwater to re-injection standards is appropriate for the groundwater remedy, these standards were not believed to be applicable or relevant to a DNAPL remedy where re-injection would occur fully within the TI Waiver Zone. This issue was not resolved during reconciliation discussions, and therefore, the re-injection standards are discussed as potential ARARs during evaluation of the candidate remedies. For DNAPL remedies which consider re-injection within the TI Waiver Zone, the ability for those candidate remedies to meet re-injection standards is considered during the evaluation in the event that the standards are subsequently determined to be ARARs for the remedy.

TBCs

- California Well Standards, Department of Water Resources Bulletins 74-90 and 74-81
- California Global Warming Solutions Act of 2006 (AB32), Health and Safety Code (§38500 et seq.)
- California DTSC, Interim Advisory for Green Remediation, December 2009
- EPA, Superfund Green Remediation Strategy, September 2010
- EPA, Principles for Greener Cleanups, August 2009

- EPA, Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites, April 2008 (EPA/542/R-08/002)
- EPA, Region 9, Smart Energy Resources Guide, March 2008 (EPA/600/R-08/049)

Although TBCs are included in this analysis, there are, by definition, materials that are not legally enforceable but contain information that would be helpful to select, carry out, or determine the level of protectiveness of a selected remedy. Although the TBCs would be considered along with other relevant factors, none of these materials contain standards or criteria that would be applicable or enforceable as "law" to a remedial selection.

However, EPA does not agree that the greenhouse gas materials listed above constitute TBCs, on the basis that they do not contain performance standards or criteria that could be enforced if they were to be adopted as TBCs in the Record of Decision. In its letter of July 22, 2011 (EPA, 2011b), EPA explicitly instructed Montrose to remove the California and EPA global warming and green remediation documents from the list of TBCs, and EPA's position remains that these materials do not belong in the "To Be Considered" category.

Greenhouse Gas TBCs

In a proposed finding dated April 17, 2009, EPA concluded that greenhouse gases (GHGs) endanger the public health and welfare of current and future generations. Reducing or minimizing generation of GHGs is a principal subject of current "green remediation" initiatives being implemented by EPA nationally, EPA Region 9 regionally, and the State of California. EPA Region 9's Smart Energy Resources Guide (SERG) emphasizes that the "optimal phase in which to start considering these actions is during the Remedial Investigation/Feasibility Study (RI/FS) phase of a cleanup". EPA's Principles for Greener Cleanups indicates that GHG emissions and other "green" elements should be evaluated "during any phase of work, including…evaluation of cleanup options". Such early consideration of GHG emissions is prudent given that the remedy selection process largely determines a cleanup's carbon footprint. Further, the California Global Warming Solutions Act of 2006 establishes aggressive targets for the reduction of greenhouse gas emissions within California. A large carbon footprint would impede California's statutory mandate to reduce GHG emissions.

Although compliance with ARARs is a threshold criterion under the NCP, compliance with TBCs is not a threshold requirement. Candidate remedial alternatives with high GHG emissions cannot be eliminated from consideration in the FS. According to EPA's Principles for Greener Cleanups, remedial alternatives

that do not satisfy threshold requirements for protectiveness or site-specific cleanup objectives are not considered to be "greener". Instead, GHG emissions are considered along with the other balancing criteria identified in the NCP. Specifically, GHG emissions are considered as part of the short-term effectiveness criterion as described in Section 6.1.2. GHG emissions are not used to screen out candidate remedial alternatives but are used to evaluate remedial alternatives offering the best balance of short-term effectiveness, long-term effectiveness, implementability, cost, and reduction of toxicity, mobility, or volume. GHG emissions are also expected to be a concern for the State of California and possibly for the community as well.

TABLES

Table 3-1
DNAPL ARARs and TBCs
Montrose Superfund Site

Authority	Citation	Synopsis of Requirement	Action to be Taken to Attain Requirement	Applicable	Relevant and Appropriate	TBC	Remedial Alternative
CHEMICAL SPECIFIC ARARs							
Porter-Cologne Water Act (CWA), California Water Code	California Water Code §13140-13147, 13172, 13240, 13260, 13263, 13267, 13304, 13360 27 CCR §20200-20230	These provisions establish a classification system for solid wastes that cannot be discharged directly or indirectly to waters of the State, and instead, must be discharged to waste management units. Wastes classified as a threat to water quality (designated waste) may be discharged to a Class I hazardous waste or Class II designated waste management unit. Non-hazardous solid waste may be discharged to a Class I, II, or III waste management unit. Inert waste would not be required to be discharged into a SWRCB-classified waste management unit. Establishes water quality objectives, including narrative and numerical standards and establishes implementation plans to meet objectives and protect beneficial uses. Incorporates state-wide water quality control plans and policies.	Solid wastes not meeting cleanup criteria will be classified for disposal to appropriate permitted off-site waste management units. Candidate DNAPL remedial alternatives that generate wastes that cannot be discharged to waters of the State will need to comply with these ARARs.		X		RAs 1-6b
South Coast Air Quality Management District (SCAQMD), Permit Screening Emission Level for Chloroform	SCAQMD Permit Application Package "L", Table 1A, September 10, 2010	SCAQMD has established screening emission levels for various toxic air contaminants to determine if a screening risk assessment should be performed. The screening emission levels for chloroform, at three distances from the emission source, are as follows (may vary based upon cumulative health risk of all toxic air contaminants being emitted): Acute: 25 Meters: .0852 pounds per year 50 Meters: .17 pounds per year 100 Meters: .456 pounds per year Chronic: 25 Meters: 6.01 pounds per year 50 Meters: 15.8 pounds per year 100 Meters: 47.0 pounds per year	Chloroform is a site-related VOC that may be generated by candidate DNAPL remedial alternatives. Alternatives that generate chloroform would require an assessment of emissions in comparison to these screening levels to determine if a more detailed screening risk assessment would be required under SCAQMD Rule 1401.	X			RAs 3-6b
LOCATION SPECIFIC ARARs							
Migratory Bird Treaty Act	Title 16 USC §703-712	Except as permitted by regulations, it is unlawful to pursue, hunt, take, capture, offer to sell, barter, purchase, or deliver any migratory bird, nest, or egg.	No migratory birds, nests, or eggs are present at the Site; however, these regulations would be applicable if migratory birds were discovered at the site during DNAPL remedy implementation.		X		RAs 1-6b
Endangered Species Act of 1973; Protection of Endangered and Threatened Species	Title 16 USC §1531-1536; 50 CFR Parts 17 and 402	Requires action to conserve endangered species and critical habitats upon which endangered species depend. Includes consultation with the Dept. of the Interior. Activities at all remedial sites must be performed in such a manner as to identify the presence of and protect endangered or threatened plants and animals at the site.	Remedial actions should avoid disturbance of terrain which is habitat for endangered species. No currently known endangered species are present at the site; however, these regulations will be considered and followed if endangered or threatened species are discovered.		X		RAs 1-6b
ACTION SPECIFIC ARARs							
State Water Resources Control Board (SWRCB)	Resolution No. 68-16 Statement of Policy with Respect to Maintaining High Quality of Waters in California; Water Code §13140	State Anti-degradation Policy sets forth in State Board Resolution No. 68-16, which has been incorporated into all Regional Board Basin Plans. The resolution requires protection of the existing quality of water whenever it is better than that necessary to protect present and potential beneficial uses. Applies to the discharge of waste to waters, including re-injection into the aquifer.	A Technical Impracticability (TI) Waiver Zone was established for groundwater underlying the Montrose Site by EPA in the 1999 Groundwater ROD. Outside the TI Waiver Zone, groundwater would require treatment in compliance with the SWRCB provisions. Within the TI Waiver Zone, groundwater would require treatment in compliance with the conditions established by EPA for the TI Waiver Zone as indicated in the Groundwater ROD.		X		RAs 1-6b

Table 3-1
DNAPL ARARs and TBCs
Montrose Superfund Site

Authority	Citation	Synopsis of Requirement	Action to be Taken to Attain Requirement	Applicable	Relevant and Appropriate	TBC	Remedial Alternative
	Resolution No. 92-49 III.G 23 CCR §2550.4 Background Water Quality; Policy and Procedures for Investigation and Cleanup and Abatement of Discharges under Water Code §13304 (amended 4/21/94)	To protect groundwater, the resolution requires cleanup to either background water quality or the best water quality that is reasonable if background water quality cannot be restored. Non-background cleanup levels must be consistent with maximum benefit to the public, present and anticipated future beneficial uses, and conform to water quality control plans and policies.	Restoration of groundwater quality associated with the Montrose Site was addressed by the Groundwater ROD (EPA 1999). A TI Waiver Zone was established for groundwater underlying the Site and extends beyond the extents of DNAPL impacts to soils. These regulations will be considered in connection with the DNAPL-impacted containment zone and TI Waiver Zone.		X		RAs 1-6b
Code of Federal Regulations and California Code of Regulations Identification and Characterization of Hazardous Waste	40 CFR Part 261 et seq. 22 CCR §66261 et seq.	Defines wastes that are subject to regulation as a RCRA (or California) hazardous waste. Contaminated soil and groundwater (solid wastes), once extracted for treatment, must be managed as state and federal hazardous waste if such soil or groundwater contains levels of hazardous substances that meet or exceed state and federal hazardous waste toxicity criteria for specific hazardous wastes and/or contains one or more RCRA-listed hazardous wastes. 40 CFR §261.24 identifies waste containing >100 mg/L chlorobenzene as hazardous under the toxicity characteristic (waste code D021). 40 CFR 261.33 identifies waste containing DDT, as a discarded commercial product, as hazardous (waste code U061). In addition to federal hazardous waste standards, California also has specific state-regulated hazardous wastes. DNAPL exhibits the characteristic of "toxicity" if representative samples have: > 100.0 mg/L chlorobenzene by Toxicity Characteristic Leaching Potential (TCLP) > 1.0 mg/kg wet-weight DDT > 0.1 mg/L DDT by Soluble Threshold Limit Concentration (STLC)	These regulations establish provisions for characterizing wastes as hazardous (characteristic or by rule) and would be applicable to candidate DNAPL remedial alternatives which generate solid wastes. The determination of whether wastes generated during remedial activities are hazardous will be made at the time the wastes are generated. Some contaminated media treated to specified cleanup levels will no longer need to be managed as a hazardous waste; applicable to toxicity characteristic wastes (e.g., chlorobenzene, federal waste code D021).	X			RAs 3-6b
Solid Waste Disposal Act and Resource Conservation and Recovery Act (RCRA) Code of Federal Regulations and California Code of Regulations Generators of Hazardous Waste	40 CFR Part 262 et seq. 22 CCR §66262 et seq. Ch 12 incorporates by reference: • 49 CFR parts 172, 173, 178, and 179 • 40 CFR part 265, Subparts C, D, I, J, AA, BB, CC • 22 CCR Chapter 15, Articles 3, 4, 9, 10, 27, 28, and 28.5	Under 42 USC §6901 et seq., RCRA mandates "cradle-to-grave" management of hazardous waste, and regulates three types of hazardous waste handlers: (1) generators, (2) transporters, and (3) owners and operators of treatment, storage, or disposal facilities (TSDFs). Only the substantive requirements of RCRA must be met if a CERCLA action is to be conducted on-site (do not require RCRA permits, nor compliance with the administrative requirements). Standards applicable to generators include requirements for waste determination, reporting, shipment, packaging, labeling, accumulation, documentation, and recordkeeping. In California, the State's promulgated regulations replace the equivalent Federal regulations as potential ARARs. See RCRA 3006(b), and 40 CFR §271. See Chapter 6.5 of H&S Code (HWCA), §25100 et seq.	DNAPL associated with the former operations of the Montrose plant may be classified as a California and/or RCRA hazardous waste, if the source of any toxic constituents (such as MCB) in the DNAPL is known (i.e., a listed waste). If the source of the toxic constituents is not generally known, the DNAPL may still be classified as a characteristic hazardous waste (e.g., toxicity, flammability, etc…). If the source of the toxic constituents is generally not known and the DNAPL and/or DNAPL-related waste (e.g., filters or PPE) is not characteristically hazardous, then the waste will not be classified as hazardous. In the course of remediating the DNAPL contamination, DNAPL and/or DNAPL-related waste will be generated, accumulated and possibly stored, and transported for off-site disposal.	X			RAs 3-6b

Table 3-1
DNAPL ARARs and TBCs
Montrose Superfund Site

Authority	Citation	Synopsis of Requirement	Action to be Taken to Attain Requirement	Applicable	Relevant and Appropriate	TBC	Remedial Alternative
Resource Conservation and Recovery Act (RCRA) Interim Control of Hazardous Waste Injection	42 U.S.C. § 6939b(b)	Under 42 U.S.C. §6939b(b), for actions under CERCLA, contaminated groundwater must be treated to substantially reduce hazardous constituents prior to reinjection into the aquifer from which it was withdrawn, if the water-bearing units beneath the site are a underground source of drinking water.	Hazardous constituents in extracted groundwater will be substantially reduced prior to reinjection either through removal of separate-phase DNAPL and/or through removal of dissolved-phase constituents. The degree of reduction that will be considered "substantial" will be determined on a case-by-case basis.	X			RAs 4a-4b
Code of Federal Regulations and California Code of Regulations Land Disposal Restrictions	40 CFR Part 268 et seq., 22 CCR §66268 et seq.	Chapter 18 of both 40 CFR and 22 CCR identifies hazardous wastes that are restricted from land disposal and defines those limited circumstances under which an otherwise prohibited waste may continue to be land disposed. This chapter includes regulations governing various aspects of land disposal requirements, including waste analysis, treatment, and storage and recordkeeping. 22 CCR §66268.100 establishes land disposal prohibitions for non-RCRA hazardous wastes.	"Disposal" means: (a) the discharge, deposit, injection, dumping, spilling, leaking or placing of any waste or hazardous waste into or on any land or water so that such waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwaters; (b) the abandonment of any waste. DNAPL remedial alternatives that generate hazardous wastes would be required to comply with the applicable provisions of these regulations. Land disposal restrictions would not be triggered if the media is treated to reduce contaminant concentrations in compliance with the treatment standards.	X			RAs 3-6b
California Code of Regulations Waste Management and Classification	27 CCR §20200-20220	Contains a waste classification system which applies to solid wastes that cannot be discharged directly or indirectly to waters of the state, and which therefore, must be discharged to waste management units (Units) for treatment, storage, or disposal.	Wastes generated during DNAPL remedy implementation would be required to meet these standards.	X			RAs 3-6b
	27 CCR §20220(b), (c), (d)	All non-hazardous waste, except for liquids, may be discharged to a landfill authorized to accept such waste.	Wastes generated during DNAPL remedy implementation would be required to meet these standards.	X			RAs 3-6b
California Hazardous Waste Control Act (HWCA)	California Health and Safety Code §25100, et seq.	HWCA has many elements that control hazardous wastes from their point of generation through handling, treatment, and ultimate destruction or disposal.	Wastes generated during DNAPL remedy implementation would be required to meet these standards.	X			RAs 3-6b
Code of Federal Regulations Requirement for the Underground Injection Control Program	40 CFR Parts 144-148	Underground Injection Control program federal requirements for state programs. Regulations apply to owners or operators of Class I hazardous waste injection wells. Sections 146.61-146.73 set forth criteria and standards applicable to Class I hazardous waste injection wells. Part 148 sets forth hazardous waste injection restrictions.	If a UIC permit is necessary, the remedy will comply with all substantive requirements.		X		RAs 4a-6b
Clean Air Act of 1963 (CAA)	42 USC §7401-7462, 40 CFR Parts 60-69	Establishes National Emissions Standards for Hazardous Air Pollutants (NESHAPs) for those industrial hazardous air pollutants for which no ambient air quality standards exists, but which cause, or contribute to, air pollution that may result in an increase in mortality or an increase in serious irreversible or incapacitating reversible illness.	Since benzene is not anticipated to be present at levels regulated under NESHAPs, those standards are not applicable. Nor are NESHAPs relevant and appropriate for the remedial activities anticipated since the "fugitive leaks" regulations apply to equipment contacting benzene at concentrations greater than 10% by weight.	X			RAs 4a-6b

Table 3-1
DNAPL ARARs and TBCs
Montrose Superfund Site

Authority	Citation	Synopsis of Requirement	Action to be Taken to Attain Requirement	Applicable	Relevant and Appropriate	TBC	Remedial Alternative
		NESHAP standards are currently limited to very few chemicals for specific sources of those contaminants. The standard for benzene, the only chemical found at the Montrose site for which a NESHAP standard exists, varies depending upon the industrial process. Benzene waste operations, including manufacturing processes are regulated in 61.340-61.358. Chloroform, methylene chloride and toluene are also discussed under NESHAPs; however, no specific emission standards are described (40 CFR 61.01; 50 Federal Register (FR) 39626 and 32628 are the notices announcing that chloroform and that chlorinated benzenes are potentially toxic air pollutants and EPA intends to establish emission standards for the compounds).	If benzene is processed during DNAPL remedial alternatives at concentrations meeting the minimum requirements, or if NESHAP standards for chloroform or other site-related toxic air contaminants are promulgated, then the remedial system would be required to comply with these provisions.				
South Coast Air Quality Management District (South Coast AQMD) Regulation II	Rule 201 and 201.1	Requires that any person building, erecting, installing, altering or replacing any equipment which may cause the discharge of air contaminants obtain a permit and construct/operate the equipment in accordance with the permit conditions.	DNAPL remedial alternatives must have vapor control and treatment systems, designed to comply with the substantive portions of South Coast Air Quality Management District requirements.	X			RAs 3-6b
South Coast AQMD Regulation IV	Rule 401	Limits the discharge of visible emissions.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable.	X			RAs 3-6b
	Rule 402	Prohibits discharge of pollutants that (i) cause injury, detriment, nuisance, or annoyance, (ii) endanger the health or safety of the public, or (iii) cause (or tend to cause) injury or damage to business or property.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable.	X			RAs 3-6b
	Rule 403	Requires actions to prevent, reduce, or mitigate fugitive dust.	DNAPL remedial alternatives that involve soil handling during remedy construction will need to comply with these requirements. Fugitive dust would need to be controlled using water spray or other common methods. Measurement of dust levels would be performed to document compliance with this rule.	X			RAs 3-6b
	Rule 404	Prohibits discharge of particulate matter in excess of certain concentrations.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable.	X			RAs 3-6b
	Rule 405	Prohibits discharge of solid particulate matter in excess of certain rates.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable.	X			RAs 3-6b
	Rule 408	Can not build, install or use any equipment that reduces or conceals an emission that would otherwise be a violation.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable.	X			RAs 3-6b
	Rule 409	Limits the emission of particulate matter from a combustion source to 0.10 grain per standard cubic foot, at 12% carbon dioxide, averaged over 15 minutes.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable. This rule is potentially applicable to natural gas fired steam boilers or thermal oxidizers.	X			RAs 3-6b

Table 3-1
DNAPL ARARs and TBCs
Montrose Superfund Site

Authority	Citation	Synopsis of Requirement	Action to be Taken to Attain Requirement	Applicable	Relevant and Appropriate	TBC	Remedial Alternative
	Rule 466	Any pump, compressor, valve, etc exposed to reactive organic compounds must be equipped with adequate seals and in good working order, except for equipment that is exempted from the requirements for reasons listed in the rule, including equipment in contact with liquid with greater than 80% water content.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable.	X			RAs 3-6b
	Rule 474	Limits the concentration of oxides of nitrogen to a range of 125 to 300 ppm for gaseous fuels and 225-400 ppm for solid and liquid fuels depending on equipment size.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable. This rule includes provisions for steam generating equipment, which would be applicable to DNAPL remedial alternatives using steam boilers. This rule would additionally apply to natural gas-fired thermal oxidizers for treatment of vapor-phase contaminants.	X			RAs 3-6b
	Rule 476	Steam generating equipment: Prohibits discharge into the atmosphere of certain combustion contaminants from equipment having a heat input rate of more than 50 million BTUs.	DNAPL remedial alternatives involving steam generating equipment would need to comply with this rule if rated at more than 50 million BTUs.	X			RAs 5a-6b
South Coast AQMD Regulation X	Rule 1001	Regulation of toxic air contaminants. Implements national emissions standards for hazardous air pollutants (NESHAPs) at the local level. Applied to specific process units that discharge specific air toxics.	DNAPL remedial alternatives with process units subject to NESHAP standards, if any, would need to comply with this rule.	X			RAs 3-6b
South Coast AQMD Regulation XI	Rule 1146	Prohibits discharge of certain limits of nitrogen dioxide from steam generators and process heaters rated greater than 5 million BTUs per hour (or between 2-5 million for small operators).	Vapor control and treatment systems associated with DNAPL remedial alternatives (e.g., steam generators used for thermal remediation alternatives) must be designed and operated to comply with these regulations to the extent applicable.	X			RAs 3-6b
	Rule 1166	Regulates volatile organic compound (VOC) emissions from decontamination of soil. This rule establishes requirements for excavation, grading, or handling of soil containing VOCs (i.e., to prevent uncontrolled evaporation of VOCs to the atmosphere). This rule includes requirements for monitoring, odor control, stockpiling, segregation, loading, and transporting VOC-impacted soils. Handling of less than one cubic yard of VOC-impacted soil is exempt from this rule.	DNAPL remedial alternatives that generate more than one cubic yard of VOC-impacted soils (e.g., chlorobenzene) will be subject to this rule. Soil cuttings generated during remedy construction (i.e., well installation) would be subject to this rule and must be handled in a manner consistent with the provisions of this rule to minimize evaporation of VOCs to atmosphere during soil handling.	X			RAs 3-6b
	Rule 1176	Regulates volatile organic compound leaks and emissions from facilities.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable.	X			RAs 3-6b
South Coast AQMD Regulation XIII	Rule 1301	Sets forth pre-construction review requirements for new, modified, or relocated sources/facilities, to ensure that the operation of such facilities does not interfere with progress in attainment of the national ambient air quality standards.	Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with these regulations to the extent applicable.	X			RAs 3-6b
South Coast AQMD Regulation XIV	Rule 1401	New source review of toxic air contaminants. This rule specifies limits for maximum individual cancer risk (MICR), cancer burden, non-cancer acute, and chronic hazard index. This rule limits emissions of toxic air contaminants to: (a) an MICR less than $1x10^{-6}$ for systems without best available control technology (BACT); (b) an MICR less than $1x10^{-5}$ for systems with BACT; (c) a cancer burden less than 0.5; (d) a chronic hazard index less than 1.0; (e) a non-cancer acute hazard index less than 1.0.	This rule establishes the primary air emission limits for site-related toxic air contaminants including chlorobenzene and chloroform. Chloroform contributes to the MICR and cancer burden. Chlorobenzene is not a carcinogen and only contributes to the hazard index. Vapor control and treatment systems associated with DNAPL remedial alternatives must be designed and operated to comply with this rule.	X			RAs 3-6b

Table 3-1
DNAPL ARARs and TBCs
Montrose Superfund Site

Authority	Citation	Synopsis of Requirement	Action to be Taken to Attain Requirement	Applicable	Relevant and Appropriate	TBC	Remedial Alternative
South Coast AQMD	Rule 1470	Requirements for Stationary Diesel-Fueled Internal Combustion and Other Compression Ignition Engines. This rule applies to any person who owns or operates a stationary IC engine in the South Coast Air Quality Management District with brake horsepower greater than 50. This rule controls the particulate matter emissions from such engines by establishing fuel requirements, operating requirements, emission standards, and reporting and monitoring requirements.	During implementation of the DNAPL remedy (primarily during construction), large diesel engines may be used for specific tasks, e.g., drilling rigs, air compressor, or mobile generator. For diesel engines with greater than 50 brake horsepower, only engines with valid and current SCAQMD emission certificates will be used. Any large diesel engines without a valid emissions certification will be prohibited from working at the site.	X			RAs 3-6b
Land Use Covenant Regulation	22 CCR §67391.1 (a), (d)	Establishes substantive requirements for land use restrictive covenants. If hazardous materials, hazardous wastes, or constituents, or hazardous substances will remain at the property after implementation of the remedy at levels which are not suitable for unrestricted use of the land, this requirement would be relevant and appropriate.	A response action decision document which includes limitations on land use or other institutional controls, requires that the limitations or controls are clearly set forth and defined in the response action decision document, specifies that the limitation or controls will be incorporated into a an appropriate land use covenant as required by Section 67391.1, and includes an implementation and enforcement plan. All DNAPL remedial alternatives will be subject to these standards.		X		RAs 1-6b
Environmental Covenant Requirements	CA Civil Code §1471	Specifies manner by which environmental covenants are recorded and binding on successors to the land restricted by the covenant.	If hazardous materials, hazardous wastes or constituents, or hazardous substances will remain at the property after implementation of the remedy at levels which are not suitable for unrestricted use of the land, this requirement would be relevant and appropriate. All DNAPL remedial alternatives will be subject to these standards.		X		RAs 1-6b
Mandatory Greenhouse Gas Reporting Rule	40 CFR Part 98	Establishes reporting requirements for sources generating in excess of 25,000 metric tons per year of greenhouse gases.	Estimated emissions of greenhouse gases, certified by a third party, must be submitted to EPA.		X		RAs 3-6b
TO BE CONSIDERED (TBCs)							
California Well Standards, Department of Water Resources	Bulletins 74-90 and 74-81	Provides minimum construction and destruction/abandonment criteria and specifications for groundwater monitoring wells, extraction wells, injection wells, and exploratory borings. The standards are meant to be a model of minimum standards and are enforced locally through Los Angeles County, but are not enforced by the State.	Design, construction, and destruction of wells or borings into the saturated zone must comply with the substantive portions of these standards. Hydraulic displacement and thermal remediation technologies would include wells installed within the saturated zone at the Site and would be subject to these standards.			X	RAs 4a-6b
California Global Warming Solutions Act of 2006 (AB32)	Heath and Safety Code §38500 et seq.	California is committed to reducing greenhouse gas emissions to 1990 levels by 2020, which is a reduction of approximately 25%. AB32 includes mandatory reporting rules for significant sources, adoption of a greenhouse gas emissions reduction plan, and adoption of greenhouse gas emission reduction regulations.	The amount of greenhouse gas emissions generated by the candidate DNAPL remedial alternatives will be evaluated. Remedial alternatives that emit high amounts of greenhouse gases will not be ranked as highly as other alternatives for short-term effectiveness.			X	RAs 3-6b
EPA Superfund Green Remediation Strategy, September 2010	"Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites"	Encourages consideration and implementation of "green" alternatives for remedial activities, with a focus on energy use, air emissions, water requirements and impacts on water resources, land and ecosystem impacts, material consumption and waste generation and long-term stewardship actions (including reduction of greenhouse gases).	Impact on the environment of all candidate DNAPL remedial alternatives will be evaluated, including evaluation of energy use, waste generation, and greenhouse gas emissions. Alternatives that emit higher quantities of greenhouse gases will not be ranked as highly as other alternatives for short-term effectiveness.			X	RAs 3-6b

Table 3-1
DNAPL ARARs and TBCs
Montrose Superfund Site

EPA Region 9, Cleanup-Clean Air Initiative, March 2008	Smart Energy Resources Guide (SERG), EPA/600/R-08/049	The Smart Energy Resources Guide was created for Region 9's Cleanup-Clean Air Initiative (CCA). The CCA seeks to aid the Superfund Program to remediate sites in a manner that minimizes environmental impacts and to set positive examples for the public and other agencies. The SERG provides information on emissions reduction opportunities to help Superfund remedial project managers make economic decisions about reducing greenhouse gas emissions from energy use in remediation activities at Superfund sites.	Evaluate greenhouse gas emissions from energy use for the various candidate DNAPL remedial alternatives. Alternatives that emit higher quantities of greenhouse gases will not be ranked as highly as other alternatives for short-term effectiveness.			X	RAs 3-6b
EPA Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites, April 2008	EPA 542-R-08-002 Office of Solid Waste and Emergency Response, Technology Primer	Outlines the principles of green remediation and describes opportunities to reduce the footprint of cleanup activities throughout the life of a project. Identifies a range of alternatives to improve sustainability of cleanup activities and help decision-makers balance the alternatives within existing regulatory frameworks. Best management practices (BMPs) are identified to help decision-makers and other stakeholders identify new strategies for sustainability. Primer provides tools to navigate the range of green remediation options and introductory information on use of renewable energy sources.	Evaluate greenhouse gas emissions from energy use for the various candidate DNAPL remedial alternatives. Alternatives that emit higher quantities of greenhouse gases will not be ranked as highly as other alternatives for short-term effectiveness. BMPs and other tools identified in the Technology Primer can also be used to maximize the sustainability of the DNAPL remedy following selection and during design, construction, and cleanup operations.			X	RAs 3-6b
EPA Principles for Greener Cleanups, August 2009	EPA Office of Solid Waste and Emergency Response	Optimize environmental performance and implement protective cleanups that are greener by increasing understanding of the environmental footprint, and when appropriate, taking steps to minimize that footprint. Promotes green cleanup practices that help achieve cleanup objectives by ensuring protectiveness while decreasing the environmental footprint of the cleanup activity. Intended to improve the decision-maker process for cleanup activities in a way that protects human health and the environment and reduces the environmental impact on communities. Approaches included environmental footprint assessment, resource efficiency, best management practices, and technology innovation.	Evaluate greenhouse gas emissions from energy use for the various candidate DNAPL remedial alternatives. Alternatives that emit higher quantities of greenhouse gases will not be ranked as highly as other alternatives for short-term effectiveness. Resource efficiency and best management practices can be carried forward into remedy design, construction, and implementation.			X	RAs 3-6b
DTSC Interim Advisory for Green Remediation, December 2009		Introduces the concepts of sustainability and life-cycle management and shows how to incorporate the concepts into any stage of environmental cleanup, including feasibility study phase. Provides the green remediation evaluation matrix (GREM) tool for performing qualitative comparisons of treatment alternatives. Overall goal of advisory is to introduce principles of sustainability and life cycle management related to green remediation and formulate them into a tool that decision-makers, project managers, and responsible parties can use.	Evaluate greenhouse gas emissions from energy use for the various candidate DNAPL remedial alternatives. Alternatives that emit higher quantities of greenhouse gases will not be ranked as highly as other alternatives for short-term effectiveness. Concepts of sustainability and life cycle management can be carried forward into remedy design, construction, and implementation.			X	RAs 3-6b

Section 4.0

Identification and Screening of DNAPL Remedial Technologies and Process Options

4.0 IDENTIFICATION AND SCREENING OF DNAPL REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS

The purpose of this section of the DNAPL FS is to initially screen a list of potentially applicable remedial technologies and process options for each GRA identified in Section 3.2. The remedial technologies and process options are initially screened against three performance criteria including effectiveness, implementability, and relative cost. Remedial technologies and process options retained following this initial screening are then assembled into remedial alternatives as described in Section 5.0.

Several broad technology types may be identified for each GRA, and numerous technology process options may exist within each technology type. The term "technology process options" refers to specific processes within each technology type. For example, ex-situ treatment of soil vapors is a technology type that includes such process options as disposable carbon adsorption, steam-regenerable carbon adsorption, and thermal oxidation. A list of remedial technologies and process options considered for each GRA is provided below:

Candidate Remedial Technologies and Process Options

General Response Action	Remedial Technology/Process Option
No Action	None
Institutional Controls	Deed Restrictions
	Access Restrictions
	Limit Groundwater Use
	DNAPL and Groundwater Monitoring
Containment	Barrier Walls
Extraction Technologies	Soil Vapor Extraction (unsaturated zone)
	Excavation (conventional or large diameter auger)
	Passive DNAPL Extraction
	Hydraulic Displacement (with water injection)
	Surfactant Injection
	Cosolvent Injection
	Polymer Flooding
	Alcohol Flooding
In-Situ Non-Thermal Technologies	In-Situ Bioremediation
	Stabilization (Deep Soil Mixing)
	In-Situ Chemical Reduction using Zero-Valent Iron
	In-Situ Chemical Oxidation
In-Situ Thermal Technologies	Electrical Resistance Heating
	Conductive Heating
	Steam Injection
Ex-Situ Groundwater Treatment	Liquid-Phase Granular Activated Carbon (for MCB) and Advanced Oxidation (for pCBSA)
Ex-Situ Vapor Treatment	Thermal Oxidation with Acid Gas Scrubbing
	Regenerable Carbon/Resin Adsorption
	Disposable Carbon/Resin Adsorption
Disposal	Injection of Treated Water as part of Groundwater Remedy
	Injection of Treated Water as part of Hydraulic Displacement
	Injection of Untreated Water as part of Hydraulic Displacement
	Off-Site Incineration of DNAPL

The remedial technologies and process options are initially screened based on three performance criteria prescribed in the Guidance for Conducting Remedial Investigations and Feasibility Studies under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (EPA, 1988) and summarized as follows:

Effectiveness. Each specific technology is evaluated based on its relative effectiveness in meeting RAOs and protecting human health and the environment. Remedial technologies and process options are evaluated and ranked as effective, moderately effective, minimally effective, potentially effective, or ineffective. The term "potentially effective" indicates that the effectiveness is uncertain. Technologies identified with this ranking are potentially effective, but there is insufficient evidence to further qualify the effectiveness as minimally effective, moderately effective, or effective. A potentially effective ranking is greater than an ineffective ranking but is not necessarily any better or worse than the other three effectiveness rankings. This evaluation includes:

- The effectiveness of the remedial technology or process option in achieving the RAOs,
- The potential impacts to human health and the environment during the construction and implementation phase, and
- The reliability of the remedial technology or process option with respect to the contaminants and conditions at the Site.

Implementability. Each remedial technology is evaluated based on the technical and administrative feasibility of implementing the specific technology. Technical feasibility refers to the applicability or compatibility of a remedial process option to site conditions and contaminants of concern. Administrative feasibility refers to such issues as permitting and availability of equipment, among other factors. Each technology is evaluated and ranked as implementable, difficult to implement, or not implementable.

Cost. A limited cost evaluation is performed in this screening phase and is based primarily on engineering judgment and technology vendor experience. Capital costs, such as construction costs, and long-term monitoring or operation and maintenance costs are considered. Each option is evaluated and ranked as very high, high, medium, low, or no cost.

Retention. Following preliminary screening against the above-referenced three performance criteria, a determination is made whether to retain the process options for assembly into remedial alternatives. Process options which are potentially effective and implementable are retained for further consideration. Process options which are not likely to be effective or implementable are eliminated from further

consideration. Relative cost is considered in the determination but is not, by itself, a criterion for eliminating a process option from further evaluation.

As described in Section 2.0, DNAPL occurs at the Site in both the unsaturated zone and saturated UBA. Remedial technologies and process options may be applicable to one or both of the DNAPL-impacted zones. Where application of a remedial technology is fundamentally unique to a particular zone, preliminary screening of the technology is conducted separately for that zone. Where a remedial technology is applicable to both zones and not unique to either, preliminary screening is conducted simultaneously for both zones. Preliminary screening of the DNAPL remedial technologies and process options against the three performance criteria is presented in **Table 4.1** and discussed in the following sections. In preparing this FS, Montrose consulted with a wide range of DNAPL industry experts and academics in evaluating candidate DNAPL remedial technologies including:

- Dr. Bernie Kueper of Queen's University;
- Dr. Brent Sleep of the University of Toronto;
- Dr. Paul Johnson of Arizona State University; and
- Dr. Bruce McGee of McMillan-McGee Corporation.

EPA additionally consulted with Dr. David Huntley of San Diego State University in reviewing the 2009 version of the DNAPL FS and in reconciling outstanding technical issues leading to the 2011 Revised FS. Remediation of DNAPL from a low permeability, heterogeneous, and saturated aquitard such as the UBA poses numerous technical challenges, and consultation with industry experts was necessary to realistically evaluate candidate DNAPL remedial technologies as described in the following sections.

4.1 NO ACTION

The "No Action" GRA is included in accordance with CERCLA and the NCP. This GRA involves no further action at the Site other than those actions implemented as part of the soil and/or groundwater remedies. The No Action GRA is evaluated simultaneously for both the unsaturated and saturated zones.

Process Description. No further action would be taken at the Site regarding DNAPL other than actions conducted as part of the soil and groundwater remedies. Currently, the Site is covered with a temporary asphalt cap to reduce exposure to shallow unsaturated soils and soil gas containing contaminants of concern. The temporary asphalt cap also reduces the infiltration of rainwater and the rate of contaminant leaching into groundwater from the unsaturated zone. A soil remedy has not yet been selected for the Site but is expected to effectively protect human health and the environment from exposure to shallow contaminated soils and soil gas. Groundwater within the TI Waiver Zone and DNAPL-impacted zones

will be hydraulically contained and monitored in the long-term during remedy implementation, as described in Sections 4.3 and 4.2.4 respectfully. Groundwater use within the TI Waiver Zone will also be restricted as described in Section 4.2.3.

Effectiveness. The No Action GRA would not meet DNAPL RAOs or be protective of human health and the environment. Although the No Action GRA is by definition a reliable process with no adverse impacts, the mass of mobile DNAPL would not be reduced to the extent practicable under the No Action GRA. Consequently, the potential for uncontrolled migration of the mobile DNAPL and recontamination of the aquifers would remain in the long-term. Although dissolved-phase MCB would be hydraulically contained by the groundwater remedy and DNAPL mass slowly reduced over time through dissolution, the probability of containing the dissolved-phase plume is not increased by the No Action GRA. Additionally, institutional controls would not be in place to protect human health against exposure to DNAPL, although institutional controls for soil and groundwater are likely to limit contaminant exposure pathways at the Site and protect human health to some extent. Also, VOC migration in soil gas would not be controlled in the unsaturated zone under the No Action GRA. ***Rank: Not Effective.***

Implementability. By definition, the No Action GRA is highly implementable. ***Rank: Implementable.***

Cost. By definition, there is no cost associated with the No Action GRA. ***Rank: No Cost.***

Retain for Assembly of Remedial Alternatives? As required by the NCP, the No Action GRA will be retained for further evaluation as the baseline for comparison with other remedial technologies and process options. ***Retained? Yes.***

4.2 INSTITUTIONAL CONTROLS

Institutional controls include process options for reducing or eliminating potential exposure to the contaminated media, and they maintain compatible Site use. T he applicable process options for institutional controls include deed restrictions, access restrictions, limitations on groundwater use, and groundwater monitoring. Each of these process options are evaluated in the following sections.

4.2.1 DEED RESTRICTIONS

Process Description. Legal restrictions can be added to a Deed of Trust that would limit future use of the Site (e.g. industrial use only). These limitations would address any Site use that may impair protection of human health and the environment such as excavation, drilling, or construction activities. A soil remedy has not yet been selected for the Site, but it is anticipated that deed restrictions will be put in place as part

of the soil remedy to protect human health and the environment from exposure to shallow contaminated soil and soil gas.

Effectiveness. Deed restrictions would be effective in limiting future use of the Property and reducing the potential for human exposure to contaminated media. This institutional controls process option meets some of the DNAPL RAOs, and when combined with other GRA process options, would be effective in protecting human health. There are no adverse impacts to human health or the environment associated with the implementation of this process option. This process option is reliable, particularly because much of the area that requires a deed restriction is within the Montrose Property and under the control of Montrose. DNAPL mass will be slowly reduced in the long-term by dissolution and the hydraulic containment aspect of the groundwater remedy as specified in Section 4.3. However, this process option does not reduce the mass of mobile DNAPL to the extent practicable, limit the potential for DNAPL migration, or reduce the potential for recontamination of the underlying aquifer units. ***Rank: Minimally Effective.***

Implementability. There are no technical or administrative aspects that would limit the implementability of recording a deed restriction for the on-Property portion of the Site, where nearly all of the DNAPL occurs in the subsurface. However, a small portion of the DNAPL may be present below the adjacent property to the north (GLJ Holdings property), and application of deed restrictions at the off-Property areas would require consent of the land owners. ***Rank: Implementable.***

Cost. The relative cost for this alternative is low. ***Rank: Low.***

Retain for Assembly of Remedial Alternatives? Deed restrictions will be retained as a process option for limiting actions which may create exposure to contaminated media. Since some residual DNAPL mass is likely to be left in place following any remedy that may be implemented, this process option is expected to be a required component of the selected remedial alternative. In addition, this institutional controls process option very likely will be a required component of a soil remedy. ***Retained? Yes.***

4.2.2 ACCESS RESTRICTIONS

Process Description. Site access can be limited using physical means such as fences, walls, guards, or security systems. Currently, Site access is restricted by a perimeter chain-link and wrought iron fence, and "No Trespassing" signs are posted along the fenced perimeter. A soil remedy has not yet been selected for the Site, but it is anticipated that access restrictions will be put in place as part of the soil remedy to protect human health and the environment from exposure to shallow contaminated soil and soil gas.

Effectiveness. Access limitations can be effective in reducing the potential for human exposure to Site contaminants. This institutional controls process option meets some of the DNAPL RAOs, and when combined with other GRA process options, would be effective in protecting human health. There are no adverse impacts to human health or the environment associated with the implementation of this process option. This process option is reliable, particularly because much of the area that requires access restriction is within the Montrose Property and under the control of Montrose. DNAPL mass will be slowly reduced in the long-term by dissolution and the hydraulic containment aspect of the groundwater remedy as specified in Section 4.3. However, this process option does not reduce the mass of mobile DNAPL to the extent practicable, limit the potential for DNAPL migration, or reduce the potential for recontamination of the underlying aquifer units. ***Rank: Minimally Effective.***

Implementability. There are no technical or administrative aspects that would limit the implementability of this process option. This process option does not require any special equipment or personnel. ***Rank: Implementable.***

Cost. The relative cost for this alternative is low. ***Rank: Low.***

Retain for Assembly of Remedial Alternatives? Access limitations are retained as a process option for reducing the potential for human exposure to contaminated media, particularly when combined with other response actions, such as deed restrictions. Since some residual DNAPL mass is likely to be left in place regardless which remedy is implemented, this process option is expected to be a required component of the selected remedial alternative. In addition, this institutional controls process option will very likely be a required component of a soil remedy. ***Retained? Yes.***

4.2.3 LIMIT GROUNDWATER USE

Process Description. Limitations on groundwater use can reduce potential exposure to contaminants and aid in maintaining the integrity of remedial activities. There are several means of restricting use at the Site, including the authority of the Watermaster. Limitations on groundwater use may range from providing notice to future owners of the affected property of the nature and extent of the environmental impacts at the Site, to restricting the use of groundwater. Groundwater use restrictions may limit the ways in which groundwater may be used, or may completely prohibit extraction of groundwater. Legal restrictions can be added to a Deed of Trust that would limit groundwater use. This institutional controls process option is a required component of the groundwater remedy.

Effectiveness. Limiting groundwater use would be effective in eliminating potential exposure routes to DNAPL. Effective means of restricting site use include zoning or land use controls and limitations on

groundwater use. Zoning controls are put in place under the authority of the City of Los Angeles or the State of California. This institutional controls process option meets some of the DNAPL RAOs, and when combined with other GRA process options, would be effective in protecting human health. There are no adverse impacts to human health or the environment associated with the implementation of this process option. DNAPL mass will be slowly reduced in the long-term by dissolution and the hydraulic containment aspect of the groundwater remedy as specified in Section 4.3. However, this process option does not reduce the mass of mobile DNAPL to the extent practicable, limit the potential for DNAPL migration, or reduce the potential for recontamination of the underlying aquifer units. ***Rank: Minimally Effective.***

Implementability. Limitations on groundwater use may be implemented such that future activity at the Property is compatible with the presence of impacted groundwater. In this case, the restrictions could preclude residential use of the property, prohibit installation of groundwater wells for potable or non-potable use, and generally restrict uses not otherwise required by the groundwater remedy. It is anticipated that the community and the City will desire Site use options which are compatible with surrounding land uses, whenever possible, providing they are consistent with maintaining the integrity of the remedial actions. ***Rank: Implementable.***

Cost. The cost for this process option is low. ***Rank: Low.***

Retain for Assembly of Remedial Alternatives? This process option is retained because of its effectiveness in reducing the potential for human exposure to contaminated groundwater, particularly when combined with other response actions. This institutional controls process option is a required component of the groundwater remedy. ***Retained? Yes.***

4.2.4 DNAPL AND GROUNDWATER MONITORING

Process Description. Monitoring can be performed to determine if DNAPL is migrating laterally or vertically within the subsurface. The sudden appearance of DNAPL in wells that have not contained DNAPL for a significant period of time following installation would be an indication of DNAPL pool migration. Changes in the concentration of dissolved DNAPL constituents in groundwater can be monitored to indirectly assess DNAPL migration. This process option would potentially require installation of wells dedicated for the purpose of monitoring DNAPL. Groundwater monitoring is a required component of the groundwater remedy.

Effectiveness. Monitoring of DNAPL and groundwater can be effective in assessing possible migration of DNAPL or dissolved constituents to other hydrologic units. This institutional controls process option

meets some of the DNAPL RAOs, and when combined with other GRA process options, would be effective in protecting human health. There are no adverse impacts to human health and the environment associated with the implementation of this process option. DNAPL mass will be slowly reduced in the long-term by dissolution and the hydraulic containment aspect of the groundwater remedy as specified in Section 4.3. However, this process option does not reduce the mass of mobile DNAPL to the extent practicable, limit the potential for DNAPL migration, or reduce the potential for recontamination of the underlying aquifer units. ***Rank: Minimally Effective.***

Implementability. There are no technical or administrative aspects that would limit the implementability of this process option. A series of DNAPL and groundwater monitoring wells would be required downgradient, down dip, and beneath current sources to monitor for evidence of DNAPL migration. Similar wells were previously installed at the Site during DNAPL and groundwater characterization activities, and it is assumed that installation of similar wells would not pose any significant implementability challenges. ***Rank: Implementable.***

Cost. The relative cost for this process is low. ***Rank: Low.***

Retain for Assembly of Remedial Alternatives? This process option is retained because of its effectiveness in assessing possible migration of DNAPL or aqueous phase plumes derived from DNAPL dissolution, particularly when combined with other response actions. This institutional controls process option is a required component of the groundwater remedy. ***Retained? Yes.***

4.3 CONTAINMENT

4.3.1 BARRIER WALLS

Process Description. Barrier walls are a process option for physically containing DNAPL sources in the subsurface. Barrier walls can be used to control lateral migration of DNAPL in the subsurface and are commonly implemented in conjunction with some type of source area DNAPL mass reduction technology. However, barrier walls will not restrict vertical migration of DNAPL, which is the primary concern at the Montrose Site. Common methods for establishing barrier walls include (a) slurry walls, (b) sheet piling, and (c) grout curtains. Each of these common methods are briefly described below:

- Slurry Walls: For this type of physical barrier, trenches are excavated using conventional construction methods and filled with a cement-bentonite slurry. Slurry walls are limited by the depth of conventional excavation methods and are not fully impermeable to dissolved-phase flow.

- Sheet Piling: For this type of physical barrier, a series of interlocking steel sheets are driven or vibrated into the subsurface without any soil removal. Sheet piling is typically limited to relatively shallow depths (i.e., shallower than the base of the UBA) depending on the soil density. However, the sheets are subject to corrosion and are not a permanent remedy. Additionally, the joints between sheets require an effective seal or gasket to prevent leakage.

- Grout Curtain: For this type of physical barrier, a series of very closely spaced soil borings are drilled and pressure grouted using a cement-bentonite slurry. Grout curtains can be installed to greater depth than slurry walls but are subject to similar limitations of dissolved-phase flow.

Effectiveness. Barrier walls such as those described above may be effective in preventing lateral migration of mobile DNAPL at the Site, at least in the short-term. Given the depth of DNAPL-impacts at the Site (105 feet bgs and 45 feet below the water table), a grout curtain is likely the most applicable. Sheet piling may also be effective but is not a permanent solution and likely would have difficulty reaching a target depth of 105 feet bgs. Sands between approximately 25 and 45 feet bgs are relatively dense, and a hard cemented layer at approximately 45 feet bgs has previously obstructed soil sampling using CPT rigs. Using conventional trenching equipment, slurry walls are likely infeasible at the Montrose Site given the depth of DNAPL impacts.

However, none of the above barrier wall methods will prevent vertical migration of mobile DNAPL at the Site, which is one of the principal threats to be addressed by the DNAPL remedy. For effective containment of mobile DNAPL, barrier walls must be keyed into an existing, continuous, and effective capillary barrier (such as a thick clay layer) that underlies the DNAPL. However, no such capillary barrier exists at the Montrose Site. The DNAPL-impacted UBA is underlain by the Bellflower Sand Aquifer. Furthermore, the barrier wall would have to be permanent if not combined with some other DNAPL mass reduction technology. Corrosion or chemical impacts to the barrier wall would be a significant concern as a long-term permanent remedy. ***Rank: Not Effective.***

Implementability. Construction of barrier walls at the Montrose Site by at least one of the methods described above would be implementable. Although construction of slurry walls using conventional trenching methods would likely be infeasible, sheet piling or a grout curtain could potentially be implemented to prevent lateral migration of mobile DNAPL in the short-term. A grout curtain is the most implementable of the barrier wall methods but would require a significant number of borings along the roughly 1,000 linear foot perimeter of the mobile DNAPL extent. This barrier wall method would generate a significant amount of soil waste, some of which would be hazardous and require off-site incineration. ***Rank: Implementable.***

Cost. Given the depth of the DNAPL-impacted area, the cost of barrier walls would be low to medium depending on the method used, linear footage of the wall, and volume of hazardous soils generated, if any. Construction of a barrier wall to 105 feet bgs along a mobile DNAPL circumference of approximately 1,000 linear feet would likely be a medium cost, particularly if hazardous soils were generated during construction. ***Rank: Medium.***

Retain for Assembly of Remedial Alternatives? Containment via barrier walls will not prevent vertical migration of mobile DNAPL, which is a principal threat at the Site. ***Retained? No.***

4.4 EXTRACTION TECHNOLOGIES

Process options associated with this GRA include direct extraction of DNAPL from the subsurface. The majority of the process options evaluated in this section include extraction of DNAPL or DNAPL/groundwater. However, MCB, a volatile component of DNAPL, can additionally be removed as a vapor-phase constituent in soil gas from the unsaturated zone. Extraction technologies evaluated in this section include SVE, passive DNAPL recovery, hydraulic displacement, and four process options for enhanced DNAPL recovery. The four process options for enhanced DNAPL recovery are discussed in Sections 4.4.4 through 4.4.7 and include surfactant injection, cosolvent injection, polymer flooding, and alcohol flooding. These four process options are all mobilization technologies that are very similar in nature, and therefore, the performance evaluation of these process options is also similar. These process options do not involve in-situ destruction or thermal remediation of DNAPL, which are discussed in subsequent sections.

4.4.1 SOIL VAPOR EXTRACTION

Process Description. SVE is a remedial technology for removing VOCs, including MCB, from permeable unsaturated soils. VOCs occurring in the unsaturated zone, sorbed to soil grains or as a component of DNAPL, will partition into soil gas (air-filled pore spaces) according to their physical properties and can be extracted using SVE. Under this process option, a series of extraction wells would be positioned throughout the VOC-impacted unsaturated zone, and a vacuum would be applied to wells to induce soil vapor flow through permeable soil layers. The soil vapors are extracted from the wells using a vacuum blower and treated ex-situ prior to atmospheric discharge.

The basic components of this technology include unsaturated zone extraction wells, vacuum blowers, and a piping network. SVE can be implemented as a stand-alone technology for the unsaturated zone or as a component of saturated zone technologies that convert liquid-phase contaminants to vapor-phase (e.g.

thermal technologies). SVE will not remove the non-volatile DDT component of DNAPL and is not applicable to the saturated zone (i.e., water-filled pore spaces). With the exception of DNAPL extraction by hydraulic displacement, all of the remedial process options discussed in this DNAPL FS will result in DDT being left in the subsurface, either in the unsaturated zone or below the water table, once the volatile MCB component is removed. DDT is a hazardous substance, and the volume or mass of DDT removed by the candidate RAs is presented in this FS. However, DDT is relatively insoluble in water and does not pose a significant risk to groundwater resources. The MCB component of the DNAPL is the principal threat to groundwater resources, and MCB removal is weighed more heavily than DDT removal.

Effectiveness. SVE is highly effective in reducing DNAPL mass and mobility in permeable unsaturated soils and meets DNAPL RAOs. The effectiveness of SVE is primarily dependent on two factors, contaminant volatility and soil permeability to air. SVE will be effective for removal of volatile contaminants from permeable soils. SVE will be significantly less effective (or ineffective) for removal of contaminants from low permeability soils or for removal of semi-volatile or non-volatile contaminants. The effectiveness of SVE to remove MCB and other VOCs from the unsaturated zone was tested in 2003, as summarized in Section 2.6.4. Based on the pilot test results, SVE was found to be effective for removal of MCB and other VOCs from the PVS (25-45 feet bgs) and unsaturated UBA (45-60 feet bgs). Between 223 and 472 pounds per day of VOCs was removed from one well screened within each of these two unsaturated zone layers, where approximately 261,000 pounds of MCB is estimated to occur (Section 2.2.4). The effective radius of influence observed during the pilot test was 123 feet for the PVS and 64 feet for the unsaturated UBA. However, SVE was found to be significantly less effective for removal of MCB and other VOCs from the low permeability PD (4-25 feet bgs), which was composed of primarily silts and clays. An elevated vacuum of 18 inches of mercury was required to initiate soil vapor flow in the PD, and subsequently, a significant amount of vertical communication between the PD and underlying PVS was observed. Control of VOC migration in soil gas from the PD to land surface is being addressed as part of the Soil FS.

Although SVE will not remove the non-volatile DDT component of the DNAPL, the mobility of the DNAPL in the unsaturated zone would be significantly reduced by vaporization of the MCB component. As the MCB component of the DNAPL is vaporized, the DDT component will precipitate, sorb to soil, and become relatively immobile in the environment (DDT tends to sorb strongly to soil). Removal of the MCB component of the DNAPL is an effective method for reducing the mass and mobility of the DNAPL in the subsurface. Implementation of SVE would additionally control and prevent VOC migration in soil gas within the unsaturated zone. SVE will not be effective in treating any DNAPL in the saturated zone (water-filled pore spaces). Additionally, the water table has been slowly rising for several years as

indicated in Section 1.5.2, and continued rising of the water table will reduce the thickness of the unsaturated UBA available for application of SVE. ***Rank: Effective.***

Implementability. There are no technical or administrative aspects that would limit the implementability of this remedial technology. A remedial alternative including SVE would have to meet ARARs for air emissions. ***Rank: Implementable.***

Cost. The relative cost for SVE is medium. While the cost of extracting soil vapors is low, the cost to treat the soil vapors ex-situ increases the ranking to medium. Ex-situ soil vapor treatment process options are evaluated in Section 4.8. ***Rank: Medium.***

Retain for Assembly of Remedial Alternatives? SVE is retained because of its effectiveness in extracting MCB and other VOCs from permeable unsaturated soils, specifically the PVS and unsaturated UBA. ***Retain? Yes.***

4.4.2 EXCAVATION

Process Description. Excavation is the process of physically removing DNAPL-impacted soils from the subsurface using mechanical methods. Conventional methods include use of a backhoe or excavator with sidewall sloping, benching, or shoring as needed for deeper excavations. Alternately, a large diameter auger (LDA) can be used to remove soils vertically across a 5 to 12 foot diameter.

Effectiveness. Excavation of the DNAPL-impacted soils at the Montrose property using conventional methods is infeasible. DNAPL-impacted soils occur over an area of approximately 160,000 square feet and to a depth up to 105 feet bgs, which is approximately 45 feet below the water table and equivalent to between 9 and 10 stories deep. Significant bench sloping would be required using conventional methods, and there is insufficient room at the Montrose property to accommodate this type of excavation approach. There are active industrial and commercial businesses located adjacent to the Montrose property, including commercial warehouses that border the northern extent of DNAPL at the Site and a chlorine plant at the southern border. Also bordering the DNAPL-impacted area are the Kenwood Avenue soil cells to the west and the groundwater remediation system to the east. Furthermore, the amount of dewatering required to support a conventional excavation to this depth would be substantial and would pose significant health hazards given the high concentrations of MCB within the DNAPL-impacted area.

Given the depth of the DNAPL impacts to soil, the only excavation method that could reasonably be considered would be LDA. Even using this method, excavation of the DNAPL-impacted soil would be infeasible and would require thousands of closely spaced borings. Some type of large structure would be

required to control odors, vapor emissions, and DDT-impacted dust during soil excavation. MCB has a low odor threshold, and elevated VOC concentrations in soil vapor exceeding 10,000 parts per million by volume were previously detected during soil vapor extraction testing at the Site. Even with proper engineering controls, excavating such a massive quantity of DNAPL-impacted soils at the Site would likely pose significant air emission risks to the surrounding neighbors, commercial businesses, and downwind residents. Excavation is typically an effective method for removing DNAPL-impacted soils, but given the setting, depth, and conditions at the Montrose Site, this process option is infeasible. ***Rank: Infeasible.***

Implementability. As described above, excavation of DNAPL-impacted soils at the Montrose Site is infeasible, and therefore, is also not implementable. Drilling of thousands of closely spaced LDA borings is not a realistic approach for excavation of the DNAPL-impacted soils at the Site. This process option would generate massive quantities of hazardous waste requiring handling at the property and subsequent off-site transport. A large engineered structure would be required to enclose the excavation area for purposes of controlling odors, VOC emissions, and DDT-impacted dust exposure. Given the size and depth of the DNAPL-impacted soils, and the proximity of neighboring businesses, excavation is not implementable at the Site. ***Rank: Not Implementable.***

Cost. Even if excavation were technically feasible at the Montrose Site, the cost of this process option would be prohibitively high. Excavation of the entire DNAPL-impacted area by LDA would require literally thousands of borings. This process option would generate up to approximately 1 million tons of hazardous soils requiring off-site incineration at a cost of roughly $500 million. <u>The estimated cost to excavate all of the DNAPL-impacted soils using LDA, backfill with cement, and T&D the excavated soil for off-site disposal would be roughly $1 billion.</u> ***Rank: Prohibitively High Cost.***

Retain for Assembly of Remedial Alternatives? This process option is not retained because excavation of DNAPL-impacted soils at the Montrose Site is infeasible. Even if this process option were feasible, it would be cost prohibitive. ***Retained? No.***

4.4.3 PASSIVE EXTRACTION OF DNAPL

Process Description. Passive extraction is a process option for removal of mobile DNAPL that accumulates in wells (gravity induced migration) screened within the saturated UBA. As described in Section 2.5.6, mobile DNAPL passively accumulates in a small number of wells located in the CPA and screened in the saturated UBA. Under this remedial technology, a higher density of wells would be installed within the source area to recover mobile DNAPL pooled above low permeability silt layers (capillary barriers). DNAPL would be purged from the well sumps as it passively accumulates and then

be disposed off-Site. DNAPL collection would continue as long as DNAPL accumulates in the well sumps. Under this process option, injection and/or withdrawal of water to hydraulically displace the DNAPL is not utilized.

Effectiveness. Passive recovery is effective in recovering mobile DNAPL that intercepts the well screens and meets DNAPL RAOs. As described in Section 2.5.6, a total of 313 gallons of DNAPL has been passively recovered at the Site since 1988, which is less than 2% of the 21,000 to 33,000 gallons of mobile DNAPL estimated to be present in the saturated UBA (Section 2.5.5 and Appendix E). It is noted that a substantial portion of the DNAPL present at the Site may already be at residual concentrations and thus immobile and not affected by this process option. While a significantly higher density of wells than exist now would be implemented under this process option, only a portion of the mobile DNAPL present in the subsurface would be expected to intercept the passive recovery wells. This process option is effective in removing some mobile DNAPL, but the potentially low volumes yielded would have a minimal impact in reducing the mass of DNAPL in the subsurface. ***Rank: Minimally Effective.***

Implementability. Passive DNAPL recovery has been on-going at the Site since 1988 and is implementable. There are no technical or administrative aspects that would limit the implementability of this remedial technology. ***Rank: Implementable.***

Cost. The relative cost of this process option is low. ***Rank: Low.***

Retain for Assembly of Remedial Alternatives? This process option is not retained because, as a source depletion technology, it is minimally effective in recovering mobile DNAPL from the saturated UBA. ***Retained? No.***

4.4.4 HYDRAULIC DISPLACEMENT

Process Description. Under this process option, groundwater is simultaneously extracted and injected to induce hydraulic gradients that mobilize DNAPL towards extraction wells. Unlike passive recovery, this process option actively facilitates DNAPL movement towards the extraction wells for subsequent extraction. Longer DNAPL pools, which contain large amounts of mass, are easier to displace than shorter pools containing small amounts of mass. Implementation of this process option requires installation of extraction wells throughout the DNAPL-impacted zone and simultaneous pumping of groundwater and DNAPL. The DNAPL can be extracted as a commingled mixture with the groundwater or pumped separately if accumulating in the well sumps. Initially, the extracted DNAPL/groundwater requires separation, followed by off-Site disposal of the DNAPL and re-injection of the groundwater. The groundwater can additionally be treated ex-situ to remove dissolved-phase contaminants prior to re-

injection, as needed. Process options for groundwater re-injection or disposal are evaluated separately in Section 4.9.

Effectiveness. Hydraulic displacement is an effective method for recovering mobile DNAPL. This process option meets DNAPL RAOs, is effective in reducing DNAPL mass and mobility. DNAPL mobility is a function of saturation, and the highest saturations are the most mobile. Hydraulic displacement is a depletion technology that continuously reduces the DNAPL mobility over time until residual saturations are achieved. As indicated in Section 2.1.2, a residual DNAPL saturation of 18.9% was measured in one soil core following water displacement at increasing capillary pressures (residual saturation observed at capillary pressure of 1.8 psi). Although residual saturations of DNAPL would be left in place by this process option, residual DNAPL is immobile in the environment and poses little or no risk of mobilization (other than as a continuing source of dissolved-phase MCB to groundwater). Furthermore, it is not necessary to remove 100% of the mobile DNAPL to meet the RAOs, which specify mobile DNAPL mass reduction to the extent practicable. The mobility of the DNAPL is a function of the saturation, and DNAPL saturations slightly above the residual limit (e.g., 19% to 21%) may not be particularly mobile under normal hydrologic conditions and capillary pressures. Reducing the saturations of DNAPL to levels approaching the residual limit may be sufficient to limit the potential for uncontrolled migration and recontamination of the aquifers.

Hydraulic displacement was field pilot tested at the Site in 1991, 2004/2005, and 2008 as described in Section 2.6.2. In 1991, a 28-day DNAPL extraction pilot test was conducted at well UBE-1 (H+A, 1992), and approximately 300 gallons of DNAPL was recovered at an average rate of approximately 10.4 gallons per day. Groundwater was extracted at an average rate of approximately 7.0 gpm. The DNAPL recovery rate observed during this pilot was approximately 100 to 1,000 times faster than recovered at the Site via passive extraction.

A second DNAPL extraction pilot test was conducted from March 2004 through January 2005 at wells UBT-1 and UBE-1 through UBE-4 (H+A, 2007c). Approximately 420 gallons of DNAPL was recovered during the pilot test with DNAPL recovery rates varying from 0.5 to 5.6 gallons per day. Groundwater was extracted at varying rates between 1.9 and 11.8 gpm, and hydraulic displacement was found to be most effective at the higher groundwater extraction rates (i.e. higher hydraulic gradient). Hydraulic displacement was also found to be most effective for wells located at the source areas within the CPA. Particularly, moderate to elevated DNAPL recovery rates were observed at UBE-1, UBT-1, and UBE-4 located at the DNAPL source areas within the CPA. Wells UBE-2 and UBE-3 are located east of the DNAPL source areas and are believed to be located in areas containing only residual DNAPL (i.e., no

mobile DNAPL). Hydraulic displacement pilot testing at wells UBE-2 and UBE-3 confirmed that there is minimal or no mobile DNAPL at these two locations.

A third DNAPL extraction pilot test (short-term test) was conducted in December 2008 at well UBE-5, located adjacent to DNAPL reconnaissance boring SSB-12. During the 5-day extraction test, approximately 1.4 gallons of DNAPL was recovered from UBE-5. The drawdown in the extraction well was increased to approximately 24 feet on the last day, and during this short period, DNAPL was recovered at an increased rate equivalent to 5.4 gallons per day (0.23 gallons per hour). The screened interval at UBE-5 is only 10 feet long (from 75 to 85 feet bgs) so that hydraulic displacement could be focused on a specific DNAPL-impacted interval. As a result, groundwater extraction rates during the short-term test were between 1.0 and 1.75 gpm. Hydraulic displacement effectively recovered mobile DNAPL at UBE-5, located southeast of the CPA in an isolated area exhibiting mobile DNAPL saturations.

The DNAPL extraction pilot tests conducted at the Site did not include groundwater re-injection for purposes of enhanced gradient control and DNAPL displacement. Groundwater was successfully re-injected during the 2004/2005 test outside of the DNAPL-impacted area and for disposal purposes only. Although dissolved VOCs were not treated prior to re-injection, groundwater was successfully injected into the UBA wells at a rate up to 6 gpm without significantly fouling. The effectiveness of hydraulic displacement is expected to increase when groundwater is re-injected to enhance the hydraulic gradient. Although not tested at the Montrose Site, the effectiveness of re-injecting groundwater to enhance DNAPL recovery has been demonstrated at numerous other sites. Although the site and contaminant conditions are different from the Montrose Site, hydraulic displacement was used with substantial success to recover approximately 95,000 and 1,800,000 gallons of creosote DNAPL at the Union Pacific Railroad Sites in The Dalles, Oregon and Laramie, Wyoming, respectively (see Appendix K for details).

Under typical hydraulic gradients, residual DNAPL, by definition, cannot be mobilized by hydraulic displacement and would not be removed by this process option. Although residual DNAPL is already immobile in the environment, the MCB component of the DNAPL will solubilize into groundwater at an accelerated rate as a result of the hydraulic displacement if the extracted groundwater is treated first to remove VOCs prior to re-injection (as compared with the natural hydraulic gradient at the Site). To facilitate such solubilization, dissolved-phase MCB can be treated ex-situ prior to re-injection and is evaluated in Section 4.9.

The saturated UBA is heterogeneous and layered. Discontinuous sand layers which are not in hydraulic communication with the extraction wells may limit the effectiveness of a displacement technology,

although the same is true for other technologies under consideration (e.g., steam injection). Mobile DNAPL must be in hydraulic communication with the injection and extraction well network to be effectively removed by this technology. Although there is the potential for stagnation zones to occur during displacement (also true for steam injection and ERH), injection of groundwater creates high horizontal gradients towards the extraction wells. These high gradients, more than 100 times normal hydrologic gradients, significantly increase the groundwater flow velocities within the UBA and reduce the potential for stagnation zones to occur, particularly under relatively high well densities.

There is also a small risk of vertical pool mobilization, although the horizontally bedded nature of the deposits is expected to limit such migration. The silt layers in the UBA are not believed to be continuous across the Site, and there is the potential under hydraulic displacement for mobile DNAPL to migrate vertically downward. If mobilized DNAPL encounters a discontinuity prior to an extraction well, the DNAPL may migrate vertically downward through the discontinuity to the underlying sand layer or basal silty sand layer. The potential for downward mobilization was evaluated by H+A and Intera by modeling as described in Section 2.6.4. Model results indicated there was no downward mobilization past the basal silty sand member of the UBA during or after hydraulic displacement assuming conservatively thick DNAPL pool heights up to 8 feet (H+A, 2009b). Although the HD modeling indicated that the risk of vertical migration during HD was minimal under specific assumptions, there is some uncertainty associated with the continuity of the basal layer across the Property and the pore entry pressures required to penetrate the silty sands, if continuous. Although the risk of vertical migration during hydraulic displacement may not be fully mitigated by the basal silty sand layer, the potential for DNAPL to migrate through the UBA to the BFS in sufficient quantity as to threaten hydraulic containment is low. To reach the BFS during hydraulic displacement, DNAPL would have to (a) migrate downward through multiple discontinuities without being recovered by multi-phase extractions under a high horizontal hydraulic gradient and without being reduced to residual saturations, and (b) pool above the basal silty sand layer at a sufficient height as to overcome the pore entry pressure, if continuous. Although there is some risk of vertical pool mobilization during hydraulic displacement, the relative risk is low given the above limitations. Furthermore, a higher density of injection and extraction wells can mitigate this risk to a large part by reducing the potential for a discontinuity to occur between wells. ***Rank: Effective.***

Implementability. This remedial technology is implementable and has been pilot tested at the Site, without groundwater re-injection for enhanced hydraulic gradients. Extraction wells can be installed using standard drilling methods and equipment. Standard separation techniques can be used to separate DNAPL from groundwater. Precipitate fouling of the extraction pump and piping was observed during the extraction pilot test, and a frequent cleaning program would be required to abate such effects during

implementation. This remedial technology would require skilled operators and a moderate to high level of maintenance given the impact of precipitate fouling during the field pilot test.

This technology relies on groundwater injection to enhance the horizontal hydraulic gradient and displace mobile DNAPL to extraction wells for removal. Injection well fouling is a common problem and could increase the difficulty of implementing this technology. Groundwater was re-injected into the UBA through two wells during field pilot testing (UBI-1 and UBI-2), and initial and final injection capacities were measured. Although the injection capacity at UBI-2 did not decrease during the field pilot test, the injection capacity at UBI-1 decreased by approximately 50%. A routine well redevelopment program combined with an appropriate number of injection wells or spare injection wells may be required to abate the effects of injection well fouling and prevent limitations on groundwater extraction rates. Accordingly, a conceptual design with a 2:1 ratio of injection wells to extraction wells or more should be considered for this remedy.

If re-injection of untreated groundwater is selected as the disposal process option for the remedy, then administratively, the re-injection limits specified in the groundwater ROD would need to be waived in order to implement the remedy (which was approved for the 2004/2005 extraction test). Although re-injection would occur within the footprint of the TI waiver zone, there may be some administrative challenges in waiving the treatment requirements if identified as an ARAR for DNAPL and if re-injection of untreated groundwater is selected as the disposal process option. ***Rank: Implementable.***

Cost. The relative cost for hydraulic displacement is low to medium, depending on the groundwater treatment process option selected as part of the remedial alternative. If the groundwater is separated from the DNAPL and re-injected untreated, then the relative cost for this remedial technology is low. However, if groundwater treatment is required to meet re-injection limits specified in the groundwater ROD, then the relative cost of this process option increases to medium, due to the elevated concentrations of MCB and pCBSA in UBA groundwater. Groundwater treatment/disposal process options are evaluated in Section 4.9, and ex-situ groundwater treatment technologies are evaluated in Section 4.7. ***Rank: Low to Medium.***

Retain for Assembly of Remedial Alternatives? This process option is retained because of its effectiveness in recovering mobile DNAPL, reducing DNAPL mass and mobility, as demonstrated during field pilot studies. ***Retain? Yes.***

4.4.5 SURFACTANT INJECTION

Process Description. A surfactant is a surface active agent that serves to change fluid wettability and interfacial tension. Injecting surfactant solutions into a DNAPL-impacted zone can both increase the rate of DNAPL dissolution into water (solubilization flood) and increase the rate of DNAPL recovery during hydraulic displacement (mobilization flood). Surfactants chosen to achieve ultra-low interfacial tensions are employed in a mobilization flood. Surfactants chosen to increase DNAPL solubility without achieving ultra-low interfacial tensions are employed in a solubilization flood. Surfactants chosen to facilitate a solubilization flood will lower the DNAPL-water interfacial tension, but not to the same extent as surfactants chosen for a mobilization flood. Likewise, surfactants chosen to facilitate a mobilization flood will increase the rate of DNAPL dissolution into water. Surfactant injection is a process known as surfactant-enhanced aquifer remediation (SEAR). This process option involves injection of a surfactant which is flushed through the source zone, followed by recovery of the injected solution and targeted DNAPL.

Effectiveness. Surfactant injection has not been bench or pilot tested for this Site, and its potential effectiveness is highly uncertain. Surfactant injection has been infrequently applied as a full-scale remedy at DNAPL sites, and its potential effectiveness has not been demonstrated at a site comparable to the Montrose Site. Although DNAPL mass may be reduced by this process option, DNAPL mobility would be increased rather than reduced, which is not in accordance with DNAPL RAOs.

This process option is potentially effective in removing additional DNAPL (both pooled and residual) from the saturated UBA as an enhancement to a hydraulic displacement remedy. Surfactants chosen to facilitate a mobilization flood can significantly reduce the interfacial tension between the water and DNAPL (below 0.1 dynes per centimeter), liberating more DNAPL for recovery by hydraulic displacement. Alternatively, a solubilization flood could be implemented following hydraulic displacement to facilitate further removal of DNAPL through dissolution. However, the greatest limitation to the use of surfactants at the Site is the heterogeneous nature of the UBA. In order for surfactants to be effective at removing DNAPL, they must first come in physical contact with the DNAPL. Injected surfactants may channel along preferential flow paths toward extraction wells, and the majority of benefits of surfactants would only be realized in these areas of preferential flow.

Mobilization risks for DNAPL, either downward or laterally outside the recovery wellfield, are increased under this process option. This technology is more effective at sites underlain by a thick, continuous, and low permeability confining layer. With injected surfactants, the DNAPL mobility must be controlled and the mobilized DNAPL must be recoverable to prevent uncontrolled lateral or vertical spreading of the

contamination. Additionally, DNAPL and groundwater/surfactant solutions can be difficult to separate once recovered, resulting in additional aboveground treatment costs. ***Rank: Potentially Effective.***

Implementability. This process option is potentially implementable at the Site, although achieving a uniform distribution of the surfactant throughout the heterogeneous UBA will reduce the effectiveness of this process option. Laboratory studies would also be necessary to determine an appropriate surfactant mixture based on the nature of the DNAPL and Site geochemistry. Specialized chemicals and contractors would be required to implement this process option, and regulatory approval of the use of surfactants would be required prior to injection. A tracer test would be required to assess the degree of heterogeneity in the saturated zone prior to implementing this process option. ***Rank: Difficult to Implement.***

Cost. The relative cost for this process option is high. Increased waste disposal costs can be incurred under this process option due to the difficulty in separating DNAPL from a groundwater/surfactant solution. ***Rank: High.***

Retain for Assembly of Remedial Alternatives? This process option is not retained for further evaluation partly because surfactant injection has been infrequently applied as a full-scale remedy at DNAPL sites, and its potential effectiveness has not been demonstrated at a site comparable to the Montrose Site. Although DNAPL mass may be reduced by this process option, DNAPL mobility would be increased rather than reduced, which is not in accordance with DNAPL RAOs. Another limitation is the preferential flow of the surfactants along the coarse-grained portions of the UBA. Additionally, this process option is not retained due to the lack of an effective confining layer overlying the BFS and the increased potential for downward mobilization of DNAPL, as compared with other remedial technologies. The uncertainty associated with the potential effectiveness of this process option is very high. ***Retained? No.***

4.4.6 COSOLVENT INJECTION

Process Description. Cosolvents are typically low-concentration (approximately 1% to 5% by volume) alcohol solutions used to enhance DNAPL dissolution and facilitate mobilization. This process option is an enhancement to hydraulic displacement and involves injection of a cosolvent, flushing it through the source zone, and recovery of the injected solution and DNAPL. Cosolvents are compounds miscible in both water and DNAPL, which may partition preferentially into one or the other depending on the chemical properties and concentration of the cosolvent and DNAPL. Alcohols, ethyl lactate, and ketones are types of compounds used as cosolvents. Cosolvents are similar to surfactants in that they can alter the properties of DNAPLs by increasing the solubility and lowering the interfacial tension. Enhanced dissolution and DNAPL mobilization are the two general removal mechanisms of cosolvents.

Effectiveness. Cosolvent injection has not been bench or pilot tested for this Site, and its potential effectiveness is highly uncertain. Cosolvent injection has been infrequently applied as a full-scale remedy at DNAPL sites, and its potential effectiveness has not been demonstrated at a site comparable to the Montrose Site. Although DNAPL mass may be reduced by this process option, DNAPL mobility would be increased rather than reduced, which is not in accordance with DNAPL RAOs.

This process option is potentially effective in removing additional DNAPL (both pooled and residual) from the saturated UBA as an enhancement to a hydraulic displacement remedy. The density of DNAPL will decrease as the lower density alcohol partitions into the DNAPL, which has the advantage of decreasing the potential for vertical DNAPL mobilization. However, the low density of many alcohols (lighter than water) can pose challenges in delivering cosolvents to all target soil horizons below the water table.

The effectiveness and implementability of using cosolvents at the Site are limited by the same factors that limit the use of surfactants. In order for cosolvents to be effective at removing DNAPL, they must first come in physical contact with the DNAPL. C osolvents would channel along preferential flow paths towards extraction wells, and the benefits of the cosolvents would be realized in these areas of preferential flow. The DNAPL mobility must be controlled and the mobilized DNAPL must be recoverable to prevent uncontrolled lateral or vertical spreading of the contamination. Large volumes of water, DNAPL, and cosolvent waste are generated that must be separated and treated at the surface. It can be difficult to remove the DNAPL from extracted groundwater when cosolvents are present.

An unknown with this technology is the potential for in-situ precipitation of the DDT. DDT is less soluble in some alcohols than in MCB. As the cosolvent partitions into the DNAPL, a portion of the DDT may precipitate. This phenomenon was previously demonstrated at the Site by adding methanol to the Montrose DNAPL. Significant in-situ precipitation of the DDT may result in plugging of the soil pores, reducing the effective permeability of the formation. ***Rank: Potentially Effective.***

Implementability. This process option is potentially implementable at the Site, although uniform distribution of the cosolvent throughout the heterogeneous UBA may be problematic. Laboratory studies would be necessary to determine the correct cosolvent based on the nature of the DNAPL and site geochemistry. Specialized chemicals and contractors would be required to implement this process option, and regulatory approval of the use of cosolvents would be required prior to injection. A tracer test would be required to assess the degree of heterogeneity in the saturated zone prior to implementing this process option. ***Rank: Difficult to Implement.***

Cost. The relative cost of this process option is high. Increased waste disposal costs can be incurred under this process option due to the difficulty in separating groundwater from a DNAPL/co-solvent solution. ***Rank: High.***

Retain for Assembly of Remedial Alternatives? This process option is not retained for further evaluation partly because cosolvent injection has been infrequently applied as a full-scale remedy at DNAPL sites, and its potential effectiveness has not been demonstrated at a site comparable to the Montrose Site. Although DNAPL mass may be reduced by this process option, DNAPL mobility would be increased rather than reduced, which is not in accordance with DNAPL RAOs. Another limitation is the preferential flow of the cosolvents along the coarse-grained portions of the UBA. Additionally, this process option is not retained due to the lack of an effective confining layer overlying the BFS and the potential for in-situ precipitation of the DDT and plugging of the formation. The uncertainty associated with the potential effectiveness of this process option is very high. ***Retained? No.***

4.4.7 POLYMER FLOODING

Process Description. Injecting polymers into a DNAPL-impacted zone may enhance the extraction rate of DNAPL from the subsurface by increasing the viscosity of the displacing fluid (groundwater). Polymers, such as xanthan gum, are added to groundwater and re-injected to improve the mobility ratio of the DNAPL-water system by increasing the aqueous solution viscosity to above that of the DNAPL. Viscosities in the range of 5 to 20 centipoises are common for polymer solutions. Polymers have been used to reduce the fingering of the displacing fluid (water) past the displaced fluid (DNAPL) and to help ensure that the contaminated area is more efficiently swept. Polymers can be used to increase the sweep efficiency (degree of contact with the DNAPL) during a surfactant flood, a cosolvent flood, an alcohol flood, and during hydraulic displacement. As a stand-alone technology, polymer flooding can only displace mobile DNAPL.

Effectiveness. Polymer flooding has not been bench or pilot tested for the Site, and its potential effectiveness is highly uncertain. Polymer flooding has been infrequently applied as a full-scale remedy at DNAPL sites, and its potential effectiveness has not been demonstrated at a site comparable to the Montrose Site. Although DNAPL mass may be reduced by this process option, DNAPL mobility would be increased rather than reduced, which is not in accordance with DNAPL RAOs.

This process option is potentially effective in removing additional mobile DNAPL from the saturated UBA as an enhancement to a hydraulic displacement remedy. Unlike surfactant and cosolvent injection, polymers can effectively increase the mobility of the DNAPL by increasing the viscosity of the injected groundwater. Although the use of polymers can enhance the efficiency of hydraulic displacement, the

technology is still subject to many of the same limitations as other remedial technologies that rely on injection and recovery from the UBA. For contaminant-impacted areas as heterogeneous as the UBA, significant limitations on the effectiveness of polymer injection exist. The polymer would preferentially flow through the portions of the aquitard with the highest conductivities. This means that the majority of benefits from the polymer would be realized in areas of preferential flow, much like other technologies where flushing of the contaminant zone is required. A disadvantage of polymer injection is the increased potential for injection well fouling, further limiting the effectiveness of this process option. ***Rank: Potentially Effective.***

Implementability. This process option is potentially implementable at the Site. Specialized chemicals and contractors would be required to implement this process option, and agency approval of the use of polymers would be required prior to injection. The injection of polymers into the subsurface may be problematic. Injection rates are often only 50 percent of the extraction rates due to a variety of factors which may affect the performance of injection wells in the DNAPL-impacted area. A tracer test would be required to assess the degree of heterogeneity in the saturated zone prior to implementing this process option. ***Rank: Difficult to Implement.***

Cost. The relative cost of this process option is high. Increased costs can be incurred due to injection well fouling. ***Rank: High.***

Retain for Assembly of Remedial Alternatives? This process option is not retained for further evaluation partly because polymer flooding has been infrequently applied as a full-scale remedy at DNAPL sites, and its potential effectiveness has not been demonstrated at a site comparable to the Montrose Site. Although DNAPL mass may be reduced by this process option, DNAPL mobility would be increased rather than reduced, which is not in accordance with DNAPL RAOs. Another limitation is the preferential flow of the polymers along the coarse-grained portions of the UBA and the potential for severe plugging of the formation and wells. Additionally, this process option is not retained due to the lack of an effective confining layer overlying the BFS and the increased potential for downward mobilization of DNAPL, as compared with other remedial technologies. The uncertainty associated with the potential effectiveness of this process option is very high. ***Retained? No.***

4.4.8 ALCOHOL FLOODING

Process Description. Alcohol flooding is a process involving the use of very high-concentration alcohol solutions to extract both residual and pooled DNAPL. The distinction between this process option and cosolvent injection is the concentration (cosolvent injection involves dilute forms of alcohols, i.e. 1-5% by volume). The use of alcohol concentrations greater than approximately 70% by volume will eliminate

the interfacial tension between DNAPL and water, resulting in a miscible mixture of water, alcohol, and DNAPL components. This miscible mixture can be either less or more dense than water depending on the particular alcohol employed and the associated phase behavior. The use of alcohol concentrations less than those required to achieve miscibility would result in increased DNAPL dissolution into water and a lowering of DNAPL-water interfacial tension, similar to that achieved with surfactants (but due to a different mechanism). Low molecular weight alcohols, such as methanol and ethanol, have principally been used for high concentration alcohol flooding of source zones. Higher molecular weight alcohols, such as propanols, can result in significant DNAPL swelling and reduction of DNAPL density, thereby off-setting the risk of vertical DNAPL mobilization associated with interfacial tension lowering. The application of an upward hydraulic gradient during alcohol flooding also reduces the risk for downward vertical mobilization.

Effectiveness. Alcohol flooding has not been bench or pilot tested at the Site, and its potential effectiveness is highly uncertain. Alcohol flooding has been infrequently applied as a full-scale remedy at DNAPL sites, and its potential effectiveness has not been demonstrated at a site comparable to the Montrose Site. Although DNAPL mass may be reduced by this process option, DNAPL mobility would be increased rather than reduced, which is not in accordance with DNAPL RAOs.

This process option is potentially effective in removing pooled and residual DNAPL from the saturated UBA. The density of the DNAPL will decrease as the lower density alcohol partitions into the DNAPL, which has the advantage of decreasing the potential for downward vertical DNAPL mobilization. However, the low density of many alcohols that are lighter than water can pose challenges in delivering them to all target soil horizons below the water table. The effectiveness of an alcohol flood at the Site is limited by the same factors that limit the use of surfactants and cosolvents. The DNAPL mobility must be controlled and the mobilized DNAPL must be recoverable to prevent uncontrolled lateral or vertical spreading of the contamination. Large volumes of water, DNAPL, and alcohol waste are generated that must be separated and treated at the surface. It is also difficult to remove the groundwater from the DNAPL/alcohol mixture at surface.

Field observations of the Montrose DNAPL mixed with methanol indicated rapid precipitation of DDT. This occurs because the solubility of DDT is higher in chlorobenzene than in alcohol. This precipitate may foul subsurface pores and reduce the effectiveness of an alcohol flooding alternative for the Site. ***Rank: Potentially Effective.***

Implementability. This process option is potentially implementable at the Site, although uniform distribution of the alcohol throughout the heterogeneous UBA and subsequent recovery of the

alcohol/DNAPL mixture may be problematic. Laboratory studies would be necessary to determine the correct alcohol based on the nature of the DNAPL and site geochemistry. Specialized chemicals and contractors would be required to implement this process option, and regulatory approval of the use of the alcohol would be required prior to injection. Handling of the high concentration alcohols would require special health and safety measures and would need to comply with all regulations governing the handling of flammable liquids. A tracer test would be required to assess the degree of heterogeneity in the saturated zone prior to implementing this process option. ***Rank: Difficult to Implement.***

Cost. The relative cost of this process option is high. The high volumes of alcohol required by this process option would be very costly. ***Rank: High.***

Retain for Assembly of Remedial Alternatives? This process option is not retained for further evaluation partly because high concentration alcohol floods have been infrequently applied as a full-scale remedy at DNAPL sites, and its potential effectiveness has not been demonstrated at a site comparable to the Montrose Site. Although DNAPL mass may be reduced by this process option, DNAPL mobility would be increased rather than reduced, which is not in accordance with DNAPL RAOs. Another limitation is the preferential flow of the alcohols along the coarse-grained portions of the UBA and the potential for severe plugging of the formation and wells. Additionally, this process option is not retained due to the lack of an effective confining layer overlying the BFS and the increased potential for downward mobilization of DNAPL, as compared with other remedial technologies. The uncertainty associated with the potential effectiveness of this process option is very high. ***Retained? No.***

4.5 IN-SITU NON-THERMAL TECHNOLOGIES

In-situ bioremediation, stabilization, chemical reduction, and chemical oxidation are non-thermal in-situ technologies for binding, transforming, or degrading DNAPL constituents. These fourin-situ technology process options are evaluated in the following sections.

4.5.1 IN-SITU BIOREMEDIATION

In-situ bioremediation is a subsurface process in which microbes are used to convert target organic contaminants, preferably to less toxic compounds. There are two general types of bioremediation: aerobic and anaerobic. Aerobic bioremediation involves microbes that require oxygen to degrade contaminants, whereas anaerobic bioremediation involves microbes that degrade contaminants in an oxygen-free environment. MCB can biodegrade both aerobically and anaerobically, although it is believed that the aerobic biodegradation pathway is faster. The World Health Organization (WHO) indicated in a 2004 publication (WHO, 2004) that "*the less chlorinated benzenes are more readily degraded than the higher*

chlorinated ones", and that although "*biodegradation under anaerobic conditions has also been reported, this occurs at a slower rate than aerobic biodegradation*". In-situ bioremediation process options for the unsaturated zone and saturated zone are evaluated separately in the following sections.

