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Environmental Assessment and Corrective Measures Study Report for Remediating Contamination at Lawrence Berkeley National Laboratory Regulated under the Resource Conservation and Recovery Act

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LIST OF ABBREVIATIONS

AOC	Area of Concern
ARARs	Applicable or Relevant and Appropriate Requirements
ASTM	American Society of Testing and Materials
BAAQMD	Bay Area Air Quality Management District
Berkeley Lab	Lawrence Berkeley National Laboratory
Cal-EPA	California Environmental Protection Agency
CAP	Corrective Action Program
CCR	Code of California Regulations
CEQA	California Environmental Quality Act
CFR	Code of Federal Regulations
CMI	Corrective Measures Implementation
CMS	Corrective Measures Study
COC	Chemical of Concern
DCA	Dichloroethane
DCE	Dichloroethene
DNAPLs	Dense Non-Aqueous Phase Liquids
DOE	U.S. Department of Energy
DPE	Dual Phase Extraction
DTSC	Cal-EPA Department of Toxic Substances Control
EBMUD	East Bay Municipal Utility District
EH&S	Berkeley Lab Environment, Health and Safety Division
EPC	Exposure Point Concentration
ERA	Ecological Risk Assessment
ERP	Environmental Restoration Program
ESL	Environmental Screening Level
FRTR	Federal Remediation Technology Screening Matrix and Reference Guide
FY	Fiscal Year (October 1 through September 30)
GAC	Granular Activated Carbon
gpd	gallons per day
HHRA	Human Health Risk Assessment
HI	Hazard Index
HRC	Hydrogen Release Compounds
HQ	Hazard Quotient
HSWA	Hazardous and Solid Waste Amendments
HWHF	Hazardous Waste Handling Facility
ICMs	Interim Corrective Measures
ILCR	Incremental Lifetime Cancer Risk
IS	Initial Study
LRDP	Berkeley Lab Long Range Development Plan
LUC	Land Use Covenant
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MCS	Media Cleanup Standard

MNA	Monitored natural Attenuation
NEPA	National Environmental Policy Act
NFA	No Further Action
NFI	No Further Investigation
ORC	Oxygen Release Compounds
PCB	Polychlorinated Biphenyl
PCE	tetrachloroethene
POC	Point of Compliance
PRG	Preliminary Remediation Goal
RBCA	Risk-Based Corrective Action
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
RWQCB	Regional Water Quality Control Board
SVE	Soil Vapor Extraction
SWMU	Solid Waste Management Unit
SWRCB	State Water Resources Control Board
TCA	Trichloroethane
TCE	Trichloroethene
TDS	Total Dissolved Solids
TI	Technical Impracticability
TSCA	Toxic Substances Control Act
UC	University of California
UCL	Upper Confidence Limit
ULR	Urban Land Redevelopment
USEPA	U. S. Environmental Protection Agency
UST	Underground Storage Tank
VOCs	Volatile Organic Compounds
WQO	Water Quality Objective

EXECUTIVE SUMMARY

The Ernest Orlando Lawrence Berkeley National Laboratory (Berkeley Lab) is currently in the Corrective Measures Study (CMS) phase of the Resource Conservation and Recovery Act (RCRA) Corrective Action Process (CAP). A CMS Plan was prepared by Berkeley Lab (Berkeley Lab, 2002a) and approved by the California Environmental Protection Agency (Cal-EPA), Department of Toxic Substance Control (DTSC) on June 18, 2002 (DTSC, 2002). The CMS Plan established the requirements and procedures to be used for completing the CMS. This report describes the results of the CMS, which was conducted in accordance with that approved plan. The purpose of the CMS Report is to recommend appropriate remedies that can eliminate or reduce potential risks to human health from anthropogenic chemicals in soil and groundwater, and protect groundwater and surface water quality under provisions of the Porter-Cologne Water Quality Control Act (Division 7 of the California Water Code).

The Ecological Risk Assessment (ERA) (Berkeley Lab, 2002b) concluded that there are currently no hazards to ecological receptors (plants or animals). The Human Health Risk Assessment (HHRA) (Berkeley Lab, 2003a) identified the chemicals of concern (COCs) at Berkeley Lab as volatile organic compounds (VOCs) and polychlorinated biphenyls (PCBs). Risks from these chemicals were estimated by calculating theoretical incremental lifetime cancer risks (ILCRs) and non-cancer hazard indices (HIs), assuming an industrial/institutional land use scenario. This scenario is consistent with the current and potential future land use at Berkeley Lab. These calculated measures of risk were compared to established threshold values. The theoretical ILCRs were compared to the United States Environmental Protection Agency (USEPA) target cancer risk range of 10^{-4} to 10^{-6}, which is considered by the agency to be safe and protective of public health [Federal Register 56(20): 3535, Wednesday, January 30, 1991]. Exposure to chemicals with a Hazard Index (HI) below 1.0 is considered unlikely to result in adverse non-cancer health effects over a lifetime of exposure, so the calculated HIs were compared to this value. The HHRA also addressed protection of beneficial uses of groundwater by comparing COC concentrations to drinking water standards. Based on these comparisons, the HHRA recommended that four areas of soil contamination and eleven areas of groundwater contamination should be further evaluated in the CMS.

The initial step in the evaluation process was development of Corrective Action Objectives. The objectives were developed based on both risk-based and regulatory-based criteria. The primary Corrective Action Objective, which is risk based, is to reduce COC concentrations, so that theoretical ILCRs are less than, or at the lowest reasonably achievable level within the USEPA target range for risk managers (between 10^{-4} and 10^{-6}) and HIs are less than 1. Although an ILCR anywhere within the USEPA target range for risk managers (also referred to as the "risk management range" is considered to be safe and protective of public health, the lowest reasonably achievable level within the risk management range was selected as the risk-based Corrective Action Objective for the following reasons:

1. The USEPA has expressed a preference for cleanups achieving the more protective end of the risk range (i.e., 10^{-6}) (USEPA, 1997).
2. The DTSC has also expressed a preference for the cleanup achieving the more protective end of the risk range (i.e., 10^{-6}), if reasonably achievable. The required cleanup levels will be specified by the Standardized Permits and Corrective Action Branch of the DTSC in a modification to Berkeley Lab's RCRA Hazardous Waste Handling Facility Permit.
3. Institutional controls will be required for those areas where the theoretical ILCR>10^{-6} and/or HI>1. These controls would result in added costs for new building construction and possibly preclude development in some areas.

The following Corrective Action Objectives were developed based on regulatory requirements that address concerns other than direct exposure pathways to workers at Berkeley Lab:

- Protect and/or restore groundwater quality to levels that are protective of beneficial uses.
- Control the migration of contaminated groundwater so that COCs do not migrate to groundwater in adjacent uncontaminated areas or to surface water.
- Control the migration of contaminated groundwater so that COCs above risk-based levels do not migrate to groundwater in adjacent areas where concentrations are below risk-based levels.

These objectives were selected for the following reasons:

1. They are California state requirements specified in Resolutions of the SWRCB under the Porter-Cologne Water Quality Control Act.
2. Institutional controls will be required for those areas where the groundwater is considered a potential drinking water source and MCLs are exceeded.

There are various costs and benefits associated with compliance or non-compliance with the risk-based and regulatory-based objectives listed above. Cleanup to less stringent risk-based levels (e.g., 10^{-4} or 10^{-5} rather than 10^{-6}) would be less expensive and would still be in the range that is considered safe and protective of public health. However, less stringent cleanup levels would result in added costs for new building construction and would possibly preclude development in some areas. In addition, there would likely be a negative impact on the value of the property. Less stringent risk-based levels would also adversely affect the project schedule and incur additional costs since they would require negotiation with the regulatory agencies. Non-compliance with the regulatory-based objectives or risk-based objectives required by the regulatory agencies could result in enforcement actions and resultant legal costs.

Media Cleanup Standards (MCSs) were developed to address both the risk-based and regulatory-based Corrective Action Objectives. Two sets of risk-based MCSs were developed for VOCs: the first set, the target risk-based MCSs, was based on theoretical ILCRs of 10^{-6} and non-cancer HIs of 1; the second set, the upper-limit risk-based MCSs, was based on theoretical ILCRs of 10^{-4} and non-cancer HIs of 1.

Regulatory-based MCSs associated with protection of potential future drinking water sources are considered applicable in areas of Berkeley Lab where the groundwater meets SWRCB well yield criteria (>200 gallons per day) for potential drinking water sources. MCSs for groundwater in those areas were set at MCLs for drinking water. Regulatory-based MCSs for VOCs in soil in those areas were set at levels that would protect groundwater from adverse impacts that could potentially result in COC concentrations exceeding MCLs. MCLs are also considered to be applicable long-term goals for all groundwater at Berkeley Lab.

In addition to MCSs, a compliance level of non-detect was set for areas of groundwater and surface water that are not currently contaminated, but could potentially be impacted by migration of COCs. This addresses the SWRCB non-degradation policy (Resolution 68-16) under the Porter-Cologne Water Quality Control Act.

Potential corrective measures alternatives that could meet the Corrective Action Objectives were identified. The alternatives were selected from the following general categories:

- No Action
- Risk and Hazard Management
- Monitored Natural Attenuation
- Containment and Hydraulic Control
- Active Treatment/Disposal.

The corrective measures alternatives that were recommended for implementation were developed from the list of identified technologies using the following procedure:

1. Selection of technologies that are potentially applicable to the COCs (VOCs and PCBs).

2. Preliminary screening of those alternatives based on potential applicability and effectiveness in achieving MCSs and/or protecting human health under site-specific conditions.

3. Evaluation of retained alternatives to assess whether they could potentially meet the following standards:
   - Protect human health and the environment
   - Comply with applicable standards for the management of waste
   - Attain MCSs
   - Control migration (if applicable)

4. Development of the specific Corrective Action Objectives that are applicable at each area of groundwater or soil contamination.

5. Evaluation of the retained alternatives that could potentially meet the area-specific Corrective Action Objectives using the following decision factors:
   - Long-term reliability and effectiveness
   - Reduction of toxicity, migration potential, or volume of the COCs
   - Short-term effectiveness
   - Cost.

6. Recommendation of corrective measures for implementation.

Based on the screening process, the following technologies were retained for the site-specific evaluations applied to each of the areas of soil and groundwater contamination.

Soil

- No Action
- Institutional Controls
- Containment (Capping, Solidification, Stabilization)
- Chemical Oxidation
- Soil Vapor Extraction (SVE) or Dual Phase Extraction (DPE)
- Thermally Enhanced SVE/DPE
- In Situ Soil Flushing (with water)
- Soil Mixing
- Excavation with offsite disposal.

Groundwater

- No Action
- Monitored Natural Attenuation (plume core and periphery zones)
- Institutional Controls
- Containment (slurry walls, sheet pile walls, grout curtains)
- Groundwater capture (drains, trenches, extraction wells)
- Permeable Reactive Barrier and Funnel and Gate
- Chemical Oxidation
- Enhanced Bioremediation
- Groundwater Extraction/Flushing
- Dual-Phase (groundwater and soil-vapor) Extraction.

Where cleanup of solvent-contaminated groundwater to MCSs is demonstrated to be technically impracticable, provision is made for developing an alternative remedial strategy protective of human health and the environment.

The following table describes the specific corrective measures alternative recommended for implementation at each area of soil and groundwater contamination included in the CMS. The potential human receptors of concern and exposure pathways for which COC concentrations currently exceed target risk-based MCSs are also provided in the table. In addition, regulatory compliance issues are noted where applicable. The list of corrective measures alternatives is based on cleanup to the target risk-based MCSs (theoretical ILCR = 10^{-6} and HI = 1) or the regulatory-based MCSs (MCLs), whichever is applicable. Cleanup to risk-based MCSs, which are less conservative than regulatory-based MCSs, is considered the short-term goal for areas where groundwater does not meet SWRCB criteria for potential drinking water sources (i.e., areas where well yield is less than 200 gallons per day). Cleanup to regulatory-based MCSs associated with protection of potential future drinking water sources is the short-term goal for areas where groundwater meets SWRCB criteria for potential drinking water sources (well yield is 200 gallons per day or greater) and is a long-term goal for all areas of Berkeley Lab. Regulatory compliance measures to prevent the migration of groundwater COCs to areas of uncontaminated groundwater or to surface water are applicable in all areas where migration is a potential threat.

The HHRA identified PCBs as the COC at two units, the Building 88 Hydraulic Gate Unit and the Building 75 Former Hazardous Waste Handling and Storage Facility. Subsequent to completion of the HHRA, Berkeley Lab conducted Interim Corrective Measures (ICMs) (soil excavation and offsite disposal) that resulted in reduction of residual PCB concentrations to less than the proposed MCS for PCBs of 1 mg/kg at both units. The MCS was set at the Toxic Substances Control Act (TSCA) (40 Code of Federal Regulations [CFR] Parts 750 and 761) self-implementing cleanup level of 1 mg/kg, for soil in high occupancy areas, which is both a risk-based and regulatory-based level. Verification sampling found compliance with this level, which is consistent with unrestricted future land use. No additional corrective action is therefore recommended for either of these units.

Recommended Corrective Measures Alternatives

Unit	Potential Human Receptors and Risk-Based Exposure Pathways of Concern[(a)]	Chemicals of Concern (COC)[(d)]	Recommended Corrective Measure Alternative for Cleanup[(c)]
Soil Units			
Building 51L Groundwater Plume Source Area	Future Indoor Worker (I) [(b)]	**PCE** **TCE** **chloroform** **vinyl chloride**	Excavation and offsite disposal.
AOC 6-3: Building 88 Hydraulic Gate Unit	Landscape Worker (I,F,D) Construction Worker (F,D)	none	No further action recommended. Excavation was completed to the Toxic Substances Control Act (TSCA) self implementing cleanup level as an Interim Corrective Measure (ICM) (See text paragraph preceding this table for description of ICM.)
AOC 2-5: Building 7 Sump	Future Indoor Worker(I) [(b)] Landscape Worker (I)	**PCE** **TCE** cis-1,2-DCE 1,1,1-TCA 1,1-DCA 1,1-DCE benzene **carbon tetrachloride** chloroform vinyl chloride	Excavation and offsite disposal.
SWMU 3-6: Building 75 Former Hazardous Waste Handling and Storage Facility	Landscape Worker (F,D) Construction Worker (F,D)	none	No further action recommended. (Excavation was completed to the TSCA self implementing cleanup level as an Interim Corrective Measure. (See text paragraph preceding this table for description of ICM.)

Recommended Corrective Measure Alternatives (cont'd.)

Unit	Potential Human Receptors and Risk-Based Exposure Pathways of Concern[(a)]	Chemicals of Concern (COC)[(d)]	Recommended Corrective Measure Alternative for Cleanup[(c)]
Groundwater Units			
AOC 9-13: Building 51/64 Groundwater Solvent Plume	Future Indoor Worker (I) [(b)]	TCE **PCE** **carbon tetrachloride** cis-1,2-DCE trans-1,2-DCE 1,1-DCE methylene chloride **1,1-DCA** 1,2-DCA **vinyl chloride** 1,1-TCA 1,1,2-TCA	In situ soil flushing combined with groundwater capture in plume source area. Monitored Natural Attenuation for downgradient portion of plume. Continued surface water (subdrain effluent) capture and treatment until groundwater discharge to surface water is shown to be below detectable levels.
Building 51L Groundwater Solvent Plume	Future Indoor Worker (I) [(b)]	**vinyl chloride**	Excavation and offsite disposal of saturated and unsaturated zone soils in the plume source zone. Monitored Natural Attenuation for remaining plume area. Reroute or line storm drain to prevent migration of groundwater COCs to surface water

Recommended Corrective Measure Alternatives (cont'd.)

Unit	Potential Human Receptors and Risk-Based Exposure Pathways of Concern[(a)]	Chemicals of Concern (COC)[(d)]	Recommended Corrective Measure Alternative for Cleanup[(c)]
Groundwater Units (cont'd.)			
AOC 1-9: Building 71 Groundwater Solvent Plume Building 71B lobe	Future Indoor Worker (I) [(b)]	TCE **PCE** cis-1,2-DCE vinyl chloride	The following combination of corrective measures alternatives is recommended for the plume source area: 1) excavation and offsite disposal of accessible shallow unsaturated zone soil, 2) limited in situ chemical oxidation of unsaturated zone soils adjacent to the building foundation, and 3) in situ soil flushing. For contaminated groundwater adjacent to the source area, enhanced bioremediation using Hydrogen Release Compounds (HRC) is the recommended measure. In addition, surface water (hydrauger effluent) capture and treatment will continue until groundwater discharge to surface water is shown to be below detectable levels.

Recommended Corrective Measure Alternatives (cont'd.)

Unit	Potential Human Receptors and Risk-Based Exposure Pathways of Concern[(a)]	Chemicals of Concern (COC)[(d)]	Recommended Corrective Measure Alternative for Cleanup[(c)]
Groundwater Units (cont'd.)			
AOC 2-4: Building 7 Lobe of the Old Town Groundwater Solvent Plume	Future Indoor Worker (I) [(b)] Construction Worker (D) Landscape Worker (I)	**TCE** **PCE** **carbon tetrachloride** cis-1,2-DCE trans-1,2-DCE 1,1-DCE chloroform methylene chloride 1,1-DCA 1,2-DCA 1,2-dichloropropane vinyl chloride 1,1,2-TCA benzene	The following combination of corrective measures alternatives is recommended for the different areas of the plume: 1) soil excavation (as described under AOC 2-5) for the plume source area; 2) continued in situ soil flushing combined with groundwater capture for the plume core area 4) Monitored Natural Attenuation (MNA) in the downgradient area, and 3) continued groundwater capture and treatment within and at downgradient edge of plume until groundwater concentrations are reduced to levels where downgradient migration of COCs above applicable MCSs or beyond the plume boundary would not occur without controls.
AOC 10-5: Building 52 Lobe of the Old Town Groundwater Solvent Plume	none	TCE PCE carbon tetrachloride cis-1,2-DCE	In situ soil flushing in contaminant source area. Continued capture and treatment at downgradient lobe boundary until groundwater discharge to surface water is shown to be below detectable levels.
AOC 10-5: Building 25A Lobe of the Old Town Groundwater Solvent Plume	none	TCE PCE carbon tetrachloride 1,1-DCE	In situ soil flushing in contaminant source area, Monitored Natural Attenuation for remainder of lobe area.