Unsaturated Zone (0 to 60 feet bgs)

Process Description. Aerobic bioremediation of compounds in the unsaturated zone is termed "bioventing". Bioventing supplies oxygen to the unsaturated zone to stimulate indigenous aerobic bacteria that degrade the target contaminants. Bioventing is designed to maximize biodegradation of aerobically biodegradable compounds while minimizing removal of compounds by volatilization, which would require ex-situ treatment of contaminated vapors. A bioventing system typically consists of a series of injection wells and blower to introduce atmospheric air into the subsurface at the minimum flow rate necessary to achieve about 4% oxygen by volume or greater in soil gas.

Effectiveness. Bioventing may be effective in biodegrading MCB in the unsaturated zone, although this process option has not been field pilot tested at the Site. Biodegradation of the MCB component of the DNAPL would reduce mass and therefore meet DNAPL RAOs. Although bioventing will not biodegrade the recalcitrant DDT component of the DNAPL, the mobility of the DNAPL in the unsaturated zone, if not already immobile, would be reduced by biodegradation of the MCB component. As the MCB component of the DNAPL is biodegraded (or further partitioned into soil gas for subsequent biodegradation), the DDT component will precipitate, sorb to soil, and become relatively immobile in the environment (DDT tends to sorb strongly to soil). Biodegradation of the MCB component of the DNAPL would be an effective method for reducing the mass and mobility of the DNAPL in the subsurface.

Although bioventing is infrequently implemented at sites impacted with MCB, it has been applied at some sites. At the Dover National Test Site, MCB mass reduction of approximately 77% was observed during one field bioventing experiment. A 1993 laboratory study (Lee and Swindoll, 1993) conducted simultaneous bioventing and SVE experiments of unsaturated soils impacted with a variety of contaminants, including MCB. While both bioventing and SVE were demonstrated to effectively reduce MCB mass, SVE was found to be more effective. The authors concluded that SVE was "*more effective than bioventing for the volatile compounds such as …chlorobenzene and chlorinated aliphatic solvents*".

A key for effective bioventing is the relationship between a compound's biodegradability (represented by its degradation half-life) versus its volatility (represented by its vapor pressure) (EPA, 1995). If the rate of volatilization greatly exceeds the rate of biodegradation, bioventing likely will be less successful because mass transfer from the sorbed phase to the air phase will exceed the rate of biodegradation. The aerobic biodegradation half-life of MCB is relatively long at approximately 150 days [Howard, et. al.,

1991]. Therefore, MCB may tend to volatilize rather than biodegrade under a constant delivery of air to the unsaturated zone even though only a minimal air flow would be required to maintain elevated oxygen levels. Additionally, migration of VOCs in soil gas within the unsaturated zone would not be controlled by bioventing (i.e., no SVE).

Application of this technology additionally requires porous, permeable, and unsaturated soils to support air injection. Bioventing is not expected to be effective in the low permeability soils within the PD, although oxygen may slowly diffuse into the PD at a reduced rate as compared with the other unsaturated zone layers. Bioventing is expected to be more effective in the PVS and unsaturated UBA, between 25 and 60 feet bgs, which exhibit higher permeabilities, as long as oxygen can be effectively delivered to these deeper units.

Elevated concentrations of DDT and DNAPL are present within the unsaturated zone and may have detrimental effects on microbial populations. While unsuccessful bioventing applications are rarely due to a lack of microbial activity (EPA, 1995), the presence of DDT and DNAPL in the Site soil could decrease the effectiveness of in-situ bioremediation and would need to be studied. ***Rank: Potentially Effective.***

Implementability. Bioventing is implementable within permeable unsaturated zone soils. Air can be readily injected into permeable soils within the PVS and unsaturated UBA to stimulate aerobic biodegradation of MCB. However, due to the relatively long half-life of MCB, the rate of air injection would need to be carefully managed to prevent uncontrolled migration of MCB vapors in the unsaturated zone. Additionally, bioventing would be more difficult to implement in the low permeability PD soils. ***Rank: Implementable.***

Cost. The relative cost for bioventing in the unsaturated zone is low. ***Rank: Low.***

Retain for Assembly of Remedial Alternatives? In-situ bioremediation is not retained for the unsaturated zone because SVE would be more effective than bioventing in remediating the elevated concentrations of MCB in the unsaturated zone. Although this process option may biodegrade MCB in the unsaturated zone, the rate of aerobic biodegradation is expected to be slower than the rate of volatilization by SVE due to the relatively long half-life of MCB. Additionally, bioventing is infrequently applied to DNAPL-impacted sites. ***Retained? No.***

Saturated UBA (60 to 105 feet bgs)

Process Description: This process option involves either aerobic or anaerobic bioremediation of dissolved-phase contaminants in the saturated zone. Aerobic bioremediation in the saturated zone involves the addition of oxygen, nutrients, and/or microorganisms to the impacted groundwater to enhance aerobic degradation. The groundwater may be oxygenated using a dilute hydrogen peroxide solution or by aerating the water with air, oxygen-releasing compounds, or pure oxygen. Under aerobic conditions, microbial degradation of VOCs can occur by metabolic or cometabolic transformation reactions (such as using methane to stimulate the growth of methanotrophs).

Anaerobic bioremediation requires the addition of electron donors, such as lactate or ethanol, to dechlorinate the dissolved contaminants. Anaerobic bioremediation primarily occurs under reducing conditions (a redox reaction) that requires electron donors for dechlorination (i.e., replacement of the chlorine atom with a hydrogen atom). Reductive dechlorination is the principal mechanism for anaerobic biodegradation of most highly chlorinated VOCs such as TCE and PCE. Anaerobic bioremediation can be implemented as a passive technology, such as injection of an emulsified vegetable oil, or as an active technology with groundwater extraction, electron donor addition, and re-injection of the amended groundwater.

In-situ bioremediation in the saturated zone is primarily a process option for treating dissolved-phase contaminants and is infrequently used for remediation of DNAPL. However, if effective, some DNAPL-phase MCB would slowly solubilize into groundwater over time as dissolved-phase MCB was biodegraded in-situ. This iterative process would continue until all DNAPL-phase MCB was solubilized and subsequently biodegraded.

Effectiveness. This in-situ bioremediation process option is potentially effective in treating dissolved-phase MCB in the saturated UBA. Laboratory microcosm studies have demonstrated the potential effectiveness of aerobic biodegradation of dissolved-phase MCB at lower concentrations. Although not impacted with DNAPL, a 1997 microcosm study using UBA soils and groundwater demonstrated a 38% reduction in MCB after 4 weeks under aerobic conditions (Zeneca, SPEL, 1997). This microcosm study demonstrates the potential effectiveness of aerobic bioremediation at the Site, although since dissolved-phase MCB concentrations will be 10 to 30 times higher in the DNAPL-impacted area, additional microcosm studies would be required to verify effective MCB biodegradation under high concentration conditions. If the microcosm experiments demonstrate the feasibility of biodegrading MCB in-situ under these conditions, then a field pilot test would be required to verify the effectiveness in the field and obtain preliminary biodegradation rates and biological oxygen demand for full-scale design.

The 1997 microcosm experiments were conducted without the need for microbial augmentation of MCB-degrading bacteria. Therefore, naturally occurring bacteria at the Site may be adequate to support an aerobic in-situ bioremediation component of the RA. However, if microbial populations are low, then bioaugmentation would additionally be required as part of the in-situ bioremediation remedy component, although bioaugmentation is not always successful.

This technology has been infrequently applied at DNAPL sites (or suspected DNAPL sites). The majority of applications were anaerobic bioremediation projects at sites impacted with chlorinated ethenes such as dichloroethylene (DCE) isomers, TCE, or PCE, which are more common environmental contaminants as compared to MCB, which is less common. Other studies and reference documents addressing in-situ bioremediation of DNAPL-impacted areas include:

- In a 2004 paper (Geosyntec, 2004), Geosyntec Consultants reported that dechlorinating microorganisms are not inhibited by dissolved concentrations approaching the solubility limit, and therefore, anaerobic degradation is a process option that is applicable to TCE or PCE DNAPL source areas.

- In a 2003 study (McCarty, et.al., 2003), the authors demonstrated that reductive dechlorination in the presence of a TCE, PCE, or carbon tetrachloride DNAPL was possible. Reductive dechlorination was additionally found to increase the rate of DNAPL dissolution (into groundwater), which serves to accelerate the rate of biodegradation. However, it is noted that anaerobic bioremediation of MCB has been infrequently studied or field pilot tested.

- Reductive dechlorination of chlorinated benzenes, among other chemicals, by various strains of Dehalococcoides is currently being studied by Dr. Stephen Zinder at Cornell University. Bioaugmentation of naturally occurring microorganisms with MCB-degrading bacterial strains may be an effective method for enhancing the rate of anaerobic biodegradation at the Site but is uncertain. Bioaugmentation using various strains of Dehalococcoides is a widely used enhancement for this bioremediation process option.

- In-situ bioremediation can be implemented as a primary, stand-alone remediation technology or as a secondary technology, following a more aggressive primary remediation technology. In a 2004 paper, Geosyntec Consultants indicated that in-situ "*bioremediation can work synergistically with other DNAPL treatment technologies…to speed up DNAPL treatment, or be used as a polishing step to cost effectively remove residual DNAPL left behind from more aggressive technologies*." The compatibility of in-situ bioremediation with another technology would require evaluation and bench-scale testing, at a minimum, but this approach has been used at some DNAPL sites.

- In a 2005 paper (Christ, et.al., 2005), the authors evaluated coupling in-situ bioremediation with more aggressive DNAPL mass removal technologies, although only anaerobic reductive dechlorination was evaluated for highly chlorinated ethenes (e.g., TCE, PCE). The authors noted that following aggressive mass removal technologies, "*some DNAPL will likely remain within the porous medium even when treatment is most effective*", and that "*application of such technologies may not substantially reduce risk and could potentially worsen site conditions (e.g., through mobilization and redistribution of DNAPL…)*".

Based on review of available data, Site conditions range from aerobic to anaerobic, with anaerobic conditions prevailing in areas with high MCB concentrations. Therefore, distribution of oxygen in the subsurface would be critical to the effectiveness of an aerobic bioremediation process option. Like many other process options, the heterogeneous nature of the UBA may reduce the effectiveness of this process option due to non-uniform distribution, particularly in lower permeability areas. A relatively high density of wells may be required to effectively deliver oxygen and mineral nutrients throughout the DNAPL-impacted UBA. Additionally, a portion of the oxygen may be consumed by other organics or minerals within the UBA during remedy implementation. Therefore, sufficient oxygen must be delivered to overcome the natural oxygen demand of the UBA and support in-situ aerobic bioremediation.

Additional bench-testing would be required to verify that MCB-degrading bacteria would not be significantly inhibited in the presence of DNAPL-phase MCB (i.e., high concentrations of MCB). A study performed by Fritz, et. al (1991) evaluated the sensitivity of a particular MCB-degrading strain, RHO1, to high concentrations of MCB. The study showed that MCB concentrations higher than approximately 394,000 µg/L were toxic to *Pseudomonas* species strain RHO1. MCB concentrations at or near the solubility limit (approximately 500,000 µg/L) are expected near the DNAPL-water interface at the Site and may inhibit biodegradation of MCB in the immediate vicinity of the DNAPL. While the RHO1 strain of *Pseudomonas* species is not the only MCB-degrading bacteria, these findings suggest that a bench test may be required to evaluate whether MCB-degrading bacteria present at the Site would be inhibited by high MCB concentrations approaching the solubility limit.

Similarly, the DDT component of the DNAPL may also have detrimental effects on MCB-degrading bacteria and could lessen the effectiveness of this bioremediation process option. Although this process option will not biodegrade the recalcitrant and insoluble DDT component of the DNAPL, the DDT component will precipitate, sorb to soil, and become relatively immobile in the environment (DDT tends to sorb strongly to soil).

However, even if effective, an exceptionally long treatment period would be required if in-situ bioremediation were used as a primary DNAPL remediation technology. In-situ bioremediation projects typically require a few years to biodegrade one pore volume of dissolved-phase contamination. The Focused Treatment Area contains between approximately 237,000 and 390,000 pounds of DNAPL-phase MCB. Even if this process option was effective despite the heterogeneous aquitard and toxicity of the DNAPL and DDT, a treatment period up to several hundred years may be required to biodegrade the substantial mass of MCB present in the saturated zone.

The potential effectiveness of this technology to biodegrade the MCB component of the DNAPL is highly uncertain in the absence of comparable microcosm studies or field pilot tests. Given the uncertainties and relatively high DNAPL-phase mass containing DDT at the Site, in-situ bioremediation is unlikely to be effective as a primary DNAPL remediation technology. ***Rank: Not Effective.***

Implementability. This bioremediation process option is implementable and would require groundwater extraction wells, an oxygen and mineral nutrient amendment system, and groundwater re-injection wells. Hydrogen peroxide and mineral nutrients are readily available chemicals and could be added to groundwater prior to re-injection to stimulate in-situ aerobic biodegradation of MCB. However, the heterogeneous nature of the UBA will impede uniform distribution of the oxygen and amendments, but these effects could largely be offset by a higher density of extraction/injection wells. A relatively low level of maintenance is required to implement this process option, and highly skilled field operators are not required. Some of the bioremediation amendments, such as hydrogen peroxide, can require special safety and handling procedures depending on the relative strength of the source chemical. Additionally, routine redevelopment of the extraction/injection wells may be required to restore hydraulic conductivities reduced by biofouling. However, an exceptionally long treatment period up to several hundred years would substantially increase the difficulty of implementing an in-situ bioremediation project at the Site. ***Rank: Moderately Implementable.***

Cost: The relative cost for in-situ bioremediation would be high to prohibitively high depending on the duration required. In-situ bioremediation is a relatively low mass reduction technology, and the duration of an in-situ bioremediation process option at the Montrose Site would be exceptionally long due to the high DNAPL mass present in the saturated UBA. Although in-situ bioremediation is not typically a high cost alternative, a treatment period up to several hundred years would result in a high or prohibitively high cost. ***Rank: High to Prohibitively High.***

Retain for Assembly of Remedial Alternatives? Given the large DNAPL mass present in the saturated UBA and other complexities associated with the Site, implementation of in-situ bioremediation is unlikely to be effective and would require an exceptionally long duration. Additionally, the potential effectiveness of in-situ bioremediation to reduce DNAPL mass is uncertain and has not been demonstrated at a comparable site. Hence, additional laboratory testing would be required simply to demonstrate the feasibility of biodegradation at the elevated MCB and DDT concentrations present at the Site.

If the microcosm experiments were successful, then a field pilot test would be required to determine the potential effectiveness of this technology at the Site and within the heterogeneous UBA. In-situ

bioremediation is a technology that primarily addresses reduction of dissolved-phase contaminants, and it is uncertain whether such reduction would occur at rates sufficient to significantly impact DNAPL mass. Even if effective (which is unlikely), a period up to several hundred years may be required to treat the relatively large mass of DNAPL-phase MCB at the Site. The cost of such a long remedy would be high or prohibitively high. This process option is not retained for further evaluation. ***Retained? No.***

4.5.2 SOIL STABILIZATION

Process Description. This process option involves mixing DNAPL-impacted soils in-situ with a binding agent to permanently stabilize and immobilize the DNAPL. Although shallow soil mixing can be done using conventional construction equipment, deep soil mixing such as required at the Montrose Site would require use of a large diameter mixing auger. The mixing auger is different from a traditional flight auger (not designed to remove soil) and is equipped with a series of jets for delivering liquid stabilizing agents. The mixing augers are typically 3 to 12 feet in diameter and would be used to mix soils in-situ with one or more stabilizing agents, which for this application, would likely include cement to reduce the permeability of the mixed soil. The stabilizing agents are mixed with the soil as the auger is rotated throughout a vertical column. Repeated and overlapping columns of soil are mixed and stabilized until the entire target DNAPL-impacted area has been treated. The stabilized soil column is then tested to verify that the permeability was sufficiently reduced as to immobilize DNAPL within the column. Shallow soil mixing augers can typically achieve depths between 45 and 65 feet bgs, while deep soil mixing augers can achieve depths up to between 100 and 120 feet bgs depending on the soil density and site conditions.

Effectiveness. Deep soil mixing and stabilization would potentially immobilize the DNAPL at the Montrose Site. Although no mobile DNAPL mass would be reduced, the DNAPL would potentially be immobilized through a reduction in the soil permeability. However, there is some risk that DNAPL could vertically migrate downward as a result of soil mixing, either prior to complete stabilization or down the interface of a stabilized column. The UBA is composed of multiple low permeability layers or capillary barriers, above which mobile DNAPL is perched. The integrity of the capillary barriers will be compromised during soil mixing. ***Rank: Potentially Effective.***

Implementability. To ensure that all DNAPL-impacted soils are stabilized, the soil columns overlap slightly. Given a target treatment depth of 105 feet bgs, a smaller diameter mixing auger of approximately 3 feet in diameter would likely be required. Accounting for 15% overlap, more than 4,200 vertical columns of soil would require mixing to treat the mobile DNAPL extent and up to 26,000 soil columns would require mixing to treat the entire DNAPL-impacted area. A period of 20 to 100 years

would be required to stabilize such a massive number of soil columns. Furthermore, the soil mixing would generate DDT-impacted dust, odors, and VOC vapors. Engineering controls, such as a ventilation collection and off-gas system, would be required to control emissions during soil mixing. ***Rank: Not Implementable.***

Cost. The cost to mix and stabilize 4,200 to 26,000 vertical soil columns of DNAPL-impacted soils to 105 feet bgs at the Montrose Site would be prohibitively high. ***Rank: Prohibitively High Cost.***

Retain for Assembly of Remedial Alternatives? Although deep soil mixing is potentially effective, it is not implementable in light of the excessive number of vertical soil columns that would require stabilization at the Montrose Site. Even if this alternative were implementable, it would be at a prohibitively high cost. ***Retained? No.***

4.5.3 IN-SITU CHEMICAL REDUCTION (ZERO VALENT IRON)

Process Description. Zero valent iron (ZVI) is a process option for chemically reducing contaminants in-situ. ZVI is a reactive product and electron donor. As the ZVI is oxidized, contaminants are reductively dechlorinated to less toxic byproducts. ZVI is most effective in anaerobic environments and in reducing chlorinated ethenes such as PCE, TCE, and other contaminants. There are several different types of ZVI including (a) macro or micro ZVI, (b) nano-scale ZVI, and (c) emulsified ZVI. Macro/micro or granular ZVI has been widely used in the construction of permeable reactive barriers (PRBs), which chemically reduce dissolved contaminants as groundwater flows across the barrier. In recent years, nano-scale ZVI has grown in popularity due to its ability to more readily penetrate soil pores and increase contaminant contact. Emulsified ZVI is a chemical reduction product combining ZVI with emulsified vegetable oil for enhanced biodegradation. PRBs are typically constructed by backfilling a trench or row of closely spaced borings with a ZVI product. ZVI can also be delivered to the subsurface through soil mixing.

Effectiveness. This process option is unlikely to be effective in chemically reducing MCB at the Montrose Site. Laboratory studies have demonstrated that ZVI is less effective in reducing chlorinated benzenes, and MCB in particular, than other common dissolved contaminants. Studies have reported low percentages of MCB transformation between approximately 0% and 20% without the presence of a catalyst (such as palladium). Furthermore, MCB is chemically reduced to benzene, which is a more toxic contaminant and is resistant to further chemical reduction using this process option. MCB and benzene both degrade aerobically, which is not compatible with a ZVI PRB (oxygen will consume ZVI and make it unavailable for chemical reduction). Most importantly, ZVI primarily treats dissolved-phase contaminants and would have a minimal impact on DNAPL mass at the Site. Finally, this process option

relies on contaminated groundwater flow across the PRB, but the horizontal flow rate within the UBA is typically low (except under HD). ***Rank: Not Effective.***

Implementability. Construction of a PRB using ZVI at the Montrose Site is technically implementable. PRBs using ZVI are commonly implemented and do not require specialized drilling equipment (except for soil mixing). Several vendors offer ZVI products, and although some groundwater monitoring is required, PRB systems are frequently passive and do not require much maintenance (although repeated applications can be required). ***Rank: Implementable.***

Cost. The relative cost of in-situ chemical reduction using ZVI is medium. A series of closely spaced borings would be required to initially deliver ZVI to the target treatment area. The borings would generate some hazardous soil waste requiring off-site incineration, and repeated applications of ZVI would likely be required over time. A groundwater recirculation system may also be required to increase the flow across the ZVI PRB. ***Rank: Medium.***

Retain for Assembly of Remedial Alternatives? This remedial technology will not be effective in reducing DNAPL mass or mobility at the Site and is not retained for further evaluation. ***Retained? No.***

4.5.4 IN-SITU CHEMICAL OXIDATION

Process Description. In-situ chemical oxidation (ISCO) involves the injection of chemical oxidants into the DNAPL-impacted zone to destroy dissolved-phase constituents and DNAPL. The process is achieved by injecting an oxidant mixed with water into the treatment zone via a series of injection wells. Once in the subsurface, oxidants are transported by advection, dispersion, and diffusion to reach the targeted contaminants. Common oxidants used for groundwater remediation include potassium permanganate, sodium permanganate, persulfate, peroxide, ozone, and Fenton's solution. The strong oxidants will react with most organic compounds and cause the contaminants to degrade into non-toxic end products. Under this process, the contaminants are destroyed in-situ and are not extracted for ex-situ recovery or treatment. Sufficient oxidant solution must also be injected to overcome the natural oxidant demand of the aquifer solids. Depending on the mineralogy and the amount of naturally occurring organic carbon, the oxidant demand can exceed the demand of the contaminant.

Effectiveness. This process option is potentially effective but has not been bench or field pilot tested at the Site. This process option would meet DNAPL RAOs by reducing DNAPL mass, which in turn reduces its mobility. ISCO has been applied at a number of DNAPL sites with increasing frequency, although none with the estimated in-situ mass comparable to the Montrose Site. The Arkema Site in Portland, Oregon is also impacted with an MCB/DDT DNAPL, a former DDT manufacturer, and has

pilot tested an ISCO process option using sodium persulfate for groundwater remediation. MCB concentrations in groundwater were reduced during the test but rebounded quickly. In spite of the marginal pilot test results, Arkema is pursuing ISCO as an interim remedial measure for groundwater at the site. However, the volume of DNAPL at that site is significantly below the amount estimated to be present in the saturated UBA beneath the Montrose Site, and the potential effectiveness of this in-situ destruction process option is uncertain.

A primary advantage of this process option is destruction of the contaminants, rather than extraction and capture. Additionally, an ISCO alternative can be implemented in a relatively short time period because the oxidation reaction is fast compared to other technologies, such as in-situ bioremediation. However, the effectiveness of ISCO at the Site is limited by the same factors that limit the use of surfactants, cosolvents, or any other remedial technology which relies on uniform distribution in the subsurface. The oxidants must come in physical contact with the DNAPL to be effective, and heterogeneities within the UBA will limit the ability to control the distribution of oxidant into the DNAPL-impacted zone. Additionally, naturally-occurring organic matter in the soil would be oxidized, thereby decreasing the effectiveness of this process option and increasing the oxidant demand. Some reaction products of oxidation, like precipitation of manganese oxide in the case of permanganate, can reduce soil permeability leading to inefficient distribution of the oxidants. Additionally, precipitation of inorganics due to pH and/or redox changes may result in plugging of the formation. ***Rank: Potentially Effective.***

Implementability. An ISCO process option is potentially implementable at the Site. Liquid-phase oxidants can be injected into the saturated UBA via injection wells, although mobile DNAPL may be displaced during injection. This technology does not require an aboveground treatment system, and would not generate a large volume of waste materials during the field application. This process option requires skilled operators and technology vendors. The oxidizing agents pose a safety hazard to site workers and must be handled with care. Depending on the rate of oxidation, implementation of an ISCO process option can additionally result in elevated concentrations of carbon dioxide being released from the saturated zone into the unsaturated zone (posing surface exposure hazards at some sites). ***Rank: Implementable.***

Cost. The relative cost of ISCO application would be high due to the large mass of DNAPL present in the saturated UBA. Material cost for oxidants would be high and multiple rounds of oxidant injection would be required to appreciably reduce the DNAPL mass. ***Rank: High.***

Retain for Assembly of Remedial Alternatives? This remedial technology is not retained for further evaluation because an exceptionally large quantity of oxidants would be required to treat the estimated

DNAPL mass in the saturated UBA. Additionally, the potential effectiveness of ISCO is uncertain and partly because it has not been demonstrated at the Site through bench or field pilot testing. ***Retained? No.***

4.6 IN-SITU THERMAL TECHNOLOGIES

Three separate in-situ thermal treatment process options are evaluated in this section, electrical resistance heating (ERH), thermal conductive heating (TCH), and steam injection. These process options heat the subsurface and remediate DNAPL by vaporization (of the MCB component), oxidation, or displacement. Each of the candidate thermal process options are evaluated against the three preliminary performance criteria in the following sections. From 2009, when this FS was originally drafted, to 2013, there has been a number of thermal remediation projects conducted in the United States. The majority of the thermal remediation projects conducted over this recent period have been either ERH or TCH, with a lesser percentage being steam injection. Although this FS has not been updated to reflect all recent thermal remediation projects, none of the recent thermal projects remediated a DNAPL composed of MCB and DDT or implemented a "hot floor" for purposes of preventing downward migration.

4.6.1 ELECTRICAL RESISTANCE HEATING

Process Description. ERH is an in-situ technology for vaporizing DNAPLs. This is accomplished by installing electrodes throughout the treatment zone and transmitting an electric current between them to heat the soil by electrical resistance. The electrodes are typically spaced from 12 to 25 feet apart depending upon soil resistivity. The vapors generated by this process option are then recovered by SVE for ex-situ vapor treatment as evaluated in Section 4.8. The ERH process benefits from the co-boiling of DNAPL VOCs at temperatures below the boiling point of groundwater. Co-boiling allows reduction of the DNAPL VOC contaminants without having to boil off all of the groundwater, which would otherwise reduce the electrical conductivity and power delivery to the saturated zone. Electrodes are installed in the target treatment interval within soil borings drilled using standard methods. The electrodes are typically constructed using highly conductive materials, such as steel pipe, steel shot or a combination of steel shot and graphite, and are limited in effective length. Treatment of intervals thicker than 16 feet may be accomplished by stacking electrodes in the same borehole. In order to prevent a loss of conductivity, water is circulated within the electrode via a drip line. Some of the technology vendors hold patents for electrode design elements and operation.

Three commercially ERH process options are available:

- Three-phase heating (Thermal Remediation Services); Three-phase heating uses three-phase electrical power with one phase delivered to each of three electrodes positioned in a triangular pattern.

- Electro-Thermal Dynamic Stripping Process (ET-DSP™; McMillan-McGee); The ET-DSP™ process option uses a patented and pre-fabricated electrode, which is subsequently installed within a soil boring (as opposed to constructing the electrode in the field). Unlike the other ERH technologies, ET-DSP™ injects 0.1 to 0.2 gpm of water per electrode for the purpose of dynamic (steam) stripping of the contaminants.

- Six-phase heating (SPH; Current Environmental Solutions); SPH splits a three-phase power source into six phases with one phase delivered to each of six wells positioned in a hexagonal pattern.

Effectiveness. ERH has not been implemented at a site comparable to Montrose, and therefore, its potential effectiveness is uncertain. ERH has been applied to a number of NAPL sites but never to a DNAPL site where either MCB or DDT was a primary component of the DNAPL. The co-boiling point for the Montrose DNAPL (with water) is 96°C, which approaches the upper limit of potential effectiveness for ERH (i.e., 100°C at atmospheric pressure). However, ERH has been used to successfully treat soils containing VOCs with similarly high co-boiling points. At the TRW/Northrop Site in Hawthorne, California, ERH was used to treat soils containing PCE (co-boiling point of 88°C), ethylbenzene (92°C), and xylenes (95°C). Similarly, at the Lowry Landfill Site in Aurora, Colorado, ERH was used to treat soils containing a PCE DNAPL and a xylenes LNAPL. Although ERH is most effective at treating VOCs with low co-boiling points, such as TCE (73°C) and benzene (69°C), this thermal technology has been demonstrated to be effective at treating VOCs with higher co-boiling points comparable to MCB.

In a 2007 evaluation (CH2M Hill, 2007), EPA reported the largest ERH treatment area conducted to date at approximately 44,000 square feet (Fort Richardson site in Anchorage, Alaska) and the largest ERH treatment volume at approximately 80,000 cubic yards (Savannah River site in Aiken, South Carolina). CES additionally conducted SPH at a former manufactured gas plant (MGP) site in Bloomington, Illinois over an area of approximately 91,000 square feet, but the treatment depth was less than 20 feet (treatment volume of approximately 60,000 cubic yards). A full-scale ERH remedy is currently being implemented in phases at the Paducah Gaseous Diffusion Plant over an area of 22,000 square feet and volume of 80,000 cubic yards. The average ERH treatment area and volume are significantly smaller than the dimensions of the entire DNAPL-impacted soils at the Montrose Site. Based on a review of full-scale

ERH sites (Earth Tech, 2007c), the average treatment area and volume were approximately 17,000 square feet and 22,000 cubic yards.

If ERH were applied over the entire DNAPL-impacted area at the Montrose Property, it would be one of the largest ERH projects ever implemented in the United States. The entire DNAPL-impacted UBA covers an area of approximately 160,000 square feet and over a saturated interval of 45 feet. The target treatment volume at the Montrose Property would be approximately 267,000 cubic yards. There are no comparable sites of this size where ERH has been implemented. Considering the thickness of the treatment interval, the nature of the Montrose DNAPL, and the heterogeneous nature of the saturated UBA, ERH over the entire DNAPL-impacted area at the Montrose Site would likely be the most complicated thermal remediation project, if undertaken.

Factors affecting the potential effectiveness of ERH at the Montrose Site include:

- The resistivity of the soils in the treatment area. Highly resistive soils, such as bedrock, very dry soil, and fractured rock, will inhibit the transmission of electricity and reduce the effectiveness of ERH. Desaturated soils, due to boiling of the groundwater, can yield higher resistivity soils that can result in inefficient and non-uniform heating of the treatment zone. The relative high co-boiling point of the Montrose DNAPL (96°C), only 4°C below the boiling point of water (at 1 atmosphere), increases the potential for desaturation to occur during ERH implementation. Desaturation of soils surrounding the electrodes reduces the transmission of electrical current and is a common performance problem at ERH sites. Soils with very low resistivity, such as saline or saltwater conditions, can also pose problems for ERH and result in inadequate heating. Although the resistivity of the soils at the Site has not previously been tested, a review of the hydrogeologic conditions at the Site (OTIE, 2010) indicates that conditions appear to be conducive for conducting electricity through soils during ERH.

- Additionally, water influx from the surrounding formation or underlying layers can result in cooling, requiring additional energy and longer treatment times in order to achieve and sustain a temperature above the co-boiling point. In the presence of upward vertical gradients, underlying aquifers can cool the base of the thermal treatment zone and pose significant challenges to effective heating by ERH. High groundwater flow can also result in excessive heat dissipation and cooling. Non-uniform heating and water influx have been the primary reasons reported at other sites for reduced effectiveness of ERH.

- Another effectiveness issue related to ERH is treatment interval thickness. Thick treatment intervals can pose some technical challenges for ERH with respect to uniform heating. The electrical current from the electrodes tends to be highest at the poles (ends). A long electrode may not effectively heat soils in the middle of the treatment interval, and for this reason, multiple electrodes are typically stacked for thick treatment intervals. Based on a review of thermal case sites, a treatment interval of 30-feet or less is typically implemented at ERH sites, while at the Montrose Site, the DNAPL-impacted UBA is 45 feet thick.

  However, ERH has been implemented over thick saturated intervals of 45 feet or more at some sites. A treatment thickness of 60 feet (35 to 95 feet bgs) was heated using ERH at the Pemaco Superfund Site in Maywood, California. Target temperatures were achieved at the majority of the monitoring points within the treatment interval, although soils at the base of the treatment interval (i.e., 95 feet bgs) were slower to heat and only 33% of the thermocouples at this depth met the performance benchmark. In 2008 and 2009, a saturated thickness of 65 feet was also heated by ERH at the former TRW/Northrop facility in Hawthorne, California. Shallow electrodes were placed from 65 to 105 feet bgs, while deep electrodes were positioned from 110 to 130 feet bgs. Although non-uniform heating occurred during the ERH remedy, target temperatures were achieved over the majority of the vertical thickness including generally from 65 to 100 feet and 110 to 130 feet bgs. However, soils between approximately 100 and 110 feet (immediately above DNAPL occurrence) were only heated to temperatures between approximately 65°C and 80°C. Additionally, the soils at this site were composed primarily of a homogeneous sand unit. Additional details regarding these sites are provided in Appendix K.

- Although the heterogeneous nature of the saturated UBA may not inhibit heating by ERH, it may reduce the effectiveness of recovering volatilized contaminants by SVE. The extraction system efficiency is critical for a successful ERH remedy, and VOCs that are not effectively recovered will cool and re-condense in the subsurface.

The potential for downward mobilization is another concern associated with thermal treatment technologies, although less problematic for ERH than some other thermal technologies, specifically steam injection. ERH is not a displacement technology, so there is a reduced risk of uncontrolled contaminant migration as compared with some other remedial technologies.

Heating of the underlying hydrologic unit, known as a “hot floor”, was implemented at six ERH sites in an attempt to reduce the potential for downward mobilization during thermal remediation. However, two of the six attempted hot floors were not successful in reaching target temperatures. At the Westside

Corporation site in Queens, New York (a PCE site with no DNAPL), target temperatures were not reached in the hot floor due to influx of cool groundwater. Similar conditions were experienced at the Gaseous Diffusion Plant site in Paducah, Kentucky (a TCE DNAPL site), where hot floor temperatures only reached to between 30 and 70°C. The ERH hot floors conducted at other sites typically extended into an underlying low permeability aquitard, while at the Montrose Site, the underlying hydrologic unit is a permeable sand aquifer (the BFS). There are a very limited number of hot floor sites upon which to evaluate the potential effectiveness of a hot floor at the Montrose Site, and none of which are comparable to the Montrose Site,

A "bottom up" heating approach has been used at some ERH sites to reduce the potential for downward migration. Under this approach, the bottom of the target treatment zone is heated first, followed by successively shallower intervals, to reduce the potential for condensing of contaminant vapors at the base of the treatment zone. A "bottom up" heating approach for ERH can be used in lieu of a hot floor, reducing the risk of vertical DNAPL migration during or following well construction. This approach was successfully used during ERH of saturated soils at the Young-Rainey STAR Site in Pinellas, Florida.

ERH has several advantages over steam injection for application to the Montrose Site including:

- ERH heats resistively and does not rely on soil permeability for heat distribution;
- ERH is not a displacement technology and has lower risks of uncontrolled DNAPL migration;
- ERH is a volatilization technology and has lower risks of downward DNAPL migration;
- ERH typically has a higher well density, increasing the potential for encountering DNAPL and recovering MCB vapors in the heterogeneous UBA;
- Using a bottom up heating approach, a hot floor is not required in the BFS;
- ERH requires no steam boilers, boiler emissions, or brine waste disposal.

ERH has the potential to be effective at the Montrose Site and meet the DNAPL RAOs, and given the above advantages, may be highly applicable to DNAPL remediation within the heterogeneous UBA at the Site. ***Rank: Effective.***

Implementability. Although three qualified ERH vendors (TRS, CES, and MC2) are available, this process option would be moderately implementable or difficult to implement, depending on the size of the treatment area. Although ERH has been widely used to treat areas similar to the Focused Treatment Area, an ERH remedy over the entire DNAPL-impacted area at the Montrose Site would be one of the largest ERH projects ever implemented. A significant amount of complex above- and below-ground

infrastructure would be required to generate and deliver electricity throughout the DNAPL-impacted area. A large number of electrodes would be required to treat the DNAPL-impacted area and would generate a significant amount of waste requiring management and disposal. This process option would additionally require implementation of SVE to recover VOCs for ex-situ vapor treatment. T his process option requires skilled operators and a high level of maintenance. E RH is an energy-intensive remedial technology, and the amount of energy required to heat the entire DNAPL-impacted area would be very high. The resulting carbon footprint for a full-scale ERH remedy would be similarly large. ***Rank: Moderately Implementable or Difficult to Implement.***

Cost. The relative cost for this thermal technology process option is high to very high depending on the size of the treatment area. High costs are incurred for not only electrode and multiphase extraction well installation, but also waste disposal and electricity consumption. This process option requires both soil vapor and groundwater extraction, resulting in high ex-situ treatment costs. A bottom-up heating approach can be used with ERH to sequentially heat overlying soil intervals, eliminating the need for a hot floor approach and reducing treatment costs to some extent. ***Rank: High to Very High.***

Retain for Assembly of Remedial Alternatives? The potential effectiveness of this process option is uncertain given the Site conditions and nature of the Montrose DNAPL. Additionally, the potential effectiveness of this thermal technology at the Site has not been demonstrated through bench or field pilot testing. However, ERH is one of the few technologies that may be effective in the heterogeneous UBA and has several advantages over other technologies for application to the Montrose Site. Therefore, ERH is retained for further evaluation based on its potential effectiveness in meeting the RAOs and reducing DNAPL mass and mobility by vaporizing the MCB component of the Montrose DNAPL. ***Retained? Yes.***

4.6.2 THERMAL CONDUCTIVE HEATING

Process Description. In-Situ Thermal Destruction (ISTD) is a commercially available thermal conductive heating process option offered by TerraTherm, Inc. Under this process, conductive heating wells are installed throughout the target treatment zone and spaced approximately 6 to 20 feet apart. The heating wells are typically positioned in a hexagonal pattern with six heating-only wells positioned around one central heater-vacuum well (i.e. 7-spot pattern). Electrically-powered heating elements are positioned in the wells to coincide with the target thermal remediation zone. The elements are heated to elevated temperatures between approximately 650 and 800°C, and heat is transferred conductively from the wells to the surrounding formation. Contaminants in close proximity to the heater wells are oxidized in-situ to carbon dioxide, water vapor, and acid gas (if a chlorinated VOC). Contaminants which are not directly oxidized are instead vaporized and withdrawn from the subsurface using SVE. A vacuum is

applied to the heater-vacuum wells to extract soil vapors and volatilized contaminants from the subsurface. During the extraction process, soil vapors pass across the heating elements, thereby partially oxidizing the vapor-phase contaminants. The partially oxidized VOCs, steam, and acid gas are then extracted for aboveground treatment. The vapors exiting the heater-vacuum wells are cooled to condense the steam, scrubbed to neutralize the acid gas, and then finally treated to remove any residual vapor-phase contaminants using standard methods as evaluated in Section 4.8.

Effectiveness. This conductive heating process option is not expected to be effective in remediating the Montrose DNAPL. While the MCB can be treated by this process option, a portion of the DDT will additionally be oxidized resulting in the generation of a significant amount of acid gas that would corrode metal piping and equipment. The Montrose DNAPL is heavily chlorinated, and application of ISTD to the Site would be expected to generate a significant quantity of acid gas. DDT is reported to decompose and/or boil at temperatures between approximately 185°C and 260°C, and ISTD heats soils conductively at temperatures up to approximately 650°C (at heater wells). As a result, a portion of the DDT would be decomposed and/or boiled during conductive heating, resulting in the generation of significant acid gas. Excessive acid gas production during ISTD implementation has been shown to corrode metal wall casings, heater elements, wellhead controls, and aboveground piping.

In March 2002, TerraTherm implemented ISTD at a chlorinated pesticide site in Colorado, the Rocky Mountain Arsenal (RMA) site. The pesticide at the RMA site, hexachlorocyclopentadiene, was heavily chlorinated with a boiling point of approximately 239°C, similar to the DDT at the Montrose Site. ISTD remediation of the RMA site was terminated after only 14 days due to excessive acid gas production and severe metallurgical damage to the remediation system components. In a report entitled *Field Evaluation of TerraTherm In Situ Thermal Destruction (ISTD) Treatment of Hexachlorocyclopentadiene* (EPA, July 2004), EPA reported that "*components of the ISTD system at the Hex Pit failed due to severe and rapid corrosive attack*". The Remediation Venture Office conducted an evaluation of the system failure (Appendix B of aforementioned document) and concluded that "*the primary causes of failure of this system were due to an underestimation of volume of HCl generation during remediation, an inappropriate equipment material choice for the site conditions, and an overestimation of buffering capacity of surrounding soils*". ISTD is not readily applicable to soils impacted with highly chlorinated pesticides due to in-situ formation of acids and acid gases which can result in severe corrosion of metal well casings and other remediation components. ***Rank: Not Effective.***

Implementability. This conductive heating process option is not implementable at the Site due to the high chlorine content of the Montrose DNAPL (combined MCB and DDT). ***Rank: Not Implementable.***

Cost. The relative cost of this conductive heating process option is very high. ***Rank: Very High.***

Retain for Assembly of Remedial Alternatives? This process option is not retained for further evaluation. Although TerraTherm has improved their system design in recent years, in-situ generation of acid and acid gases remains a significant challenge for implementation of ISTD at sites with highly chlorinated pesticides. ***Retained? No.***

4.6.3 STEAM INJECTION

Process Description. Patented steam injection processes, including Dynamic Underground Stripping (DUS) and Steam Enhanced Extraction (SEE), have been available for site remediation since 1991. Under these processes, pressurized steam is injected into the subsurface to vaporize contaminants for recovery by SVE. The steam will condense in the subsurface and can additionally displace or flush contaminants towards recovery wells at the condensate front. The increased heat may also cause a decrease in the DNAPL viscosity and interfacial tension, thereby increasing the mobility of the contaminant. A series of steam injection and multi-phase extraction wells are positioned throughout the DNAPL-impacted zone to optimize steam delivery and contaminant recovery, typically in 5-spot or 7-spot patterns. Vapor-phase contaminants are removed by SVE and liquid-phase contaminants (groundwater, DNAPL, and steam condensate) are removed by direct extraction. DNAPL is separated from the groundwater/steam condensate and disposed off-Site. Soil vapors are treated by the process options evaluated in Section 4.8, and groundwater is treated by the process options evaluated in Section 4.7. A steam boiler or steam generator is required to implement this process option.

Effectiveness. Steam injection has not been pilot tested at the Site, and its potential effectiveness is uncertain. Steam injection has been implemented at DNAPL-impacted sites in the past, although not at a site comparable to Montrose and much less frequently in recent years. ERH or TCH are the predominant thermal technologies being employed today. The two primary reasons why steam injection is less frequently implemented than the other thermal technologies are as follows:

- Permeable Soils: Permeable soils are required to deliver steam to the DNAPL-impacted area, and steam will preferentially flow through higher permeability soil layers. Lower permeability soil layers will receive a reduced steam injection rate or no steam. Heating of low permeability soils may be problematic, slow, and reliant on thermal heat conduction from adjacent sand layers. Although low permeability layers may eventually be at least partially heated by conduction during steam injection, this approach is less efficient and increases the overall cost and duration

of the remedy. By comparison, ERH and TCH are less dependent on soil permeability for heating and are more frequently implemented today.

- Steam Condensate/Downward Mobilization: Under a steam injection process option, there is an increased potential for downward mobilization of DNAPL or dissolved-phase contaminants in steam condensate. As the steam front expands in the DNAPL-impacted zone, a buildup of DNAPL occurs at the edge of the steam front. Because the mobility of DNAPL is highly dependent on the saturation of DNAPL, this increase in DNAPL saturation at the edge of the steam front will lead to an increased potential for vertical mobilization of the DNAPL to a greater degree than for all other RAs presented. Desaturation of confining layers or capillary barriers could additionally lead to downward migration. Downward mobilization through a desaturated capillary barrier was observed during 2-dimensional bench-scale testing as indicated in Section 2.6.5. It was also observed during 2-dimensional bench-scale testing conducted for the Solvents Recovery Services of New England site (She and Sleep, 1999). Downward mobilization of DNAPL could exacerbate the environmental impacts rather than mitigate them. By comparison, ERH and TCH rely primarily on contaminant vaporization, rather than mobilization.

A fundamental issue related to the effectiveness of a steam injection remedy is steam distribution. Steam will preferentially flow along the path of least resistance, and uncontrolled steam distribution can result in spreading of the contamination within the saturated zone. McMillan-McGee Corporation, a thermal remediation and former steam vendor, indicated in a paper dated February 22, 2011 (McMillan-McGee, 2011), that the complex lithology of the Site cannot be easily engineered away and that control of steam migration at the Montrose Site would be a significant challenge. Although the heterogeneous nature of the UBA limits the effectiveness of all candidate remedial technologies to some degree, displacement technologies such as steam injection would be most affected by the complex nature of the Site lithology. Within the saturated UBA, DNAPL extends to the northern Property boundary. Uncontrolled steam distribution near the northern Property boundary has the potential to result in displacement of DNAPL, vapor-phase MCB, or dissolved-phase MCB away from the treatment area and potentially under the adjacent industrial building (located on the GLJ Holdings property). This type of contaminant spreading, if it were to occur, would not meet the DNAPL RAOs and would reduce the effectiveness of this process option.

Another issue related to the potential effectiveness of a steam injection remedy is steam over-ride, where steam rises (due to buoyancy effects) to the top of a permeable sand layer, thereby by-passing DNAPL accumulated at the bottom of the sand layer. In a heterogeneous environment such as the saturated UBA, steam flow will predominantly be in the lateral direction within the sand layers. Steam over-ride along

the top of the sand layer is a potential inefficiency in displacing DNAPL which is pooled along the bottom of the sand layers. This inefficiency is most predominant in thicker sand layers.

If steam injection were applied over the entire DNAPL-impacted area at the Montrose Property, it would be one of the largest steam injection projects ever implemented in the United States. Four of the largest steam injection projects implemented to date include:

- The SCE Pole Yard Site in Visalia, California
- The AG Communications Site in Northlake, Illinois
- The Savannah River Site M Area Settling Basin in Aiken, South Carolina
- The Pacific Wood Treating Site in Port of Ridgefield, Washington

However, there are, in fact, numerous fundamental differences between these sites and the Montrose Site as described in Section 5.2.6, Appendix K, and discussed in part as follows:

Contaminant: The primary contaminant at the SCE Visalia and Pacific Wood Treating sites was creosote (with pentachlorophenol). SCE reported that the creosote became an LNAPL at temperatures greater than 50°C, and therefore, the physical properties of the primary contaminants are fundamentally different from the Montrose Site, with no significant risk of downward migration. There was no DNAPL present at the AG Communications site, which was primarily impacted with dissolved concentrations of TCE, cis-1,2-DCE, benzene, and xylenes. The maximum pre-remediation TCE concentration in groundwater at the AG Communications site was 20,000 ug/L, which is only 1.8% of the solubility limit, and increased to 45,000 ug/L following the start of steam injection. The primary contaminants at the Savannah River Site were PCE and TCE. Although TCE has a relatively low co-boiling point (73°C), PCE has similar physical properties (co-boiling point of 88°C) as MCB as described in Section 2.1.2.

Lithology: At the SCE Visalia site, steam was injected into the Intermediate Aquifer from 80 to 100 feet bgs, which was described as a medium to coarse-grained sand with some gravel. At the Savannah River Site, steam was injected into the M-Area Aquifer, which had a saturated sand thickness of 25 to 30 feet. The lithology at both of these sites is far more suited to steam injection than the layered and highly heterogeneous lithology of the saturated UBA at the Montrose Site (sequences of thin sands interbedded with layers of silt). At the AG Communications site, the majority of the steam injection wells were screened in the unsaturated zone to enhance SVE operations due to low permeabilities of $9x10^{-8}$ to $1x10^{-8}$ cm/sec. The steam injection wells that were completed in the saturated zone only extended between 6 and 8 feet below the water table.

Treatment Area: Although SCE reported steaming an area of approximately 155,000 square feet (including area outside the perimeter steam injection wells), the actual target treatment area was much smaller. Eleven (11) steam injection wells were located outside the perimeter of the treatment area. The area inside the steam injection wells was approximately 100,000 square feet, and the target treatment area was even smaller at approximately 80,000 square feet, which is half the size of the DNAPL-impacted area at the Montrose Site. The treatment area and volume was mis-reported for the AG Communications site as 250,000 square feet and 330,000 cubic yards respectively. However, in fact, the sum of the two treatment areas at the AG Communications site was approximately 80,000 square feet, resulting in combined treatment volume of approximately 85,000 cubic yards.

Steam Injection Rate: At the SCE Visalia site, steam was injected at a combined rate up to 200,000 lbs/hr into 11 wells (average of 15,000 to 20,000 lbs/hr per well). The conceptual full-scale steam injection rate for the Montrose Site (as described in Section 5.1.6) was reduced from 60,000 to 40,000 lbs/hr following EPA comments on preliminary remediation cost estimates (into a minimum of 48 wells). Lower steam injection rates may result in reduced MCB mass removal efficiencies. At the AG Communications site, steam was injected at low pressures of only 3 to 7 psig. By comparison, steam was injected at 38 psig at Visalia and would be injected at approximately 20 psig at the Montrose Site.

Pore Volumes/Energy Consumption: SCE has reported that "approximately 8" pore volumes of steam were flushed through the Intermediate Aquifer during the steam remedy at the Visalia site. At the Savannah River Site, more than 2.5 times more steam was required than originally expected based on computer modeling. Steam was injected into the primary sand aquifer (M-Area Aquifer) over a period of nearly 4 years to thermally remediate a DNAPL composed primarily of PCE (co-boiling point of 88°C). Although not reported by the Westinghouse Savannah River Company, Montrose estimates that more than 4.3 pore volumes of steam were flushed through the M-Area Aquifer at the Savannah River Site. Had steam injection been terminated at the target energy demand, less than 60% of the DNAPL removed to date would have been recovered from the site. The Montrose Site, given the heterogeneous UBA and complicated DNAPL architecture, may require more pore volumes of steam flushing than the SCE Visalia Site, not less.

Contaminant Recovery: SCE recovered between 130,000 and 150,000 gallons of liquid-phase creosote, which was more than double the volume originally estimated as being in-situ. The majority of the contaminant mass was removed as liquid-phase NAPL. Smaller percentages were

recovered in the vapor-phase, dissolved-phase, or destroyed in-situ (estimated). By comparison, the majority of the DNAPL mass removal at the Montrose Site would be in the vapor-phase (i.e., the MCB component of the DNAPL). An estimated 425,000 pounds of VOCs was removed at the Savannah River Site, which reflects only 21% of the 2 million pounds originally estimated to be present at the Savannah River Site, although the pre-remediation mass may have been overestimated. At the AG Communications Site, only 33,000 pounds of VOCs were removed over a period of 4.2 years. No liquid-phase DNAPL was recovered, and steam injection was implemented to remediate dissolved-phase contamination and enhance SVE within a low permeability unsaturated zone.

Hot Floor: At the Savannah River Site, the M-Area Aquifer is underlain by a low permeability clay (the Green Clay), which serves as a capillary barrier preventing further downward migration of the PCE DNAPL. As a result, a hot floor was not implemented or required at the Savannah River Site. Although steam was injected into the Deep Aquifer at the SCE Visalia site, the purpose was to prevent continued influx of cool groundwater into the thermal treatment zone and not to mitigate the potential for downward migration. Furthermore, only a small portion of the underlying Deep Aquifer at the SCE Visalia site was heated using just 3 steam injection wells. At the Montrose Site, a 20 to 25 foot thick sand aquifer (the BFS) underlies the DNAPL-impacted UBA and would require heating over the entire thermal treatment area.

DNAPL Displacement: CH2M Hill has indicated displacement of liquid-phase DNAPL as an advantage for steam injection over other thermal technologies (CH2M Hill, 2007). However, at the Savannah River Site, less than 0.1% of the DNAPL mass was recovered in liquid-phase; greater than 99.9% of the mass recovered was in the vapor-phase. Therefore, this advantage may be overstated, although EPA indicates that it can be difficult to account for contaminants removed in the vapor-phase versus the DNAPL-phase due to the complexity of the phase transfer mechanisms during steam injection of volatile DNAPLs.

In addition to the above-referenced sites, steam injection was also field pilot tested across a thick and heterogeneous saturated interval at the Williams Air Force Base in Mesa, Arizona. Steam was injected over a 70-foot thick and highly layered saturated zone at this site (approximately 170 to 240 feet bgs). Although the lower saturated zone was effectively heated by preferential steam flow through the higher permeability layers, the lower permeability layers were not effectively heated, reaching temperatures of less than 60°C. Although this site had a thick and layered saturated zone, numerous differences with the Montrose Site exist and there were some performance problems associated with the manner in which the pilot test was conducted. Consequently, the performance of the steam injection pilot test at the Williams

Air Force Base does not demonstrate the potential effectiveness of steam injection at the Montrose Site (see Appendix K for more details).

A hot floor created by steam injection into underlying hydrologic layer can be applied in the BFS in an attempt to reduce the potential for downward mobilization. However, the potential effectiveness of a hot floor is highly uncertain and implementation of a hot floor presents its own increased risk of downward mobilization. Hot floors are very infrequently implemented, and the effectiveness of a steam injection hot floor in reducing downward mobilization has not been reliably demonstrated in the field. In the limited number of cases where a hot floor was implemented, ERH or TCH was typically used to heat the hydrologic layer underlying the DNAPL-impacted zone. In only one case (the SCE Site in Visalia, California), steam injection was implemented in an underlying aquifer unit to heat an overlying DNAPL-impacted aquitard. For that case, and as indicated above, steam was injected into the underlying aquifer during a subsequent treatment phase to reduce the upward flow of cool groundwater into the heated treatment zone (not a true hot floor). A hot floor in the underlying BFS would theoretically reduce, to some extent, the risk of vertical migration during a steam remedy. However, a hot floor would not eliminate or fully mitigate vertical migration risks. Steam injection hot floors are infrequently implemented, and there is an absence of experience at comparable sites upon which to reliably predict the performance of a hot floor at the Montrose Site. The hot floor at the Montrose Site would not be a clay, like most other hot floor applications, but instead would be a "thermal barrier", which has to prevent DNAPL from migrating into the BFS, a highly transmissive aquifer. While it is difficult to predict the potential effectiveness of a hot floor at evaporating MCB to reduce its downward movement, EPA has indicated that the geologic conditions of the BFS at the Montrose Site appear to be suitable for injecting steam. In a paper dated February 22, 2011, McMillan-McGee indicated that a hot floor in the underlying BFS had a low chance of success in preventing downward migration of the DNAPL (McMillan-McGee, 2011). McMillan-McGee indicated that the preferential path for steam flow would be laterally through the BFS, instead of vertically upward into the UBA. Without the vertical flow of steam to flush the DNAPL vapors upward, McMillan-McGee indicated that downward mobilization cannot be prevented. Although a hot floor may not prevent DNAPL from entering the BFS, EPA indicated in a memorandum dated April 14, 2011 (EPA, 2011a), that a hot floor could treat DNAPL migrating into the BFS.

At the Del Amo Superfund Site located less than 0.25 miles east of the Montrose Site, thermal remediation technologies were also evaluated for treatment of a light non-aqueous phase liquid (LNAPL). A Soil and NAPL FS was issued for that site in July, 2008 (URS, 2008). According to the FS, "*the low permeability and heterogeneous character of soils at the former plant site would interfere with the uniform transmission of the steam through the subsurface*". Consequently, the FS concluded that "*the*

source areas at this site are generally not well suited for application of this technology compared to other aggressive thermal technologies considered". The LNAPL-impacted aquitard at the Del Amo Site is similar to the DNAPL-impacted UBA at the Montrose Site in at least one source area located on the west side of the Del Amo Site. The aquitard, also identified as the Upper Bellflower (UBF), was characterized as being highly layered with interbedded sands and silts. The aquitard at the Del Amo Site becomes less layered to the east, and the layers are generally more continuous at the Del Amo Site. However, the two aquitard zones have a significant number of similarities. Although URS indicated that steam injection was retained at EPA's request, it was not assembled into a formal remedial alternative. In comments dated January 27, 2010 (EPA, 2010a), EPA indicated that the LNAPL at the Del Amo Site does not pose the same vertical migration risk to deeper water-bearing units as the Montrose DNAPL. While DNAPLs do pose a greater risk to underlying hydrologic units, the statement referenced above refers to the applicability of steam injection to the hydrogeology at the Del Amo Site, which is similar to the nearby Montrose Site.

Although steam injection has the potential to be effective at the Montrose Site and meet DNAPL RAOs, the layered and low permeability nature of the UBA is not ideal for steam injection and will pose significant challenges for a steam remedy. Given all the uncertainties described above and the lack of a steam remedy at a site comparable to the Montrose Site, an effectiveness ranking of "potentially effective" is the most appropriate. ***Ranking: Potentially Effective.***

Implementability. This thermal remediation process option would be difficult to implement. A significant amount of infrastructure would be required to generate and deliver steam throughout the DNAPL impacted zone. A large number of wells, steam injection and multiphase extraction, would be required to treat the entire DNAPL-impacted area and would generate a significant amount of waste requiring management and disposal. This process option would additionally require implementation of SVE to recover VOCs for ex-situ treatment. This process option additionally requires extraction and ex-situ treatment of total fluids including groundwater/condensed steam and DNAPL. Under this process option, implementation of a hot floor in the underlying BFS may additionally be required to reduce the risks associated with downward migration of DNAPL.

This process option would require highly skilled operators and a high level of maintenance, including boiler maintenance and management of boiler brine waste. S team injection is an energy-intensive remedial technology, and the amount of energy required to heat the entire DNAPL-impacted area would be significant. The resulting carbon footprint for a full-scale steam injection remedy would be similarly large. Because steam is injected under pressure, there is additionally an increased potential for heated vapors or contaminated steam to be accidentally released to atmosphere as a fugitive emission. For

example, at the SCE Visalia site, one monitoring well suffered a catastrophic failure due to incompatibility of the bentonite annular seal materials with the elevated temperatures of the full-scale steam remedy, although EPA indicates that no contaminants were released to atmosphere from this well.

Another important factor limiting the implementability of this process option is a lack of steam vendors. Only one thermal remediation vendor, TerraTherm, continue to pursue steam injection for site remediation. Previously, SteamTech, Praxis Environmental, and McMillan-McGee offered and actively marketed steam injection as a remedial technology. However, SteamTech has since been dissolved, and McMillan-McGee no longer pursues steam injection as a commercial technology. Praxis Environmental is a small, independent firm (one person) with insufficient resources to implement a project of this size unless partnered with a larger remediation contractor, and is pursuing alternate remediation technologies following their participation in the Williams Air Force Base field pilot test. TerraTherm is the only thermal remediation vendor still pursuing steam injection as a commercial technology with the potential to implement a project of this size, although the majority of thermal remediation projects implemented by TerraTherm are smaller in size than the Montrose Site. A lack of commercial steam injection vendors may limit the implementability of this process option, although a steam consultant could work with a remediation contractor to implement a steam remedy. ***Ranking: Difficult to Implement.***

Cost. The relative cost for this thermal technology process option is very high. Under this thermal process option, high costs are incurred for steam injection and multiphase extraction well installation, waste disposal, and energy consumption (primarily natural gas for steam boiler). Although pressure cycling can be implemented to reduce the energy demand of a steam injection remedy, there are also a number of potential inefficiencies that could increase the energy demand. This process option requires both soil vapor and groundwater extraction, resulting in high ex-situ treatment costs. If a hot floor is implemented as a component of the steam injection remedy, costs for this process option are further increased. Moreover, the paucity of steam vendors may add to the costs due to a lack of competition. Steam injection costs would be further increased if more than 2 to 3 pore volumes of steam flushing are required by the thermal remedy, as suggested by the experience at the SCE Visalia Site. ***Ranking: Very High.***

Retain for Assembly of Remedial Alternatives? The potential effectiveness of this process option is uncertain given the Site conditions and nature of the Montrose DNAPL. Additionally, the potential effectiveness of this thermal technology has not been demonstrated through field pilot testing. Although 2-dimensional bench-testing indicated that approximately 60% of the MCB could be removed by steam injection, under ideal conditions, the study raises some concerns about the potential for vertical migration through thin and discontinuous capillary barriers. A hot floor within the underlying BFS would be

required as a component of steam injection to reduce the potential for downward migration. Despite its technical uncertainties, implementability challenges, and high cost, EPA has indicated a desire to evaluate candidate thermal remediation technologies in this FS. Therefore, steam injection is retained for further evaluation based on its potential effectiveness in meeting the RAOs and in reducing DNAPL mass and mobility by vaporizing the MCB component and displacing the Montrose DNAPL. ***Retained? Yes.***

4.7 EX-SITU GROUNDWATER TREATMENT

Process Description. Ex-situ groundwater treatment technologies for the Site have been extensively evaluated. The Groundwater ROD identified liquid-phase granular activated carbon (LGAC) as the primary treatment technology for MCB and other VOCs in groundwater, and the performance of LGAC in treating these contaminants has previously been tested on three occasions (McLaren-Hart, 1997; H+A, 2005; Earth Tech, 2008i). The Groundwater ROD additionally identified advance oxidation as a GRA for treatment of pCBSA in groundwater, and the performance of two advanced oxidation technologies (Trojan UV-PHOX™ and APT HiPOx™) in treating this contaminant have previously been tested on two occasions (Earth Tech, 2004b and 2008h, respectively). Trojan UV-PHOX™ is a technology that uses ultraviolet light (UV) and hydrogen peroxide to catalyze formation of hydroxyl radicals which oxidize dissolved constituents in groundwater. APT HiPOx™ is a technology that uses ozone and hydrogen peroxide to form hydroxyl radicals and oxidize dissolved constituents in groundwater.

The full-scale treatment system for the groundwater remedy is currently in design but is expected to be air stripping, LGAC and HiPOx™. Although air stripping was recently incorporated into the remedial design for the groundwater remedy, it is not clear that air stripping would be required for treatment of groundwater from a DNAPL remedy. Air stripping was incorporated in the groundwater remedy to treat low concentrations of non-polar compounds, specifically methylene chloride, which is not effectively treated by either LGAC or HiPOx™. At this preliminary stage, it is unclear whether methylene chloride would be detected in groundwater extracted during a DNAPL remedy. For costing purposes, it is assumed that air stripping will not be required for treatment of groundwater during a DNAPL remedy. Additionally, it is assumed that a separate pre-treatment plant (separate from the groundwater remedy treatment plant) would be used to treat groundwater extracted as part of a DNAPL remedy. Dissolved contaminant concentrations within the DNAPL-impacted zone are substantially higher than those to be addressed by the groundwater remedy. Therefore, to simplify design considerations, a separate groundwater pre-treatment system dedicated to the DNAPL remedy is assumed for this FS. In addition to dissolved contaminants, groundwater would be treated using physical separation methods to remove DNAPL and filter out suspended solids. The ex-situ groundwater treatment system would be connected to the DNAPL wellfield via an aboveground piping network.

Effectiveness. Ex-situ treatment of UBA groundwater using a combination of LGAC and advanced oxidation will be effective. The effectiveness of treating MCB in groundwater using LGAC was previously demonstrated during bench tests conducted in 2005 (H+A, 2005) and 2008 (Earth Tech, 2008i). MCB concentrations in groundwater up to 33,000 ug/L were treated during these tests, and LGAC was found to be highly effective in removing MCB from groundwater with up to 33% adsorption on a weight basis. Although dissolved MCB concentrations within the DNAPL-impacted zone can exceed 100,000 ug/L, LGAC will be no less effective in treating MCB (although more LGAC may be consumed).

The effectiveness of treating pCBSA in groundwater using either HiPOx™ or Trojan UV-PHOX™ was demonstrated during field and bench tests conducted in 2003 (Earth Tech, 2004b) and 2008 (Earth Tech, 2008h), respectively. pCBSA concentrations in groundwater up to 81,000 ug/L were treated during these tests, and both advanced oxidation process options were found to be effective in meeting target remediation goals as low as 100 ug/L. However, discoloration of the groundwater was observed during UV-oxidation testing, inhibiting UV transmittance and formation of hydroxyl radicals. As a result, Trojan UV-PHOX™ may not be as effective on a full-scale basis as HiPOx™, which does not rely on groundwater clarity or UV transmittance. ***Rank: Effective.***

Implementability. There are no technical or administrative aspects that would limit the implementability of this ex-situ groundwater treatment technology, which is also expected to be implemented as part of the groundwater remedy. ***Rank: Implementable.***

Cost. The relative cost of this process option is high due to the high dissolved concentrations present within the DNAPL-impacted zone, although it is the only ex-situ treatment technology considered for groundwater. ***Rank: High.***

Retain for Assembly of Remedial Alternatives? As the only ex-situ groundwater treatment technology evaluated in the FS, this process option is automatically retained for assembly in remedial alternatives. ***Retained? Yes.***

4.8 EX-SITU VAPOR TREATMENT

Ex-situ treatment of extracted soil vapors will be necessary if SVE is included as a component of an assembled remedial alternative. Three ex-situ vapor treatment process options are potentially applicable to the Site, including thermal oxidation with acid gas scrubbing, steam-regenerable carbon or resin, and disposable carbon or resin. Each of the three vapor treatment process options are evaluated against the three preliminary screening criteria in the following sections.

4.8.1 THERMAL OXIDATION/ACID GAS SCRUBBING

Process Description. Thermal oxidation is a destructive technology for treatment of VOCs in off-gas vapors. VOC-impacted soil vapors from an SVE remedial alternative would be directed to a combustion chamber for oxidation at temperatures exceeding 1,500°F. The products of combustion would include carbon dioxide, water vapor, and acid gas, and the effluent from the thermal oxidizer would then be further treated for removal of the acid gas via a water-cooled quench and wet scrubber.

Thermal oxidation systems are either direct-fired or flameless. For direct-fired systems, combustion of VOC-impacted soil vapors is achieved using a propane or natural gas fired flame. Flameless thermal oxidizers (FTOs) achieve combustion using either a heated porous ceramic tube burner or ceramic packed-bed reactor. Both thermal oxidation systems require the addition of either propane or natural gas as supplemental fuel for combustion, particularly when the energy or BTU-content of the soil vapors is low. Recuperative and regenerative thermal oxidation systems have the ability to recover heat and use less supplemental fuel.

Effectiveness. Thermal oxidation is an effective and reliable method for treating chlorinated hydrocarbon vapors and is widely used throughout the environmental industry. Direct-flame thermal oxidizers typically achieve VOC destruction efficiencies of approximately 99%, while FTOs offer destruction efficiencies up to 99.99%. Because of the higher efficiency, FTOs are capable of treating higher influent contaminant concentrations such as would be experienced during a DNAPL remedy. Wet scrubbers are also widely used for neutralization of acid gases. Thermal oxidizers are effective in meeting air quality emission standards, particularly FTOs which offer low emissions of nitrogen and sulfur oxides. ***Rank: Effective.***

Implementability. Thermal oxidation of soil vapors is implementable. Pre-engineered systems for thermal oxidation of chlorinated hydrocarbons are available from a variety of manufacturers, although FTOs are not as widely available as direct-fired thermal oxidizer systems. An FTO was recently used to treat soil vapors at the Pemaco Superfund Site in Maywood, California as a component of a thermal remediation and SVE alternative. It is noted that thermal oxidation is a candidate ex-situ vapor treatment technology evaluated in the Soil and NAPL FS for the Del Amo Superfund Site (URS, 2008). Thermal oxidizers meet the technical and administrative air quality standards established by the South Coast AQMD. A primary advantage of this process option is that the vapor-phase contaminants are destroyed, not captured, and do not require subsequent waste management and disposal. However, because thermal oxidation is a combustion process, analysis of the system effluent for products of incomplete combustions is often required. Additionally, thermal oxidizers with acid gas scrubbers are complex systems that

require skilled operators and a relatively high level of maintenance. Acid gas scrubbers additionally generate a constant wastewater stream that requires management and disposal. Additionally, in Southern California, it is necessary to soften the city water for use as cooling water for thermal oxidizing quench and scrubbing. ***Rank: Implementable.***

Cost. The relative cost for this soil vapor treatment process option is moderate to high, depending on the type of thermal oxidization system selected. Direct-fired thermal oxidizers are lower in cost and recuperative heat methods can be used to reduce the cost of make-up fuel. FTOs are higher in cost and are expensive to maintain. For sites with chlorinated VOCs (which have a low energy content), the cost of supplemental fuel (propane or natural gas) is high. ***Rank: Medium to High.***

Retain for Assembly of Remedial Alternatives? This process option is retained because it is an effective method for destroying MCB and other VOCs in soil vapors extracted using an SVE remedial technology. ***Retained? Yes.***

4.8.2 REGENERABLE CARBON/RESIN ADSORPTION

Process Description. In this process, the extracted soil vapors are treated using granular activated carbon or resin. Soil vapors are passed through a packed bed or vessel containing activated carbon or resin and are removed from the vapor stream by adsorption. The vapor treatment process is the same as with disposable carbon, but under this process option, spent carbon/resin beds are regenerated on-Site using low pressure steam. The steam heats the carbon/resin beds up to approximately 300°F, thereby desorbing and volatilizing the contaminants. The steam and contaminated vapors are purged to a liquid-cooled condenser and subsequent decanter for separation of the liquid-phase contaminants (DNAPL) from steam condensate. The recovered liquid-phase contaminants are then transported off-Site for recycling or disposal. The condensed steam contains dissolved-phase contaminants and is either disposed directly or treated off-Site, typically via disposable LGAC, prior to disposal. The steam regenerated carbon/resin is air-cooled and then placed back into service. Typically, these systems are designed with paired lead vessels, one active and one inactive, to eliminate the need for interruption in soil vapor treatment during carbon/resin regeneration. The active lead vessel is switched once it is ready for steam regeneration.

Effectiveness. This process option is effective in treating soil vapors from the Site. Disposable carbon, which treats soil vapors in an identical manner, was used during the SVE pilot test conducted at the Site in 2003 (Earth Tech, 2004a). Approximately 4,700 pounds of vapor-phase contaminants were treated during that test in compliance with South Coast AQMD emission criteria. Multiple carbon vessels were connected in series in order to effectively treat the elevated VOC concentrations in soil gas, up to

approximately 14,000 ppmv as total gaseous non-methane organics (the majority of which was MCB and chloroform). A high rate of VOC mass adsorption, approximately 25% by weight, was observed during that field pilot test. A steam regenerable carbon/resin system is expected to be equally effective in treating VOCs in soil vapor, although multiple vessels may need to be connected in series in order to achieve a high enough removal efficiency to comply with emission standards. Steam has been widely and successfully used to regenerate or reactivate carbon for reuse. The efficiency of the reactivation process diminishes over time, and after a sufficient number of reactivation cycles, the regenerable carbon is replaced. ***Rank: Effective.***

Implementability. Ex-situ treatment of soil vapors using steam-regenerable carbon/resin is implementable. Pre-engineered regenerable carbon/resin systems are available from a variety of manufacturers, although resin is not as widely used as carbon. These vapor treatment systems meet the technical and administrative air quality standards established by the South Coast AQMD. Steam-regenerable carbon/resin systems require skilled operators and a relatively high level of maintenance. Challenges with implementing this option include corrosion of the carbon/resin support screens, effective gravity separation of the condensed contaminants and steam, and management of the relatively large volumes of contaminated steam condensate and recovered solvent. ***Rank: Implementable.***

Cost. The relative cost for this soil vapor treatment process option is moderate to high, depending on the volume of waste generated for off-Site disposal. The primary disadvantage of this process option is the high cost associated with managing and disposing of the waste streams. Unlike thermal oxidation, VOCs are captured and require off-Site disposal as a liquid waste. Although the carbon used for this process option requires only infrequent replacement, the steam condensate becomes contaminated via the regeneration process and requires off-Site disposal or treatment (or both). ***Rank: Medium to High.***

Retain for Assembly of Remedial Alternatives? This process option is retained because it is an effective method for removing MCB and other VOCs from soil vapors extracted using an SVE remedial technology. Additionally, this vapor treatment process option is particularly applicable for remedial alternatives involving steam injection. ***Retained? Yes.***

4.8.3 DISPOSABLE CARBON/RESIN ADSORPTION

Process Description. In this process, the extracted soil vapors are treated using disposal carbon or resin adsorption beds. Soil vapors are passed through a packed bed/vessel containing activated carbon or resin and are removed from the vapor stream by adsorption. Multiple vessels are connected in series as needed to meet emission goals. Once the carbon/resin in the lead vessel becomes spent, it is replaced with fresh carbon or resin and repositioned to the end of the treatment train. Spent carbon/resin is transported off-

Site for reactivation or disposal. Virgin or reactivated carbon can be used for this process option, or alternately a polymeric resin such as the Ambersorb® product line.

Effectiveness. This process option is effective in treating MCB and other VOCs in soil vapors as demonstrated during the 2003 SVE field pilot test (Earth Tech, 2004a). As described in Section 4.8.2, multiple disposable carbon vessels connected in series were effective in treating approximately 4,700 pounds of vapor-phase contaminants during the field pilot testing and in compliance with South Coast AQMD emission limits. A high rate of VOC mass adsorption, approximately 25% by weight, was observed during that pilot test. Resin would be expected to exhibit a similarly high MCB mass adsorption efficiency. It is noted that disposable carbon adsorption was implemented as the ex-situ vapor control technology for the former waste pits at the Del Amo Superfund Site located immediately east of the Montrose Site. ***Rank: Effective.***

Implementability. Ex-situ treatment of soil vapors using disposable carbon/resin is implementable. This process option requires only a low level of maintenance and does not require highly skilled operators. This vapor treatment process option meets the technical and administrative air quality standards established by the South Coast AQMD. The primary disadvantage of this vapor treatment process option is the high volume of spent carbon/resin to manage and dispose. High carbon/resin usage rates can increase the difficulty of implementing this process option, particularly in coordinating carbon/resin replacement. ***Rank: Implementable.***

Cost. The relative cost for this vapor treatment process option is moderate to high, depending on the volume of carbon/resin consumed during the remedy. As the volume of disposable carbon/resin consumed increases, the cost effectiveness of this vapor treatment process option decreases. For an SVE alternative targeting the PVS and unsaturated UBA only, the relative cost of this process option would be moderate and potentially comparable with the other vapor treatment process options. However, for a combined thermal remediation/SVE remedial alternative for example, targeting both the unsaturated and saturated zones, the relative cost of this process option would be very high and likely higher than the other vapor treatment process options. ***Rank: Medium to High.***

Retain for Assembly of Remedial Alternatives? This process option is retained because it is an effective method for removing MCB and other VOCs from soil vapors extracted using an SVE remedial technology. This ex-situ soil vapor treatment process option may be cost effective in combination with SVE in the unsaturated zone and will be considered for some alternatives. However, the volume of disposable carbon/resin required to treat vapor-phase contaminants removed by a thermal remediation technology implemented in the saturated UBA would be excessive and cost prohibitive. For remedial

alternatives where thermal remediation of the saturated UBA is a component, either steam-regenerable carbon/resin or thermal oxidation/acid gas scrubbing will be considered for ex-situ soil vapor treatment. ***Retained? Yes.***

4.9 DISPOSAL

This section evaluates three different process options for disposal (recycling) of groundwater extracted during a DNAPL remedial action. The various DNAPL remedial technologies considered in this FS are expected to generate up to approximately 250 gpm of groundwater. All process options evaluated for groundwater disposal involve re-injection, either into the saturated UBA or alternately into the BFS and Gage Aquifers. Re-injection of both treated and untreated groundwater into the UBA is evaluated.

Disposal process options evaluate (a) whether groundwater is treated prior to re-injection, and (b) whether groundwater is re-injected on-Property into the UBA or off-Property into the BFS and Gage Aquifers. For disposal process options involving groundwater treatment, the technologies identified in Section 4.7 are assumed. Disposal process options do not evaluate different ex-situ treatment technologies. Since two of the three disposal process options include ex-situ groundwater treatment, the cost of ex-situ treatment is included for these options in order to provide a comparative evaluation with the option that excludes ex-situ treatment.

Re-injection preserves the groundwater resource and enhances hydraulic gradients. Disposal of extracted groundwater to the industrial sewer or municipal storm drain do not preserve the groundwater resource or enhance hydraulic gradients and are not considered by this FS. Additionally, obtaining an industrial sewer discharge permit for a new source can be problematic due to limited sewer capacities, and there is no cost benefit to discharging treated groundwater to the municipal storm drain. Further, no storm catch basin exists along the western side of Normandie Avenue. One process option is also evaluated for disposal of recovered DNAPL.

4.9.1 INJECTION OF TREATED WATER AS PART OF GROUNDWATER REMEDY

Process Description. Under this disposal process option, groundwater extracted as part of a DNAPL remedy would be treated for dissolved contaminants as discussed in Section 4.7 and then transferred to the groundwater remedy treatment system for re-injection into the off-Property BFS and Gage Aquifer injection wells that are part of the groundwater remedy. Because the dissolved concentrations of MCB and pCBSA in the UBA groundwater will be substantially higher than the water treated as part of the groundwater remedy, a separate treatment train dedicated to the DNAPL remedy was assumed. This process option does not require installation of any re-injection wells.

Effectiveness. This disposal process option is effective to address extracted groundwater. The location of re-injected groundwater under this option particularly impacts thermal remedial technologies because re-injection of treated groundwater into the DNAPL-impacted UBA could serve to cool the subsurface and reduce the effectiveness of a thermal remedial alternative. Pilot testing conducted as part of the groundwater remedy indicates that injection of water into the BFS and Gage Aquifer can be effectively implemented. However, because treated groundwater is not re-injected into the saturated UBA, it does not serve to enhance the hydraulic gradient or increase flushing associated with a hydraulic displacement remedial alternative. Recycling extracted groundwater is an effective pollution prevention strategy for reducing the volume of wastewater requiring disposal to publicly owned treatment works. ***Rank: Effective.***

Implementability. This disposal process option is implementable and would need to meet the administrative requirements for groundwater re-injection specified in the Groundwater ROD. However, the increased groundwater volume requiring re-injection into the BFS and Gage Aquifers must be considered during groundwater Remedial Design (RD). The increased re-injection flow rate may affect wellfield design, equipment and piping sizing, and in-situ hydraulic gradients, particularly for DNAPL process options with up to 200 to 250 gpm of treated groundwater (approximately 30% to 35% of the planned re-injection rate for the groundwater remedy). ***Rank: Implementable.***

Cost. The relative cost for this process option is high since dissolved-phase concentrations of both MCB and pCBSA will be elevated and a separate treatment train would have to be implemented to address treatment of these contaminants. ***Rank: High.***

Retain for Assembly of Remedial Alternatives? This disposal process option for groundwater is retained for assembly into remedial alternatives. Although alternate groundwater disposal process options may be more effective for hydraulic displacement, this process option would be effective for DNAPL thermal remediation technologies. ***Retained? Yes.***

4.9.2 INJECTION OF TREATED WATER AS PART OF HYDRAULIC DISPLACEMENT

Process Description. Under this disposal process option, groundwater extracted as part of a DNAPL remedy would be treated for dissolved contaminants and then re-injected back into the saturated UBA for purposes of enhancing hydraulic gradients and DNAPL displacement. This process option is specifically evaluated for purposes of supporting a hydraulic displacement remedy. Under this option, a separate treatment train dedicated to the DNAPL remedy is assumed to treat elevated dissolved concentrations of MCB and pCBSA to the re-injection standards established in the Groundwater ROD, which is identical to the option for re-injection of treated groundwater as part of a groundwater remedy. A series of injection

wells spaced throughout the DNAPL-impacted zone and an associated piping network would be required for this process option.

Effectiveness. This groundwater disposal process option is technically effective and would substantially enhance gradients under a hydraulic displacement alternative, as compared to the process option set forth in 4.9.1 above. Recycling extracted groundwater is an effective pollution prevention strategy for reducing the volume of wastewater requiring disposal to publicly owned treatment works. Approximately 1.8 million gallons of groundwater was re-injected into two UBA wells during the 2004/2005 DNAPL extraction pilot test (H+A, 2007c). The initial specific capacities of the two UBA injection wells, UBI-1 and UBI-2, were measured at 2.1 and 4.8 gpm per foot respectively. The differences in specific capacities were related to differences in the thickness and permeability of the saturated sand layers screened by the injection wells. Although the two injection wells were successful in disposing of the groundwater back to the UBA, the specific capacity of injection well UBI-1 had decreased to approximately 0.9 gpm per foot after 12 months of field pilot testing (a 57% reduction in the re-injection capacity). However, these wells were not redeveloped during the field pilot test, and often times, routine re-development can reduce the effects of fouling and regain much of the lost specific capacity. Spare injection wells can also be included in the remedial design and activated while fouled injection wells are redeveloped. Having injection to extraction well ratios of 1.5:1 or 2:1 is a common approach for routinely managing injection well fouling. Mounding between 1 and 6 feet was observed at the injection wells during the field pilot test, and therefore, re-injection of the groundwater did not flood the unsaturated zone which could inhibit remedial technologies such as soil vapor extraction. For this process option to be effective, groundwater must be delivered back to the layers in which DNAPL occurs. Additionally, dissolved contaminants are removed from groundwater prior to re-injection, marginally increasing the rate of contaminant mass removal. ***Rank: Effective.***

Implementability. This groundwater disposal process option is technically and administratively implementable. Treatment of the dissolved VOCs would meet re-injection standards established in the Groundwater ROD, and no waiver of the standards within the TI Waiver Zone would be required to implement this process option. However, injection well fouling could increase the difficulty of implementing this process option. Dissolved VOC and pCBSA concentrations in the separated groundwater will be high, and a robust treatment system will be required to meet re-injection standards, increasing the difficulty of implementing this disposal process option. ***Rank: Implementable.***

Cost. The relative cost for this groundwater disposal process option is high since dissolved concentrations of both MCB and pCBSA will be elevated and will require a separate treatment train. Treatment of dissolved contaminants and an injection well network are both required for this process

option. A relatively high number of injection wells may be required to dispose of the groundwater, and fouling of the injection wells will increase the cost of this process option. ***Rank: High.***

Retain for Assembly of Remedial Alternatives? In accordance with reconciliation discussions from November 2010 (AECOM, 2010e and 2011f), this groundwater disposal process option is retained for assembly into remedial alternatives. Although ex-situ treatment of groundwater is not required to implement hydraulic displacement, this process option is administratively implementable in meeting the re-injection standards established in the Groundwater ROD. ***Retained? Yes.***

4.9.3 INJECTION OF UNTREATED WATER AS PART OF HYDRAULIC DISPLACEMENT

Process Description. Under this disposal process option, untreated groundwater extracted as part of a DNAPL remedy would be re-injected back into the saturated UBA for purposes of enhancing hydraulic gradients and DNAPL displacement. T his process option is specifically evaluated for purposes of supporting a hydraulic displacement remedy. Unlike the two process options for reinjection of treated groundwater, the dissolved concentrations of MCB and pCBSA would not be treated prior to re-injection. Groundwater would be separated from DNAPL and filtered prior to re-injection to remove suspended solids and minimize fouling, but groundwater would otherwise not be treated to remove dissolved contaminants. This approach was utilized during the most recent DNAPL extraction testing conducted at the Site, since the impacted groundwater was injected into the UBA within the footprint of the TI Waiver Zone. I njected groundwater within that zone would be contained indefinitely through groundwater containment systems and eventually treated through the groundwater remedy. A series of injection wells spaced throughout the DNAPL-impacted zone and an associated piping network would be required for this process option.

Effectiveness. Although no dissolved MCB or pCBSA will be removed from the groundwater, this process option is equally effective in terms of enhancing hydraulic gradients and DNAPL displacement. This process option was implemented during the 2004/2005 DNAPL extraction pilot test and found to be effective in delivering groundwater back to the UBA. Prior to injection, extracted groundwater was separated from DNAPL and filtered to remove suspended solids to minimize the potential for plugging which could result in loss of injection well capacity. Fouling of the UBA injection wells during a DNAPL remedy would make this groundwater disposal process option less effective. However, fouling of injection wells is not uncommon and, often times, routine re-development can regain much of the lost specific capacity. Additionally, for this process option to be effective, groundwater must be delivered back to the layers in which DNAPL occurs.

The impact of injecting untreated groundwater from extraction wells was assessed during the 2004/2005 DNAPL extraction pilot test (H+A, 2007c). Analytical data for the groundwater samples collected prior to, during, and following the DNAPL extraction testing program revealed that dissolved concentrations were within the typical range of values for both the upgradient monitoring well, MW-8, located approximately 400 feet northwest of the Property, and the downgradient monitoring well, MW-14, located approximately 800 feet south-southeast of the Property. Re-injection of untreated groundwater during the 2004/2005 DNAPL extraction test did not adversely impact groundwater quality around the CPA within the TI Waiver Zone footprint. ***Rank: Effective.***

Implementability. This groundwater disposal process option is technically implementable but may not be administratively implementable. The dissolved contaminants in the groundwater will exceed the re-injection standards established in the Groundwater ROD, and for this process option to be administratively implementable, the re-injection standards would need to be waived by both EPA and the State, which was done for the 2004/2005 extraction testing. Based on the 2004/2005 pilot test, re-injection of untreated groundwater is not expected to adversely impact groundwater quality within the saturated UBA and within the footprint of the TI Waiver Zone. Furthermore, hydraulic containment will serve to control any potential contaminant migration in the long-term. This approach was also previously used at two UPRR sites in Wyoming and Oregon (AECOM, 2010e), where groundwater was re-injected without treatment for purposes of enhancing the hydraulic gradient and recovery rates of creosote DNAPL. A hydraulic containment system was used at both UPRR sites to control the flow of groundwater outside the DNAPL-impacted area. Using this approach, between approximately 100,000 and 1.8 million gallons of DNAPL were recovered from these two UPRR sites.

Nonetheless, in their comments on the Revised DNAPL FS, both EPA and the State indicated that they are unlikely to waive the groundwater quality standards to allow re-injection of untreated groundwater as part of a DNAPL remedy for the Site. Montrose believes that re-injection of groundwater satisfies the requirements of 42 U.S.C. §6939b(b) since separation of the DNAPL from groundwater following total fluids extraction will initially remove up to 90% of the total contaminant mass before re-injection. Furthermore, re-injection of untreated groundwater at the Site would occur full within the TI Waiver Zone and hydraulic containment wells. ***Rank: Difficult to Implement (unless ARAR is waived or agreement is reached on application of 42 U.S.C. §6939b(b)).***

Cost. The relative cost for this groundwater disposal process option is low because treatment of dissolved contaminants is not required. However, a relatively high number of injection wells may be required to dispose of the groundwater given the low hydraulic conductivities of the UBA, and fouling of the injection wells likely will increase the cost of this process option. ***Rank: Low.***

Retain for Assembly of Remedial Alternatives? In accordance with reconciliation discussions from November 2010 (AECOM, 2010e and 2011f), this groundwater disposal process option is retained for assembly into remedial alternatives. Although posing administrative challenges with respect to implementability, this process option would enhance DNAPL recovery during hydraulic displacement at a significantly lower cost. ***Retained? Yes.***

4.9.4 OFF-SITE INCINERATION OF DNAPL

DNAPL extracted as part of a remedial action would require off-Site disposal as a hazardous waste. However, there are limited options for disposal of the Montrose DNAPL, which is composed of MCB and DDT. There is no commercial market for recycled DNAPL of this composition, and a review of several leading waste companies confirmed that recycling or non-destructive disposal of the Montrose DNAPL is not commercially available (AECOM, 2011d). Therefore, the only disposal process option considered for DNAPL is off-Site incineration.

Process Description. Recovered DNAPL would be drummed, manifested as a hazardous waste, and transported off-Site for incineration within 90 days of generation.

Effectiveness. This disposal process option is effective. ***Rank: Effective.***

Implementability. This disposal process option has historically been used to manage DNAPL waste generated at the Site and is readily implementable. Off-Site disposal of DNAPL waste within 90 days of generation eliminates administrative aspects that would otherwise limit the implementability of this process option. ***Rank: Implementable.***

Cost. The relative cost for this disposal process option is high, although it is the only process option considered for DNAPL waste. ***Rank: High.***

Retain for Assembly of Remedial Alternatives? As the only disposal process option considered for DNAPL waste, off-Site incineration is retained for assembly into remedial alternatives. ***Retained? Yes.***

4.10 SUMMARY OF REMEDIAL TECHNOLOGY/PROCESS OPTIONS RETAINED FOR ASSEMBLY INTO REMEDIAL ALTERNATIVES

This section summarizes the GRA remedial technologies and process options retained, following the preliminary screening, for assembly into remedial alternatives.