Recommended Corrective Measure Alternatives (cont'd.)

Unit	Potential Human Receptors and Risk-Based Exposure Pathways of Concern[(a)]	Chemicals of Concern (COC)[(d)]	Recommended Corrective Measure Alternative for Cleanup[(c)]
Groundwater Units (cont'd.)			
AOC 4-5: Solvents in Groundwater South of Building 76	none	none	No Action (COC concentrations are below risk-based MCSs and groundwater characteristics do not meet criteria of SWRCB Resolution 88-63 – *Sources of Drinking Water Policy*).
Support Services Area (Building 69A Area)	Future Indoor Worker (I) [(b)]	**vinyl chloride**	Monitored Natural Attenuation.
Support Services Area (Building 75/75A Area)	none	none	No Action (COC concentrations are below risk-based MCSs and groundwater characteristics do not meet criteria of SWRCB Resolution 88-63 – *Sources of Drinking Water Policy*).
Support Services Area (Building 77 Area)	none	none	No Action (COC concentrations are below risk-based MCSs and groundwater characteristics do not meet criteria of SWRCB Resolution 88-63 – *Sources of Drinking Water Policy*).
Benzene Detected in Wells East of Building 75A	none	none	No Action (COC concentrations are below risk-based MCSs and groundwater characteristics do not meet criteria of SWRCB Resolution 88-63 – *Sources of Drinking Water Policy*).

(a) I:Inhalation, F:Ingestion, D:Dermal Contact

(b) Current risks and/or hazards to indoor workers are within acceptable levels; future workers are those who might occupy future buildings located over plume areas.

(c) Recommended corrective measures based on cleanup to theoretical ILCR=10^{-6}, HI=1, and cleanup to address regulatory compliance issues

(d) Chemicals of Concern:

- Chemicals of Concern (COCs) for groundwater units where groundwater is a potential drinking water source are those VOCs that were detected at concentrations above Maximum Contaminant Levels (MCLs) for drinking water in fiscal year 2003 (FY03).
- COCs for groundwater units where groundwater is not a potential drinking water source are those VOCs that were detected at concentrations exceeding the target risk-based groundwater Media Cleanup Standard (MCS).
- COCs for soil units are those VOCS that were detected at concentrations exceeding the target risk-based soil MCS; and for those soil units where the underlying groundwater is a potential drinking water source, the groundwater COCs that have been detected in soil at the unit.
- Boldface concentrations indicate concentrations that exceed the relevant target risk-based MCS.

Cost estimates to achieve both risk-based cleanup levels and cleanup levels based on protection of potential future drinking-water sources are provided in the following table for each soil and groundwater unit. Although the target risk-based MCSs have been set at a theoretical ILCR of 10^{-6} and HQ of 1, estimated costs for cleanup to the upper-limit MCSs (theoretical ILCR = 10^{-4}, HI = 1) and to an intermediate level (theoretical ILCR = 10^{-5}, HI = 1) are also provided for comparison. Where cleanup to levels that are protective of potential drinking-water sources is not required, cost is shown as \$0; however, risk-based cleanup and the associated costs shown will still be required for those areas. In addition, the incremental costs associated with controlling migration of contaminated groundwater are also provided, where applicable. Although these costs are indicated under regulatory compliance, if current migration control measures were terminated, there could also be a potential risk to the environment. The total costs of recommended corrective measures shown in the right-hand column of the table are based on the recommended level of cleanup (target risk-based MCSs or MCLs, whichever are applicable) and any recommended migration control measures.

This report also provides the required National Environmental Policy Act (NEPA) documentation, which includes a summary of the proposed RCRA corrective actions at Berkeley Lab and their consequences. The proposed corrective actions would not have significant direct, indirect, or cumulative effects on the human environment. The proposed actions would have the beneficial effect of improving soil and water quality by removing soil and groundwater contamination at the Berkeley Lab.

Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units

Soil and Groundwater Units	Risk-Based Cleanup Costs			Potential Future Drinking Water Source Cleanup Costs(a)	Regulatory Compliance Costs(b)	Total Costs(d) of Recommended Corrective Measures
	Risk = 10^{-4}	Risk = 10^{-5}	Risk = 10^{-6}	MCS = MCLs(c)	Incremental Cost of Migration Control	
Building 51/64 Groundwater Solvent Plume						
Corrective Measure	No Action	Soil Flushing and Extraction Trench and MNA.	Soil Flushing and Extraction Trench and MNA	Soil Flushing and Extraction Trench and MNA.	Capture and Treat Groundwater from Building 51 Subdrain	
Assumed End Date	N/A	Soil Flushing = 2011 MNA = indeterminate	Soil Flushing = 2011 MNA = indeterminate	Soil Flushing = 2011 MNA = indeterminate	indeterminate	
Capital Cost	$0	$29,000	$29,000	$29,000	$0	$29,000
Annual O&M Cost	$0	$106,000	$106,000	$106,000	$20,000	$126,000
Total Cost (NPV) through 2011	$0	$682,000	$682,000	$682,000	$124,000	$806,000
Annual Cost After 2011	$0	$26,000	$26,000	$26,000	$20,000	$46,000
Building 51L Groundwater Solvent Plume and Building 51L Source Area						
Corrective Measure	No Action	Soil Excavation and MNA.	Soil Excavation and MNA.	No Action	Reroute/line storm drain	
Assumed End Date	N/A	Excavation = 2006 MNA = indeterminate	Excavation = 2006 MNA = indeterminate	N/A	2006	
Capital Cost	$0	$569,000	$569,000	$0	$147,000	$716,000
Annual O&M Cost	$0	$26,000	$26,000	$0	$0	$26,000
Total Cost (NPV) through 2011	$0	$730,000	$730,000	$0	$138,000	$868,000
Annual Cost After 2011	$0	$26,000	$26,000	$0	$0	$26,000

Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	**Risk-Based Cleanup Costs**			**Potential Future Drinking Water Source Cleanup Costs(a)**	**Regulatory Compliance Costs(b)**	**Total Costs(d) of Recommended Corrective Measures**
	Risk = 10^{-4}	**Risk = 10^{-5}**	**Risk = 10^{-6}**	**MCS = MCLs(c)**	**Incremental Cost of Migration Control**	
Building 71 Groundwater Solvent Plume						
Corrective Measure	No Action	Chemical Oxidation (source area) and Soil Flushing	Chemical Oxidation (source area) and Soil Flushing	Chemical Oxidation (source area) and Soil Flushing	Capture and Treat Hydrauger Effluent	
Assumed End Date	N/A	Soil Flushing = 2011 Chemical Oxidation = 2006	Soil Flushing = 2011 Chemical Oxidation = 2006	Soil Flushing = 2011 Chemical Oxidation = 2006	indeterminate	
Capital Cost	$0	$380,000	$380,000	$380,000	$0	$380,000
Annual O&M Cost	$0	$80,000	$80,000	$80,000	$20,000	$100,000
Total Cost (NPV) through 2011	$0	$959,000	$959,000	$959,000	$124,000	$1,083,000
Annual Cost After 2011	$0	$0	$0	$0	$20,000	$20,000
Old Town Groundwater Solvent Plume Building 7 Lobe and Former Building 7 Sump						
Corrective Measure	Source Excavation, Soil Flushing and Groundwater Extraction,	Source Excavation, Soil Flushing and Groundwater Extraction	Source Excavation, Soil Flushing and Groundwater Extraction	Source Excavation, Soil Flushing and Groundwater Extraction, MNA in Downgradient Area	Capture and Treat Groundwater from Trenches	
Assumed End Date	2011	indeterminate	indeterminate	indeterminate	indeterminate	
Capital Cost	$591,000	$591,000	$591,000	$591,000	$0	$591,000
Annual O&M Cost	$62,000	$62,000	$62,000	$62,000	$20,000	$82,000
Total Cost (NPV) through 2011	$970,000	$970,000	$970,000	$970,000	$124,000	$1,094,000
Annual Cost After 2011	$0	$62,000	$62,000	$62,000	$20,000	$82,000

Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	Risk-Based Cleanup Costs			Potential Future Drinking Water Source Cleanup Costs[(a)]	Regulatory Compliance Costs[(b)]	Total Costs[(d)] of Recommended Corrective Measures
	Risk = 10^{-4}	Risk = 10^{-5}	Risk = 10^{-6}	MCS = MCLs[(c)]	Incremental Cost of Migration Control	
Old Town Groundwater Solvent Plume Building 52 Lobe						
Corrective Measure	No Action	No Action	No Action	Soil Flushing with 4 New Injection Wells	Capture and Treat Groundwater from B46 Subdrain	
Assumed End Date	N/A	N/A	N/A	indeterminate	indeterminate	
Capital Cost	$0	$0	$0	$66,000	$0	$66,000
Annual O&M Cost	$0	$0	$0	$49,000	$20,000	$69,000
Total Cost (NPV) through 2011	$0	$0	$0	$364,000	$124,000	$488,000
Annual Cost After 2011	$0	$0	$0	$49,000	$20,000	$69,000
Old Town Groundwater Solvent Plume Building 25A Lobe						
Corrective Measure	No Action	No Action	No Action	Soil Flushing and Groundwater. Extraction, MNA in Downgradient Area	No Action	
Assumed End Date	N/A	N/A	N/A	indeterminate	N/A	
Capital Cost	$0	$0	$0	$0	$0	$0
Annual O&M Cost	$0	$0	$0	$51,000	$0	$51,000
Total Cost (NPV) through 2011	$0	$0	$0	$318,000	$0	$318,000
Annual Cost After 2011	$0	$0	$0	$51,000	$0	$51,000

Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	Risk-Based Cleanup Costs			Potential Future Drinking Water Source Cleanup Costs[(a)]	Regulatory Compliance Costs[(b)]	Total Costs[(d)] of Recommended Corrective Measures
	Risk = 10^{-4}	Risk = 10^{-5}	Risk = 10^{-6}	MCS = MCLs[(c)]	Incremental Cost of Migration Control	
Solvents in Groundwater South of Building 76						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	\$0	\$0	\$0	\$0	\$0	\$0
Annual O&M Cost	\$0	\$0	\$0	\$0	\$0	\$0
Total Cost (NPV)	\$0	\$0	\$0	\$0	\$0	\$0
Building 75/75A Area of Groundwater Contamination						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	\$0	\$0	\$0	\$0	\$0	\$0
Annual O&M Cost	\$0	\$0	\$0	\$0	\$0	\$0
Total Cost (NPV)	\$0	\$0	\$0	\$0	\$0	\$0
Building 69A Area of Groundwater Contamination						
Corrective Measure	No Action	No Action	MNA	No Action	No Action	
Assumed End Date	N/A	N/A	indeterminate	N/A	N/A	
Capital Cost	\$0	\$0	\$0	\$0	\$0	\$0
Annual O&M Cost	\$0	\$0	\$26,000	\$0	\$0	\$26,000
Total Cost (NPV) through 2011	\$0	\$0	\$160,000	\$0	\$0	\$160,000
Annual Cost After 2011	\$0	\$0	\$26,000	\$0	\$0	\$26,000

Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	Risk-Based Cleanup Costs			Potential Future Drinking Water Source Cleanup Costs(a)	Regulatory Compliance Costs(b)	Total Costs(d) of Recommended Corrective Measures
	Risk = 10^{-4}	Risk = 10^{-5}	Risk = 10^{-6}	MCS = MCLs(c)	Incremental Cost of Migration Control	
Building 77 Area of Groundwater Contamination						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	$0	$0	$0
Annual O&M Cost	$0	$0	$0	$0	$0	$0
Total Cost (NPV)	$0	$0	$0	$0	$0	
Benzene in Wells East of Building 75A						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	$0	$0	$0
Annual O&M Cost	$0	$0	$0	$0	$0	$0
Total Cost (NPV)	$0	$0	$0	$0	$0	
Building 88 Hydraulic Gate Unit						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	N/A	$0	$0
Annual O&M Cost	$0	$0	$0	N/A	$0	$0
Total Cost (NPV) through Assumed End Date	$0	$0	$0	$0	$0	$0

Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	**Risk-Based Cleanup Costs**			**Potential Future Drinking Water Source Cleanup Costs[a]**	**Regulatory Compliance Costs[b]**	**Total Costs[d] of Recommended Corrective Measures**
	Risk = 10^{-4}	**Risk = 10^{-5}**	**Risk = 10^{-6}**	**MCS = MCLs[c]**	**Incremental Cost of Migration Control**	
Building 75 Former Hazardous Waste Handling and Storage Facility						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	N/A	$0	$0
Annual O&M Cost	$0	$0	$0	N/A	$0	$0
Total Cost (NPV) through Assumed End Date	$0	$0	$0	$0	$0	$0
Grand Total (NPV) through 2011	$970,000	$3,341,000	$3,501,000	$3,293,000	$634,000	$4,817,000[e]
Grand Total (Annual Cost After 2011)	$0	$114,000	$140,000	$188,000	$80,000	$320,000[e]

(a) Where regulatory-based cleanup is not required, the cost for regulatory-based cleanup is shown as $0.00; however, risk-based cleanup and the associated costs shown will still be required for those areas.

(b) Control the migration of contaminated groundwater so that COCs do not migrate to groundwater in adjacent uncontaminated areas or to surface water.

(c) Regulatory-based MCSs apply in plume areas where well yield ≥ 200 gallons per days

(d) Total costs only include estimated direct costs associated with task scopes described in the CMS report. General compliance costs and program administration/management costs are not included.

(e) The Total Costs of Recommended Corrective Measures (column 7) is the sum of either the Risk Based Cleanup Cost (column 4) or the Potential Drinking Water Source Cleanup Cost (column 5), whichever is applicable at each unit, and the Regulatory Compliance Cost (column 6). Therefore the Total Costs of Recommended Corrective Measures does not sum across each row.

SECTION 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

The Ernest O. Lawrence Berkeley National Laboratory (Berkeley Lab) has prepared this Corrective Measures Study (CMS) Report in accordance with the terms of its Hazardous Waste Facility Permit, issued by the California Environmental Protection Agency Department of Toxic Substances Control (DTSC) (DTSC, 1993). The requirements for completing the CMS and preparing this CMS Report were based on the provisions of the Permit and the guidance provided in the USEPA RCRA Corrective Action Plan (USEPA, 1994). Those requirements were incorporated into the CMS Plan (Berkeley Lab, 2002a), which was submitted to the DTSC on May 24, 2002, and approved by the DTSC on June 18, 2002 (DTSC, 2002).

The primary purpose of the CMS is to provide the information necessary to support the DTSC in the selection of remedies to be implemented at Berkeley Lab, so that risks to human health and the environment are eliminated, reduced, or controlled. The first step in the CMS consisted of characterizing the risk to human health and the environment. This step was addressed by completing both a Human Health and an Ecological Risk Assessment (HHRA and ERA) (Berkeley Lab, 2003a, 2002b). The risk assessments evaluated potential present and future human health and ecological risks associated with environmental contamination, assuming that no cleanup activities would take place at the site. The results of the risk assessments are summarized in Section 1.3.4.

In order to provide the necessary information to support the DTSC in its decision making process, the CMS Report first screens various corrective measures alternatives that could reduce or eliminate potentially adverse effects to human health or the environment from chemicals of concern (COCs) in environmental media at Berkeley Lab. The CMS Report then compares those alternatives that passed the initial screening process based on a formal evaluation procedure, and recommends which alternatives should be implemented. The report also recommends media-specific chemical concentrations (Media Cleanup Standards [MCSs]) that corrective measures should ultimately achieve.

Section 1 of this report contains the background information and includes: the purpose for conducting the CMS; a description of the site; an overview of regulatory oversight, a discussion of the Resource Conservation and Recovery Act (RCRA) Corrective Action Process (CAP) at Berkeley Lab; and a description of the CMS process, including the methodology and results of the previously completed risk assessments. Section 2 contains a description of the physiography, geology and hydrogeology of Berkeley Lab. Section 3 presents a detailed description of the methodology used to complete the CMS. MCSs are developed and potential corrective measures alternatives are evaluated for volatile organic compounds (VOCs) (primarily solvents and solvent-related chemicals) in Section 4 and for PCBs in Section 5. Sections 4 and 5 contain a unit-by-unit discussion of the following:

- Physical characteristics, including geology and hydrogeology
- Current conditions, including the magnitude and extent of contamination
- Interim Corrective Measures (ICMs) and/or pilot tests that were implemented
- Proposed Media Cleanup Standards (MCSs) and Points of Compliance (POCs)
- An evaluation of corrective measures alternatives
- Recommendation of corrective measures to implement.

Section 6 provides cost estimates to achieve both risk-based cleanup levels and cleanup levels based on protection of potential future drinking water sources. Section 7 provides National Environmental Policy Act (NEPA) documentation which includes a summary of the proposed RCRA corrective actions at Berkeley Lab and a discussion of their consequences. Supplemental information for this report is provided in Appendices A through J, including **Appendix J** which contains regulatory agency comments and Berkeley Lab responses on the initial Draft CMS Report dated July 2004.

1.2 SITE DESCRIPTION AND OVERVIEW

Berkeley Lab is a multi-program National Laboratory managed by the University of California (UC) for the United States Department of Energy (DOE), with primary funding and oversight provided by the DOE. It is located in the Berkeley/Oakland Hills in Alameda County, California and encompasses approximately 200 acres adjacent to the northeast side of the UC

Berkeley campus **(Figure 1.2-1)**. The western three-quarters of the site are in the city of Berkeley and the eastern quarter is in the city of Oakland. The property consists of 29 parcels that are separately leased to the DOE from the University of California. DOE renews its contract with UC to manage the site every five years, at which times expiring leases are renewed for the five-year term of the contract.

Approximately half the site is developed and half is open space. The developed areas include buildings, paved areas, and landscaped areas. The buildings house laboratories, offices, meeting rooms, and fabrication/maintenance shops that support Berkeley Lab research activities. In addition, the site has a hazardous waste handling facility, a fire station, and a medical clinic. In general, the structures at Berkeley Lab are owned by the DOE. In 2002, there were 110 buildings of conventional construction and 86 trailers and other structures on the site. The site is fenced and access is restricted.