Remedial Technologies and Process Options Retained For Assembly into RAs

General Response Action	Remedial Technology/Process Option
No Action	None
Institutional Controls	Deed Restrictions
	Access Restrictions
	Limit Groundwater Use
	DNAPL and Groundwater Monitoring
Extraction Technologies	Soil Vapor Extraction (unsaturated zone)
	Hydraulic Displacement (with water injection)
In-Situ Thermal Technologies	Electrical Resistance Heating
	Steam Injection
Ex-Situ Groundwater Treatment	Liquid-Phase Granular Activated Carbon (for MCB) and Advanced Oxidation (for pCBSA)
Ex-Situ Vapor Treatment	Thermal Oxidation with Acid Gas Scrubbing
	Regenerable Carbon/Resin Adsorption
	Disposable Carbon/Resin Adsorption
Disposal	Injection of Treated Water as part of Groundwater Remedy
	Injection of Treated Water as part of Hydraulic Displacement
	Injection of Untreated Water as part of Hydraulic Displacement
	Off-Site Incineration of DNAPL

The above remedial technologies and process options will be assembled into candidate remedial alternatives in Section 5.0. The candidate remedial alternatives will be described and further evaluated.

TABLES

TABLE 4.1
Preliminary Screening of DNAPL Remedial Technologies and Process Options
Final DNAPL FS
Montrose Superfund Site

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
No Action	None	No further action will be taken at the Site other than actions implemented as part of the soil and/or groundwater remedies	• Not effective • No institutional controls limiting potential for exposure to DNAPL • No reduction of DNAPL mass in the unsaturated or saturated zones	• Implementable	None	Yes
Institutional Controls	Deed Restrictions	Restrict future use of the Site or activities conducted at the Site through a Land Use Covenant	• Minimally effective • Will restrict human exposure to Site contaminants	• Implementable • Deed restriction in off-Property areas would require consent of the land owners	Low	Yes
	Access Restrictions	Restrict access to the Site through fencing and warning signs	• Minimally effective • Will restrict human exposure to Site contaminants	• Implementable • Already in place at Site	Low	Yes
	Limit Groundwater Use	Limit the ways in which groundwater may be used and prohibit extraction of groundwater for beneficial purposes	• Minimally effective • Will limit human exposure to contaminants in groundwater	• Implementable • Part of groundwater remedy	Low	Yes
	DNAPL and Groundwater Monitoring	Monitor for migration of DNAPL and dissolved-phase MCB to verify hydraulic containment	• Minimally effective • Will verify effectiveness of hydraulic containment program	• Implementable • Part of groundwater remedy	Low	Yes
Containment	Barrier Walls	Process for physically containing DNAPL sources and controlling lateral migration in the subsurface. Commonly implemented in conjunction with some type of source area DNAPL mass reduction technology. Common methods for establishing barrier walls include (a) slurry walls, (b) sheet piling, and (c) grout curtains.	• Not Effective • Slurry walls are likely infeasible given the depth of DNAPL impacts • Will not prevent vertical migration of mobile DNAPL, which is principal threat • Corrosion or chemical impacts to the barrier wall would be a significant concern as a long-term permanent remedy	• Implementable • Grout curtain is most implementable process option • Sheet piling may have difficulty reaching DNAPL impacted soil depths • Slurry walls are likely infeasible	Medium	No

TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
Extraction Technologies	Soil Vapor Extraction (SVE)	Soil gas containing vapor-phase contaminants is extracted under vacuum for ex-situ treatment	• Effective for removal of VOCs from permeable unsaturated soils • Was field pilot tested in 2003; high VOC mass removal rate observed from PVS and unsaturated UBA • MCB component of DNAPL will be volatilized by SVE; reduces DNAPL mass and mobility • Will prevent VOC migration in soil gas in unsaturated zone • Not effective for removal of DDT • Will be significantly less effective in low permeability PD soils	• Implementable	Medium	Yes
	Excavation	Process of physically removing DNAPL-impacted soils from the subsurface using mechanical methods including use of a backhoe or excavator with sidewall sloping, benching, or shoring. A large diameter auger (LDA) can also be used to remove soils vertically across a 5 to 12 foot diameter.	• Infeasible • Significant dewatering and bench sloping would be required • Insufficient room to accommodate conventional excavation approach • Active industrial and commercial businesses located adjacent to the Montrose property • Kenwood Avenue soil cells and the groundwater remediation system also border the DNAPL-impacted area.	• Not Implementable • Drilling of thousands of closely spaced LDA borings is not a realistic approach • Would generate massive quantities of hazardous waste • A large engineered structure would be required to enclose the excavation area for controlling odors and emissions	Prohibitively High	No
	Passive DNAPL Extraction	DNAPL passively accumulates in wells and is removed for off-Site disposal	• Minimally effective • Only mobile DNAPL that intercepts the wells is available to be recovered • Less than 300 gallons of DNAPL recovered since 1988 from a small number of wells	• Implementable • Passive DNAPL recovery has been on-going since 1988	Low	No

TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
Extraction Technologies (cont'd)	Hydraulic Displacement	Hydraulic gradients are created by simultaneous groundwater extraction and re-injection to displace DNAPL towards recovery wells for direct extraction and off-Site disposal	• Effective in recovering mobile DNAPL • Field pilot tested three times; DNAPL recovery rates up to 1,000 times faster than passive recovery rates • Reduces DNAPL mass and mobility, is a depletion technology • Higher DNAPL recovery rates are expected if water is re-injected to increase hydraulic gradients • Will not be effective for residual DNAPL occurring in low saturations (already immobile) • Higher density of wells may be required to effectively displace and recover DNAPL in the heterogeneous UBA	• Implementable • Moderate to high level of maintenance required to abate precipitate fouling of extraction equipment • Routine injection well redevelopment program would be required	Low to Medium	Yes
	Surfactant-Enhanced Aquifer Remediation (SEAR)	Surfactants are injected into the saturated zone to mobilize DNAPL for recovery by hydraulic displacement; the surfactants lower the interfacial tension between water and DNAPL	• Potentially effective; has not been bench or field pilot tested • Technology is infrequently applied; no sites comparable to Montrose • Higher density of wells may be required to effectively deliver surfactants throughout heterogeneous UBA • Increased risk of downward mobilization; no underlying confining layer to prevent impacts to BFS	• Difficult to implement • Specialized chemicals and contractors are required • Regulatory approval is required for surfactant injection • Separation of DNAPL at surface can be problematic	High	No

TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
Extraction Technologies (cont'd)	Cosolvent Injection	Cosolvents are injected into the saturated zone to mobilize DNAPL for recovery by hydraulic displacement; cosolvents are miscible in water and DNAPL and serve to decrease interfacial tension and increase dissolution	• Potentially effective; has not been bench or field pilot tested • Technology is infrequently applied; no sites comparable to Montrose • Higher density of wells may be required to effectively deliver cosolvents throughout heterogeneous UBA • Increased risk of uncontrolled mobilization; DNAPL mobility is increased, not reduced; no underlying confining layer to prevent impacts to BFS • DDT is likely to precipitate and potentially foul permeable soils and wells	• Difficult to implement • Specialized chemicals and contractors are required • Regulatory approval is required for cosolvent injection • Separation of DNAPL at surface can be problematic	High	No
	Polymer Flooding	Polymers are injected into the saturated zone to mobilize DNAPL for recovery by hydraulic displacement; polymers increase the viscosity of the soil washing fluid (i.e. groundwater) increasing the effectiveness of DNAPL displacement	• Potentially effective; has not been bench or field pilot tested • Technology is infrequently applied; no sites comparable to Montrose • Higher density of wells may be required to effectively deliver polymers throughout heterogeneous UBA • Increased risk of uncontrolled mobilization; DNAPL mobility is increased, not reduced; no underlying confining layer to prevent impacts to BFS	• Difficult to implement • Injection of viscous polymer solutions into saturated UBA may be problematic, resulting in frequent well fouling • Specialized chemicals and contractors are required • Regulatory approval is required for polymer injection	High	No

TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
Extraction Technologies (cont'd)	Alcohol Flooding	High concentration alcohols are injected into the saturated zone to mobilize DNAPL for recovery by hydraulic displacement; the alcohols are miscible with DNAPL, reducing their density and interfacial tension	• Potentially effective; has not been bench or field pilot tested • Technology is infrequently applied; no sites comparable to Montrose • Higher density of wells may be required to effectively deliver alcohol throughout heterogeneous UBA • Increased risk of uncontrolled mobilization; DNAPL mobility is increased, not reduced; no underlying confining layer to prevent impacts to BFS • DDT is likely to precipitate and potentially foul permeable soils and wells	• Difficult to implement • Specialized chemicals and contractors are required • High concentration alcohols are flammable liquids requiring careful handling • Regulatory approval is required for alcohol injection • Separation of DNAPL at surface can be problematic	High	No
In-Situ Non-Thermal Technologies	In-Situ Bioremediation (unsaturated zone)	Oxygen (or air) is delivered to the unsaturated zone to aerobically biodegrade MCB in-situ; this technology is commonly referred to as bioventing	• Potentially effective in biodegrading MCB; has not been bench or field pilot tested • MCB has relatively long half-life of approximately 150 days • MCB biodegradation rate may be slower than volatilization rate by SVE • Not effective in biodegrading DDT	• Implementable in permeable unsaturated soils • Potential risk of MCB volatilization and spreading • Difficult to implement in the low permeability PD soils	Low	No

TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
In-Situ Non-Thermal Technologies (cont'd)	In-Situ Bioremediation (saturated zone)	Oxygen and mineral nutrients are delivered to the saturated zone to aerobically degrade MCB in-situ; microbial augmentation can also be implemented to enhance degradation rates	• Not effective • Was bench tested in 1997; 38% MCB biodegradation in 4-week microcosm study • Additional testing required to verify effectiveness at high MCB and DDT concentrations present in source areas; biodegradation rate may be inhibited by MCB concentrations approaching solubility limit or high concentrations of DDT • Primarily treats dissolved-phase mass; would have limited impact on DNAPL phase mass • Higher density of wells may be required to effectively deliver oxygen and mineral nutrients throughout heterogeneous UBA • Given the high DNAPL phase mass in low permeability aquitard, in-situ bioremediation could require several hundred years of treatment before having an impact	• Moderately implementable • Oxygen and mineral nutrients are readily available and can be added to groundwater prior to re-injection • Highly skilled field operators are not required • Safe handling precautions may be required for hydrogen peroxide depending on concentration of source solution • Additional oxygen may be required to overcome oxygen demand of naturally occurring organics and minerals • Routine re-development of the wells may be required to restore hydraulic conductivities reduced by biofouling	High to Prohibitively High	No
	Soil Stabilization	Involves mixing DNAPL-impacted soils in-situ with a binding agent to permanently stabilize and immobilize the DNAPL. Mixing flight augers are typically 3 to 12 feet in diameter and would mix soils in-situ with one or more stabilizing agents (e.g., cement).	• Potentially Effective • Would potentially immobilize DNAPL through a reduction in the soil permeability • Risk of DNAPL vertical migration • Capillary barrier integrity would be compromised during in-situ mixing	• Not Implementable • Would require more than 4,000 mixed vertical soil columns • Would require more than 20 years to complete • Would generate significant odors and emissions	Prohibitively High	No

TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
In-Situ Non-Thermal Technologies (cont'd)	In-Situ Chemical Reduction (Zero Valent Iron)	Zero valent iron (ZVI) is a reactive product and electron donor that reduces contaminants in-situ. As the ZVI is oxidized, contaminants are reductively dechlorinated to less toxic byproducts. Different types include (a) macro or micro ZVI, (b) nano-scale ZVI, and (c) emulsified ZVI.	• Not Effective • Less effective in reducing chlorinated benzenes (low rate of transformation) • MCB is chemically reduced to benzene, which is more toxic and is resistant to further reduction • Primarily treats dissolved-phase and would have minimal impact on DNAPL mass	• Implementable • Construction of a permeable reactive barrier (PRB) using ZVI is technically implementable	Medium	No
	In-Situ Chemical Oxidation (ISCO)	Oxidizing agents are injected into the saturated zone to destroy contaminants in-situ; common oxidizing agents include: permanganate, persulfate, peroxide, ozone, and Fenton's reaction	• Potentially effective in oxidizing MCB; has not been bench or field pilot tested • Exceptionally large volume of oxidants would be required to remediate DNAPL mass in the saturated UBA • Higher density of wells may be required to effectively deliver oxidants throughout heterogeneous UBA • Precipitation of inorganics due to pH and/or redox changes may result in plugging of the aquifer	• Implementable • No ex-situ treatment required • Additional oxidants may be required to overcome oxidant demand of naturally occurring organics and minerals • Oxidant injection may displace DNAPL • Specialized chemicals and contractors are required	High	No

TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
In-Situ Thermal Technologies	Electrical Resistance Heating (ERH)	Soils are heated resistively by passing electrical current between a dense pattern of electrodes; VOCs are volatilized for removal by SVE and ex-situ vapor treatment; three technology vendors are available including TRS (three-phase heating), CES (six-phase heating), and McMillan-McGee (ET-DSP™)	• Effective in volatilizing MCB component of DNAPL; has not been bench or field pilot tested • Equally effective in treating low and high permeability soils • Not a displacement technology; reduced risk of uncontrolled migration • Would not require underlying hot floor if bottom up heating approach was used • Heterogeneous nature of UBA may reduce effectiveness of recovering volatilized VOCs by SVE • Water influx from surrounding formation may result in cooling • 45-foot thick treatment interval may pose some challenges for uniform heating • Full-scale system would be largest ERH project ever implemented • Relatively high MCB co-boiling point of 92°C • Long-term hydraulic containment still required even if ERH was successful	• Moderately to difficult to implement • Large number of electrodes and associated infrastructure would be required • Requires implementation of SVE to recover VOCs for ex-situ vapor treatment • Requires skilled operators and high level of maintenance • High energy consumption and large carbon footprint • Three qualified ERH vendors available to implement • Does not require steam boiler or brine waste disposal	High to Very High	Yes
	Conductive Heating	Soils are heated conductively by a dense pattern of electric heater wells; one technology vendor is available, TerraTherm (ISTD™); wells are heated to more than 1,000°F to thermally oxidize VOCs in-situ	• Not effective for highly chlorinated DNAPL • TerraTherm has previously determined that ISTD can result in significant acid gas generation when treating organochlorine pesticides; severe equipment corrosion can occur	• Not implementable due to the corrosive effects of the acid gas on metal equipment, piping, and wells	Very High	No

TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
In-Situ Thermal Technologies (cont'd)	Steam Injection	Pressurized steam is injected into the saturated zone to volatilize VOCs and flush DNAPL towards recovery wells; DNAPL, steam condensate, and VOCs are recovered from multiphase extraction wells positioned around the steam injection points; soil vapors and groundwater are treated ex-situ and DNAPL is disposed off-Site	• Potentially effective; has not been field pilot tested • Was bench tested; 57% to 63% of the MCB mass was removed after 3.4 to 5.2 pore volumes of steam flushing • Steam injection is less frequently applied relative to ERH and conductive heating • Steam will preferentially flow through permeable soil layers; low permeability layers may not be effectively heated; rely on conductive heating • Controlling the distribution of steam may be problematic; increased potential for lateral spreading • Increased potential for downward mobilization of DNAPL and steam • The effectiveness of a hot floor in reducing the potential for downward mobilization is not assured; large-scale steam injection hot floor has never been implemented at comparable site • Full-scale system would be one of the largest steam injection projects ever implemented • Has never been implemented on DNAPL composed primarily of MCB and DDT • Long-term hydraulic containment still required even if steam injection was successful	• Difficult to implement • Large number of steam injection/multiphase extraction wells and associated infrastructure would be required • Requires implementation of SVE to recover VOCs for ex-situ vapor treatment • Requires implementation of groundwater extraction to recover steam condensate and DNAPL for ex-situ treatment and disposal • Implementation of hot floor in BFS is required to reduce potential for downward migration • Requires highly skilled operators and a high level of maintenance, including boiler maintenance and brine disposal • High energy consumption and large carbon footprint • Limited availability of qualified steam injection vendors; license holder may need to work with remediation contractor	Very High	Yes
Ex-Situ Groundwater Treatment	Liquid-Phase Granular Activated Carbon and Advanced Oxidation	Extracted groundwater would be treated to remove dissolved VOCs by liquid-phase granular activated carbon (LGAC) and pCBSA by advanced oxidation (e.g. APT HiPOx™.	• Effective • Treatment technologies identified in Groundwater ROD • Bench and field pilot tests confirm effectiveness in treating VOCs by LGAC and pCBSA by HiPOx™	• Implementable • Will be implemented as part of groundwater remedy	High	Yes

TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
Ex-Situ Vapor Treatment	Thermal Oxidation with Acid Gas Scrubbing	Extracted soil vapors are thermally oxidized at temperatures exceeding 1,500°F to destroy VOCs; acid gases are scrubbed and neutralized.	• Effective • Able to achieve high levels of contaminant destruction • Will meet SCAQMD emission standards	• Implementable • May require analysis for products of incomplete combustion • Requires skilled operators and high level of maintenance	Medium to High	Yes
	Regenerable Carbon/Resin Adsorption	Extracted soil vapors are passed through beds of carbon/resin to remove VOCs by adsorption; beds are thermally reactivated on-Site using low pressure steam; VOCs are condensed and captured for off-Site disposal	• Effective • Captures contaminants by adsorption • Will need more than one vessel connected in series to meet SCAQMD emission standards	• Implementable • Low volume of spent carbon to manage and dispose • Requires skilled operators and high level of maintenance	Medium to High	Yes
	Disposable Carbon/Resin Adsorption	Extracted soil vapors are passed through beds of carbon/resin to remove VOCs by adsorption; the spent carbon/resin is transported for off-Site disposal/reactivation and replaced with virgin material	• Effective • An MCB adsorption efficiency of 25% by weight was observed during 2003 SVE pilot test • Will need more than one vessel connected in series to meet SCAQMD emission standards	• Implementable • High volume of spent carbon to manage and dispose • Does not require highly skilled operators or high level of maintenance	Medium to High	Yes
Disposal	Injection of Treated Water as part of Groundwater Remedy	Extracted groundwater would be treated to remove dissolved VOCs and pCBSA and transferred to the Groundwater Remedy Treatment System for re-injection into the BFS and Gage Aquifers	• Effective • Applicable for thermal technologies where water re-injection could cool the saturated UBA	• Implementable • Would need to meet groundwater re-injection criteria specified in ROD • Would need to be considered by Groundwater RD	High	Yes
	Injection of Treated Water as part of Hydraulic Displacement	Extracted groundwater would be treated to remove dissolved VOCs and pCBSA prior to re-injection into the saturated UBA	• Effective • Enhances hydraulic gradient and DNAPL displacement • Treatment not required for hydraulic displacement	• Implementable • Groundwater re-injection criteria specified in ROD may need to be waived if an ARAR	High	Yes

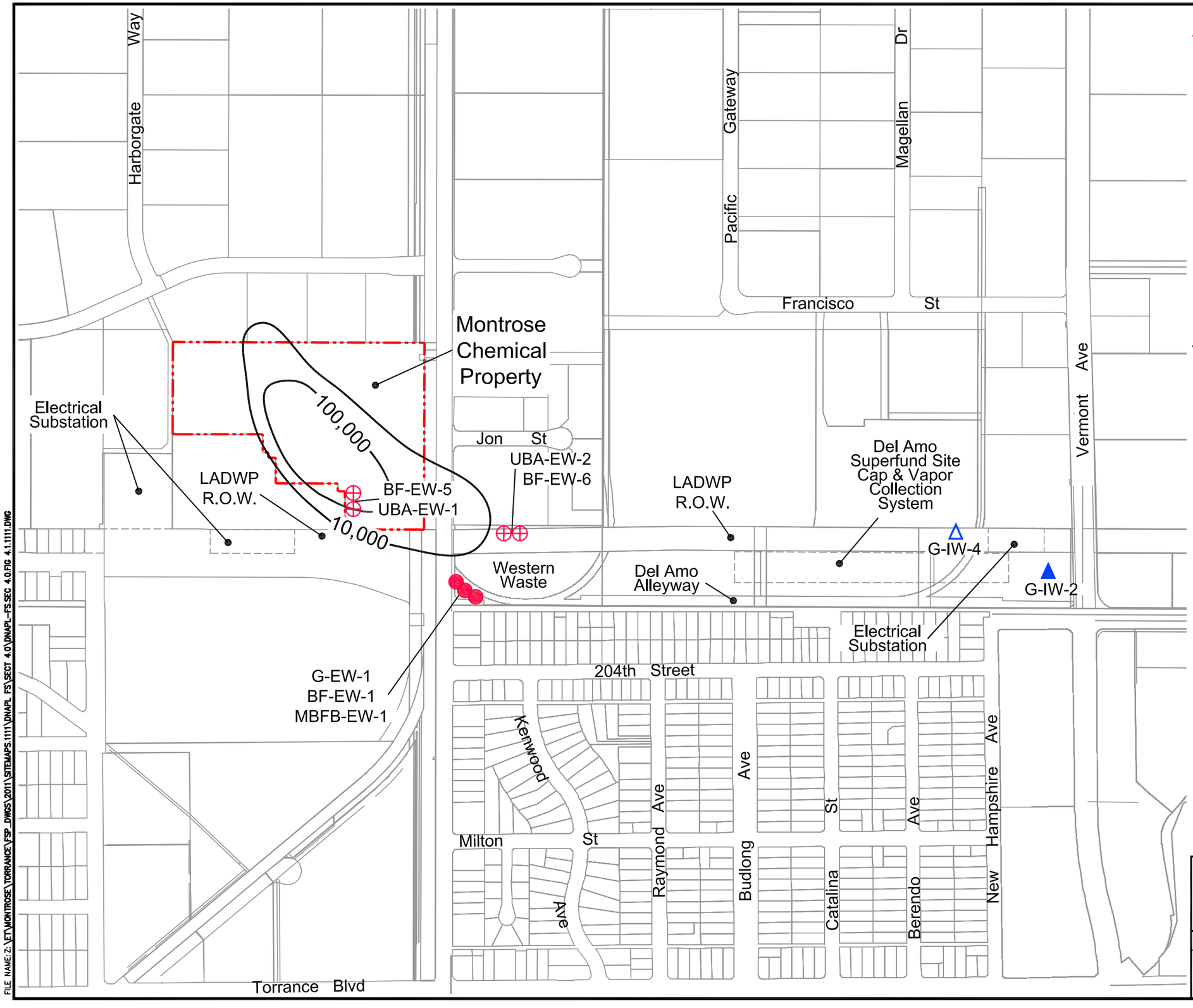
TABLE 4.1 (continued)
Preliminary Screening of DNAPL Remedial Technologies and Process Options

General Response Action	Remedial Technology/ Process Option	Description	Technical Effectiveness	Implementability	Relative Cost	Retain for Assembly into Remedial Alternatives (Yes/No)
Disposal (cont'd)	Injection of Untreated Water as part of Hydraulic Displacement	Extracted groundwater would be filtered and re-injected without treatment to remove dissolved VOCs and pCBSA	• Effective • Treatment for dissolved VOCs and pCBSA not required for hydraulic displacement of DNAPL	• Difficult to implement • Would require waiver of re-injection standards by both EPA and the State in order to be administratively implementable	Low	Yes
	Off-Site Incineration of DNAPL	Recovered DNAPL would be transported for off-Site incineration	• Effective	• Implementable • Only available disposal option for Montrose DNAPL	High	Yes

Notes:

DNAPL = Dense Non-Aqueous Phase Liquid
DDT = Dichlorodiphenyltrichloroethane
MCB = Monochlorobenzene
pCBSA = para-Chlorobenzene sulfonic acid
UBA = Upper Bellflower Aquitard
BFS = Bellflower Sand
SVE = Soil vapor extraction
VOCs = Volatile organic compounds
ISCO = In-situ chemical oxidation
ERH = Electrical resistance heating
ISTD = In-situ thermal destruction
SEAR = Surfactant-enhanced aquifer remediation
LGAC = Liquid-phase granular activated carbon
ROD = Record of Decision
SCAQMD = South Coast Air Quality Management District
°F = Degrees Fahrenheit

FIGURES



Legend:

Location of Current Montrose Property Boundary

Well Legend:

- Existing Extraction Well
- Existing Injection Well
- Proposed Extraction Well
- Proposed Injection Well

Well Identifiers:
EW = Extraction Well
IW = Injection Well
UBA = Upper Bellflower Aquitard
MBFB = Middle Bellflower B Sand
BF = Bellflower Sand
G = Gage Aquifer

10,000 Contour Line Reflects Dissolved Monochlorobenzene in Micrograms per Liter, shown in the UBA. Source: Hargis + Associates, Inc. 2007a.

Note:

1. Containment is also required in the BFS and Gage but those contours are not shown.
2. Source: Environmental Protection Agency, 2008b.

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works Bureau of Engineering Online ArcInfo GIS database, Copyright 2007. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Source: Geosyntec, 2011. Groundwater Remedy Infrastructure, Montrose Chemical Corporation of California, Dual Site Groundwater Operable Unit, Montrose and Chemical and Del Amo Superfund Sites. May 2, 2011.
3. Additonal base map information are based and from Hargis & Associates map dated August 2008, file name 410–6730.dwg.
4. Proposed locations are approximate, not for construction use.

NORTH

0 200 400 FEET

SCALE: 1"= 400'

Montrose Chemical Corporation

Containment Well Location Map

Date: 11-11	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	4.1

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1111\DNAPL FS\SECT 4.0\DNAPL-FS.SEC 4.0.FIG 4.1.1111.DWG

Section 5.0

Assembly and Screening of Remedial Alternatives

5.0 ASSEMBLY AND SCREENING OF REMEDIAL ALTERNATIVES

The purpose of this section is to assemble remedial alternatives (RA) using the GRA remedial technologies and process options retained following the preliminary screening in Section 4.0. Once the RAs are assembled, they are evaluated against the same three performance criteria used in Section 4.0 as an intermediate screening step. R As that are retained following this intermediate screening are then evaluated in detail, in Section 6.0, against the nine performance criteria identified in the NCP.

5.1 ASSEMBLY OF REMEDIAL ALTERNATIVES

The remedial technologies retained following preliminary screening have been assembled into six RAs. The RAs are assembled such that each successive RA potentially provides a higher level of DNAPL mass removal. The least amount of Site remediation is provided by RA 1, while RAs 5 and 6 could potentially provide the most mass removal. F or RAs 4, 5 a nd 6, each include two different process options; therefore, the RAs are split into two different alternatives for separate evaluation (e.g. RA 5a and 5b). The RAs assembled for evaluation in this section are summarized below:

Summary of Assembled Remedial Alternatives

Remedial Alternative	GRA Remedial Technologies/Process Options
Remedial Alternative 1	No Action
Remedial Alternative 2	Institutional Controls
Remedial Alternative 3	Institutional Controls SVE (unsaturated zone)
Remedial Alternative 4a	Institutional Controls SVE (unsaturated zone) Hydraulic Displacement, with untreated water injection
Remedial Alternative 4b	Institutional Controls SVE (unsaturated zone) Hydraulic Displacement, with treated water injection
Remedial Alternative 5a	Institutional Controls SVE (unsaturated zone) Steam Injection, focused treatment area, with hot floor
Remedial Alternative 5b	Institutional Controls SVE (unsaturated zone) Steam Injection, entire treatment area, with hot floor
Remedial Alternative 6a	Institutional Controls SVE (unsaturated zone) ERH, focused treatment area, without hot floor
Remedial Alternative 6b	Institutional Controls SVE (unsaturated zone) ERH, entire treatment area, without hot floor

Three soil vapor treatment and three groundwater disposal process options were each retained following preliminary screening in Section 4.0. While these treatment/disposal process options are not uniquely identified in the above list of RAs, they are discussed in the following description of the RAs where appropriate. In the following sections, a detailed description and conceptual design for each of the assembled RAs is provided.

In order to evaluate and compare these candidate RAs, the carbon footprint (i.e., equivalent quantity of GHGs) of each RA was estimated. The methodology used to estimate the carbon footprints was established in 2011 following reconciliation discussions. Montrose submitted a memorandum describing the approach for estimating GHG emissions to EPA in February 2011 (AECOM, 2011c). EPA commented on the methodology in May 2011 (EPA, 2011a), and the approach for calculating the carbon footprints was subsequently revised as described in the Montrose responses to EPA comments letter dated August 15, 2011 (AECOM, 2011h) and as follows:

- Carbon footprints are based on estimated carbon dioxide (CO_2) emissions from power consumption. Other sources of CO_2 emissions and other GHGs (e.g., nitrogen oxides, sulfur oxides, etc…) are excluded from this preliminary evaluation. Although actual GHG emissions from all sources will be higher, energy-based CO_2 emissions are expected to be the largest source of GHG emissions. The intent of the analysis is not to identify with a high degree of accuracy the total carbon footprint from all GHG sources, but instead, to provide a consistent basis for a fair evaluation of the candidate RAs. Given the limitations of the analysis, energy-based CO_2 emission estimates are believed to be adequate for evaluation of the candidate RAs in this FS;
- CO_2 emissions from combustion of natural gas at the Site are calculated in accordance with the mandatory EPA reporting rule (40 CFR Part 98). Because emissions are based on natural gas combustion at the property (e.g., steam boilers) and not for electricity generation, it is not necessary to account for turbine efficiency or transmission losses;
- CO_2 emissions from consumption of electrical power is calculated using an emission factor of 1.228 pounds of CO_2 per kilowatt-hour as reported by the Los Angeles Department of Water and Power in 2007 (LADWP, 2007). The aforementioned emission factor reflects power generation, transmission, and distribution from both owned and purchased power generation. LADWP is the local electricity supplier for the Montrose Site, and therefore, this emission factor was determined to provide the most accurate representation of the carbon footprint.

The carbon footprint of each candidate RA is presented in this section, and detailed supporting calculations are provided in **Appendix H**. The GHG emission estimates presented in this FS exclude procurement of carbon offsets, which, if available at the time of remedy implementation, may be one option for partially mitigating the carbon footprint of the selected DNAPL remedy. However, it should be noted that procurement of carbon offsets does not reduce the GHG emissions generated by a DNAPL remedy (emissions are offset on paper through emission credits). Furthermore, the carbon offsets market may continue to undergo significant changes as new GHG regulations come into effect, and it is unclear whether or not purchased offsets will have any value in the future. Similarly, the GHG emission estimates do not consider renewable energy sources (e.g., solar panels) beyond what is offered through LADWP. There are two LADWP electrical substations located adjacent to the Montrose property, and purchasing cleaner sources of electricity is not a realistic option for this Site. Furthermore, that level of detail is not required for comparing candidate alternatives in the FS, and instead, will be considered as necessary during the Remedial Design phase of the selected remedy.

5.1.1 REMEDIAL ALTERNATIVE 1 – NO ACTION

This RA includes the following two remedial technologies and process options:

No Action

Under this alternative, no action would be taken to reduce DNAPL mass or mobility, or comply with the DNAPL RAOs, other than those actions required by the groundwater and soil remedies. This no action alternative was assembled in accordance with EPA protocols for establishing a baseline alternative against which the other RAs will be compared.

While institutional controls are not part of this RA, two of the process options associated with that GRA would be implemented as part of the Groundwater remedy, including:

> Limiting Groundwater Use: Limitations on groundwater and Site use would be implemented in the form of deed restrictions to prevent exposure to groundwater impacted by DNAPL constituents, specifically MCB.
>
> Groundwater Monitoring: Groundwater monitoring would be implemented as part of the groundwater remedy and would document the effectiveness of the containment program.

5.1.2 REMEDIAL ALTERNATIVE 2 – INSTITUTIONAL CONTROLS

This RA includes the following one remedial technology and process option:

Institutional Controls

Institutional controls would be implemented to prevent access to DNAPL-impacted soils. A land use covenant (deed restriction) would be established to restrict future activities at the Property for industrial use only and to place limits on construction, excavation, or drilling activities. Access to the Site is currently restricted by perimeter fencing and warning signs. These access restrictions would continue as part of a formal site inspection and maintenance program. The two groundwater-related institutional controls identified in Section 5.1.1 would additionally be implemented as part of the groundwater remedy.

A soil remedy has not yet been selected for the Site, but it is anticipated that institutional controls will be required as part of the soil remedy to protect human health and the environment from exposure to shallow contaminated soil and soil gas. Institutional controls for DNAPL would be limited to DNAPL-impacted areas including the Montrose Property and potentially a small portion of the GLJ Holdings property to the north.

5.1.3 REMEDIAL ALTERNATIVE 3 - SVE

This RA includes the following two remedial technologies and process options:

Institutional Controls

Institutional controls would be implemented as described in Section 5.1.2.

SVE (unsaturated zone)

SVE would be implemented in the unsaturated zone between approximately 10 and 60 feet bgs, where an estimated 403,000 pounds of MCB occurs. As described in Section 2.6.4, SVE was found to be effective in removing VOCs from permeable unsaturated soils during pilot testing conducted in 2003. MCB and chloroform were the predominant VOCs recovered during the pilot test. Moderate to large vacuum influences were observed within the PVS and unsaturated UBA during pilot testing, with estimated effective radius of vacuum influences of 64 and 123 feet.

A relatively high percentage of the MCB is expected to be removed by SVE from the permeable unsaturated sands, but MCB removal from the low permeability silts will not be as effective. For the

purposes of this FS, mass removal efficiencies between 90% and 95% were assumed for the permeable unsaturated sands while substantially lower mass removal efficiencies between 10% and 20% were assumed for the low permeability silts. While actual mass removal may vary from these assumptions, the efficiencies provide a reasonable estimate for purposes of evaluating candidate RAs in this FS. Accordingly, between 249,000 and 276,000 pounds of MCB may be removed from the unsaturated zone by SVE under RA 3.

Limitation to Application to Lithologic Zones

As described in Section 1.5.1, soils within the PD are composed primarily of silts/clays (77% on average) and exhibited low permeabilities (1.1×10^{-05} cm/s on average) during SVE pilot testing in 2003. An elevated vacuum of approximately 18 inches of mercury was required to initiate soil vapor flow within the PD, following which a significant amount of vertical influence with the higher permeability, underlying PVS was observed. The pilot test results from the PD reflect a combination of soil vapors from both the PD and PVS, and therefore, it was not possible to uniquely distinguish the potential effectiveness of the SVE within the PD. However, SVE is expected to be significantly less effective in low permeability soils such as the PD, and control of soil vapors near land surface from the PD is being evaluated as part of the Soil FS.

However, in some soil borings, silty sands were reported in the PD as shown in **Figure 5.1**. 20 of 48 soil borings (42%) within the possible extent of DNAPL contained some silty sands within the PD according to the lithologic logs. 10 of the 20 soil borings (50%) containing silty sands in the PD are located within the extent of definite DNAPL. SVE within the silty sands may be more effective than in the low permeability silts and clays as demonstrated during the field pilot testing. I n accordance with reconciliation discussions (AECOM, 2010g), the silty sands would be screened for remediation by SVE if encountered in the PD during SVE well installation.

SVE Wellfield

The conceptual design of the SVE system would include a series of extraction wells positioned throughout the VOC and DNAPL-impacted unsaturated zone. The spacing between wells would be based on the ROIs but allowing for some overlap to ensure that all unsaturated soils in these two layers are effectively evacuated. Because the lithologic layers exhibited different flow properties, two sets of wells would be installed to separately evacuate the lower and higher permeability soils as shown in **Figures 5.2 and 5.3**. An estimated 23 SVE wells would be required to evacuate the unsaturated zone as shown in these figures. For the purpose of this FS, the SVE wells are assumed to be screened over a discrete

interval, 25 to 45 feet bgs for permeable sands and 10 to 25 and 45 to 60 feet bgs for lower permeability silty sands and sandy silts. Also for the purpose of this FS, any silty sands or sandy silts screened in the Playa Deposits (i.e., 10 to 25 feet bgs) are assumed to have the same permeability as the unsaturated soils in the UBA. Under this assumption, the conceptual well spacing and radius of influence within the Playa Deposits would be identical to that of the unsaturated UBA. This assumption is necessary since SVE was found to be significantly less effective in the Playa Deposits during the field pilot test (soils were composed primarily of silts and clays). An aboveground piping network would connect the SVE wells to an ex-situ extraction and treatment system located at the Property.

SVE Treatment System

Soil vapors would be extracted using either a positive displacement or liquid-ring vacuum blower. Suspended solids would be filtered, and entrained moisture would be separated or condensed. Soil vapors would then be passed to a treatment system for removal or destruction of the VOC contaminants prior to atmospheric discharge. A process flow diagram of the conceptual SVE system is provided as **Figure 5.4**. Three different soil vapor treatment process options were retained following preliminary screening in Section 4.8, including disposal GAC/resin, steam-regenerable GAC/resin, and thermal oxidation with acid-gas scrubbing. Both of the GAC/resin-type process options remove the VOC contaminants from the vapor stream via adsorption. The thermal oxidation process options destroy the VOC contaminants at elevated temperatures, converting them to carbon dioxide, water vapor, and acid gas. The acid gas is subsequently quenched and pH neutralized prior to discharge. Based on the number of wells identified in Figures 5.2 and 5.3, the estimated total SVE flow rate would be approximately 1,500 scfm.

JCI Property

The conceptual design of the SVE system under RA 3 excludes treatment of any VOCs from the JCI property. As discussed during the reconciliation meetings (AECOM, 2011a) and subsequently documented in a letter dated June 1, 2011 (L&W, 2011c), there are no technical or cost advantages to simultaneously treating soil vapors from both properties for the reasons identified below:

- No DNAPL was found at the JCI property;
- The Montrose VOC sources in soil are primarily located within the former Central Process Area and are isolated from the JCI property. The VOC sources in soil from the two properties are not commingled;

- The Montrose SVE system will not extend onto the JCI property. If necessary, passive (or active) air injection wells could be positioned along the property boundary to prevent vapor migration between properties;
- The VOCs detected in soil and soil gas at the JCI property differ from those detected at the Montrose property in many respects. At the Montrose property, the primary VOCs detected in soil gas are MCB and chloroform. However, at the JCI property, a broader range of VOCs occur in soil gas including PCE, TCE, 1,1-dichloroethene (1,1-DCE), c-1,2-dichloroethene (c-1,2-DCE), 1,1-dichlorethane (1,1-DCA), 1,1,2-trichloroethane (1,1,2-TCA), and vinyl chloride. Some of these VOCs are poorly adsorbed by GAC, specifically 1,1-DCE, 1,1-DCA, and 1,1,2-TCA. The presence of these VOCs in soil gas may significantly limit the soil vapor treatment process options and unnecessarily burden Montrose with a higher cost treatment technology as MCB is very effectively treated using GAC;
- A relatively high VOC mass loading rate from the Montrose source areas is already anticipated. An efficient ex-situ vapor treatment system will be required to effectively treat vapor-phase VOCs in accordance with regulatory emission standards. Adding the VOC mass loading from the JCI property would burden Montrose with unnecessary technical challenges in meeting emission standards;
- Finally, a commingled SVE system would create unnecessary cost sharing issues with JCI.

Since there are no technical or cost advantages to combining an SVE remedy between the Montrose and JCI properties, the VOC sources from the JCI property were excluded from the conceptual design for SVE under RA 3.

Estimated Operational Time Period

SVE operations would continue for a period of approximately 3 to 5 years and until VOC concentrations in soil gas had declined to low asymptotic levels (i.e., not cost effective to continue SVE operations). An example first order exponential decline curve is provided as **Figure 5.5**, showing MCB mass in the unsaturated zone asymptotically approaching zero in Year 4. This duration of SVE operations reflects approximately 5,000 pore volumes of soil vapor flushing within the treatment area, which exceeds the range recommended by some guidance documents (i.e., 1,000 to 1,500 pore volumes; USACE, 2002). However, given the lower permeability nature of some unsaturated soils at the Site, the presence of DNAPL, the proximity of groundwater in the unsaturated UBA, and the relatively low vapor pressure of MCB, it is expected that SVE operations at the Site will require more time to achieve the cleanup goals

than is typically required by SVE projects. Additionally, Montrose has completed a similar SVE remedy at a site in Henderson, Nevada, where soils were impacted with primarily MCB and some other VOCs. An operating period of 4 to 5 years was required to complete SVE operations at that site and remove a VOC mass comparable to the estimated mass present at the Montrose Superfund Site. Although the operational time period is longer than recommended by some guidance documentation, it is believed to be reasonably appropriate for the site-specific conditions and chemical properties for the purpose of this FS.

Soil Vapor Monitoring and Verification

A series of soil vapor monitoring points or wells would additionally be installed as part of this remedy. The wells would be used to monitor the performance of the SVE system between and surrounding the extraction wells. In order to monitor the vacuum influence within each of the three distinct unsaturated zone layers, three nested monitoring points would be constructed at each location within a single borehole as shown in **Figure 5.6**. The points would be used to monitor vacuum influences both laterally within the extraction well field and vertically within each of the three unsaturated soil layers. The monitoring points will demonstrate vacuum influence throughout the target treatment area, including along the northern property boundary where VOCs in soil gas were detected at concentrations exceeding industrial screening levels. The concentration of VOCs in soil gas within the monitoring points would also be tested routinely to demonstrate a reduction in VOC concentrations over time. For costing purposes, a total of 10 monitoring points are assumed to be tested quarterly during the SVE remedy.

To confirm the reduction in sorbed VOC concentrations, soil borings would be drilled and samples collected to verify the effectiveness of the SVE remedy in the unsaturated zone. Residual VOC concentrations in soil would be compared against EPA Region 9 PRGs, risk-based cleanup goals, or leaching model-based cleanup goals. Residual VOCs from the low permeability PD and underlying groundwater surface will slowly volatilize into soil gas during SVE operations, even though these VOC sources are not the objective of the SVE remedial action. Therefore, the decision criteria for terminating SVE operations in the unsaturated zone would be based on the sorbed concentration of VOCs remaining in soil, the vertical concentration trend in the target treatment zone, the VOC mass removal rate, and the cost-benefit of continuing SVE operations. For costing purposes, a total of 10 soil verification borings are assumed for this RA.

Carbon Footprint

The SVE component of this RA, excluding hydraulic containment, is expected to consume approximately 4,700 megawatt-hours in electricity. The carbon footprint (i.e., equivalent quantity of GHGs) of this RA

is estimated to be 6 million pounds of carbon dioxide. The carbon footprint calculation for this RA is provided in **Appendix H**, and a summary of the carbon footprints for all the RAs is provided in **Table 5.1**.

5.1.4 REMEDIAL ALTERNATIVE 4A – HYDRAULIC DISPLACEMENT WITH UNTREATED WATER RE-INJECTION

This RA includes the following three remedial technologies and process options:

Institutional Controls

Institutional controls would be implemented as described in Section 5.1.2.

SVE (unsaturated zone)

SVE would be implemented in the unsaturated zone as described in Section 5.1.3.

Hydraulic Displacement with untreated water re-injection

Hydraulic displacement would be implemented within the saturated UBA to remove mobile DNAPL. The conceptual design of a hydraulic displacement RA was previously reconciled with EPA during a conference call held on February 21, 2008. Additionally, it is noted that groundwater would be re-injected into the UBA under this RA, rather than into the BFS and Gage Aquifer. Therefore, implementation of this RA would not affect the design or operation of the Torrance Groundwater Remediation System.

Area of Application

A series of groundwater/DNAPL extraction wells and groundwater injection wells would be positioned throughout the DNAPL-impacted area where mobile DNAPL is believed to occur (Focused Treatment Area), which is approximately 26,000 square feet as shown in **Figure 5.7**. This area was estimated based on the known occurrence of mobile DNAPL in source area wells and DNAPL concentrations in saturated UBA soils exceeding 53,000 mg/kg. This concentration is equivalent to a DNAPL saturation of 18.9%, which was determined to be the minimum residual DNAPL saturation in one soil core as described in Section 2.1.2. The concentration is additionally based on the average effective porosity and wet soil density of sand layers measured during physical properties testing of soils collected at boring 2DSB-1.

An area surrounding SSB-12 is additionally included as part of the conceptual design for this hydraulic displacement RA. An elevated DNAPL concentration of 103,000 mg/kg was measured in a 82.5-foot bgs soil sample at this location (Section 2.5.6), but the presence of mobile DNAPL at this remote location was unexpected and was investigated in December 2008. A short-term hydraulic extraction test was conducted at well UBE-5, located adjacent to SSB-12, which confirmed the presence of mobile DNAPL at this location. DNAPL was recovered from UBE-5 at a peak rate of 0.8 liters per hour during the short-term field test.

The area defined above does reasonably match the known occurrence of mobile DNAPL at the Site. As described in Section 2.6.2, mobile DNAPL has been recovered from several wells at the Montrose property including UBE-1, UBE-4, and UBE-5, all of which are located within the Focused Treatment Area. Similarly, no mobile DNAPL has been recovered from wells UBE-2 and UBE-3 which are located outside the Focused Treatment Area.

One core testing result was used in the DNAPL FS for defining the extent of mobile DNAPL at the Site and establishing residual saturations for all DNAPL-impacted soil types in conjunction with other lines of evidence. Additional core and DNAPL saturation testing will be conducted in the future. P re-remediation core samples will be collected and tested to verify the extent of mobile DNAPL at the Site. Post-remediation core samples will also be collected and tested to verify the extent and mobility of any DNAPL remaining in place following treatment. The extent of the Focused Treatment Area may be revised in the future depending on the results of more extensive core and DNAPL saturation testing.

Hydraulic Displacement System Description

The extraction and injection wells would be positioned in a 5-spot type pattern, with four extraction wells surrounding one injection well. Injection wells would additionally be positioned around the perimeter of the treatment area to hydraulically flush mobile DNAPL inwards, towards the recovery wells. A conceptual hydraulic displacement well pattern using a 50-foot well spacing is provided as **Figure 5.8** and includes 23 extraction wells and 46 injection wells (including the isolated area surrounding boring SSB-12). Injection wells are prone to fouling, and in accordance with reconciliation discussions (AECOM, 2010g), the ratio of injection wells to extraction wells was conceptually designed to be 2:1. Spare injection wells were incorporated into the well pattern on the upgradient side of the mobile DNAPL extent. As injection wells become fouled, they would be redeveloped while the spare injection wells would be activated.

Also in accordance with the reconciliation discussions, five additional hydraulic containment wells were incorporated into the conceptual design of this candidate RA. As shown in Figure 5.8, these wells would be located on the downgradient side of the possible DNAPL extent and would be spaced approximately 80 feet apart. Because HD is a displacement technology, the additional wells were incorporated into the conceptual design to hydraulically contain any displaced groundwater and increase the certainty that an HD remedy would not adversely impact the containment program for groundwater in accordance with RAO 3.

The spacing of 50-feet between extraction wells was reconciled during a scoping conference call held on February 21, 2008 between EPA and Montrose is assumed based on the following rationale:.

> H+A and Intera evaluated various well spacings as part of the hydraulic displacement modeling (H+A, 2009b), and the modeling results indicated that a well spacing of 120 feet or less would be required to effectively displace mobile DNAPL for extraction. The preliminary modeling results support selection of a 50-foot well spacing for this hydraulic displacement conceptual design. All wells would be screened across the DNAPL-impacted interval ranging from approximately 60 to 100 feet bgs depending on the occurrence of DNAPL accumulation, and the extraction wells would additionally be constructed with a 5-foot sump at the bottom for DNAPL or solids accumulation. Conceptual well construction diagrams for the extraction and injection wells are provided as **Figures 5.9 and 5.10**.

Operations and Treatment

A process flow diagram of the conceptual hydraulic displacement system is provided as **Figure 5.11**. Groundwater would be extracted at a rate of approximately 7 to 10 gpm per well (based on 2004/2005 field pilot test) using electric submersible pumps and transferred via an aboveground piping network to a DNAPL/water separator. Separated water would be filtered to remove suspended solids and then re-injected without further treatment to remove dissolved VOCs. A combined groundwater extraction and re-injection rate of approximately 150 gpm is assumed for this hydraulic displacement RA.

Recovered DNAPL would be transferred to a collection tank and transported for off-Site disposal every 90 days or less. DNAPL accumulating in the sump of the groundwater extraction well would be extracted using low flow pneumatic bladder pumps and discharged to a gravity separator (decanter). Separated DNAPL would be transferred to the collection tank for subsequent off-Site disposal, and separated groundwater would be transferred to the groundwater/DNAPL separator for subsequent filtering and re-injection.

Operational Duration

The duration of a hydraulic displacement remedy is assumed to be approximately 5 years, as reconciled with EPA in February 2008. Because groundwater is re-injected into the UBA, implementation of this RA would not impact the design or operation of the Torrance Groundwater Remediation System.

As described in Section 2 and shown in Appendix E, between approximately 221,800 to 340,000 pounds of mobile DNAPL (are estimated to be contained within the saturated UBA. The total mass of DNAPL in the UBA (residual plus mobile) was estimated to be between 796,100 and 900,000 pounds as described in Section 2.5.5, and therefore, between approximately 28% and 38%of the DNAPL in the UBA is believed to be present in potentially mobile saturations. This estimate is based on DNAPL concentrations (sum of MCB and Total DDT) in soil measured during investigation activities in 2003-2005 (H+A, 2004b and 2006a) and an assumed residual DNAPL saturation of 18.9% (assumed to be constant throughout the UBA).

It is recognized that residual DNAPL saturations will vary throughout the UBA and that there is a limited amount of DNAPL concentrations in soil upon which to base the estimate. Although there is uncertainty associated with the volume/mass of mobile DNAPL in the UBA, the aforementioned estimate is considered reasonable, consistent with the estimated mass of DNAPL at the Site, and acceptable for purposes of this FS. Additional DNAPL saturation and mobility testing will be conducted to reliably establish the extent of mobile DNAPL and target residual saturations in varying soil types.

Although Montrose and EPA have established an estimated range of mobile DNAPL mass present at the Site, there is a fair amount of uncertainty regarding what portion of the mobile DNAPL mass would be recovered by HD. If HD were 100% effective, then 100% of the mobile mass would be recovered. However, DNAPL/water capillary pressure testing (Section 2.1.2 and Appendix B) suggests that elevated capillary pressures would be required to displace the final 1% to 1.5% of mobile DNAPL (e.g., 18.9% to 20.4% DNAPL saturations). Therefore, high mass removal efficiencies approaching 100% are unlikely for this RA. Additionally, some DNAPL may sorb to pore spaces as it is moves through the porous soils to the extraction wells, even though water is believed to be the wetting fluid (i.e., water will preferentially wet the pore surfaces over the DNAPL). Since some of the DNAPL may sorb to soil grains during the displacement process, mass removal efficiencies over 90% are also unlikely for HD.

However, for the purposes of this FS, an 80% mobile DNAPL mass removal efficiency is assumed forHD, which is an upper end estimate but consistent with the relatively high well density assumed for this RA and the low capillary pressures required to hydraulically displace DNAPL at higher saturations.

A relatively high well density reduces the distance that the DNAPL must travel to reach the extraction well and would be expected to result in a higher mass removal efficiency (i.e., less of an opportunity for DNAPL to sorb to soil grains before reaching the extraction well). DNAPL will be more mobile at higher saturations and become progressively less mobile as the saturation is depleted towards residual levels. While an 80% mobile DNAPL mass removal efficiency is a simplification of the depletion process, it reasonably bounds the upper end of the technology performance range for the purposes of this FS. Assuming 80% mobile DNAPL mass reduction, an estimated 177,400 to 272,000 pounds of liquid-phase DNAPL (MCB+DDT) would be removed by this RA. Assuming that MCB represents 50% of the DNAPL mass, the estimated amount of MCB mass reduction under RA 4a would therefore be between 88,700 and 136,000 pounds.

Carbon Footprint

The combination of SVE in the unsaturated zone and hydraulic displacement in the saturated UBA without groundwater treatment is expected to consume approximately 9,100 megawatt-hours of electricity. The equivalent carbon footprint of this RA is estimated at approximately 11 million pounds of carbon dioxide (Table 5.1 and Appendix H).

Monitoring and Verification Program

The HD remedy would include a monitoring program to evaluate the effectiveness of the remedy. The monitoring program would include a series of monitoring wells located throughout the HD well field. The monitoring wells would be gauged routinely to demonstrate hydraulic influence from the extraction/injection wells and the absence of stagnation zones. The monitoring wells would also be gauged for the presence of DNAPL accumulation and routinely sampled for monitoring the performance of the remedy for any adverse conditions.

In addition to monitoring the UBA, the underlying BFS will be monitored for evidence of adverse migration during the remedy, if any. BFS monitoring wells beneath and surrounding the Focused Treatment Area will be routinely monitored for the presence of DNAPL, and the MCB concentrations in these wells will be monitored for evidence of increasing concentration trends. Furthermore, groundwater will also be monitored at the Site in accordance with the future Monitoring and Aquifer Compliance Plan as required by the Groundwater ROD (EPA, 1999).

The rate of DNAPL recovery from each extraction well would be monitored, and once DNAPL recovery rates had declined to zero or asymptotic levels, the HD system would be turned off. If no mobile DNAPL

accumulated in the HD remedy wells, then a series of soil verification borings would be drilled at the midpoint between the extraction and injection wells to test for residual MCB and DNAPL. MCB concentrations would be compared against residual saturations to evaluate the mobility of residual MCB concentrations in the saturated zone. For costing purposes, a total of 10 soil verification borings are assumed for this RA, consistent with the number of verification borings assumed for other focused treatment area RAs (i.e., RAs 5a and 6a).

5.1.5 REMEDIAL ALTERNATIVE 4B – HYDRAULIC DISPLACEMENT WITH TREATED WATER RE-INJECTION

This RA includes the following three remedial technologies and process options:

Institutional Controls

Institutional controls would be implemented as described in Section 5.1.2.

SVE (unsaturated zone)

SVE would be implemented in the unsaturated zone as described in Section 5.1.3.

Hydraulic Displacement, with treated water re-injection

Hydraulic displacement would be implemented within the saturated UBA to remove mobile DNAPL as described in Section 5.1.4, with the exception that groundwater would be treated ex-situ and prior to re-injection. After DNAPL separation and filtering, groundwater would be treated on Site using a combination of LGAC to remove MCB and other VOCs by adsorption and HiPOx™ to destroy pCBSA by oxidation. The effectiveness of these two technologies in treating the primary dissolved contaminants at the Site has been demonstrated (Earth Tech, 2004b and 2008i). As the dissolved concentration of MCB in the extracted groundwater will approach solubility limits, a relatively robust treatment train is required for this RA. A process flow diagram of the conceptual hydraulic displacement system is provided as **Figure 5.12**.

Although air stripping was recently incorporated into the remedial design for the groundwater remedy, it is not clear that air stripping would be required for treatment of groundwater from a DNAPL remedy. Air stripping was incorporated in the groundwater remedy to treat low concentrations of non-polar compounds, specifically methylene chloride, which is not effectively treated by either LGAC or HiPOx™. At this preliminary stage, it is unclear whether methylene chloride would be detected in

groundwater extracted during this RA. For costing purposes, it is assumed that air stripping will not be required for treatment of groundwater during a DNAPL remedy.

Since treated groundwater will be re-injected under this alternative, the conceptual design for RA 4b excludes the five additional hydraulic containment wells shown in Figure 5.8 on the downgradient side of the possible DNAPL extent. The additional hydraulic containment wells are not required under this alternative to increase the probability of achieving and maintaining containment of the dissolved-phase plume. Therefore, in accordance with the consensus reached at the March 12, 2013 meeting between EPA, DTSC, and Montrose, a total of 18 extraction and 46 injection wells are assumed for RA 4b.

Carbon Footprint

The combination of SVE in the unsaturated zone and hydraulic displacement in the saturated UBA with groundwater treatment is expected to consume approximately 21,200 megawatt-hours of electricity. The equivalent carbon footprint of this RA is estimated at approximately 26 million pounds of carbon dioxide (Table 5.1 and Appendix H).

5.1.6 REMEDIAL ALTERNATIVE 5A – STEAM INJECTION, FOCUSED TREATMENT AREA WITH HOT FLOOR

This RA includes the following three remedial technologies and process options:

Institutional Controls

Institutional controls would be implemented as described in Section 5.1.2.

SVE (unsaturated zone)

SVE would be implemented in the unsaturated PD and PVS as described in Section 5.1.3. However, SVE within the unsaturated UBA is additionally a component of a steam injection RA and used to recover steam and volatilized VOCs from the underlying saturated UBA. Depending on depth, some of the SVE wells are used for both purposes. SVE in the unsaturated zone from 10 to 45 feet bgs remains the same as previously described in Section 5.1.3. However, the multiphase extraction wells used for a thermal remedy would be screened up to 45 feet bgs in the unsaturated zone, and therefore, SVE over the unsaturated UBA from 45 to 60 feet bgs is combined with the steam injection remedy as indicated below. Under this steam injection RA, installation of separate SVE wells within the unsaturated UBA, between

45 and 60 feet bgs, will not be required. Therefore, the cost of the SVE remedial component for this steam injection RA is reduced.

Steam Injection, Focused Treatment Area with Hot Floor

Steam injection would be implemented within the saturated UBA over a focused treatment area to thermally treat both residual and mobile DNAPL. The entire DNAPL impacted area is approximately 160,000 square feet, which is exceptionally large for thermal remediation as indicated in Section 4.6.3. Based on thermal case study evaluations conducted by EPA and Montrose in 2007, the majority of thermal remediation projects treated areas between approximately 10,000 and 50,000 square feet.

As an alternative, thermal remediation over a smaller focused treatment area of approximately 26,000 square feet was identified as shown in **Figure 5.13**. Candidate focused treatment areas were evaluated by Montrose in June 2008 based on varying DNAPL thickness and concentration criteria (Earth Tech, 2008b). That evaluation recommended the focused treatment area shown in Figure 5.13, which includes all areas believed to contain mobile DNAPL. While the focused treatment area represents only 16% of the entire DNAPL-impacted area, it contains between approximately 60% and 87% of the estimated DNAPL mass in the saturated UBA (473,700 to 780,000 pounds).

Assuming that MCB represents 50% of the DNAPL mass, an estimated 236,800 to 390,000 pounds of MCB is present in the focused treatment area and potentially subject to thermal remediation (although only a portion of this estimated mass would be recovered by steam injection). Although steam injection may remove some liquid-phase DNAPL, it would primarily remove the volatile MCB component of the DNAPL, leaving the DDT component behind (in-situ). DDT is a hazardous substance, and the volume or mass of DDT removed by the candidate RAs is presented in this FS. However, DDT is relatively insoluble in water and does not pose a significant risk to groundwater resources. The MCB component of the DNAPL is the principal threat to groundwater resources, and MCB removal is weighed more heavily than DDT removal.

EPA commented on the Focused Treatment Area Evaluation in correspondence dated September 10, 2008 (EPA, 2008d). While EPA did not necessarily concur with the rationale used in the evaluation, EPA did concur that the recommended focused treatment area reasonably encompassed the area believed to contain mobile DNAPL. EPA concurred with the recommended focused treatment area for use in this FS, although modifications to the focused treatment area may be required if actual conditions are found to be different from assumed conditions. If the extent of mobile DNAPL is greater than currently represented

by the focused treatment area, then the associated costs presented in this FS are under-estimated. Expansion of the focused treatment area would result in higher thermal remedy costs under RA 5a.

Conceptual Design of RA

Montrose and EPA have been working to establish a conceptual approach (and costs) for the thermal remediation technologies considered for the Site since 2007. A series of reconciliation conference calls were held from December 2007 to February 2008. Based on these reconciliation discussions, Montrose prepared detailed scoping memorandums and cost estimates for various thermal remediation alternatives, which were submitted to EPA between July 21 and August 22, 2008 (Earth Tech, 2008c, 2008d, 2008e, and 2008f). Following review of the memorandums, EPA requested additional revisions to the scoping assumptions. The conceptual design for this steam injection RA is based on the results of those technical memorandums, associated EPA comments, and subsequent reconciliation discussions with EPA in 2010 and 2011.

Pilot Test

No steam injection pilot has been conducted at the Site, and the relatively small size of the Focused Treatment Area does not readily lend itself to implementation of a pilot (a pilot test would cover approximately 50% of the focused treatment area). Therefore, for purposes of costing, it is assumed that no pilot test would be implemented under this focused treatment area RA. The absence of a pilot test in the conceptual scope does not impact the effectiveness evaluation of this candidate RA.

Steam Injection and Multiphase Extraction Well Configuration

Steam injection and multiphase extraction wells (groundwater, DNAPL, and soil vapors) would be installed throughout the focused treatment area in either a 5-spot or 7-spot pattern. A 5-spot pattern is composed of four multiphase extraction wells, in a square pattern, surrounding one steam injection well. A 7-spot pattern is composed of six multiphase extraction wells, in a hexagonal pattern, surrounding one steam injection well.

For the purposes of this FS and in accordance with reconciliation discussions (AECOM, 2011f), wells are assumed to be spaced 42 feet apart in a 5-spot pattern as shown in **Figure 5.14**. As shown in this figure, a total of 14 steam injection and 27 multi-phase extraction wells would be required. Because the perimeter of the focused treatment area is still within the DNAPL-impacted area, the outer wells of the pattern would be extraction wells in order to recover any contaminants displaced away from the source area. The

conceptual scope of work for this steam injection RA includes the area surrounding SSB-12, where mobile DNAPL was observed during a short-term field pilot test in 2008.

Steam injection wells would be constructed using 2-inch diameter stainless steel casings, with three casings at each location (in the same borehole). The steam injection casings would be screened approximately as follows: 70 to 75, 85 to 90, and 100 to 105 feet bgs. A conceptual well construction diagram is provided as **Figure 5.15**. Because steam will flow preferentially through the highest permeability soil layers, the three independent casings at each location offer the ability to control the amount of steam delivered to each of the three intervals, as needed. The multiphase extraction wells will be constructed using 6-inch diameter casing, with one screened interval over the entire treatment zone from 45 to 105 feet bgs (both unsaturated and saturated UBA). A conceptual multiphase extraction well construction diagram is provided as **Figure 5.16**.

Hot Floor

Due to the risk of downward DNAPL mobilization imposed by a steam injection RA, a hot floor would be implemented within the underlying BFS. The conceptual design for the hot floor includes 20 steam injection wells and 9 multiphase extraction wells spaced 60 feet apart in a 7-spot pattern (**Figure 5.18**). The wells would be installed using mud-rotary drilling methods to install permanent conductor casings to seal off the DNAPL-impacted zone and reduce the potential for DNAPL migration during drilling activities or within the annulus of the borehole. The wells would be screened from 110 to 115 feet bgs. Well construction diagrams for the conceptual hot floor wells are provided in **Figures 5.19 and 5.20**. Steam would be injected into the hot floor at least 30 days in advance of heating the UBA. Pre-heating of the hot floor would reduce the potential for downward migrating DNAPL to travel through the BFS, although some risk would remain. Upon entering the hot floor, downward migrating DNAPL would be thermally treated (i.e., volatilization of the MCB component), providing that the hot floor was effectively and uniformly heated to target temperatures. Sufficient groundwater would be recovered from the multiphase extraction wells to off-set the cold water equivalent of the steam injected to reduce the potential for displacement and spreading of the dissolved contaminant plume within the BFS. It is noted that the hot floor at the Montrose Site would not be a clay, like many other sites, but would rather serve as a “thermal barrier”, which has to prevent DNAPL from migrating into the BFS, a highly transmissive aquifer.

Treatment Volume:

Due to the irregular shape of the focused treatment area, the remediation well pattern covers an area larger than the target treatment area. The area within the well pattern is approximately 57,900 square feet versus the 26,000 square feet of the focused treatment area. With a treatment interval from 60 to 105 feet bgs, the target treatment volume for this RA would be 43,400 cubic yards within the saturated UBA.

Energy Requirements

Steam would be injected into each of the steam injection wells via an aboveground piping network. Flow control valves and meters would be provided at each of the injection well casings. One 29 million BTUs per hour (MM BTUs/hr) natural gas-fired steam boiler would be used to generate and deliver the required steam. For the focused treatment area, approximately 275,000 thousand cubic feet (MCF) of natural gas is estimated to be required assuming 2.5 equivalent pore volumes of steam flushing in the saturated UBA and 3 pore volumes of steam flushing in the hot floor (i.e. cold water equivalent of cumulative steam flow). The assumed energy requirements for this RA are based on an energy balance, calculated at the request of EPA and provided in **Appendix I**.

It should be noted that EPA does not concur with all aspects of the energy balance provided in Appendix I, and in particular, does not agree with the assumed steam boiler efficiency (CH2M Hill, 2013). The energy balance was extensively peer reviewed and is believed to reasonably estimate the energy requirement for a steam injection remedy at the Site. There are several assumptions associated with this energy balance and associated heat losses, and therefore, the energy required for a steam injection remedy has some inherent uncertainty.

SVE and Ex-Situ Vapor Treatment

Steam and heated soil vapors would be extracted from the multiphase phase for on-Site treatment. Approximately 750 scfm of soil vapors would be extracted using two liquid-ring vacuum blowers and cooled to condense the steam before being delivered to the vapor treatment system. Three soil vapor treatment process options were evaluated in Section 4.8, but steam-regenerable carbon/resin is particularly applicable to this RA because of the steam boiler required for the remedy. A process flow diagram of the conceptual steam injection remedial system is provided as **Figure 5.17**.

Ex-Situ Groundwater Treatment and Disposal

Approximately 75 gpm of groundwater and steam condensate would be extracted from the multiphase wells for on-Site treatment. As described in Section 4.7, groundwater would be treated by a combination of LGAC to remove MCB and other VOCs by adsorption and HiPOx™ to destroy pCBSA by oxidation. Re-injection of the treated water is not fundamental to the steam injection remedy and may serve to cool the subsurface. For this reason, treated groundwater is assumed to be transferred to the Groundwater Remedy Treatment System for subsequent re-injection into the BFS and Gage aquifers (as evaluated in Section 4.9). The remedial design for the Groundwater Remedy Treatment System would need to consider the treated groundwater flow transferred from this DNAPL RA.

DNAPL Disposal

As specified in Section 4.7, all recovered DNAPL would be disposed off-Site every 90 days or less.

Temperature Monitoring Points

Approximately 14 temperature monitoring points would be installed throughout the focused treatment area to monitor subsurface heating both laterally and vertically. At each temperature monitoring point, thermocouples would be positioned every 5 vertical feet from approximately 25 to 115 feet bgs, to monitor temperatures both above the treatment interval and below, within the hot floor.

Operational Duration

Steam injection would be conducted until the thermal performance objectives for the remedy were achieved. In accordance with reconciliation discussions (AECOM, 2011a) and subsequent correspondence (EPA, 2011a and AECOM, 2011e), the thermal performance objectives would include:

1) Achievement of a target temperature that would be determined during remedial design. The temperature monitoring points would be used to determine if this performance goal was met; and
2) Demonstration that MCB concentrations in the saturated UBA were at or below residual saturations in accordance with RAO 4. Soil verification borings and samples would be used to determine if this performance goal was met.

In addition, the energy input and the MCB mass removal rate would be used as a guide for determining when to conduct the soil verification sampling. As documented in a memorandum dated March 25, 2011 (AECOM, 2011e), achieving residual saturations of MCB would be expected to occur sometime after the

peak mass removal rate but before the rate declines to a low asymptotic level. Once the MCB mass removal rate had declined to approximately 50% of the peak removal rate and the target temperature goal had been met, soil verification sampling would be conducted for determining compliance with RAO 4 and the second thermal performance goal.

For purposes of costing, the duration of the heating portion is estimated to be 12 months in the saturated UBA and 15 months in the hot floor (i.e., the hot floor must be heated in advance of the UBA). Accordingly, the total duration of the RA would be approximately 4 years including design, construction, operation and maintenance, verification, and abandonment.

Although thermal performance objectives would not be established until the ROD or remedial design, Montrose had additionally recommended a third thermal performance goal which limited the amount of energy consumed after reaching the target temperature goal. Some amount of heating after reaching target temperature is likely to be required, but to confine the cost and duration of a thermal remedy, Montrose had additionally recommended an energy goal of one pore volume of steam flushing after reaching target temperature. This performance goal is consistent with the conceptual design of this RA. Target temperatures are expected to be achieved after 1 to 1.5 pore volumes of steam flushing, and the total energy demand for this candidate RA would be approximately 2.5 pore volumes of steam flushing as shown in the energy balance provided in Appendix I. Multiple concurrent thermal performance objectives, as described above, would ensure that the subsurface is effectively treated to the extent of the technology's capabilities.

Thermal Verification Sampling

Thermal remediation soil verification sampling would be conducted to verify that MCB concentrations had been reduced to or below residual saturations. In accordance with memorandums dated March 25 and June 17, 2011 (AECOM, 2011e and 2011g), a total of 10 soil verification borings would be drilled at the midpoint between steam injection and multi-phase extraction wells as shown in **Figure 5.21**. If the temperature goal is not achieved in some areas, one or more of the verification borings would be relocated to coincide with those areas. The number of soil samples from each boring would vary depending on field evidence, lithology, and DNAPL occurrence, but for purposes of costing, an average of 9 soil samples were assumed to be collected from each boring and analyzed for VOCs by EPA 8260B. A minimum of 6 soil samples would be collected from each boring to provide sufficient post-remediation characterization to support statistical analysis. Because the soil would still be hot at the time of sampling, special handling procedures would be used to cool the core in the field prior to collection of discrete soil

samples as described in the aforementioned memorandums. Post-remediation soils will additionally be tested for DNAPL saturations/mobility to ensure that saturations were effectively reduced to residual levels and that all remaining DNAPL is immobile in the environment under gravitational forces and natural hydraulic gradients. The determination of remedy success will be made based on the more extensive DNAPL saturation and mobility tested conducted as part of the remedy and will not be based on the single data point collected prior to this FS as described in Section 2.5.3.

Carbon Footprint

The combination of SVE in the unsaturated zone and steam injection in the saturated UBA over the Focused Treatment Area is expected to consume approximately 275,000 MCF of natural gas and 14,300 megawatt-hours of electricity assuming 2.5 pore volumes of steam flushing in the UBA. The equivalent carbon footprint of this RA is estimated at 51 million pounds of carbon dioxide (Table 5.1 and Appendix H). However, 2.5 pore volumes of steam flushing may not be adequate to achieve the thermal performance objectives since between 3.4 and 5.2 pore volumes of steam flushing was required during 2-dimensional bench-scale testing under relatively ideal and controlled laboratory conditions (Section 2.6.6). A greater amount of steam flushing may be required under field-scale conditions. Additionally, up to 8 pore volumes of steam flushing was required at the SCE Visalia site, which had higher permeability soils as compared with the Montrose Site (see Appendix K for details). Since the amount of energy required to achieve the thermal performance objectives is relatively uncertain, an energy demand range of 2.5 to 6.0 pore volumes of steam flushing is assumed for this steam injection alternative. Accordingly, the carbon footprint would increase to approximately 106 million pounds of carbon dioxide if up to 6 pore volumes of steam flushing were required by this RA to reach the thermal performance goals.

5.1.7 REMEDIAL ALTERNATIVE 5B – STEAM INJECTION, ENTIRE DNAPL-IMPACTED AREA WITH HOT FLOOR

This RA includes the following three remedial technologies and process options:

Institutional Controls

Institutional controls would be implemented as described in Section 5.1.2.

SVE (unsaturated zone)

SVE would be implemented in the unsaturated PVS as described for RA 5a in Section 5.1.6. SVE within the unsaturated UBA is additionally a component of this steam injection RA and used to recover steam and volatilized VOCs from the underlying saturated UBA. Under this steam injection RA, installation of separate SVE wells within the unsaturated UBA, between 45 and 60 feet bgs, will not be required. Therefore, the cost of the SVE remedial component for this steam injection RA is reduced.

Steam Injection, Entire DNAPL-Impacted Area with Hot Floor

Steam injection would be implemented within the saturated UBA over the entire DNAPL-impacted area to thermally treat both residual and mobile DNAPL. Steam injection would be implemented in the same manner as for the focused treatment area, except that treatment would apply to the entire 160,000 square foot DNAPL-impacted area where an estimated 796,100 to 900,000 pounds of DNAPL are estimated to occur. Assuming that the MCB represents 50% of the DNAPL mass, an estimated 398,000 to 450,000 pounds of MCB is present at the Site and potentially subject to thermal remediation (although only a portion of this estimated mass would be recovered by steam injection). The elements of the steam injection conceptual design are summarized as follows.

Pilot Test

A pilot test would be implemented in advance of full-scale steam injection throughout the entire DNAPL-impacted area. As indicated in Section 4.6.3, implementation of steam injection throughout the entire DNAPL-impacted area at the Site would be one of the largest thermal remediation projects ever implemented in the United States and potentially the most complex given the Site lithology and nature of the DNAPL. A steam injection pilot test has not been conducted at the Site to establish either the feasibility of the technology, or if feasible, initial design parameters. Therefore, under this RA, a pilot test is assumed to be conducted in advance of full-scale design. The pilot test would thermally treat an area of approximately 11,000 square feet and 18,300 cubic yards within the saturated UBA. Assuming a 5-spot pattern and a 42-foot well spacing, 3 steam injection and 8 multiphase extraction wells would be installed to conduct the pilot. A conceptual well pattern for the pilot test is provided in **Figure 5.22**. A field pilot test could additionally be conducted around well UBE-5, although conducting a test on the downgradient side of the DNAPL-impacted area may not be as desirable if uncontrolled migration occurs outside of the pilot test area. The pilot test would be conducted for a period of approximately 6 months. Pilot-scale boiler, SVE system, and groundwater treatment system would be employed for the test.

Steam Injection and Multiphase Extraction Wells

Steam injection and multiphase extraction wells will be installed throughout the entire DNAPL-impacted area using the same well pattern and spacing indicated for the focused treatment area. Assuming a 5-spot pattern with 42-foot well spacing, a total of 61 steam injection and 53 multiphase extraction wells would be required (**Figure 5.23**). The well pattern will extend just outside the estimated extent of DNAPL, and steam injection wells would be positioned to displace DNAPL inward towards the recovery wells.

Hot Floor

The conceptual design for the hot floor includes 55 steam injection wells and 22 multiphase extraction wells spaced 60 feet apart in a 7-spot pattern (**Figure 5.24**). The actual number of hot floor wells would be determined following completion of pilot testing as indicated above.

Treatment Volume

The target treatment area is 160,000 square feet, and the treatment interval is from 60 to 105 feet bgs, consistent with the saturated UBA. Therefore, the target treatment volume for this RA would be 267,000 cubic yards within the saturated UBA.

Energy Requirements

For the entire DNAPL-impacted area, approximately 1,099,000 MCF of natural gas is estimated to be required assuming 2.5 pore volumes of steam flushing within the UBA and 3 pore volumes of steam flushing in the hot floor. The assumed energy requirements for this RA are based on an energy balance, calculated at the request of EPA and provided in Appendix I. To deliver this volume of steam, two 29 MM BTUs/hr steam boilers are assumed to be required.

SVE and Ex-Situ Vapor Treatment

Steam and heated soil vapors would be extracted from the multiphase phase for on-Site treatment. Approximately 2,000 scfm of soil vapors would be extracted using three liquid-ring vacuum blowers and cooled to condense the steam before being delivered to the vapor treatment system. A process flow diagram of the conceptual steam injection remedial system is provided as **Figure 5.25**.

Ex-Situ Groundwater Treatment and Disposal

Approximately 200 gpm of groundwater and steam condensate would be extracted from the multiphase wells for on-Site treatment by LGAC and HiPOx™. Treated groundwater would be transferred to the Groundwater Remedy Treatment System for re-injection into the BFS and Gage Aquifers.

DNAPL Disposal

All recovered DNAPL would be disposed off-Site every 90 days or less.

Temperature Monitoring Points

Approximately 70 temperature monitoring points would be installed throughout the DNAPL-impacted area to monitor subsurface heating both laterally and vertically.

Operational Duration

The total duration is estimated to be 7 years including pilot testing, design, construction, operation and maintenance, verification, and abandonment. The duration of the heating portion only over the entire DNAPL-impacted area is estimated to be 24 months.

Thermal Verification Sampling

Thermal remediation soil verification sampling would be conducted in the same manner as described for RA 5a in Section 5.1.6, except that borings would be drilled across the entire DNAPL-impacted area instead of only the Focused Treatment Area. A total of 20 soil verification borings would be drilled including 10 borings within the Focused Treatment Area where mobile DNAPL occurs (one boring per 2,600 square feet) and 10 borings outside the Focused Treatment Area where only residual DNAPL is believed to occur (one boring per 13,400 square feet).

Carbon Footprint

The combination of SVE in the unsaturated zone and steam injection in the saturated UBA over the entire DNAPL-impacted area is expected to consume approximately 1,110,000 MCF of natural gas and 45,000 megawatt-hours of electricity assuming 2.5 pore volumes of steam flushing in the UBA. The equivalent carbon footprint of this RA is estimated at 189 million pounds of carbon dioxide (Table 5.1 and Appendix H). The carbon footprint would increase to approximately 412 million pounds of carbon dioxide if up to 6 pore volumes of steam flushing were required by this RA to reach the thermal performance goals.

5.1.8 REMEDIAL ALTERNATIVE 6A – ERH, FOCUSED TREATMENT AREA WITHOUT HOT FLOOR

This RA includes the following three remedial technologies and process options:

Institutional Controls

Institutional controls would be implemented as described in Section 5.1.2.

SVE (unsaturated zone)

SVE would be implemented in the unsaturated zone as described for RA 5a in Section 5.1.6. SVE within the unsaturated UBA is additionally a component of an ERH RA and used to recover volatilized VOCs from the underlying saturated UBA. Under this ERH RA, installation of separate SVE wells within the unsaturated UBA, between 45 and 60 feet bgs, will not be required. Therefore, the cost of the SVE remedial component for this ERH RA is reduced.

ERH, Focused Treatment Area without Hot Floor

ERH would be implemented within the saturated UBA over a focused treatment area of 26,000 square feet, including the isolated area around boring SSB-12, where mobile DNAPL was observed during a short-term field pilot test. Under this RA, the focused treatment area would be thermally treated using ERH instead of steam injection. An estimated 473,700 to 780,000 pounds of DNAPL is estimated to occur within this focused treatment area, of which an estimated 236,800 to 390,000 pounds would be the volatile MCB component of the DNAPL and potentially subject to thermal remediation (although only a portion of this estimated mass would be recovered by ERH). ERH is a volatilization technology and would exclusively remove the MCB component of the DNAPL, leaving the DDT component in-situ. Although DDT is relatively insoluble in water and does not pose a significant threat to groundwater resources. Montrose submitted technical memorandums identifying the conceptual approach for ERH to EPA on August 7 and 22, 2008 (Earth Tech, 2008e and 2008f).

Pilot Test

While no ERH pilot test has been conducted at the Site, the relatively small size of the focused treatment area does not readily lend itself to implementation of a pilot test (would cover approximately 50% of the focused treatment area). Therefore, for purposes of costing, it is assumed that no pilot test would be conducted for this focused treatment area RA. The absence of a pilot test in the conceptual scope does not impact the effectiveness evaluation of this candidate RA.

ERH Electrodes and Multiphase Extraction Wells

A total of 87 ERH electrodes would be installed throughout the main focused treatment area on a 21-foot spacing and in an offset linear pattern (21-foot equilateral triangles). Each row of ERH electrodes would extend to or slightly beyond the edge of the focused treatment area as shown **Figure 5.26**. As shown in this figure, a total of 57 multiphase extraction wells are also spaced in a similar pattern but with 27-foot spacing throughout the main focused treatment area. An additional 15 ERH electrodes and 9 multiphase extraction wells would be required to treat the SSB-12 area, and therefore, a total of 102 ERH electrodes and 66 multi-phase extraction wells would be required for this RA. Because the perimeter of the focused treatment area is still within the DNAPL-impacted area, the outer wells of the pattern are extraction wells, intended to recover volatilized contaminants which may migrate away from the source area. Therefore, multiphase extraction wells are positioned around the perimeter of the focused treatment area (even beyond the estimated extent of mobile DNAPL) to recover volatilized contaminants along the edge of the thermal treatment area.

A conceptual ERH electrode construction diagram is provided as **Figure 5.27** and is based on the ET-DSP™ technology offered by McMillan-McGee. Each location would be constructed using three stacked 10-foot electrodes positioned at approximately 58 to 68, 75 to 85, and 92 to 102 feet bgs. The electrodes are capable of heating approximately 3 to 4 feet above and below the electrode length, and therefore, the electrodes were vertically positioned 6 to 8 feet apart. The multiphase extraction wells would be constructed as previously specified in Section 5.1.7 (screened from 45 to 105 feet bgs).

Hot Floor

Because ERH relies almost exclusively on volatilization, there is a reduced risk of downward mobilization relative to steam injection. Furthermore, for purposes of costing, it is assumed that a "bottom up" approach would be used, and therefore, no hot floor is assumed for this ERH RA.

Treatment Volume

The focused treatment area is 26,000 square feet, and the treatment depths for this ERH RA would be 60 to 105 feet bgs, consistent the saturated UBA. Therefore, the target treatment volume for this area would be 43,400 cubic yards within the saturated UBA, including the treatment area surrounding boring SSB-12.

Energy Requirements

The energy requirement for this ERH RA was estimated assuming a unit requirement of 200 kilowatt-hours per cubic yard as recommended by McMillan-McGee. Given the treatment volume of the saturated UBA (43,400 cubic yards), the total energy requirement for the saturated UBA is 8,680 megawatt-hours, including the treatment area surrounding SSB-12. If up to 400 kilowatt-hours per cubic yard were required, the total energy demand would be 17,360 megawatt-hours.

SVE and Ex-Situ Vapor Treatment

Heated soil vapors would be extracted from the multiphase extraction wells for on-Site treatment. Approximately 750 scfm of soil vapors would be extracted using two liquid-ring vacuum blowers and cooled to condense moisture before being delivered to the vapor treatment system. Three soil vapor treatment process options were evaluated in Section 4.8, although a steam regenerable carbon/resin system is particularly applicable to this RA. A process flow diagram of the conceptual ERH remedial system is provided as **Figure 5.28**.

Ex-Situ Groundwater Treatment and Disposal

Approximately 75 gpm of groundwater would be extracted from the multiphase wells for on-Site treatment. As described in Section 4.7, groundwater would be treated by a combination of LGAC to remove MCB and other VOCs by adsorption and HiPOx™ to destroy pCBSA by oxidation. Re-injection of the treated water is not fundamental to the ERH remedy and may serve to cool the subsurface. For this reason, treated groundwater would be transferred to the Groundwater Remedy Treatment System for subsequent re-injection into the BFS and Gage Aquifers (which was a process option specified in Section 4.9).

DNAPL Disposal

As specified in Section 4.9, all recovered DNAPL would be disposed off-Site every 90 days or less.

Temperature Monitoring Points

Approximately 14 temperature monitoring points would be installed throughout the focused treatment area to monitor subsurface heating both laterally and vertically. At each temperature monitoring point, thermocouples would be positioned every 5 vertical feet from approximately 25 to 115 feet bgs.

Operational Duration

The total RA duration would be approximately 4 years including design, construction, operation and maintenance, verification, and abandonment. The duration of the heating portion only is estimated to be 12 months.

Although thermal performance objectives would not be established until the ROD or remedial design, Montrose has recommended a thermal performance goal which limited the amount of energy consumed after reaching the target temperature goal. Some amount of heating after reaching target temperature is likely to be required, but to confine the cost and duration of a thermal remedy, Montrose had additionally recommended an energy goal of 50 kilowatt-hours per cubic yard after reaching target temperature. This performance goal is consistent with the conceptual design of this RA. Target temperatures are expected to be achieved after approximately 150 kilowatt-hours per cubic yard, and the total energy demand for this candidate RA is 200 kilowatt-hours per cubic yard. Multiple concurrent thermal performance objectives, as described above, would ensure that the subsurface is effectively treated to the extent of the technology's capabilities.

Thermal Verification Sampling

Thermal remediation soil verification sampling would be conducted in the same manner as described for RA 5a in Section 5.1.6. For purposes of costing, it was assumed that 10 soil verification borings would be drilled throughout the Focused Treatment Area at the midpoint between extraction wells (**Figure 5.29**) and that an average of 9 soil samples per boring would be analyzed for VOCs by EPA 8260B. Post-remediation soils will additionally be tested for DNAPL saturations/mobility to ensure that saturations were effectively reduced to residual levels and that all remaining DNAPL is immobile in the environment under gravitational forces and natural hydraulic gradients. The determination of remedy success will be made based on the more extensive DNAPL saturation and mobility tested conducted as part of the remedy and will not be based on the single data point collected prior to this FS as described in Section 2.5.3.

Carbon Footprint

The combination of SVE in the unsaturated zone and ERH in the saturated UBA over the Focused Treatment Area is expected to consume approximately 13,000 MCF of natural gas and 25,700 megawatt-hours of electricity assuming 200 kilowatt-hours per cubic yard of the UBA. The equivalent carbon footprint of this RA is estimated at 33 million pounds of carbon dioxide (Table 5.1 and Appendix H).

The carbon footprint would increase to approximately 61 million pounds of carbon dioxide if up to 400 kilowatt-hours per cubic yard were required to achieve the thermal performance goals.

As described in Section 5.1, renewable energy sources, such as solar panels. are not considered in this FS but will be considered during Remedial Design of the selected DNAPL remedy as appropriate. However, it is worth noting that solar panels only produce between approximately 0.75 and 1.5 kW-hrs of electricity per day each (depending on size, wattage rating, and peak sun hour days). At least 1,500 solar panels occupying roughly 27,000 square feet would be required to produce just 10% of the energy demand for RA 6a. Furthermore, there will be insufficient open space at the Montrose property to support a large solar panel array given the area that is or will be occupied by the groundwater remediation system, the Kenwood Avenue soil cells, and DNAPL remediation wells. ERH is a high energy demand remedy, and using solar panels as a renewable energy source may not have a significant impact on the carbon footprint of the remedy. Furthermore, over the 12 month O&M duration of the remedy, the savings generated by using the renewable energy source would not pay for the capital cost of the solar panels. This type of renewable energy source is more applicable to low energy and long duration remedies. Solar power panels would not be a cost effective renewable energy source for this project given the limited land available and the short duration and high electrical demand. The high capital cost of the solar panels would conflict with the NCP cost criterion.

5.1.9 REMEDIAL ALTERNATIVE 6B – ERH, ENTIRE DNAPL-IMPACTED AREA WITHOUT HOT FLOOR

This RA includes the following three remedial technologies and process options:

Institutional Controls

Institutional controls would be implemented as described in Section 5.1.2.

SVE (unsaturated zone)

SVE would be implemented in the unsaturated zone as described for RA 5b in Section 5.1.7. SVE within the unsaturated UBA is additionally a component of this ERH RA and used to recover volatilized VOCs from the underlying saturated UBA. Under this ERH RA, installation of separate SVE wells within the unsaturated UBA, between 45 and 60 feet bgs, will not be required. Therefore, the cost of the SVE remedial component for this ERH RA is reduced.