Berkeley Lab is bordered on the west and northwest by private homes and multi-unit dwellings. To the west-southwest are student residence halls, the UC Berkeley campus, and the downtown area of Berkeley. North and northeast of Berkeley Lab are the University’s Lawrence Hall of Science, the Space Sciences Institute, and the Mathematical Sciences Research Institute. To the east, the land is mostly undeveloped and includes Tilden Regional Park and open space. The area to the southeast, which is owned by UC, is maintained largely in a natural state and includes UC-Berkeley recreational facilities and the University Botanical Gardens.

Berkeley Lab began operations as an accelerator laboratory in 1931 on the campus of the University of California at Berkeley. In 1939 the Laboratory moved to its current location with the construction of the 184-Inch Cyclotron. The area of the cyclotron building (the original Building 6) and adjacent support shops and laboratories to the north and east of Building 6 formed the core of Berkeley Lab operations throughout the 1940s, and therefore is commonly referred to as "Old Town".

From an initial emphasis on high-energy and nuclear physics, research at Berkeley Lab has diversified to also include material sciences, chemistry, earth sciences, biosciences, environmental sciences and energy sciences. The operation of laboratories and support facilities in support of these types of research activities are the basis for the institutional land use scenario used to develop the MCSs proposed in this report. Berkeley Lab is in the process of preparing an updated 2004 Long Range Development Plan (LRDP) (Berkeley Lab, 2003b), which will address continuing and future uses and activities as a research institution through 2025. The Land Use Plan, included as part of the LRDP, will include the following three categories of general development zones consistent with current land use at Berkeley Lab:

- Facilities Development Area – research and support activities. Would encompass primarily the already developed central portion of the Lab. The LRDP would promote development on infill and existing building sites and would look to consolidating research activities.
- Vegetation Management Areas – managed landscape, wildland fire, and natural areas. Would be located entirely along the perimeter of the site and would provide an open space buffer to neighboring land uses. Vegetation in these areas would continue to be managed to reduce wildland fire risks. Environmental monitoring structures and access roadways would be allowed in these areas.
- Special Habitat Protection Areas – no regular vegetation management or development is anticipated. Would provide for protection of identified special status species habitats and riparian zones.

As a result of Berkeley Lab's mission as a research facility, many types of chemicals have been used or produced as wastes over the more than 60 years of operation. These include gasoline, diesel, waste oil, polychlorinated biphenyls (PCBs), Freon®, solvents, metals, acids, caustics, and lead- and chromate-based paints. Additionally, radionuclides have been used or produced as waste at Berkeley Lab. Some of these chemicals have been released to the environment.

The principal chemicals that have been detected in the environment at Berkeley Lab are chlorinated VOCs in the soil and groundwater, and PCBs in the soil. The detected VOCs primarily include tetrachloroethene (PCE), trichloroethene (TCE), carbon tetrachloride, 1,1-dichloroethene (1,1-DCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), 1,1,1-trichloroethane (TCA), and 1,1-dichloroethane (DCA). Most of these VOCs are solvents (and their degradation products) that were used as degreasers for cleaning equipment at Berkeley Lab. PCB contamination is primarily associated with spilled transformer oils and former waste oil tanks. Other contaminants that have been detected in soil and/or groundwater include petroleum hydrocarbons (in most cases associated with former underground storage tank [UST] sites), semi-volatile organic compounds (SVOCs), polynuclear aromatic hydrocarbons (PAHs), and metals.

1.3 THE RCRA PROCESS AT BERKELEY LAB

Berkeley Lab's Hazardous Waste Handling Facility (HWHF) operates under a RCRA Hazardous Waste Facility Permit. Section 3004(u) of RCRA, as amended by the Hazardous and Solid Waste Amendments (HSWA) and Title 40 of the Code of Federal Regulations (CFR) §264, requires that permits issued after November 8, 1984 address corrective action for all releases of hazardous wastes, including hazardous constituents from any Solid Waste Management Unit (SWMU). Therefore, the Permit requires that Berkeley Lab investigate and address historic releases of hazardous waste and constituents that may have occurred both at the HWHF and at SWMUs throughout the Berkeley Lab site. Berkeley Lab's Environmental Restoration Program (ERP) is responsible for conducting those investigations. The ERP is part of the Environmental Services Group of Berkeley Lab's Environment, Health and Safety (EH&S) Division.

The DTSC is the regulatory agency responsible for enforcing the provisions of Berkeley Lab's Hazardous Waste Facility Permit, including the activities required under the RCRA CAP. Corrective action refers to the activities related to the investigation, characterization, and cleanup of releases of hazardous waste or hazardous waste constituents under RCRA. In July 1993, the DTSC delegated some CAP oversight agency authority and responsibilities at Berkeley Lab to other regulatory agencies. The City of Berkeley was assigned as the lead agency for the technical review of USTs. The San Francisco Bay Region of the California Regional Water Quality Control Board (RWQCB) was assigned as the lead agency for the technical review of surface water and groundwater impacts. The DTSC retained authority and responsibility for technical review of all units that would not be addressed by the RWQCB or City of Berkeley. It also retained authority to review the evaluations and decisions of the other regulatory agencies, to ensure compliance with RCRA requirements.

The five primary components of the CAP are:

- RCRA Facility Assessment (RFA)
- RCRA Facility Investigation (RFI)
- Interim Corrective Measures (ICMs)
- Corrective Measures Study (CMS)
- Corrective Measures Implementation (CMI).

1.3.1 RCRA Facility Assessment

In 1991 and 1992, the DTSC (DTSC, 1991) and Berkeley Lab (Berkeley Lab, 1992a) conducted independent RCRA Facility Assessments (RFAs) to identify known and potential past releases of hazardous waste and hazardous constituents to the environment from Solid Waste Management Units (SWMUs) and Areas of Concern (AOCs) at Berkeley Lab. SWMUs, AOCs, and other areas of known or potential release are collectively referred to as "units" in this report.

A SWMU is defined as any unit at a hazardous waste facility from which hazardous constituents might migrate. "Hazardous constituent" means a constituent identified in California Code of Regulations (CCR), Title 22, Division 4.5, Chapter 11 (Identification and Listing of Hazardous Waste); or any component of a hazardous waste or leachate which has a chemical or physical property that causes the waste or leachate to be identified as a hazardous waste (CCR, Title 22, Section 66260.10).

An AOC is defined as any suspected release of a hazardous waste or hazardous constituent that is not associated with a Solid Waste Management Unit.

SWMUs identified at Berkeley Lab included primarily above-ground and underground waste storage tanks, sumps, scrap yards, plating shops, the former hazardous waste handling facility, waste accumulation areas, hazardous waste storage areas, and waste treatment units. AOCs identified at Berkeley Lab primarily included chemical product storage tanks (e.g., fuel tanks), transformers, and hazardous materials storage areas. In addition, for the purpose of identification and assessment, Berkeley Lab also designated groundwater plumes and sanitary sewer lines as AOCs.

A total of 75 SWMUs and 88 AOCs were identified during the RFAs and subsequent investigations. The RFAs found that hazardous waste or hazardous constituents had been released to soil and groundwater. Based on these findings, DTSC concluded that remedial investigations would be needed to characterize areas at the site where releases had occurred, and requested that Berkeley Lab submit a workplan for conducting a RCRA Facility Investigation (RFI) to further assess the extent of those releases.

1.3.2 RCRA Facility Investigation

Berkeley Lab submitted the RFI Work Plan to DTSC in November 1992 (Berkeley Lab, 1992b). A primary objective of the RFI, which was conducted between October 1992 and September 2000, was to collect adequate information to support corrective action decisions. To meet this objective, the RFI included identification of the source and nature of hazardous wastes and hazardous constituents that had been released to the environment, and characterization of the magnitude and extent of those releases.

Due to the complexity of the investigations needed at Berkeley Lab, the RFI was divided into three phases. RFI Phase I (Berkeley Lab 1994a) and Phase II (Berkeley Lab 1995a) Progress Reports were submitted to the DTSC in 1994 and 1995, respectively. The Draft Final RFI Report, which described the investigations conducted subsequent to the two progress reports, was submitted to the DTSC on September 29, 2000 (Berkeley Lab 2000).

The Draft Final RFI Report, which was subsequently approved as the Final RFI Report by DTSC, contained detailed information on the history, operations; adjacent land use; meteorology; utilities, ecology, physiography, geology, and hydrogeology of the site. In addition, the following detailed information was included:

- a description of the SWMUs and AOCs that were investigated
- results of contamination characterization activities that were completed
- potential and identified sources of contamination
- contaminant migration pathways
- Interim Corrective Measures (ICMs) that were implemented.