ERH, Entire DNAPL-Impacted Area without Hot Floor

ERH would be implemented within the saturated UBA over the entire DNAPL-impacted area to thermally treat both residual and mobile DNAPL. ERH would be implemented in the same manner as for the focused treatment area, except that treatment would apply to the entire 160,000 square foot DNAPL-impacted area where an estimated 796,100 to 900,000 pounds of DNAPL are estimated to occur. Assuming that the MCB represents 50% of the DNAPL mass, an estimated 398,000 to 450,000 pounds of MCB is present at the Site and potentially subject to thermal remediation (although only a portion of this estimated mass would be recovered by ERH). The elements of the ERH conceptual design are summarized as follows:

Pilot Test

A pilot test would be implemented in advance of full-scale ERH remedy throughout the entire DNAPL-impacted area. As indicated in Section 4.6.1, implementation of an ERH remedy throughout the entire DNAPL-impacted area at the Site would be the largest ERH project ever implemented in the United States and potentially the most complex given the Site lithology and nature of the DNAPL. An ERH pilot test has not been conducted at the Site to establish either the feasibility of the technology, or if feasible, initial design parameters. Therefore, under this RA, a pilot test would be conducted in advance of full-scale design. The pilot test would thermally treat an area of approximately 11,000 square feet and 18,300 cubic yards within the saturated UBA. Assuming the same well spacing as for the full-scale remedy, 30 ERH electrodes and 21 multiphase extraction wells would be installed within the saturated UBA to conduct the pilot. A conceptual well pattern for the pilot test is provided in **Figure 5.30**. The pilot test would be conducted for a period of approximately 6 months. Pilot-scale SVE system and groundwater treatment system would be employed during the test.

ERH Electrodes and Multiphase Extraction Wells

ERH electrodes and multiphase extraction wells would be installed throughout the entire DNAPL-impacted area using the same well pattern and spacing indicated for the focused treatment area. A total of 456 ERH electrodes and 203 multiphase extraction wells would be installed as shown in **Figure 5.31**. The ERH electrode well pattern would overlay the estimated extent of the DNAPL.

Hot Floor

Because ERH relies exclusively on volatilization, there is a reduced risk of downward mobilization relative to steam injection. Furthermore, for purposes of costing, it is assumed that a "bottom up" approach would be used, and therefore, no hot floor is assumed for this ERH RA.

Treatment Volume

The target treatment area is 160,000 square feet, and the treatment interval is from 60 to 105 feet bgs, consistent with the saturated UBA. Therefore, the target treatment volume for this RA would be 267,000 cubic yards within the saturated UBA, which if implemented, would be the largest ERH remedy ever to be undertaken.

Energy Requirements

For the entire DNAPL-impacted area, a total of 53,400 megawatt-hours of electrical power would be required based on an assumed unit requirement of 200 kilowatt-hours per cubic yard (as recommended by McMillan-McGee). If up to 400 kilowatt-hours per cubic yard were required, the total energy demand would be 106,800 megawatt-hours.

SVE and Ex-Situ Vapor Treatment

Heated soil vapors would be extracted from the multiphase phase for on-Site treatment. Approximately 2,000 scfm of soil vapors would be extracted using three liquid-ring vacuum blowers and cooled to condense moisture before being delivered to the vapor treatment system. A process flow diagram of the conceptual ERH remedial system is provided as **Figure 5.32**.

Ex-Situ Groundwater Treatment and Disposal

Approximately 200 gpm of groundwater would be extracted from the multiphase wells for on-Site treatment by LGAC and HiPOx™. Treated groundwater would be transferred to the Groundwater Remedy Treatment System for re-injection into the BFS and Gage Aquifers.

DNAPL Disposal

All recovered DNAPL would be disposed off-Site every 90 days or less.

Temperature Monitoring Points

Approximately 70 temperature monitoring points would be installed throughout the DNAPL-impacted area to monitor subsurface heating both laterally and vertically.

Operational Duration

The total duration is estimated to be 7 years including pilot testing, design, construction, operation and maintenance, verification, and abandonment. The duration of the heating portion only is estimated to be 24 months.

Thermal Verification Sampling

Thermal remediation soil verification sampling would be conducted in the same manner as described for RA 5b in Section 5.1.7. A total of 20 soil verification borings would be drilled including 10 borings within the Focused Treatment Area where mobile DNAPL occurs (one boring per 2,600 square feet) and 10 borings outside the Focused Treatment Area where only residual DNAPL is believed to occur (one boring per 13,400 square feet).

Carbon Footprint

The combination of SVE in the unsaturated zone and ERH in the saturated UBA over the entire DNAPL-impacted area is expected to consume approximately 39,000 MCF of natural gas and 113,000 megawatt-hours of electricity assuming 200 kilowatt-hours per cubic yard of the UBA. The equivalent carbon footprint of this RA is estimated at 143 million pounds of carbon dioxide (Table 5.1 and Appendix H). The carbon footprint would increase to approximately 227 million pounds of carbon dioxide if up to 400 kilowatt-hours per cubic yard were required by this RA to reach the thermal performance goals.

5.2 SCREENING OF REMEDIAL ALTERNATIVES

The purpose of this section is to conduct an intermediate screening of the assembled RAs as prescribed in EPA guidance documentation for conducting feasibility studies under CERCLA (EPA, 1988). The RAs will be evaluated against the same three performance criteria used in Section 4.0: effectiveness, implementability, and relative cost. A brief description of these performance criteria is provided below. Following the intermediate screening evaluation, the surviving RAs will be retained for detailed evaluation in Section 6.0.

Effectiveness. Each RA is evaluated based on its relative effectiveness in meeting RAOs and protecting human health and the environment. RAs are evaluated and ranked as effective, moderately effective, minimally effective, potentially effective, or ineffective. The term "potentially effective" indicates that the effectiveness is uncertain. Technologies identified with this ranking are potentially effective, but there is insufficient evidence to further qualify the effectiveness as minimally effective, moderately effective, or effective. A potentially effective ranking is greater than an ineffective ranking but is not necessarily any better or worse than the other three effectiveness rankings. This evaluation includes:

- The effectiveness of the RA in achieving the RAOs,
- The potential impacts to human health and the environment during the construction and implementation phase, and
- The reliability of the RA with respect to the contaminants and conditions at the Site.

Implementability. Each RA is evaluated based on the technical and administrative feasibility of implementing the specific technology. Technical feasibility refers to the applicability or compatibility of an RA to site conditions and contaminants of concern. Administrative feasibility refers to such issues as permitting and availability of equipment, among other factors. Each RA is evaluated and ranked as highly implementable, moderately implementable, difficult to implement, or not implementable.

Cost. A limited cost evaluation is performed in this screening phase and is based primarily on engineering judgment and technology vendor experience. Capital costs, such as construction costs, and long-term monitoring or operation and maintenance costs are considered. Each RA is evaluated and ranked as very high, high, medium, low, or no cost.

5.2.1 REMEDIAL ALTERNATIVE 1 – NO ACTION

This RA includes one GRA: No Action for DNAPL in both the unsaturated and saturated zones.

Effectiveness. The No Action RA would not meet DNAPL RAOs in the long-term. Mobile DNAPL mass and the potential for recontamination of the aquifers would not be reduced to the extent practicable by this RA. Migration of mobile DNAPL would not be limited by this RA, and the probability of maintaining containment of the dissolved-phase contamination would not be increased. Additionally, VOCs in the unsaturated zone would not be removed.

However, containment of dissolved-phase contaminants is required by the remedy for groundwater, which effectively eliminates groundwater exposure pathways. Migration of dissolved-phase contaminants

would be controlled through hydraulic extraction, and DNAPL mass is slowly reduced over time through dissolution. Human exposure to contaminated groundwater at the Property would be restricted (and eliminated outside the TI Waiver Zone). Monitoring of groundwater conditions would also be conducted to ensure that hydraulic containment is achieved. Access to the Site is already restricted and inspected/maintained on a routine basis, and the No Action RA is by definition a reliable process with no adverse impacts.

Based on the available data, significant migration of mobile DNAPL has not been observed at the Site. Wells UBE-2 and UBE-3 are located immediately east and down-dip from the DNAPL source areas, but no mobile DNAPL has been recovered from these wells in over 7 years. Although these two wells are insufficient, by themselves, to demonstrate that DNAPL is not migrating at the Site, it is worth noting that the presence of mobile DNAPL at the Site does not mean that the DNAPL is currently migrating under relatively static hydraulic conditions. The sources of DNAPL at the Site were abandoned more than 30 years ago, and use of the former wastewater pond was discontinued approximately 60 years ago. The extent of DNAPL migration at the Site is already mature, and there are no remaining overlying hydraulic heads to drive the DNAPL downward (other than gravitational forces).

However, unless saturations are reduced to residual levels, mobile DNAPL has the potential to migrate either laterally or vertically in the future. Under the No Action RA, there is the potential to exacerbate the current distribution of DNAPL, and therefore, this alternative would not meet the DNAPL RAOs. ***Rank: Not Effective.***

Implementability. By definition, the No Action RA is highly implementable. ***Rank: Highly Implementable.***

Cost. By definition, there is no cost associated with the No Action RA. The containment aspect of this RA would be implemented as part of the remedy for groundwater. ***Rank: No Cost.***

Retain for Detailed Analysis? As required by the NCP, this No Action RA is retained for detailed evaluation as a baseline for comparison with other RAs. ***Retain? Yes.***

5.2.2 REMEDIAL ALTERNATIVE 2 – INSTITUTIONAL CONTROLS

This RA includes one GRA: institutional controls.

Effectiveness. The effectiveness of this alternative is similar to RA 1, with the addition of institutional controls. Under this RA, future use of the Property would be limited by a deed restriction, and access

limitations to the Site would be implemented as a formal component of the remedy. This RA would be effective in reducing the potential for human exposure to contaminated soils, DNAPL, and groundwater. Human exposure to contaminants at surface is excluded from this evaluation and will be addressed by the Soil FS for the Site. Institutional controls for DNAPL would be limited to DNAPL-impacted areas including the Montrose Property and potentially a small portion of the GLJ Holdings property to the north. The institutional controls RA is a reliable process with no adverse impacts to human health or the environment. The hydraulic containment component of the remedy for groundwater prevents migration of dissolved-phase contaminants through hydraulic extraction and reduces DNAPL mass over time by dissolution.

However, as under the No Action RA, mobile DNAPL mass and the potential for recontamination of the aquifers would not be reduced to the extent practicable by this RA. Migration of mobile DNAPL would not be limited by this RA, and the probability of maintaining containment of the dissolved-phase contamination would not be increased. Additionally, VOCs in the unsaturated zone would not be removed. Although protective of human health and minimally effective in the short-term, this RA would not be effective or meet the RAOs in the long-term. ***Rank: Minimally Effective.***

Implementability. There are no technical or administrative aspects that would limit the implementability of recording a deed restriction for the on-Property portion of the Site, where nearly all of the DNAPL occurs in the subsurface. However, a small portion of the DNAPL may be present below the adjacent property to the north (GLJ Holdings), and application of deed restrictions at the off-Property areas would require consent of the land owners. ***Rank: Highly Implementable.***

Cost. The relative cost for this institutional controls RA is very low. There is only a minimal cost associated with implementation of a deed restriction and other pre-existing institutional controls. ***Rank: Low.***

Retain for Detailed Analysis? This institutional controls RA would be effective in protecting human health by controlling the contaminant exposure pathways and is the lowest cost RA, other than the No Action alternative. Although this institutional controls RA would not reduce the mobile DNAPL mass or be effective in the long-term, it is a component of other candidate RAs and is retained for detailed evaluation. ***Retain? Yes.***

5.2.3 REMEDIAL ALTERNATIVE 3 – SVE IN THE UNSATURATED ZONE

This RA includes two GRAs: (1) SVE in the unsaturated zone, and (2) institutional controls.

Effectiveness. This RA would be highly effective in reducing DNAPL mass and mobility in permeable unsaturated soils. Under this RA, the mass and mobility of VOCs and DNAPL in the unsaturated zone would be effectively reduced by SVE. The future risk to groundwater from contaminant leaching would also be significantly reduced by SVE. The effectiveness of SVE to remove VOCs from the unsaturated zone was demonstrated by field pilot testing in 2003 as summarized in Section 2.6.4. The MCB component of the DNAPL would be volatilized and extracted for ex-situ vapor treatment. The DDT component of the DNAPL would be left in place, where it poses no risk to human health and the environment due to a lack of exposure pathways. D DT is not volatile, relatively insoluble in groundwater, and relatively immobile in deeper soils (no migration risk). The Soil FS will address VOC migration at land surface.

This RA would additionally include the protectiveness offered by institutional controls as specified for RA 2. The institutional controls aspect of the RA would be effective in preventing human exposure to contaminated soils, DNAPL, and groundwater. The hydraulic containment component of the remedy for groundwater prevents migration of dissolved-phase contaminants through hydraulic extraction and slowly reduces DNAPL mass over time by dissolution.

However, SVE may not be effective within the PD soils from approximately 4 to 25 feet bgs due to the low permeability of these soils observed at most boring locations. During field pilot testing in 2003, SVE was found to be significantly less effective for removal of VOCs from the low permeability PD soils. VOCs present in the PD would remain in place as a potential source to shallow soil gas. Although effective in the unsaturated zone, this RA would not reduce the mobile DNAPL mass in the saturated UBA. ***Rank: Moderately Effective.***

Implementability. This RA is implementable. There are no technical or administrative aspects that would limit the implementability of this RA. SVE is a widely used technology for remediating VOCs in permeable soils, and equipment required to implement the RA is readily available. H ighly skilled operators are not required for this RA, and there are a large number of contractors available to provide SVE remediation services. The SVE aspects of this RA would have to meet ARARs for air emissions. ***Rank: Highly Implementable.***

Cost. The relative cost of this SVE RA is low to medium. Installation of approximately 23 extraction wells in the unsaturated zone and ex-situ soil vapor treatment would be required under this RA. ***Rank: Low to Medium.***

Retain for Detailed Analysis? The SVE component of this RA would reduce the mass of VOCs and DNAPL in the unsaturated zone, thereby increasing the protectiveness of groundwater and controlling VOC migration in soil gas. Field pilot testing has demonstrated the potential effectiveness of SVE to initially remove a relatively high mass of vapor-phase VOCs from permeable unsaturated soils. The institutional controls component of the RA would protect human health by controlling the contaminant exposure pathways. Although this SVE RA would not reduce the mobile DNAPL mass in the saturated zone, which is the principal threat at the Site, it is a component of other candidate RAs and is retained for detailed evaluation. ***Retain? Yes.***

5.2.4 REMEDIAL ALTERNATIVE 4A – HYDRAULIC DISPLACEMENT WITH UNTREATED WATER INJECTION

This RA includes three GRAs: (1) hydraulic displacement with untreated water re-injection in the saturated UBA, (2) SVE in the unsaturated zone, and (3) institutional controls.

Effectiveness. Hydraulic displacement would remove DNAPL in saturations exceeding residual, and both the mass and mobility of DNAPL in the saturated UBA would be reduced under this RA, thereby meeting DNAPL RAOs. Simultaneous groundwater extraction and re-injection would displace mobile DNAPL towards recovery wells for extraction. This process was shown to be effective during DNAPL extraction testing in 2004/2005 where DNAPL was recovered at a rate up to 5.6 gallons per day from a single well even though the testing was conducted without the benefit of increased hydraulic gradients from groundwater re-injection (as proposed by this RA). During extraction testing, the rate of DNAPL recovery increased with increasing hydraulic gradients. Since re-injection of groundwater will increase hydraulic gradients over what was field pilot tested, an increased rate of DNAPL recovery, above those observed during testing, may be realized by this hydraulic displacement RA.

Although some DNAPLs are not readily mobilized for extraction by hydraulic displacement (i.e., DNAPLs exhibiting high density, high viscosity, and/or high interfacial tension), field pilot testing has demonstrated that the Montrose DNAPL can be effectively recovered by this technology. The Montrose DNAPL is considered to be moderately mobile, as indicated in Section 2.1.2. Although the DNAPL density (1.25 g/cc) is 25% higher than that of water (1 g/cc), this density difference is not so high as to preclude the use of this technology. Mobile DNAPL has been successfully recovered through active hydraulic extraction from all pilot test wells located within the estimated mobile DNAPL footprint, and the rate of DNAPL recovery increases with increasing hydraulic gradients. Any concerns related to the potential effectiveness of hydraulic displacement to mobilize the Montrose DNAPL (CH2M Hill, 2007)

have been definitively addressed through field pilot testing (Section 2.6.3) and computer modeling (Section 2.6.4).

Higher saturations of DNAPL (i.e., highest mass) are the most mobile and would be the easiest to recover by hydraulic displacement. DNAPL occurring just slightly above residual levels would be the least mobile, but it poses a reduced risk of mobilization laterally or vertically to the BFS. H ydraulic displacement depletes DNAPL saturations, making the remaining DNAPL less and less mobile over time. Although hydraulic displacement relies on fluid flow through porous and permeable saturated soils, other candidate RAs are equally reliant on these site conditions. Discontinuous sand layers which are not in hydraulic communication with the extraction and injection wells may the limit the effectiveness of this RA and other displacement technologies (e.g., steam injection). S tagnation zones between wells may leave some mobile DNAPL in place if not effectively flushed by multi-phase extraction or groundwater injection. A dditionally, DNAPLs trapped within the low permeability layers of the UBA will not be available for remediation by hydraulic displacement, although DNAPL trapped in low permeability soils inherently pose a lower risk of migration.

As is true for all RAs under consideration, residual saturations of DNAPL would be left in place following the hydraulic displacement component of the RA (e.g., such as the 18.9% residual DNAPL saturation measured in one UBA soil core [Section 2.1.2]). However, residual DNAPL is immobile in the environment under gravitational forces and poses no risk to the underlying BFS other than as a continuing source of dissolved-phase MCB, which is effectively addressed by the hydraulic containment aspect of the remedy for groundwater.

Re-injection of untreated groundwater will be effective in displacing DNAPL, and removal of the dissolved-phase constituents by ex-situ treatment is not required for this hydraulic displacement RA. Contaminant mass reduction under RA 4a occurs by removal of the liquid-phase DNAPL. Initially, when DNAPL saturations are highest, between approximately 69% and 90% of the extracted contaminant mass is expected to be mobile DNAPL. The dissolved-phase mass is very small in comparison, and other than DNAPL separation and solids filtration, groundwater would not be treated ex-situ prior to re-injection into the UBA.

Discontinuous silt layers have the potential to allow some downward migration during hydraulic displacement; however, the risk of this migration can be reduced to some extent by a sufficiently high well density. T he potential for downward mobilization was evaluated by H+A and Intera using preliminary modeling, and model results indicated there was no downward mobilization past the basal

silty sand member of the UBA during or after hydraulic displacement (H+A, 2009b). However, there is some uncertainty associated with the continuity of the basal layer across the Property and the pore entry pressures required to penetrate through the silty sands, if continuous. The basal silty sand would be expected to support DNAPL pool heights between 1.3 and 8 feet if continuous and depending on the pore entry pressure. The preliminary modeling also indicated that DNAPL would be effectively mobilized to the extraction wells at spacings up to 120 feet, and therefore, the 50-foot well spacing identified in Section 5.1.4 is expected to be effective.

The SVE component of the RA would reduce VOC and DNAPL mass/mobility in the unsaturated zone and would control VOC migration in soil gas. Lowering of the water table around the extraction wells will additionally expose soils to SVE in the overlying unsaturated zone. The institutional controls component would protect human health by controlling contaminant exposure pathways. The hydraulic containment component of the remedy for groundwater will prevent migration of dissolved-phase contaminants and reduce the mass of residual DNAPL in the long-term. ***Rank: Effective.***

Implementability. This RA is technically implementable. Extraction wells can be installed using standard drilling methods and equipment, although the number of wells required under this RA (69 extraction and injection wells) would generate a substantial amount of waste. Standard separation techniques can be used to separate the Montrose DNAPL from groundwater, and specialized field equipment is not required for this RA. However, skilled operators and a moderate to high level of routine maintenance would be required for this RA to abate precipitate fouling of the extraction pumps/piping, which was observed during the extraction pilot test. Additionally, injection well fouling is a common problem and could increase the difficulty of implementing this technology. A routine well development program would be required to abate the effects of injection well fouling. Although the degree of injection fouling cannot be reliably predicted, severe fouling was not observed during field pilot testing where one of the two wells lost 50% of its injection capacity after a lengthy test period with no redevelopment program (partially due to mounding in the unsaturated zone). Furthermore, spare upgradient injection wells were incorporated into the conceptual design for this remedy, reducing the impact of injection well fouling on the implementability of this RA. Therefore, the implementability of re-injecting water into the UBA at the Site has already been successfully demonstrated.

Administratively, RA 4a may be difficult to implement because a waiver of the re-injection standards would be required from EPA and the State over the 5-year duration of the remedy (which was approved for the 2004/2005 extraction test). However, the administrative challenges may not be prohibitive as re-injection of untreated groundwater was approved for the field pilot test, and EPA has previously approved

this approach for full-scale hydraulic displacement remedies at Union Pacific Railroad sites located in Laramie, Wyoming and The Dalles, Oregon (Regions 8 and 10 respectively; see Appendix K for details). Furthermore, the re-injection would occur entirely at the Montrose property and within the footprint of the TI Waiver Zone. Additionally, since separation of the DNAPL from groundwater following total fluids extraction would initially remove up to 90% of the total contaminant mass, RA 4a would also meet the requirements of 42 U.S.C. § 6939(b) by substantially reducing hazardous constituents prior to groundwater re-injection. ***Rank: Difficult to Implement (unless waiver of ARAR is granted in short-term).***

Cost. The relative cost of this hydraulic displacement RA is medium. Installation of approximately 23 multiphase extraction and 46 injection wells (50-foot well spacing) would be required under this RA, including the isolated area surrounding boring SSB-12. Recovered DNAPL would be transported off-Site for disposal, but extracted groundwater would only be filtered prior to re-injection (no treatment for VOCs or pCBSA). Re-injection of untreated groundwater substantially reduces the cost of this RA. This RA would additionally include SVE within the unsaturated zone. ***Rank: Medium.***

Retain for Detailed Analysis? This RA would reduce mobile DNAPL mass, reducing the potential for recontamination of the aquifers and increasing the probability of achieving containment of the dissolved-phase contamination. Field pilot testing has demonstrated the potential effectiveness of hydraulic displacement to initially remove a relatively high volume of mobile DNAPL from the saturated UBA. Although some mobile DNAPL may be left in place by this RA, the mobility of the remaining DNAPL in the saturated UBA would be substantially reduced and may not pose a significant risk to the groundwater remedy. Treatment of the dissolved chemicals in groundwater is not performed under this RA, and the re-injection standards within the TI Waiver Zone would have to be waived in order for this alternative to be administratively implementable. The SVE component of this RA would reduce the mass of VOCs and DNAPL in the unsaturated zone, thereby increasing the protectiveness to groundwater and controlling VOC migration in soil gas. The institutional controls component of the RA would protect human health by controlling the contaminant exposure pathways. The hydraulic containment component of the remedy for groundwater will prevent migration of dissolved-phase contaminants in the saturated zone and will reduce DNAPL mass in the long-term by dissolution. This RA is retained for detailed evaluation. ***Retain? Yes.***

5.2.5 REMEDIAL ALTERNATIVE 4B – HYDRAULIC DISPLACEMENT WITH TREATED WATER INJECTION

This RA includes three GRAs: (1) hydraulic displacement with treated water re-injection in the saturated UBA, (2) SVE in the unsaturated zone, and (3) institutional controls.

Effectiveness. The effectiveness of this candidate alternative is identical to that of RA 4a except that dissolved VOCs are treated ex-situ using LGAC and HiPOx™. Ex-situ treatment of dissolved VOCs to re-injection standards is primarily an implementability issue but does increase the rate of DNAPL solubilization in the short-term. However, ex-situ treatment of groundwater does not further reduce the mass of mobile DNAPL or the potential for recontamination of the aquifers. Ex-situ treatment of the groundwater also does not limit the potential for uncontrolled migration of mobile DNAPL or increase the probability of maintaining containment.

The SVE component of the RA would reduce VOC and DNAPL mass/mobility in the unsaturated zone and would control VOC migration in soil gas. The institutional controls component would protect human health by controlling contaminant exposure pathways. The hydraulic containment component of the remedy for groundwater will prevent migration of dissolved-phase contaminants and reduce the mass of residual DNAPL in the long-term. ***Rank: Effective.***

Implementability. This RA is technically implementable as described for RA 4a. More highly skilled operators and a higher level of maintenance will be required to treat the groundwater ex-situ prior to re-injection. An LGAC and advanced oxidation treatment train will be required to treat the dissolved VOCs and pCBSA in the separated UBA groundwater. High inlet concentrations would be expected, and therefore, a robust treatment system would be required which increases the difficulty of implementing this alternative relative to RA 4a. Additionally, ex-situ treatment of the groundwater using an advance oxidation process could result in mineral precipitation that hinders the re-injection of groundwater at the Site.

However, administratively, this alternative is more implementable than RA 4a. Since dissolved chemical concentrations would be treated prior to re-injection, no waiver of the ROD requirements would be needed. There would be no administrative challenges associated with implementation of this RA involving ex-situ treatment of groundwater prior to re-injection. ***Rank: Moderately Implementable.***

Cost. The relative cost of this hydraulic displacement RA is high. Ex-situ treatment of the groundwater for dissolved chemicals prior to re-injection will add several million dollars in cost to this alternative as

compared with RA 4a. Although the conceptual design for this RA assumes a 150 gpm groundwater flow rate, the initial concentrations of VOCs are expected to be high. As a result, the initial mass loading of VOCs to the treatment system will be greater than the full-scale remedy for groundwater. Treatment of groundwater containing high concentrations of dissolved chemicals significantly increases the relative cost of this hydraulic displacement RA. ***Rank: High.***

Retain for Detailed Analysis? Like RA 4a, this alternative would reduce mobile DNAPL mass, reducing the potential for recontamination of the aquifers and increasing the probability of achieving containment of the dissolved-phase contamination. Ex-situ treatment of the dissolved-phase contamination prior to re-injection would improve the administrative implementability of this RA but is not necessary for removal of mobile DNAPL and would significantly increase the cost of this alternative relative to RA 4a. However, in accordance with reconciliation discussions (AECOM, 2011f) and because this alternative has the potential to meet RAOs, this RA is retained for detailed evaluation. ***Retain? Yes.***

5.2.6 REMEDIAL ALTERNATIVE 5A – STEAM INJECTION OVER FOCUSED TREATMENT AREA

This RA includes three GRAs: (1) steam injection over a focused treatment area, (2) SVE in the unsaturated zone, and (3) institutional controls.

Effectiveness. This RA may be effective in reducing the DNAPL mass and mobility within a focused treatment area, consistent with the estimated extent of mobile DNAPL at the Property. Steam injection has the potential to reduce DNAPL mass, both residual and mobile, within the focused treatment area either through MCB volatilization or DNAPL flushing. Although the focused treatment area is only 16% of the entire DNAPL-impacted area, it is estimated to contain 100% of the mobile DNAPL and between approximately 60% and 87% of the total DNAPL mass in the saturated zone. DNAPL occurs in the highest concentrations within the focused treatment area covering approximately 22,900 square feet of the CPA and a 3,100 square foot area surrounding boring SSB-12 (located east/southeast of the CPA). Outside of the focused treatment area, DNAPL occurs in lower concentrations that are believed to be relatively immobile in the environment (i.e. residual DNAPL). Based on a review of case study sites, the size of the focused treatment area is consistent with the average treatment area applied at other thermal remediation sites.

However, steam injection has not been pilot tested at the Site, and the potential effectiveness of this RA is uncertain. As indicated in Section 4.6.3, there are numerous technical challenges that could reduce the effectiveness of this RA including preferential steam flow, steam over-ride, downward mobilization, and the inability to recover volatilized MCB, among others. The saturated UBA is highly layered, with

alternating layers of permeable sand layers and low permeability silt layers, and steam injection is dependent on permeable soils for delivery of steam to the treatment area. Steam will preferentially flow through the sand layers, and heating of the less permeable layers would rely on thermal heat conduction from adjacent sands. Although this thermal RA has the potential to at least partially treat the low permeability layers of the UBA, conductive heating is less efficient than direct steam contact with DNAPL-impacted soil and could increase the operational duration and energy demand for this RA. In a document entitled *Contaminants in the Subsurface: Source Zone Assessment and Remediation* (National Academy Press, 2005), the author indicated that "*heat conduction from the steam channels to the lower permeability zones will eventually lead to contaminant removal from these zones, but more steam, more energy for steam production, and more time will be required*". The author additionally indicated that heterogeneous formations may reduce the effectiveness of steam injection, "*as the degree of heterogeneity increases, the efficiency of steam flushing decreases, with the steam channeling through high permeability pathway*".

It is for these reasons that steam injection was not assembled into a formal RA at the Del Amo Superfund Site where the lithology of one of the benzene LNAPL-impacted areas is similar to the Montrose Site (URS, 2008). The rationale for excluding a formal steam injection alternative at the Del Amo Site was that the low permeability and heterogeneous nature of the aquitard soils were not well suited for application of steam injection. While there are differences in site conditions, risks, and contaminant properties, the lithology of the NAPL-impacted areas is similar to Montrose, and therefore, relevant to this evaluation.

Steam injection was field pilot tested at the Williams Air Force Base in Mesa, Arizona, where an aviation fuel LNAPL was smeared across two layered and heterogeneous water-bearing units. Although the high permeability sand layers were effectively heated by steam injection, the low permeability zones did not reach target temperatures and a significant amount of NAPL mass was left in place. Numerous differences with the Montrose Site exist and there were some performance problems associated with the manner in which the pilot test was conducted as discussed in Appendix K.

The layered nature of the UBA may additionally limit the ability to recover volatilized MCB. If volatilized MCB vapors are not effectively recovered, they have the potential to condense, resulting in MCB accumulation in another part of the saturated UBA. The National Academy Press (2005) indicated that "*as soil permeability decreases, steam zone expansion and recovery of vaporized contaminants will become more difficult, increasing remediation time and potentially reducing effectiveness*". Increasing remediation time and energy, by itself, may not be sufficient to effectively treat the saturated UBA during

steam injection. Preferential steam flow through higher permeability soils may limit the ability of this RA to achieve target temperatures uniformly through the treatment area. Even if effectively heated, there is the potential for discontinuous sand layers to not be in hydraulic communication with a multi-phase extraction well or for development of stagnation zones, which would reduce the MCB removal efficiency during steam injection. Like hydraulic displacement, DNAPL mobilized by steam injection could encounter a discontinuity in the capillary barrier resulting in downward vertical migration to the underlying sand layer or basal silty sand layer. For steam injection to be effective, the saturated UBA must be effectively heated to target temperatures and displaced DNAPL or MCB vapors must be effectively recovered. Reaching target temperatures alone is not sufficient, the contaminants must be recovered or they will condense elsewhere within the saturated UBA, potentially outside the remediation footprint of the RA.

Steam injection has not been applied to a DNAPL site where either MCB or DDT was a primary component of the DNAPL. The relatively high co-boiling point of the Montrose DNAPL (96°C) and low vapor pressure of MCB (12 mm Hg at 20°C) may result in reduced mass removal efficiencies as compared with some other VOCs with lower co-boiling points, such as TCE (73°C). The effectiveness of steam injection to thermally treat soils impacted with an MCB DNAPL has not been demonstrated at either pilot or full-scale.

Steam injection will mobilize DNAPL via flushing and concentrate the DNAPL at the steam front. Mobilized DNAPL that is not effectively recovered has the potential to migrate laterally and/or downward through discontinuous silt layers. Uncontrolled steam distribution could result in spreading of the contamination within the saturated zone. The National Academy Press (2005) indicated that "*as heterogeneity increases, the ability to predict and control steam movement in the subsurface decreases*" and that "*control of steam movement is important in avoiding undesired downward mobilization of DNAPLs*". This type of contaminant spreading, if it were to occur, would not meet the DNAPL RAOs and would reduce the effectiveness of this RA.

For the above reasons, implementation of a hot floor is required for this RA to thermally treat DNAPL migrating into the BFS, if any. However, hot floors are very infrequently implemented, and there is an absence of experience at comparable sites upon which to reliably predict the performance of a hot floor at the Montrose Site. In the limited number of cases where a hot floor was implemented, ERH or TCH was primarily used to heat the hydrologic layer underlying the DNAPL-impacted zone. Although steam was injected into an underlying aquifer unit at the SCE Site in Visalia, California, the primary reason was to prevent the upward flow of cool groundwater into the thermal treatment zone (not to prevent downward

flow of DNAPL). The geologic conditions of the BFS will support steam injection, and a hot floor in the BFS would reduce to some extent the risk of vertical migration during a steam remedy. However, a hot floor would not eliminate or fully mitigate vertical migration risks. Furthermore, drilling the hot floor wells through DNAPL-impacted soils increases the risk of downward migration to occur during drilling or as a result of drilling if efforts to isolate the overlying UBA are not successful. The effectiveness of the isolation efforts during drilling are not guaranteed and would not effectively isolate overlying soils if the conductor were set in a sand layer.

This RA would additionally include the effectiveness offered by the components of RA 3. The VOC/DNAPL mass in the unsaturated zone would be significantly reduced by SVE, and VOC migration in soil gas would be controlled. If successful, this RA would be effective in protecting human health and the environment by limiting exposure to DNAPL-impacted soils and groundwater. Migration of the dissolved contaminant plume in groundwater would be controlled through the hydraulic containment aspect of the remedy for groundwater. This RA would meet RAOs if effective, but there are a number of uncertainties regarding the potential effectiveness of steam injection at the Site. ***Rank: Potentially Effective.***

Implementability. This steam injection RA would be moderately implementable. A significant amount of complex above- and below-ground infrastructure would be required to generate and deliver steam throughout the focused treatment area. A large number of wells (steam injection, multiphase extraction, and temperature monitoring) would be required and would generate a significant amount of waste, although this is true for several of the candidate RAs. This RA additionally includes implementation of SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment. Unlike RAs 4a and 4b, where the groundwater is re-injected into the UBA to enhance hydraulic gradients, the groundwater under this RA would require ex-situ treatment for re-injection into the BFS and Gage through the Groundwater Remedy Treatment System. Re-injection of the treated groundwater into the UBA would potentially cool the subsurface, reducing the effectiveness of the thermal remedy. The re-injection flow requirement of the DNAPL remedy would need to be considered during design of the Groundwater Remedy Treatment System. Implementation of a hot floor in the underlying BFS would additionally be required to reduce the risks associated with downward migration of DNAPL. Installation of the hot floor wells would require more sophisticated and more costly drilling methods (such as mud-rotary) in an effort to isolate the overlying DNAPL-impacted soils during drilling, although contractors offering these services are readily available. Significant care would be required to ensure that DNAPL did not migrate downward into the BFS during or as a result of hot floor well installation. This RA would require highly skilled operators and a high level of maintenance.

Steam injection is an energy-intensive remedial technology, and the amount of energy required to heat the focused treatment area would be large. The resulting carbon footprint is similarly large between approximately 51 and 106 million pounds of greenhouse gases depending on the energy demand required to achieve the thermal performance objectives.

Another factor increasing the difficulty of implementing this RA is a lack of steam vendors. Only one thermal remediation vendor, TerraTherm, continues to pursue steam injection for site remediation. Praxis Environmental is a small, independent one-person firm with insufficient resources to implement a project of this size unless partnered with a larger remediation contractor, and is pursuing other remedial technologies following their participation in the steam injection pilot test at the Williams Air Force Base. A lack of adequate commercial steam injection vendors may limit the implementability of this RA. However, at some sites, steam injection consultants have worked with a remediation contractor to implement a steam injection remedy.

Given the infrastructure requirements and need for a hot floor in the underlying BFS, steam injection over a focused treatment area of approximately 26,000 square feet is moderately implementable. ***Rank: Moderately Implementable.***

Cost. The relative cost of this focused treatment area steam injection RA is high. Approximately 40,000 cubic yards of saturated UBA soils would be thermally heated by this RA. The resulting energy requirement for this RA is high at approximately 275,000 MCF of natural gas (for the saturated UBA), even though it addresses a focused treatment area. Implementation of a hot floor in the underlying BFS (upper 10 feet) further increases the cost of this RA and would increase the thermal treatment volume by approximately 22%. Additionally, the hot floor wells are costly to install (approximately 3 times that of UBA wells drilled using standard techniques) since conductor casings are required to isolate the DNAPL-impacted UBA during drilling. Combined with SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment, the relative cost of this RA is high. ***Rank: High.***

Retain for Detailed Analysis? The steam injection component of this RA has not been field pilot tested, and the potential effectiveness of steam injection at the Site is uncertain. Steam injection may not be effective in treating the low permeability and heterogeneous saturated UBA, which can pose significant challenges for permeability-dependent technologies. As indicated in Section 2.6.6, 2-dimensional bench-scale testing suggests that between 57% and 64% of the DNAPL-phase MCB may be recovered by steam injection (AECOM, 2011k). Steam would be expected to flow preferentially along the higher permeability layers, and heating of the lower permeability layers would rely on conductive heat transfer

which is not as efficient as direct steam contact with DNAPL-impacted soils. There is also an increased potential for downward mobilization associated with steam injection due to the build-up of DNAPL at the steam front. A hot floor in the underlying BFS would be required to thermally treat DNAPL migrating down from the UBA, if any. Although the BFS is sufficiently permeable for steam injection, steam injection hot floors are very infrequently implemented and effectiveness of the hot floor to thermally treat all downward migrating DNAPL is not assured. A steam hot floor such as considered by this FS has never been attempted at another site. Although steam was injected into an underlying aquifer at the SCE Visalia Site, the purpose was to cut off a source of groundwater influx, not remediate downward migrating DNAPL. Furthermore, the creosote at the SCE Visalia Site can become an LNAPL at elevated temperatures and does not pose the same vertical migration risks as the DNAPL at the Montrose Site.

Steam injection is infrequently implemented, in comparison with other thermal technologies and is no longer being pursued as a commercial technology by some vendors. Only one technology vendor has sufficient resources to potentially implement a steam injection RA of this size, although steam consultants could work in coordination with a remediation contractor. Additionally, a higher amount of greenhouse gases would be generated by this steam injection RA (73% more) as compared with the equivalent ERH RA (RA 6a).

In spite of the disadvantages, steam injection has the potential to achieve the RAOs if effective and EPA has expressed interest in the candidacy of steam injection as a RA for the Montrose Site. Accordingly, this steam injection RA is retained for detailed evaluation as requested by EPA. ***Retain? Yes.***

5.2.7 REMEDIAL ALTERNATIVE 5B – STEAM INJECTION OVER ENTIRE DNAPL-IMPACTED AREA

This RA includes three GRAs: (1) steam injection over the entire DNAPL-impacted area, (2) SVE in the unsaturated zone, and (3) institutional controls.

Effectiveness. This RA along with RA 6B reflects the highest level of DNAPL source removal action considered in the FS. The entire DNAPL-impacted area would be thermally treated under this RA including both mobile and residual DNAPL within the source areas at the CPA and east of the CPA where the DNAPL generally thins and occurs in lower saturations. This RA (and RA 6b) has the potential to remove the most DNAPL mass, although, at a significantly higher cost, it would not reduce the mobile DNAPL mass over the focused treatment area alternatives, nor would it meaningfully reduce required timeframes for groundwater containment. Steam would be injected into approximately 61 wells to heat the saturated UBA, volatilizing MCB for removal in soil vapor and displacing liquid-phase DNAPL for recovery at extraction wells. This RA's effectiveness is similar to that of RA 5a, except that

it would additionally remove DNAPL mass from outside the focused treatment area where only 13% to 40% of the DNAPL mass is estimated to occur and is already at residual saturations (and therefore immobile in the environment). Over the large treatment area of this RA, the effectiveness of steam injection may be reduced due to non-uniform heating, formation of cold spots, and an inability to reach and maintain target temperatures.

However, as previously indicated in Section 4.6.3, if implemented, this RA would be one of the largest thermal remediation projects ever conducted in the United States. There are no comparable sites (to the Montrose Site) where steam injection has been implemented. The SCE Site in Visalia, California and the Savannah River Site in Aiken, South Carolina have been cited as being comparable to the Montrose Site. However, there are many critical differences that detract from the comparability of these sites to Montrose as described in Appendix L.

Considering the thickness of the DNAPL-impacted interval (45 feet), the highly layered nature of the saturated UBA, and the unusual nature of the Montrose DNAPL, this RA likely would be the most complicated thermal remediation ever attempted. All of these factors increase the degree of uncertainty related to the effectiveness of the RA at the Site, as described for RA 5a. The treatment area considered by this RA is approximately six times larger than the focused treatment area considered by RA 5a. Large treatment areas are subject to a higher potential for non-uniform heating and preferential steam flow, resulting in "cold spots" where the effectiveness of the thermal technology will be reduced. Large treatment areas are also subject to a higher potential for downward migration to occur through discontinuous silt layers, since a much higher number of potential discontinuities would be encountered within the larger treatment area. Steam injection within the previously residual DNAPL areas has the potential to cause MCB in the subsurface to migrate if vapors are not effectively recovered. Unrecovered MCB vapors may condense in another portion of the saturated UBA. In addition, the effectiveness of the hot floor over such a large area may be less effective, as the potential for cold spots increases.

Under RAs 5a and 5b, there is a potential for heated vapors or contaminated steam to be accidentally released to atmosphere as a fugitive emission. Contaminated steam or vapors can escape to surface through previously drilled borings or wells that are not able to withstand the elevated temperatures associated with these RAs, although an effort would be made to abandon all such borings/wells in advance of heating (over 200 borings have previously been drilled at the Montrose property). For example, at the SCE Visalia site, one well suffered a catastrophic failure due to incompatibility of the bentonite annular seal materials with the elevated temperatures of the full-scale steam remedy, although EPA indicates that the well failure did not result in the release of contaminated steam, vapors, or

sediment. Additionally, the subsurface will remain hot even if remediation system operations are interrupted. VOC vapors would continue to be generated in-situ even when the remediation system is not in operation. Long periods of system downtime, without adequate soil vapor recovery, have the potential to cause VOC migration in the unsaturated zone. Adequate engineering controls would be required in order to minimize the potential for fugitive emissions to occur during thermal remediation. The low permeability and shallow Playa Deposits will restrict vertical communication with the surface during thermal remediation although the permeability of the soils could increase if exposed to heated vapors. SVE in the high permeability Palos Verdes Sand will also help to mitigate fugitive emission risks to some extent. Fugitive emissions, if any, during remedy implementation would reduce the protectiveness of RAs 5a and 5b in the short-term.

This RA would additionally include the effectiveness offered by the components of RA 3. The VOC/DNAPL mass in the unsaturated zone would be significantly reduced by SVE, and VOC migration in soil gas would be controlled. The DDT component would be left in place but would not pose a risk to human health or the environment (DDT is not volatile and relatively insoluble in groundwater). If successful, this RA would be effective in protecting human health and the environment by limiting exposure to DNAPL-impacted soils and groundwater. Migration of the dissolved contaminant plume in groundwater would be controlled through the hydraulic containment component of the remedy for groundwater. The duration required for hydraulic containment in the saturated zone under this maximum DNAPL mass removal RA would not be significantly reduced (Section 2.6.1) and would still be required for hundreds or thousands of years. While there is some variability in the assumptions used in estimating the containment timeframes, this estimate is significant because it shows that hydraulic containment will be required for a very long duration, even following a successful thermal remediation. This RA would meet RAOs if effective, but there are a number of uncertainties regarding the potential effectiveness of steam injection at the Site. ***Rank: Potentially Effective.***

Implementability. This full-scale steam injection RA would be even more difficult to implement than RA 5a, due to the increased size of the project. A significant amount of above- and below-ground infrastructure would be required to generate and deliver steam throughout the DNAPL-impacted zone. A large number of wells, 184 remedy wells (steam injection, multiphase extraction, and temperature monitoring), would be required and would generate a significant amount of waste. This RA additionally includes implementation of SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment. The treated groundwater, approximately 200 gpm, would be transferred to the Groundwater Remedy Treatment System for re-injection into the BFS and Gage. The re-injection flow from the DNAPL remedy would need to be considered during design of the Groundwater Remedy

Treatment System. Implementation of a hot floor in the underlying BFS would additionally be required to attempt to reduce the risks associated with downward migration of DNAPL and steam condensate. This RA would require highly skilled operators and a high level of maintenance, including boiler maintenance and management of boiler brine waste. Another factor affecting the implementability of this RA is the limited number of steam vendors, as indicated for RA 5a.

The carbon footprint of this RA is very high, between approximately 189 and 412 million pounds of greenhouse gases depending on the amount of energy required to achieve the thermal performance objectives, and by far the highest considered in this FS. Mandatory greenhouse gas reporting regulations would likely be triggered by this RA including both 40 CFR Part 98 and 17 CCR §95100-95133. If this RA were to be implemented, Montrose would be required to submit annual reports, verified by a third party, containing detailed information on fuel consumption, greenhouse gas emissions, and electricity usage. Both the State and Federal reporting regulations are triggered by facilities that emit more than 25,000 metric tons of carbon dioxide per year, not including indirect emissions attributable to electricity usage. The pertinent operations associated with this RA are expected to exceed the 25,000 metric ton threshold on an annual basis, increasing the difficulty of implementing this full-scale thermal RA. ***Rank: Difficult to Implement.***

Cost. The relative cost of this large full-scale steam injection RA is very high. Implementation of steam injection over an area of 160,000 square feet and volume of 267,000 cubic yards would be one of the largest thermal remediation projects ever conducted in the United States. High well installation and waste management costs would be incurred under this RA. The energy requirement for this large thermal remediation project is also very high at approximately 1,099,000 MCF of natural gas, including a field pilot test. Implementation of a hot floor in the underlying BFS further increases the cost of this RA and would increase the thermal treatment volume by approximately 22%. Additionally, the hot floor wells, up to 77 steam injection and multiphase extraction, are costly to install since conductor casings are required to isolate the DNAPL-impacted UBA and provide the most protective method for preventing vertical cross-contamination during drilling. Combined with the infrastructure requirements associated with SVE in the unsaturated zone, ex-situ soil vapor treatment, and ex-situ groundwater treatment, the relative cost of this RA is very high.

While a small number of steam injection case sites have been implemented on a large-scale, nearly all of them were either fully or partially funded by government agencies. The SCE Visalia Site was a technology demonstration project under partnership with Lawrence Livermore National Labs, a U.S. Department of Energy organization. Pacific Wood Treating had declared bankruptcy, and the thermal

remedy at that site is being implemented by the Port of Ridgefield and State of Washington, with grants from both EPA and the U.S. Department of Housing and Urban Development. The Savannah River Site is being implemented by the U.S. Department of Energy (DOE). A full-scale steam injection RA at the Montrose Site, if implemented, may be the largest privately funded thermal remediation project and would be a significant financial burden for Montrose. The financial burden to Montrose would be far more significant, if not prohibitive, than the financial burden to the Federal Government or State agencies for the thermal remediation projects listed above. Montrose does not possess the financial resources of the government agencies funding many of the large-scale thermal remediation projects. As a result, the very high relative cost of this full-scale steam injection RA must be given serious consideration during remedy evaluation. ***Rank: Very High.***

Retain for Detailed Analysis? The scale and complexity of a full-scale steam injection RA at the Montrose Site would be unprecedented. While a handful of other large-scale thermal remediation sites have been implemented, none are similar to Montrose in terms of contaminant type and geology. Additionally, the size of the full-scale RA is significantly larger than the average size applied at other case sites. The focused treatment area as considered by RAs 5a and 6a are far more consistent with the application of thermal remediation technologies at other sites.

This full-scale steam injection RA may be the largest privately funded thermal remedy ever implemented. The financial burden to Montrose to fund a thermal remedy of this size would be prohibitive. Furthermore, the high cost of this RA may not be justified since it would not meaningfully reduce the amount of time that hydraulic containment would be required. The potential benefit of implementing a full-scale remedy in order to significantly shorten the remedy duration and eliminate the need for long-term containment would not be recognized at the Montrose Site. While there is some variability in the assumptions used to estimate containment timeframes, the estimates clearly demonstrate that even a full-scale thermal remedy would not remove sufficient DNAPL mass to meet MCLs, and thus, would not eliminate the need for long-term hydraulic containment nor significantly reduce the duration of necessary containment. Residual DNAPL (immobile in the environment) is estimated to occur over 84% of the DNAPL-impacted area but represent only 13% to 40% of the estimated DNAPL mass. Based on the above factors, there does not appear to be any significant technical merit or cost benefit in thermally remediating areas containing residual DNAPL, which does not pose a risk to the groundwater remedy at the Site.

There is only one steam injection vendor with the potential capability to implement a remedy of this scale, which limits the implementability of this RA. It is also unclear if the technology vendor would be able to

obtain a performance bond or other form of financial assurance and performance guarantee for a project of this scale.

The carbon footprint for this full-scale steam injection RA is very large at approximately 189 million pounds of greenhouse gases, and is nearly four times higher than the carbon footprint of the steam injection focused area considered in RA 5a. Like RA 5a, steam injection is dependent on permeable soils and is not as applicable to the low permeability saturated UBA. Although steam injection can heat low permeability layers conductively, it will be less efficient than direct contact between the steam and DNAPL-impacted soils. There is an increased risk of contaminant spreading by steam injection if displaced DNAPL and MCB vapors are not effectively recovered. Steam is less frequently implemented than ERH and has an increased risk of downward mobilization. For this RA, a hot floor would be required in the BFS to thermal treat DNAPL migrating down from the UBA, if any. The size of the hot floor required for this RA would be the largest ever implemented, and steam injection hot floors are very infrequently implemented (Although the permeability of the BFS can support steam injection, the potential for non-uniform heating and failure of the hot floor at the large scale increases proportionally. However, as requested by EPA and in accordance with reconciliation discussions and because this alternative has the potential to meet RAOs, this full-scale steam injection RA is retained for detailed evaluation in spite of the prohibitive costs and other factors listed above. ***Retain? Yes.***

5.2.8 REMEDIAL ALTERNATIVE 6A – ERH OVER FOCUSED TREATMENT AREA

This RA includes three GRAs: (1) ERH over a focused treatment area, (2) SVE in the unsaturated zone, and (3) institutional controls.

Effectiveness. The DNAPL mass and mobility in the saturated UBA may be reduced under this RA within a focused treatment area, consistent with the estimated extent of mobile DNAPL at the Property. ERH has the potential to reduce DNAPL mass, both residual and mobile, within the focused treatment area through MCB volatilization. The effectiveness of this RA would be similar to RA 5a, with the exception that heating of the saturated UBA within the focused treatment area is accomplished via ERH instead of steam injection. However, ERH has not been pilot tested at the Site, and its potential effectiveness at the Site is uncertain. ERH is fundamentally different from steam injection because heating is not as significantly affected by soil permeabilities, and ERH is more commonly applied at sites with lower permeability soils such as the saturated UBA. Soils are heated through electrical resistivity, and therefore, soils with high resistivity will not be heated as effectively because current will not flow between electrodes. Although the resistivity of the soils at the Site has not previously been tested, a

review of the hydrogeologic conditions at the Site (OTIE Solutions, 2010) indicates that conditions appear to be conducive for conducting electricity through soils during ERH. Variances in electrical resistivities can result in non-uniform heating, leading to desaturation between electrodes and loss of electrical current in those soils. Non-uniform heating and desaturation of soils is a common performance problem observed at other ERH sites. At those sites, the electrical resistance of the desaturated soils climbs, thereby decreasing electrical current flow and reducing the effectiveness of an ERH RA.

Water influx from the surrounding or underlying formation can cool the target treatment area increasing the duration required for heating. The groundwater flow through the UBA is primarily horizontal, and therefore, groundwater influx may result in some cooling along the upgradient boundary of the thermal treatment area. However, the horizontal gradient within the UBA is not significant, and the rate of groundwater influx may be relatively low during an ERH remedy. The vertical gradient at the Site is downward (from the UBA to the BFS), and therefore, significant cooling from the underlying BFS would not be expected. However, the depth to water in the BFS is only slightly deeper than the UBA, so some cooling from the underlying BFS may occur at the bottom of the thermal treatment zone. Water influx has been identified as one of the primary reasons for lower contaminant mass removal efficiencies at other ERH sites.

The 45-foot saturated thickness of the DNAPL-impacted UBA at the Montrose Site may pose some challenges for effective and uniform heating by ERH as discussed in Section 4.6.1. ERH was used to treat vertical thicknesses of 60 and 65 feet at the Pemaco Superfund Site and TRW/Northrop Hawthorne Site respectively. Although some non-uniform heating occurred at both sites, the temperature goals were met over the majority of the vertical thickness by the end of the treatment period.

Although heating heterogeneous soils such as the saturated UBA is less problematic for ERH, it may be problematic for recovering volatilized contaminants by SVE. The extraction system efficiency is critical for a successful ERH remedy, and VOCs that are not effectively recovered will cool and re-condense in the subsurface, reducing the effectiveness of the ERH remedy. VOCs that are not effectively recovered, or not able to migrate upward to the unsaturated zone for recovery, may also migrate laterally and outside the thermal treatment zone, which would not be consistent with DNAPL RAOs. However, ERH is implemented using a higher well density than steam injection increasing the likelihood of recovering volatilized VOCs to some degree. Additionally, ERH is less prone to downward mobilization because it relies exclusively on volatilization and does not flush DNAPL laterally. A “bottom up” heating approach has additionally been used at some sites (e.g., Young-Rainey STAR Site in Pinellas, Florida) to further reduce the potential for condensed vapors to migrate vertically downward during remedy implementation.

ERH has not been applied to a DNAPL site where either MCB or DDT was a primary component of the DNAPL. The co-boiling point for the Montrose DNAPL is 96°C, which approaches the upper limit of potential effectiveness for ERH (i.e., 100°C at atmospheric pressure). However, ERH has been used to treat soils containing VOCs with similarly high co-boiling points at the TRW/Northrop Hawthorne Site and Lowry Landfill Site, including PCE (88°C), ethylbenzene (92°C), and xylenes (95°C).

ERH was evaluated by EPA for the Del Amo Superfund Site, located near the Montrose Site, where a benzene LNAPL is smeared across the UBA in some areas between 60 and 90 feet bgs. Benzene does not pose the same downward migration risks as the Montrose DNAPL, but it has a low co-boiling point (69°C) and will volatilize at lower temperatures than the Montrose DNAPL. ERH of a benzene NAPL smeared throughout a low permeability aquitard similar to the Montrose Site was estimated to remove between 60% and 90% of the benzene as documented in the Final FS for Soil and NAPL (URS, 2010). Given the differences in chemical properties, ERH would be expected to remove a somewhat lower fraction of the DNAPL at the Montrose Site. It is noted that ERH was not field pilot tested or selected as the remedy for NAPL at the Del Amo Site (EPA, 2010c), although there are differences in site conditions, risks, and contaminant properties,

This RA would additionally include the effectiveness offered by the components of RA 3. The VOC/DNAPL mass in the unsaturated zone would be significantly reduced by SVE, and VOC migration in soil gas would be controlled. If successful, this RA would be effective in protecting human health and the environment by limiting exposure to DNAPL-impacted soils and groundwater. Migration of the dissolved contaminant plume in groundwater would be controlled through the hydraulic containment component of the remedy for groundwater. This RA would meet RAOs if effective, but there are some uncertainties regarding the potential effectiveness of ERH at the Site. ***Rank: Potentially Effective.***

Implementability. This RA would be difficult to implement. The implementability of this RA is the same as for RA 5a, with heating of the saturated UBA by ERH instead of steam injection. A relatively large number of electrodes (106) would be required to treat the focused treatment area, creating a significant amount of waste requiring management and disposal, and increasing the risk of downward DNAPL pool mobilization within the UBA prior to the start of heating. This RA would additionally require implementation of SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment. This RA would require skilled operators and a high level of maintenance. However, unlike steam injection, three qualified ERH vendors (TRS, CES, and MC2) are available to implement this RA, and ERH is more frequently implemented than steam injection (i.e., a broader range of experience). Additionally, this RA would not require the use of any steam boilers or generate boiler emissions or brine

waste. ERH is an energy-intensive remedial technology, and the amount of energy required to heat the focused treatment area (8,680 megawatt-hours) is significant. A source of electrical power is readily available to the Site as two LADWP substations are located adjacent to the JCI property (see Figure 1.7). The resulting carbon footprint for this RA would be between approximately 33 and 61 million pounds of greenhouse gases depending on the amount of energy required to achieve the thermal performance objectives, which is about 60% of the carbon footprint for steam injection over the focused area (RA5a). ***Rank: Moderately Implementable.***

Cost. The relative cost of this focused treatment ERH RA is high. The cost of this RA is comparable to RA 5a, which addresses the same focused treatment area using steam injection. The infrastructure requirements for this RA are high, similar to that of RA 5a, except that the number of ERH electrodes required (106) exceeds the number of steam injection wells. The energy requirement for this RA is high at 8,680 megawatt-hours, even though it addresses a focused treatment area. However, because ERH is less prone to downward mobilization risks and if a "bottom up" heating approach were used, a hot floor may not be necessary in the underlying BFS which would reduce the cost of this RA below that of the equivalent steam injection RA. Combined with SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment, the relative cost of this RA is high. ***Rank: High.***

Retain for Detailed Analysis? The ERH component of this RA has not been bench or field pilot tested, and therefore, the potential effectiveness of ERH at the Site is uncertain. However, although high in cost, if effective, ERH would reduce mobile DNAPL mass in the saturated UBA within a focused treatment area, which is comparable in size to those implemented at other ERH sites. ERH is potentially applicable to the geology of the saturated UBA and is not dependent on soil permeability for heating the subsurface. Because ERH does not hydraulically displace DNAPL, it decreases the likelihood of lateral spreading of contaminants outside the treatment area, unless MCB vapors are not effectively recovered by SVE and the multiphase extraction wells. ERH uses a relatively high density of wells and would offer improved lateral and vertical control over heating and contaminant recovery. ERH is not significantly prone to downward mobilization and if a "bottom up" heating approach is used, implementation of a hot floor in the underlying BFS may not be required. Three technology vendors are available to implement ERH, and ERH is the most frequently implemented thermal technology. The carbon footprint of this focused treatment ERH RA is significantly lower than the carbon footprint of full-scale ERH RA 6b and would generate approximately 77% fewer greenhouse gases.

The SVE component of this RA would reduce the mass of VOCs and DNAPL in the unsaturated zone, thereby increasing the protectiveness of the RA to groundwater and controlling VOC migration in soil

gas. The institutional controls component of the RA would protect human health by controlling the contaminant exposure pathways. The hydraulic containment component of the remedy for groundwater will prevent migration of dissolved-phase contaminants in the saturated zone and will reduce DNAPL mass in the long-term by dissolution. This focused ERH RA is retained for detailed evaluation. ***Retain? Yes.***

5.2.9 REMEDIAL ALTERNATIVE 6B – ERH OVER ENTIRE DNAPL-IMPACTED AREA

This RA includes three GRAs: (1) ERH over the entire DNAPL-impacted area, (2) SVE in the unsaturated zone, and (3) institutional controls.

Effectiveness. This RA reflects the highest level of remedial action considered in the FS and its effectiveness would be similar to RA 5b, except that heating of the entire DNAPL-impacted area would be accomplished by ERH instead of steam injection and it would present a decreased risk of downward mobilization because contaminants would not be concentrated at a steam front. The entire DNAPL-impacted area, including both mobile and residual DNAPL, would be thermally treated under this RA which includes the source areas at the CPA and east of the CPA where the DNAPL generally thins and occurs in lower saturations. This RA (and RA 5b) has the potential to remove the most DNAPL mass, although it would not reduce the mobile DNAPL mass over the focused treatment area alternatives, nor would it meaningfully reduce the amount of time required for groundwater containment. Electricity would be delivered to more than 450 electrodes to heat the saturated UBA, volatilizing the MCB component of the DNAPL for removal in soil vapor. This RA has the same effectiveness as RA 6a, except that it would additionally remove DNAPL mass from outside the focused treatment area where only 13% to 40% of the DNAPL mass is estimated to occur at residual saturations (and therefore immobile in the environment).

However, as previously indicated in Section 4.6.1 and if implemented, this RA would be the largest ERH project ever conducted in the United States. The target treatment area and volume for this RA would be 160,000 square feet and 267,000 cubic yards. By comparison, the largest ERH treatment area and volume previously implemented was reported as 91,000 square feet and 80,000 cubic yards. There are no sites comparable to the Montrose Site where ERH has been implemented. Given the thick treatment interval, highly layered UBA, and unusual nature of the Montrose DNAPL, this RA would likely be the most complicated ERH remedy ever implemented. The treatment area considered by this RA is more than six times larger than the focused treatment area considered by RA 6a. Large treatment areas are subject to a higher potential for non-uniform heating, resulting in “cold spots” where the effectiveness of the thermal

technology will be reduced. ERH within the previously residual DNAPL areas has the potential to cause migration of MCB in the subsurface if vapors are not effectively recovered. Unrecovered MCB vapors may condense in another portion of the saturated UBA. The number of ERH electrodes required would be very high (456) despite a relatively high electrode spacing of 21 feet. The very large number of wells required by this RA (a total of 729 electrodes, multiphase extraction wells, and temperature monitoring points) significantly increases the potential for downward DNAPL migration to occur as a result of drilling activities. All of these factors increase the uncertainty of the effectiveness of RA 6b at the Site.

RAs 6a and 6b present a potential for heated vapors or contaminated steam to be accidentally released to atmosphere as a fugitive emission. Contaminated steam or vapors can escape to surface through previously drilled borings or wells that are unable to withstand the elevated temperatures associated with these RAs (over 200 borings have previously been drilled at the Montrose property). The subsurface will remain hot even if remediation system operations are interrupted. VOC vapors would continue to be generated in-situ even after the remediation system is shut down. Long periods of system downtime without adequate soil vapor recovery have the potential to cause VOC migration in the unsaturated zone. The low permeability and shallow Playa Deposits will restrict vertical communication with the surface during thermal remediation although the permeability of the soils could increase if exposed to heated vapors. SVE in the high permeability Palos Verdes Sand will also help to mitigate fugitive emission risks to some extent. Fugitive emissions, if any, during remedy implementation would reduce the protectiveness of RAs 6a and 6b in the short-term.

Additionally, this RA would include the effectiveness offered by the components of RA 3. The VOC/DNAPL mass in the unsaturated zone would be significantly reduced by SVE, and VOC migration in soil gas would be controlled. If successful, this RA would be effective in protecting human health and the environment by limiting exposure to DNAPL-impacted soils and groundwater. Migration of the dissolved contaminant plume in groundwater would be controlled through the hydraulic containment component of the remedy for groundwater. Even if highly effective, this RA will not significantly reduce the required duration of hydraulic containment, which would still be required for hundreds or thousands of years as described in Section 2.6.1. This RA would meet RAOs if effective, but there are a number of uncertainties regarding the potential effectiveness of ERH at the Site. ***Rank: Potentially Effective.***

Implementability. The implementability of this RA is very similar to that of RA 5b, with heating by ERH instead of steam injection. This RA would be difficult to implement. An exceptionally large number of electrodes would be required (456) to treat the DNAPL-impacted area and would create a significant amount of waste requiring management and disposal. This RA would additionally require

implementation of SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment.

This RA would require highly skilled operators and a high level of maintenance. Unlike steam injection, three qualified ERH vendors (TRS, CES, and MC2) are available to implement this RA, and ERH is more frequently implemented today than steam injection, although not at the size of this full-scale RA. ERH is an energy-intensive remedial technology, and the amount of energy required to heat the entire DNAPL-impacted area (approximately 53,400 megawatt-hours or more) is significant. The resulting carbon footprint is estimated to be between 143 and 227 million pounds of greenhouse gases depending on the amount of energy required to achieve the thermal performance objectives and is also significant. Mandatory greenhouse gas reporting regulations would be triggered by this RA including 40 CFR Part 98 and 17 CCR §95100-95133. If this RA were to be implemented, Montrose would be required to submit annual reports, verified by a third party, containing detailed information on fuel consumption, greenhouse gas emissions, and electricity usage. Both the State and Federal reporting regulations are triggered by facilities that emit more than 25,000 metric tons of carbon dioxide per year, not including indirect emissions attributable to electricity usage. The pertinent operations associated with this RA are expected to exceed the 25,000 metric ton threshold on an annual basis, increasing the difficulty of implementing this full-scale thermal RA. ***Rank: Difficult to Implement.***

Cost. The relative cost of this large full-scale ERH RA is very high. Implementation of ERH over an area of 160,000 square feet and volume of 267,000 cubic yards would be the largest ERH project ever conducted in the United States. High well installation and waste management costs would be incurred under this RA. The infrastructure requirements for this RA are very high, similar to that of RA 5b, except that the number of ERH electrodes required (456) is higher than the number of steam injection wells under RA 5b. However, because ERH is less prone to downward mobilization risks and if a "bottom up" heating approach were used, a hot floor may not be necessary in the underlying BFS which would reduce the cost of this RA below that of the equivalent steam injection RA. The energy requirement for this RA would be exceptionally high at 53,400 megawatt-hours, including a field pilot test. Combined with SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment, the relative cost of this full-scale ERH RA is very high.

If implemented, this RA would be the largest and probably the most expensive ERH RA ever implemented in the United States and highly financially burdensome for Montrose. The financial burden to Montrose would be far more significant, if not prohibitive, than the financial burden to the Federal Government or State agencies at some other full-scale thermal remediation sites. For example, a full-

scale ERH remedy is currently being implemented at the Paducah Gaseous Diffusion Plant, a DOE site, to treat an estimated 80,000 cubic yards of DNAPL-impacted soil at an estimated cost of approximately $19.7 MM. Montrose does not possess financial resources comparable to those of the government agencies funding many of the large-scale thermal remediation projects. As a result, the very high relative cost of this full-scale ERH RA must be given serious consideration during remedy evaluation. ***Rank: Very High.***

Retain for Detailed Analysis? The scale and complexity of a full-scale ERH RA at the Montrose Site would be unprecedented. No other ERH site has ever been implemented to this size, scale, and complexity. Additionally, the size of the full-scale RA is significantly larger than the average sized ERH technology applied at other case sites (approximately 6 to 8 times larger). The focused treatment area as considered by RAs 5a and 6a are far more consistent with the application of thermal remediation technologies at other sites.

This full-scale ERH RA, if implemented, would be the largest privately funded thermal remedy ever implemented. T he financial burden to Montrose to fund a thermal remedy of this size would be prohibitive. Furthermore, the high cost of this RA may not be justified since the amount of time required for long-term hydraulic containment would not be meaningfully reduced and containment would remain necessary for hundreds or thousands of years. While there is some variability in the assumptions used to estimate containment timeframes, the estimates clearly demonstrate that even a full-scale thermal remedy will not remove sufficient DNAPL to eliminate the need for long-term hydraulic containment. Based on the above factors, there does not appear to be any significant technical merit or cost benefit in thermally remediating areas containing residual DNAPL which is immobile in the environment and does not pose a risk to the groundwater remedy at the Site.

The carbon footprint for this full-scale RA is very large (approximately 143 million pounds of greenhouse gases and is more than four times higher than the carbon footprint of the ERH focused treatment area considered in RA 6a. The number of electrodes, multiphase extraction wells, and temperature monitoring points required by a full-scale ERH RA would be significant (729 total locations) and greatly increase the risk of vertical DNAPL mobilization during or as a result of drilling in spite of using protective methods. Additionally, the amount of waste generated by the large number of wells would be significant. It is also unknown if any of the three ERH vendors would have sufficient financial assurance to obtain a performance bond or other type of financial assurance or performance guarantee. However, at the request of EPA and because this alternative has the potential to meet RAOs, this full-scale ERH RA is retained for detailed evaluation in spite of the prohibitive costs and other factors listed above. ***Retain? Yes.***

5.3 SUMMARY OF ALTERNATIVES RETAINED FOR DETAILED EVALUATION

All nine of the RAs screened in Section 5.2 were retained for detailed evaluation. Six of the RAs retained for evaluation (RAs 4a through 6b) are more effective in accelerating DNAPL mass and mobility reduction in the saturated UBA. The No Action RA is retained in compliance with NCP guidelines. A summary of the intermediate screening evaluation is provided in **Table 5.2**, and the RAs retained for detailed evaluation are listed below:

RAs Retained for Detailed Evaluation

Remedial Alternative	**GRA Remedial Technologies/Process Options**
Remedial Alternative 1	No Action
Remedial Alternative 2	Institutional Controls
Remedial Alternative 3	Institutional Controls SVE (unsaturated zone)
Remedial Alternative 4a	Institutional Controls SVE (unsaturated zone) Hydraulic Displacement, with untreated water injection
Remedial Alternative 4b	Institutional Controls SVE (unsaturated zone) Hydraulic Displacement, with treated water injection
Remedial Alternative 5a	Institutional Controls SVE (unsaturated zone) Steam Injection, focused treatment area, with hot floor
Remedial Alternative 5b	Institutional Controls SVE (unsaturated zone) Steam Injection, entire treatment area, with hot floor
Remedial Alternative 6a	Institutional Controls SVE (unsaturated zone) ERH, focused treatment area, without hot floor
Remedial Alternative 6b	Institutional Controls SVE (unsaturated zone) ERH, entire treatment area, without hot floor

A detailed analysis of these remaining alternatives is provided in Section 6.

TABLES

Table 5.1
Carbon Footprint Analysis
DNAPL Remedial Alternatives
Montrose Superfund Site

Remedial Alternative		Electricity Usage (MW-hrs)	CO_2 Emissions from Electricity Usage (lbs)	Natural Gas Usage (MCF)	CO_2 Emissions from Natural Gas Usage (lbs)	Total CO_2 Emissions (lbs)
RA 1	No Action	0	0	0	0	0
RA 2	ICs	NA	NA	NA	NA	NA
RA 3	SVE, ICs	4,748	5,830,339	0	0	5,830,339
RA 4a	HD without water treatment , SVE, ICs	9,118	11,196,461	0	0	11,196,461
RA 4b	HD with water treatment , SVE, ICs	21,242	26,084,835	0	0	26,084,835
RA 5a	Steam Injection over Focused Treatment Area (2.5 UBA PVs), SVE, ICs	14,279	17,534,581	282,126	33,900,841	51,435,421
	Steam Injection over Focused Treatment Area (6 UBA PVs), SVE, ICs	23,774	29,194,350	636,756	76,513,900	105,708,249
RA 5b	Steam Injection over Entire DNAPL-Impacted Area (2.5 UBA PVs) , SVE, ICs	45,047	55,317,826	1,109,219	133,285,936	188,603,761
	Steam Injection over Entire DNAPL-Impacted Area (6 UBA PVs), SVE, ICs	85,640	105,165,546	2,554,542	306,958,846	412,124,391
RA 6a	ERH over Focused Treatment Area (200 kW-hrs/cubic yard), SVE, ICs	25,749	31,619,215	12,786	1,536,425	33,155,640
	ERH over Focused Treatment Area (400 kW-hrs/cubic yard), SVE, ICs	46,924	57,623,244	25,572	3,072,843	60,696,086
RA 6b	ERH over Entire DNAPL-Impacted Area (200 kW-hrs/cubic yard), SVE, ICs	112,947	138,699,011	39,006	4,687,002	143,386,012
	ERH over Entire DNAPL-Impacted Area (400 kW-hrs/cubic yard), SVE, ICs	177,147	217,536,620	78,011	9,374,002	226,910,622

Notes:
CO_2 = Carbon dioxide
DNAPL = Dense non-aqueous phase liquid
ERH = Electrical resistance heating
HD = Hydraulic displacement
ICs = Institutional controls
kW-hrs = Kilowatt-hours
lbs = pounds
MCF = Thousand cubic feet
MW-hrs = Megawatt-hours
NA = Not Applicable
RA = Remedial alternative
SVE = Soil vapor extraction
UBA PVs = Upper Bellflower Aquitard pore volumes

Table 5.2
Intermediate Screening of DNAPL Remedial Alternatives
Montrose Superfund Site

Remedial Alternative	Remedial Technology Components	Technical Effectiveness	Implementability	Relative Cost	Retain for Detailed Evaluation? (Yes/No)
RA 1	• No Action	• Not effective • Does not reduce DNAPL mass in the unsaturated or saturated zones • No institutional controls to limit potential for exposure to DNAPL	• Highly implementable	• None	Yes
RA 2	• Institutional Controls	• Minimally effective • ICs will protect human health by controlling contaminant exposure pathways; land use/activities and Site access would be restricted • Does not reduce DNAPL mass in the unsaturated or saturated zones	• Highly implementable • ICs will be required as component of soil and groundwater remedies • Nearly all DNAPL occurs at Montrose Property where land use/activities can be restricted; deed restriction at adjacent GLJ Holdings property, if necessary, would require consent of land owner	• Low	Yes
RA 3	• SVE, Unsaturated Zone • Institutional Controls	• Moderately effective • SVE will reduce mass of VOCs/DNAPL in the unsaturated zone, increase protectiveness of groundwater, and control VOC migration in soil gas • SVE was field pilot tested at Site and removed VOCs at an elevated rate from PVS and unsaturated UBA • SVE in low permeability PD soils was significantly less effective • ICs will protect human health by controlling contaminant exposure pathways • Does not reduce mobile DNAPL mass in the saturated zone to the extent practicable; does not reduce the potential for uncontrolled migration or recontamination of the aquifers	• Highly implementable • SVE is widely implemented; does not require highly skilled operators and large number of contractors are available to implement • Ex-situ vapor treatment required in compliance with air emission ARARs • ICs will be required as component of soil and groundwater remedies • Smallest carbon footprint (6 million pounds of GHGs)	• Low to Medium	Yes

TABLE 5.2 (continued)
Intermediate Screening of DNAPL Remedial Alternatives

Remedial Alternative	Remedial Technology Components	Technical Effectiveness	Implementability	Relative Cost	Retain for Detailed Evaluation? (Yes/No)
RA 4a	• Hydraulic Displacement, untreated groundwater injection • SVE, Unsaturated Zone • Institutional Controls	• Effective • HD will reduce DNAPL mass and significantly reduce DNAPL mobility; residual DNAPL is immobile in the environment (other than as source for dissolved-phase contaminants) • Highest saturations are most mobile; HD depletes saturations making DNAPL less and less mobile • Re-injection of untreated groundwater effective for hydraulic displacement of mobile DNAPL • HD modeling indicates that well spacings under 120 feet will effectively mobilize DNAPL to recovery wells; no downward migration below basal silty sand layer predicted by model assuming basal layer is continuous and depending on the pore entry pressure • HD was field pilot tested at Site and removed DNAPL at a moderate rate • SVE will reduce mass of VOCs/DNAPL in the unsaturated zone, increase protectiveness of groundwater, and control VOC migration in soil gas • ICs will protect human health by controlling contaminant exposure pathways	• Difficult to implement • Waiver of re-injection standards is required by EPA and the State • Standard drilling methods can be used to install wells • No specialized equipment or highly skilled operators required • DNAPL is readily separated from groundwater • Moderate to high level of maintenance required to abate precipitate fouling • Re-injection into UBA was successfully pilot tested • SVE with ex-situ vapor treatment required; must meet air emission ARARs • ICs will be required as component of soil and groundwater remedies • Relatively small carbon footprint (11 million pounds of GHGs)	• Medium	Yes
RA 4b	• Hydraulic Displacement, treated groundwater injection • SVE, Unsaturated Zone • Institutional Controls	• Effective • Same technical effectiveness as RA 4a; treatment of the dissolved VOCs in groundwater does not increase the technical effectiveness	• Moderately implementable • Treatment of groundwater prior to injection eliminates need to waive re-injection standards • High VOC mass loading would require robust treatment train composed of LGAC/HiPOx • Both water treatment technologies have been tested and are implementable • Increased level of maintenance and complexity due to water treatment system • Carbon footprint increases to 26 million pounds of GHGs	• High	Yes

TABLE 5.2 (continued)
Intermediate Screening of DNAPL Remedial Alternatives

Remedial Alternative	Remedial Technology Components	Technical Effectiveness	Implementability	Relative Cost	Retain for Detailed Evaluation? (Yes/No)
RA 5a	• Steam Injection with Hot Floor, Focused Treatment Area • SVE, Unsaturated Zone • Institutional Controls	• Potentially effective • Steam injection may reduce DNAPL mass within a focused treatment area containing mobile DNAPL; 60% to 87% of the mass is located within 16% of the DNAPL-impacted area • Steam injection has not been field pilot tested at Site • Was bench-tested; 57% to 63% of the MCB mass was removed after 3.4 to 5.2 pore volumes of steam flushing; substantial redistribution observed using thin and discontinuous capillary barrier • Steam injection is dependent on soil permeability; steam will preferentially flow through high permeability soil layers; not well-suited to low permeability and heterogeneous UBA; was not assembled into formal RA at nearby Del Amo Site for this reason • Has never been applied to DNAPL composed of primarily MCB or DDT • Will mobilize and concentrate DNAPL at steam front; increased potential for lateral spreading and downward migration • Hot floor in underlying BFS would be required but effectiveness is not assured and has not been demonstrated at a comparable site • SVE will reduce mass of VOCs/DNAPL in the unsaturated zone, increase protectiveness of groundwater, and control VOC migration in soil gas • ICs will protect human health by controlling contaminant exposure pathways	• Moderately implementable • Large amount of infrastructure required • SVE and ex-situ vapor treatment required; must meet air emission ARARs • Ex-situ groundwater treatment required with re-injection into BFS and Gage via Groundwater Remedy Treatment System; groundwater RD will need to account for increased re-injection flow • Requires skilled field operators • High level of maintenance required including boiler maintenance, water conditioning, and brine disposal • High energy requirement; large carbon footprint (51 to 106 million pounds of GHGs • Limited steam vendors; license holder may need to work with remediation contractor • Less frequently implemented as compared with other thermal remediation technologies • ICs will be required as part of soil and groundwater remedies	• High	Yes

TABLE 5.2 (continued)
Intermediate Screening of DNAPL Remedial Alternatives

Remedial Alternative	Remedial Technology Components	Technical Effectiveness	Implementability	Relative Cost	Retain for Detailed Evaluation? (Yes/No)
RA 5b	• Steam Injection with Hot Floor, Entire DNAPL-Impacted Area • SVE, Unsaturated Zone • Institutional Controls	• Potentially effective • Highest level of remedial action considered in FS • Includes treatment outside of focused area, where 13% to 40% of the DNAPL mass is located over 84% of the target area; treatment area is 6x larger than focused treatment area • Will not reduce DNAPL mobility over RA 5a • Would be one of the largest steam injection projects ever implemented and likely the most complex • Greater potential for non-uniform heating, formation of "cold spots", and downward migration • Residual DNAPL, which was previously immobile, has the potential to be mobilized and may not be effectively recovered over large treatment area • Hot floor in underlying BFS would be required but effectiveness over large treatment area is not assured and unprecedented • Steam injection has not been field pilot tested at Site • Steam injection is dependent on soil permeability; steam will preferentially flow through high permeability soil layers; not well-suited to low permeability and heterogeneous UBA; was not assembled into formal RA at nearby Del Amo Site for this reason • Will mobilize and concentrate DNAPL at steam front; increased potential for lateral spreading and downward migration • SVE will reduce mass of VOCs/DNAPL in the unsaturated zone, increase protectiveness of groundwater, and control VOC migration in soil gas • ICs will protect human health by controlling contaminant exposure pathways • Required duration of hydraulic containment not significantly reduced by highest cost full-scale RA; no cost-benefit	• Difficult to implement • Large number of wells, up to 184, would be required and would generate a significant amount of waste • Large amount of infrastructure required • SVE and ex-situ vapor treatment required; must meet air emission ARARs • Ex-situ groundwater treatment (200 gpm) required with re-injection into BFS and Gage via Groundwater Remedy Treatment System; groundwater RD will need to account for increased re-injection flow • Requires skilled field operators • High level of maintenance required including boiler maintenance, water conditioning, and brine disposal • Very high energy requirement; largest carbon footprint of all RAs (189 to 412 million pounds of GHGs) • Limited steam vendors; license holder may need to work with remediation contractor • Less frequently implemented as compared with other thermal remediation technologies	• Very High • Would be largest privately-funded thermal remedy ever implemented; prohibitive financial burden to Montrose	Yes

TABLE 5.2 (continued)
Intermediate Screening of DNAPL Remedial Alternatives

Remedial Alternative	Remedial Technology Components	Technical Effectiveness	Implementability	Relative Cost	Retain for Detailed Evaluation? (Yes/No)
RA 6a	• ERH without Hot Floor, Focused Treatment Area • SVE, Unsaturated Zone • Institutional Controls	• Potentially effective • ERH may reduce DNAPL mass within a focused treatment area containing mobile DNAPL; 60% to 87% of the mass is located within 16% of the DNAPL-impacted area • Has not been bench or field pilot tested at Site • More applicable to low permeability UBA than steam injection • Water influx will cool treatment area extending duration of remedy • 45-foot thickness may pose some technical challenges for uniform heating • Relies exclusively on contaminant volatilization (no displacement mechanism); higher well density than steam injection reduces potential for contaminant spreading; although unrecovered vapors may re-condense in another area of the UBA • No steam front; reduced potential for downward mobilization as compared with steam injection • Bottom up heating approach eliminates need for hot floor • 96°C co-boiling point for Montrose DNAPL is one of highest • ERH identified as a candidate at Del Amo Site for LNAPL; benzene co-boiling and boiling points are 69°C and 80°C • SVE will reduce mass of VOCs/DNAPL in the unsaturated zone, increase protectiveness of groundwater, and control VOC migration in soil gas • ICs will protect human health by controlling contaminant exposure pathways	• Moderately implementable • Large amount of infrastructure required • Would require installation of 102 electrode locations and management of waste • Three qualified vendors are available to implement ERH • ERH is more frequently implemented than steam injection • High energy RA; carbon footprint is large (33 to 61 million pounds of GHGs; lower than steam injection RA 5a • Source of electrical power (two LADWP substations) located adjacent to site • SVE and ex-situ vapor treatment required; must meet air emissions ARARs • Ex-situ groundwater treatment required with re-injection into BFS and Gage via Groundwater Remedy Treatment System; groundwater RD will need to account for increased re-injection flow • Requires skilled field operators • Does not require steam boilers or brine waste disposal • High level of maintenance required • ICs will be required as part of soil and groundwater remedies	• High	Yes

TABLE 5.2 (continued)
Intermediate Screening of DNAPL Remedial Alternatives

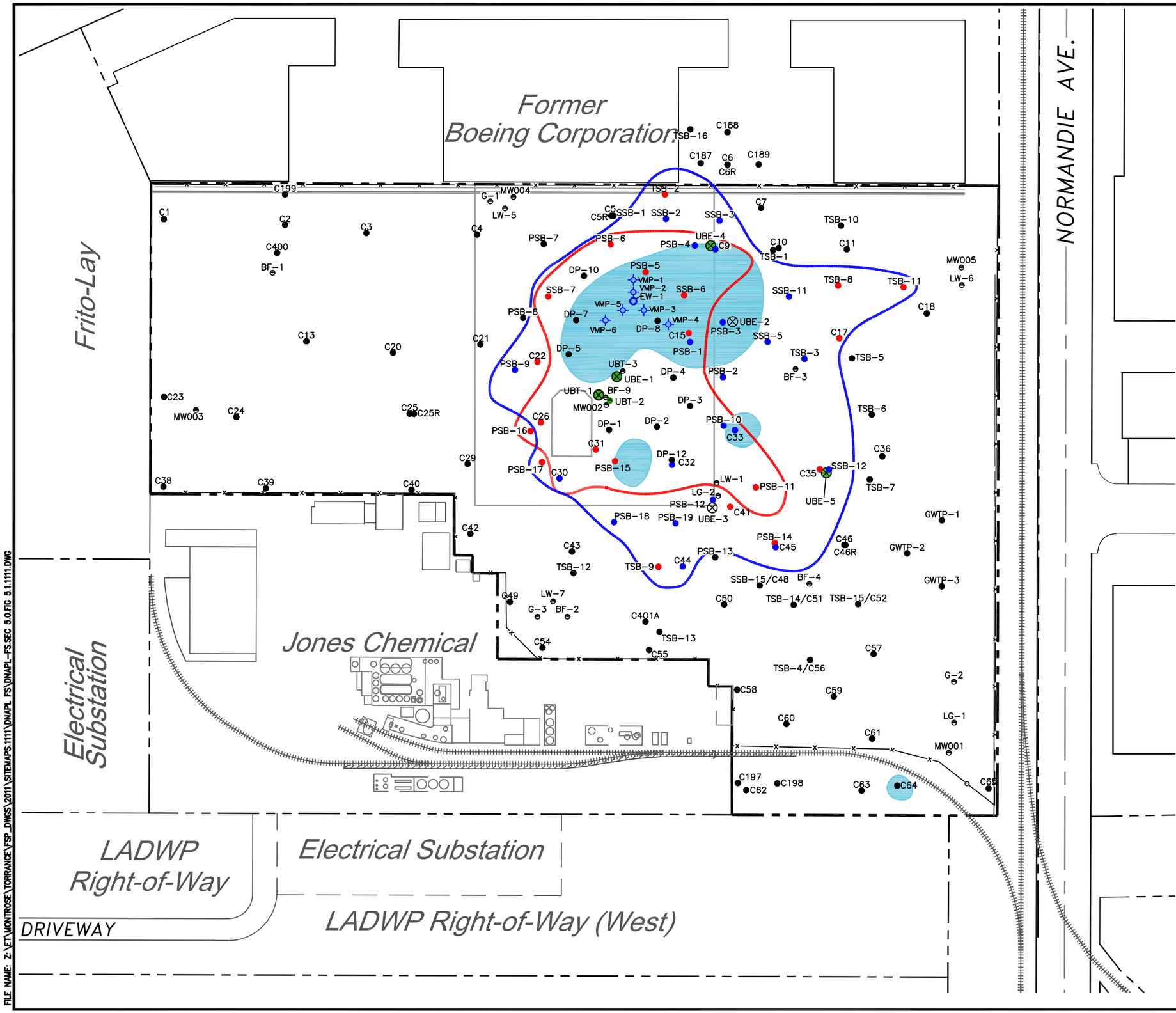
Remedial Alternative	Remedial Technology Components	Technical Effectiveness	Implementability	Relative Cost	Retain for Detailed Evaluation? (Yes/No)
RA 6b	• ERH without Hot Floor, Entire DNAPL-Impacted Area • SVE, Unsaturated Zone • Institutional Controls	• Potentially effective • Highest level of remedial action considered in FS • Includes treatment outside of focused area, where 13% to 40% of the DNAPL mass is located over 84% of the target area; treatment area is 6x larger than focused treatment area • Will not reduce DNAPL mobility over RAs 5a or 6a • Would be the largest ERH project ever implemented and likely the most complex; there are no comparable sites • Greater potential for non-uniform heating; • Residual DNAPL, which was previously immobile, has the potential to be mobilized and may not be effectively recovered over large treatment area • Water influx will cool treatment area extending duration of remedy • 45-foot thickness may pose some technical challenges for uniform heating • Increased potential for downward migration to occur as a result of drilling large number of electrodes, wells, and monitoring points (729) • Relies exclusively on contaminant volatilization (no displacement mechanism); higher well density than steam injection reduces potential for contaminant spreading; although unrecovered vapors may re-condense in another area of the UBA • Bottom up heating approach eliminates need for hot floor • 96°C co-boiling point for Montrose DNAPL is one of highest • ERH identified as a candidate at Del Amo Site for LNAPL; benzene co-boiling and boiling points are 69°C and 80°C • SVE will reduce mass of VOCs/DNAPL in the unsaturated zone, increase protectiveness of groundwater, and control VOC migration in soil gas • ICs will protect human health by controlling contaminant exposure pathways • Required duration of hydraulic containment not significantly reduced by highest cost full-scale RA; no cost-benefit	• Difficult to implement • Large amount of infrastructure required • Would require a significant number of electrodes, multiphase extraction wells, and temperature monitoring points (729), generating a significant amount of waste • Three qualified vendors are available to implement ERH • ERH is more frequently implemented than steam injection • Exceptionally high energy RA; carbon footprint is very large (143 to 227 million pounds of GHGs) • SVE and ex-situ vapor treatment required; must meet air emission ARARs • Ex-situ groundwater treatment required with re-injection into BFS and Gage via Groundwater Remedy Treatment System; groundwater RD will need to account for increased re-injection flow • Requires skilled field operators • High level of maintenance required • ICs will be required as part of soil and groundwater remedies	• Very High • Would be largest privately-funded thermal remedy ever implemented; prohibitive financial burden to Montrose	Yes

TABLE 5.2 (continued)
Intermediate Screening of DNAPL Remedial Alternatives

Notes:

RA = Remedial alternative
ICs = Institutional controls
HD = Hydraulic displacement
DNAPL = Dense Non-Aqueous Phase Liquid
DDT = Dichlorodiphenyltrichloroethane
MCB = Monochlorobenzene
UBA = Upper Bellflower Aquitard
BFS = Bellflower Sand
SVE = Soil vapor extraction
VOCs = Volatile organic compounds
ERH = Electrical resistance heating
ROD = Record of Decision
RD = Remedial design
ARARs = Appropriate Relevant and Applicable Requirements
°C = Degrees Centrigrade
TBCs = Criteria *To Be Considered* in this DNAPL FS

FIGURES



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Existing Site Features
- LADWP — Los Angeles Department of Water and Power
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- EW-1 — SVE Pilot Test Extraction Well Location; Sand Not Encountered between 0–25' bgs
- VMP-5 — SVE Pilot Test Monitoring Point Location; Sand Not Encountered between 0–25' bgs
- PSB-5 — Soil Boring Location Shown in Red; Sand Encountered between 0–25' bgs
- SSB-5 — Soil Boring Location Shown in Blue; Sand Not Encountered between 0–25' bgs
- SSB-15 — Soil Boring Location Shown in Black is Outside DNAPL Impacted Area or the Geological Description Not Available
- Definite DNAPL Extent in Unsaturated Zone
- Entire Possible DNAPL Impacted Area
- MCB >530 mg/kg in Playa Deposits

Notes:

1. Historic remedial investigation soil borings were excluded and soil boring locations drilled less than 25 feet in the DNAPL impacted area were excluded.
2. Not all historical building locations are shown.