During the RFI, a screening process was implemented to determine which soil units exceeded the screening criteria and should therefore be included in the CMS because of potential risk to human health, and which units would be excluded from any further action. The former units were designated for No Further Investigation (NFI) and the latter for No Further Action (NFA). The screening process consisted of a comparison between the concentrations of chemicals detected in soil to California-modified Preliminary Remediation Goals (PRGs) and United States Environmental Protection Agency (USEPA) Region 9 PRGs (USEPA 1996a, 1998, 1999) for residential soil. Concentrations of naturally occurring inorganic elements detected in the soil were also compared to Berkeley Lab background levels. Subsequent to submittal of the Draft Final RFI Report (Berkeley Lab 2000), the DTSC requested that Berkeley Lab reevaluate the NFA-approved units to determine whether any should be reclassified as NFI based on the most recent PRGs available at that time (USEPA 2000). Two NFA-approved units were reclassified as NFI as a result of this comparison, and were subsequently included in the CMS (Berkeley Lab, 2002a). The RFI soil screening levels used for these evaluations are provided in **Appendix F**.

1.3.3 Interim Corrective Measures

During the RFI, Berkeley Lab implemented ICMs with the concurrence of the DTSC to address hazards where immediate action was required to protect human health or the environment. The ICMs primarily involved excavation and offsite disposal of contaminated soil from the areas that posed the greatest risk to human health or the environment and installation of groundwater and soil vapor extraction systems in areas where it was necessary to control the migration of contaminants. The locations of the soil excavation ICMs are listed in **Table 1.3.3-1.**

Table 1.3.3-1. Locations of Soil Excavation ICMs Implemented at Berkeley Lab

Unit Number	Unit Name
Units Included in CMS Report	
SWMU 3-6	Building 75 Former Hazardous Waste Handling and Storage Facility
AOC 1-9	Building 71 Groundwater Solvent Plume: Building 71B Lobe
AOC 2-5	Building 7 Sump
AOC 6-3	Building 88 Hydraulic Gate Unit
AOC 10-5	Building 52A Groundwater Plume Source Area
Units Not Included in CMS Report	
AOC 1-10	Building 71 Room 003 Mercury Release
AOC 5-5	Building 77 Diesel Generator Pad
AOC 9-2	Building 51 Former Diesel UST
AOC 9-9	Building 51 Sanitary Sewer and Drainage System
AOC 9-10	Building 51/64 Catch Basin
AOC 9-13	Building 51/64 Groundwater Solvent Plume
AOC 11-1	Building 74 Former Diesel UST
AOC 14-1	Building 2 Diesel UST
AOC 14-7	Building 37 Electrical Substation
SWMU 2-1	Former Building 7 Plating Shop
SWMU 2-2	Former Building 52B Abandoned Above-Ground Liquid Waste Storage Tank
SWMU 2-3	Former Building 17 Scrap Yard and Drum Storage Area
SWMU 9-4	Building 51 Vacuum Pump Room Sump and Collection Basins
SWMU 9-6	Building 51 Motor Generator Room Sump
SWMU 10-10	Building 25 Plating Shop Floordrains
not a unit	Building 51 Basement Oil Pumps

1.3.4 Corrective Measures Study

Based on results of the RFI, the DTSC determined that: 1) chemicals detected in the soil and groundwater at Berkeley Lab posed a potential threat to human health and the environment and 2) a CMS was required. As the initial step in the CMS, Berkeley Lab completed both an Ecological and a Human Health Risk Assessment (ERA and HHRA) (Berkeley Lab 2002b, 2003a).

The risk assessments estimated the potential risks to human health and the environment (plants and wildlife) from anthropogenic chemicals in soil, groundwater, sediment, and surface water at Berkeley Lab assuming that no cleanup would take place. The risk assessments consisted of the following four steps:

- Identifying the hazards associated with the chemicals of concern
- Assessing the magnitude, frequency, and duration of exposure of humans and wildlife to the chemicals
- Assessing the toxicity of the chemicals
- Estimating the potential risk.

The HHRA and ERA provided the basis for requiring further action for the soil and groundwater units, and identified the potential exposure pathways that need to be addressed. The remaining stages of the CMS, which are the subject of this report, include the identification and evaluation of potential corrective measures alternatives for the soil and groundwater units that require further action.

1.3.4.1 Ecological Risk Assessment

The Ecological Risk Assessment evaluated the potential for chemical contaminants detected in soil, sediment, surface water, and groundwater at Berkeley Lab to adversely affect the reproduction, growth, or survival of plant and wildlife individuals and populations (ecological receptors). Exposure estimates were calculated for representative terrestrial plants, terrestrial wildlife (vertebrates and invertebrates), aquatic plants, and aquatic wildlife (vertebrates and invertebrates). A description of the area within an approximately 1-mile radius of Berkeley Lab was prepared to identify any species that could potentially inhabit the site.

Special species evaluated included California species of special concern; state and federally listed rare, threatened, or endangered species; and species that were proposed or recommended for state or federal listing. No special status plant or animal species were identified at Berkeley Lab; however, one special status species known to occur within 5 miles of the lab, the Cooper’s hawk was retained in the ERA as an individual predatory organism whose exposure could be significant for chemicals with a high biomagnification potential (Berkeley Lab, 2002b).

Direct exposure to most soils and groundwater within the central developed area of Berkeley Lab were eliminated as completed exposure pathways in the ERA because suitable habitat for wildlife, is restricted to the natural, perimeter areas of Berkeley Lab, and is not present in the central developed area. The ERA concluded that no hazards exist to plants or animals from exposure to chemicals in soil, groundwater, or surface water at Berkeley Lab. The DTSC approved the ERA on April 14, 2003 (DTSC, 2003a)

1.3.4.2 Human Health Risk Assessment

The HHRA (Berkeley Lab, 2003a) identified the current and reasonably likely future land use at Berkeley Lab as industrial-type institutional land use. The potential receptors and exposure routes for the institutional land-use scenario were described in detail in the HHRA. The activities associated with institutional land use are described in Section 1.2 of this report. The potential receptors associated with this land-use scenario are Berkeley Lab employees (laboratory workers, office workers, and outdoor workers such as landscape maintenance workers) and construction workers.

The HHRA also evaluated a hypothetical future residential land use scenario that included on-site residents and recreational users as potential receptors. The Residential scenario was included for informational purposes only. Off-site human receptors (i.e., local residents) were not evaluated in the HHRA because there are no complete exposure pathways to those individuals and none is anticipated in the future. There are no complete exposure pathways to potential offsite receptors from groundwater pathways because the groundwater plumes at Berkeley Lab have not migrated beyond the site boundary and are stable (Berkeley Lab, 2000). The stability of the plumes is indicated by measured groundwater concentrations that are generally static or decreasing throughout the plume areas and by the long-term absence of detectable concentrations of contaminants in wells monitoring the areas downgradient from the plumes.

Based on the RFI soil screening process described above, DTSC determined that 15 soil SWMUs and 12 soil AOCs should be evaluated in the HHRA. In addition, two undesignated areas of soil contamination that did not pass the screening process (Building 51L Groundwater Plume Source Area and Slope West of Building 53) were retained for evaluation in the HHRA. All areas where chemicals were detected in groundwater or surface water (i.e., groundwater units and surface water units) were also addressed in the HHRA. The SWMUs, AOCs, and other locations that were included in the HHRA are listed in **Table 1.3.4-1**. The Module designations given in the table correspond to designations given in the RFI report (Berkeley Lab, 2000).

Table 1.3.4-1. List of SWMUs, AOCs, and Other Areas Evaluated in the HHRA

Berkeley Lab Unit Name	Berkeley Lab Unit Number	DTSC[(a)] Unit Number	Oversight Agency
SOIL UNITS			
Bevalac Area			
Building 51 Vacuum Pump Room Sump and Collection Basins	SWMU 9-4	SWMU-1	DTSC
Building 51 Motor Generator Room Sump	SWMU 9-6	—	DTSC
Building 51 Sanitary Sewer and Drainage System	AOC 9-9	—	DTSC
Buildings 51/64 Former Temporary Equipment Storage Area	AOC 9-12	—	DTSC
Building 51L Groundwater Plume Source Area	—	—	DTSC
Old Town Area			
Building 7 Former Plating Shop	SWMU 2-1	—	DTSC
Building 52B Abandoned Liquid Waste Above Ground Storage Tank (AST) and Sump	SWMU 2-2	SWMU-4	DTSC
Building 17 Former Scrap Yard and Drum Storage Area	SWMU 2-3	SWMU-11	DTSC
Building 16 Former Waste Accumulation Area	SWMU 10-4	SWMU-9	DTSC
Building 25 Plating Shop Floor Drains	SWMU 10-10	—	DTSC
Building 7E Former Underground Storage Tank (UST)	AOC 2-1	AOC-4	COB[(b)]
Building 7 Former Hazardous Materials Storage Area	AOC 2-2	—	DTSC
Building 7 Sump	AOC 2-5	—	DTSC
Building 46 Hazardous Materials Storage Area	AOC 7-3	—	DTSC
Building 58 Former Hazardous Materials Storage Area	AOC 7-6	—	DTSC
Building 52 Former Hazardous Materials Storage Area	AOC 10-2	—	DTSC
Building 37 Proposed Electrical Substation	AOC 14-7	—	DTSC
Slope West of Building 53	—	—	DTSC
Support Services Area			
Building 69A Former Hazardous Materials Storage and Delivery Area	SWMU 3-1	SWMU-15	DTSC
Building 69A Storage Area Sump	SWMU 3-5	—	DTSC
Building 75 Former Hazardous Waste Handling and Storage Facility	SWMU 3-6	—	DTSC

Table 1.3.4-1. List of SWMUs, AOCs, and Other Areas Evaluated in the HHRA (cont'd.)