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online GIS data set, ©2009. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin & Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Georeferenced Satellite Image from U.S. Geological Survey, July 31, 2007. Google Earth Pro ©2009.
3. Source: Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, California, Revision 1.0. (H+A, 2004); Technical Memorandum to Susan Keydel, US EPA, DNAPL Reconnaissance Borings in Support of Earth Tech Soil Sampling Program, Montrose Site, Torrance, California (H+A, 2006); Geotechnical and Chemical Evaluation, Groundwater Treatment Plant Site Soils, Montrose Superfund Site (Earth Tech, 2008).

NORTH

0 60 120 FEET

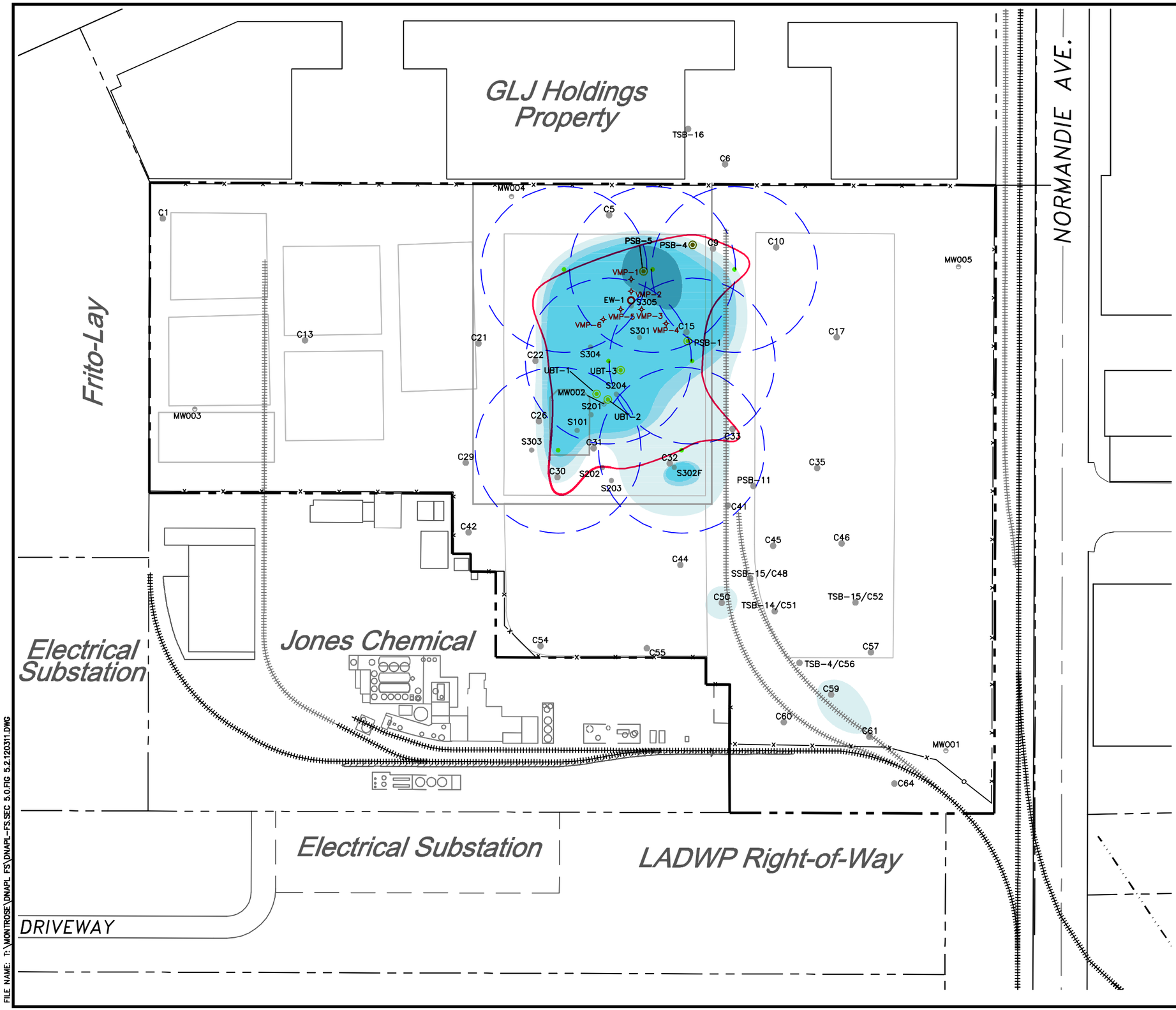
SCALE: 1"= 120'

Montrose Chemical Corporation

Silty Sands in the Playa Deposits Boring Location Map

Date: 11-11	Montrose Superfund Site	Figure 5.1
Project No. 60150255	AECOM	

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2011\SITEMAPS.1111\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.1.1111.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- Soil Boring Location
- Monitoring Well Location
- Maximum MCB Isoconcentration in Soil Contour Interval 10–100 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 100–1000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 1000–10,000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval >10,000 mg/kg
- DNAPL Present
- DNAPL Present in Vadose Zone Boring Location
- SVE Pilot Test Well Location
- Pilot Test Monitoring Point Location
- Radius of Influence (103 Ft.) Palos Verdes Sands (Number of Wells = 7)

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b

NORTH

0 60 120 FEET

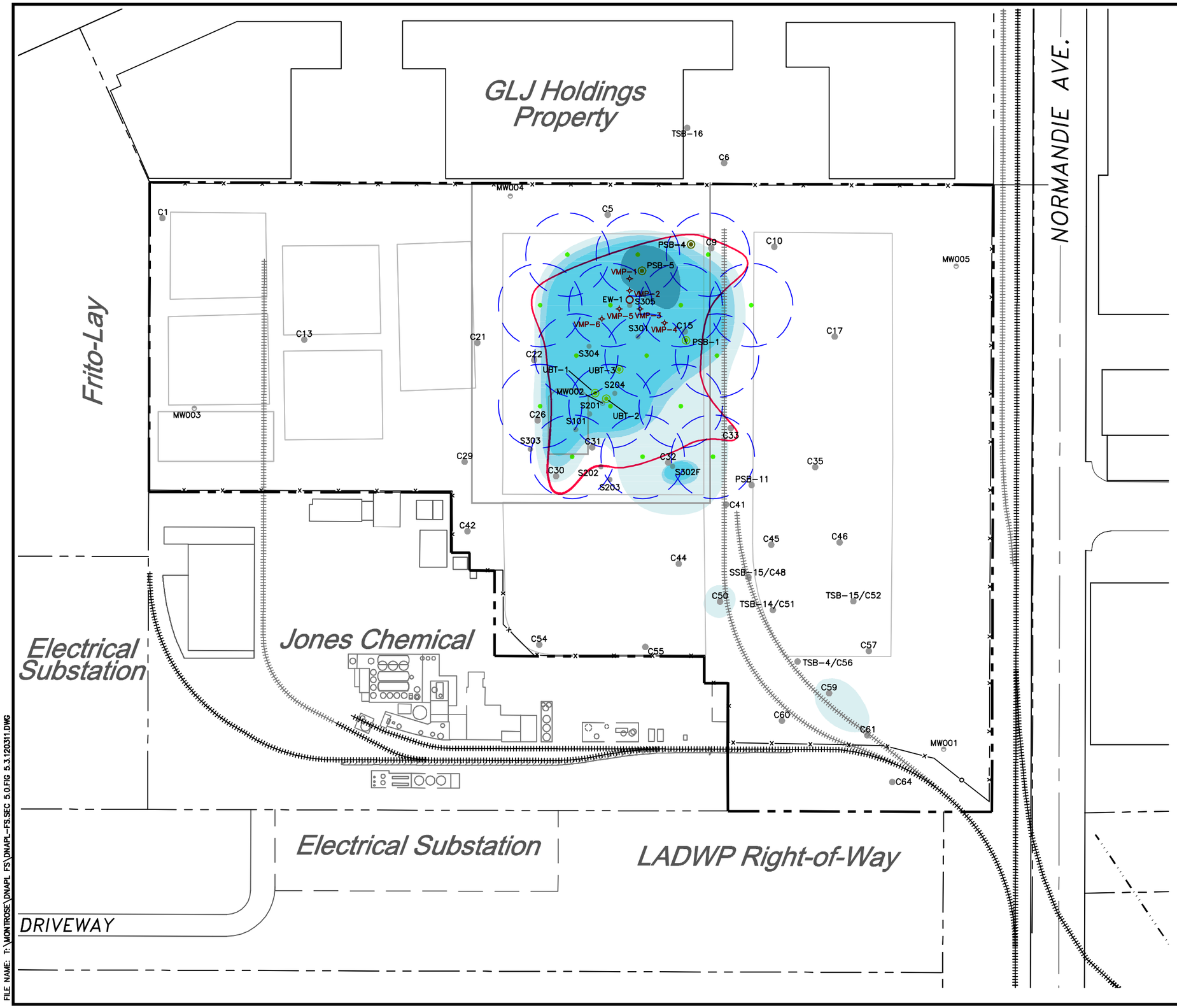
SCALE: 1"= 120'

Montrose Chemical Corporation

Conceptual SVE Wells
Palos Verdes Sands,
Radius of Influence 103 Feet

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.2

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.2.120311.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- Soil Boring Location
- Monitoring Well Location
- Maximum MCB Isoconcentration in Soil Contour Interval 10–100 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 100–1000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval 1000–10,000 mg/kg
- Maximum MCB Isoconcentration in Soil Contour Interval >10,000 mg/kg
- DNAPL Present
- DNAPL Present in Vadose Zone Boring Location
- SVE Pilot Test Well Location
- Pilot Test Monitoring Point Location
- Radius of Influence (52 Ft.) Unsaturated Upper Bellflower Aquitard and Playa Deposits (Number of Wells = 16)

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: AECOM, 2011; Earth Tech, 2008j; Earth Tech, 2007b; Earth Tech, 2008g; Earth Tech, 2004a; EPA, 1998; H+A, 2004b; H+A, 2006a; H+A, 2008b

NORTH

0 60 120 FEET

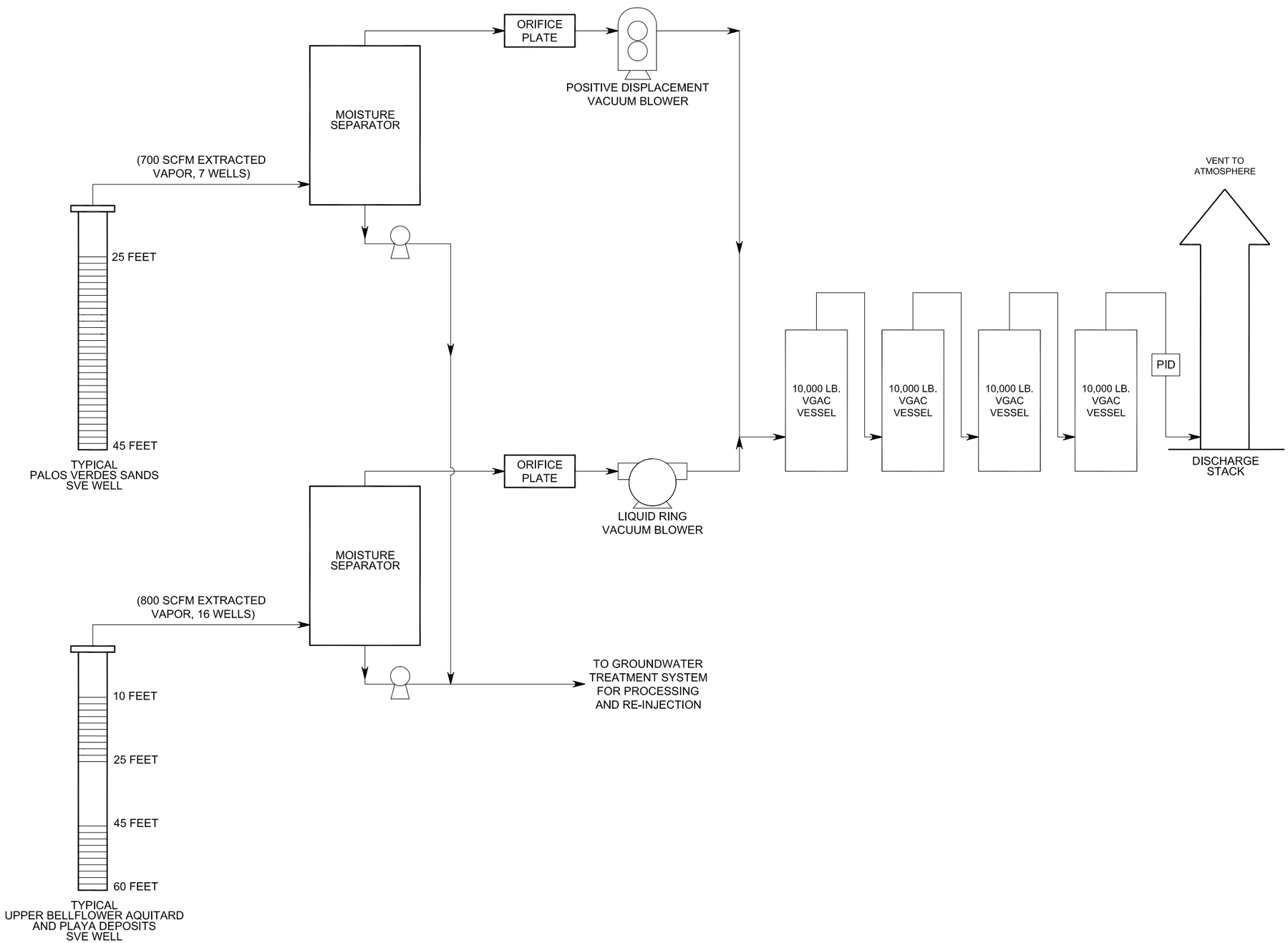
SCALE: 1"= 120'

Montrose Chemical Corporation

Conceptual SVE Wells
Upper Bellflower Aquitard and Playa Deposits,
Radius of Influence 52 Feet

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.3

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.3.120311.DWG



Legend:

PID	PHOTOIONIZATION DETECTOR
	TRANSFER PUMP

Notes:

SCFM	STANDARD CUBIC FEET PER MINUTE
VGAC	VAPOR–PHASE GRANULAR ACTIVATED CARBON

PLAYA DEPOSITS SCREENED WHERE SILTY SANDS ARE PRESENT

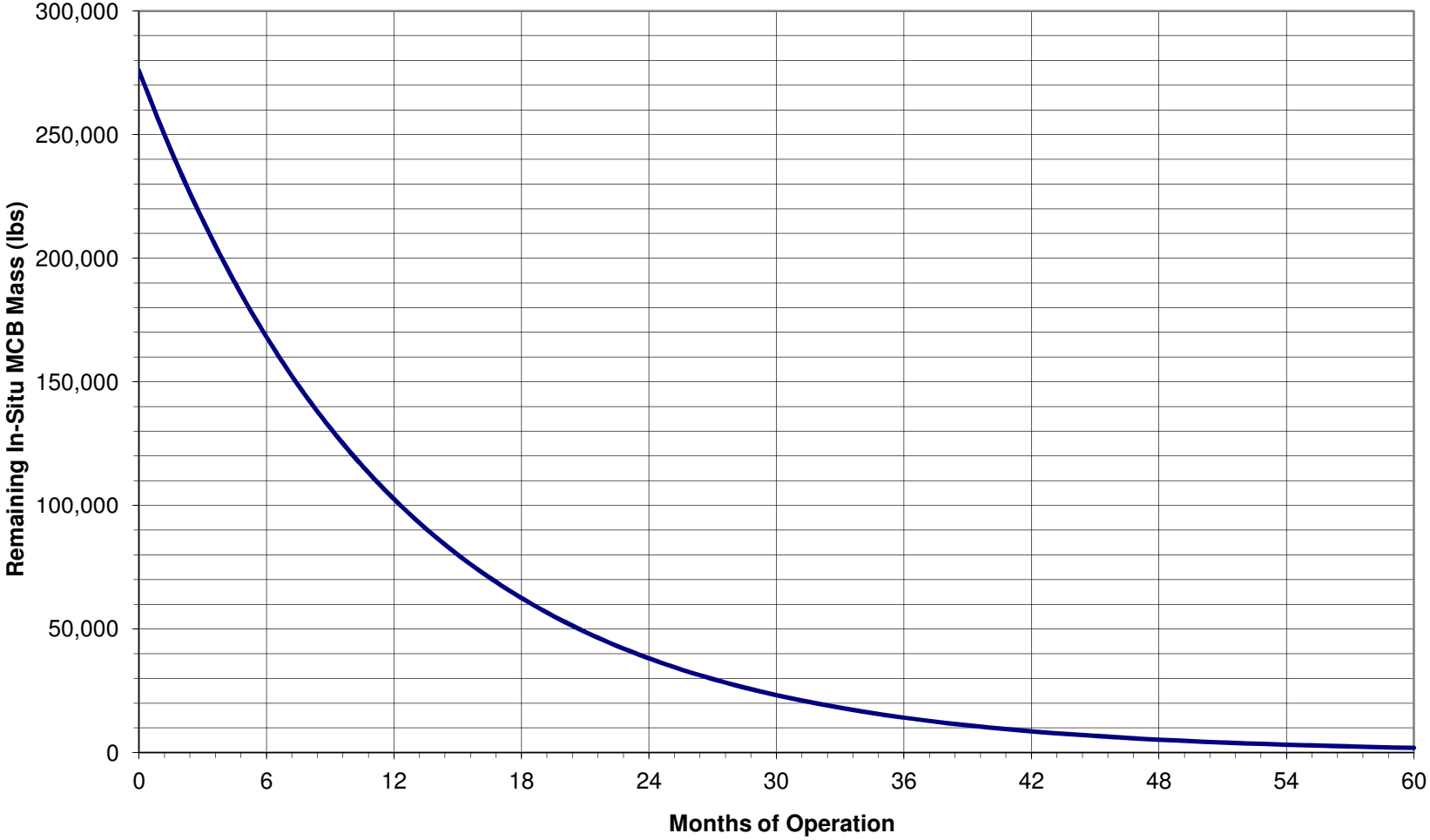
Montrose Chemical Corporation

Conceptual Soil Vapor Extraction Process Flow Diagram

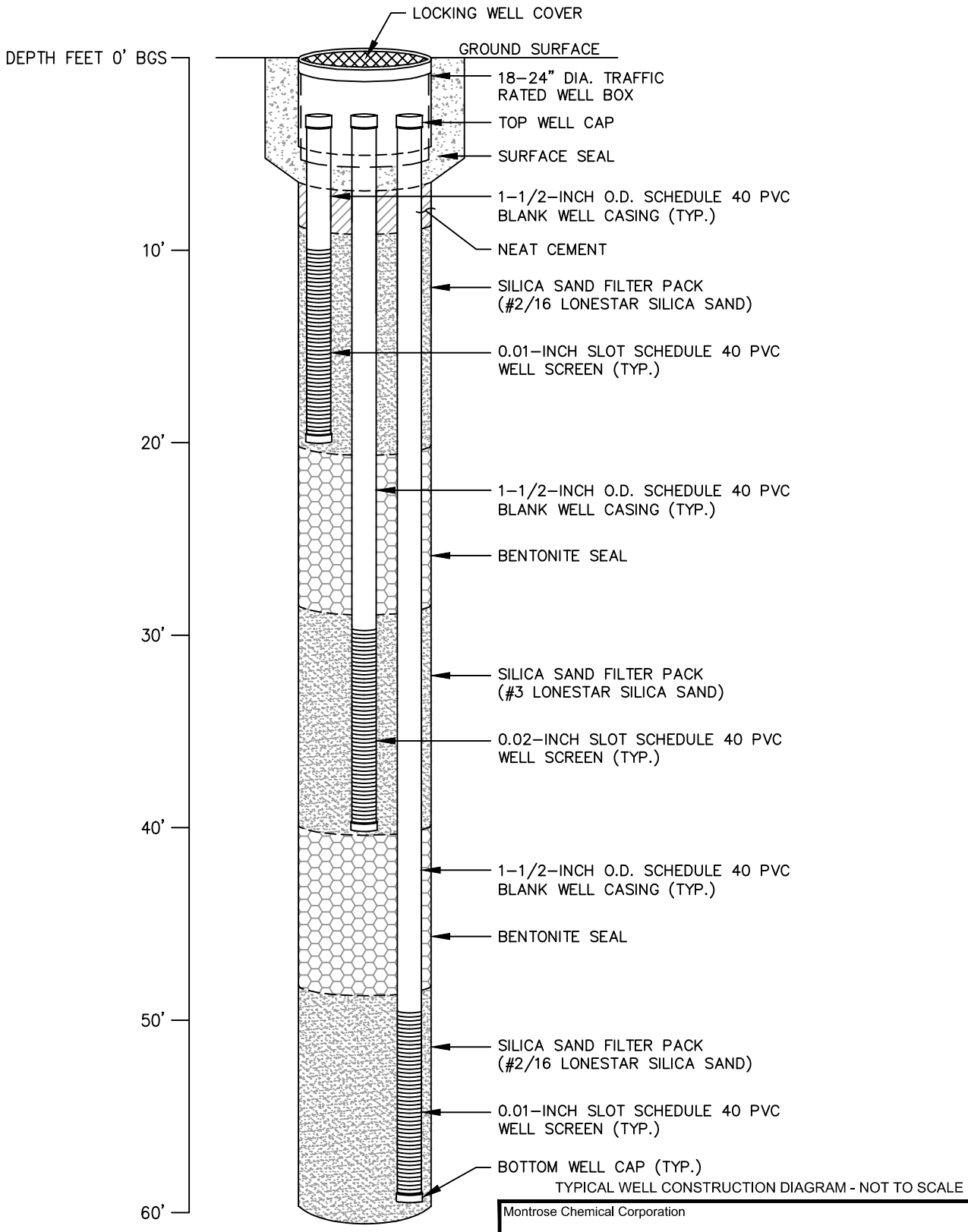
Date: 12-11	Montrose Superfund Site	Figure 5.4
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL–FS.SEC 5.0.FIG 5.4.120311.DWG

Figure 5.5
Example MCB Mass Decline Curve
Implementation of SVE in Unsaturated Zone (25-60 feet bgs)
Montrose Superfund Site



Note: Data was generated using a first order decay



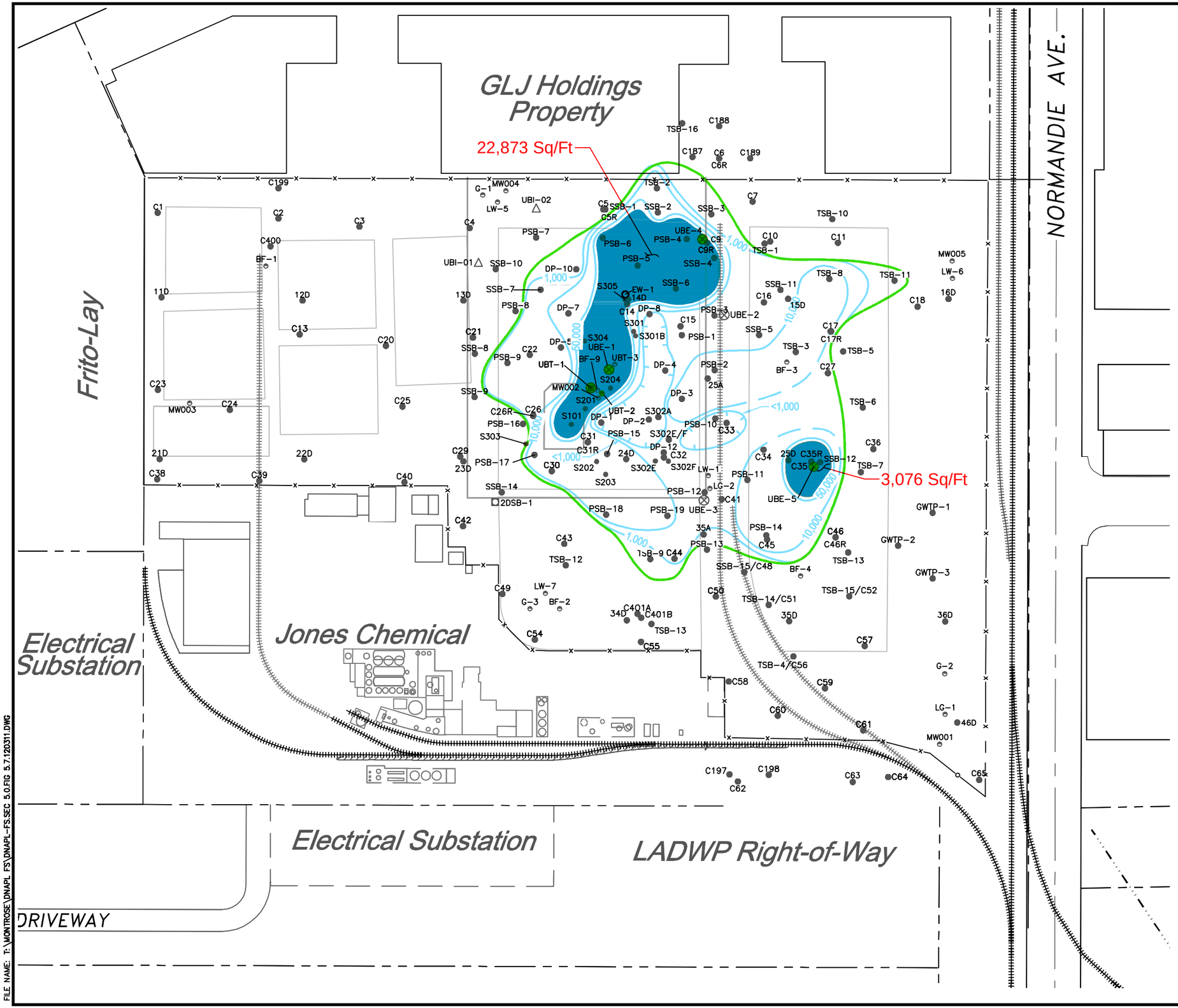
TYPICAL WELL CONSTRUCTION DIAGRAM - NOT TO SCALE

Montrose Chemical Corporation

Construction Diagram
Soil Vapor Monitoring Point

Date: 06-13	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.6

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2013\SITEMAPS.0613\DNAPL FS\SECT 5.0\DNAPL-FS.SEC 5.0.FIG 5.6.0613.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- EW-1 — SVE Well Location
- UBI-01 — Injection Well Location
- 2DSB-1 — 2-Dimensional Bench Scale Test Soil Boring, Saturated Upper Bellflower Aquitard
- Entire DNAPL Impacted Area
- 1,000 — DNAPL Isoconcentration in mg/kg (MCB + Total DDT)
- 10,000 — DNAPL Isoconcentration in mg/kg (MCB + Total DDT)
- 50,000 — DNAPL Isoconcentration in mg/kg (MCB + Total DDT)
- Estimated Extent of Mobile DNAPL Contiguous Area >53,000 mg/kg Total Area: 25,949 Sq. Ft.

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b

NORTH

0 60 120 FEET

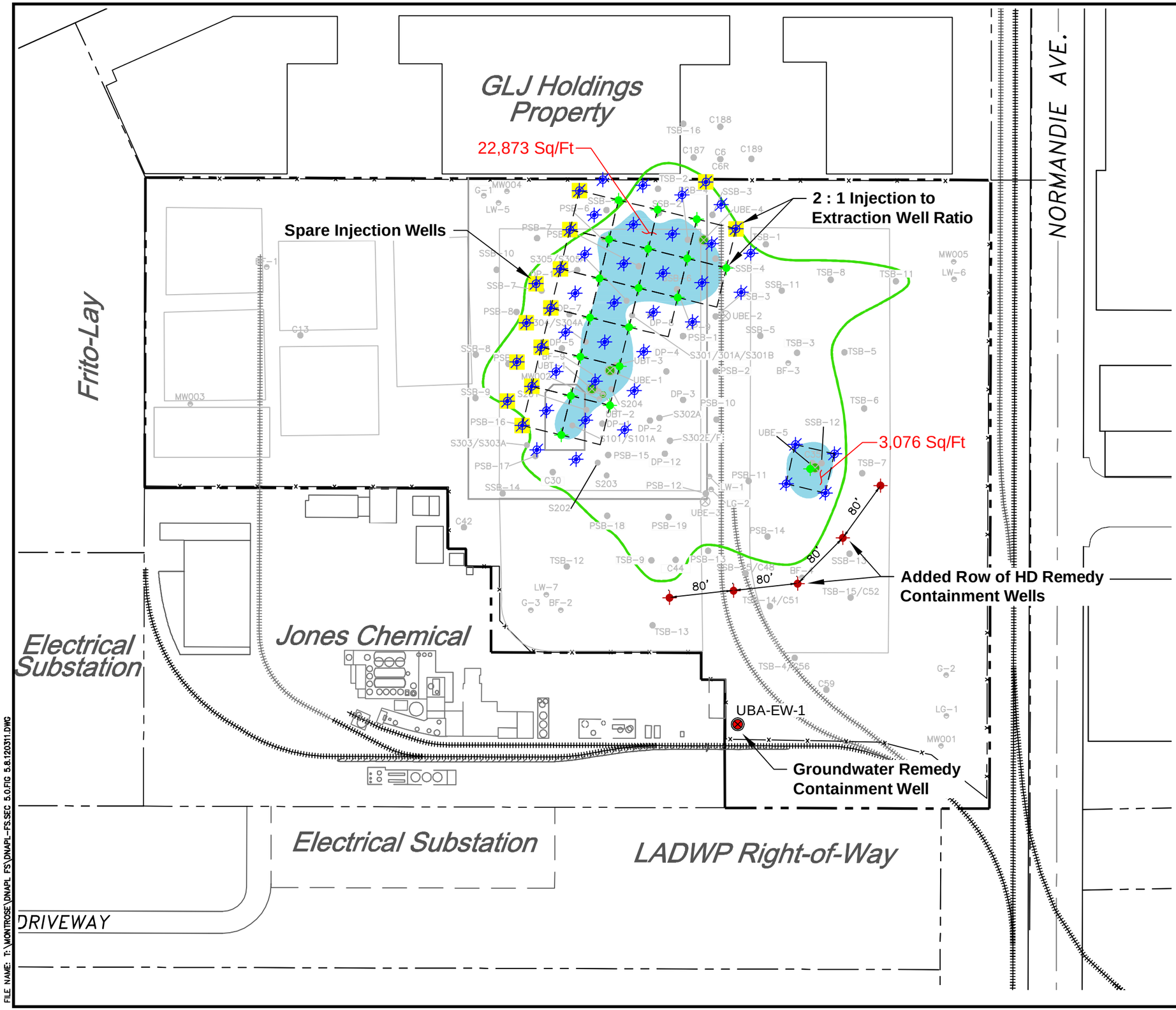
SCALE: 1"= 120'

Montrose Chemical Corporation

Estimated Extent of Mobile DNAPL in Saturated UBA

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.7

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.7.120311.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- Entire DNAPL Impacted Area
- Estimated Extent of Mobile DNAPL Contiguous Area >53,000 mg/kg Total Area: 25,949 Sq. Ft.
- Injection Well Location (46)
- Extraction Well Location (23)
- Groundwater Remedy Containment Well (1)
- Spare Injection Well Location (13)
- HD Remedy Containment Wells (5)

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b

NORTH

0 60 120 FEET

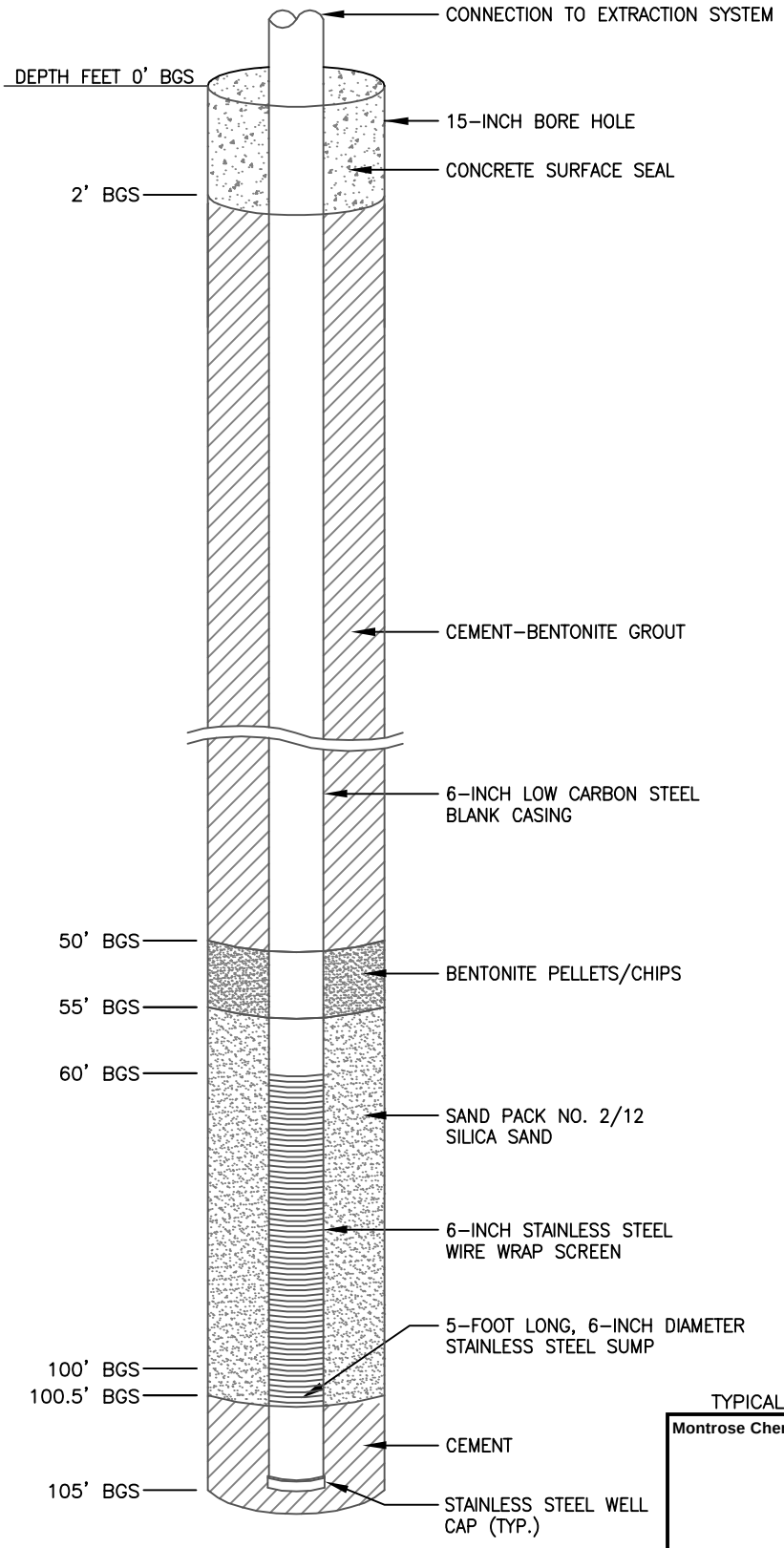
SCALE: 1"= 120'

Montrose Chemical Corporation

UBA Conceptual Hydraulic Displacement Well Pattern -50 Foot Spacing

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.8

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.8.120311.DWG



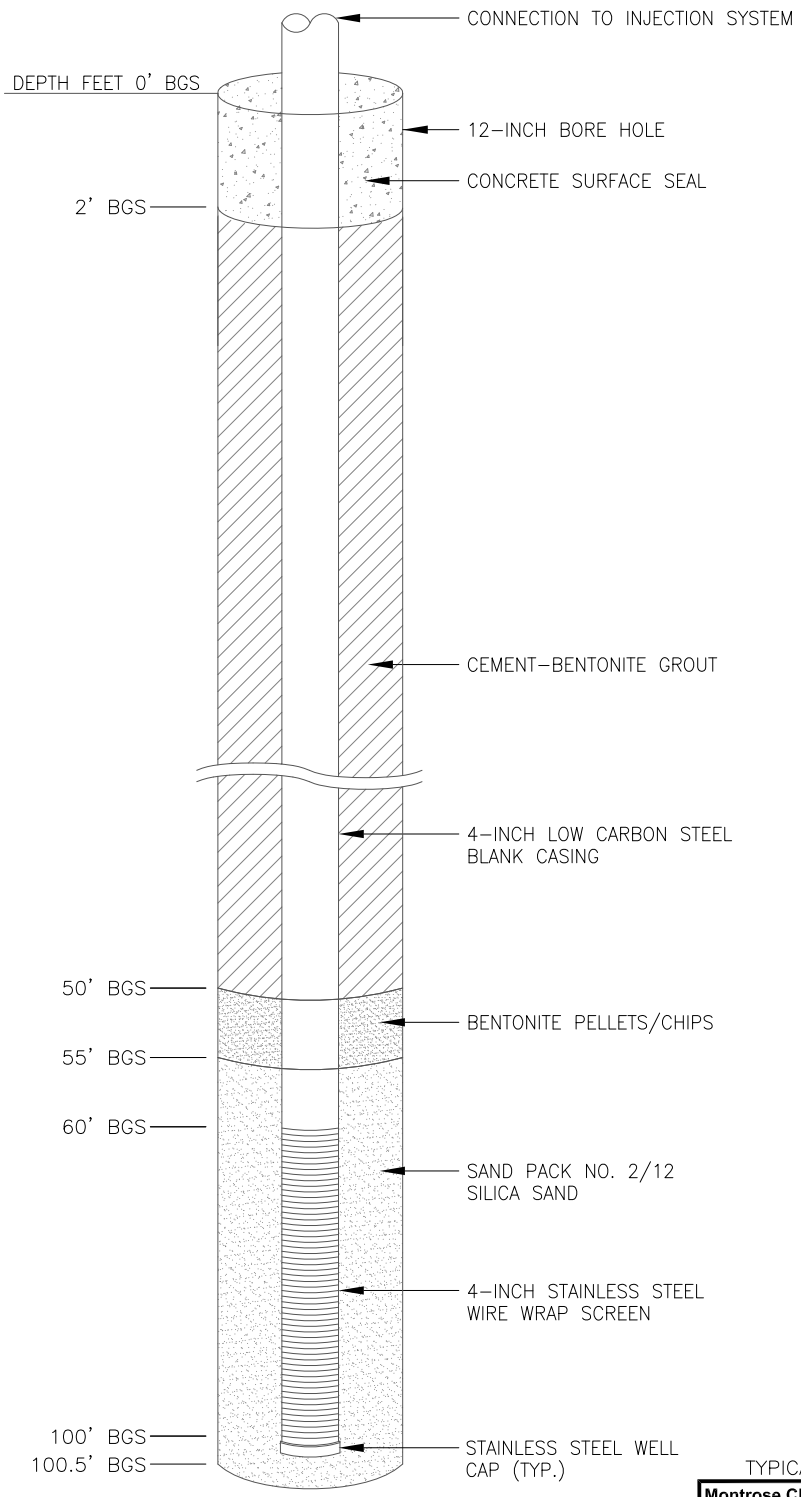
TYPICAL WELL CONSTRUCTION DIAGRAM – NOT TO SCALE

Montrose Chemical Corporation

DNAPL Extraction Well
Construction Diagram

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.9

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.9.120311.DWG



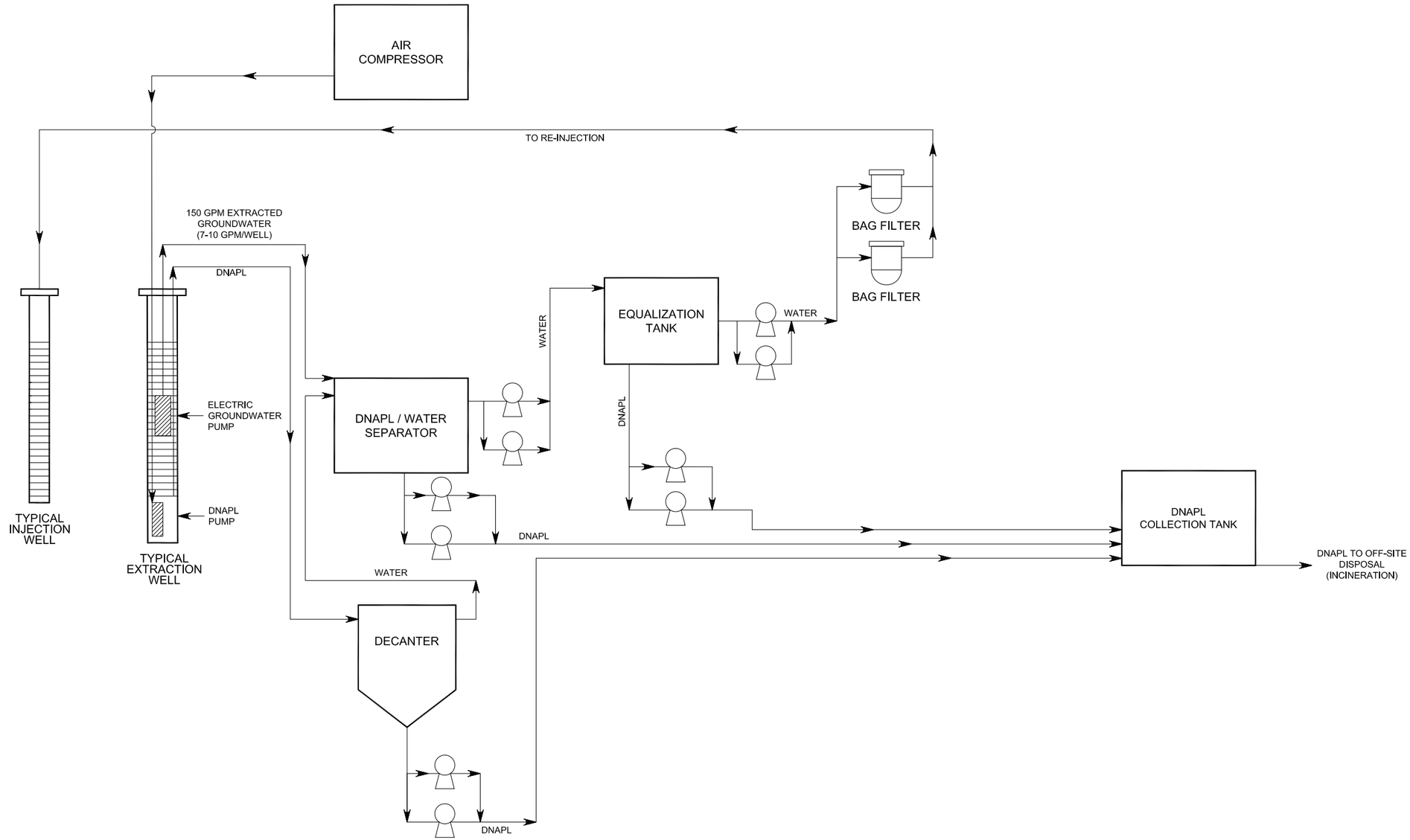
TYPICAL WELL CONSTRUCTION DIAGRAM – NOT TO SCALE

Montrose Chemical Corporation

Groundwater Injection Well Construction Diagram

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.10

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.10.120311.DWG



LEGEND:

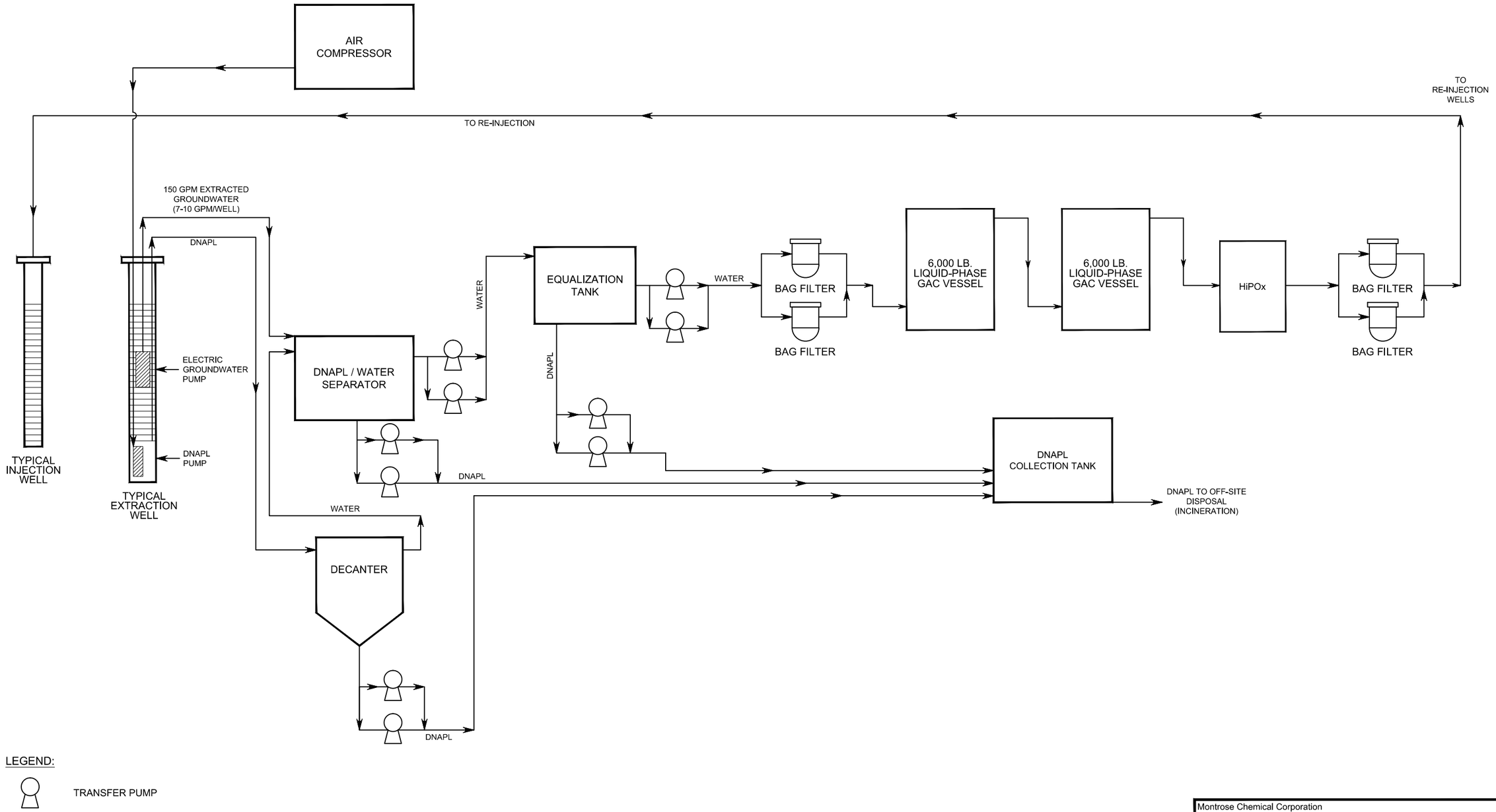
TRANSFER PUMP

Montrose Chemical Corporation

Conceptual HD Remedy Process Flow Diagram with Untreated Water Re-Injection

Date: 12-11	Montrose Superfund Site	Figure 5.11
Project No. 60212541	AECOM	

FILE NAME: T:\Montrose\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.11.120311.dwg

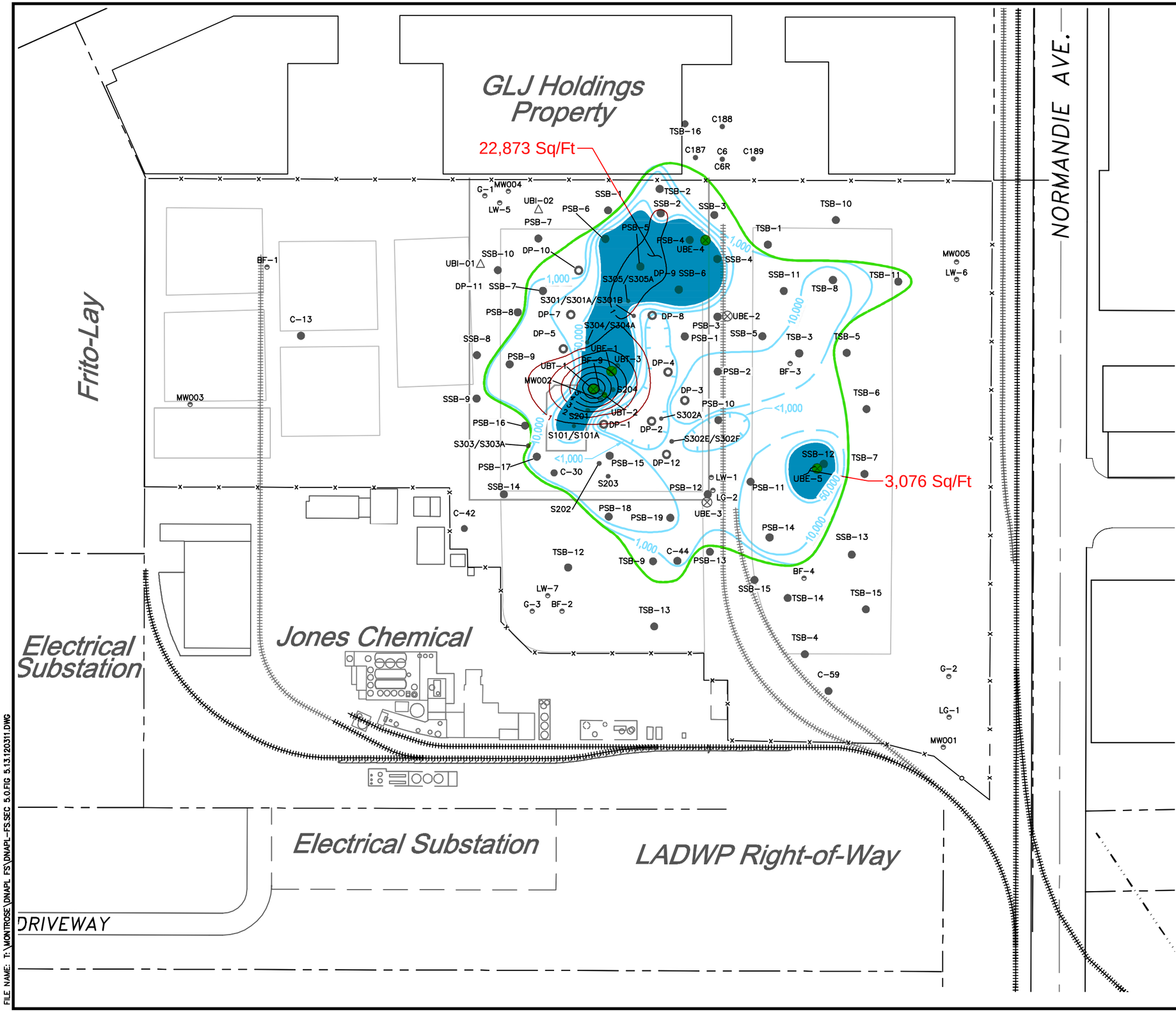


Montrose Chemical Corporation

Conceptual HD Remedy Process Flow Diagram with Treated Water Re-Injection

Date: 06-13	Montrose Superfund Site	Figure 5.12
Project No. 60150255	AECOM	

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2013\SITEMAPS.0613\DNAPL FS\SECT 5.0\DNAPL-FS.SEC 5.0.FIG 5.12.0613.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- PSB-7 — Sonic Boring Location
- DP-10 — Direct Push Boring Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- 1,000 — DNAPL Isoconcentration in mg/kg (MCB + Total DDT)
- 10,000 — DNAPL Isoconcentration in mg/kg (MCB + Total DDT)
- 50,000 — DNAPL Isoconcentration in mg/kg (MCB + Total DDT)
- 1 — DNAPL Definite Thickness in Feet
- Estimated Extent of Mobile DNAPL Contiguous Area >53,000 mg/kg Total Area: 25,949 Sq. Ft.

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin–Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b

NORTH

0 60 120 FEET

SCALE: 1"= 120'

Montrose Chemical Corporation

Focused Treatment Area, DNAPL Concentration >53,000 mg/kg

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.13

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.13.120311.DWG

Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- Estimated Extent of Mobile DNAPL Contiguous Area >53,000 mg/kg Total Area: 25,949 Sq. Ft.
- Steam Injector Well Location (14)
- Multi-Phase Extraction Well Location (27)
- 60-Foot Spacing Between Steam Injection Wells (42-Foot Spacing Between Steam Injection and Extraction Wells)

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008d

NORTH

0 60 120 FEET

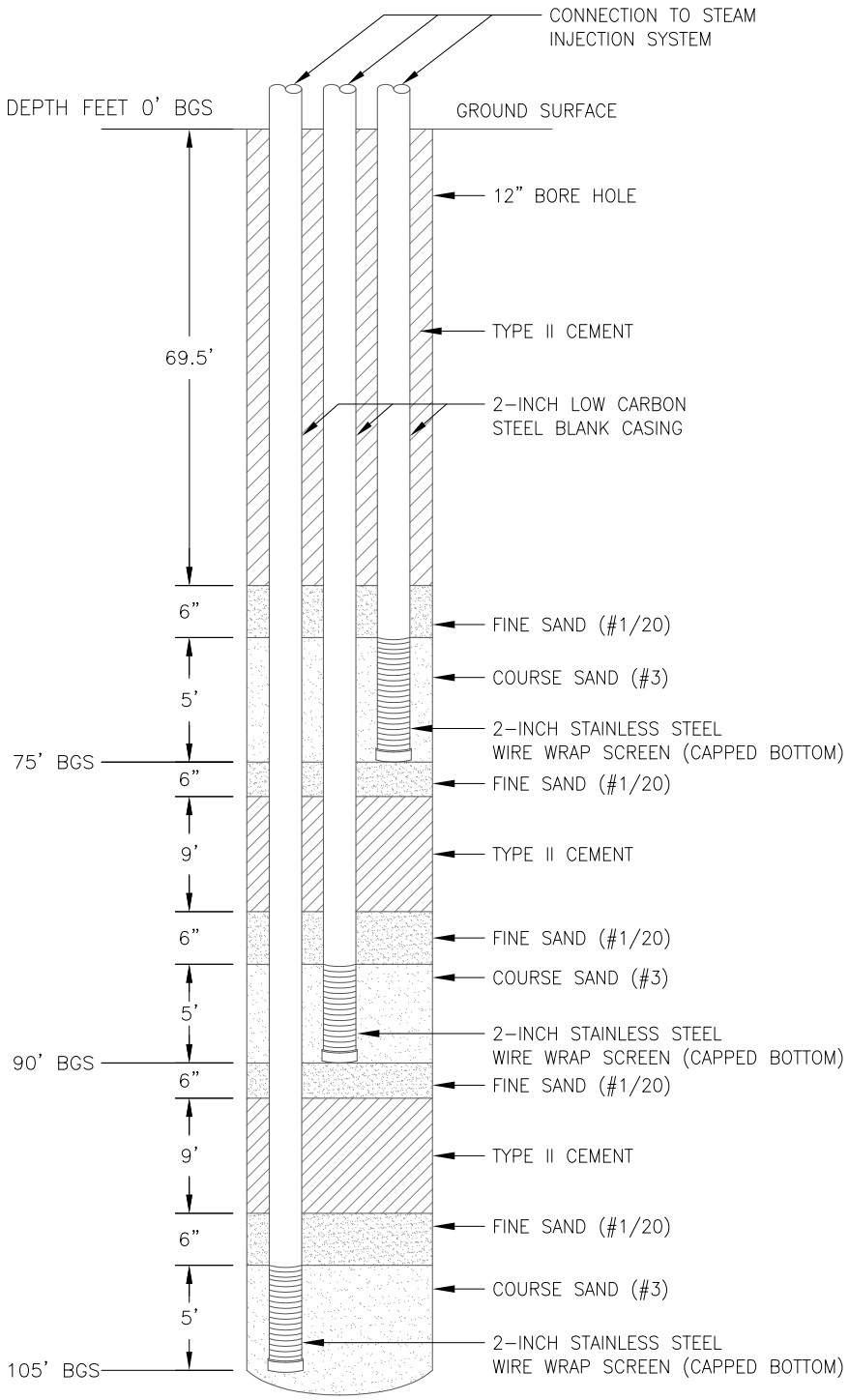
SCALE: 1"= 120'

Montrose Chemical Corporation

UBA Conceptual Steam Remedy
Well Pattern - 42 Foot Spacing

Date: 12-11	Montrose Superfund Site	Figure 5.14
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.14.120311.DWG



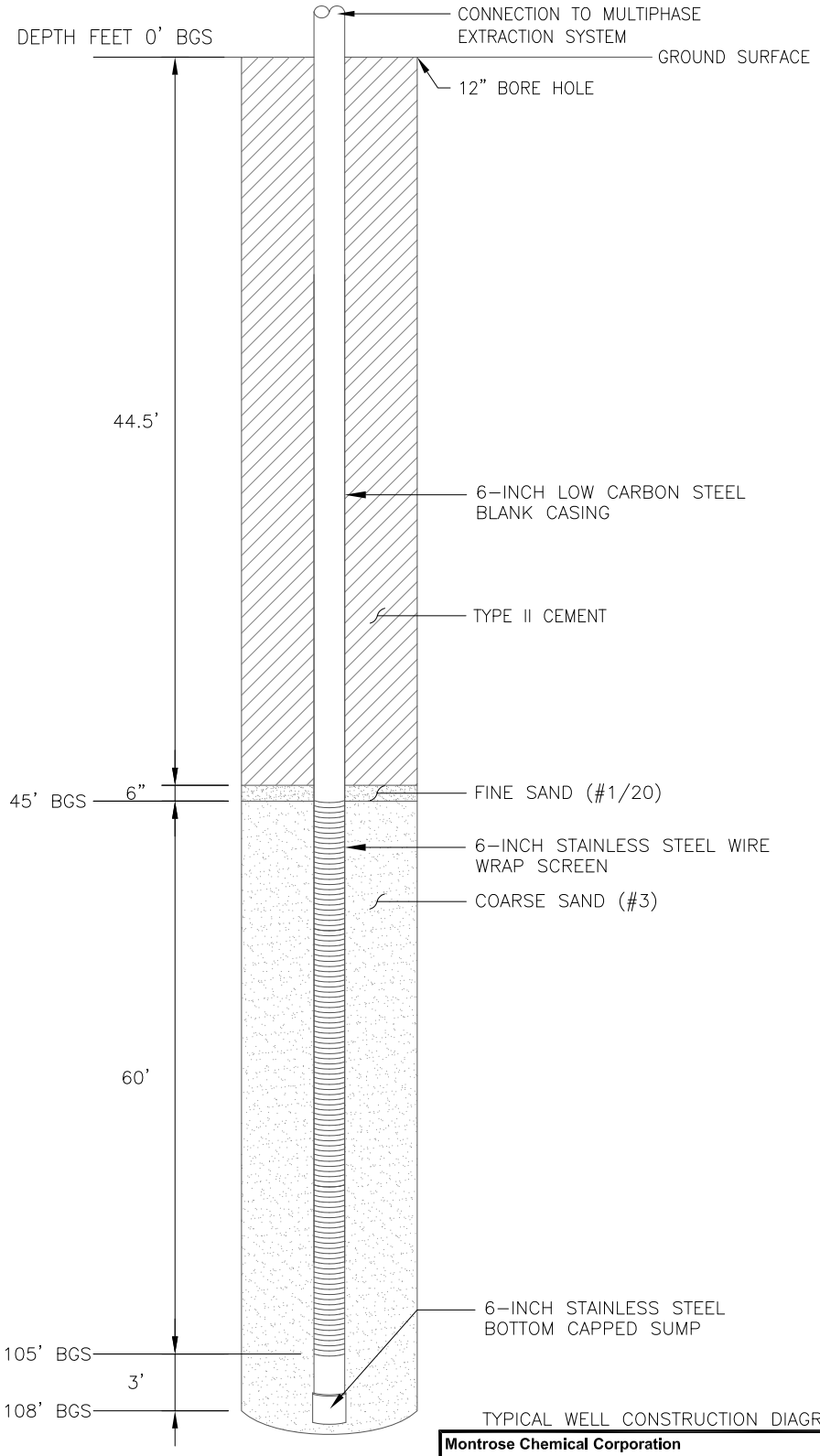
TYPICAL WELL CONSTRUCTION DIAGRAM – NOT TO SCALE

Montrose Chemical Corporation

Upper Bellflower Aquitard Steam Injection Well Construction Diagram

Date: 12-11	Montrose Superfund Site	Figure 5.15
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.15.120311.DWG



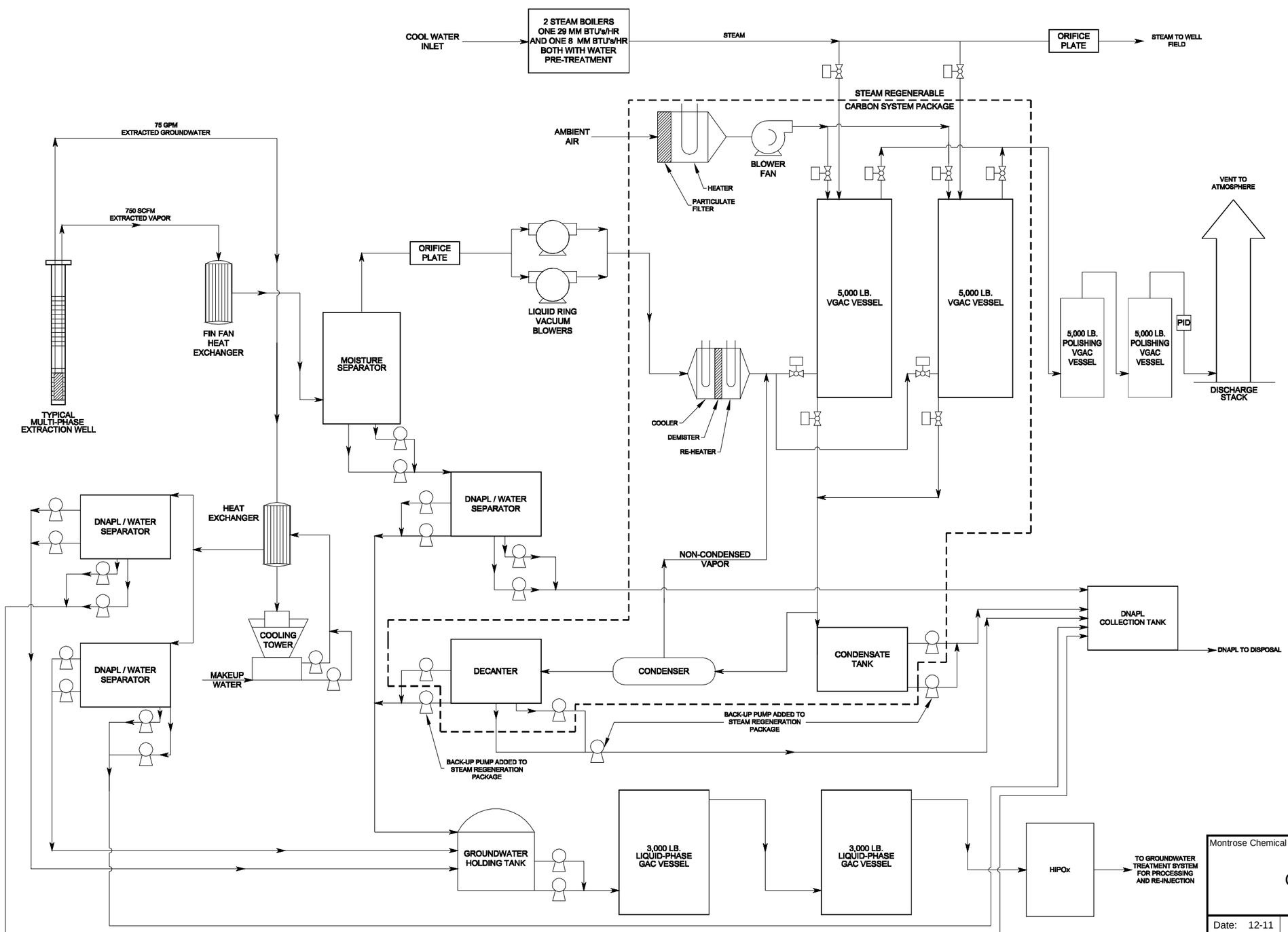
TYPICAL WELL CONSTRUCTION DIAGRAM – NOT TO SCALE

Montrose Chemical Corporation

Upper Bellflower Aquitard
Multi-Phase Extraction
Well Construction Diagram

Date: 12-11	Montrose Chemical Corporation	Figure
Project No. 60212541	AECOM	5.16

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.16.120311.DWG

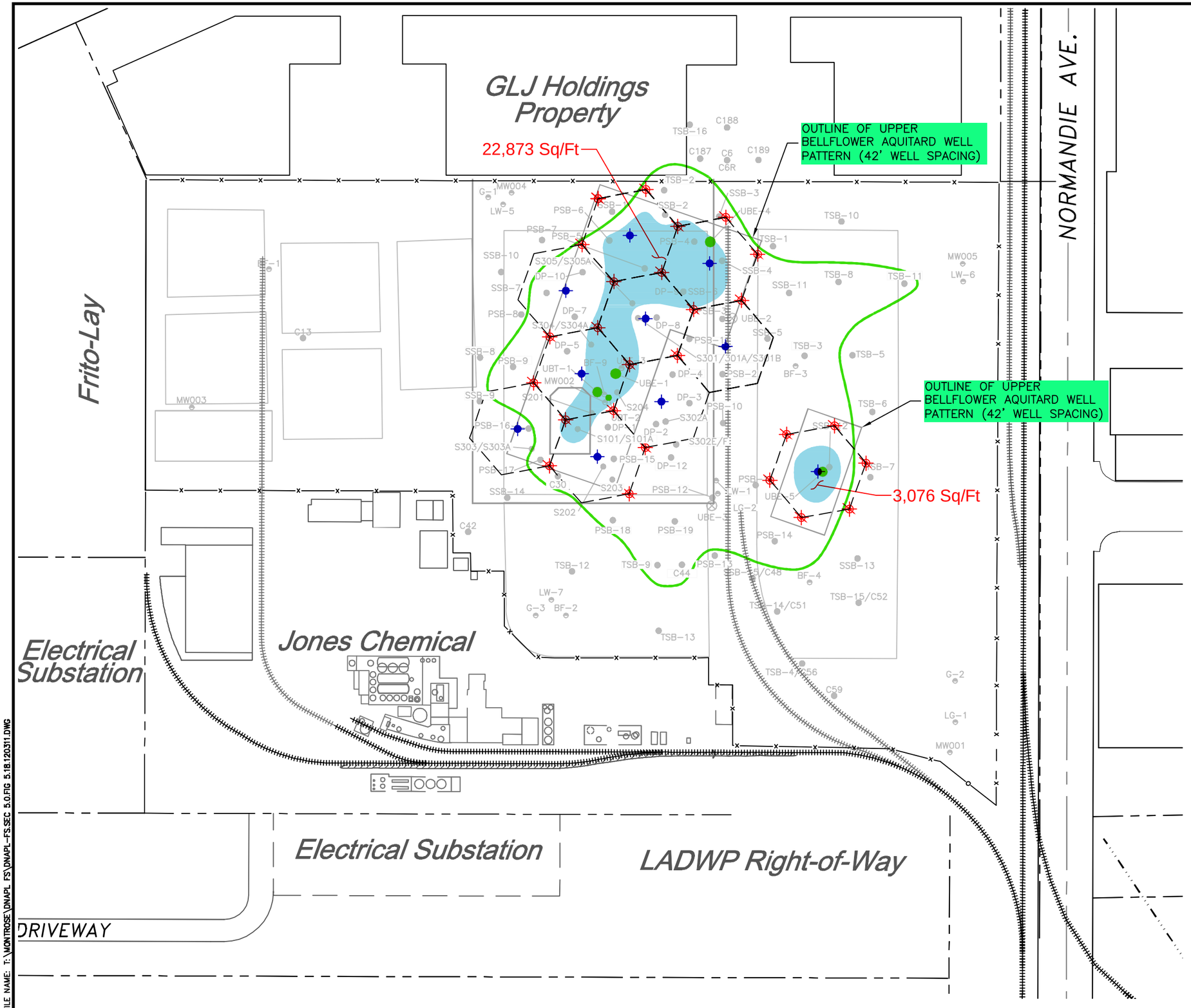


Montrose Chemical Corporation

Focused Treatment Area
Conceptual Steam Remedy
Process Flow Diagram

Date: 12-11	Montrose Superfund Site	Figure 5.17
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.17.120311.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- Estimated Extent of Mobile DNAPL Contiguous Area >53,000 mg/kg Total Area: 25,949 Sq. Ft.
- Steam Injector Well Location (26)
- Multi-Phase Extraction Well Location (10)
- 60-Foot Spacing Between Steam Injection Wells

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008d

NORTH

0 60 120 FEET

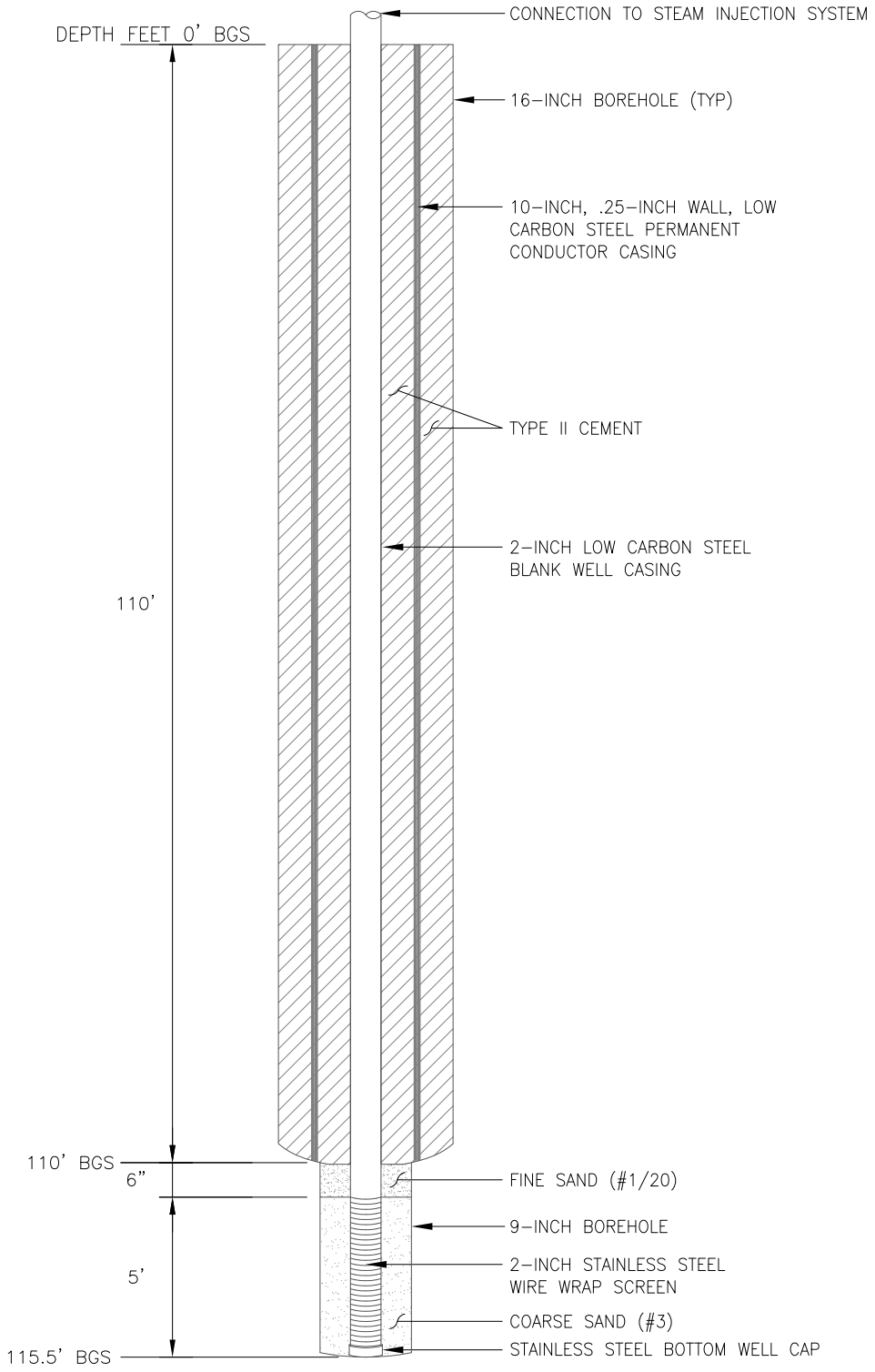
SCALE: 1"= 120'

Montrose Chemical Corporation

Hot Floor Conceptual Steam Remedy Well Pattern

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.18

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.18.120311.DWG



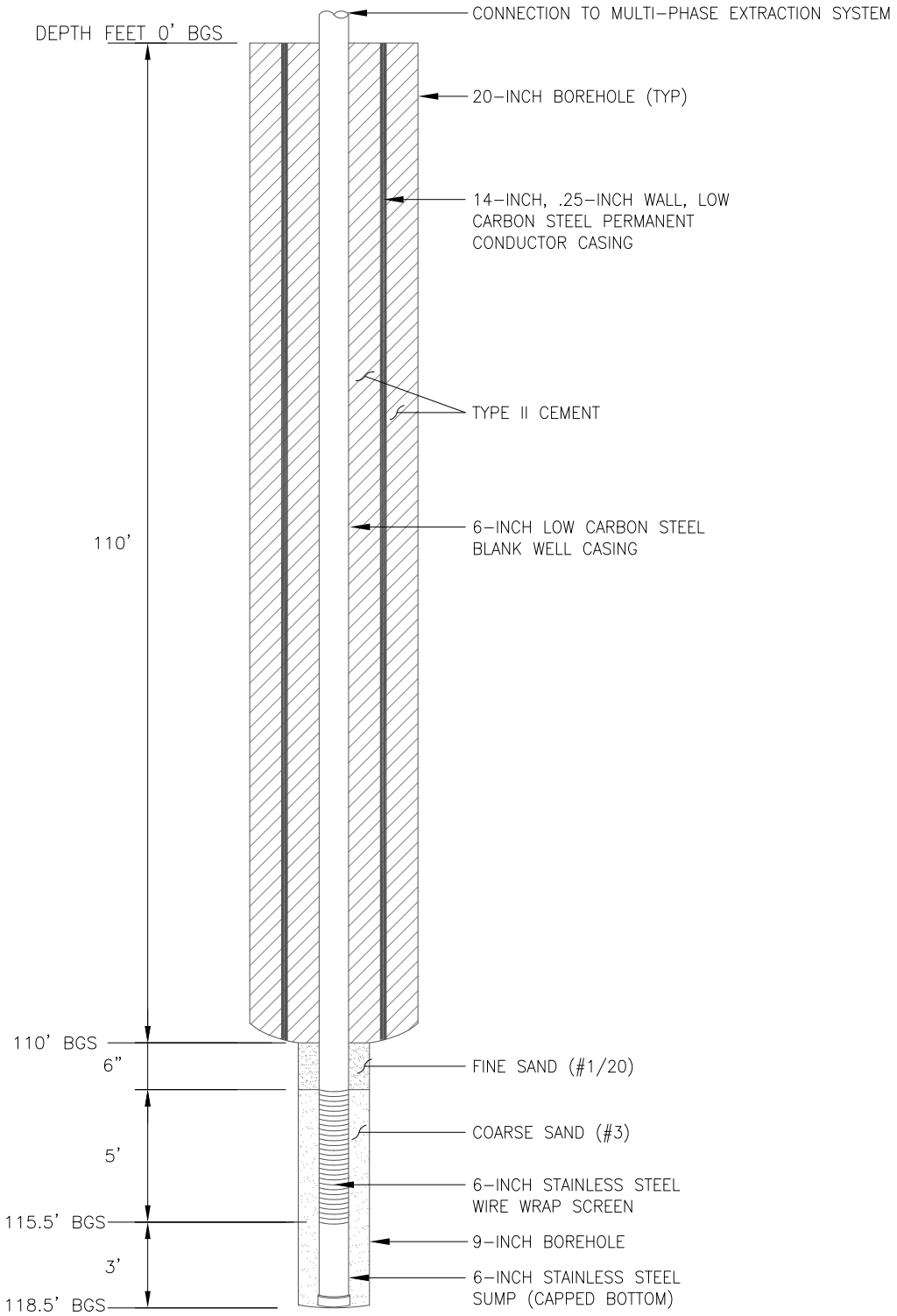
TYPICAL WELL CONSTRUCTION DIAGRAM – NOT TO SCALE

Montrose Chemical Corporation

Hot Floor Steam Injection Well Construction Diagram

Date: 12-11	Montrose Superfund Site	Figure 5.19
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.19.120311.DWG



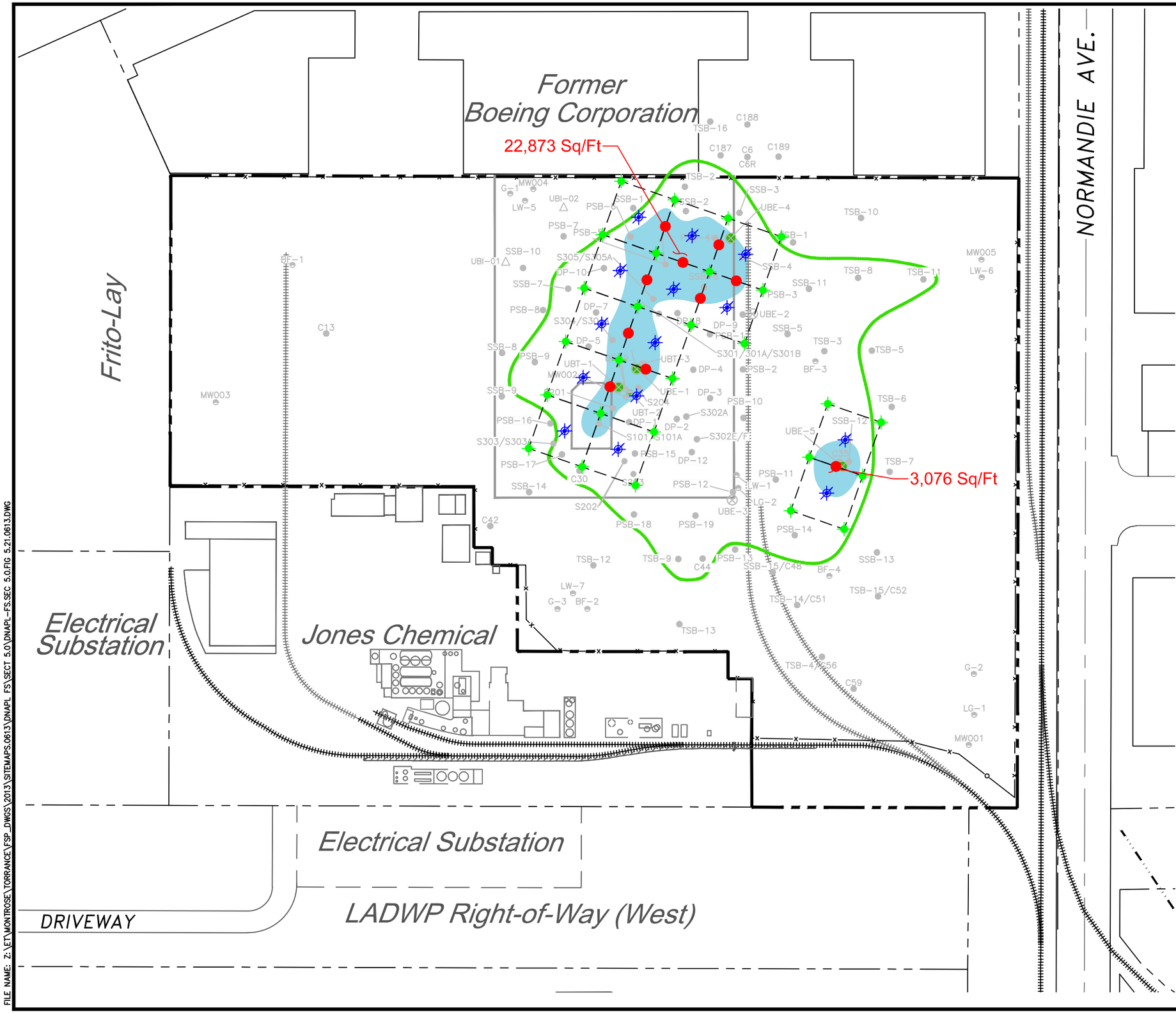
TYPICAL WELL CONSTRUCTION DIAGRAM – NOT TO SCALE

Montrose Chemical Corporation

Hot Floor Multi-phase Extraction Well Construction Diagram

Date: 12-11	Montrose Superfund Site	Figure 5.20
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.20.120311.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- Estimated Extent of Mobile DNAPL Contiguous Area >53,000 mg/kg Total Area: 25,949 Sq. Ft.
- Steam Injector Well Location (14)
- Multi-Phase Extraction Well Location (27)
- 60-Foot Spacing Between Steam Injection Wells (42-Foot Spacing Between Steam Injection and Extraction Wells)
- Conceptual Soil Verification Boring Location

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008d

NORTH

0 60 120 FEET

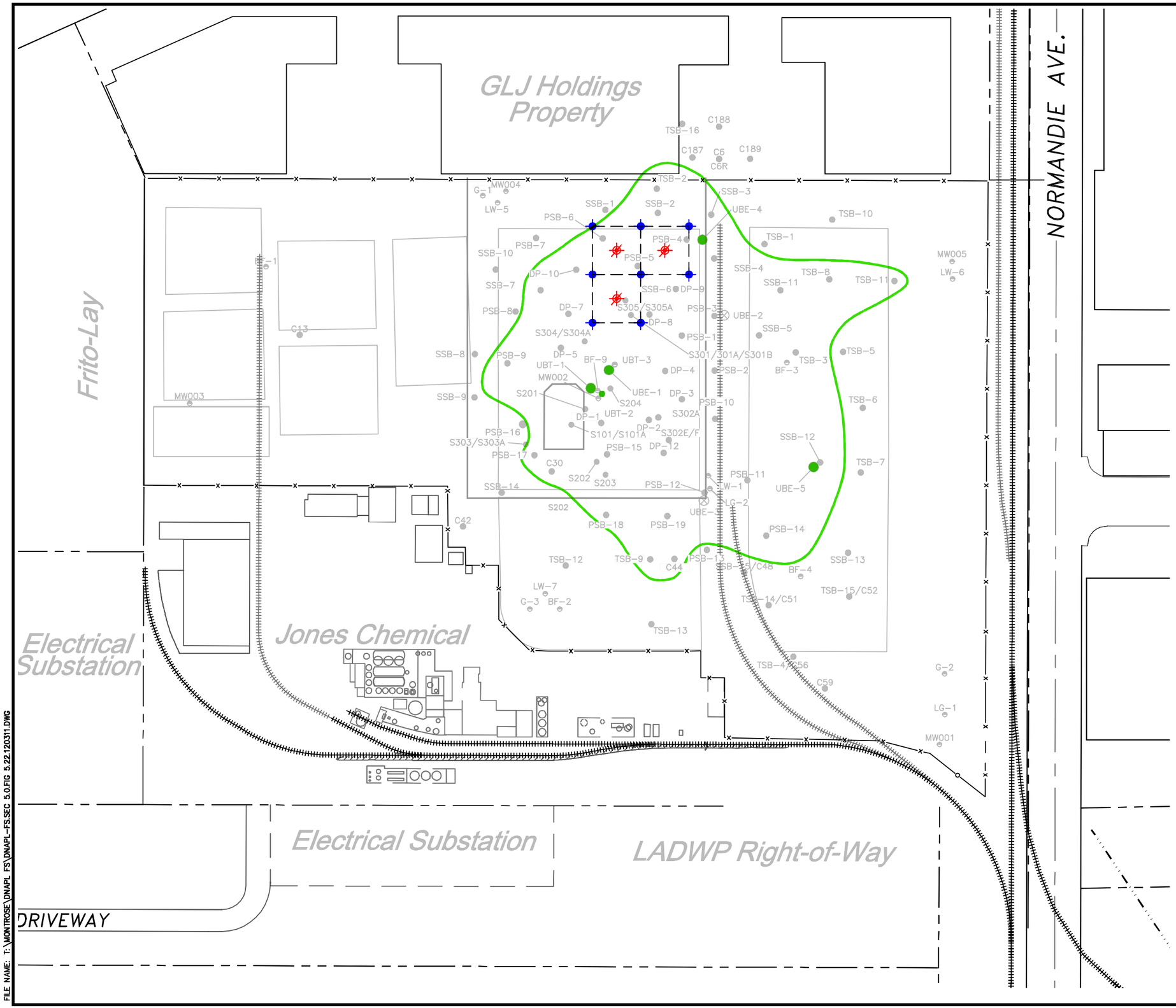
SCALE: 1"= 120'

Montrose Chemical Corporation

Thermal Verification Boring Location Map
RA 5a

Date: 06-13	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	5.21

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2013\SITEMAPS.0613\DNAPL_FS\SECT 5.0\DNAPL-FS.SEC 5.0.FIG 5.21.0613.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- Steam Injector Well Location (3)
- Multi-Phase Extraction Well Location (8)
- 60-Foot Spacing Between Steam Injection Wells