Berkeley Lab Unit Name	Berkeley Lab Unit Number	DTSC[(a)] Unit Number	Oversight Agency
SOIL UNITS (cont'd.)			
Support Service Area (cont'd.)			
Building 76 Motor Pool and Collection Trenches and Sump	SWMU 4-3	SWMU-29	DTSC
Building 76 Present and Former Waste Accumulation Area #3	SWMU 4-6	SWMU-35	DTSC
Building 77 Plating Shop	SWMU 5-4	SWMU-30	DTSC
Building 77 Former Yard Decontamination Area	SWMU 5-10	—	DTSC
Module D: Outlying Areas			
Building 50 Inactive Underground Residual Photographic Solution Storage Tank (TK-09-50)	SWMU 12-1	SWMU-5	COB
Building 88 Hydraulic Gate Unit	AOC 6-3	AOC-2	DTSC
Building 58/Building 70 Sanitary Sewer	AOC 8-6	—	DTSC
Building 62 Hazardous Materials Storage Area	AOC 13-1	—	DTSC
GROUNDWATER UNITS			
Bevalac Area			
Building 71 Groundwater Solvent and Freon Plumes	AOC 1-9	—	RWQCB[(c)]
Buildings 51/64 Groundwater Plume	AOC 9-13	—	RWQCB
Building 51L Groundwater Plume	—	—	RWQCB
Old Town Area			
Old Town Groundwater Solvent Plume (Buildings 7 Lobe)	AOC 2-4	—	RWQCB
Solvent-Contaminated Groundwater in Area 10 (Building 25A Lobe of the Old Town Groundwater Solvent Plume)	AOC 10-5	—	RWQCB
Solvent-Contaminated Groundwater in Area 10 (Building 52 Lobe of the Old Town Groundwater Solvent Plume)	AOC 10-5	—	RWQCB
Well MWP-7 Groundwater Contamination	AOC 14-5	—	RWQCB

Table 1.3.4-1. List of SWMUs, AOCs, and Other Areas Evaluated in the HHRA (cont'd.)

Berkeley Lab Unit Name	Berkeley Lab Unit Number	DTSC[(a)] Unit Number	Oversight Agency
GROUNDWATER UNITS (cont'd.)			
Support Services Area (cont'd.)			
Solvents in Groundwater South of Building 76	AOC 4-5	—	RWQCB
Building 69A Area	—	—	RWQCB
Building 75/75A Area	—	—	RWQCB
Building 75B Area	—	—	RWQCB
Building 77 Area	—	—	RWQCB
Benzene Detected in Two Wells East of Building 75A	—	—	RWQCB
SURFACE WATER UNITS			
Site-Wide Contaminated Hydrauger Discharges (Buildings 51 and 77 areas)	AOC SW1	AOC-8	RWQCB
Surface Water (Creeks and Building 71 spring)	—	—	RWQCB

(a) DTSC: California Environmental Protection Agency, Department of Toxic Substances Control.

(b) COB: City of Berkeley Planning and Development Department, Toxics Management Division.

(c) RWQCB: San Francisco Bay Region Regional Water Quality Control Board.

The HHRA estimated the theoretical incremental lifetime cancer risks (ILCRs) and non-cancer health hazards for on-site workers that could potentially be exposed to anthropogenic chemicals in soil, groundwater, and surface water at Berkeley Lab. The theoretical ILCRs and non-cancer Hazard Indices (HIs)were evaluated relative to the following two risk comparators to determine which units should be retained in the CMS: 1) the USEPA-recommended risk management range (i.e., a theoretical ILCR between 10^{-6} and 10^{-4}) also referred to as the "risk management range" and 2) a non-cancer HI of 1. The risk management range of 10^{-4} to 10^{-6} is considered by the USEPA to be safe and protective of public health (Federal Register 56(20): 3535, Wednesday, January 30, 1991). Exposure to chemicals with an HI below 1.0 is considered unlikely to result in adverse non-cancer health effects over a lifetime of exposure. Risk levels below these two criteria are generally considered by regulatory agencies to be *de minimis* levels. The theoretical ILCRs and HIs provided data necessary to support the development of appropriate corrective actions, or at units where there was a very low level of risk or hazard, a recommendation that no remedial action should be required.

In addition to comparison to risk-based levels, the HHRA also considered promulgated standards and regulatory policies when recommending which units should be retained in the CMS. Groundwater is not used for drinking or other domestic water supply at Berkeley Lab (or in the City of Berkeley) and water for domestic use will likely be supplied to the Lab and Berkeley residents by the East Bay Municipal Utility District (EBMUD) for the foreseeable future. Thus, exposure to chemicals in groundwater via water ingestion or other domestic use was not evaluated in the risk assessment. Although groundwater is not used for domestic supply at Berkeley Lab, potential impacts to the beneficial use of groundwater were evaluated in the HHRA. State Water Resources Control Board (SWRCB) Resolution No. 88-63, "Sources of Drinking Water" specifies that except under specifically identified circumstances, all surface waters and groundwaters are to be protected as existing or potential sources of municipal and domestic supply.

The HHRA concluded that four areas of soil contamination and eleven areas of groundwater contamination posed a potential risk to human health and/or beneficial uses of groundwater, and therefore should be retained for further evaluation in subsequent parts of the CMS. These 15 units are listed in **Table 1.3.4-2** (soil units) and **Table 1.3.4-3** (groundwater units) along with the following information:

- A notation as to whether the unit was retained in the CMS based on risk or regulatory policy.
- For the units included in the CMS based on potential risk, the exposure pathways and the corresponding human receptors of potential concern.

Table 1.3.4-2. Soil Units Recommended to be Retained in Corrective Measures Study in the Human Health Risk Assessment (Berkeley Lab, 2003a)

Unit	Retained in CMS Based on Regulatory Policy[a]	Retained in CMS Based on Risk[b]	Risk-Based Chemicals of Concern[e]	Soil Exposure Pathway of Potential Concern (b)(c)	Potential Receptor of Concern[b]
MODULE A: BEVALAC AREA					
Building 51L Groundwater Plume Source Area	yes	yes	chloroform **vinyl chloride** **1,1-DCE** **TCE** carbon tetrachloride 1,2-DCA	I	Potential Future Indoor Worker
MODULE B: OLD TOWN AREA					
AOC 2-5: Former Building 7 Sump	yes	yes	**carbon tetrachloride** **PCE** TCE	I I	Potential Future Indoor Worker Landscape Worker
MODULE C: SUPPORT SERVICES AREA					
SWMU 3-6: Building 75 Former Hazardous Waste Handling and Storage Facility	no	yes	**PCBs**[d]	F[d], D[d] F[d], D[d]	Landscape Worker [d] Construction Worker[d]
MODULE D: OUTLYING AREAS					
AOC 6-3: Building 88 Hydraulic Gate Unit	no	yes	**PCBs**[d]	I[d], F[d], D[d] F[d], D[d]	Landscape Worker[d] Construction Worker[d]

(a) SWRCB Resolution 88-63 (Sources of Drinking Water Policy)

(b) Theoretical Incremental Lifetime Cancer Risks equaled or exceeded 10^{-6} or non-cancer Hazard Indices (HIs) equaled or exceeded 1.0.

(c) I:Inhalation, F:Ingestion, D:Dermal Contact

(d) ICMs completed in 2003 or 2004 (excavation and offsite disposal of PCB-contaminated soil) reduced risks below levels of concern (to levels consistent with unrestricted land use). No further action is proposed for these units.

(e) Theoretical incremental lifetime cancer risk equaled or exceeded 10^{-6} or non-cancer Hazard Quotient equaled or exceeded 1. Boldface type indicates primary chemical(s) that contribute to the estimated risk.

Table 1.3.4-3. Groundwater Units Recommended to be Retained in Corrective Measures Study in the Human Health Risk Assessment

Unit	Retained in CMS Based on Regulatory Policy[(a)]	Retained in CMS Based on Risk[(b)]	Risk-Based Chemicals of Concern[(d)]	Groundwater Exposure Pathway of Potential Concern[(b)(c)]	Potential Receptor of Concern[(b)]
MODULE A: BEVALAC AREA					
AOC 9-13: Building 51/64 Groundwater Solvent Plume	yes	yes	**1,1-DCA** **vinyl chloride** carbon tetrachloride TCE	I	Potential Future Indoor Worker
Building 51L Groundwater Solvent Plume	yes	yes	**vinyl chloride** TCE	I	Potential Future Indoor Worker
AOC 1-9: Building 71 Groundwater Solvent Plume Building 71B lobe	yes	yes	**vinyl chloride**	I	Potential Future Indoor Worker
MODULE B: OLD TOWN AREA					
AOC 2-4: Building 7 Lobe of the Old Town Groundwater Solvent Plume	yes	yes	**carbon tetrachloride** **PCE** TCE vinyl chloride	I D	Potential Future Indoor Worker Construction Worker
AOC 10-5: Building 52 Lobe of the Old Town Groundwater Solvent Plume	yes	yes	**carbon tetrachloride** chloroform	I	Potential Future Indoor Worker
AOC 10-5: Building 25A Lobe of the Old Town Groundwater Solvent Plume	yes	yes	(e)	(e)	(e)
MODULE C: SUPPORT SERVICES AREA					
AOC 4-5: Solvents in Groundwater South of Building 76	yes	no			
Support Services Area (Building 69A Area)	yes	yes	**vinyl chloride**	I	Potential Future Indoor Worker

Unit	Retained in CMS Based on Regulatory Policy[a]	Retained in CMS Based on Risk[b]	Risk-Based Chemicals of Concern[d]	Groundwater Exposure Pathway of Potential Concern[b][c]	Potential Receptor of Concern[b]
MODULE C: SUPPORT SERVICES AREA (cont'd.)					
Support Services Area (Building 75/75A Area)	yes	no			
Support Services Area (Building 77 Area)	yes	no			
Benzene Detected in Wells East of Building 75A	yes	no			

(a) SWRCB Resolution 88-63 (Sources of Drinking Water Policy). Note the Human Health Risk Assessment (HHRA) did not include an evaluation of well yield when recommending areas of groundwater contamination to be retained in the CMS based on regulatory policy.