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008c

NORTH

0 60 120 FEET

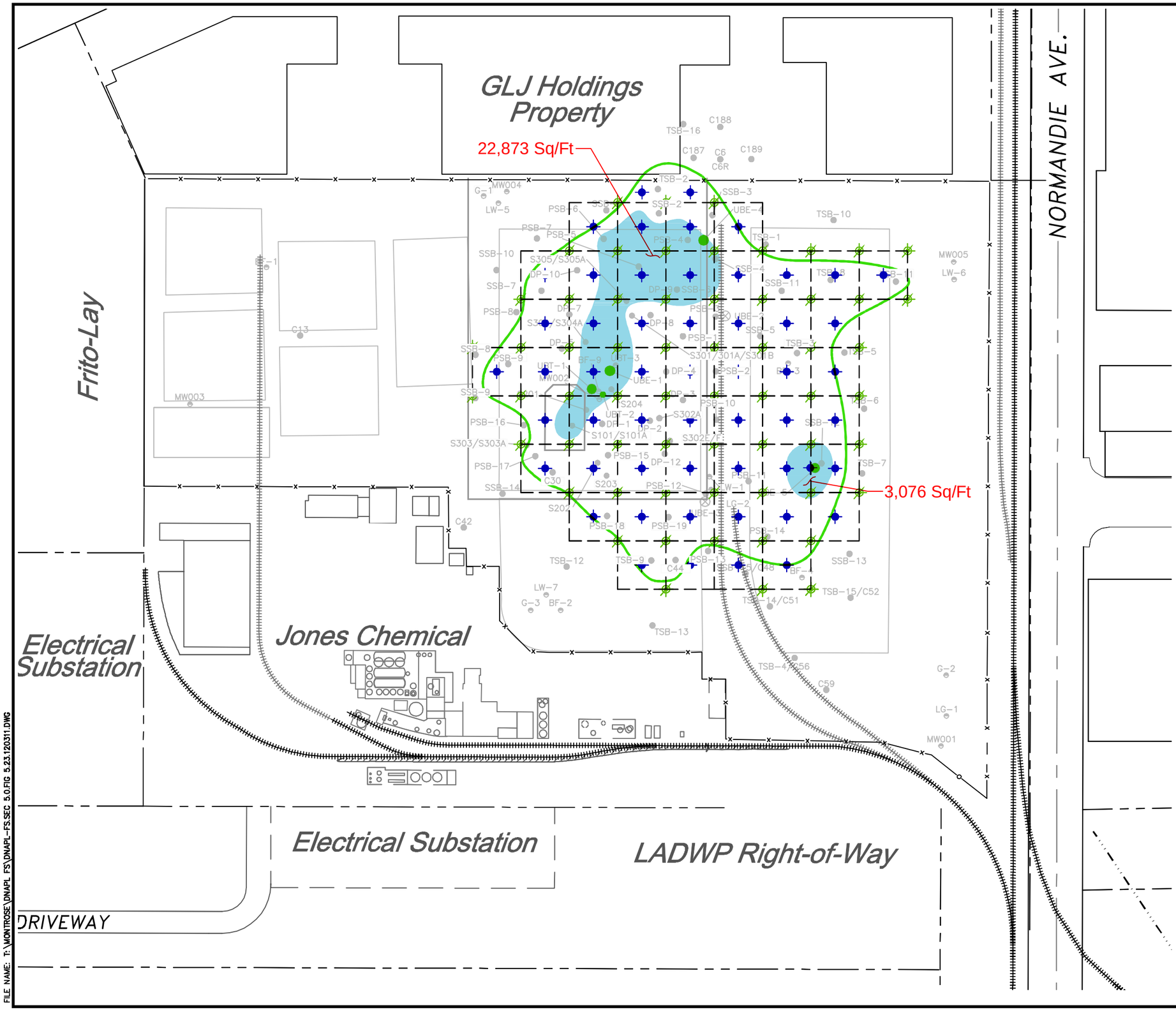
SCALE: 1"= 120'

Montrose Chemical Corporation

Upper Bellflower Aquitard Conceptual Steam Remedy Pilot Test Well Pattern

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.22

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.22.120311.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- Estimated Extent of Mobile DNAPL Contiguous Area >53,000 mg/kg Total Area: 25,949 Sq. Ft.
- Steam Injector Well Location (61)
- Multi-Phase Extraction Well Location (53)
- 60-Foot Spacing Between Steam Injection Wells (42-Foot Spacing Between Steam Injection and Extraction Wells)

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008d

NORTH

0 60 120 FEET

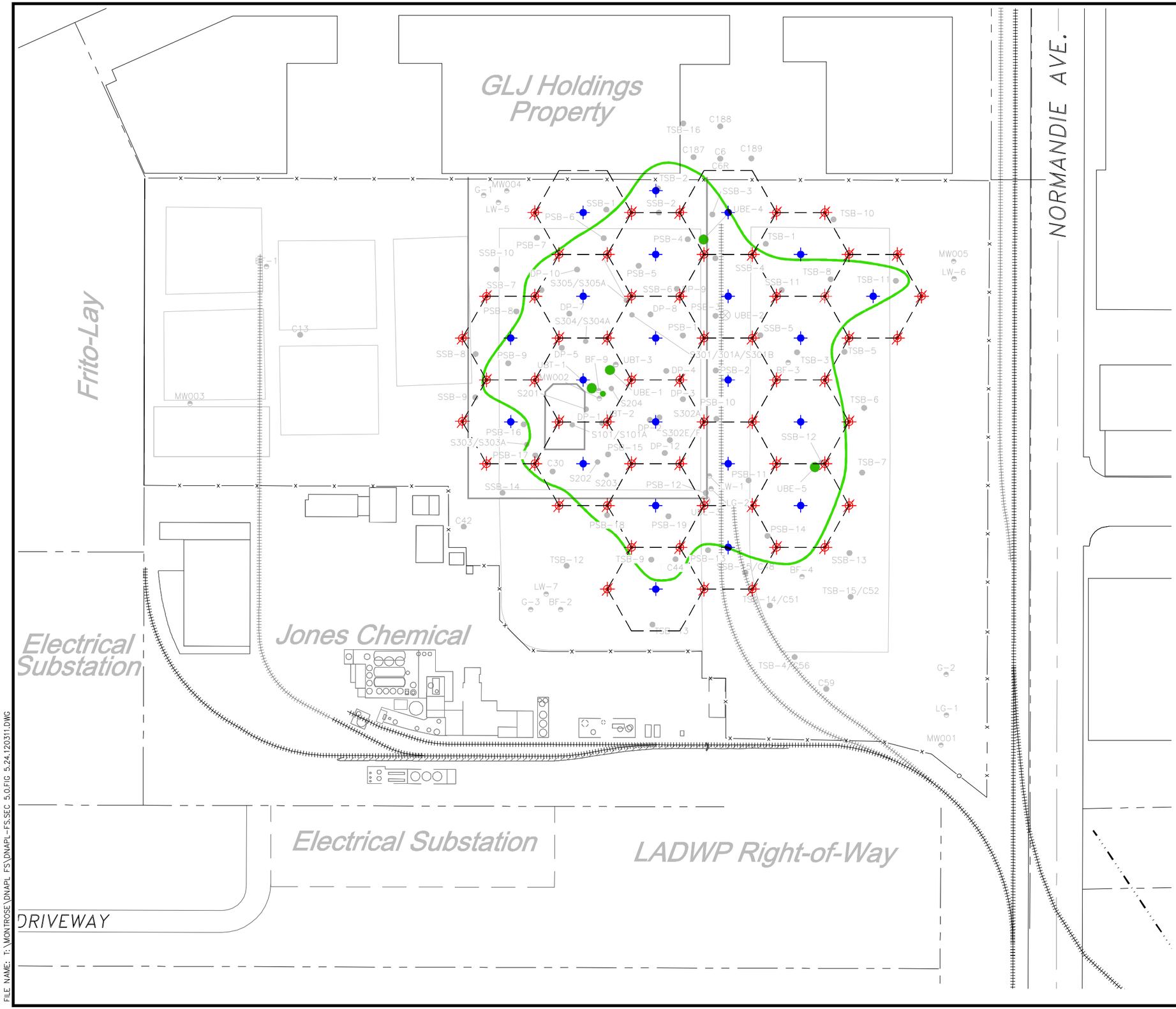
SCALE: 1"= 120'

Montrose Chemical Corporation

UBA Conceptual Steam Remedy
Well Pattern - 42-Foot Spacing
Entire DNAPL Impacted Area

Date: 12-11	Montrose Superfund Site	Figure 5.23
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.23.120311.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- Steam Injector Well Location (55)
- Multi-Phase Extraction Well Location (22)
- 60-Foot Spacing Between Steam Injection Wells

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008c

NORTH

0 60 120 FEET

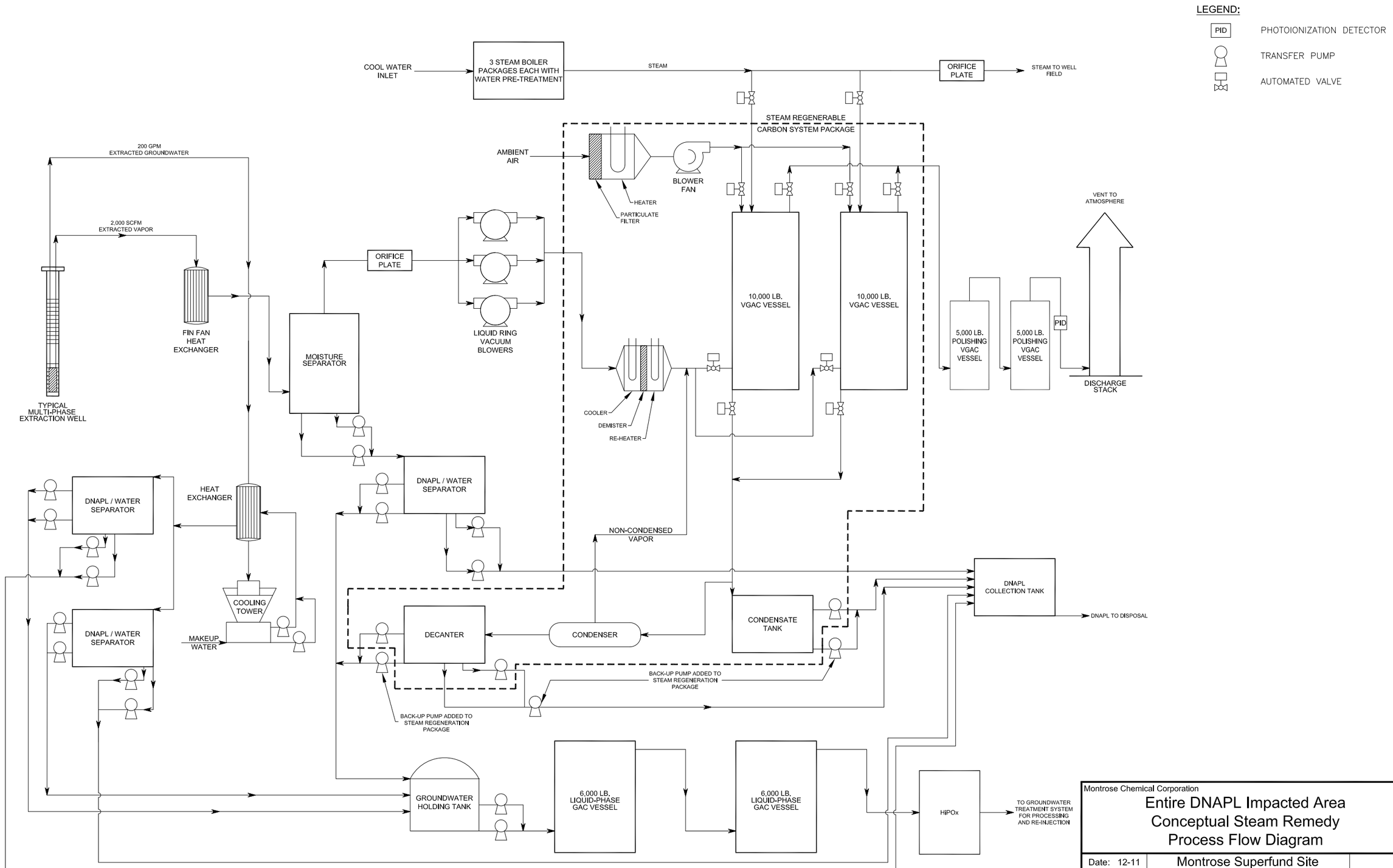
SCALE: 1"= 120'

Montrose Chemical Corporation

Hot Floor Conceptual Steam Remedy Well Pattern

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.24

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.24.120311.DWG

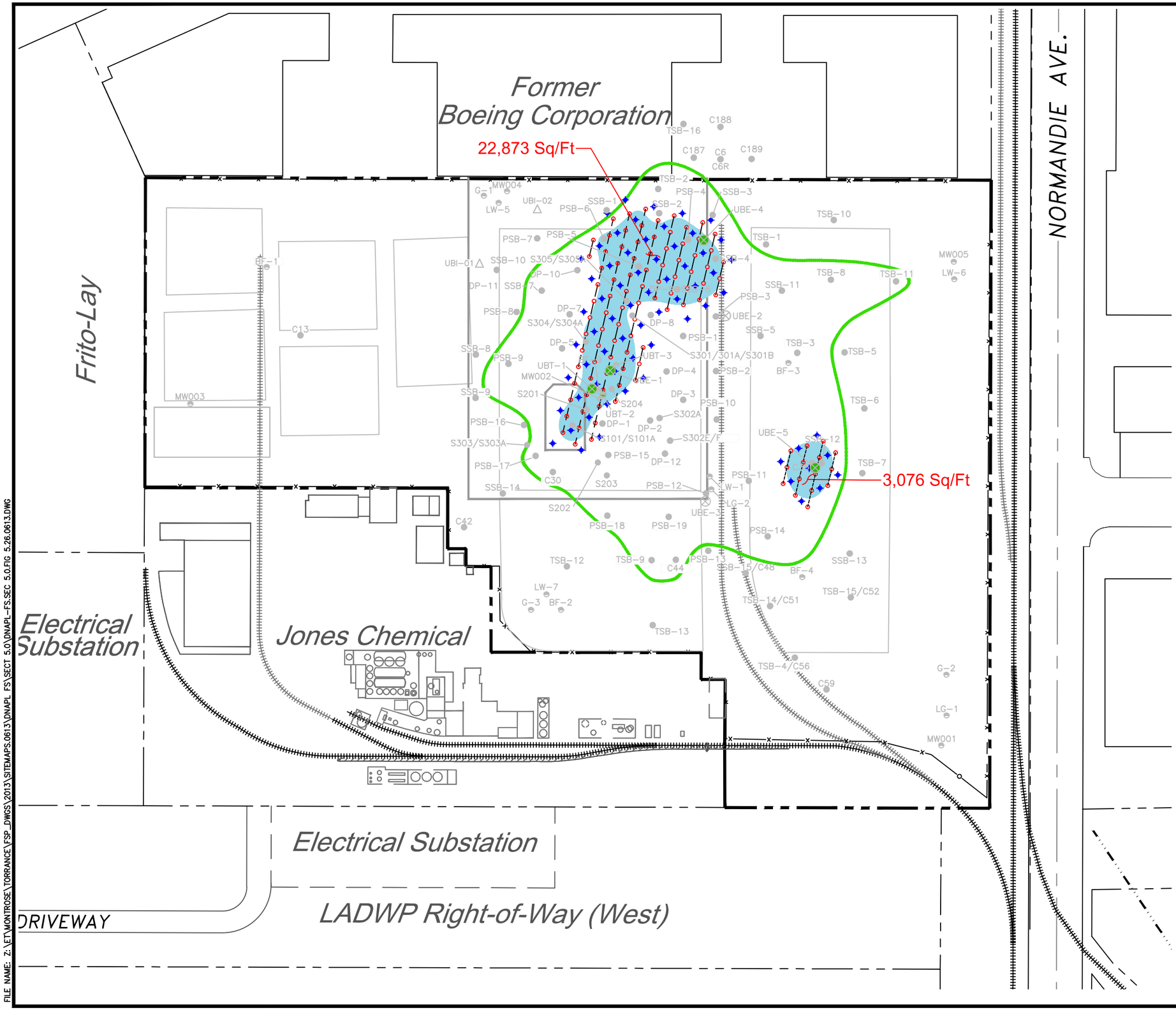


Montrose Chemical Corporation

Entire DNAPL Impacted Area
Conceptual Steam Remedy
Process Flow Diagram

Date: 12-11	Montrose Superfund Site	Figure 5.25
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.25.120311.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- ET-DSP Electrode Location (102)
- Multi-Phase Extraction Well Location (66)
- 21-Foot Spacing Between Electrode Locations
- Estimated Extent of Mobile DNAPL Contiguous Area >53,000 mg/kg Total Area: 25,949 Sq. Ft.

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008f

NORTH

0 60 120 FEET

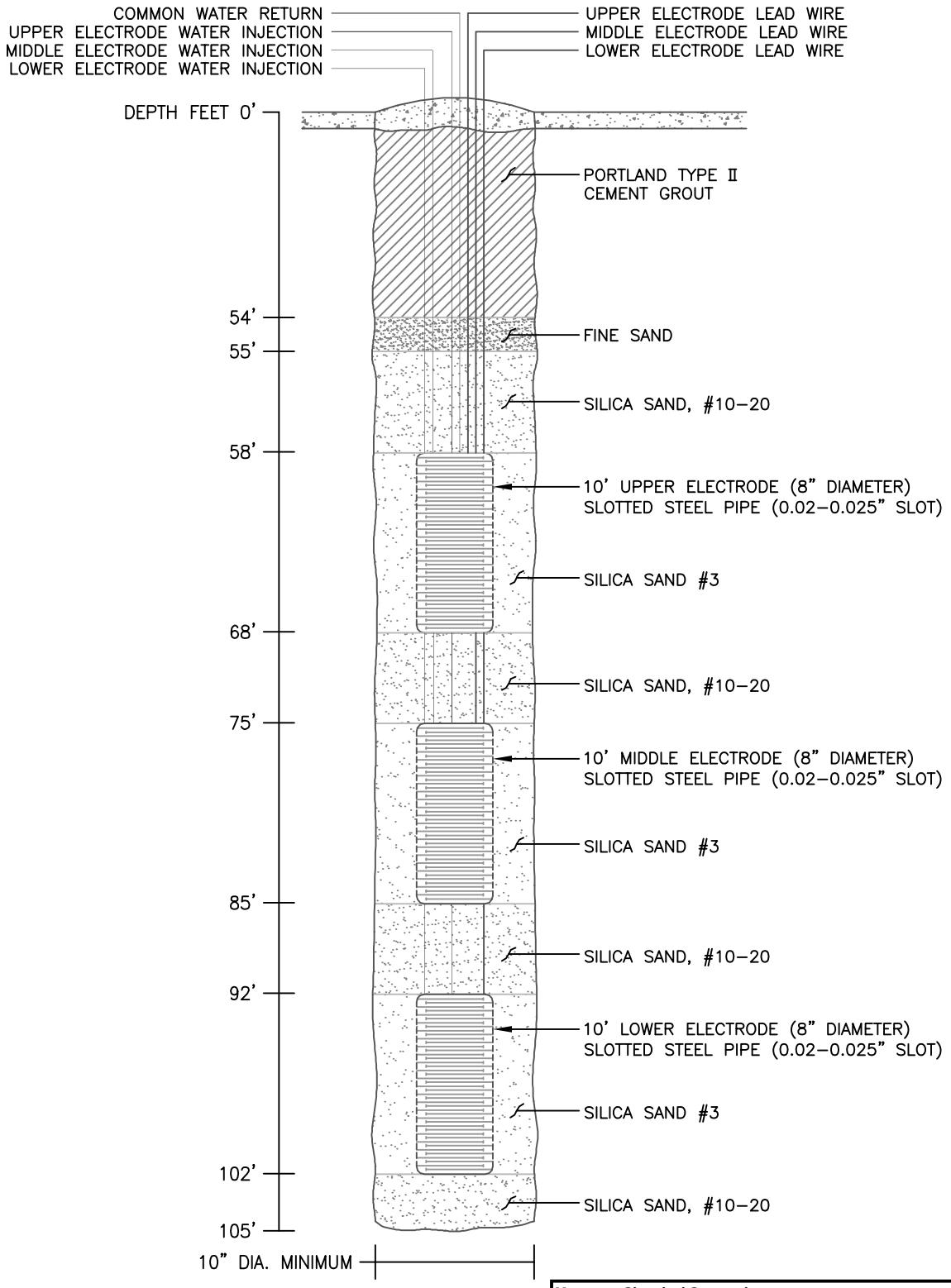
SCALE: 1"= 120'

Montrose Chemical Corporation

UBA Conceptual ERH Remedy
Well Pattern
Focused Treatment Area

Date: 06-13	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	5.26

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2013\SITEMAPS.0613\DNAPL FS\SECT 5.0\DNAPL-FS.SEC 5.0.FIG 5.26.0613.DWG



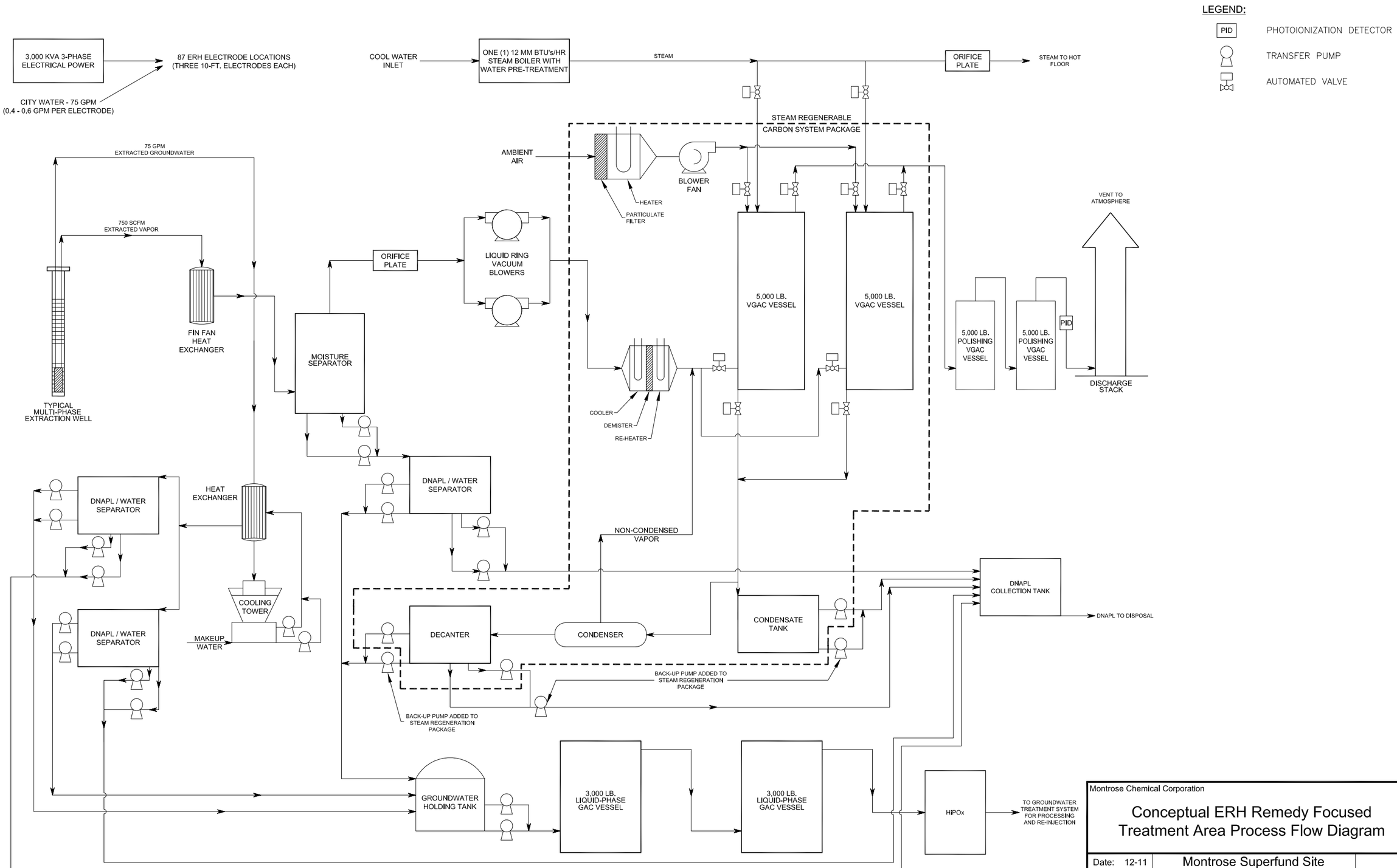
TYPICAL WELL CONSTRUCTION DIAGRAM – NOT TO SCALE

Montrose Chemical Corporation

UBA ERH Electrode Well Construction Diagram

Date: 12-11	Montrose Superfund Site	Figure 5.27
Project No. 61212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.27.120311.DWG

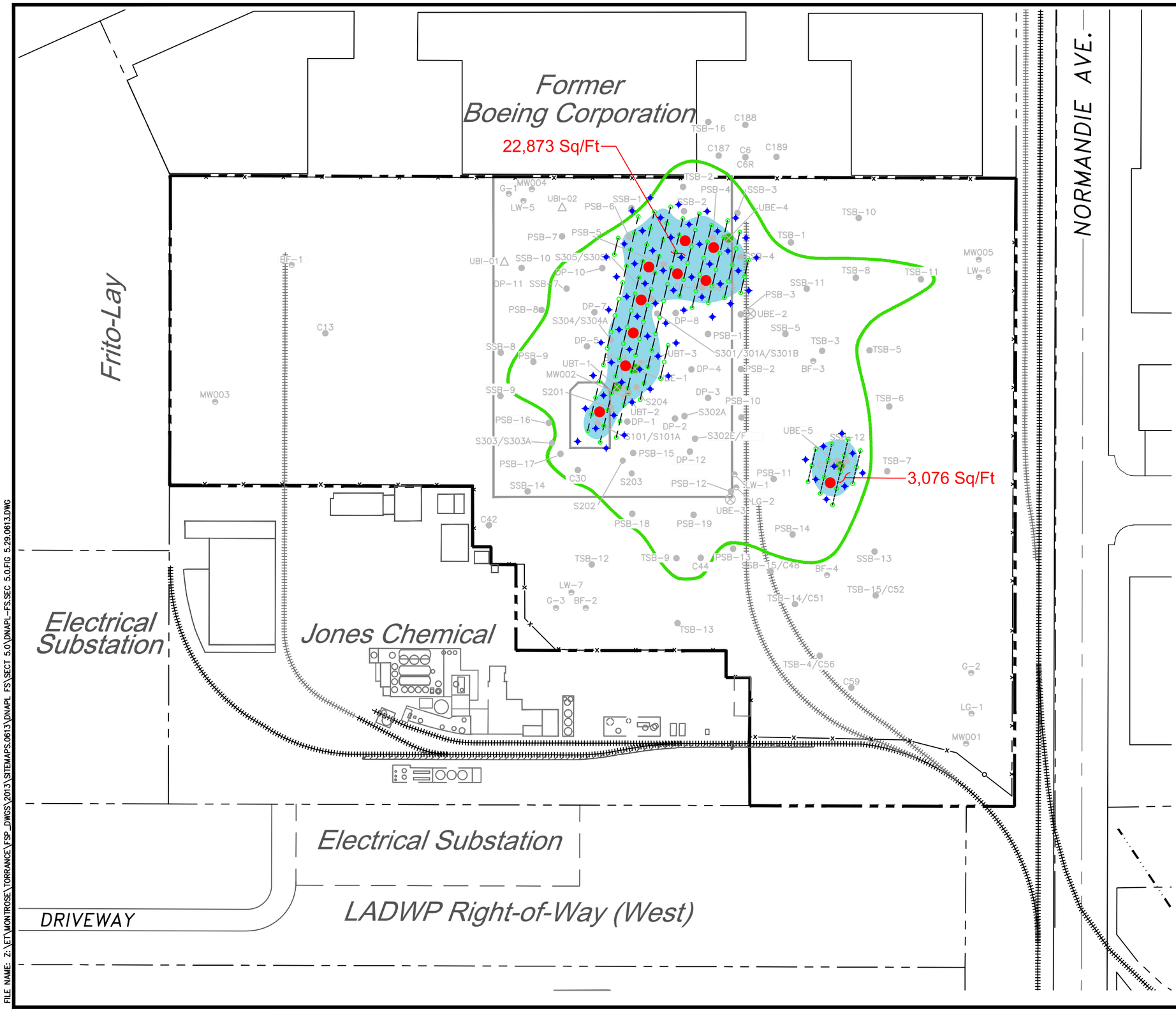


Montrose Chemical Corporation

Conceptual ERH Remedy Focused Treatment Area Process Flow Diagram

Date: 12-11	Montrose Superfund Site	Figure 5.28
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.28.120311.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- ET-DSP Electrode Location (102)
- Multi-Phase Extraction Well Location (66)
- 21-Foot Spacing Between Electrode Locations
- Estimated Extent of Mobile DNAPL Contiguous Area >53,000 mg/kg Total Area: 25,949 Sq. Ft.
- Conceptual Soil Verification Boring Location

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008f

NORTH

0 60 120 FEET

SCALE: 1"= 120'

Montrose Chemical Corporation

Thermal Verification Boring Location Map
RA 6a

Date: 06-13	Montrose Superfund Site	Figure
Project No. 60150255	AECOM	5.29

FILE NAME: Z:\ET\MONTROSE\TORRANCE\FSP_DWGS\2013\SITEMAPS.0613\DNAPL FS\SECT 5.0\DNAPL-FS.SEC 5.0.FIG 5.29.0613.DWG

Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- Existing DNAPL Recovery Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- ET-DSP Electrode Location (30)
- Multi-Phase Extraction Well Location (21)
- 21-Foot Spacing Between Electrode Locations

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008e

NORTH

0 60 120 FEET

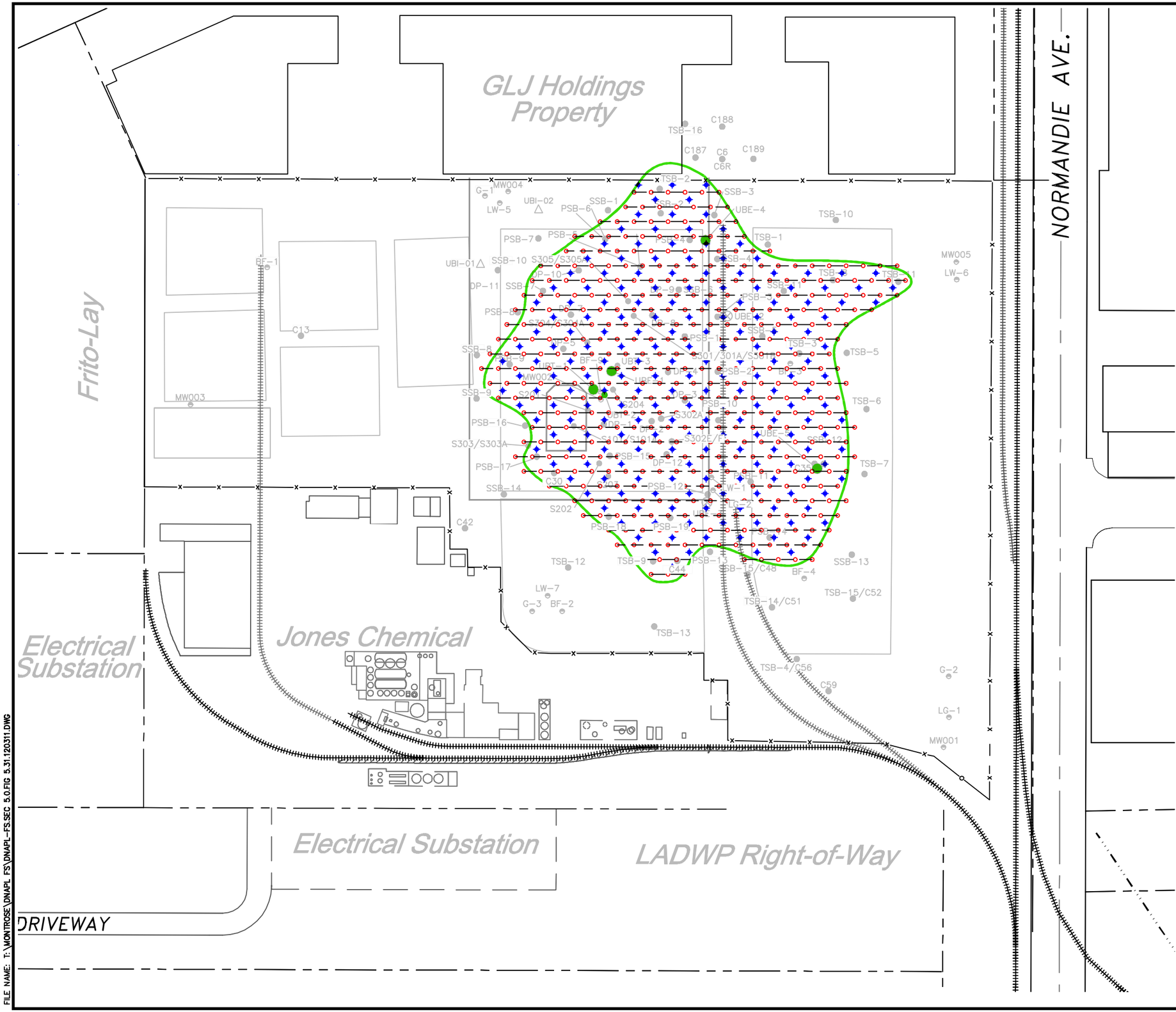
SCALE: 1"= 120'

Montrose Chemical Corporation

Upper Bellflower Aquitard Conceptual ERH Remedy Pilot Test Well Pattern

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.30

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.30.120311.DWG



Legend:

- Location of Current Montrose Property Boundary
- Parcel Boundary / Right-of-Way
- Surveyed Fence Line
- Existing Railroad Tracks
- Former Railroad Tracks
- Existing Building
- LADWP — Los Angeles Department of Water and Power
- S204 — Soil Boring Location
- MW002 — Monitoring Well Location
- UBE-2 — Extraction Well Location
- UBI-01 — Injection Well Location
- Entire DNAPL Impacted Area
- ET-DSP Electrode Location (456)
- Multi-Phase Extraction Well Location (203)
- 21-Foot Spacing Between Electrode Locations

References:

1. Parcel Boundary Information from Los Angeles, CA, Department of Public Works, Online ArcInfo GIS data set, 2004. Montrose Chemical Corporation Boundary Survey conducted August 13, 2001 by Dulin-Boynton Land Surveyors.
2. Satellite/Aerial Photos Reference: Urban Areas Georeferenced Satellite Imagery, March 29, 2004.
3. DNAPL Present Contour from Hargis & Assoc., Inc,. Technical Memorandum Addendum 2 to the Results of DNAPL Reconnaissance Investigation, Montrose Site, Torrance, CA to the EPA dated February 20, 2008.
4. Source: Earth Tech, 2008b and 2008e

NORTH

0 60 120 FEET

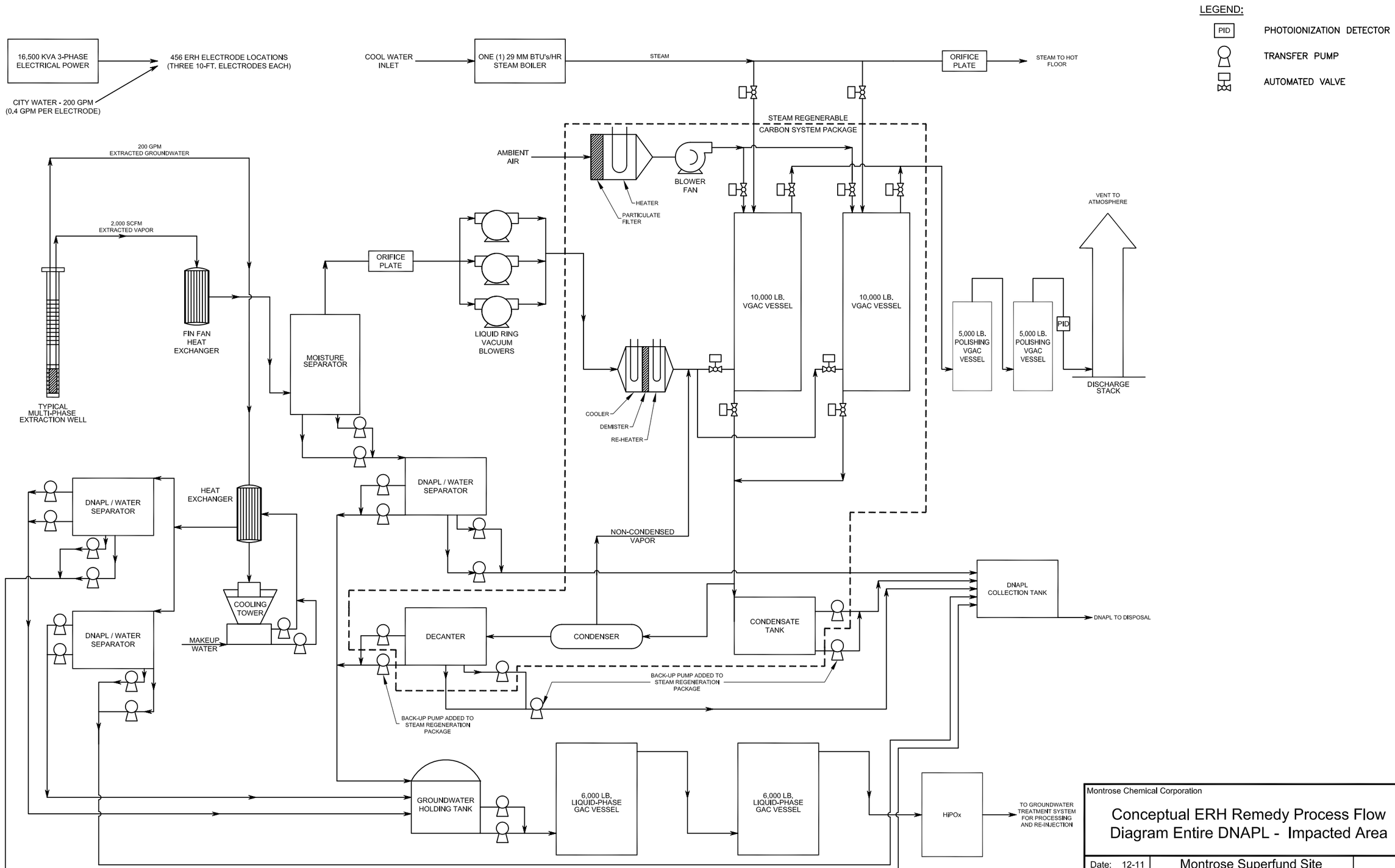
SCALE: 1"= 120'

Montrose Chemical Corporation

UBA Conceptual ERH Remedy Well Pattern
Entire DNAPL - Impacted Area

Date: 12-11	Montrose Superfund Site	Figure
Project No. 60212541	AECOM	5.31

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.31.120311.DWG



Montrose Chemical Corporation

Conceptual ERH Remedy Process Flow Diagram Entire DNAPL - Impacted Area

Date: 12-11	Montrose Superfund Site	Figure 5.32
Project No. 60212541	AECOM	

FILE NAME: T:\MONTROSE\DNAPL FS\DNAPL-FS.SEC 5.0.FIG 5.32.120311.DWG

Section 6.0

Detailed Analysis of Alternatives

6.0 DETAILED ANALYSIS OF ALTERNATIVES

This section presents the detailed analysis of the nine RAs retained following the intermediate screening in Section 5.0. The candidate RAs are evaluated according to nine performance criteria defined by the NCP (40 CFR 300.430 (e)(9)). Section 6.1 briefly identifies and presents an overview of the nine performance criteria. The detailed evaluation of the candidate RAs is provided in Section 6.2. The performance of the RAs relative to the nine criteria is then compared in Section 7.0. The RAs to be evaluated in this section are summarized as follows:

Candidate DNAPL Remedial Alternatives

Remedial Alternative	GRA Remedial Technologies/Process Options
Remedial Alternative 1	No Action
Remedial Alternative 2	Institutional Controls
Remedial Alternative 3	Institutional Controls SVE (unsaturated zone)
Remedial Alternative 4a	Institutional Controls SVE (unsaturated zone) Hydraulic Displacement, with untreated water injection
Remedial Alternative 4b	Institutional Controls SVE (unsaturated zone) Hydraulic Displacement, with treated water injection
Remedial Alternative 5a	Institutional Controls SVE (unsaturated zone) Steam Injection, focused treatment area, with hot floor
Remedial Alternative 5b	Institutional Controls SVE (unsaturated zone) Steam Injection, entire treatment area, with hot floor
Remedial Alternative 6a	Institutional Controls SVE (unsaturated zone) ERH, focused treatment area, without hot floor
Remedial Alternative 6b	Institutional Controls SVE (unsaturated zone) ERH, entire treatment area, without hot floor

6.1 DESCRIPTION OF EVALUATION CRITERIA

The NCP categorizes the nine evaluation criteria into three groups: threshold criteria, primary balancing criteria, and modifying criteria. Two of the nine criteria are designated as threshold criteria. The threshold criteria relate directly to statutory findings that must ultimately be met for remedy selection in the ROD. The two threshold criteria are:

- Overall protection of human health and the environment
- Compliance with ARARs

Five of the nine criteria are designated as balancing criteria. These are the primary performance criteria for the detailed analysis considering technical, cost, institutional, and risk concerns:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume throughout treatment
- Short-term effectiveness
- Implementability
- Cost

The final two criteria are designated as modifying criteria, which are used in the final analysis of remedial alternatives to modify an otherwise acceptable alternative, rather than choose among specific different alternatives:

- State acceptance
- Public acceptance

Modifying criteria are considered after public comments have been received on the draft FS documents and the proposed remedial plan. Those comments would be summarized in a Responsiveness Summary that is issued with the ROD. The following paragraphs briefly describe each of the evaluation criteria to be employed in this section.

6.1.1 THRESHOLD CRITERIA

The threshold criteria are described as follows:

Overall Protection of Human Health and the Environment. CERCLA requires that human health and the environment are protected by the selected remedy. RAs are evaluated for their ability to protect human health and the environment both in the short and long-term. Protectiveness can be achieved either through treatment, engineering, or institutional controls.

Compliance with ARARs. CERCLA requires that remedial actions comply with ARARs, as identified in Section 3.0. RAs are evaluated for their ability to comply with ARARs during remedy implementation, or alternately, if a waiver of ARARs is applicable. The TBCs identified in Section 3.0 are not ARARs, and compliance with the TBCs is not a threshold requirement for candidate RAs. While compliance with

TBCs can be considered for purposes of remedy evaluation, none of the RAs can be eliminated from consideration in the FS for lack of compliance with TBCs, which are not enforceable.

6.1.2 BALANCING CRITERIA

The balancing criteria are described as follows:

Long-Term Effectiveness and Permanence. Long-term effectiveness refers to the period after the remedial action is complete. RAs are evaluated for their ability to meet DNAPL RAOs and protect human health and the environment in the long-term. The permanence and reliability of the RAs are evaluated relative to the risks posed by residual contaminants left at the Site.

Reduction in Toxicity, Mobility, or Volume Through Treatment. RAs are evaluated for their ability to reduce the toxicity, mobility, or volume of hazardous substances at the Site. This criterion focuses on the quantity of hazardous substances removed, destroyed, or treated, the irreversibility of the treatment process, and the type, quantity, and mobility of residuals left in place following remedial action.

Short-Term Effectiveness. Short-term effectiveness refers to the period during remedy implementation. RAs are evaluated for their ability to protect human health and the environment in the short-term. The short-term is defined by the remedy duration and is based on the time required for RAOs to be met. The remedy duration will vary for each RA. If treatment at the Site is part of the RA, this evaluation will assess how well the ex-situ treatment system meets the cleanup goals or discharge criteria (i.e., for air or water). The short-term effectiveness evaluation focuses on protection to Site workers and the community during remedy construction and implementation.

In accordance with a memorandum dated February 18, 2011 (AECOM, 2011c), the carbon footprint of each candidate RA will be considered under this balancing criterion. Greenhouse gases generated from natural gas combustion or generation of electrical power would only be emitted during the operational period of the remedy. Therefore, the amount of energy-based GHG emissions from each candidate RA will be evaluated under the short-term effectiveness criterion.

There is a large disparity in GHG emissions between candidate alternatives, including some that exceed the federal reporting threshold of 25,000 metric tons per year and have carbon footprints greater than several California power plants. Incorporation of GHG emissions as one of several factors under the short-term effectiveness criterion allows for a balancing of factors without trading cleanup objectives for other environmental objectives. GHG emissions are not being evaluated as a threshold criteria or being used to screen out or exclude remedial alternatives from consideration. GHG emissions are also not being

considered under or against any other balancing criteria such as long-term effectiveness. GHG emissions are being used to evaluate remedial alternatives offering the best balance of short-term effectiveness with the other NCP criteria including long-term effectiveness, implementability, cost, and reduction of toxicity, mobility, or volume.

Implementability. Alternatives are evaluated relative to the technical and administrative feasibility of implementing the RA, as well as the availability of necessary goods and services. The technical feasibility refers to the ability to construct and reliably operate and maintain the components of the RAs. The administrative feasibility refers to the ability to obtain approvals from regulatory agencies and the availability of vendors, specific equipment, technical specialists, or waste disposal services.

Cost. The cost of each RA is estimated in accordance with EPA guidance document *Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA, 2000). In accordance with this guidance document, order-of-magnitude cost estimates (+50/-30 percent) were prepared based on a conceptual design for each RA as presented in Section 5.1. However, significant efforts have been made to estimate costs for many of the candidate RAs, and the relative accuracy of the cost estimates is believed to be narrower than the typical range required for feasibility studies as indicated above. Where applicable, RA costs include remedial design, construction, operation and maintenance, remedy verification, and abandonment. Costs are based on subcontractor/vendor quotations, catalogue or list prices, California Means prices, cost reconciliation discussions, and engineering experience.

The present-worth of each RA was estimated in accordance with the 2000 EPA guidance document and for purposes of comparing RAs with different remedy durations. The present-worth of a project is the amount of money that, if invested at the start of the remedial action, would be sufficient to fund all the costs associated with that RA over its planned duration. Annual RA costs are discounted to present-worth dollars (i.e., at Time 0), meaning that Year 1 costs are discounted one year. Year 2 costs are discounted two years, and so on. For this DNAPL FS, the present-worth costs (or net present value (NPV)) have been estimated assuming discount rates of both 4% and 7%. For privately funded remedies, the EPA guidance document specifies that "*a real discount rate of 7 percent should generally be used for all non-Federal facility sites.*" As requested by EPA and in accordance with the above referenced guidance document, remedial alternative costs are presented at a 7% discount rate in this FS.

Since the 7% discount rate specified in the EPA guidance document has not been updated since the Year 2000, Montrose additionally elected to present remedial alternative costs at a 4% discount rate. The EPA guidance document recommends that Federally-funded sites use the real discount rate specified in

Appendix C of the Office of Management and Budget (OMB) Circular A-94, which is updated annually. The discount rate specified in Circular A-94 is based on treasury notes and bonds, which have a lower rate of return than private responsible parties can achieve through other investment options. As reported by the OMB, the average long-term real discount rate (30-Year) over the past 30 years is 4%.

Although current rates of return and inflation are both very low, use of these values for estimating NPV costs in this FS were not recommended as described in a letter authored by Richard White of Gnarus Advisors LLC, a copy of which is provided in **Appendix M**. In any event, the durations of the candidate DNAPL remedial alternatives in this FS are relatively short and vary from 4 to 9 years including remedial design, construction, O&M, verification, and abandonment. Over these relatively short durations, variations in the discount rate will not have a significant impact on the estimated NPV cost of the candidate alternatives.

6.1.3 MODIFYING CRITERIA

The modifying criteria are discussed as follows:

State Acceptance. This criterion considers the concerns that the State, both technical and administrative, regarding the candidate RAs and DNAPL FS. State concerns and acceptance issues will be presented in the ROD once the State has commented on the DNAPL FS and Proposed Plan. As such, State acceptance cannot be discussed in this FS and is deferred to the ROD.

Public Acceptance. This criterion considers the concerns that the public may have regarding the candidate RAs and DNAPL FS. Following preparation of the DNAPL FS and Proposed Plan, the public will be invited to comment on the DNAPL FS and candidate RAs. Public comments will be addressed by EPA in the ROD.

6.2 ANALYSIS OF REMEDIAL ALTERNATIVES

The detailed analysis of each candidate RA is presented in this section, including RAs 1, 2, 3, 4a and 4b, 5a and 5b, and 6a and 6b. The performance of each RA relative to the nine NCP criteria is discussed in each subsection below in sequential order, from RA 1 through RA 6b. A summary of the RA performance analysis is provided in **Table 6.1**, and detailed cost estimates for each of the candidate RAs is provided in **Appendix J**. The performance of the RAs will be compared against one another in Section 7.0, and therefore, is not discussed in this section (with a few exceptions).

6.2.1 REMEDIAL ALTERNATIVE 1 – NO ACTION

This RA includes one GRA: No Action for DNAPL in both the unsaturated and saturated zones.

Overall Protection of Human Health and the Environment. The No Action RA would not be protective of the environment. Mobile DNAPL mass, the principal threat, would not be reduced under this RA, and the potential for recontamination of the aquifers would remain. Although the DNAPL may not be migrating significantly under current hydraulic conditions, this RA would not be protective of groundwater resources. Additionally, institutional controls are not a component of this RA and would not be in place to protect human health against exposure to DNAPL, although institutional controls for soil and groundwater are likely to limit contaminant exposure pathways at the Site and protect human health to some extent. Under this No Action RA, DNAPL and MCB would remain in the unsaturated zone as a long-term source for soil vapor and groundwater pathways. ***Rank: Not Protective.***

Compliance with ARARs. Although the remedies for soil and groundwater will include institutional controls, this No Action RA may not be in compliance with Land Use Covenant requirements under CCR Title 22 and the California Civil Code. Deed restrictions may be required to prevent exposure to DNAPL-impacted soils in the long-term, depending on the provisions established for soil and groundwater. The remedy for groundwater ensures compliance with groundwater-related ARARs, and the DNAPL occurs fully within the TI Waiver Zone. ***Rank: Does Not Comply.***

Long-Term Effectiveness and Permanence. The No Action RA would not reduce mobile DNAPL mass or the potential for recontamination of the aquifers to the extent practicable. This RA would not limit migration of mobile DNAPL or increase the certainty of maintaining hydraulic containment. DNAPL and MCB mass in the unsaturated zone would not be reduced by this RA. This RA would not meet RAOs and would not be effective in the long-term. ***Rank: Not Effective.***

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents. The No Action RA does not reduce the toxicity, mobility, or volume of DNAPL in the subsurface. No DNAPL mass or MCB vapors would be reduced or removed under this RA. ***Rank: Does Not Reduce Toxicity, Mobility, and Volume.***

Short-Term Effectiveness. Without formal institutional controls in place to protect human health, this No Action RA would not be effective in the short-term, although institutional controls from the soil and groundwater programs may provide some protection at the Site. By definition, there is no carbon footprint associated with this No Action RA. ***Rank: Not Effective.***

Implementability. By definition, the No Action RA is highly implementable. ***Rank: Highly Implementable.***

Cost. By definition, there is no cost associated with the No Action RA. ***Rank: No Cost.***

State Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the State. EPA will address this criterion in the ROD. However, it is unlikely that a No Action RA would be acceptable to the State. ***Rank: Not Applicable.***

Public Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the public. However, it is unlikely that a No Action RA would be acceptable to the public since none of the DNAPL or MCB contamination would be removed from the Site. ***Rank: Not Applicable.***

6.2.2 REMEDIAL ALTERNATIVE 2 – INSTITUTIONAL CONTROLS

This RA includes one GRA: institutional controls.

Overall Protection of Human Health and the Environment. The institutional controls component of this RA protects human health by restricting Site access and uses that may result in exposure to DNAPL-impacted soils. The extent of DNAPL occurs fully within the TI Waiver Zone, and nearly all of the DNAPL occurs at the Montrose Property where land use can be effectively controlled. Additionally, the hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase

However, this institutional controls RA would not be protective of the environment. Mobile DNAPL mass, the principal threat, would not be reduced under this RA, and the potential for recontamination of the aquifers would remain. This RA would not be protective of groundwater resources. Under this RA, DNAPL and MCB would remain in the unsaturated zone as a long-term source for soil vapor and groundwater pathways. ***Rank: Not Protective.***

Compliance with ARARs. The institutional controls component of this RA would comply with Land Use Covenant requirements under CCR Title 22 and the California Civil Code. Compliance with this ARAR at the Montrose Property where nearly all of the DNAPL occurs should not be problematic. However, a small amount of DNAPL may occur at the GLJ Holdings property bordering the Property to the north. Compliance with land use ARARs at the off-Site property would require consent by the land owner and may be problematic. ***Rank: Complies.***

Long-Term Effectiveness and Permanence. While human exposure to DNAPL would be controlled, this institutional controls RA would not reduce mobile DNAPL mass or the potential for recontamination of the aquifers to the extent practicable. This RA would not limit migration of mobile DNAPL or increase the certainty of maintaining hydraulic containment. DNAPL and MCB mass in the unsaturated zone would not be reduced by this RA. This RA would not meet RAOs and would not be effective in the long-term. ***Rank: Not Effective.***

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents. The institutional controls RA does not reduce the toxicity, mobility, or volume of DNAPL in the subsurface. No DNAPL mass or MCB vapors would be reduced or removed under this RA. ***Rank: Does Not Reduce Toxicity, Mobility, and Volume.***

Short-Term Effectiveness. Institutional controls would be protective of human health in the short-term by limiting the exposure pathways. There are no adverse effects resulting from application of institutional controls, and additionally, there is no carbon footprint associated with this RA. However, RA 2 would not be protective of the environment in the short-term. RA 2 does not reduce the mobile DNAPL mass in the saturated zone or the potential for uncontrolled migration in either the unsaturated or saturated zones. ***Rank: Not Effective.***

Implementability. As described in Section 5.2.2, there are no technical or administrative aspects that would limit the implementability of recording a deed restriction for the on-Property portion of the Site, where nearly all of the DNAPL in the subsurface occurs. A small portion of the DNAPL may be present below the adjacent property to the north (GLJ Holdings), and application of deed restrictions at the off-Property areas would require consent of the land owners. ***Rank: Highly Implementable.***

Cost. The estimated cost of RA 2 is $0.2 MM NPV at a discount rate of both 4% and 7% as shown in Table 6.1 and Appendix J. This estimated cost reflects recording of a Land Use Covenant at the Montrose Property and annual site inspections by the State for purposes of verifying that the Site is being used in accordance with the land use restrictions. Although potential costs for establishing a deed restriction in off-Property areas, if necessary, are uncertain, an allowance of $15,000 per property is included in this estimate. In accordance with EPA guidance protocols, the cost of this institutional controls component is included for the first 30 years. ***Rank: Low Cost ($0.2 MM NPV).***

State Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the State. EPA will address this criterion in the ROD. However, it is unlikely that

an institutional controls RA, by itself, would be acceptable to the State. The State is likely to accept institutional controls in combination with other DNAPL remedial technologies. ***Rank: Not Applicable.***

Public Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the public. However, it is unlikely that an institutional controls RA would be acceptable to the public since none of the DNAPL or MCB contamination would be removed from the Site. ***Rank: Not Applicable.***

6.2.3 REMEDIAL ALTERNATIVE 3 – SVE IN THE UNSATURATED ZONE

This RA includes two GRAs: (1) SVE in the unsaturated zone, and (2) institutional controls.

Overall Protection of Human Health and the Environment. RA 3 protects the environment by removing the source of VOCs and DNAPL in the permeable unsaturated zone overlying groundwater. The mass of VOCs and DNAPL in the permeable unsaturated zone would be significantly reduced by SVE, thereby reducing the future risk to groundwater from contaminant leaching. However, for all RAs, it is noted that VOCs will likely be left in place within the low permeability PD soils (4 to 25 feet bgs), where SVE is significantly less effective. RA 3 additionally protects human health and the environment by controlling VOC migration in soil gas in the short-term.

Human health is protected by the institutional controls and SVE components of the remedy by limiting contaminant exposure pathways. Exposure to contaminants at surface will be addressed by the remedy for soil, and exposure to dissolved-phase contaminants are addressed by the remedy for groundwater. The institutional controls component of this RA restricts Site access and uses that may result in exposure to DNAPL-impacted soils. The SVE component of RA 4b additionally protects human health and the environment by removing the source of VOCs/DNAPL in the unsaturated zone and controlling VOC migration in soil gas in the short-term. The hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase, and DNAPL mass is reduced over time by dissolution.

Although SVE would be protective of human health and the environment within the unsaturated zone, this RA would not limit uncontrolled migration of mobile DNAPL or be protective of the environment in the saturated zone. Without removing mobile DNAPL from the saturated zone, the principal threat, this RA would not reduce the potential for recontamination of the aquifers. ***Rank: Not Protective in the Saturated Zone.***

Compliance with ARARs. RA 3 would comply with DNAPL ARARs. The institutional controls component of this RA would comply with Land Use Covenant requirements under CCR Title 22 and the California Civil Code. The SVE component of this RA would need to comply with federal and state ARARs related to air quality including the Clean Air Act and SCAQMD regulations. Additionally, RA 3 would need to comply with SCAQMD regulations governing emissions of toxic chemicals and potentially particulate matter and products of incomplete combustion, depending on the vapor treatment technology selected for the RA. All three vapor treatment technologies considered by this FS are capable of meeting the air emission ARARs.

The system would be designed to automatically terminate SVE operations in advance of exceeding the air emission ARARs. This RA would generate solid waste including soil cuttings, decontamination water, PPE, and spent carbon, and would need to comply with regulations governing waste classification, management, and disposal including CFR Title 40 and CCR Title 22. ***Rank: Complies.***

Long-Term Effectiveness and Permanence. RA 3 will reduce the mass of VOCs and DNAPL in the permeable unsaturated zone to a level that significantly reduces the future risk to the underlying groundwater from contaminant leaching. However, SVE would be significantly less effective in the low permeability PD soils, and the VOC mass may not be significantly reduced within this interval (4 to 25 feet bgs). The permanence of the remedy is improved by removal of VOC/DNAPL mass from the unsaturated zone, but the required duration of hydraulic containment in the long-term is not reduced by this RA.

However, mobile DNAPL mass and the potential for recontamination of the aquifers would not be reduced in the saturated zone by RA 3. The probability of maintaining containment in the long-term would not be significantly increased, and the potential for uncontrolled migration of mobile DNAPL would not be limited in the saturated zone. Although this RA would be effective in the unsaturated zone, it would not be effective in the saturated UBA. ***Rank: Not Effective.***

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents. The volume (and mass) of hazardous constituents in the unsaturated zone is reduced by RA 3. As described in Section 5.1.3, an estimated 249,000 to 276,000 pounds of MCB would be removed from the unsaturated zone by SVE depending on the removal efficiency within the layers of varying permeability. This mass corresponds to a volume of approximately 27,000 to 30,000 gallons of MCB. VOCs, including the volatile fraction of DNAPL (i.e., MCB), are extracted from the unsaturated zone by SVE. DNAPL mobility in the unsaturated zone is also reduced by volatilization of the MCB component since the DDT component of

the DNAPL will sorb strongly to soil and is relatively immobile in the environment. The toxicity of the unsaturated soils and soil gas is also reduced by this RA. However, this RA does not reduce the toxicity, mobility, or volume of mobile DNAPL mass in the saturated zone. ***Rank: Reduces Toxicity, Mobility, and Volume in the Unsaturated Zone Only (approximately 27,000 to 30,000 gallons of MCB).***

Short-Term Effectiveness. RA 3 has a total duration of 7 years but is not effective in protecting human health and the environment in the short-term. Under this RA, soil vapors are extracted from the permeable unsaturated zone for ex-situ treatment. All three candidate ex-situ vapor treatment technologies would be effective in treating Site contaminants and complying with air quality ARARs. Disposable carbon/resin is identified as the lowest cost treatment technology for this RA and was highly effective in meeting air emission standards during SVE field pilot testing in 2003. Vapor-phase Site contaminants (most notably MCB) are effectively treated by carbon/resin adsorption, and a relatively high MCB mass adsorption efficiency of 25% by weight was observed during field pilot testing. Additionally, this vapor treatment technology does not involve any combustion processes (such as thermal oxidation), steam-regeneration processes (such as with on-site carbon/resin regeneration), or any on-Site accumulation of condensed VOCs/DNAPL (such as with steam-regenerable carbon/resin). Spent carbon/resin is evacuated for off-Site recycling or disposal, and virgin carbon/resin is placed into the adsorber beds. Safe-work procedures would be employed during replacement of the carbon/resin to protect the health of on-Site workers and prevent release of any VOCs, nuisance odors, or carbon dust. Disposable carbon/resin is the least complex vapor treatment technology and is a reliable method for protecting human health and the environment during remedy implementation. However, RA 3 does not reduce the mobile DNAPL mass in the saturated zone or the potential for uncontrolled migration. Therefore, this RA is not effective in protecting the environment in the short-term.

Engineering controls would be used to automatically terminate SVE operations if air emissions exceed limits, to ensure compliance with air quality standards at all times. A small volume of moisture condensate would also be generated by this SVE RA and, if the full scale groundwater remediation system is not on-line, temporarily accumulated on-Site in drums, and transported for off-Site disposal within 90 days of generation. The moisture separator and drum storage would be located within a secondary containment area to prevent accidental releases to the surface and stormwater pathways. Contaminated soil cuttings would be generated during SVE well installation and temporarily accumulated on-Site (in sealed roll-off bins) pending disposal. Safe-work procedures would be employed to protect the health of on-site workers during well installation activities and prevent release of any VOCs, nuisance odors, or dust. As described in Section 5.1.3, this RA has an energy-based carbon footprint of 6 million pounds of GHGs. This RA has the smallest carbon footprint (other than the zero footprints of RAs 1 and

2) of all the RAs considered in this FS. This carbon footprint is below the mandatory reporting threshold of 25,000 metric tons per year (660 metric tons per year). ***Rank: Not Effective (6 million pounds of GHGs).***

Implementability. As described in Section 5.2.3, there are no technical or administrative aspects that would limit the implementability of this RA. SVE is a widely used technology for remediating VOCs in permeable unsaturated soils, and equipment required to implement the RA is readily available. Highly skilled operators are not required for this RA, and there are a large number of contractors available to provide SVE remediation services. The SVE aspects of this RA would have to meet ARARs for air emissions. ***Rank: Highly Implementable.***

Cost. The estimated cost of RA 3 is $4.4 to $4.8 MM NPV at discount rates of 7% and 4%, respectively, as shown in Table 6.1 and Appendix J. This cost includes $0.2 MM NPV for institutional controls as estimated for RA 2. As described in Section 5.1.3, this cost assumes a total of 23 extraction wells and a 1,500 scfm vapor extraction and treatment system. Soil vapors are assumed to be treated using disposable carbon/resin, which was found to be the lowest cost treatment technology for the estimated MCB mass in the permeable unsaturated zone. If a steam-regenerable carbon system were used to treat soil vapors, the cost of this RA would increase to approximately $6 MM NPV. If a thermal oxidizer with acid gas scrubber were used to treat soil vapors, the cost of this RA would increase to nearly $7 MM NPV.

The duration of the remedy, which directly affects costs, is assumed to be 7 years total based on the following schedule of activities:

- Year 1 = Design
- Year 2 = Construction
- Years 3-6 = 4 years of O&M
- Year 7 = Verification and Abandonment

SVE operations are assumed to be approximately 4 years based on (i) an estimated 261,000 pounds of MCB in the permeable unsaturated zone; (ii) an initial MCB mass removal rate of 5,000 pounds per week; and (iii) a first order decay curve (Figure 5.4). Although the assumed 4-year duration reflects approximately 5,000 pore volumes of soil vapor flushing, the operational period is believed to be a reasonable assumption given the geologic conditions, presence of DNAPL, proximity to groundwater, and relatively low vapor pressure of MCB. Assuming a 25% MCB mass adsorption capacity, an estimated 20,000 pounds of disposable carbon would be consumed weekly at the start of the project. A 25% MCB mass adsorption efficiency was observed during SVE pilot testing and is consistent with carbon

performance expectations based on published isotherms from carbon suppliers. The estimated cost for this RA also includes 10 soil verification borings following completion of active remediation. ***Rank: Low to Moderate Cost ($4.4 to $4.8 MM NPV).***

State Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the State. EPA will address this criterion in the ROD. However, it is unlikely that an SVE RA, by itself, would be acceptable to the State since no mobile DNAPL mass would be reduced in the saturated zone. The State is likely to accept SVE in the unsaturated zone in combination with other saturated zone DNAPL remedial technologies. ***Rank: Not Applicable.***

Public Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the public. However, it is unlikely that an SVE RA, by itself, would be acceptable to the public since no mobile DNAPL mass would be removed from the saturated zone. Additionally, the public would be expected to have concerns regarding the type of ex-situ soil vapor treatment technology used as part of an SVE remedy in the unsaturated zone. ***Rank: Not Applicable.***

6.2.4 REMEDIAL ALTERNATIVE 4A – HYDRAULIC DISPLACEMENT WITH UNTREATED WATER INJECTION

This RA includes three GRAs: (1) hydraulic displacement with untreated water re-injection in the saturated UBA, (2) SVE in the unsaturated zone, and (3) institutional controls.

Overall Protection of Human Health and the Environment. This alternative is protective of human health and the environment. RA 4a protects the environment by significantly reducing the mobile DNAPL mass at the Site, the principal threat, and the potential for recontamination of the aquifers following treatment. The mobility of the remaining DNAPL will be significantly reduced and unlikely to pose a significant threat to the environment or risk of uncontrolled migration under normal hydrologic conditions. Hydraulic displacement depletes the DNAPL saturation, thereby significantly reducing the mobility of the remaining DNAPL. The hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase and reducing DNAPL mass in the long-term by dissolution. The SVE component of RA 4a additionally protects human health and the environment by removing the source of VOCs/DNAPL in the permeable portions of the unsaturated zone and controlling VOC migration in soil gas in the short-term.

Human health is protected by the institutional controls and SVE components of the remedy by limiting contaminant exposure pathways. Exposure to contaminants at surface will be addressed by the remedy

for soil, and exposure to dissolved-phase contaminants are addressed by the remedy for groundwater. The institutional controls component of this RA restricts Site access and uses that may result in exposure to DNAPL-impacted soils. The SVE component of RA 4b additionally protects human health and the environment by removing the source of VOCs/DNAPL in the unsaturated zone and controlling VOC migration in soil gas in the short-term. The hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase, and DNAPL mass is reduced over time by dissolution.

Mobile DNAPL is hydraulically displaced during this remedy and effective recovery of the DNAPL is necessary to protect the environment from lateral spreading or downward migration. The capillary barriers within the UBA may not be continuous across the DNAPL-impacted area, and mobilized DNAPL could migrate vertically downward through a discontinuity between injection and extraction wells. However, the risks associated with uncontrolled contaminant migration can be off-set to some extent by a high well density, i.e. a closer well spacing. A conceptual well spacing of 50 feet is considered for this hydraulic displacement RA and is less than computer modeled distances, which predicted that hydraulic displacement would be effective even at a well spacing of 120 feet. Additionally, computer modeling of hydraulic displacement predicted that no DNAPL would be mobilized past the basal silty sand member of the UBA or to the underlying BFS (H+A, 2009b). Although there is some uncertainty with regards to the continuity and pore entry pressures of the basal layer, it is expected to be able to support DNAPL pool heights between 1.3 and 8 feet, if continuous. ***Rank: Protective.***

Compliance with ARARs. RA 4a would not comply with ARARs unless a waiver was granted to allow re-injection of untreated groundwater (as approved during field pilot testing). However, it is Montrose's position that RA 4a meets the requirements of 42 U.S.C. § 6939(b) by substantially reducing hazardous constituents prior to groundwater re-injection. The degree of reduction that will be considered "substantial" is determined on a case-by-case basis. *See* Applicability of Land Disposal Restrictions To RCRA and CERCLA Groundwater Treatment Reinjection Superfund Management Review: Recommendation No. 26, OSWER Directive # 9234. 1-06 (Dec. 27, 1989). It is anticipated that separation of the DNAPL from groundwater following total fluids extraction under RA 4a will initially remove up to 90% of the total contaminant mass before re-injection. Pilot tests at the Site have already demonstrated the ability of RA 4a to comply with all ARARs and substantially reduce hazardous constituents prior to re-injection. In a 28-day field pilot study in 1991, 298 gallons of DNAPL were removed from a single well prior to re-injection of the groundwater. In August 2003 and February 2004, the State and EPA respectively approved a more expansive DNAPL extraction pilot test in which groundwater from the DNAPL-impacted area was extracted, passed through an in-line DNAPL/water

separator and filtration system, and returned to the UBA via injection wells. The expanded pilot test approved by EPA and the State yielded similar results as the 1991 pilot study, conclusively demonstrating the ability of RA 4a to substantially reduce hazardous constituents.

Additionally, re-injection of untreated groundwater above MCLs has previously been approved at two hydraulic displacement sites in EPA Regions 8 and 10 as described in Appendix K: Baxter/Union Pacific Tie Treating Site (Laramie, Wyoming) and Union Pacific Railroad Tie-Treating Plant (Dalles, Oregon). Furthermore, the reinjection of groundwater pursuant to RA 4a would not trigger the State's anti-degradation policy because it would not negatively impact existing groundwater quality in the area as the re-injection would take place entirely within the boundaries of the already contaminated TI Waiver Zone established by EPA in the ROD, and would improve, rather than degrade groundwater quality by removing mobile DNAPL form the subsurface. The anti-degradation policy applies only to high quality waters and is not triggered if the receiving groundwater is already contaminated and the re-injection of contaminated water back into the area would not make matters worse. *See* ARAR Q's and A's: General Policy, RCRA, CWA, SDWA, Post-ROD Information, and Contingent Waivers, Publication 9234.2-01/FS-A (June 1991).

The institutional controls component of this RA would comply with Land Use Covenant requirements under CCR Title 22 and the California Civil Code. The SVE component of this RA would need to be constructed and operated to comply with federal and state ARARs related to air quality including the Clean Air Act and SCAQMD regulations. This RA would generate solid waste including soil cuttings, decontamination water, PPE, DNAPL, and spent carbon, and would need to comply with regulations governing waste classification, management, and disposal including CFR Title 40 and CCR Title 22.

Hydraulic displacement wells installed under this RA would need to comply with California Well Standards. Separate-phase DNAPL is also temporarily accumulated on-Site (pending disposal) under this RA, and therefore, the aboveground tank would have to comply with regulations for hazardous material accumulation, including CFR Title 40 and CCR Title 22.

Despite EPA and State approval during the pilot studies at this Site and other sites, EPA largely disagrees with Montrose that RA 4a meets the standards of 42 U.S.C. § 6939(b) by substantially reducing hazardous constituents prior to reinjection, and has required that RA 4a be ranked as not complying with ARARs unless the re-injection standards are temporarily waived in the short-term. ***Rank: Does Not Comply (unless waiver of ARAR is granted in the short-term).***

Long-Term Effectiveness and Permanence. RA 4a is moderately effective in the long-term. Under this RA, mobile DNAPL mass is removed from the saturated UBA by hydraulic displacement. Field pilot testing has demonstrated the ability for hydraulic displacement to recover mobile DNAPL, reducing both the volume and mobility of hazardous constituents in the UBA. Up to 5.6 gallons per day per well of mobile DNAPL were recovered during field pilot testing at moderate hydraulic gradients, without the benefit of groundwater re-injection. Mobile DNAPL was recovered by hydraulic displacement from all wells located within the estimated mobile DNAPL footprint. Additionally, computer modeling predicted that hydraulic displacement would effectively mobilize DNAPL for recovery at spacings up to 120 feet. Since a conceptual well spacing of only 50 feet is considered by this RA, hydraulic displacement is expected to effectively recover mobile DNAPL in the saturated UBA for removal.

RA 4a is expected to remove a substantial portion of mobile DNAPL and significantly reduce the mobility of any DNAPL left in place. The horizontal gradients during hydraulic displacement will be more than 100 times greater than the gradients during normal hydrologic conditions. With the exception of stagnation zones, which can occur for all displacement technologies (such as steam injection), any DNAPL not mobilized by these high hydraulic gradients is unlikely to be mobile under normal hydraulic gradients. However, RA 4a is unlikely to remove as much mobile DNAPL mass as other candidate alternatives, and any mobile DNAPL mass left in place following HD may reduce the long-term effectiveness of this RA.

Although hydraulic displacement relies on fluid flow through porous and permeable saturated soils, other candidate RAs are equally reliant on these site conditions. Discontinuous sand layers which are not in hydraulic communication with the extraction and injection wells may the limit the effectiveness of this RA and other displacement technologies (e.g., steam injection). Discontinuous capillary barriers may allow DNAPL to migrate vertically downward to the BFS, which would reduce the long-term effectiveness of this remedy and other displacement technologies (e.g., steam injection). However, the basal silty sand layer in the UBA is believed to be continuous across the DNAPL-impacted area and is expected to support DNAPL pool heights between 1.3 and 8 feet, if continuous and depending on the capillary pressures required to penetrate the layer. Additionally, DNAPLs trapped within the low permeability layers of the UBA will not be available for remediation by hydraulic displacement, although DNAPL trapped in low permeability soils inherently pose a lower risk of migration.

Re-injecting untreated groundwater will not threaten hydraulic containment of the groundwater plume. The groundwater flow in the UBA will be balanced (i.e., identical extraction and injection rates), and in accordance with reconciliation discussions, the conceptual design of RA 4a includes a series of additional

containment wells located on the downgradient side of the DNAPL extent as shown in Figure 5.8. These wells will serve as a barrier to protect the groundwater remedy containment wells. Therefore, re-injection of untreated groundwater will have no deleterious effects on hydraulic containment of groundwater in the UBA.

Treatment of the groundwater prior to re-injection is also not required to achieve long-term effectiveness for this RA. Treating the dissolved-phase contaminant concentrations will not reduce the concentration of MCB in groundwater following a DNAPL remedy. Following the DNAPL remedy, MCB will solubilize into groundwater from residual DNAPL in the UBA. Even after the remedy, MCB concentrations in groundwater will remain at or near solubility limits. None of the candidate RAs can remove sufficient DNAPL mass as to meaningfully lower the concentration of MCB in groundwater within the TI Waiver Zone. For this reason, hydraulic containment of groundwater will be required for hundreds or thousands of years following remediation, regardless of which DNAPL RA is selected.

This fact was also recognized by EPA in evaluating candidate NAPL remedies for the Del Amo Superfund Site. In the Final FS (URS, 2010), all of the candidate NAPL remedies indicated that dissolved benzene concentrations would remain at or near the solubility limit following remedy implementation. The time required for hydraulic containment following NAPL remediation at the Del Amo Superfund Site was several thousand years. Although there are differences between the Montrose and Del Amo Sites, the relative impact to groundwater from dissolved VOCs following a NAPL remedy will be similar.

The SVE component of this RA would reduce the VOC/DNAPL mass in the permeable unsaturated zone to a level that significantly reduces the future risk to the underlying groundwater from contaminant leaching. The permanence of the remedy is improved by removal of VOC/DNAPL mass from both the unsaturated and saturated zones. ***Rank: Moderately Effective.***

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents. RA 4a reduces the volume of DNAPL in the saturated zone and significantly reduces the mobility of the DNAPL. An estimated 28% to 38% of the DNAPL mass at the Site is mobile DNAPL (221,800 to 340,000 pounds) and available for removal by hydraulic displacement. Mobile DNAPL is removed by the hydraulic displacement component of this RA, reducing the saturation of DNAPL remaining in the subsurface. The highest DNAPL saturations are the most mobile and are the easiest to recover by hydraulic displacement. DNAPL becomes significantly less mobile as the saturation is reduced. Hydraulic displacement is a depleting technology that works within the existing DNAPL architecture and continuously reduces the

DNAPL mobility over time. If hydraulic displacement is effective in reducing DNAPL saturations to residual levels, then the DNAPL would be immobile and no longer a risk of further migration (other than as a source for dissolved-phase contaminants which are effectively addressed by hydraulic containment). However, DNAPL/water capillary pressure testing (Section 2.1.2 and Appendix B) suggests that elevated capillary pressures would be required to displace the final 1% to 1.5% of mobile DNAPL (e.g., 18.9% to 20.4% DNAPL saturations). Therefore, high mass removal efficiencies approaching 100% are unlikely for RA 4a. Additionally, some DNAPL may sorb to pore spaces as it is moves through the porous soils to the extraction wells, even though water is believed to be the wetting fluid (i.e., water will preferentially wet the pore surfaces over the DNAPL). Therefore, mass removal efficiencies over 90% are also unlikely for HD.

However, for the purposes of this FS, an 80% mobile DNAPL mass removal efficiency is assumed for RA 4a. Given the relatively high well density considered for this RA, DNAPL would have to travel lateral distances of 50 feet or less to reach an extraction well, resulting in a higher mass removal efficiency (i.e., less of an opportunity for DNAPL to sorb to soil grains before reaching the extraction well). While an 80% mobile DNAPL mass removal efficiency is a simplification of the depletion process, it reasonably bounds the upper end of the technology performance range for the purposes of this FS. Assuming 80% mobile DNAPL mass reduction, an estimated 177,400 to 272,000 pounds of liquid-phase DNAPL would be removed by RA 4a. Assuming that MCB represents 50% of the DNAPL mass, the estimated amount of MCB mass reduction under RA 4a would therefore be between 88,700 and 136,000 pounds or approximately 9,000 to 13,000 gallons of MCB.

The SVE component of this RA also reduces the volume (and mass) of hazardous constituents in the unsaturated zone and the toxicity of unsaturated zone soils and soil gas. Lowering of the water table around the HD extraction wells will additionally expose soils to SVE in the overlying unsaturated zone. VOCs, including the volatile fraction of DNAPL (i.e., MCB), are extracted from the subsurface by SVE. DNAPL mobility in the unsaturated zone is also reduced by volatilization of the MCB component since the DDT component of the DNAPL will sorb strongly to soil and is relatively immobile in the environment. ***Rank: Moderately Reduces Toxicity, Mobility, and Volume (9,000-13,000 gallons of MCB in the saturated zone and 27,000 to 30,000 gallons in the unsaturated zone).***

Short-Term Effectiveness. RA 4a has a total duration of 8 years and is effective in protecting human health and the environment in the short-term. Under this RA, groundwater and DNAPL are extracted from the subsurface for ex-situ handling. DNAPL would be separated from groundwater and temporarily accumulated at the Property pending off-Site transport and disposal. Groundwater would be filtered and

re-injected into the UBA to enhance hydraulic gradients. Engineering controls would be provided to ensure the protection of human health and the environment in the short-term during DNAPL and groundwater handling. DNAPL would be accumulated in a dual-contained tank with engineering controls to prevent over-filling and automatically detect leaks. Secondary containment with leak detection would also be provided for the groundwater handling system to effectively prevent releases of contaminated groundwater to surface. No ex-situ dissolved-phase contaminant treatment system is required for this RA. During installation of the multiphase extraction and groundwater injection wells, safe-work procedures would be employed to protect the health of on-site workers and prevent release of any VOCs, nuisance odors, or dust.

The short-term effectiveness of the SVE component is the same as for RA 3. Disposable carbon/resin would be the lowest cost ex-situ treatment technology for soil vapors and would effectively treat vapor-phase contaminants in compliance with air emission ARARs. VOC migration in soil gas would be controlled by SVE during remedy implementation.

This displacement alternative, like steam injection, will mobilize DNAPL and has the potential to result in downward vertical migration through discontinuous capillary barriers in the UBA. Any DNAPL migration into the BFS as a result of hydraulic displacement would not be effective in the short-term. However, modeling suggests that DNAPL may not penetrate through the basal layer in the UBA if continuous. Under varying capillary pressure assumptions, the basal layer is expected to support DNAPL pool heights between 1.3 and 8 feet, if continuous. The underlying BFS will be monitored for evidence of adverse migration during the remedy, if any. BFS monitoring wells beneath and surrounding the Focused Treatment Area will be routinely monitored for the presence of DNAPL, and the MCB concentrations in these wells will be monitored for evidence of increasing concentration trends. Furthermore, groundwater will also be monitored at the Site in accordance with the future Monitoring and Aquifer Compliance Plan as required by the Groundwater ROD (EPA, 1999).

As described in Section 5.1.4, the energy-based carbon footprint of this RA is approximately 11 million pounds of GHGs. This RA has one of the smaller carbon footprints of the RAs considered in this FS (smallest of the focused treatment area RAs) and would not exceed the mandatory reporting threshold of 25,000 metric tons per year (approximately 1,000 metric tons per year). The relatively low carbon footprint complies with EPA and State green remediation initiatives and advances the goals of the California Global Warming Act of 2006. ***Rank: Effective (11 million pounds of GHGs).***

Implementability. As described in Section 5.2.4, this RA is technically implementable, and field pilot testing has demonstrated the feasibility of removing DNAPL at a moderate rate by hydraulic displacement. Extraction wells can be installed using standard drilling methods and equipment, although the number of wells required under this RA (69 extraction and injection wells) would generate a substantial amount of waste. Standard separation techniques can be used to separate the Montrose DNAPL from groundwater, and specialized field equipment or contractors are not required for this RA. However, skilled operators and a moderate to high level of routine maintenance would be required to abate precipitate fouling of the extraction pumps/piping, which was observed during the extraction pilot test. A routine well development program would be required to abate the effects of injection well fouling. Severe fouling was not observed during field pilot testing, where one of the two injection wells lost 50% of its capacity after a lengthy test period with no redevelopment program (partially due to mounding in the unsaturated zone). Furthermore, spare upgradient injection wells were incorporated into the conceptual design for this remedy, reducing the impact of injection well fouling on the implementability of this RA. Therefore, the implementability of re-injecting water into the UBA at the Site has already been successfully demonstrated.

Administratively, RA 4a may be difficult to implement because a waiver of the re-injection standards would be required from EPA and the State over the 5-year duration of the remedy. However, re-injection of untreated groundwater was previously approved by EPA and the State for the 2004/2005 field pilot test, and EPA has previously approved this approach for full-scale HD remedies at the Union Pacific Railroad sites located in Laramie, Wyoming and The Dalles, Oregon (Regions 8 and 10 respectively; see Appendix K for details). Furthermore, the re-injection would occur entirely at the Montrose property and within the footprint of the TI Waiver Zone. Additionally, since separation of the DNAPL from groundwater following total fluids extraction would initially remove up to 90% of the total contaminant mass, RA 4a would also meet the requirements of 42 U.S.C. § 6939(b) by substantially reducing hazardous constituents prior to groundwater re-injection. However, in spite of the above arguments and in accordance with EPA comments, RA 4a is ranked as difficult to implement unless the re-injection standards are temporarily waived in the short-term. ***Rank: Difficult to Implement (unless waiver of ARAR is granted in short-term).***

Cost. The estimated cost of RA 4A is $11.0 to $12.2 MM NPV at discount rates of 7% and 4%, respectively, as shown in Table 6.1 and Appendix J. The cost of RA 4A includes installing and operating 23 extraction and 46 injection wells on a 50-foot spacing, including the isolated area surrounding boring SSB-12. Hydraulic displacement costs were previously estimated and submitted to EPA in November 2007 (Earth Tech, 2007e). Hydraulic displacement costs were subsequently revised in accordance with

EPA cost reconciliation discussions held in February 2008 and December 2010 (AECOM, 2010g). Budgetary price quotations were obtained from subcontractors and equipment vendors to increase the relative accuracy and reliability of these remedy cost estimates.

The duration of the remedy is assumed to be 8 years total based on the following schedule of activities:

- Year 1 = Design
- Year 2 = Construction
- Years 3-7 = O&M (5 years)
- Year 8 = Verification and Abandonment

The amount of DNAPL recovery is assumed to be highest in the first year of O&M, with DNAPL recovery decreasing each successive year. No ex-situ treatment of groundwater is assumed for this RA other than physical separation. The cost of the institutional controls and SVE components of this RA are identical to RAs 2 and 3 respectively. The estimated cost for this RA includes 10 soil verification borings following completion of active remediation. ***Rank: Moderate Cost ($11.0 to $12.2 MM NPV).***

State Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the State. EPA will address this criterion in the ROD. However, the State may not waive the groundwater standards, and in order for RA 4a to comply with DNAPL ARARs, groundwater re-injection standards must be waived as they were during the field pilot testing. It is noted that this RA has a relatively small carbon footprint, smallest of the focused treatment area RAs, which may be favorable to the State. ***Rank: Not Applicable.***

Public Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the public. However, RA 4a may be accepted by the public because it is protective of human health and reduces mobile DNAPL mass in the long-term. ***Rank: Not Applicable.***

6.2.5 REMEDIAL ALTERNATIVE 4B – HYDRAULIC DISPLACEMENT WITH TREATED WATER INJECTION

This RA includes three GRAs: (1) hydraulic displacement with treated water re-injection in the saturated UBA, (2) SVE in the unsaturated zone, and (3) institutional controls,.

Overall Protection of Human Health and the Environment. Like RA 4a, this alternative is protective of human health and the environment. RA 4b protects the environment by significantly reducing the mobile DNAPL mass at the Site, the principal threat, and the potential for recontamination of the aquifers

following treatment. The mobility of the remaining DNAPL will be significantly reduced and unlikely to pose a significant threat to the environment or risk of uncontrolled migration under normal hydrologic conditions. T he hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase and slowly reducing DNAPL mass in the long-term by dissolution.

Ex-situ treatment of the groundwater prior to re-injection will not increase the protectiveness of this remedy. Like all candidate RAs, insufficient DNAPL mass can be removed to meaningfully reduce the concentration of MCB in groundwater following treatment. Treating the groundwater over an estimated 5 year hydraulic displacement remedy would not further protect the environment in the long-term.

Human health is protected by the institutional controls and SVE components of the remedy by limiting contaminant exposure pathways. Exposure to contaminants at surface will be addressed by the remedy for soil, and exposure to dissolved-phase contaminants are addressed by the remedy for groundwater. The institutional controls component of this RA restricts Site access and uses that may result in exposure to DNAPL-impacted soils. The SVE component of RA 4b additionally protects human health and the environment by removing the source of VOCs/DNAPL in the unsaturated zone and controlling VOC migration in soil gas in the short-term. T he hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase, and DNAPL mass is reduced over time by dissolution.

Like RA 4a, any DNAPL migrating vertically downward into the BFS would not be protective of the environment. A reasonably high well density was incorporated into the conceptual design for this remedy to reduce the potential for mobile DNAPL to migrate downward through a discontinuous capillary barrier. Additionally, computer modeling suggests that the basal silty sand layer of the UBA would be able to support DNAPL pool heights between 1.3 and 8 feet if continuous over the treatment area. However, there is some uncertainty regarding the continuity of the basal layer at the Site and the capillary pressures required to penetrate the layer. ***Rank: Protective.***

Compliance with ARARs. RA 4b would unconditionally comply with DNAPL ARARs. Although ex-situ treatment of the dissolved-phase contaminants would allow compliance with the re-injection standards, it would not increase the removal of mobile DNAPL mass or reduce the concentration of MCB in groundwater in the long-term. None of the candidate RAs can remove sufficient DNAPL mass as to significantly lower the concentration of MCB in groundwater within the TI Waiver Zone in the short-

term. For this reason, hydraulic containment of groundwater will be required for hundreds or thousands of years following remediation, regardless of which DNAPL RA is selected. ***Rank: Complies.***

Long-Term Effectiveness and Permanence. Like RA 4a, this alternative is moderately effective in the long-term through removal of mobile DNAPL mass and reduction of DNAPL mobility. The volume of mobile DNAPL would be significantly reduced by this RA, providing a permanent remedy in the long-term. Although this remedy is unlikely to remove as much mobile DNAPL as other candidate alternatives, the remaining DNAPL is expected to have limited mobility under normal hydrologic conditions, thereby reducing the potential for recontamination of the aquifers and increasing the probability of maintaining containment. However, any mobile DNAPL mass left in place or migrating vertically downward through a discontinuity to the underlying BFS may reduce the long-term effectiveness of this RA. However, the basal silty sand layer is expected to support DNAPL pool heights between 1.3 and 8 feet if continuous across the treatment area and depending on the capillary pressures required to penetrate the layer.

The addition of ex-situ groundwater treatment prior to injection does not increase the long-term effectiveness or permanence of the hydraulic displacement remedy. The concentration of MCB in groundwater within the focused treatment area will remain at or near solubility limits following hydraulic displacement, even with treatment of the groundwater prior to injection. Treatment of groundwater over a 5-year duration will also not reduce the time required for hydraulic containment following remedy implementation. This fact was also recognized by EPA in evaluating candidate NAPL remedies for the Del Amo Superfund Site. In the Final FS (URS, 2010), all of the candidate NAPL remedies indicated that dissolved benzene concentrations would remain at or near the solubility limit following remedy implementation. The time required for hydraulic containment following NAPL remediation at the Del Amo Superfund Site was several thousand years. Although there are differences between the Montrose and Del Amo Sites, the relative impact to groundwater from dissolved VOCs following a NAPL remedy will be similar.

The SVE component of this RA would reduce the VOC/DNAPL mass in the permeable unsaturated zone to a level that significantly reduces the future risk to the underlying groundwater from contaminant leaching. The permanence of the remedy is improved by removal of VOC/DNAPL mass from both the unsaturated and saturated zones. ***Rank: Moderately Effective.***

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents. RA 4b reduces the volume and mobility of DNAPL in the saturated zone as described for RA 4a. Mobile DNAPL is

hydraulically displaced towards wells for extraction and aboveground separation. Assuming that 80% of the mobile DNAPL mass is removed by this RA, an estimated 89,000 to 136,000 pounds of MCB would be removed from the saturated zone (volume of 9,000 to 13,000 gallons of MCB).

Ex-situ treatment of the groundwater prior to re-injection does not appreciably increase the criterion ranking of this alternative relative to RA 4a. The mass of dissolved-phase contamination is relatively insignificant compared with the mass of the DNAPL, and even after 5 years of treatment, the dissolved-phase concentration of MCB in the UBA will remain at or near the solubility limit. Like all of the RAs under consideration in this FS, an insufficient amount of DNAPL mass can be removed to reduce dissolved contaminant concentrations in the short-term or meaningfully reduce the duration of hydraulic containment required in the long-term.

The SVE component of this RA also reduces the volume (and mass) of hazardous constituents in the unsaturated zone and the toxicity of unsaturated zone soils and soil gas. VOCs, including the volatile fraction of DNAPL (i.e., MCB), are extracted from the subsurface by SVE. DNAPL mobility in the unsaturated zone is also reduced by volatilization of the MCB component since the DDT component of the DNAPL will sorb strongly to soil and is relatively immobile in the environment.

Although RA 4b is unlikely to remove all of the mobile DNAPL in place, it is expected to remove a substantial portion of mobile DNAPL and significantly reduce the mobility of any DNAPL left in place. With the exception of stagnation zones, which can occur for all displacement technologies (including steam injection), any DNAPL not mobilized by this RA is unlikely to be very mobile under normal hydraulic gradients. ***Rank: Moderately Reduces Toxicity, Mobility, and Volume (9,000-13,000 gallons of MCB in the saturated zone and 27,000-30,000 gallons of MCB in the unsaturated zone).***

Short-Term Effectiveness. RA 4b has a total duration of 8 years and is effective in protecting human health and the environment in the short-term as previously described for RA 4a. Ex-situ treatment of the groundwater prior to re-injection does not appreciably increase the criterion ranking of this alternative relative to RA 4a. As described in Section 5.1.5, the energy-based carbon footprint of this RA is approximately 26 million pounds of GHGs. This RA has one of the smaller carbon footprints of the RAs considered in this FS and would not exceed the mandatory reporting threshold of 25,000 metric tons per year (approximately 2,400 metric tons per year). The relatively low carbon footprint complies with EPA and California green remediation initiatives and advances the goals of the California Global Warming Act of 2006. ***Rank: Effective (26 million pounds of GHGs).***

Implementability. This RA is technically implementable as described for RA 4a. However, more highly skilled operators and a higher level of maintenance would be required to treat the groundwater prior to re-injection. An LGAC and HiPOx™ treatment train would be required to treat the dissolved VOCs and pCBSA in the separated UBA groundwater. High inlet concentrations would be expected, and therefore, a robust treatment system would be required which increases the difficulty of implementing this alternative relative to RA 4a. The initial MCB and pCBSA mass loading rate to the 150 gpm treatment system would likely exceed that of the larger 700 gpm remedy for groundwater at the Site. A relatively high amount of disposable LGAC and HiPOx™ system consumables (oxygen and hydrogen peroxide) would also be required to implement this RA, and use of an advanced oxidation system could result in mineral precipitation that hinders the re-injection of groundwater at the Site.

There would be no administrative challenges associated with implementation of this RA involving ex-situ treatment of groundwater prior to re-injection. ***Rank: Moderately Implementable.***

Cost. The estimated cost of RA 4b is $18.0 to $20.1 MM NPV at discount rates of 7% and 4%, respectively, as shown in Table 6.1 and Appendix J. The cost of RA 4b includes treatment of groundwater at a rate of 150 gpm using LGAC and HiPOx™ prior to re-injection. Because dissolved MCB and pCBSA concentrations will be high (approaching solubility limits for MCB), the cost to treat the dissolved-phase contaminants prior to re-injection will be similarly high. Over the assumed 5 year operational duration, more than one million pounds of disposable LGAC would be consumed during treatment. With the exception of ex-situ groundwater treatment, all other aspects of the cost for this alternative are identical to RA 4a. ***Rank: High Cost ($18.0 to $20.1 MM NPV).***

State Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the State. EPA will address this criterion in the ROD. RA 4b has a relatively small carbon footprint, which may be favorable to the State. ***Rank: Not Applicable.***

Public Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the public. However, RA 4b may be accepted by the public because it is protective of human health and reduces mobile DNAPL mass in the long-term. ***Rank: Not Applicable.***

6.2.6 REMEDIAL ALTERNATIVE 5A – STEAM INJECTION OVER FOCUSED TREATMENT AREA

This RA includes three GRAs: (1) Steam injection over a focused treatment area, (2) SVE in the unsaturated zone, and (3) institutional controls,.

Overall Protection of Human Health and the Environment. This RA protects the environment by removing mobile and residual DNAPL mass (via steam injection) within a focused treatment area where the majority of the DNAPL mass (and all of the mobile DNAPL) is located within the UBA. This RA would limit uncontrolled DNAPL migration in the long-term and reduce the potential for recontamination of the aquifers. This RA does increase the probability of achieving and maintaining containment of dissolved-phase contamination, but like all candidate thermal remediation RAs, some residual DNAPL mass will be left in place following steam injection. However, the hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase and reducing DNAPL mass in the long-term by dissolution. The SVE component of RA 5a additionally protects human health and the environment by removing the source of VOCs/DNAPL in the unsaturated zone and controlling VOC migration in soil gas in the short-term. However, VOCs may be left in place within the low permeability PD soils (4 to 25 feet bgs), where SVE is expected to be significantly less effective.

As described in Section 5.2.6, steam injection presents an increased risk of contaminant migration. Uncontrolled steam distribution can result in lateral spreading, potentially outside of the remediation footprint, and a reduction in the protectiveness of this RA. In a paper dated February 18, 2011 (Kueper, 2011), Dr. Kueper indicated that it is uncertain whether the proposed well configuration will be able to contain all of the horizontally mobilized DNAPL within the treatment area. Dr. Kueper additionally indicated that DNAPL not heated to its boiling point will experience a reduced viscosity resulting in faster and possibly uncontrolled rates and direction of migration. Additionally, there is an increased risk of downward migration associated with steam injection. In his paper, Dr. Kueper also indicated that a DNAPL bank will build during as DNAPL vapors are condensed at the steam injection front and coalesce with any DNAPL in the path of the steam. The DNAPL bank will grow in size, saturation, and height as it migrates towards extraction wells. If the bank becomes too high, vertical mobilization can occur. If not effectively recovered, the DNAPL may migrate downward into the BFS through discontinuous capillary barriers or through capillary barriers de-saturated by steam temperatures as observed during 2-dimensional bench-scale testing (see Section 2.6.6). Please note that EPA does not agree with the above characterization of DNAPL migration risks during steam injection (CH2M Hill, 2013).

For the above reasons, this RA includes implementation of a hot floor within the underlying BFS in an effort to abate the risks of downward migration. Steam would be injected into the upper 5 feet of the BFS to abate DNAPL migrating down from the UBA. However, the effectiveness of a steam injection hot floor in the underlying aquifer is uncertain and has not been implemented at a comparable site. Although steam was injected into an underlying aquifer unit (the Deep Aquifer) at the SCE Site in Visalia, California, the primary reason was to prevent the upward flow of cool groundwater into the overlying thermal treatment zone as described in Appendix K. Additionally, only a small portion of the underlying aquifer at the SCE Site was heated, using just three steam injection wells. By comparison, 26 steam injection wells would be required for the hot floor at the Montrose Site under RA 5a. In a paper dated February 22, 2011 (McMillan-McGee, 2011), McMillan-McGee (a thermal remediation contractor) indicated that attempts to prevent downward migration of DNAPL into the BFS had a low chance of success, even with a hot floor. The preferential path of steam in the BFS will be laterally, and without the vertical flow of steam into the UBA, downward mobilization could not be prevented (although abatement within the BFS could still occur). McMillan-McGee additionally indicated that DNAPL could reflux at the boundary of the hot floor and condense as the hot floor cools with time, thereby contaminating the BFS and reducing the protectiveness of the remedy in the long-term.

Although a hot floor in the BFS would theoretically reduce, to some extent, the risk of DNAPL migrating through the UBA during steam injection, 100% effectiveness is not assured. DNAPL could accumulate at the base of the BFS, below the depth of steam injection, and not be effectively displaced, heated, or volatilized for recovery by the multi-phase extraction wells. Steam injection hot floors are infrequently implemented, and there is an absence of experience at comparable sites to reliably predict the performance of a hot floor at the Montrose Site. At some steam injection sites, air is co-injected with steam in an effort to reduce the potential for downward migration. However, the potential effectiveness of air co-injection within the highly layered UBA has not been demonstrated and is uncertain. Please note that EPA does not agree with the above characterization of hot floor effectiveness during steam injection (CH2M Hill, 2013).

Similar to other RAs, the remedies for soil and groundwater are expected to limit contaminant exposure pathways thereby protecting human health. Exposure to contaminants at surface will be addressed by the remedy for soil, and exposure to dissolved-phase contaminants are addressed by the remedy for groundwater. The institutional controls component of this RA provides additional protectiveness by restricting Site access and uses that may result in exposure to DNAPL-impacted soils. ***Rank: Protective.***

Compliance with ARARs. RA 5a would comply with DNAPL ARARs. The institutional controls component of this RA would comply with Land Use Covenant requirements under CCR Title 22 and the California Civil Code. The SVE component of this RA would need to comply with federal and state ARARs related to air quality including the Clean Air Act and SCAQMD regulations. A steam boiler is required for this RA and would also need to comply with the above-referenced air emission standards. This RA would generate solid waste including soil cuttings, decontamination water, PPE, DNAPL, boiler brine waste, and spent carbon, and would need to comply with regulations governing waste classification, management, and disposal including CFR Title 40 and CCR Title 22. Steam injection, multiphase extraction, and temperature monitoring wells installed under this RA would need to comply with California Well Standards. Separate-phase DNAPL is also temporarily accumulated on-Site (pending disposal) under this RA, and therefore, the aboveground accumulation tank would have to comply with regulations for hazardous materials accumulation, including CFR Title 40 and CCR Title 22. Re-injection of treated groundwater into the BFS and Gage Aquifer off-Property would comply with Groundwater ROD in-situ groundwater standards. ***Rank: Complies.***

Long-Term Effectiveness and Permanence. Under this RA, DNAPL mass (both mobile and residual) is reduced by steam injection in the saturated UBA over a focused treatment area. The ability of steam injection to reduce the mobile DNAPL mass at the Site has not been pilot tested and is uncertain as described in Section 5.1.6. However, steam injection was bench-scale tested as described in Section 2.6.6, and between 57% and 64% of the DNAPL-phase MCB mass (and all of the mobile DNAPL mass) was removed under relatively ideal and controlled laboratory conditions (AECOM, 2011k).

Where target temperatures are achieved and MCB is recovered by multi-phase extraction wells, steam injection is expected to be effective in reducing mobile DNAPL mass and the potential for recontamination of the aquifers. However, steam injection will not remove all of the DNAPL mass from within the focused treatment area. Some residual DNAPL will be left in-situ, both inside and outside the focused treatment area, and will serve as a continuing source of dissolved-phase contamination to groundwater. Consequently, the required duration of long-term containment is not meaningfully reduced by this RA. Despite implementing a steam injection remedy within a focused treatment area containing between 60% and 87% of the total DNAPL-phase MCB mass (and all of the mobile DNAPL mass), long-term hydraulic containment would still be required for hundreds or thousands of years because none of the candidate RAs can remove sufficient DNAPL mass to meaningfully reduce the containment timeframe.

Contaminant mobilization in the short-term (if it were to occur) may result in lateral spreading or downward mobilization, thereby reducing the effectiveness of this RA in the long-term. As identified in Section 5.2.6, water influx from outside the treatment area may inhibit the effectiveness of steam injection in reaching target temperatures, particularly along the upgradient perimeter of the treatment area. The saturated UBA is highly layered, and steam injection is dependent on permeable soils for delivery of steam to the treatment area. Steam will preferentially flow through the higher permeability sand layers, and heating of the less permeable layers would rely on thermal heat conduction from adjacent sands. Although this thermal RA has the potential to at least partially treat the low permeability layers of the UBA, conductive heating is less efficient than direct steam contact with DNAPL-impacted soil and could increase the operational duration, energy demand, and costs for this RA.

It is for these reasons that steam injection was not assembled into a formal RA at the Del Amo Superfund Site where the lithology of the NAPL-impacted aquitard is similar to the Montrose Site (URS, 2008). The rationale for excluding a formal steam injection alternative was that the low permeability and heterogeneous nature of the aquitard soils were not well suited for application of steam injection. While there are differences in site conditions, risks, and contaminant properties, the lithology of the NAPL-impacted areas is similar to Montrose, and therefore, relevant to this evaluation.

Although a highly layered saturated zone was field pilot tested using steam injection at the Williams Air Force Base in Mesa, Arizona, numerous differences with the Montrose Site exist as discussed in Appendix K. Although the high permeability sand layers were effectively heated by steam injection at that site, the low permeability zones did not reach target temperatures and a significant amount of aviation fuel LNAPL mass was left in place. Additionally, there was some performance problems associated with the manner in which the pilot test was conducted.

Steam injection will mobilize DNAPL via flushing and concentration the DNAPL at the steam front. Mobilized DNAPL that is not effectively recovered may migrate laterally and/or downward through discontinuous silt layers or de-saturated capillary barriers. Uncontrolled steam distribution could result in spreading of the contamination within the saturated zone. This type of contaminant spreading, if it were to occur, would reduce the effectiveness of this RA in the long-term. This RA includes implementation of a hot floor within the underlying BFS, which will abate to some extent DNAPL migrating down from the UBA. However, effectiveness of the hot floor is not assured as steam injection hot floors are very infrequently implemented and there is an absence of experience at comparable sites to reliably predict the performance of a hot floor at the Montrose Site. Although steam was injected into an underlying aquifer at the SCE Visalia Site, the purpose was to cut off a source of groundwater influx, not remediate

downward migrating DNAPL. Please note that EPA does not agree with the above characterization of mobilization risks during steam injection or the potential effectiveness of a steam hot floor (CH2M Hill, 2013).

The SVE component of this RA would reduce the VOC/DNAPL mass in the permeable unsaturated zone to a level that significantly reduces the future risk to the underlying groundwater from contaminant leaching, although some VOCs would remain in place within the low permeability PD soils (4 to 25 feet bgs). The permanence of the remedy is improved by removal of VOC/DNAPL mass from both the unsaturated and saturated zones, but ultimately, an insufficient amount of mass can be removed to significantly reduce the required duration of hydraulic containment in the long-term. ***Rank: Effective.***

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents. RA 5a reduces the volume, mobility, and toxicity of residual and mobile DNAPL in the saturated zone within a focused treatment area where approximately 60% to 87% of the DNAPL mass at the Site is located (i.e., an estimated 473,700 to 780,000 pounds). DNAPL volume is reduced by either (a) steam flushing of liquid-phase DNAPL to multiphase extraction wells, or (b) volatilization of the MCB component of the DNAPL. A portion of the liquid-phase DNAPL will be displaced at the steam front and potentially recoverable under this RA. Although less than 1% of the PCE DNAPL (similar to MCB DNAPL) was recovered as a separate-phase during full-scale steam injection at the Savannah River Site in Aiken, South Carolina, some liquid-phase DNAPL was recovered during 2-dimensional bench-scale testing as described in Section 2.6.6. In spite of the experience at the Savannah River Site, the potential for uncontrolled contaminant migration during steam injection exists as demonstrated during 2-dimensional bench-scale testing where substantial redistribution of the MCB was observed following steam flushing, although the experiments evaluated only thin and discontinuous capillary barriers.

The majority of the DDT component of the DNAPL would remain in-situ following steam injection, although it is not soluble in groundwater and is not expected to pose a significant risk to human health or the environment within the saturated UBA. Assuming that the MCB represents 50% of the DNAPL mass, an estimated 237,000 to 390,000 pounds of MCB is present in the focused treatment area and potentially subject to thermal remediation (although only a portion of this estimated mass would be recovered by steam injection). 2-Dimensional bench-scale testing demonstrated that between approximately 57% and 64% of the MCB mass (and all of the mobile DNAPL mass) could be removed under relatively ideal and controlled laboratory conditions. Assuming that 60% (an average of the two 2-D tests) of the MCB mass in the focused treatment area were removed by thermal remediation, then an estimated 142,000 to 234,000 pounds of MCB would be removed, which is equivalent to between 15,000

and 25,000 gallons of MCB. Some DNAPL will be left in place following steam injection, but is expected to be at residual levels and relatively immobile in the environment where target temperatures are achieved and MCB is recovered by multi-phase extraction wells. Residual MCB will serve as a continuing source of groundwater contamination but will be reduced in the long-term by dissolution and the hydraulic containment component of the remedy for groundwater.

The SVE component of this RA would reduce the volume (and mass) and toxicity of hazardous constituents in the unsaturated zone. Although some minor improvement in VOC volume reduction in the overlying unsaturated zone is likely during thermal remediation, a relatively high volume reduction was already assumed for SVE, and therefore no minor improvement is assumed for the purposes of this FS. The mobility of DNAPL in the unsaturated zone would also be reduced by volatilization of the MCB component. ***Rank: Reduces Toxicity, Mobility, and Volume (15,000-25,000 gallons of MCB in the saturated zone and 27,000-30,000 gallons of MCB in the unsaturated zone).***

Short-Term Effectiveness. RA 5a would have a total duration of 7 years and would be moderately effective in the short-term. Although RA 5a may be effective in protecting human health and the environment in the short-term, there is an increased risk of remedy excursions, upset conditions, and contaminant migration. Under this RA, liquid-phase DNAPL is flushed for extraction, and the MCB component of the DNAPL is volatilized and extracted for ex-situ treatment. Displaced DNAPL, contaminated steam condensate, and heated MCB vapors must be effectively recovered in order to prevent contaminant migration in the subsurface, either laterally outside the focused treatment area or downward into the underlying BFS. The hot floor in the BFS will abate to some extent DNAPL migrating down from the UBA, but the effectiveness of the hot floor is not assured. Air co-injection could also be considered to reduce the risk of downward migration, although the effectiveness of this approach at the Site is uncertain given the highly layered nature of the UBA. There is additionally an increased mobilization risk associated with installation of the 36 hot floor wells under this RA. To install a hot floor well, a boring must be advanced through the DNAPL-impacted zone to the very base of the UBA and substantial care must be exercised to prevent DNAPL migration as a result of drilling activities. While use of drilling muds and conductor casings are often effective in preventing cross-communication, there is nonetheless an increased risk of downward migration occurring during drilling or after drilling and behind well casing. Downward migration of DNAPL as a result of installing hot floor wells would not be protective of the environment in the short-term. The underlying BFS will be monitored for evidence of adverse migration during the remedy, if any. Furthermore, groundwater will also be monitored at the Site in accordance with the future Monitoring and Aquifer Compliance Plan as required

by the Groundwater ROD (EPA, 1999). However, it should be noted that EPA does not concur with all short-term DNAPL migration risks characterized above (CH2M Hill, 2013).

The short-term effectiveness of the ex-situ vapor treatment system and SVE component of this RA would be similar to RA 3. However, due to the increased VOC mass removal, disposable carbon/resin would no longer be the most cost-effective. One of the other two ex-situ vapor treatment technologies would be used for this RA, and steam-regenerable carbon/resin is assumed for purposes of estimating cost and remedy evaluation in this FS. Spent carbon would be regenerated on-Site using low pressure steam, cooled using air, and placed back into service. The steam and recovered VOCs would be condensed and separated. The recovered VOCs (DNAPL) would be temporarily accumulated on-Site pending disposal within 90 days of generation. The condensed steam would be combined with extracted groundwater and treated on-Site using carbon and advanced oxidation (i.e., HiPOx™). The steam-regenerable carbon/resin would be effective in protecting human health and the environment in the short-term but is a more complex system requiring an increased level of maintenance and oversight. Secondary containment would be required for the system to prevent accidental releases of steam condensate, groundwater, or DNAPL to the ground surface or stormwater pathway. Engineering controls would be required to automatically terminate system operations to ensure compliance with air quality standards, to prevent over-filling of the temporary accumulation tanks, or if leaks were detected within the secondary containment.

In addition, there is an increased potential for fugitive emissions during thermal remedy implementation. Contaminated steam or vapors can escape to surface through previously abandoned borings or wells that are not able to withstand the elevated temperatures associated with this RA. For example, at the SCE Visalia site, one well suffered a catastrophic failure due to incompatibility of the bentonite annular seal materials with the elevated temperatures of the full-scale steam remedy (Lawrence Livermore National Laboratory, 1999). Steam flow to surface was so significant that it dispersed sediment up to 200 feet from the well. However, according to EPA, no contaminated steam, vapors, or sediment was released during this well failure. It may be necessary to re-abandon several former soil borings or replace some existing wells in order to prevent the release of fugitive emissions into the atmosphere during remedy implementation. Routine inspection of the aboveground soil vapor piping and equipment would also be required during remedy implementation to detect and subsequently correct any fugitive emissions of heated soil vapors or steam. The subsurface will remain hot even if remediation system operations are interrupted, and VOC vapors may continue to be generated in-situ for a short period of time following system interruption. The low permeability and shallow Playa Deposits will restrict vertical communication with the surface during thermal remediation although the permeability of the soils could

increase if exposed to heated vapors. SVE in the high permeability Palos Verdes Sand will also help to mitigate fugitive emission risks to some extent. Fugitive emissions, if any, during remedy implementation would reduce the protectiveness of this RA in the short-term. RA 5a would additionally include air emissions from the steam boiler (nitrogen and sulfur oxides).

As described in Section 5.1.6, the energy-based carbon footprint of this RA is between approximately 51 and 106 million pounds of GHGs depending on the amount of energy required to achieve the thermal performance objectives. This alternative has a moderately large carbon footprint (largest of the focused treatment area RAs) and would approach or exceed the mandatory reporting threshold of 25,000 metric tons per year (23,000 to 26,000 metric tons per year). This RA would not be as compliant with EPA or State green remediation initiatives or advance the goals of the California Global Warming Act of 2006. ***Rank: Moderately Effective (51 to 106 million pounds of GHGs).***

Implementability. As described in Section 5.2.6, this steam injection RA would be moderately implementable. A significant amount of complex above- and below-ground infrastructure would be required to generate and deliver steam throughout the focused treatment area. A large number of UBA wells (up to 55 combined steam injection, multiphase extraction, and temperature monitoring) would be required and would generate a significant amount of waste, although this is true for several of the candidate RAs. This RA additionally includes implementation of SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment. Unlike RAs 4a and 4b, where the groundwater is re-injected into the UBA to enhance hydraulic gradients, the groundwater under this RA would require ex-situ treatment for re-injection into the BFS and Gage through the Torrance Groundwater Remediation System. Re-injection of the treated groundwater into the UBA would potentially cool the subsurface and be counter-productive to the thermal remedy. The re-injection flow requirement of the DNAPL remedy would need to be considered during design of the Torrance Groundwater Remediation System to accommodate this additional quantity of water.

Additionally, implementation of a hot floor in the underlying BFS would be required to reduce the risks associated with downward migration of DNAPL, although hot floors are very infrequently implemented. Installation of hot floor wells would require more sophisticated and more costly drilling methods (such as mud-rotary) in an effort to isolate the overlying DNAPL-impacted soils during drilling, although contractors offering these services are readily available. Significant care would be required to ensure that DNAPL did not migrate downward into the BFS during or a result of hot floor well installation. This RA would require highly skilled operators and a high level of maintenance, including boiler maintenance, water conditioning, and brine disposal. Steam injection is not implemented as frequently as other thermal

remediation technologies and has been abandoned as a commercial technology by some vendors. A lack of qualified commercial steam injection vendors may limit the implementability of this RA, although at some sites such as Williams Air Force Base, steam consultants have worked with remediation contractors to implement a steam remedy. Furthermore, the lack of vendor experience in treating the Montrose DNAPL and injecting steam into a complex, layered, and low permeability aquitard would further limit the implementability of this RA.

Given the infrastructure requirements and need for a hot floor in the underlying BFS, steam injection over a focused treatment area of approximately 26,000 square feet is moderately implementable. ***Rank: Moderately Implementable.***

Cost. The estimated cost of RA 5a is $22.3 to $32.4 MM NPV as shown in Table 6.1 and Appendix J, which varies depending on the discount rate and assumptions related to the energy demand. The estimated cost of this focused treatment area steam injection RA is high. As described in Section 5.1.7, the cost of this RA includes up to 14 steam injection, 27 multiphase extraction wells, and 14 temperature monitoring points, including the isolated area surrounding SSB-12.

Steam injection costs were previously estimated and submitted to EPA in November 2007 (Earth Tech, 2007f). Following cost reconciliation discussions in December 2007 and January 2008, steam injection costs were revised and resubmitted to EPA in July 2008 (Earth Tech, 2008d). Steam injection costs were revised a second time following additional EPA comments (EPA, 2008a). Budgetary price quotations were obtained from subcontractors and equipment vendors, as indicated in Appendix J, to increase the relative accuracy and reliability of these remedy cost estimates.

An estimated cost range is provided for RA 5a based on an assumed energy demand range of 2.5 to 6.0 pore volumes of steam flushing. The lower end of the range is consistent with the energy balance provided in Appendix I, although EPA does not concur with all assumptions used in the energy balance estimate (CH2M Hill, 2013). The upper end reflects a possible high energy demand scenario if inefficiencies in steam delivery and heating of low permeability layers results in a longer operational duration (i.e., twice as long as the lower end scenario). Although there are numerous differences between the sites, it is noted that up to 8 pore volumes of steam flushing were required at the SCE Visalia site. Because the hot floor in the BFS would be implemented slightly in advance of heating the UBA (and due to higher groundwater influx), the energy demand range assumed for the hot floor was 3.0 to 7.0 pore volumes.

The duration of the steam injection component of the remedy is assumed to be 4 years total (SVE component has a duration of 7 years as described for RA 3) based on the following schedule of activities:

- Year 1 = Design
- Year 2 = Construction
- Year 3 = O&M (1 year)
- Year 4 = Verification and Abandonment

A duration of 1 year has been assumed for steam injection over the focused treatment area based on cost reconciliation discussions with EPA. Soil vapors are assumed to be treated using steam-regenerable carbon instead of disposable carbon due to the increased VOC mass removal under this RA. Ex-situ treatment of groundwater is additionally included and reflects a combination of disposable carbon and advanced oxidation (i.e., HiPOx™). However, the estimated steam injection cost includes SVE within the unsaturated UBA (45 to 60 feet bgs), and thus the cost of the SVE component was reduced to reflect only SVE within the upper portion of the unsaturated zone where appropriate. The cost of the institutional controls component of this RA is identical to RA 2. The estimated cost for this RA also includes 10 soil verification borings following completion of active remediation. ***Rank: High Cost ($22.3 to $32.4 MM NPV).***

State Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the State. EPA will address this criterion in the ROD. However, the moderately large carbon footprint associated with this RA (51 to 106 million pounds of GHGs) may not be favorable to the State. The GHG emissions from this RA would approach or exceed the mandatory reporting threshold of 25,000 metric tons per year (23,000 to 26,000 metric tons per year), would not comply with the California interim advisory on green remediation (DTSC, 2009), and could impede the State in its efforts to comply with the California Global Warming Act of 2006. ***Rank: Not Applicable.***

Public Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the public. Although the public is likely to accept the increased DNAPL mass reduction offered by RA 5a, the public may have concerns with implementation of a thermal remedy at the Site, the large amount of infrastructure required, and candidate vapor treatment technologies. ***Rank: Not Applicable.***

6.2.7 REMEDIAL ALTERNATIVE 5B – STEAM INJECTION OVER ENTIRE TREATMENT AREA

This RA includes three GRAs: (1) Steam injection over the entire treatment area, (2) SVE in the unsaturated zone, and (3) institutional controls.

Overall Protection of Human Health and the Environment. The protectiveness of this RA is similar to that of RA 5a. This RA protects the environment by removing DNAPL mass via steam injection over the entire treatment area (160,000 square feet). Like RA 5a, mobile DNAPL mass would be reduced, limiting uncontrolled DNAPL migration and reducing the potential for recontamination of the aquifers. Although not posing a mobilization threat to the environment (other than via dissolution) and not a risk to the groundwater remedy, residual DNAPL mass would also be reduced by RA 5b. This RA does increase the probability of achieving and maintaining containment of dissolved-phase contamination, but removal of some residual DNAPL mass from the UBA does not significantly improve the protectiveness of this RA. Like all candidate thermal remediation RAs, some residual DNAPL mass will be left in place following steam injection. However, the hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase and reducing DNAPL mass in the long-term by dissolution.

As described in Section 5.2.7, steam injection presents an increased risk of contaminant migration. Uncontrolled steam distribution can result in lateral spreading, potentially outside of the remediation footprint, and a reduction in the protectiveness of this RA. Additionally, there is an increased risk of downward migration associated with steam injection, which can also reduce the protectiveness of this RA. Steam injection is a displacement technology (like hydraulic displacement), which will displace liquid-phase DNAPL and potentially concentrate it at the steam front (unlike hydraulic displacement), thereby increasing its mobility in the environment. If not effectively recovered, the DNAPL may migrate downward into the BFS through discontinuous capillary barriers or through capillary barriers de-saturated by steam temperatures.

For the above reasons, this RA includes implementation of a hot floor within the underlying BFS in an effort to abate the risks of downward migration. Steam would be injected into the upper five feet of the BFS to abate DNAPL migrating down from the UBA. However, the effectiveness of a steam injection hot floor in the underlying aquifer is uncertain and has not been implemented at a comparable site. Although steam was injected into an underlying aquifer unit (the Deep Aquifer) at the SCE Site in Visalia, California, the primary reason was to prevent the upward flow of cool groundwater into the overlying thermal treatment zone as described in Appendix K. Additionally, only a small portion of the

underlying aquifer at the SCE site was heated, using just three steam injection wells. By comparison, 55 steam injection wells would be required for the more than 160,000 square foot hot floor at the Montrose Site under RA 5b. Although a hot floor in the BFS would theoretically reduce, to some extent, the risk of DNAPL migrating through the UBA during steam injection, 100% effectiveness is not assured. DNAPL could accumulate at the base of the BFS, below the depth of steam injection, and not be effectively displaced, heated, or volatilized for recovery by the multi-phase extraction wells. Steam injection hot floors are infrequently implemented, and there is an absence of experience at comparable sites to reliably predict the performance of a hot floor at the Montrose Site. At some steam injection sites, air is co-injected with steam in an effort to reduce the potential for downward migration. However, the potential effectiveness of air co-injection within the highly layered UBA has not been demonstrated and is uncertain. Please note that EPA does not agree with the above characterization of hot floor effectiveness during steam injection (CH2M Hill, 2013).

The SVE component of RA 5b additionally protects human health and the environment by removing the source of VOCs/DNAPL in the unsaturated zone and controlling VOC migration in soil gas in the short-term. However, as with all RAs, VOCs may be left in place within the low permeability PD soils (4 to 25 feet bgs), where SVE is expected to be significantly less effective. The institutional controls component of this RA provides additional human health protectiveness by restricting Site access and uses that may result in exposure to DNAPL-impacted soils. **Rank: Protective.**

Compliance with ARARs. Like RA 5a, this alternative would comply with DNAPL ARARs. The institutional controls component of this RA would comply with Land Use Covenant requirements under CCR Title 22 and the California Civil Code. The SVE component of this RA would need to comply with federal and state ARARs related to air quality including the Clean Air Act and SCAQMD regulations. Steam boilers are required for this RA and would also need to comply with the above-referenced air emission standards. This RA would generate solid waste including soil cuttings, decontamination water, PPE, DNAPL, boiler brine waste, and spent carbon, and would need to comply with regulations governing waste classification, management, and disposal including CFR Title 40 and CCR Title 22. Steam injection, multiphase extraction, and temperature monitoring wells installed under this RA would need to comply with California Well Standards. Re-injection of treated groundwater into the BFS and Gage Aquifer off-Property would comply with Groundwater ROD in-situ groundwater standards. ***Rank: Complies.***

Long-Term Effectiveness and Permanence. This RA, along with RA 6b, reflects the highest level of DNAPL source removal considered in this FS. Under this RA, DNAPL mass (both mobile and residual)

is reduced by steam injection in the saturated UBA over the entire treatment area. This RA has the same long-term effectiveness as RA 5a, except that it would additionally remove residual DNAPL mass from outside the focused treatment area, where only 13% to 40% of the total DNAPL mass is estimated to occur. The ability of steam injection to reduce the DNAPL mass at the Site has not been pilot tested and is uncertain as described for RA 5a. However, steam injection was bench-scale tested as described in Section 2.6.6, and between 57% and 64% of the MCB mass (and all of the mobile DNAPL mass) was removed under relatively ideal laboratory conditions.

Where target temperatures are achieved and MCB is recovered by multi-phase extraction wells, steam injection is expected to be effective in reducing mobile DNAPL mass, but it will not remove all of the DNAPL mass from within the entire treatment area. Some residual DNAPL will be left in-situ and will serve as a continuing source of dissolved-phase contamination to groundwater. C onsequently, the required duration of long-term containment is not meaningfully reduced by this RA. D espite implementing a steam injection remedy across an area of 160,000 square feet at the Site, long-term hydraulic containment would still be required for hundreds or thousands of years because none of the candidate RAs can remove sufficient DNAPL mass to meaningfully reduce the containment timeframe.

Treatment of the residual DNAPL mass outside the focused treatment area would not meaningfully increase the long-term effectiveness or permanence of this RA. The residual DNAPL is not mobile in the environment, except through dissolution, and does not pose a significant risk of uncontrolled migration or threaten the probability of maintaining containment of the dissolved-phase contamination. Removal of the residual DNAPL mass from outside the focused treatment area, which does not pose a risk to the groundwater remedy, only marginally improves the effectiveness of the steam remedy by reducing the mass of DNAPL subject to dissolution in the long-term.

Contaminant mobilization in the short-term (if it were to occur) may result in lateral spreading or downward mobilization, thereby reducing the effectiveness of this RA in the long-term. As identified in Section 5.2.7, water influx from outside the treatment area may inhibit the effectiveness of steam injection in reaching target temperatures, particularly along the upgradient perimeter of the treatment area. Large treatment areas are subject to a higher potential for non-uniform heating and preferential steam flow, resulting in cold spots, where the effectiveness of the RA will be reduced. Large treatment areas are also subject to a higher potential for downward migration to occur through discontinuous capillary barriers or silt layers, since a much higher number of discontinuities may be encountered within the large treatment area. Although this RA includes implementation of a hot floor in the underlying BFS, the effectiveness of the hot floor over such a large area is not assured, as the potential for cold spots increases. T hese

inefficiencies and performance issues have occurred at other steam injection sites as described in Appendix K.

The SVE component of this RA would reduce the VOC/DNAPL mass in the permeable unsaturated zone to a level that significantly reduces the future risk to the underlying groundwater from contaminant leaching. The permanence of the remedy is improved by removal of VOC/DNAPL mass from both the unsaturated and saturated zones. ***Rank: Effective.***

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents. RA 5b reduces the volume and toxicity of residual and mobile DNAPL in the saturated zone within the entire treatment area where between 796,100 and 900,000 pounds of DNAPL is estimated to occur. The DNAPL volume is reduced by either (a) steam flushing of liquid-phase DNAPL to multi-phase extraction wells, or (b) volatilization of the MCB component of the DNAPL. Assuming that MCB represents 50% of the DNAPL mass, an estimated 398,000 to 450,000 pounds of MCB is present at the Site and potentially subject to thermal remediation (although only a portion of this estimated mass would be recovered by steam injection). Assuming that 60% of the MCB mass were removed by thermal remediation (same as for RA 5a), an estimated 239,000 to 270,000 pounds of MCB would be removed, which is equivalent to between 26,000 and 29,000 gallons of MCB. Although the potential volume reduction from the full-scale thermal remediation RAs is the largest considered in this FS, it is only minimally larger than the potential mass reduction under the focused treatment area RAs (i.e., 15,000 to 25,000 gallons of MCB). Even under full-scale thermal remediation, some DNAPL will be left in place following steam injection. Residual MCB will serve as a continuing source of groundwater contamination but will be reduced in the long-term by dissolution and the hydraulic containment component of the remedy for groundwater.

The SVE component of this RA would reduce the volume (and mass) and toxicity of hazardous constituents in the unsaturated zone. Although some minor improvement in VOC volume reduction in the overlying unsaturated zone is likely during thermal remediation, a relatively high volume reduction was already assumed for SVE, and therefore no minor improvement is assumed for the purposes of this FS. The mobility of DNAPL in the unsaturated zone would also be reduced by volatilization of the MCB component. ***Rank: Reduces Toxicity, Mobility, and Volume (26,000-29,000 gallons of MCB in the saturated zone and 27,000-30,000 gallons of MCB in the unsaturated zone).***

Short-Term Effectiveness. RA 5b has a total duration of 7 to 9 years and although it may be effective in protecting human health and the environment in the short-term, it also has the greatest potential of all the RAs considered in this FS for remedy excursions, upset conditions, and migration risks due to the scale of

the steam injection project. As previously stated in Section 5.2.7, this RA would be one of the largest steam injection projects ever conducted in the United States. The target treatment area and volume, 160,000 square feet and 267,000 cubic yards respectively, are more than six times larger than the corresponding area/volume considered by focused treatment area RA 5a. Given the relatively thick treatment interval, highly layered and low permeability UBA, and nature of the Montrose DNAPL, this full-scale RA would likely be one of the most complicated steam injection remedies ever implemented.

Large treatment areas are subject to a higher potential for non-uniform heating, resulting in "cold spots" where the effectiveness of the thermal remedy will be reduced. The potential for encountering a discontinuous sand lense or capillary barrier and for uncontrolled contaminant migration is also increased by the large treatment area. There is an increased potential for fugitive emissions under the full-scale steam injection RA. Contaminated steam or vapor can escape to surface through previously abandoned borings or wells that are not able to withstand the elevated temperatures associated with this RA. The number of former borings and wells located within the thermal treatment area is higher under RA 5b (than the focused area RAs), and it will be necessary to re-abandon several former soil borings or replace some existing wells in order to prevent release of fugitive emissions during remedy implementation. Routine inspection of the aboveground soil vapor piping and equipment would be required during remedy implementation to detect and subsequently correct any fugitive emissions of heated soil vapors or steam. The low permeability and shallow Playa Deposits will restrict vertical communication with the surface during thermal remediation although the permeability of the soils could increase if exposed to heated vapors. SVE in the high permeability Palos Verdes Sand will also help to mitigate fugitive emission risks to some extent. Fugitive emissions, if any, during remedy implementation would reduce the protectiveness of this RA in the short-term. RA 5b would additionally include air emissions from the steam boilers (nitrogen and sulfur oxides).

The large number of wells required by this RA, 184 remedy wells in the UBA (steam injection, multi-phase extraction, and temperature monitoring), significantly increases the potential for downward DNAPL migration to occur as a result of drilling activities, in spite of using protective drilling methods and procedures. The mobilization risks associated with installation of the 77 hot floor wells are greater still since borings must be advanced through the DNAPL-impacted UBA in order to access the BFS. While use of drilling muds and conductor casings are often effective in preventing cross-communication, there is nonetheless an increased risk of downward migration occurring during drilling or after drilling and behind well casing. Downward migration of DNAPL as a result of installing hot floor wells would not be protective of the environment in the short-term. The underlying BFS would be monitored for evidence of adverse migration during the remedy, if any. Furthermore, groundwater would also be

monitored at the Site in accordance with the future Monitoring and Aquifer Compliance Plan as required by the Groundwater ROD (EPA, 1999).

The short-term effectiveness of the ex-situ vapor and groundwater treatment systems of this RA would be similar to RA 5a. However, the treatment capacities of the systems will be larger. The capacity of the combined LGAC/HiPOx™ groundwater system will be 200 gpm, instead of 75 gpm for RA 5a. The capacity of the steam-regenerable carbon/resin vapor treatment system will be 2,000 scfm, instead of 750 scfm for RA 5a. The systems for vapor and groundwater treatment would be effective in protecting human health and the environment in the short-term, but the increased system capacity increases the level of required maintenance and the potential for upset conditions or fugitive emissions to occur in the short-term.

As described in Section 5.1.7, the energy-based carbon footprint of this RA is between approximately 189 and 412 million pounds of GHGs depending on the amount of energy required to achieve the thermal performance objectives. This alternative has the largest carbon footprint of all RAs considered in the FS and would exceed the mandatory reporting threshold of 25,000 metric tons per year (approximately 47,000 metric tons per year). To place this carbon footprint in perspective, it is compared against California power plant emissions reported in 2007. Of the 83 power plants reported in *America's Biggest Polluters, Carbon Dioxide Emissions from Power Plants in 2007* (Environment Oregon Research & Policy Center, 2009), the carbon footprint for this full-scale thermal RA would exceed the emissions reported for 33 California power plants. The estimated carbon dioxide emissions from RA 5b would be greater than those reported at 40% of the California power plants in 2007. Accordingly, this RA would not comply with EPA or State green remediation initiatives or advance the goals of the California Global Warming Act of 2006. ***Rank: Less Effective (189 to 412 million pounds of GHGs).***

Implementability. As described in Section 5.2.7, RA 5b would be difficult to implement. This full-scale steam injection RA would be even more difficult to implement than RA 5a, due to the increased and substantial size of the project. A significant amount of above- and below-ground infrastructure would be required to generate and deliver steam throughout the DNAPL-impacted zone. A large number of wells, 184 remedy wells (steam injection, multiphase extraction, and temperature monitoring), would be required in the UBA and would generate a significant amount of waste requiring management and disposal. An additional 77 remedy wells would require installation in the BFS hot floor and would require highly protective mud rotary drilling and conductor casing methods. This RA additionally includes implementation of SVE in the unsaturated zone, ex-situ vapor treatment at 2,000 scfm, and ex-situ groundwater treatment at 200 gpm. The treated groundwater would be transferred to the

Groundwater Remedy Treatment System for re-injection into the BFS and Gage. The re-injection flow from the DNAPL remedy would need to be considered during design of the Torrance Groundwater Remediation System. Implementation of a hot floor in the underlying BFS would additionally be required to abate downward migrating DNAPL if any. This RA would require highly skilled operators and a high level of maintenance, including boiler maintenance and management of boiler brine waste. Another factor affecting the implementability of this RA is the limited number of steam vendors, as indicated for RA 5a, although a steam consultant has worked with a remediation contractor to implement steam injection at some other sites.

The carbon footprint of this RA is very high, between approximately 213 and 412 million pounds of greenhouse gases depending on the amount of energy required to achieve the thermal performance objectives, and by far the highest considered in this FS. Mandatory greenhouse gas reporting regulations would likely be triggered by this RA including both 40 CFR Part 98 and 17 CCR §95100-95133. If this RA were to be implemented, Montrose would be required to submit annual reports, verified by a third party, containing detailed information on fuel consumption, greenhouse gas emissions, and electricity usage. The pertinent operations associated with this RA are expected to exceed the 25,000 metric ton threshold on an annual basis, increasing the difficulty of implementing this full-scale thermal RA. ***Rank: Difficult to Implement.***

Cost. The estimated cost of RA 5b is $50.8 to $84.0 MM NPV as shown in Table 6.1 and Appendix J, which varies depending on the discount rate and assumptions related to the energy demand. The estimated cost of this full-scale steam injection RA is very high. If implemented, this RA would be one of the largest and most costly steam injection remedies ever implemented in the United States and highly financially burdensome for Montrose. The financial burden to Montrose would be far more significant, if not prohibitive, than the financial burden to the Federal Government or State agencies funding many of the large-scale thermal remediation projects as described in Appendix K. Montrose does not possess the financial resources comparable to those government agencies, and therefore, the very high cost of this full-scale steam injection RA must be given serious consideration during remedy evaluation.

Steam injection costs were previously estimated and submitted to EPA in November 2007 (Earth Tech, 2007f). Following cost reconciliation discussions in December 2007 and January 2008, steam injection costs were revised and resubmitted to EPA in July 2008 (Earth Tech, 2008d). Steam injection costs were revised a second time following additional EPA comments (EPA, 2008a). Budgetary price quotations were obtained from subcontractors and equipment vendors, as indicated in Appendix J, to increase the relative accuracy and reliability of these remedy cost estimates.

An estimated cost range is provided for RA 5b based on an assumed energy demand range of 2.5 to 6.0 pore volumes of steam flushing. The lower end of the range is consistent with the energy balance provided in Appendix I, although EPA does not concur with all assumptions used in the energy balance estimate (CH2M Hill, 2013). The upper end reflects a possible high energy demand scenario if inefficiencies in steam delivery and heating of low permeability layers results in a longer operational duration (i.e., twice as long as the lower end scenario). Although there are numerous differences between the sites, it is noted that up to eight pore volumes of steam flushing were required at the SCE Visalia site. Because the hot floor in the BFS would be implemented slightly in advance of heating the UBA (and due to higher groundwater influx), the energy demand range assumed for the hot floor was three to seven pore volumes. As described in Section 5.1.7, the cost of this RA includes up to 61 steam injection, 53 multiphase extraction wells, and 70 temperature monitoring points within the saturated UBA.

The duration of the steam injection component of the remedy is assumed to be 5 years total (duration of SVE component is 7 years as described for RA 3) based on the following schedule of activities:

- Year 1 = Design
- Year 2 = Construction
- Years 3 and 4 = O&M
- Year 5 = Verification and Abandonment

A duration of 2 years has been assumed for steam injection over the entire treatment area based on cost reconciliation discussions with EPA. If up to six pore volumes of steam flushing were required to meet the thermal performance objectives, the duration of the heating phase would be 4 years (total remedy duration of 7 years). Soil vapors are assumed to be treated using steam-regenerable carbon instead of disposable carbon due to the increased VOC mass removal under this RA. Ex-situ treatment of groundwater is additionally included and reflects a combination of disposable carbon and advanced oxidation (i.e., HiPOx™). However, the estimated steam injection cost includes SVE within the unsaturated UBA (45 to 60 feet bgs), and thus the cost of the SVE component was reduced to reflect only SVE within the upper portion of the unsaturated zone where appropriate. The cost of the institutional controls component of this RA is identical to RA 2. The estimated cost for this RA also includes 20 soil verification borings following completion of active remediation.

The cost of this full-scale remedy is more than double the cost of the comparable focused treatment area remedy (RA 5a) where all of the mobile DNAPL and between 60% and 87% of the total DNAPL mass is estimated to occur. The substantially increased costs reflect treatment of residual DNAPL in saturated

soils, which is immobile in the environment and does not pose a risk to the groundwater remedy. Therefore, the relatively minor incremental benefit from thermal treating residual DNAPL may not be justified given the significant increase in costs under this full-scale thermal RA. Overall, RA 5b is a high cost remedy and is not cost-effective because it does not meaningfully reduce hydraulic containment timeframes. ***Rank: Very High Cost ($50.8 to $84.0 MM NPV).***

State Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the State. EPA will address this criterion in the ROD. However, the high GHG emissions associated with this RA (189 to 412 million pounds of GHGs) are higher than reported at approximately 40% of the California power plants in 2007 (Environment Oregon Research & Policy Center, 2009) and may not be favorable to the State. The GHG emissions for this RA would exceed the 25,000 metric tons per year threshold, would not comply with California interim advisory on green remediation (DTSC, 2009), and could impede the State in its efforts to comply with the California Global Warming Act of 2006. ***Rank: Not Applicable.***

Public Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the public. Although the public is likely to accept the increased DNAPL mass reduction offered by RA 5b, the public may have substantial concerns associated with implementation of a full-scale thermal remedy at the Site. ***Rank: Not Applicable.***

6.2.8 REMEDIAL ALTERNATIVE 6A – ERH OVER FOCUSED TREATMENT AREA

This RA includes three GRAs: (1) ERH over a focused treatment area, (2) SVE in the unsaturated zone, and (3) institutional controls.

Overall Protection of Human Health and the Environment. Similar to RA 5a, this RA protects the environment by removing mobile and residual DNAPL mass (via ERH) within a focused treatment area where the majority of the DNAPL mass (and all of the mobile DNAPL) is located within the UBA. Although some residual DNAPL mass will be left in place following ERH, the hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase and reducing DNAPL mass in the long-term by dissolution. Some mobilization risks are associated with this RA, such as failure to recover all heated soil vapors. Recovery of contaminant vapors is fundamental to the effectiveness of ERH, and unrecovered vapors may migrate to cooler areas, potentially outside of the remediation footprint, and re-condense. However, the risks associated with this RA are less than for RA 5a, which uses a displacement technology. ERH is volatilization technology with reduced risks of uncontrolled migration, and the risks are further reduced

by the high density of wells required for ERH implementation. The SVE component of RA 6a additionally protects human health and the environment by removing the source of VOCs/DNAPL in the unsaturated zone and controlling VOC migration in soil gas in the short-term. However, as with all RAs, VOCs may be left in place within the low permeability PD soils (4 to 25 feet bgs), where SVE is expected to be significantly less effective.

Similar to other RAs, the remedies for soil and groundwater are expected to limit contaminant exposure pathways thereby protecting human health. Exposure to contaminants at surface will be addressed by the remedy for soil, and exposure to dissolved-phase contaminants are addressed by the remedy for groundwater. The institutional controls component of this RA provides additional human health protectiveness by restricting Site access and uses that may result in exposure to DNAPL-impacted soils. ***Rank: Protective.***

Compliance with ARARs. RA 6a would comply with DNAPL ARARs. The institutional controls component of this RA would comply with Land Use Covenant requirements under CCR Title 22 and the California Civil Code. The SVE component of this RA would need to comply with federal and state ARARs related to air quality including the Clean Air Act and SCAQMD regulations. This RA would generate solid waste including soil cuttings, decontamination water, PPE, DNAPL, and spent carbon, and would need to comply with regulations governing waste classification, management, and disposal including CFR Title 40 and CCR Title 22. ERH electrodes, multiphase extraction, and temperature monitoring wells installed under this RA would need to comply with California Well Standards. Separate-phase DNAPL is also temporarily accumulated on-Site (pending disposal) under this RA, and therefore, the aboveground accumulation tank would have to comply with regulations for hazardous materials accumulation, including CFR Title 40 and CCR Title 22. Re-injection of treated groundwater into the BFS and Gage Aquifer off-Property would comply with Groundwater ROD in-situ groundwater standards. ***Rank: Complies.***

Long-Term Effectiveness and Permanence. Under this RA, DNAPL mass (both mobile and residual) is reduced by ERH in the saturated UBA over a focused treatment area. The ability of ERH to reduce the mobile DNAPL mass at the Site has not been pilot tested and is uncertain as described in Section 5.1.8. The co-boiling point of the Montrose DNAPL (96°C) is relatively high in comparison with other VOCs and approaches the boiling point of water (100°C). A subsurface temperature of 96°C would be required to initiate co-boiling in the subsurface (at atmospheric pressure) and would need to be maintained for a sufficiently long period of time as to reduce the volume of MCB. However, if heating is not uniform in the subsurface, soil temperatures between electrodes may not reach 96°C. Additionally, soil temperatures

near the electrodes may exceed 100°C before the mid-point between electrodes reaches 96°C. Under those circumstances, the groundwater around the electrode will begin to boil, increasing the resistivity of the soils and reducing electrical flow. If groundwater boils out of the soil at the electrodes before the mid-point between the electrodes reaches 96°C, ERH may not reduce DNAPL mass (and MCB volume) as significantly as at some other DNAPL-impacted sites. For this reason, ERH remedial designs typically incorporate electrode wetting systems to reduce the potential for these desaturation effects. Although ERH is most effective at treating VOCs with low co-boiling points, this thermal technology has been demonstrated to be effective at treating VOCs with high co-boiling points comparable to MCB. At the TRW/Northrop Hawthorne Site and Lowry Landfill Site, ERH was used to treat soils containing VOCs including PCE (co-boiling point of 88°C), ethylbenzene (92°C), and xylenes (95°C).

However, ERH will not remove all of the DNAPL mass from within the focused treatment area. Some residual DNAPL will be left in-situ, both inside and outside the focused treatment area, and will serve as a continuing source of dissolved-phase contamination to groundwater but will be hydraulically contained in the long-term by the groundwater remedy. Consequently, the required duration of long-term containment is not meaningfully reduced by this RA. Additionally, contaminant mobilization in the short-term (if it were to occur) may result in lateral spreading or downward mobilization, thereby reducing the effectiveness of this RA in the long-term. Under ERH, there is a reduced risk of downward mobilization relative to RA 5a and a "bottom up" heating approach would further reduce the risk of vertical migration in the short-term. As identified in Section 5.2.8, water influx from outside the focused treatment area may also inhibit the effectiveness of ERH in reaching target temperatures, although significant water influx to the UBA is not expected.

The SVE component of this RA would reduce the VOC/DNAPL mass in the permeable unsaturated zone to a level that significantly reduces the future risk to the underlying groundwater from contaminant leaching. The permanence of the remedy is improved by removal of VOC/DNAPL mass from both the unsaturated and saturated zones. ***Rank: Effective.***

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents. RA 6a reduces the volume, mobility, and toxicity of residual and mobile DNAPL in the saturated zone within a focused treatment area where approximately 60% to 87% of the total DNAPL mass at the Site is located (i.e., an estimated 473,700 to 780,000 pounds). ERH reduces the volume of DNAPL mass by heating the soils via electrical resistance and removing the MCB component of the DNAPL. ERH is not dependent on the soil permeability for heating and is better suited to the low permeability and layered nature of the saturated UBA than steam injection. Assuming that the MCB represents 50% of the DNAPL mass, an estimated

236,800 to 390,000 pounds of MCB is present in the focused treatment area and potentially subject to thermal remediation (although only a portion of this estimated mass would be recovered by ERH). Assuming that 60% of the MCB mass in the focused treatment area were removed by thermal remediation (consistent with assumption for RA 5a in Section 6.2.6), an estimated 142,000 to 234,000 pounds of MCB would be removed, which is equivalent to between 15,000 and 25,000 gallons of MCB. Some DNAPL will be left in place following ERH, but in the absence of cold spots or discontinuous lenses, is expected to be at residual levels. Residual MCB will serve as a continuing source of groundwater contamination but will be reduced in the long-term by dissolution and the hydraulic containment component of the remedy for groundwater.

The SVE component of this RA would reduce the volume (and mass) and toxicity of hazardous constituents in the unsaturated zone. Although some minor improvement in VOC volume reduction in the overlying unsaturated zone is likely during thermal remediation, a relatively high volume reduction was already assumed for SVE, and therefore no minor improvement is assumed for the purposes of this FS. The mobility of DNAPL in the unsaturated zone would also be reduced by volatilization of the MCB component. ***Rank: Reduces Toxicity, Mobility, and Volume (15,000-25,000 gallons of MCB in the saturated zone and 27,000-30,000 gallons of MCB in the unsaturated zone).***

Short-Term Effectiveness. RA 6a would have a total duration of 7 years (4 years for ERH component) and would be effective in the short-term. Although RA 6a is effective in protecting human health and the environment in the short-term, there is some risk associated with excursions or upset conditions. Under this RA, the MCB component of the DNAPL is volatilized and extracted for ex-situ treatment. With thermal remediation projects, there is an increased potential for accidental release of heated vapors or contaminated steam to atmosphere as a fugitive emission. However, the risks under ERH are less than for steam injection due to lower operating pressures and a more gradual heating process. The subsurface will remain hot even if remediation system operations are interrupted, and VOC vapors may continue to be generated in-situ for a short period of time following system interruption. Although co-boiling of VOCs will typically end shortly after electrical current is suspended, continued operation of the SVE system is typically required to adequately recover heated vapors. However, unplanned interruptions or failure of the SVE system can pose some challenges for control of heated vapors. The low permeability and shallow Playa Deposits will restrict vertical communication with the surface during thermal remediation although the permeability of the soils could increase if exposed to heated vapors. SVE in the high permeability Palos Verdes Sand will also help to mitigate fugitive emission risks to some extent.

The heated vapors must also be effectively recovered in order to prevent contaminant migration in the subsurface. Although the layered and heterogeneous nature of the saturated UBA may not inhibit heating of the subsurface, it may reduce the effectiveness of recovering MCB volatilized by ERH. Unrecovered MCB vapors may re-condense in cooler portions of the surbsurface, potentially located outside the footprint of the focused treatment area. The high density of ERH wells (relative to steam injection) reduces the risk associated with vapor migration and increases the potential for contaminant recovery. However, the high density of ERH wells (182 total electrode locations, multiphase, and temperature monitoring wells) also increases the risk of downward migration to occur within the UBA as a result of drilling activities. Each well drilled through the DNAPL-impacted soils to the very base of the UBA creates a vertical conduit with the potential for downward DNAPL migration in the short-term. However, the drilling risks for ERH are less than for steam injection since installation of a hot floor into the BFS is not required by this RA (i.e., no wells penetrating the BFS). Additionally, a "bottom up" heating approach using ERH further reduces the risks of downward migration in the short-term. The underlying BFS will be monitored for evidence of adverse migration during the remedy, if any, although the hydraulic containment wells associated with the groundwater water would capture any adverse migration of dissolved-phase contaminants. BFS monitoring wells beneath and surrounding the Focused Treatment Area will be routinely monitored for the presence of DNAPL, and the MCB concentrations in these wells will be monitored for evidence of increasing concentration trends. Furthermore, groundwater will also be monitored at the Site in accordance with the future Monitoring and Aquifer Compliance Plan as required by the Groundwater ROD (EPA, 1999).

The short-term effectiveness of the ex-situ vapor treatment system and SVE component of this RA would be similar to RA 3. However, due to the increased VOC mass removal, disposable carbon/resin would no longer be the most cost-effective. One of the other two ex-situ vapor treatment technologies would be used for this RA, and steam-regenerable carbon/resin is assumed for purposes of estimating cost and remedy evaluation in this FS. Spent carbon would be regenerated on-Site using low pressure steam, cooled using air, and placed back into service. The steam and recovered VOCs would be condensed and separated. The recovered VOCs (DNAPL) would be temporarily accumulated on-Site pending disposal within 90 days of generation. The condensed steam would be combined with extracted groundwater and treated on-Site using carbon and HiPOx™. The steam-regenerable carbon/resin would be effective in protecting human health and the environment in the short-term, but it is a more complex system requiring an increased level of maintenance and oversight. Secondary containment would be required for the system to prevent accidental releases of steam condensate or DNAPL to the ground surface or stormwater pathways. Engineering controls would be required to automatically terminate system operations upon

exceedance of emissions limits to ensure compliance with air quality standards. The system would also be engineered to automatically terminate operations to prevent over-filling of the temporary accumulation tanks, and upon detection of leaks within the secondary containment.

As described in Section 5.1.8, the energy-based carbon footprint of this RA is between approximately 33 and 61 million pounds of GHGs depending on the amount of energy required to achieve the thermal performance objectives. This alternative has a moderately large carbon footprint (second largest of the focused treatment area RAs) but is not expected to exceed the mandatory reporting threshold of 25,000 metric tons per year (approximately 15,000 metric tons per year). ***Rank: Effective (33 to 61 million pounds of GHGs).***

Implementability. As described in Section 5.2.8, RA 6a would be moderately implementable. The implementability of this RA is the same as for RA 5a, with heating of the saturated UBA by ERH instead of steam injection. A relatively large number of electrodes (102) and multiphase extraction wells (66) would be required to treat the focused treatment area, creating a substantial amount of waste requiring management and disposal. A large amount of electricity would be required to implement this RA (25,700 megawatt-hours), and a substantial amount of electrical equipment would require installation at the Site. Two LADWP electrical substations are located adjacent to the JCI property (Figure 1.7), and therefore, transmission of sufficient electrical power to the Montrose property is not expected to pose any significant implementabilty challenges. No steam boilers, generating boiler emissions and brine waste, would be required for this ERH RA. Additionally, this RA would require implementation of SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment. This RA would require skilled operators and a high level of maintenance. However, unlike steam injection, three qualified ERH vendors (TRS, CES, and MC2) are available to implement this RA, and ERH is more frequently implemented than steam injection (i.e., a broader range of experience). ***Rank: Moderately Implementable.***

Cost. The estimated cost of RA 6a is $18.6 to $25.0 MM NPV as shown in Table 6.1 and Appendix J, varies depending on discount rate and assumed energy demand, and is based on a preliminary estimate from McMillan-McGee, an ERH technology vendor. As described in Section 5.2.8, the cost of this RA includes 102 electrode locations and 66 multiphase extraction wells, including the isolated area surrounding SSB-12. The amount of energy consumed by the RA was assumed to be 200 kW-hr per cubic yard based on a recommendation by McMillan-McGee. The cost of a higher energy demand scenario was estimated in the event that the assumed 200 kW-hr per cubic yard is insufficient to meet thermal performance objectives. A higher energy demand of 400 kW-hr per cubic yard was assumed as

an upper end for remedy evaluation purposes and was based on a review of ERH case sites (Earth Tech, 2007d), some of which are described in Appendix K.

ERH costs were previously estimated and submitted to EPA in November 2007 (Earth Tech, 2007f). Following cost reconciliation discussions in December 2007 and January 2008, ERH costs were revised and resubmitted to EPA in August 2008 (Earth Tech, 2008f). EPA did not comment on that estimate, but it included the cost of a hot floor underlying the UBA. As explained in Section 5.1.8, ERH presents a reduced potential for downward migration (as compared with steam injection) and if a "bottom up" heating approach is used, implementation of a hot floor in the underlying BFS would not be required. Therefore, the cost of this RA excludes implementation of a hot floor in the underlying BFS as described in Section 5.1.8. Budgetary price quotations were obtained from subcontractors and equipment vendors to increase the relative accuracy and reliability of these remedy cost estimates.

The duration of the ERH component of the remedy is assumed to be 4 years (duration of SVE component is 7 years as described for RA 3) total based on the following schedule of activities:

- Year 1 = Design
- Year 2 = Construction
- Year 3 = O&M (1 year)
- Year 4 = Verification and Abandonment

A duration of 1 year has been assumed for ERH within the focused treatment area based on cost reconciliation discussions with EPA. Soil vapors are assumed to be treated using steam-regenerable carbon instead of disposable carbon due to the increased mass removal. As a result, sorbed VOCs are recovered, cooled, and temporarily accumulated pending off-Site transport and disposal. DNAPL recovered from spent carbon would be disposed off-Site by incineration. Ex-situ treatment of groundwater is additionally included and reflects a combination of disposable carbon and advanced oxidation (i.e., HiPOx). The cost of the institutional controls component is identical to RA 2. However, the estimated ERH cost includes SVE within the unsaturated UBA (45 to 60 feet bgs), and thus the SVE component was reduced to reflect only SVE within the upper portion of the unsaturated zone. The cost of the institutional controls component of this RA is identical to RA 2. The estimated cost for this RA also includes 10 soil verification borings following completion of active remediation. ***Rank: High Cost ($18.6 to $25.0 MM NPV).***

State Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the State. EPA will address this criterion in the ROD. However, the State is likely

to accept RA 6a. The volume of soils thermally treated by RA 6a is consistent with the volume at other thermal remediation sites, and the carbon footprint for this RA is not expected to exceed the 25,000 metric tons per year reporting threshold. ***Rank: Not Applicable.***

Public Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the public. Although the public is likely to accept the increased DNAPL mass reduction offered by RA 6a, the public may have concerns with implementation of a thermal remedy at the Site and candidate vapor treatment technologies. ***Rank: Not Applicable.***

6.2.9 REMEDIAL ALTERNATIVE 6B – ERH OVER ENTIRE TREATMENT AREA

This RA includes three GRAs: (1) ERH over the entire treatment area, (2) SVE in the unsaturated zone, and (3) institutional controls.

Overall Protection of Human Health and the Environment. This RA protects the environment by removing DNAPL mass via ERH over the entire treatment area (160,000 square feet). Like RA 6a, mobile DNAPL mass would be reduced, limiting uncontrolled DNAPL migration and reducing the potential for recontamination of the aquifers. Although not posing a mobilization threat to the environment (other than via dissolution) or posing a risk to the groundwater remedy, residual DNAPL mass would also be reduced by RA 6b. This RA does increase the probability of achieving and maintaining containment of dissolved-phase contamination, but removal of some residual DNAPL mass from the UBA does not significantly improve the protectiveness of this RA. Like all candidate thermal remediation RAs, some residual DNAPL mass will be left in place following ERH. However, the hydraulic containment component of the remedy for groundwater protects the environment by controlling migration of contaminants in the dissolved-phase and reducing DNAPL mass in the long-term by dissolution.

Some mobilization risks are associated with this RA (although less than for equivalent steam injection RA), such as failure to recover all heated soil vapors. Unrecovered vapors may migrate to cooler areas, potentially outside of the remediation footprint, and re-condense. Unrecovered vapors could reduce the protectiveness of this RA if they re-condense in saturations that are mobile in the environment, although not probable.

The SVE component of RA 6b additionally protects human health and the environment by removing the source of VOCs/DNAPL in the unsaturated zone and controlling VOC migration in soil gas in the short-term. However, as with all RAs, VOCs may be left in place within the low permeability PD soils (4 to 25

feet bgs), where SVE is expected to be significantly less effective. The institutional controls component of this RA provides additional human health protectiveness by restricting Site access and uses that may result in exposure to DNAPL-impacted soils. ***Rank: Protective.***

Compliance with ARARs. Like RA 6a, this alternative would comply with DNAPL ARARs. The institutional controls component of this RA would comply with Land Use Covenant requirements under CCR Title 22 and the California Civil Code. The SVE component of this RA would need to comply with federal and state ARARs related to air quality including the Clean Air Act and SCAQMD regulations. This RA would generate solid waste including soil cuttings, decontamination water, PPE, DNAPL, and spent carbon, and would need to comply with regulations governing waste classification, management, and disposal including CFR Title 40 and CCR Title 22. ERH electrodes, multiphase extraction, and temperature monitoring wells installed under this RA would need to comply with California Well Standards. Re-injection of treated groundwater into the BFS and Gage Aquifer off-Property would comply with Groundwater ROD in-situ groundwater standards. ***Rank: Complies.***

Long-Term Effectiveness and Permanence. Under this RA, DNAPL mass (both mobile and residual) is reduced by ERH in the saturated UBA over the entire treatment area. This RA has the same long-term effectiveness as RA 6a, except that it would additionally remove residual DNAPL mass from outside the focused treatment area (although not a risk to the groundwater remedy), where only 13% to 40% of the total DNAPL mass is estimated to occur. The ability of ERH to reduce the DNAPL mass at the Site has not been pilot tested and is uncertain as described for RA 6a. The co-boiling point of the Montrose DNAPL (96°C) is relatively high in comparison with other VOCs and approaches the boiling point of water (100°C). The lower the co-boiling point relative to the boiling point of water, the greater the potential for ERH to be effective in reducing DNAPL mass at the Site.

Where target temperatures are achieved, ERH is expected to be effective in reducing mobile DNAPL mass, but it will not remove all of the DNAPL mass from within the entire treatment area. Some residual DNAPL will be left in-situ and will serve as a continuing source of dissolved-phase contamination to groundwater. Consequently, the required duration of long-term containment is not meaningfully reduced by this RA. Despite implementing an ERH remedy across an area of 160,000 square feet at the Site, long-term hydraulic containment would still be required for hundreds or thousands of years because none of the candidate RAs can remove sufficient DNAPL mass to meaningfully reduce the containment timeframe.

Treatment of the residual DNAPL mass outside the focused treatment area would not meaningfully increase the long-term effectiveness or permanence of this RA. The residual DNAPL is not mobile in the environment, except through dissolution, and does not pose a significant risk of uncontrolled migration or threaten the probability of maintaining containment of the dissolved-phase contamination. Removal of the residual DNAPL mass from outside the focused treatment area only marginally improves the effectiveness of the ERH remedy by reducing the mass of DNAPL subject to dissolution in the long-term.

Contaminant mobilization in the short-term (if it were to occur) may result in lateral spreading or downward mobilization, thereby reducing the effectiveness of this RA in the long-term. As identified in Section 5.2.9, water influx from outside the treatment area may also inhibit the effectiveness of ERH in reaching target temperatures, particularly along the upgradient perimeter of the treatment area. Additionally, non-uniform heating across the 45-foot thickness of the saturated UBA would also reduce the effectiveness of this RA in the long-term. These inefficiencies and performance issues have occurred at other ERH sites as described in Appendix K, and the probability of these inefficiencies occurring is increased under this alternative because of the increase treatment volume.

The SVE component of this RA would reduce the VOC/DNAPL mass in the permeable unsaturated zone to a level that significantly reduces the future risk to the underlying groundwater from contaminant leaching. The permanence of the remedy is improved by removal of VOC/DNAPL mass from both the unsaturated and saturated zones. ***Rank: Effective.***

Reduction of Toxicity, Mobility, and/or Volume of Hazardous Constituents. RA 6b r educes the volume and toxicity of residual and mobile DNAPL in the saturated zone within the entire treatment area where between 796,100 and 900,000 pounds of DNAPL is estimated to occur. ERH reduces the volume of DNAPL by heating the soils via electrical resistance and removing the MCB component of the DNAPL. Assuming that the MCB represents 50% of the DNAPL mass, an estimated 398,000 to 450,000 pounds of MCB is present at the Site and potentially subject to thermal remediation (although only a portion of this estimated mass would be recovered by ERH). Assuming that 60% of the MCB mass were removed by thermal remediation (same as for RA 5b), an estimated 239,000 to 270,000 pounds of MCB would be removed, which is equivalent to between 26,000 and 29,000 gallons of MCB. Although the potential mass reduction from the full-scale thermal remediation RAs is the largest considered in this FS, it is only minimally larger than the potential mass reduction under the focused treatment area RAs (i.e., 15,000 to 25,000 gallons of MCB). Even under full-scale thermal remediation, some DNAPL will be left in place following ERH but is expected to be at residual saturations and relatively immobile in the environment. Residual MCB will serve as a continuing source of groundwater contamination but will be

reduced in the long-term by dissolution and the hydraulic containment component of the remedy for groundwater.

The SVE component of this RA would reduce the volume (and mass) and toxicity of hazardous constituents in the unsaturated zone. Although some minor improvement in VOC volume reduction in the overlying unsaturated zone is likely during thermal remediation, a relatively high volume reduction was already assumed for SVE, and therefore no minor improvement is assumed for the purposes of this FS. The mobility of DNAPL in the unsaturated zone would also be reduced by volatilization of the MCB component. ***Rank: Reduces Toxicity, Mobility, and Volume (26,000-29,000 gallons of MCB in the saturated zone and 27,000-30,000 gallons of MCB in the unsaturated zone).***

Short-Term Effectiveness. Although RA 6b may be effective in protecting human health and the environment in the short-term, there are increased risks and short-term effects associated with implementing an ERH remedy of this size. As previously indicated in Section 5.2.9, this RA would be the largest ERH project ever conducted in the United States. The target treatment area and volume for this RA would be 160,000 square feet and 267,000 cubic yards respectively, which is more than six times larger than the corresponding area/volume considered by RA 6a. By comparison, the largest ERH treatment area and volume previously implemented was reported as approximately 91,000 square feet and 80,000 cubic yards. Given the relatively thick treatment interval, highly layered UBA, and nature of the Montrose DNAPL, this RA would likely be the most complicated ERH remedy ever implemented.

Large treatment areas are subject to a higher potential for non-uniform heating, resulting in “cold spots” where the effectiveness of the thermal remedy will be reduced. The potential for encountering a discontinuous sand lense or capillary barrier and for uncontrolled contaminant migration is also increased by the large treatment area. Unrecovered MCB vapors may re-condense in cooler portions of the surbsurface, potentially located outside the footprint of the treatment area, reducing the effectiveness of this RA. The very large number of wells required by this RA (a total of 729 electrodes, multi-phase extraction wells, and temperature monitoring points) significantly increases the potential for downward DNAPL migration to occur as a result of drilling activities, in spite of using protective drilling methods and procedures. The underlying BFS would be monitored for evidence of adverse migration, if any. Furthermore, groundwater would also be monitored in accordance with the future Monitoring and Aquifer Compliance Plan as required by the Groundwater ROD (EPA, 1999).

The short-term effectiveness of the ex-situ vapor and groundwater treatment systems of this RA would be similar to RA 6a. However, the treatment capacities of the systems will be larger. The capacity of the

combined LGAC/HiPOx™ groundwater system will be 200 gpm, instead of 75 gpm for RA 6a. The capacity of the steam-regenerable carbon/resin vapor treatment system will be 2,000 scfm, instead of 750 scfm for RA 6a. The systems for vapor and groundwater treatment would be effective in protecting human health and the environment in the short-term, but the increased system capacity increases the level of required maintenance and the potential for upset conditions or fugitive emissions to occur in the short-term.

As described in Section 5.1.9, the energy-based carbon footprint of this RA is between approximately 143 and 227 million pounds of GHGs depending on the amount of energy required to achieve the thermal performance objectives. This alternative has the second largest carbon footprint of all RAs considered in the FS and would exceed the mandatory reporting threshold of 25,000 metric tons per year (26,000 to 33,000 metric tons per year). Similar to RA 5b, the annual GHG emissions from this full-scale thermal RA would exceed the carbon footprint of a substantial portion of the 83 California power plants reported in *America's Biggest Polluters, Carbon Dioxide Emissions from Power Plants in 2007* (Environment Oregon Research & Policy Center, 2009). Accordingly, this RA would not comply with EPA or State green remediation initiatives or advance the goals of the California Global Warming Act of 2006. ***Rank: Less Effective (143 to 227 million pounds of GHGs).***

Implementability. As described in Section 5.2.9, RA 6b would be difficult to implement. The implementability of this RA is very similar to that of RA 5b, with heating by ERH instead of steam injection. An exceptionally large number of electrodes would be required (456) to treat the DNAPL-impacted area and would create a significant amount of waste requiring management and disposal. This RA would additionally require implementation of SVE in the unsaturated zone, ex-situ vapor treatment, and ex-situ groundwater treatment.

This RA would require highly skilled operators and a high level of maintenance. Unlike steam injection, three qualified ERH vendors (TRS, CES, and MC2) are available to implement this RA, and ERH is more frequently implemented than steam injection, although not at the size of this full-scale RA. ERH is an energy-intensive remedial technology, and the amount of energy required to heat the entire DNAPL-impacted area (approximately 53,400 megawatt-hours or more) is significant. The resulting carbon footprint is estimated to be between 143 and 227 million pounds of greenhouse gases depending on the amount of energy required to achieve the thermal performance objectives and is also significant. Mandatory greenhouse gas reporting regulations would be triggered by this RA including 40 CFR Part 98 and 17 CCR §95100-95133. If this RA were to be implemented, Montrose would be required to submit annual reports, verified by a third party, containing detailed information on fuel consumption, greenhouse

gas emissions, and electricity usage. The pertinent operations associated with this RA are expected to exceed the 25,000 metric ton threshold on an annual basis, increasing the difficulty of implementing this full-scale thermal RA. ***Rank: Difficult to Implement.***

Cost. The estimated cost of RA 6b is $46.2 to $69.5 MM NPV as shown in Table 6.1 and Appendix J, which varies depending on the discount rate and assumptions related to the energy demand. The estimated cost of this full-scale ERH RA is very high. If implemented, this RA would be the largest and probably the most expensive ERH RA ever implemented in the United States and highly financially burdensome for Montrose. The financial burden to Montrose would be far more significant, if not prohibitive, than the financial burden to the Federal Government or State agencies funding many of the large-scale thermal remediation projects as described in Appendix K. Montrose does not possess the financial resources comparable to those government agencies, and therefore, the very high cost of this full-scale ERH RA must be given serious consideration during remedy evaluation.

As described for RA 6a, this estimated cost range reflects an assumed energy demand range of 200 to 400 kW-hrs per cubic yard. If 200 kW-hrs per cubic yard were insufficient to meet the thermal performance objectives due to inefficiencies or cooling, then up to a cumulative total of 400 kW-hrs per cubic yard may be required. As described in Section 5.1.9, the cost of this RA includes up to 456 electrode locations, 203 multiphase extraction wells, and 70 temperature monitoring points in the saturated UBA.

ERH costs were previously estimated and submitted to EPA in November 2007 (Earth Tech, 2007f). Following cost reconciliation discussions in December 2007 and January 2008, ERH costs were revised and resubmitted to EPA in August 2008 (Earth Tech, 2008f). EPA did not comment on that estimate, but it included the cost of a hot floor underlying the UBA. As explained in Section 5.1.8, ERH presents a reduced potential for downward migration (as compared with steam injection) and if a "bottom up" heating approach is used, implementation of a hot floor in the underlying BFS may not be required. Therefore, the cost of this RA excludes implementation of a hot floor in the underlying BFS as described in Section 5.1.8. Budgetary price quotations were obtained from subcontractors and equipment vendors to increase the relative accuracy and reliability of these remedy cost estimates.

The duration of the ERH component of the remedy is assumed to be 5 years total (duration of SVE component is 7 years as described for RA 3) based on the following schedule of activities:

- Year 1 = Design
- Year 2 = Construction
- Years 3 and 4 = O&M
- Year 5 = Verification and Abandonment

A duration of 2 years has been assumed for ERH over the entire treatment area based on cost reconciliation discussions with EPA. If up to 400 kW-hrs per cubic yard were required to meet the thermal performance objectives, the duration of the heating phase would be 4 years (total remedy duration of 7 years). Soil vapors are assumed to be treated using steam-regenerable carbon instead of disposable carbon due to the increased VOC mass removal under this RA. Ex-situ treatment of groundwater is additionally included and reflects a combination of disposable carbon and advanced oxidation (i.e., HiPOx™). The cost of the institutional controls component is identical to RA 2. However, the estimated steam injection cost includes SVE within the unsaturated UBA (45 to 60 feet bgs), and thus the cost of the SVE component was reduced to reflect only SVE within the upper portion of the unsaturated zone where appropriate. The cost of the institutional controls component of this RA is identical to RA 2. The estimated cost for this RA also includes 20 soil verification borings following completion of active remediation.

The cost of this full-scale ERH remedy is more than double the cost of the comparable focused treatment area remedy (RA 6a) where all of the mobile DNAPL and between 60% and 87% of the total DNAPL mass is estimated to occur. The substantially increased costs reflect treatment of residual DNAPL in saturated soils, which is immobile in the environment and does not pose a risk to the groundwater remedy. Therefore, the relatively minor incremental benefit from thermal treating residual DNAPL may not be justified given the significant increase in costs under this full-scale thermal RA. Overall, RA 6b is a high cost remedy and is not cost-effective because it does not meaningfully reduce hydraulic containment timeframes. ***Rank: Very High Cost ($46.2 to $69.5 MM NPV).***

State Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the State. EPA will address this criterion in the ROD. However, the high GHG emissions associated with this RA (143 to 227 million pounds of GHGs) may not be favorable to the State. The GHG emissions for this RA would exceed the 25,000 metric tons per year threshold, would not comply with California interim advisory on green remediation (DTSC, 2009), and could impede the State in its efforts to comply with the California Global Warming Act of 2006. ***Rank: Not Applicable.***

Public Acceptance. This criterion will be discussed in more detail once comments on the Final DNAPL FS are received from the public. Although the public is likely to accept the increased DNAPL mass reduction offered by RA 6b, the public may have substantial concerns associated with implementation of a full-scale thermal remedy at the Site. ***Rank: Not Applicable.***

6.3 SUMMARY OF REMEDIAL ALTERNATIVES DETAILED ANALYSIS

A comparative analysis of the nine RAs is provided in Section 7. The relative performance of the RAs under each of the nine NCP criteria is discussed and ranked. As way of review, a summary of results from the Section 6 detailed analysis is provided below:

9-CRITERIA SUMMARY TABLE
DETAILED EVALUATION OF CANDIDATE RAs

NCP Criterion	RA 1 No Action	RA 2 ICs	RA 3 SVE ICs	RA 4a HD, No Treat SVE, ICs	RA 4b HD, Treat SVE, ICs	RA 5a [1] Steam, Focused SVE, ICs	RA 5b [1] Steam, Full SVE, ICs	RA 6a [2] ERH, Focused SVE, ICs	RA 6b [2] ERH, Full SVE, ICs
Threshold Criteria									
Protection of Human Health and Environment	HH - No Env - No	HH - Yes Env - No	HH - Yes Env - Vadose	HH - Yes Env - Yes	HH - Yes Env - Yes	HH - Yes Env - Yes	HH - Yes Env - Yes	HH - Yes Env - Yes	HH - Yes Env - Yes
Compliance with ARARs	No	Yes	Yes	No (Waiver is Required)	Yes	Yes	Yes	Yes	Yes
Balancing Criteria									
Long-Term Effectiveness	Not Effective	Not Effective	Not Effective	Moderately Effective	Moderately Effective	Effective	Effective	Effective	Effective
Reduction of Toxicity, Mobility, and Volume									
Vadoze Zone Mobility Reduction	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Saturated Zone Mobility Reduction	No	No	No	Some	Some	Yes	Yes	Yes	Yes
Vadose Zone Volume Reduction (1,000 gallons of MCB)	0	0	27-30	27-30	27-30	27-30	27-30	27-30	27-30
Saturated Zone Volume Reduction (1,000 gallons of mobile DNAPL) [4]	0 MCB 0 DDT	0 MCB 0 DDT	0 MCB 0 DDT	9-13 MCB 9-13 DDT	9-13 MCB 9-13 DDT	15-25 MCB + some DDT	26-29 MCB + some DDT	15-25 MCB 0 DDT	26-29 MCB 0 DDT
Short-Term Effectiveness	Not Effective	Not Effective	Not Effective	Effective	Effective	Moderately Effective	Less Effective	Effective	Less Effective
GHG Emissions (million lbs CO2) [3]	0	0	6	11	26	51-106	189-412	33-61	143-227
Implementability	Highly Implementable	Highly Implementable	Highly Implementable	Difficult to Implement	Moderately Implementable	Moderately Implementable	Difficult to Implement	Moderately Implementable	Difficult to Implement
Cost ($million NPV, 7% to 4% discount rate respectively)	$0	$0.2	$4.4-$4.8	$11.0-$12.2	$18.0-$20.1	$22.3-$32.4	$50.8-$84.0	$18.6-$25.0	$46.2-$69.5
Modifying Criteria									
State Acceptance	NA	NA	NA	NA	NA	NA	NA	NA	NA
Public Acceptance	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes:

RA = Remedial Action

ICs = Institutional Controls

SVE = Soil Vapor Extraction

HD = Hydraulic Displacement

Treat = Separation and Treatment of Dissolved-Phase Contaminants

No Treat = Separation of DNAPL/Groundwater Only

lbs = pounds

CO2 = carbon dioxide

ERH = Electrical Resistance Heating

Focused = Focused Treatment Area, approximately 30,000 square feet

Full = Full-Scale Treatment Area, approximately 150,000 square feet

GHG = Greenhouse Gas

NA = Not Available Until State and Public Comment

NPV = Net Present Value

HH = Human Health

ENV = Environment

[1] Costs and GHG emissions based on steam flushing of 3 to 6 pore volumes

[2] Costs and GHG emissions based on electricity consumption of 200 to 400 kilowatt-hours per cubic yard

[3] GHG emissions estimated in accordance with 40 CFR 98.33

[4] HD removal efficiency assumed to be 80% of mobile DNAPL; thermal efficiency assumed to be 100% of mobile DNAPL. Mobile DNAPL volume reflects both Montrose and Huntley estimates.

TABLES

Table 6.1
Detailed Evaluation of DNAPL Remedial Alternatives
Montrose Superfund Site

Remedial Alternative Description	Overall Protection of Human Health	Compliance with ARARs	Long-Term Effectiveness And Permanence	Reduction of Toxicity, Mobility, and/or Volume	Short-Term Effectiveness	Implementability	Cost	State Acceptance	Public Acceptance
RA 1 • No Action	**Not Protective** • No institutional controls to limit potential for exposure to DNAPL, although ICs for soil and groundwater remedies may limit exposure pathways • No DNAPL mass reduction in the unsaturated or saturated zones • No control of VOC migration in soil gas within the unsaturated zone	**Does Not Comply** • Not in compliance with Land Use Covenant requirements • Deed restrictions may be required to prevent exposure to DNAPL-impacted soils	**Not Effective** • Does not reduce mobile DNAPL mass to the extent practicable • Does not limit the potential for uncontrolled migration • Does not reduce the potential for recontamination of the aquifer	**Does Not Reduce Toxicity, Mobility, and Volume** • No reduction in the short-term	**Not Effective** • Does not meet RAOs as described for Long-Term Effectiveness • No GHG emissions	**Highly Implementable**	**Cost = $0 MM NPV**	**Not Applicable[2]**	**Not Applicable[2]**
RA 2 • ICs	**Not Protective** • ICs protect human health by restricting Site access, use, and controlling exposure pathways • Does not reduce mobile DNAPL mass or the potential for recontamination of the aquifer	**Complies** • Complies with Land Use Covenant requirements	**Not Effective** • Does not reduce mobile DNAPL mass to the extent practicable • Does not limit the potential for uncontrolled migration • Does not reduce the potential for recontamination of the aquifer	**Does Not Reduce Toxicity, Mobility, and Volume** • No reduction in the short-term	**Not Effective** • Does not meet RAOs as described for Long-Term Effectiveness • No GHG emissions	**Highly Implementable** • Compliance with land use ARARs would require consent by the land owner	**Cost = $0.2 MM NPV** • Cost includes establishing Land Use Covenant at Montrose Property and annual site inspections for 30 years • Potential costs associated with land use restrictions in off-Property areas are uncertain and assigned a minimal cost	**Not Applicable[2]**	**Not Applicable[2]**
RA 3 • ICs • SVE in unsaturated zone (10-60 feet bgs)	**Not Protective in the Saturated Zone** • ICs protect human health by restricting Site access, use, and controlling exposure pathways • Future risk to groundwater is reduced by SVE and removal of MCB mass from permeable unsaturated zone • Protects human health by controlling VOC migration in soil gas • Does not reduce mobile DNAPL mass in the saturated zone	**Complies** • Complies with Land Use Covenant requirements • SVE system would need to comply with air emission ARARs • All three ex-situ vapor treatment technologies capable of meeting ARARs (disposable GAC, steam regenerable GAC, thermal oxidation)	**Not Effective** • MCB mass in the unsaturated zone is permanently reduced by SVE in the short-term • Mobile DNAPL mass is not reduced in the saturated zone • Does not limit the potential for uncontrolled migration • Does not reduce the potential for recontamination of the aquifer	**Reduces Toxicity, Mobility, and Volume in the Unsaturated Zone Only** • No short-term reduction of DNAPL mass in saturated zone • An estimated 27,000 to 30,000 gallons of MCB reduced in unsaturated zone	**Not Effective** • Disposable GAC is lowest cost ex-situ vapor treatment technology • High MCB adsorption rate in GAC demonstrated during SVE pilot testing • No on-Site regeneration of GAC or temporary storage of liquid-phase MCB • Does not meet RAOs as described for Long-Term Effectiveness • Small carbon footprint (6 million lbs GHGs)	**Highly Implementable** • SVE is a widely used technology for removing VOCs from permeable unsaturated soils • Equipment and contractors are readily available • Highly skilled operators are not required for ex-situ treatment using disposable GAC	**Cost = $4.4-$4.8 MM[1] NPV @ 4% to 7%** • $17-$19/lb MCB removed by SVE • Includes $0.2 MM NPV for ICs • 23 SVE wells screened between 10 and 60 feet bgs (selectively by zone) • 1,500 scfm SVE system • Ex-situ treatment using GAC; lowest cost treatment technology that complies with air emission ARARs • GAC adsorption capacity of 25% MCB by weight • 4 years O&M	**Not Applicable[2]**	**Not Applicable[2]**

Table 6.1
Detailed Evaluation of DNAPL Remedial Alternatives
Montrose Superfund Site

Remedial Alternative Description	Overall Protection of Human Health	Compliance with ARARs	Long-Term Effectiveness And Permanence	Reduction of Toxicity, Mobility, and/or Volume	Short-Term Effectiveness	Implementability	Cost	State Acceptance	Public Acceptance
RA 4a • ICs • SVE in unsaturated zone (10-60 feet bgs) • HD in saturated zone, with untreated water re-injection	**Protective** • ICs protect human health by restricting Site access, use, and controlling exposure pathways • Nearly all of the DNAPL occurs at the Montrose Property where land use can be effectively controlled • Future risk to groundwater is reduced by SVE and removal of MCB mass from permeable unsaturated zone • DNAPL mass and mobility are reduced, in turn reducing the future risk of DNAPL migration • Computer modeling predicts that DNAPL will not be mobilized past basal silty sand by HD, although some uncertainty	**Does Not Comply** • Does not comply with in-situ groundwater standards; would need to be waived by EPA and the State as previously done for 2004/2005 pilot test • Complies with Land Use Covenant requirements • SVE system would need to comply with air emission ARARs • Temporary on-Site storage of DNAPL would need to meet hazardous material storage regulations	**Moderately Effective** • MCB mass in the unsaturated zone is permanently reduced by SVE in the short-term • Mobile DNAPL mass in the saturated zone is permanently reduced by HD in the short-term • Unlikely to remove as much mobile DNAPL mass as other candidate RAs; any mobile DNAPL left in place following HD will reduce the long-term effectiveness • Field pilot testing has demonstrated effectiveness of HD throughout mobile DNAPL footprint, without benefit of water re-injection to enhance hydraulic gradients • Up to 5.6 gallons per day of DNAPL recovered per well • Computer modeling predicts that HD will effectively mobilize DNAPL for recovery at proposed well spacing (50 feet)	**Moderately Reduces Toxicity, Mobility, and Volume** • An estimated 27,000-30,000 gallons MCB reduced in unsaturated zone • An estimated 9,000-13,000 gallons MCB reduced in saturated zone • Will not reduce MCB volume in the saturated zone as significantly as other candidate RAs • Any DNAPL not mobilized under high hydraulic gradients are unlikely to be mobile under normal hydraulic gradients	**Effective** • Disposable GAC is lowest cost ex-situ vapor treatment technology that complies with ARARs • High MCB adsorption rate in GAC demonstrated during SVE pilot testing • Spent GAC is disposed/recycled off-Site; no on-Site regeneration of GAC • Does not involve any combustion processes; no potential for formation of dioxins/furans • Temporary on-Site storage of DNAPL is required; engineering controls effective in protecting human health • No ex-situ groundwater treatment required, other than DNAPL separation and filtration • Low carbon footprint of 11 million lbs GHGs • Annual GHG emissions would be significantly below mandatory reporting threshold	**Difficult to Implement** • Would require waiver of re-injection standards in order to be administratively implementable • SVE is a widely used technology for removing VOCs from permeable unsaturated soils • Standard separation techniques are effective for DNAPL/groundwater • Equipment and contractors are readily available • SVE with disposable GAC and HD with untreated water re-injection do not require highly skilled operators • Moderate to high level of maintenance required to abate precipitate fouling; routine injection well redevelopment program would be required • Re-injection of groundwater into UBA was demonstrated during field pilot testing	**Cost = $11.0-$12.2 MM[1] NPV @ 4% to 7%** • $54-$83/lb MCB removed by HD • Includes $4.4-$4.8 MM NPV for ICs and SVE • Includes 23 extraction and 46 injection wells on 50-foot spacing • Includes additional containment wells at downgradient edge of mobile DNAPL occurrence • 5 years O&M • Re-injection of untreated groundwater; includes DNAPL separation and groundwater filtration • Off-Site disposal of recovered DNAPL via incineration	**Not Applicable[2]**	**Not Applicable[2]**

Table 6.1
Detailed Evaluation of DNAPL Remedial Alternatives
Montrose Superfund Site

Remedial Alternative Description	Overall Protection of Human Health	Compliance with ARARs	Long-Term Effectiveness And Permanence	Reduction of Toxicity, Mobility, and/or Volume	Short-Term Effectiveness	Implementability	Cost	State Acceptance	Public Acceptance
RA 4b • ICs • SVE in unsaturated zone (10-60 feet bgs) • HD in saturated zone, with treated water re-injection	**Protective** • ICs protect human health by restricting Site access, use, and controlling exposure pathways • Nearly all of the DNAPL occurs at the Montrose Property where land use can be effectively controlled • Future risk to groundwater is reduced by SVE and removal of MCB mass from permeable unsaturated zone • DNAPL mass and mobility are reduced, in turn reducing the future risk of DNAPL migration • Computer modeling predicts that DNAPL will not be mobilized past basal silty sand by HD, although some uncertainty	**Complies** • Complies with Land Use Covenant requirements • SVE system would need to comply with air emission ARARs • Temporary on-Site storage of DNAPL would need to meet hazardous material storage regulations • Would comply with in-situ groundwater standards	**Moderately Effective** • MCB mass in the unsaturated zone is permanently reduced by SVE in the short-term • Mobile DNAPL mass in the saturated zone is permanently reduced by HD in the short-term • Unlikely to remove as much mobile DNAPL mass as other candidate RAs; any mobile DNAPL left in place following HD will reduce the long-term effectiveness • Field pilot testing has demonstrated effectiveness of HD throughout mobile DNAPL footprint, without benefit of water re-injection to enhance hydraulic gradients • Up to 5.6 gallons per day of DNAPL recovered per well • Computer modeling predicts that HD will effectively mobilize DNAPL for recovery at proposed well spacing (50 feet)	**Moderately Reduces Toxicity, Mobility, and Volume** • An estimated 27,000-30,000 gallons MCB reduced in unsaturated zone • An estimated 9,000-13,000 gallons MCB reduced in saturated zone • Will not reduce MCB volume in the saturated zone as significantly as other candidate RAs • Any DNAPL not mobilized under high hydraulic gradients are unlikely to be mobile under normal hydraulic gradients • Treatment of groundwater does not increase remedy effectiveness or volume reduction	**Effective** • Disposable GAC is lowest cost ex-situ vapor treatment technology that complies with ARARs • High MCB adsorption rate in GAC demonstrated during SVE pilot testing • Spent GAC is disposed/recycled off-Site; no on-Site regeneration of GAC • Does not involve any combustion processes; no potential for formation of dioxins/furans • Temporary on-Site storage of DNAPL is required; engineering controls effective in protecting human health • Ex-situ groundwater treatment required, using LGAC/HiPOx • Moderate carbon footprint of 26 million lbs GHGs • Annual GHG emissions would be significantly below mandatory reporting threshold	**Moderately Implementable** • SVE is a widely used technology for removing VOCs from permeable unsaturated soils • Standard separation techniques are effective for DNAPL/groundwater • More highly skilled operators and higher level of maintenance due to groundwater treatment • High VOC mass loading will require robust treatment train of LGAC and HiPOx • Moderate to high level of maintenance required to abate precipitate fouling; routine injection well redevelopment program would be required	**Cost = $18.0-$20.1 MM[1]** **NPV @ 4% to 7%** • $113-$172/lb MCB removed by HD • Includes $4.4-$4.8 MM NPV for ICs and SVE • Includes 18 extraction and 46 injection wells on 50-foot spacing • 5 years O&M • Off-Site disposal of recovered DNAPL via incineration • Treatment of groundwater significantly increases cost of HD remedy without increasing long-term effectiveness or volume reduction	**Not Applicable**	**Not Applicable**

Table 6.1
Detailed Evaluation of DNAPL Remedial Alternatives
Montrose Superfund Site

Remedial Alternative Description	Overall Protection of Human Health	Compliance with ARARs	Long-Term Effectiveness And Permanence	Reduction of Toxicity, Mobility, and/or Volume	Short-Term Effectiveness	Implementability	Cost	State Acceptance	Public Acceptance
RA 5a • ICs • SVE in unsaturated zone (10-60 feet bgs) • Steam injection in saturated zone, over focused treatment area, with hot floor	**Protective** • ICs protect human health by restricting Site access, use, and controlling exposure pathways • Future risk to groundwater is reduced by SVE and removal of MCB mass from permeable unsaturated zone • Removes DNAPL mass (primarily MCB) from focused treatment area where majority of DNAPL occurs (and all mobile DNAPL) • Increased risk of contamination migration • DNAPL mobility increased at steam front, resulting in increased risk of downward migration • Hot floor included in RA, but effectiveness is not assured; not demonstrated at comparable site	**Complies** • Complies with Land Use Covenant requirements • SVE system and steam boiler would need to comply with air emission ARARs • Temporary on-Site storage of DNAPL would need to meet hazardous material storage regulations • Additional waste generation required by this RA including boiler brine waste; must comply with waste management regulations • Re-injection of treated groundwater off-Property into the BFS and Gage would comply with in-situ groundwater standards	**Effective** • MCB mass in the unsaturated zone is permanently reduced by SVE in the short-term • DNAPL mass in the saturated zone is permanently reduced by steam injection over a focused treatment area in the short-term • Some DNAPL will be left in-situ both inside and outside the focused treatment area • Insufficient DNAPL mass can be removed to meaningfully reduce HC timeframe	**Reduces Toxicity, Mobility, and Volume** • An estimated 27,000-30,000 gallons MCB reduced in unsaturated zone • An estimated 15,000 to 25,000 gallons MCB reduced in saturated zone • Some liquid-phase DNAPL may be displaced at steam front • Steam injection has not been field pilot tested • Steam will preferentially flow through higher permeability sand layers; heating of lower permeability layers will rely on conductive heating • Groundwater influx may cool the upgradient perimeter of the focused treatment area, reducing effectiveness • Lithology at thermal sites (e.g., sand aquifers) is better suited to steam injection than heterogeneous UBA	**Moderately Effective** • Potential for remedy excursions or upset conditions • Displaced DNAPL, contaminated steam condensate, and heated MCB vapors must be effectively recovered to prevent contaminant migration • Steam injection well density lower than for RA 6a; greater risk of not recovering all mobilized contaminants • Risk of downward migration resulting from installation of 36 hot floor wells through DNAPL-impacted UBA to underlying BFS • Spent GAC would be steam regenerated on-Site for re-use • Temporary on-Site storage of DNAPL from regenerable GAC system would be required • More complex ex-situ equipment requiring an increased level of maintenance and oversight • Steam boiler will also emit nitrogen and sulfur oxides • Large carbon footprint (51 to 106 million lbs GHGs) • Annual GHG emissions will approach or exceed mandatory reporting threshold	**Moderately Implementable** • SVE is a widely used technology for removing VOCs from permeable unsaturated soils • A significant amount of infrastructure would be required • Ex-situ treatment of groundwater is required prior to re-injection off-Property into the BFS and Gage; flow requirement would need to be considered during design of Groundwater Remedy Treatment System • Hot floors are infrequently implemented at thermal remediation sites • Highly skilled operators are required • High level of maintenance is required, including boiler maintenance, water conditioning, and brine disposal • Steam injection is not implemented as frequently as ERH or ISTD; • Some vendors have abandoned steam injection as a commercial technology	**Cost = $22.3 to $32.4 MM[1] NPV @ 4% to 7%** • $91-$211/lb MCB removed by steam injection • Includes $2.2 to $2.7 MM NPV for ICs and SVE in the unsaturated zone, included as part of steam injection remedy costs • Includes 14 steam injection, 27 multiphase extraction, and 14 temperature monitoring points on 42-foot spacing • 1 year steam injection in UBA (longer in hot floor) • Energy demand reflects 2.5 to 6.0 pore volumes • Includes hot floor in BFS underlying focused treatment area • Includes ex-situ soil vapor treatment using steam regenerable GAC system (with polishing GAC for air emissions compliance) • Includes ex-situ groundwater/condensate treatment using disposable GAC and HiPOx • Off-Site disposal of recovered DNAPL via incineration	**Not Applicable[2]**	**Not Applicable[2]**

Table 6.1
Detailed Evaluation of DNAPL Remedial Alternatives
Montrose Superfund Site

Remedial Alternative Description	Overall Protection of Human Health	Compliance with ARARs	Long-Term Effectiveness And Permanence	Reduction of Toxicity, Mobility, and/or Volume	Short-Term Effectiveness	Implementability	Cost	State Acceptance	Public Acceptance
RA 5b • ICs • SVE in unsaturated zone (10-60 feet bgs) • Steam injection in saturated zone, over entire treatment area, with hot floor	**Protective** • ICs protect human health by restricting Site access, use, and controlling exposure pathways • Future risk to groundwater is reduced by SVE and removal of MCB mass from permeable unsaturated zone • Removes DNAPL mass (primarily MCB) from entire treatment area • Increased risk of contamination migration • DNAPL mobility increased at steam front, resulting in increased risk of downward migration • Hot floor included in RA, but effectiveness is not assured; not demonstrated at comparable site	**Complies** • Complies with Land Use Covenant requirements • SVE system and steam boiler would need to comply with air emission ARARs • Temporary on-Site storage of DNAPL would need to meet hazardous material storage regulations • Additional waste generation required by this RA including boiler brine waste; must comply with waste management regulations • Re-injection of treated groundwater off-Property into the BFS and Gage would comply with in-situ groundwater standards	**Effective** • MCB mass in the unsaturated zone is permanently reduced by SVE in the short-term • DNAPL mass in the saturated zone is permanently reduced by steam injection over entire treatment area in the short-term • Some DNAPL will be left in-situ • Insufficient DNAPL mass can be removed to meaningfully reduce HC timeframe, even under maximum treatment scenario	**Reduces Toxicity, Mobility, and Volume** • An estimated 27,000-30,000 gallons MCB reduced in unsaturated zone • An estimated 26,000 to 29,000 gallons MCB reduced in saturated zone • Some liquid-phase DNAPL may be displaced at steam front • Steam injection has not been field pilot tested • Steam will preferentially flow through higher permeability sand layers; heating of lower permeability layers will rely on conductive heating • Groundwater influx may cool the upgradient perimeter of the treatment area, reducing effectiveness • Lithology at thermal sites (e.g., sand aquifers) is better suited to steam injection than heterogeneous UBA	**Less Effective** • Greatest potential for remedy excursions or upset conditions • Displaced DNAPL, contaminated steam condensate, and heated MCB vapors must be effectively recovered to prevent contaminant migration • Steam injection well density lower than for RA 6b; greater risk of not recovering all mobilized contaminants • Risk of downward migration resulting from installation of 77 hot floor wells through DNAPL-impacted UBA to underlying BFS • Spent GAC would be steam regenerated on-Site for re-use • Temporary on-Site storage of DNAPL from regenerable GAC system would be required • More complex ex-situ equipment requiring an increased level of maintenance and oversight • Steam boiler will also emit nitrogen and sulfur oxides • Highest carbon footprint (189 to 412 million lbs GHGs) • Significantly exceeds mandatory GHG reporting threshold • Emissions greater than 40% of California power plants in 2007	**Difficult to Implement** • SVE is a widely used technology for removing VOCs from permeable unsaturated soils • A significant amount of infrastructure would be required • Ex-situ treatment of groundwater is required prior to re-injection off-Property into the BFS and Gage; flow requirement would need to be considered during design of Groundwater Remedy Treatment System • Hot floors are infrequently implemented at thermal remediation sites • Highly skilled operators are required • High level of maintenance is required, including boiler maintenance, water conditioning, and brine disposal • Steam injection is not implemented as frequently as ERH or ISTD; • Some vendors have abandoned steam injection as a commercial technology • Would be one of largest steam remedies ever implemented	**Cost = $50.8-$84.0 MM[1] NPV @ 4% to 7%** • $203-$345/lb MCB removed by steam injection • Includes $1.2 to $1.6 MM NPV for ICs and SVE in the unsaturated zone, included as part of steam injection remedy costs • Includes 61 steam injection, 53 multiphase extraction, and 70 temperature monitoring points on 42-foot spacing • 2 year steam injection in UBA (longer in hot floor) • Energy demand reflects 2.5 to 6.0 pore volumes • Includes hot floor in BFS underlying entire treatment area • Includes ex-situ soil vapor treatment using steam regenerable GAC system (with polishing GAC for air emissions compliance) • Includes ex-situ groundwater/condensate treatment using disposable GAC and HiPOx • Off-Site disposal of recovered DNAPL via incineration • Cost would be prohibitive and highly burdensome to Montrose • Not cost effective; significant cost increase to treat residual DNAPL over 84% of area; marginal increase in MCB volume reduction	**Not Applicable[2]**	**Not Applicable[2]**

Table 6.1
Detailed Evaluation of DNAPL Remedial Alternatives
Montrose Superfund Site

Remedial Alternative Description	Overall Protection of Human Health	Compliance with ARARs	Long-Term Effectiveness And Permanence	Reduction of Toxicity, Mobility, and/or Volume	Short-Term Effectiveness	Implementability	Cost	State Acceptance	Public Acceptance
RA 6a • ICs • SVE in unsaturated zone (10-60 feet bgs) • ERH in saturated zone, over focused treatment area, no hot floor	**Protective** • ICs protect human health by restricting Site access, use, and controlling exposure pathways • Future risk to groundwater is reduced by SVE and removal of MCB mass from permeable unsaturated zone • Removes DNAPL mass (primarily MCB) from focused treatment area where majority of DNAPL occurs (and all mobile DNAPL) • Unrecovered vapors may migrate to cooler areas and re-condense, including outside the remediation footprint • However, risks are reduced by higher density of wells, as compared with RA 5a	**Complies** • Complies with Land Use Covenant requirements • SVE system would need to comply with air emission ARARs • Temporary on-Site storage of DNAPL would need to meet hazardous material storage regulations • Additional waste generation required by high well density; must comply with waste management regulations • Re-injection of treated groundwater off-Property into the BFS and Gage would comply with in-situ groundwater standards	**Effective** • MCB mass in the unsaturated zone is permanently reduced by SVE in the short-term • DNAPL mass in the saturated zone is permanently reduced by ERH over a focused treatment area in the short-term • Some DNAPL will be left in-situ both inside and outside the focused treatment area • Insufficient DNAPL mass can be removed to meaningfully reduce HC timeframe • Mobile DNAPL mass and potential for recontamination of the aquifer is reduced	**Reduces Toxicity, Mobility, and Volume** • An estimated 27,000 to 30,000 gallons MCB reduced in unsaturated zone • An estimated 15,000 to 25,000 gallons MCB reduced in saturated zone • Groundwater influx may cool the upgradient perimeter of the focused treatment area, reducing effectiveness • Co-boiling point of DNAPL (96°C) is relatively high compared with other VOCs • Thick saturated interval of 45 feet may pose some challenges for uniform heating • ERH is not as significantly affected by the layered and low permeability UBA; heating of soils is not dependent on permeability	**Effective** • Mobile DNAPL mass in the saturated zone is reduced • ERH is not as dependent on permeability and does not present the same mobilization risks as steam injection; heating is more controlled under ERH and less prone to displacement or uncontrolled steam flow • Heated MCB vapors must be effectively recovered to prevent contaminant migration; heterogeneous and highly layered UBA may inhibit effective recovery of MCB vapors • High density of wells reduces risk of lateral spreading to some degree • Spent GAC would be steam regenerated on-Site for re-use • Temporary on-Site storage of DNAPL from regenerable GAC system would be required • Moderately large carbon footprint (33 to 61 million lbs GHGs) • Only candidate thermal RA that will not exceed mandatory GHG reporting threshold	**Moderately Implementable** • SVE is a widely used technology for removing VOCs from permeable unsaturated soils • A significant amount of infrastructure and a large amount of electricity would be required • Ex-situ treatment of groundwater is required prior to re-injection off-Property into the BFS and Gage; flow requirement would need to be considered during design of Groundwater Remedy Treatment System • Highly skilled operators are required • High level of maintenance is required • Three qualified ERH vendors are available to implement (TRS, CES, and McMillan-McGee) • ERH is implemented more frequently than steam injection • No steam boilers or brine waste disposal is required • Source of electrical power is located adjacent to site (two LADWP substations)	**Cost = $18.6 to $25.0 MM[1] NPV @ 4% to 7%** • $74-$158/lb MCB removed by ERH • Includes $2.2 to $2.7 MM NPV for ICs and SVE in unsaturated zone, included as part of ERH remedy costs • Includes 102 electrode locations, 66 multiphase extraction, and 14 temperature monitoring points on 21-foot spacing • 1 year ERH in UBA • Energy demand reflects 200 to 400 kw-hrs per cubic yard • Includes ex-situ soil vapor treatment using steam regenerable GAC system (with polishing GAC for air emissions compliance) • Includes ex-situ groundwater/condensate treatment using disposable GAC and HiPOx • Off-Site disposal of recovered DNAPL via incineration • Hot floor not required if bottom-up heating approach is used	**Not Applicable[2]**	**Not Applicable[2]**

Table 6.1
Detailed Evaluation of DNAPL Remedial Alternatives
Montrose Superfund Site

Remedial Alternative Description	Overall Protection of Human Health	Compliance with ARARs	Long-Term Effectiveness And Permanence	Reduction of Toxicity, Mobility, and/or Volume	Short-Term Effectiveness	Implementability	Cost	State Acceptance	Public Acceptance
RA 6b • ICs • SVE in unsaturated zone (10-60 feet bgs) • ERH in saturated zone, over entire treatment area, no hot floor	**Protective** • ICs protect human health by restricting Site access, use, and controlling exposure pathways • Future risk to groundwater is reduced by SVE and removal of MCB mass from permeable unsaturated zone • Removes DNAPL mass (primarily MCB) from entire treatment area • Unrecovered vapors may migrate to cooler areas and re-condense, including outside the remediation footprint	**Complies** • Complies with Land Use Covenant requirements • SVE system would need to comply with air emission ARARs • Temporary on-Site storage of DNAPL would need to meet hazardous material storage regulations • Additional waste generation required by high well density; must comply with waste management regulations • Re-injection of treated groundwater off-Property into the BFS and Gage would comply with in-situ groundwater standards	**Effective** • MCB mass in the unsaturated zone is permanently reduced by SVE in the short-term • DNAPL mass in the saturated zone is permanently reduced by ERH over entire treatment area in the short-term • Some DNAPL will be left in-situ • Insufficient DNAPL mass can be removed to meaningfully reduce HC timeframe, even under maximum treatment scenario • Mobile DNAPL mass and potential for recontamination of the aquifer is reduced	**Reduces Toxicity, Mobility, and Volume** • An estimated 27,000 to 30,000 gallons MCB reduced in unsaturated zone • An estimated 26,000 to 29,000 gallons MCB reduced in saturated zone • Groundwater influx may cool the upgradient perimeter of the treatment area, reducing effectiveness • Co-boiling point of DNAPL (96°C) is relatively high compared with other VOCs • Thick saturated interval of 45 feet may pose some challenges for uniform heating • ERH is not as significantly affected by the layered and low permeability UBA	**Less Effective** • Mobile DNAPL mass in the saturated zone is reduced • Heated MCB vapors must be effectively recovered to prevent contaminant migration; heterogeneous and highly layered UBA may inhibit effective recovery of MCB vapors • High density of wells reduces risk of lateral spreading to some degree • Spent GAC would be steam regenerated on-Site for re-use • Temporary on-Site storage of DNAPL from regenerable GAC system would be required • Large carbon footprint (143 to 227 million lbs GHGs) • Will exceed mandatory GHG reporting threshold	**Difficult to Implement** • SVE is a widely used technology for removing VOCs from permeable unsaturated soils • A significant amount of infrastructure and a large amount of electricity would be required • Ex-situ treatment of groundwater is required prior to re-injection off-Property into the BFS and Gage; flow requirement would need to be considered during design of Groundwater Remedy Treatment System • Highly skilled operators are required • High level of maintenance is required • Three qualified ERH vendors are available to implement (TRS, CES, and McMillan-McGee) • ERH is implemented more frequently than steam injection • Would be largest ERH remedy ever implemented	**Cost = $46.2-$69.5 MM[1] NPV @ 4% to 7%** • $189-$285/lb MCB removed by ERH • Includes $1.2 to $1.6 MM NPV for ICs and SVE in unsaturated zone, included as part of ERH remedy costs • Includes 456 electrode locations, 203 multiphase extraction, and 70 temperature monitoring points on 21-foot spacing • 2 year ERH in UBA • Energy demand reflects 200 to 400 kw-hrs per cubic yard • Includes ex-situ soil vapor treatment using steam regenerable GAC system (with polishing GAC for air emissions compliance) • Includes ex-situ groundwater/condensate treatment using disposable GAC and HiPOx • Off-Site disposal of recovered DNAPL via incineration • Cost would be prohibitive and highly burdensome to Montrose • Not cost effective; significant cost increase to treat residual DNAPL over 84% of area; marginal increase in MCB volume reduction	**Not Applicable[2]**	**Not Applicable[2]**

Table 6.1
Detailed Evaluation of DNAPL Remedial Alternatives
Montrose Superfund Site

Notes:
ICs = institutional controls
HD = hydraulic displacement
ERH = electrical resistance heating
bgs = below ground surface
lbs = pounds
MM = million
GHG = greenhouse gases
MCB = monochlorobenzene
GAC = granular activated carbon
NPV = net present value
VOCs = volatile organic compounds
SVE = soil vapor extraction
O&M = operations and maintenance
PVS = Palos Verdes Sand
UBA = Upper Bellflower Aquitard
BFS = Bellflower Sand
RAOs = remedial action objectives
RA = remedial alternative
ISTD = in-situ thermal destruction
kw-hrs = kilowatt-hours
[1] NPV costs determined at discount rates of 4% and 7%
[2] State and Public Acceptance cannot be evaluated until after comments on the DNAPL FS are received

Section 7.0

Comparative Analysis of Remedial Alternatives

7.0 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents a comparative analysis of the nine RAs evaluated in Section 6. The candidate DNAPL RAs evaluated in Section 6 are summarized as follows:

Candidate DNAPL RAs

RA	Remedy Components
RA 1	No Action
RA 2	Institutional Controls
RA 3	Institutional Controls SVE in Unsaturated Zone
RA 4a	Institutional Controls SVE in Unsaturated Zone Hydraulic Displacement with Untreated Water Injection
RA 4b	Institutional Controls SVE in Unsaturated Zone Hydraulic Displacement with Treated Water Injection
RA 5a	Institutional Controls SVE in Unsaturated Zone Steam Injection, Focused Treatment Area with Hot Floor
RA 5b	Institutional Controls SVE in Unsaturated Zone Steam Injection, Entire Treatment Area with Hot Floor
RA 6a	Institutional Controls SVE in Unsaturated Zone ERH, Focused Treatment Area without Hot Floor
RA 6b	Institutional Controls SVE in Unsaturated Zone ERH, Entire Treatment Area without Hot Floor

In Section 6, the candidate DNAPL RAs were evaluated against nine performance criteria defined by the NCP. In this section, the performance of those RAs is compared collectively against each criterion. A list of the nine performance criteria is provided below, and the following sections present the comparative analysis by criterion. A description of these criteria has been provided in Section 6.0.

Threshold Criteria

- Overall protection of human health and the environment
- Compliance with ARARs

Balancing Criteria

- Long-term effectiveness and permanence

- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

Modifying Criteria

- State acceptance
- Public acceptance

A summary of the comparative analysis is provided in Section 7.10. EPA will identify a recommended DNAPL remedy in the Proposed Plan following review and approval of the DNAPL FS.

7.1 OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

Six of the nine candidate RAs are fully protective of human health and the environment as follows:

Protection of Human Health and the Environment Ranking

RA	Components	Protection of Human Health and Environment Rank
RA 1	No Action	Not Protective
RA 2	ICs	Not Protective
RA 3	ICs, SVE	Not Protective
RA 4a	ICs, SVE, HD with untreated water injection	Protective
RA 4b	ICs, SVE, HD with treated water injection	Protective
RA 5a	ICs, SVE Steam Injection over focused treatment area	Protective
RA 5b	ICs, SVE Steam Injection over entire treatment area	Protective
RA 6a	ICs, SVE, ERH over focused treatment area	Protective
RA 6b	ICs, SVE, ERH over entire treatment area	Protective

Notes:
ICs = Institutional controls
SVE = Soil vapor extraction
HD = Hydraulic displacement
ERH = Electrical resistance heating

RA 1 is not protective of human health because it does not include institutional controls restricting site activities with the potential for human exposure to DNAPL-impacted soils. However, institutional

controls required for the soil and groundwater remedies are expected to restrict similar activities and protect human health to some extent. RA 1 is also not protective of the environment because mobile DNAPL mass would not be reduced in the unsaturated or saturated zones, and the potential for recontamination of the aquifers would remain.

RAs 2 and 3 are protective of human health but not the environment. The institutional controls component of this RA protects human health by restricting Site access and uses that may result in exposure to DNAPL-impacted soils. RA 3 also partially protects the environment by removing the source of VOCs and DNAPL in the permeable unsaturated zone overlying groundwater and by controlling VOC migration in soil gas in the short-term. However, these alternatives do not reduce the mobile DNAPL mass, the principal threat, or limit the potential for uncontrolled mobile DNAPL migration in the saturated zone. Therefore, RAs 2 and 3 are not protective of the environment in the saturated zone.

RAs 4a through 6b are all protective of human health and the environment. RAs 4a and 4b protect the environment by removing mobile DNAPL mass from the saturated UBA by hydraulic displacement, reducing the risk of DNAPL migration either laterally within the UBA or downward into the BFS. A conceptual well spacing of 50 feet is considered for this hydraulic displacement RA and is less than computer modeled distances of 120 feet. Additionally, computer modeling of hydraulic displacement predicted that no DNAPL would be mobilized past the basal silty sand member of the UBA or to the underlying BFS if continuous. Although there is some uncertainty with regards to the continuity and pore entry pressures of the basal layer, it is expected to be able to support DNAPL pool heights between 1.3 and 8 feet, if continuous. RAs 4a and 4b will remove the majority of the mobile DNAPL mass from the UBA, and the mobility of the remaining DNAPL will be significantly reduced and unlikely to pose a significant threat to the environment or risk of uncontrolled migration under normal hydrologic conditions. The hydraulic gradients during remedy implementation will be more than 100 times greater than the gradients during normal hydrologic conditions. With the exception of stagnation zones, which can occur for all displacement technologies (such as steam injection), any DNAPL not mobilized by these high hydraulic gradients and relatively dense well spacing is unlikely to be mobile under normal hydrologic gradients.

RAs 5a through 6b protect the environment by removing mobile and residual DNAPL mass from the saturated zone by steam injection or ERH. Although these thermal remediation RAs would remove more MCB mass than RAs 4a and 4b, they additionally present an increased risk of adverse consequences associated with remedy excursion or upset conditions. There is an increased risk of contaminant migration associated with thermal remediation, particularly during steam injection. Uncontrolled steam

distribution can result in lateral spreading and a reduction in the protectiveness of RAs 5a and 5b. Additionally, there is an increased risk of downward migration associated with steam injection as it can concentrate DNAPL at the steam front (unlike hydraulic displacement) and increase its mobility in the environment. If not effectively recovered, the DNAPL may migrate downward into the BFS through discontinuous capillary barriers or barriers de-saturated by steam temperatures as observed during 2-dimensional bench-scale testing. Although RAs 5a and 5b include implementation of a hot floor within the underlying BFS, the effectiveness of a steam injection hot floor in the underlying aquifer is uncertain and has not been implemented at a comparable site. Although a hot floor in the BFS would theoretically reduce, to some extent, the risk of DNAPL migrating through the UBA during steam injection, 100% effectiveness is not assured. Steam injection hot floors are infrequently implemented, and there is an absence of experience at comparable sites to reliably predict the performance of a hot floor at the Montrose Site. It is noted that EPA does not agree with the above characterization of mobilization risks or hot floor effectiveness during steam injection (CH2M Hill, 2013). RAs 6a and 6b do not include a hot floor but do include a "bottom up" heating approach to reduce the potential for MCB vapors to condense and migrate vertically downward. The "bottom up" heating approach would eliminate the need for a hot floor and the migration risks associated with drilling through the DNAPL-impacted UBA and into the underlying BFS.

RAs 4a through 6b all include some degree of risk associated with uncontrolled DNAPL migration during remedy implementation. Although RAs 4a and 4b do not include a hot floor, hydraulic displacement is a depleting technology which continuously reduces the DNAPL saturation and mobility. RAs 5a and 5b include a hot floor but can increase the DNAPL saturation and mobility at the steam front and can de-saturate thin capillary barriers, reducing their ability to support DNAPL pools and prevent downward migration. RAs 6a and 6b have a reduced potential for uncontrolled migration but require that heated vapors be effectively recovered to prevent them from re-condensing in another portion of the saturated zone. ERH is a volatilization technology, not a displacement technology, and the higher number of wells required for ERH reduces the potential for uncontrolled DNAPL migration in the short-term. Uncontrolled DNAPL or MCB migration during remedy implementation could reduce the protectiveness of the candidate RAs in the long-term.

7.2 COMPLIANCE WITH ARARS

All but two of the candidate RAs unconditionally complies with DNAPL ARARs as follows:

Compliance With ARARs Ranking

RA	Components	Compliance with ARARs Rank
RA 1	No Action	Does Not Comply
RA 2	ICs	Complies
RA 3	ICs, SVE	Complies
RA 4a	ICs, SVE, HD with untreated water injection	Does Not Comply (unless ARAR waived[1])
RA 4b	ICs, SVE, HD with treated water injection	Complies
RA 5a	ICs, SVE Steam Injection over focused treatment area	Complies
RA 5b	ICs, SVE Steam Injection over entire treatment area	Complies
RA 6a	ICs, SVE, ERH over focused treatment area	Complies
RA 6b	ICs, SVE, ERH over entire treatment area	Complies

Notes:
[1] A waiver to re-inject untreated groundwater would be required over the 5 year duration of the HD remedy for RA 4a.

The No Action RA (RA 1), which excludes institutional controls, may not comply with Land Use Covenant requirements established under CCR Title 22 and the California Civil Code, although these requirements may be met through the soil remedy. RA 1 would not comply with DNAPL ARARs, unless institutional controls implemented through the soil remedy addressed DNAPL exposure pathways.

RA 4a includes re-injection of untreated water during hydraulic displacement and would not comply with EPA and State re-injection standards. A waiver of the re-injection standards would be required for the 5-year duration of the HD remedy, as previously approved by EPA and the State during field pilot testing of this technology. RA 4a would meet the requirements of 42 U.S.C. § 6939(b) by substantially reducing hazardous constituents prior to groundwater injection. Separation of the DNAPL from groundwater following total fluids extraction would initially remove up to 90% of the total contaminant mass before re-injection. Additionally, the re-injection of groundwater under RA 4a would not trigger the State's anti-degradation policy because it would not negatively impact existing groundwater quality in the re-injection area, which occurs entirely on-Property and within the boundaries of the existing TI Waiver Zone. However, in accordance with EPA comments, RA 4a is ranked as not complying with ARARs unless the re-injection standards are temporarily waived in the short-term.

However, all other candidate RAs would unconditionally comply with ARARs. RAs 3 through 6b include SVE with ex-situ vapor treatment, and field pilot testing has already demonstrated the ability of activated carbon to comply with air emission ARARs including the Clean Air Act and SCAQMD regulations. All RAs would comply with waste management ARARs under CFR Title 40 and CCR Title 22. Temporary on-Site accumulation of liquid-phase DNAPL would be required for RAs 4a through 6b. The aboveground collection tank would have to comply with hazardous materials storage regulations under CFR Title 40 and CCR Title 22. Although a TBC, and not an ARAR, all remedy wells installed into groundwater would comply with California Well Standards. RAs 4b through 6b include treatment of the dissolved-phase concentrations in groundwater prior to re-injection and would also comply with Groundwater ROD in-situ groundwater standards.

7.3 LONG-TERM EFFECTIVENESS AND PERMANENCE

The long-term effectiveness of the candidate RAs is partially determined by their ability to reduce mobile DNAPL mass, the principal threat, in the short-term (as described in Section 7.4) and reduce the potential for recontamination of the aquifers in the long-term. Mobile DNAPL mass left in place following implementation of the candidate RAs could migrate laterally or vertically in the future and may pose a risk to groundwater resources in the long-term. Although residual DNAPL mass left in place following implementation of the candidate RAs will serve as a continuing source to groundwater, it is immobile under gravitational forces and does not pose a risk to the groundwater remedy. Residual DNAPL mass left in place will slowly dissolve over time and be hydraulically contained by the groundwater remedy. The estimated hydraulic containment timeframes required to meet ARARs in the UBA were estimated in Section 2.6.1.

Long-Term Effectiveness and Permanence Ranking

RA	Components	Long-Term Effectiveness Rank
RA 1	No Action	Not Effective
RA 2	ICs	Not Effective
RA 3	ICs, SVE	Not Effective (Unsaturated Zone Only)
RA 4a	ICs, SVE, HD with untreated water injection	Moderately Effective
RA 4b	ICs, SVE, HD with treated water injection	Moderately Effective

RA 5a	ICs, SVE, Steam Injection over focused treatment area	Effective
RA 5b	ICs, SVE, Steam Injection over entire treatment area	Effective
RA 6a	ICs, SVE, ERH over focused treatment area	Effective
RA 6b	ICs, SVE, ERH over entire treatment area	Effective

Notes:
Estimated reduction in MCB mass shown in Section 7.4

RAs 1 through 3 are not effective in the long-term because they do not reduce the mobile DNAPL mass in the short-term. Although RA 3 reduces the DNAPL and MCB mass in the unsaturated zone, it also does not reduce the mobile DNAPL mass in the saturated zone. Unless the mobile DNAPL mass is substantially reduced in the short-term, the potential for uncontrolled DNAPL migration and recontamination of the aquifers will remain in the long-term.

RAs 4a and 4b remove mobile DNAPL mass from the saturated zone by hydraulic displacement. These RAs are expected to remove a substantial portion of the mobile DNAPL mass and significantly reduce the mobility of DNAPL remaining in the UBA. These RAs would include installation of 23 multi-phase extraction and 46 injection wells over a focused treatment area of approximately 26,000 square feet, where all of the mobile DNAPL is estimated to occur. Horizontal hydraulic gradients in the UBA would be increased by 100 times or more during RAs 4a and 4b. Any DNAPL not mobilized by the relatively dense well pattern and high horizontal gradients is unlikely to be particularly mobile under normal hydrologic conditions. The potential for uncontrolled migration and recontamination of the aquifers would be significantly reduced by RAs 4a and 4b. However, RAs 4a and 4b are likely to remove less mobile DNAPL mass than RAs 5a and 6a, and any mobile DNAPL left in place following HD may pose a risk to groundwater resources in the long-term. Additionally, any DNAPL migrating vertically downward into the BFS would reduce the long-term effectiveness of this remedy. In a paper dated February 18, 2011 (Kueper, 2011), Dr. Kueper indicated that hydraulic displacement is a pool depletion technology, meaning that DNAPL pools get shorter in height as they move towards extraction wells (not larger in height as during steam injection). Dr. Kueper indicated that hydraulic displacement was a well established NAPL recovery technology that would allow for substantial recovery of the mobile DNAPL at the Site without posing the same vertical migration risks as candidate steam injection RAs. The basal layer of the UBA is expected to be capable of supporting DNAPL pool heights between 1.3 and 8 feet if continuous and depending on the capillary pressures required to penetrate the layer.

RAs 5a and 6a remove mobile and residual DNAPL mass over a focused treatment area in the saturated zone by steam injection and ERH, respectively. Where target temperatures are achieved and MCB is recovered by multi-phase extraction wells, RAs 5a and 6a are expected to be effective in reducing mobile DNAPL mass and the potential for recontamination of the aquifers. However, these thermal remediation technologies have not been pilot tested at the Site, and the effectiveness is uncertain. Steam injection was bench-scale tested, which demonstrated that between 57% and 64% of the MCB mass (and all of the mobile mass) could be removed under relatively ideal and controlled laboratory conditions. The highly layered and heterogeneous nature of the saturated UBA is not ideal conditions for steam injection (or hydraulic displacement), and there is a potential for steam injection to be less effective at field scale conditions. ERH is not permeability dependent and is less affected by the nature of the saturated UBA, although heated MCB vapors must still be effectively recovered in order to prevent cooling and re-condensing of the MCB in another part of the Site, potentially outside the DNAPL footprint. However, the higher density of wells required for ERH increases the probability of recovering MCB vapors as compared with steam injection. Additionally, maintaining hydraulic control during ERH is less problematic than during steam injection.

RAs 5b and 6b remove mobile and residual DNAPL mass over the entire treatment area in the saturated zone by steam injection and ERH, respectively. These RAs reflect the highest level of DNAPL source removal considered in this FS. These RAs have the same long-term effectiveness as RAs 5a and 6a, except that they would additionally remove residual DNAPL mass from outside of the focused treatment area where only 13% to 40% of the total DNAPL mass is estimated to occur. If implemented, these full-scale RAs would be one of the largest and most complex thermal remedies ever conducted. Despite implementing a large and full-scale thermal remedy over the entire treatment area at the Site, long-term hydraulic containment would still be required for hundreds or thousands of years. None of the candidate RAs can remove sufficient DNAPL mass to meaningfully reduce the time required for long-term hydraulic containment, and these full-scale thermal RAs offer little advantage over the focused treatment area alternatives in terms of containment duration. Although RAs 5b and 6b have the potential to remove the most MCB mass, their ability to reduce the mobile DNAPL mass, limit uncontrolled migration, and reduce the potential for recontamination of the aquifers is identical to RAs 5a and 6a (i.e., all of the mobile DNAPL mass is contained within the focused treatment area). Residual DNAPL is immobile under gravitational forces and does not pose a risk to the groundwater remedy. Residual DNAPL left in-situ, both inside and outside the focused treatment area, will serve as a continuing source of dissolved-phase contamination to groundwater in the long-term but will be hydraulically contained by the groundwater remedy.

Contaminant mobilization in the short-term (if it were to occur) may result in lateral spreading or downward mobilization. In a paper dated February 22, 2011 (McMillan-McGee, 2011), McMillan-McGee indicated that steam override and channeling was likely in the heterogeneous UBA. RAs 5a and 5b include implementation of a hot floor in the BFS to abate DNAPL migrating down from the UBA, but there is an absence of experience at comparable sites to reliably predict the performance of the hot floor. In their paper, McMillan-McGee indicated that the hot floor had a low chance of success in preventing downward migration of DNAPL into the BFS, although the hot floor could potentially treat DNAPL once in the upper BFS. Uncontrolled steam distribution could result in spreading of the contamination within the saturated zone as observed during 2-dimensional bench-scale testing of steam injection. Although no mobile DNAPL remained in the test cell following steam injection, significant MCB redistribution was observed throughout the test cell including above, through, and below the thin and discontinuous capillary barrier. Thin capillary barriers can be de-saturated at steam temperatures, reducing the ability for these layers to restrict the downward migration or displacement of DNAPL. The treatment area considered by full-scale RAs 5b and 6b is more than six times the size of the focused treatment area and increases the potential for uncontrolled contaminant mobilization in the short-term. Large treatment areas are subject to a greater potential for non-uniform heating, cold spots, and for DNAPL to uncontrollably migrate through a discontinuous capillary barrier or through a de-saturated thin capillary barrier. Uncontrolled contaminant mobilization in the short-term could reduce the effectiveness of these RAs in the long-term. It is noted that EPA does not agree with the above characterization of mobilization risks during steam injection (CH2M Hill, 2013).

7.4 REDUCTION OF TOXICITY, MOBILITY, AND/OR VOLUME OF HAZARDOUS CONSTITUENTS

In the long-term, all of the RAs slowly reduce the toxicity, volume, and mobility of the DNAPL in the saturated UBA via dissolution. In the short-term, DNAPL mass is reduced for the RAs as summarized below:

Estimated Volume Reduction in Short-Term

RA	Components	Reduction in Mobility or Toxicity	Reduction in Volume (gallons)			
			Unsaturated Zone MCB	Saturated Zone MCB	Total MCB	Saturated Zone Total DDT
RA 1	No Action	No	0	0	0	0
RA 2	ICs	No	0	0	0	0

RA 3	ICs, SVE	Unsaturated Zone Only	27,000-30,000	0	27,000-30,000	0
RA 4a	ICs, SVE, HD w/ untreated water injection	Some	27,000-30,000	9,000-13,000	36,000-43,000	9,000-13,000
RA 4b	ICs, SVE, HD w/ treated water injection	Some	27,000-30,000	9,000-13,000	36,000-43,000	9,000-13,000
RA 5a	ICs, SVE, Steam Injection over focused area	Yes	27,000-30,000	15,000-25,000	42,000-55,000	>0
RA 5b	ICs, SVE, Steam Injection over entire area	Yes	27,000-30,000	26,000-29,000	53,000-59,000	>0
RA 6a	ICs, SVE, ERH over focused area	Yes	27,000-30,000	15,000-25,000	42,000-55,000	0
RA 6b	ICs, SVE, ERH over entire area	Yes	27,000-30,000	26,000-29,000	53,000-59,000	0

RAs 1 and 2 do not reduce the toxicity, mobility, or volume of the DNAPL in the short-term. However, in the short-term, all other RAs include an accelerated rate of DNAPL volume and mobility reduction within source areas. RAs 3 through 6b include reduction of VOC/DNAPL volume and mobility in the unsaturated zone by SVE. An estimated 27,000 to 30,000 gallons of MCB would be removed from the unsaturated zone by SVE depending on the removal efficiency within soils of varying permeability.

RAs 4a and 4b are expected to remove between 9,000 and 13,000 gallons of mobile MCB mass from the saturated zone by hydraulic displacement, assuming an 80% mobile mass removal efficiency (upper end of performance range). Although RAs 4a and 4b would not reduce MCB mass in the saturated zone as much as RAs 5a through 6b (which also remove residual DNAPL mass), it would remove a substantial portion of the mobile DNAPL mass (the principal threat) and significantly reduce the mobility of any DNAPL left in place within the focused treatment area. DNAPL/water capillary pressure testing (Section 2.1.2 and Appendix B) suggests that elevated capillary pressures would be required to displace the final 1% to 1.5% of mobile DNAPL (e.g., 18.9% to 20.4% DNAPL saturations). Any DNAPL not mobilized by a relatively high well density under high hydraulic gradients is not expected to be particularly mobile under normal hydrologic gradients, which would be 100 times lower or more. Furthermore, RAs 4a and 4b work within the existing DNAPL architecture and would remove the most DNAPL-phase DDT of all RAs under consideration. An equal volume of DNAPL-phase DDT, approximately 9,000 to 13,000 gallons, would also be removed by hydraulic displacement under RAs 4a and 4b, assuming 80% mobile

mass removal efficiency, the majority of which would otherwise be left in-situ by the thermal remediation RAs. However, DDT is relatively insoluble in groundwater and is not expected to pose a significant environmental threat if left within the saturated UBA.

RAs 5a and 6a would remove an estimated 15,000 to 25,000 gallons of mobile and residual MCB from the saturated zone over a focused treatment area by steam injection and ERH respectively. This volume reduction is based on a 60% MCB mass removal efficiency (mobile and residual) as observed during 2-dimensional bench-scale testing of steam flushing under relatively ideal and controlled laboratory conditions. This assumption is adequate for purposes of evaluating the candidate RAs in this FS, but field application of steam injection may not result in the same degree of mass or volume reduction since heating soils in an insulated test cell would likely overestimate the mass reduction if anything. Where target temperatures are achieved and MCB is recovered by multi-phase extraction, RAs 5a and 6a would be expected to reduce MCB saturations to residual levels and be relatively immobile in the environment, as observed during 2-dimensional bench-scale testing where all remaining MCB was found to be at residual saturations. However, removal of 100% of the mobile DNAPL mass by thermal remediation is not assured throughout the treatment area. Like all saturated zone RAs under consideration in this FS, inefficiencies or stagnation zones can reduce the removal efficiency, potentially leaving behind some mobile DNAPL mass within portions of the saturated UBA. The saturated UBA is highly layered and heterogeneous, and steam will preferentially flow through the more permeable sand layers. Controlling the distribution of steam may be problematic, and heating of the less permeable silt layers will depend on heat conduction from the adjacent sands. The lithology of the UBA may also pose challenges for recovering heated MCB vapors, and if not effectively recovered, could re-condense in another part of the UBA, potentially outside the remediation footprint. Cooling of the saturated UBA may additionally occur along the upgradient boundary of the treatment area, or from the underlying BFS for RA 6a. Where these inefficiencies occur and target temperatures are not achieved by the thermal remedy, higher and potentially mobile saturations may be left in the saturated zone.

RAs 5b and 6b would remove an estimated 26,000 to 29,000 gallons of mobile and residual MCB from the saturated zone over the entire treatment area by steam injection and ERH respectively. Although the potential volume reduction from the full-scale thermal remediation RAs is the largest considered in this FS, it is only minimally larger than the potential volume reduction under the focused treatment area RAs (i.e., 15,000 to 25,000 gallons of MCB). Additionally, these full-scale RAs do not further reduce the mobility of DNAPL in the saturated UBA (i.e., the principal threat) over focused treatment area RAs 5a and 6a. Even under full-scale thermal remediation, some DNAPL will be left in place following steam injection or ERH and will serve as a long-term source to groundwater, requiring hydraulic containment

for hundreds or thousands of years. The minimal increase in volume reduction offered by RAs 5b and 6b (with no further reduction in mobility) is off-set by negative impacts on other balancing criteria including cost, short-term effectiveness, and implementability. F urthermore, there is a greater potential for inefficiencies, stagnation zones, or other performance-related issues to occur under RAs 5b and 6b, which would treat an area more than six times the size of the focused treatment area. Over a treatment area of this size, there is an increased potential for migrating DNAPL or MCB vapors to encounter a discontinuous sand lense or capillary barrier, before being recovered by a multi-phase extraction well. These inefficiencies, if encountered, would reduce the volume of DNAPL removed under the full-scale thermal remedies.

The toxicity of the unsaturated soils and soil gas at the Site is reduced by SVE for RAs 3 through 6b. MCB concentrations and sorbed mass will be significantly reduced in permeable unsaturated soils, resulting in reduced soil exposure toxicity. T he reduced MCB mass in the unsaturated zone will additionally result in reduced MCB concentrations in soil gas, reducing the soil gas exposure toxicity at depth. However, relatively high MCB concentrations in shallow soils within the low permeability PD (4 to 25 feet bgs), where SVE is expected to be significantly less effective, may remain in-situ following DNAPL remedy implementation. Shallow PD soils between 0 and 10 feet bgs are being addressed by the Soil FS. Additionally, although DNAPL mass will be reduced from the saturated UBA, the toxicity of the saturated UBA soils will not be completely reduced as residual DNAPL will remain in place (in varying quantities) following remedy implementation, regardless of which RA is selected. In the long-term, the toxicity of the DNAPL-impacted soils is further reduced through dissolution, but an insufficient volume of DNAPL can be removed by any of the candidate RAs in the short-term to meaningfully reduce the toxicity of the soils or the duration required for long-term hydraulic containment.

7.5 SHORT-TERM EFFECTIVENESS

Four of the 9 candidate RAs are either effective or moderately effective in the short-term. T wo of the candidate RAs are less effective, and three of the candidate RAs are not effective in the short-term.

Short-Term Effectiveness Ranking

RA	Components	Short-Term Effectiveness Rank	Estimated GHG Emissions (pounds of GHGs)
RA 1	No Action	Not Effective	0
RA 2	ICs	Not Effective	0

RA 3	ICs, SVE	Not Effective	6,000,000
RA 4a	ICs, SVE, HD with untreated water injection	Effective	11,000,000
RA 4b	ICs, SVE, HD with treated water injection	Effective	26,000,000
RA 5a	ICs, SVE, Steam Injection over focused treatment area	Moderately Effective	51,000,000 – 106,000,000
RA 5b	ICs, SVE, Steam Injection over entire treatment area	Less Effective	189,000,000 – 412,000,000
RA 6a	ICs, SVE, ERH over focused treatment area	Effective	33,000,000 – 61,000,000
RA 6b	ICs, SVE, ERH over entire treatment area	Less Effective	143,000,000 – 227,000,000

RA 1 is not protective of human health and the environment in the short-term because institutional controls would not be required to prevent human exposure to DNAPL-impacted soils, although institutional controls for soil and groundwater are likely to limit contaminant exposure pathways at the Site and protect human health to some degree. All other RAs (RAs 2 through 6b) include institutional controls for DNAPL and would be protective of human health in the short-term in varying levels of effectiveness. However, RA 2 would not control migration of VOCs in soil gas or reduce mobile DNAPL mass in the short-term.

RA 3 additionally includes SVE and would protect human health and the environment in the short-term by reducing DNAPL mass in the unsaturated zone and controlling VOC migration in soil gas. Disposable carbon/resin is identified as the lowest cost treatment technology for this RA and was highly effective in meeting air emission ARARs during SVE field pilot testing in 2003. Additionally, this vapor treatment technology does not involve any combustion processes (such as thermal oxidation), steam-regeneration processes (such as with on-site carbon/resin regeneration), or any on-Site storage of condensed VOCs/DNAPL (such as with steam-regenerable carbon/resin). Spent carbon/resin is removed for off-Site recycling or disposal. Disposable carbon/resin is the least complex vapor treatment technology and is a reliable method for protecting human health and the environment during remedy implementation. However, RA 3 does not reduce the mobile DNAPL mass in the saturated zone (principal threat) or the potential for uncontrolled migration. Consequently, in the short-term, RA 3 is not effective in protecting the environment within the saturated zone.

All of the candidate RAs which reduce DNAPL mass in the saturated zone (RA 4a through 6b) have remedy durations of 7 to 9 years and are expected to protect human health and the environment in the short-term but with varying amounts of risk. In the short-term, RAs 4a and 4b reduce mobile DNAPL mass in the saturated zone by hydraulic displacement. RA 4a requires the least amount of infrastructure (and least complex) and has the lowest risk of remedy excursions or upset conditions. The ex-situ system for RA 4a includes DNAPL separation and groundwater filtration, which are relatively simple and reliable processes. No additional treatment of the groundwater is performed prior to re-injection under RA 4a. RA 4b has the same short-term effectiveness as RA 4a but includes ex-situ treatment of groundwater by disposable LGAC and advanced oxidation (HiPOx™), both of which are processes that have been successfully pilot tested at the Site. No modification of the unsaturated zone SVE system or ex-situ treatment technology is required by RAs 4a and 4b.

Under RAs 4a and 4b, there is a risk that mobile DNAPL would migrate vertically downward through discontinuous capillary barriers. Although RAs 4a and 4b do not include a hot floor in the BFS (like for steam injection), these RAs do not increase the mobility of the DNAPL and continuously deplete the DNAPL saturation over time. Additionally, the basal silty sand layer in the UBA is expected to support DNAPL pool heights between 1.3 and 8 feet if continuous and depending on the capillary pressures required to penetrate the soils. Overall, the risks of downward migration under hydraulic displacement are slightly lower than for steam injection (i.e., both are displacement technologies and dependent on the permeability of the soils).

RAs 4a and 4b also have the lowest carbon footprints (11 to 26 million pounds of GHGs) of the candidate RAs which reduce DNAPL mass in the saturated zone in the short-term (i.e., RAs 4a through 6b). Hydraulic displacement does not require a significant amount of energy to implement, as reflected by the relatively low carbon footprints. RA 4b includes treatment of the dissolved-phase concentrations in groundwater, which significantly increases the carbon footprint of hydraulic displacement, although it is still lower than the candidate thermal remediation RAs. The candidate hydraulic displacement remedies would generate between 1,000 and 2,400 metric tons per year of GHGs, significantly below the mandatory reporting threshold of 25,000 metric tons per year. The relatively low carbon footprints comply with EPA and California green remediation initiatives and advance the goals of the California Global Warming Solutions Act of 2006, which are TBCs for this FS.

The short-term effectiveness of RA 6a is comparable to that for RAs 4a and 4b. Although thermal remediation projects pose an increased potential for accidental release of heated vapors or contaminated steam to atmosphere as a fugitive emission, the risks under ERH are less than for steam injection due to

lower operating pressures and a more gradual heating process. The heated vapors must also be effectively recovered in order to prevent contaminant migration in the subsurface, and the high density of ERH wells (relative to steam injection) reduces the risk associated with vapor migration and increases the potential for contaminant recovery. The high density of ERH wells (182 total electrode locations, multiphase, and temperature monitoring wells) also increases the risk of downward migration to occur within the UBA as a result of drilling activities. However, the drilling risks for ERH are less than for steam injection since installation of a hot floor into the BFS is not required by this RA. Additionally, a "bottom up" heating approach using ERH further reduces the risks of downward migration in the short-term. This alternative has a moderately large carbon footprint (33 to 61 million pounds of GHGs) and would be expected to generate approximately 15,000 metric tons per year. RA 6a is the only candidate thermal remediation alternative not expected to approach or exceed the mandatory reporting threshold of 25,000 metric tons per year.

RA 5a would be effective in protecting human health and the environment in the short-term but would also have higher risks than exhibited by RAs 4a, 4b, and 6a. Under RA 5a, there is an increased potential for heated vapors or contaminated steam to be accidentally released to atmosphere as a fugitive emission due to increased operating pressures and rapid heating process. RA 5a would additionally include air emissions from the steam boilers (nitrogen and sulfur oxides), which are not required for RA 6a. Additionally, there is an increased mobilization risk associated with installation of the 36 hot floor wells required under RA 5a. Downward migration of DNAPL as a result of well installation activities, particularly if into the BFS, would not be protective of the environment in the short-term. RA 5a has the largest carbon footprint (51 to 106 million pounds of GHGs) of the candidate focused treatment area RAs. This alternative would be expected to generate approximately 23,000 to 26,000 metric tons per year of GHGs, and will approach or exceed the mandatory reporting threshold of 25,000 metric tons per year.

RAs 5a and 5b can also increase the mobility of the DNAPL in the short-term and concentrate it at the steam front. The concentrated DNAPL has the potential to migrate downward through discontinuous capillary barriers if above residual saturations. Additionally, steam injection has the potential to de-saturate thin capillary barriers in the short-term, thereby increasing their permeability and the potential for DNAPL to migrate through the barrier, even if continuous. RAs 5a and 5b include implementation of a hot floor in the BFS to abate DNAPL migrating through the UBA, if any. Although a hot floor in the BFS would theoretically reduce, to some extent, the risk of DNAPL migrating through the UBA during steam injection, 100% effectiveness is not assured. Steam injection hot floors are infrequently implemented, and there is an absence of experience at comparable sites to reliably predict the performance of a hot floor at the Montrose Site. It is noted that EPA does not agree with the above

characterization of mobilization risks and hot floor effectiveness during steam injection (CH2M Hill, 2013).

RAs 5b and 6b have the greatest potential of all RAs considered in this FS for remedy excursions, upset conditions, and migration risks due to the scale of the thermal remediation project. These RAs would require the largest ex-situ vapor and groundwater treatment systems, 200 gpm and 2,000 scfm respectively, more than double the capacities of the comparable systems for the focused treatment area RAs. The increased system capacity increases the level of required maintenance and the potential for upset conditions or fugitive emissions to occur in the short-term. RA 5b includes 77 hot floor wells drilled through the DNAPL-impacted UBA and RA 6b includes installation of 729 total remedy wells, electrodes, and temperature monitoring points, significantly increasing the potential for downward migration to occur in the short-term as a result of drilling.

RAs 5b and 6b also have the largest carbon footprints (143 to 412 million pounds of GHGs) of all candidate RAs considered in this FS. RA 5b would be expected to generate approximately 47,000 metric tons per year of GHGs, significantly exceeding the mandatory reporting threshold. The annual GHG emissions from RA 5b would exceed the carbon footprints reported for approximately 40% of the California power plants in 2007 (Environment Oregon Research & Policy Center, 2009). These RAs would not comply with EPA or State green remediation initiatives and could impede the State's ability to comply with the California Global Warming Solutions Act of 2006.

7.6 IMPLEMENTABILITY

Six of the RAs are moderately to highly implementable, while three of the RAs would be difficult to implement as follows:

Implementability Ranking

RA	Components	Implementability Rank
RA 1	No Action	Highly Implementable
RA 2	ICs	Highly Implementable
RA 3	ICs, SVE	Highly Implementable
RA 4a	ICs, SVE, HD with untreated water injection	Difficult to Implement[1]
RA 4b	ICs, SVE, HD with treated water injection	Moderately Implementable
RA 5a	ICs, SVE, Steam Injection over focused treatment area	Moderately Implementable

RA 5b	ICs, SVE, Steam Injection over entire treatment area	Difficult to Implement
RA 6a	ICs, SVE, ERH over focused treatment area	Moderately Implementable
RA 6b	ICs, SVE, ERH over entire treatment area	Difficult to Implement

Notes:
[1] Although technically implementable, RA 4a may not be administratively implementable unless a waiver to re-inject untreated groundwater was granted over the 5 year duration of the HD remedy.

RAs 1 through 3 are highly implementable but are not protective of human health and the environment. Access restrictions are already being implemented at the Site and will be addressed as part of the Soil FS. A Land Use Covenant could be established at the Montrose Property, where nearly all of the DNAPL is located. SVE is a widely implemented technology, and disposable carbon/resin is readily available for ex-situ vapor treatment. Highly skilled operators are not required for this RA, and there are a large number of contractors available to provide SVE remediation services.

The implementability of hydraulic displacement under RAs 4a and 4b has already been demonstrated through field pilot testing, with moderate DNAPL recovery rates observed in all wells within the mobile DNAPL footprint. The Montrose DNAPL can be readily separated from groundwater using standard techniques, and the implementability of re-injecting groundwater into the UBA has already been successfully demonstrated during HD pilot testing (partially due to mounding in the unsaturated zone). However, under both HD alternatives, significant maintenance would be required to abate equipment and well fouling from DDT and mineral precipitates. Under RA 4a, treatment of the groundwater is not performed prior to re-injection, so the ex-situ equipment is the least complex and would require the least maintenance. However, administratively, RA 4a may be difficult to implement because a waiver of the re-injection standards would be required from EPA and the State over the 5-year duration of the remedy, although previously granted during field pilot testing of this technology. RA 4b would treat the dissolved VOCs ex-situ and would administratively comply with the groundwater re-injection standards but would be moderately implementable and require operation of a robust ex-situ treatment train including disposable LGAC and advanced oxidation (HiPOx™). The ex-situ groundwater treatment system would require a higher level of maintenance, more skilled operators, and a higher amount of consumables.

RAs 5a and 6a would also be moderately implementable. Thermal remediation projects require a large amount of infrastructure to heat the subsurface, recover contaminants, and treat or dispose of contaminants ex-situ. Under RAs 5a and 6a, ex-situ treatment of groundwater with subsequent re-injection off-Property into the BFS and Gage Aquifer would be required because re-injection into the UBA would cool the subsurface and reduce the effectiveness of those remedies. Although the BFS and

Gage aquifers are likely to require less frequent redevelopment than UBA wells, a routine redevelopment program will still be required and the difficulty of implementing these RAs is increased by the coordination required between the DNAPL and groundwater remedies. These RAs would additionally require more infrastructure than RAs 4a and 4b including steam boilers and delivery system for RA 5a and electricity delivery and electrode wetting systems for RA 6a. Two LADWP electrical substations are located adjacent to the JCI property (Figure 1.7), and therefore, transmission of sufficient electrical power to the Montrose property is not expected to pose any significant implementability challenges for RA 6a. The operational demands of the soil heating technologies will increase the difficulty of implementing these RAs by requiring additional maintenance and more highly skilled operators. RAs 5a and 6a would require a high level of maintenance, particularly for RA 5a which additionally requires boiler maintenance, water pre-conditioning, and brine disposal. RAs 5a and 6a would also require highly skilled field operators and specialized technology vendors. Although there are three qualified technology vendors available for ERH, steam injection is implemented less frequently and there are fewer resources available to implement this technology. At some steam injection sites, steam consultants work with a remediation contractor to implement a steam remedy. RA 5a is slightly more difficult to implement that RA 6a because it requires implementation of a hot floor in the BFS. Hot floors are very infrequently implemented and would increase the complexity of RA 5a. Additionally, hot floor wells require specialized drilling methods to isolate the DNAPL-impacted zone during drilling. Also, due to the higher mass removal rates, RAs 5a and 6a would require use of either a steam-regenerable carbon/resin or thermal oxidation ex-situ vapor treatment system. These ex-situ vapor treatment technologies are more complex and require additional maintenance and management of additional waste streams not otherwise required by the other RAs.

RAs 5b and 6b are the least implementable of the candidate alternatives considered in this FS. If implemented, these RAs would be one of the largest and most complex thermal remedies ever conducted. A significant amount of wells and infrastructure would be required by these full-scale thermal RAs, increasing the difficulty of implementing the project. RA 6b would require installation of 729 ERH electrodes, multi-phase extraction wells, and temperature monitoring points, which would be a significant implementability and cost burden to the project and would generate a significant amount of waste requiring management and disposal. RA 5b would require installation of 77 hot floors wells through the DNAPL-impacted UBA and into the underlying BFS, increasing the difficulty of implementing this RA and the potential for downward migration to occur as a result of drilling. The capacities of the ex-situ soil vapor and groundwater treatment systems would more than double as compared with RAs 5a and 6a, i.e., 75 to 200 gpm and 750 to 2,000 scfm. Additionally, multiple steam boilers would be required under RA

5b, which would require water conditioning and management of boiler brine waste. RAs 5b and 6b have all the implementability challenges of RAs 5a and 6a but also the increased implementability challenges associated with the substantially increased scale and size of the remedy.

7.7 COST

Costs for the nine RAs ranged from $0 to $84.0 MM NPV (Table 6.1 and Appendix J) as follows:

Cost Ranking

RA	Components	Cost Rank	Estimated NPV Cost (million $)		Unit NPV Cost @4% ($/lb MCB removed)
			@7%	@4%	
RA 1	No Action	No Cost	$0 MM	$0 MM	NA
RA 2	ICs	Low	$0.2 MM	$0.2 MM	NA
RA 3	ICs, SVE	Low to Moderate	$4.4 MM	$4.8 MM	$17-$19/lb removed by SVE
RA 4a	ICs, SVE, HD with untreated water injection	Moderate	$11.0 MM	$12.2 MM	$54-$83/lb removed by HD
RA 4b	ICs, SVE, HD with treated water injection	High	$18.0 MM	$20.1 MM	$113-$172/lb removed by HD
RA 5a	ICs, SVE, Steam Injection over focused treatment area	High	$22.3-$29.8 MM	$24.0-$32.4 MM	$91-$211/lb removed by steam injection
RA 5b	ICs, SVE, Steam Injection over entire treatment area	Very High	$50.8-$71.7 MM	$56.3-$84.0 MM	$203-$345/lb removed by steam injection
RA 6a	ICs, SVE, ERH over focused treatment area	High	$18.6-$23.0 MM	$20.1-$25.0 MM	$74-$158/lb removed by ERH
RA 6b	ICs, SVE, ERH over entire treatment area	Very High	$46.2-$59.7 MM	$52.6-$69.5 MM	$189-$285/lb removed by ERH

Notes:
NA = not applicable; no mass reduction in short-term
Unit cost reflects NPV cost of remedial component (i.e., SVE, HD, steam, or ERH) divided by estimated MCB mass reduction in pounds (lb); HD, steam injection, and ERH unit costs do not reflect costs or mass reduction offered by SVE in the unsaturated zone.

RAs 1, 2, and 3 are the lowest cost RAs considered in this FS ($0 to $4.8 million NPV) but are not fully protective of human health and the environment. RA 2 includes institutional controls but does not include any reduction in DNAPL mass, either within the unsaturated or saturated zones. RA 3 includes SVE in the unsaturated zone, which is expected to remove an estimated 27,000 gallons of MCB at an incremental

cost of $4.2 to $4.6 million NPV at discount rates of 7% and 4%, respectively. This RA is highly cost effective in removing MCB at a unit cost of approximately $17 to $19 per pound of MCB removed by SVE.

RA 4a is the lowest cost ($11.0 to $12.2 million NPV) of the focused treatment area RAs, which also includes RAs 4b, 5a, and 6a. Under RA 4a, dissolved-phase VOCs are not removed from groundwater during hydraulic displacement and prior to re-injection. Although treatment of the dissolved-phase VOCs unconditionally complies with ARARs, it does not increase the mobile DNAPL mass removal in the short-term. Re-injection of untreated groundwater reduces the cost of this focused treatment RA but would require waiving the groundwater re-injection standards within the hydraulic containment area and TI waiver zone (as previously done during field pilot testing). RA 4a is expected to remove between 9,000 and 13,000 gallons of MCB at an incremental cost of $6.7 to $7.4 million NPV at discount rates of 7% and 4%, respectively. This RA is cost effective in removing MCB at a unit cost of approximately $54 to $83 per pound of MCB removed by hydraulic displacement (excludes cost effectiveness of SVE).

RAs 4b, 5a, and 6a all have similar costs ($18.0 to $32.4 million NPV) to remove DNAPL mass over a focused treatment area. RA 4b includes ex-situ treatment of groundwater during hydraulic displacement and prior to re-injection. The dissolved-phase concentrations are expected to be high, so groundwater treatment costs substantially increase the cost of a hydraulic displacement remedy at the Site by $7.0 to $7.9 million NPV but without increasing the DNAPL mass removal. Consequently, RA 4b is substantially less cost effective than RA 4a at approximately $113 to $172 per pound of MCB removed by hydraulic displacement (i.e., more than double the unit cost of RA 4a).

RAs 5a and 6a both have a cost range which varies depending on the amount of energy required to achieve the thermal performance objectives. RA 6a, ERH over a focused treatment area, has a slightly lower cost range ($18.6 to $25.0 million NPV) than the equivalent steam injection alternative, RA 5a ($22.3 to $32.4 million NPV). These thermal RAs can remove both mobile and residual DNAPL mass from the focused treatment area and are expected to remove between 15,000 and 25,000 gallons of MCB by steam injection or ERH. At the low end of the cost ranges, the cost effectiveness of these alternatives is similar to or slightly higher than RA 4a at $74 to $91 per pound of MCB removed by ERH and steam injection respectively. However, if additional energy and time is required to achieve the thermal performance objectives, these alternatives are significantly less cost effective at approximately $158 to $211 per pound of MCB removed by ERH and steam injection respectively. The upper end of the unit cost range is between two and four times the unit costs for RA 4a. The cost effectiveness of RAs 5a and 6a is highly dependent on the amount of energy required to achieve the thermal performance objectives,

and therefore, establishing reasonable and achievable thermal performance objectives, similar to those identified in Section 5.1.6, will be necessary if one of these focused treatment area thermal remediation RAs is selected. In a memorandum dated March 25, 2011 (AECOM, 2011e), Montrose recommended a thermal performance goal which limited the amount of energy consumed after reaching the target temperature goal. To confine the cost and duration of a thermal remedy, Montrose recommended an energy goal of one pore volume of steam flushing for steam injection or 50 kilowatt-hours per cubic yard for ERH after reaching target temperature. This approach would ensure implementation of a thermal remedy, if selected, within an energy demand range that is cost effective.

RAs 5b and 6b are the highest cost RAs considered in this FS, between $46.2 and $84.0 million NPV, depending on the amount of energy required to achieve the thermal performance objectives. These full-scale thermal remediation alternatives would remove both mobile and residual DNAPL over the entire treatment area at the Site (160,000 square feet), which is more than six times larger than the focused treatment area considered by RAs 5a and 6a. Although treating a significantly larger area, these full-scale alternatives are estimated to remove minimally more MCB (all at residual saturation) from the saturated zone than RAs 5a and 6a, approximately 26,000 to 29,000 gallons of MCB. Consequently, these full-scale RAs are not cost effective at $189 to $345 per pound of MCB removed by thermal remediation, even at the low end of the assumed range. The unit costs of the full-scale thermal RAs are between three and six times greater than the unit costs for RA 4a. Despite implementing a high cost thermal remedy over the entire treatment area (i.e., maximum treatment scenario), hydraulic containment would still be required for hundreds or thousands of years. Since the long-term hydraulic containment timeframe is not meaningfully reduced, the very high costs of these full-scale thermal RAs are not justified.

7.8 STATE ACCEPTANCE

This criterion cannot be evaluated until the State has commented on the draft DNAPL FS and Proposed Plan. Therefore, evaluation of this criterion is deferred and will be addressed by EPA in the ROD. As a result, all RAs are ranked equally for State Acceptance (i.e., Not Applicable). However, the State issued an interim advisory on green remediation in December 2009 (DTSC, 2009), a TBC for this FS, and may have concerns regarding candidate DNAPL RAs with high carbon footprints. RAs 5a, 5b, and 6b are expected to approach or exceed the 25,000 metric tons of GHGs per year reporting threshold and may not be acceptable to the State. The full-scale thermal remedies under RAs 5b and 6b would be one of the largest and most complex thermal remedies ever conducted. The energy-based carbon footprint for RA 5b is expected to be larger than 40% of the carbon footprints reported for California power plants in 2007 (Environment Oregon Research & Policy Center, 2009). A carbon footprint of this magnitude may

impede the State's ability to comply with the Global Warming Solutions Act of 2006, a TBC for this FS. RA 6a, ERH over a focused treatment area, is the only candidate thermal remedy with an estimated carbon footprint below the 25,000 metric tons of GHGs per year reporting threshold.

7.9 PUBLIC ACCEPTANCE

This criterion cannot be evaluated until the public has commented on the draft DNAPL FS and Proposed Plan. Therefore, evaluation of this criterion is deferred and will be addressed by EPA in the ROD. As a result, all RAs are ranked equally for Public Acceptance (i.e., Not Applicable).

7.10 SUMMARY OF COMPARATIVE ANALYSIS

A summary of the comparative analysis for the nine RAs is provided below:

SUMMARY OF COMPARATIVE ANALYSIS

NCP Criterion	RA 1 No Action	RA 2 ICs	RA 3 SVE ICs	RA 4a HD, No Treat SVE, ICs	RA 4b HD, Treat SVE, ICs	RA 5a [1] Steam, Focused SVE, ICs	RA 5b [1] Steam, Full SVE, ICs	RA 6a [2] ERH, Focused SVE, ICs	RA 6b [2] ERH, Full SVE, ICs
Threshold Criteria									
Protection of Human Health and Environment	HH - No Env - No	HH - Yes Env - No	HH - Yes Env - Vadose	HH - Yes Env - Yes	HH - Yes Env - Yes	HH - Yes Env - Yes	HH - Yes Env - Yes	HH - Yes Env - Yes	HH - Yes Env - Yes
Compliance with ARARs	No	Yes	Yes	No (Unless ARAR is Waived)	Yes	Yes	Yes	Yes	Yes
Balancing Criteria									
Long-Term Effectiveness	Not Effective	Not Effective	Not Effective	Moderately Effective	Moderately Effective	Effective	Effective	Effective	Effective
Reduction of Toxicity, Mobility, and Volume									
Vadoze Zone Mobility Reduction	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Saturated Zone Mobility Reduction	No	No	No	Some	Some	Yes	Yes	Yes	Yes
Vadose Zone Volume Reduction (1,000 gallons of MCB)	0	0	27-30	27-30	27-30	27-30	27-30	27-30	27-30
Saturated Zone Volume Reduction (1,000 gallons of mobile DNAPL) [4]	0 MCB 0 DDT	0 MCB 0 DDT	0 MCB 0 DDT	9-13 MCB 9-13 DDT	9-13 MCB 9-13 DDT	15-25 MCB + some DDT	26-29 MCB + some DDT	15-25 MCB 0 DDT	26-29 MCB 0 DDT
Short-Term Effectiveness	Not Effective	Not Effective	Not Effective	Effective	Effective	Moderately Effective	Less Effective	Effective	Less Effective
GHG Emissions (million lbs CO2) [3]	0	0	6	11	26	51-106	189-412	33-61	143-227
Implementability	Highly Implementable	Highly Implementable	Highly Implementable	Difficult to Implement	Moderately Implementable	Moderately Implementable	Difficult to Implement	Moderately Implementable	Difficult to Implement
Cost ($million NPV)	$0	$0.2	$4.4-$4.8	$11.0-$12.2	$18.0-$20.1	$22.3-$32.4	$50.8-$84.0	$18.6-$25.0	$46.2-$69.5
Modifying Criteria									
State Acceptance	NA	NA	NA	NA	NA	NA	NA	NA	NA
Public Acceptance	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes:

RA = Remedial Action

ICs = Institutional Controls

SVE = Soil Vapor Extraction

HD = Hydraulic Displacement

Treat = Separation and Treatment of Dissolved-Phase Contaminants

No Treat = Separation of DNAPL/Groundwater Only

lbs = pounds

CO2 = carbon dioxide

ERH = Electrical Resistance Heating

Focused = Focused Treatment Area, approximately 30,000 square feet

Full = Full-Scale Treatment Area, approximately 150,000 square feet

GHG = Greenhouse Gas

NA = Not Available Until State and Public Comment

NPV = Net Present Value

HH = Human Health

ENV = Environment

[1] Costs and GHG emissions based on steam flushing of 3 to 6 pore volumes

[2] Costs and GHG emissions based on electricity consumption of 200 to 400 kilowatt-hours per cubic yard

[3] GHG emissions estimated in accordance with 40 CFR 98.33

[4] HD removal efficiency assumed to be 80% of mobile DNAPL; thermal efficiency assumed to be 100% of mobile DNAPL. Mobile DNAPL volume reflects both Montrose and Huntley estimates.

Summary

In summary, a total of nine candidate DNAPL RAs were evaluated against the NCP performance criteria. RAs 1 through 3 do not meet the required threshold criteria for protection of human health and the environment because they do not include mobile DNAPL mass reduction in the saturated zone, which is the principal threat at the Site. RA 4a would not comply with ARARs unless the re-injection standards were waived in the short-term over the 5-year duration of the HD remedy. However, RAs 4b through 6b all unconditionally meet the required threshold criteria and could be selected by EPA as the remedy for DNAPL. These five candidate RAs and RA 4a offer varying performance relative to the five balancing criteria as summarized below:

RAs 4a and 4b: These RAs are effective in the long-term by reducing the mobile DNAPL mass by hydraulic displacement. These RAs would remove an estimated 36,000 to 43,000 gallons of MCB from the unsaturated and saturated zones combined and would significantly reduce the mobility of DNAPL remaining in the saturated zone. This reduction in DNAPL volume and mobility would limit the potential for uncontrolled migration and reduce the potential for recontamination of the aquifers. However, these HD RAs are likely to remove less mobile DNAPL mass than the thermal remediation RAs, and any mobile DNAPL mass left in place may reduce the long-term effectiveness of the remedy. Although there are vertical migration risks under these hydraulic displacement RAs, the risks are believed to be comparable to those of RA 6a and less than the risks posed by the steam injection and full-scale thermal RAs. These RAs have the highest ranking for short-term effectiveness due to reduced implementation risks (no thermal remedy) and relatively small carbon footprints. RA 4b would be moderately implementable with technical challenges associated with injection well fouling and ex-situ treatment of groundwater containing high dissolved-phase VOC concentrations. RA 4a has the lowest cost and is between 17% and 61% of the cost of other candidate RAs but may not be administratively implementable unless the re-injection standards are waived over the 5-year duration of the remedy. These RAs rank highly in some of the balancing criteria and pose reduced risks of uncontrolled DNAPL migration relative to steam injection.

RAs 5a and 6a: These RAs are effective in the long-term by reducing the mobile and residual DNAPL mass over a focused treatment area by steam injection or ERH. These RAs have not been field pilot tested at the Site but have the potential to remove more MCB mass than RAs 4a and 4b, if effective. Where target temperatures are achieved and MCB is effectively recovered, these RAs may reduce DNAPL saturations to residual levels. However, these thermal

remediation RAs, particularly RA 5a, also have an increased risk of uncontrolled contaminant migration, either laterally within the UBA or vertically downward into the BFS. For this reason, RA 5a includes a steam injection hot floor within the BFS, and RA 6 includes a bottom up heating approach for ERH. Although these approaches will reduce, to some extent, the risks associated with downward vertical migration, 100% effectiveness is not assured. The layered and heterogeneous UBA is not ideally suited for steam injection (or hydraulic displacement), and as a result, there are risks that steam injection may not achieve target temperatures uniformly throughout the treatment area. Of the two candidate thermal technologies, ERH is better suited to the lithology of the UBA and is not dependent on permeability for heating the soils (only dependent on permeability for recovering the MCB vapors).

These RAs would remove an estimated 42,000 to 55,000 gallons of MCB from the unsaturated and saturated zones combined and would significantly reduce the mobility of DNAPL remaining in the saturated zone. Although these RAs would likely remove more MCB volume than RAs 4a and 4b, a portion of the volume reduction would be from residual DNAPL which is immobile in the environment and not a risk to the groundwater remedy. RA 6a is more highly ranked for short-term effectiveness than RA 5a because of reduced migration and implementation risks and a smaller carbon footprint. RA 6a is the only candidate thermal remediation alternative not expected to approach or exceed the mandatory reporting threshold of 25,000 metric tons per year. These RAs have a moderate ranking for implementability because thermal remediation systems require substantial infrastructure, highly skilled and trained operators, and a relatively high level of maintenance. RAs 5a and 6a have a relatively high cost and are between 70% and 170% higher than the cost of RA 4a. RAs 5a and 6a rank highly in long-term effectiveness and reduction of toxicity, mobility, and/or volume, and RA 6a is the highest ranked alternative in all categories except for cost (RA 4a is the lowest cost alternative that meets the threshold criteria).

Of the two candidate thermal remediation alternatives, RA 6a has some advantages over RA 5a for application to the Montrose Site including:

- ERH heats resistively and does not rely on soil permeability for heat distribution. Under ERH, heating of the treatment zone is not be hindered by the heterogeneous and layered nature of the UBA;
- ERH is not a displacement technology and has lower risks of uncontrolled DNAPL migration. Maintaining hydraulic control during ERH is easier than during steam injection;

- ERH is a volatilization technology, does not concentrate the DNAPL, and has lower vertical migrations risks;
- RA 6a has a smaller well spacing (27 versus 60 feet between multi-phase extraction wells) and a higher number of multi-phase extraction wells (66 versus 27 wells) than RA 5a, increasing the potential for encountering DNAPL and recovering MCB vapors;
- Using a bottom up heating approach under ERH, a hot floor is not required in the BFS, which reduces the risks of vertical migration associated with well drilling and the complexity of the remedy;
- The risk of fugitive emissions during ERH is less than for steam injection due to lower operating pressures and a more gradual heating process;
- RA 6a is less costly than RA 5a, $18.6-$25.0 million NPV versus $22.3-$32.4 million NPV;
- RA 6a has lower GHG emissions, approximately 40% lower, than RA 5a, 33-61 million pounds versus 51-106 million pounds. Additionally, RA 6a is the only candidate thermal remediation alternative with GHG emissions below the mandatory reporting threshold (15,000 metric tons per year versus 23,000-26,000 metric tons per year for RA 5a);
- There is already a source of electrical power (two LADWP substations) located adjacent to the Montrose Site (see Figure 1.7);
- ERH requires no steam boilers, boiler emissions, or brine waste disposal;
- ERH is more commonly implemented than steam injection with a broader range of experience.

RAs 5b and 6b: These RAs are effective in the long-term by reducing the mobile and residual DNAPL mass over the entire treatment area by steam injection or ERH. These RAs would remove an estimated 53,000 to 59,000 gallons of MCB from the unsaturated and saturated zones combined. Although RAs 5b and 6b are the highest ranked in MCB volume reduction, they offer no advantages over RAs 5a and 6a in terms of mobility reduction or mobile DNAPL mass reduction, the principal threat. Residual DNAPL mass outside of the focused treatment area is immobile under gravitational forces, poses no risk to the groundwater remedy, and will be hydraulically contained in the long-term. Despite implementing thermal remediation over a large area of approximately 160,000 square feet, these RAs would not meaningfully reduce the containment timeframes required for groundwater. Long-term hydraulic containment would still

be required for hundreds or thousands of years following the DNAPL remedy. Furthermore, these RAs, if implemented, would be one of the largest and most complex thermal remedies ever conducted. RAs 5b and 6b are ranked the lowest in terms of short-term effectiveness, implementability, and cost. There are substantial risks associated with a thermal remedy of this size and complexity, and the carbon footprint of RA 5b is so significant as to exceed the GHG emissions reported for 40% of the power plants in California in 2007 (Environment Oregon Research & Policy Center, 2009). A thermal remedy of this size would be difficult to implement due to the number of wells, volumes of waste to be handled, level of maintenance required, and number of highly skilled and trained operators required. Finally, the cost of the full-scale thermal RAs would exceed $50 million NPV and would be cost prohibitive for Montrose, who does not possess the financial resources of the government agencies that implement large-scale thermal remedies at some sites. Although RAs 5b and 6b rank highly in volume reduction, they offer no benefit over RAs 5a and 6a in terms of mobility or mobile DNAPL mass reduction and are the lowest ranked alternatives for short-term effectiveness, implementability, and cost.

The performance and protectiveness of the selected remedy will be monitored closely and reviewed every 5 years. Although some DNAPL mass will be left in place following remediation, none of the candidate alternatives are capable of removing all of the DNAPL mass from the low permeability UBA. It is technically infeasible at this time to cost effectively remove all of the DNAPL mass from the Site. For this reason, EPA established a TI Waiver Zone at the Site in 1999. However, as treatment technologies for DNAPL source areas continue to advance, a cost effective method for removing all of the DNAPL mass may be developed and could be implemented at the Site in the future.

Section 8.0

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