(b) Theoretical ILCRs to one or more receptors equaled or exceeded 10^{-6} or non-cancer Hazard Indices (HIs) equaled or exceeded 1.0

(c) I:Inhalation, F:Ingestion, D:Dermal Contact

(d) Theoretical incremental lifetime cancer risk equaled or exceeded 10^{-6} or non-cancer Hazard Quotient equaled or exceeded 1. Boldface type indicates primary chemical(s) that contribute to the estimated risk. Note that the Chemicals of Concern in the HHRA differ from those in the CMS Report due to updates in the risk evaluations.

(e) A revised risk estimate based on USEPA withdrawal of the cancer potency factor for 1,1-DCE indicates there are no risk-based COCs for this unit (Appendix C of the HHRA).

The HHRA recommended no additional investigation or remedial action to address human health issues associated with surface water at Berkeley Lab. Theoretical ILCRs for exposure to COCs in surface water were below the USEPA risk management range ($<10^{-6}$) and the non-cancer HI was less than 1, for all surface water units except for effluent from the Building 51 hydraugers. However, the theoretical ILCRs from the hydrauger effluent only marginally exceed the 10^{-6} level, and there is no exposure pathway since the hydrauger effluent is piped to a groundwater treatment system where it has been collected and treated to non-detectable contaminant levels for the past 12 years. The treated hydrauger effluent has been discharged to the sanitary sewer under conditions of Berkeley Lab's Wastewater Discharge Permit issued by the East Bay Municipal Utility District (EBMUD).

The HHRA also evaluated potential adverse effects to human health based on a hypothetical future restricted residential use scenario. The receptors evaluated under this scenario included on-site future hypothetical residents and recreational users (recreationists). The theoretical ILCRs and non-cancer HIs presented under this scenario in the HHRA would be appropriate (for screening purposes) only if the institutional land use status for Berkeley Lab were to be changed to residential land use.

The DTSC accepted the HHRA on August 19, 2003 (DTSC, 2003b). The acceptance was conditional, pending a final approval determination after the CMS Report has been submitted and a formal public comment period has been held on the proposed remedy selection.

1.3.4.3 Screening, Evaluating, and Selecting Corrective Measures Alternatives

This CMS Report identifies and screens potential corrective measures alternatives for the soil and groundwater units that require further action based on the results of the HHRA. It also recommends which alternative should be implemented at each unit based on a comprehensive evaluation process that was described in the CMS Plan (Berkeley Lab, 2002a). DTSC will evaluate the results and recommendations of the CMS Report and select the specific corrective measures that Berkeley Lab will implement.

1.3.4.4 Community Involvement in the CMS Process

After the CMS has been completed, the DTSC will prepare a Statement of Basis for the selected remedies. The public will be invited to comment on the proposed remediation decisions at that time, including the corrective measures that are proposed for implementation and the MCS that should be achieved. In addition, the public will be invited to comment on the California Environmental Quality Act (CEQA) initial study to evaluate the environmental effects of the selected remedies at that time. After consideration of the public comments, the DTSC will respond to the comments; approve the CMS Report and final remedy selection, if appropriate; and issue a Modified Hazardous Waste Handling Facility Permit.

SECTION 2

PHYSIOGRAPHY, GEOLOGY AND HYDROGEOLOGY OF BERKELEY LAB

2.1 PHYSIOGRAPHY AND SURFACE WATER HYDROLOGY

The physiography at Berkeley Lab is dominated by steep west and southwest-facing slopes that have been modified by erosion of stream canyons, by mobilization of landslides, and by cut and fill operations associated with construction of the Berkeley Lab facilities. Berkeley Lab lies within the upper portion of the Strawberry Creek watershed, which consists of approximately 874 acres of land east of the UC Berkeley campus. The entire Strawberry Creek watershed occupies approximately 1,163 acres, and includes other UC properties, public streets of both Oakland and Berkeley, and private property. In the vicinity of Berkeley Lab, the Strawberry Creek watershed is subdivided into the Blackberry Canyon and Strawberry Canyon watersheds. The tributaries feeding North Fork Strawberry Creek, which flows in Blackberry Canyon, have been altered by extensive surface grading and fill placement during past building construction activities. Hence, surface water from these tributaries is collected and conveyed through reinforced concrete pipes. Both Strawberry Creek and North Fork Strawberry Creek are perennial and are fed by springs during the summer.

2.2 GEOLOGY AND HYDROGEOLOGY

2.2.1 Geologic Units

The geology and hydrogeology at Berkeley Lab are described in detail in the Draft Final RFI Report (Berkeley Lab 2000). A geologic map of the area discussed in this report is provided in **Appendix I (Figure I-1).**

Bedrock at Berkeley Lab consists primarily of Cretaceous and Miocene sedimentary and volcanic units. These units form a northeast-dipping, faulted homocline, which underlies most of the facility, and has been disrupted in places by ancient and modern landslides. From the structurally lowest to structurally highest units, the homocline includes the Great Valley Group, the Orinda Formation, and the Moraga Formation. The Great Valley Group and Orinda Formation consist of mudstones and fine- to medium-grained sandstones. The Moraga Formation is a resistant ridge-forming unit that is composed primarily of andesitic volcanic rocks that are typically highly fractured, jointed, and brecciated. At the base of several bodies of Moraga Formation, volcanic rocks are interleaved with siltstones, tuffs, and sandstones immediately above the underlying contact with the Orinda Formation. This zone has been informally named the Mixed Unit. Outcrops of both the Moraga Formation and Mixed Unit at Berkeley Lab appear to have been emplaced as ancient landslides that predated the present topography.

Most of the developed portion of Berkeley Lab is underlain by the Orinda or Moraga Formation. In the easternmost portion of Berkeley Lab, the homocline is disrupted by the north-striking Wildcat and East Canyon Faults. The area to the east of these faults is underlain by Miocene marine sedimentary rocks of the Claremont Formation and rocks interpreted to belong to the San Pablo Group. At Berkeley Lab’s western property boundary, the homocline is truncated by the north-northwest striking Hayward Fault, a regionally extensive, active, right-lateral strike-slip fault. Rocks west of the Hayward fault consist of the Jurassic to Cretaceous Franciscan Complex.

Surficial geologic units at Berkeley Lab consist primarily of artificial fill, colluvium, and landslide deposits. The soil profile developed on the bedrock is typically a moderately to highly expansive silty clay less than 2 feet thick. Colluvial deposits, which are loose masses of soil material and/or rock fragments, are generally found along the bases of slopes and in hillside concavities.

The overall geometry of both the bedrock and surficial units in the portion of Berkeley Lab described in this report is shown on the geologic map (**Appendix I, Figure I-1**) and in hydrogeologic cross sections A-A’ through F-F’ (**Appendix I, Figures I-2 through I-7**).

2.2.2 Hydrogeologic Characteristics and Groundwater Yield

The hydrogeological characteristics of the bedrock units and surficial materials, along with the physiography of the site, are the primary factors controlling groundwater flow and contaminant transport. Groundwater generally flows in a downslope direction relative to the surface topography, with westward groundwater flow in the western portion of Berkeley Lab and southward elsewhere. However, at some locations flow directions deviate from this pattern due to contrasts in the subsurface geology or man-made features such as building subdrains.

There are several bedrock geologic units in the areas of Berkeley Lab where groundwater contamination is present. The primary bedrock unit in these areas is the Orinda Formation, consisting of sedimentary rocks that dip moderately toward the northeast. Overlying this unit in most areas of the site are colluvium, artificial fill, and/or isolated masses of Moraga formation volcanic rock that are interpreted to be paleolandslide (ancient landslide) deposits. Each of these geologic units consists of a distinct assemblage of soil and rock types with its own characteristic hydrogeologic properties. Due to the complex structural geometry of these units, the hydrogeology at Berkeley Lab is characterized by a number of discrete, relatively permeable zones (primarily. Moraga Formation and some surficial units), where groundwater flow is relatively rapid, separated and underlain by broad areas where underlying relatively impermeable rocks (i.e., primarily the Orinda Formation) inhibit flow. As a result of this geometry, most of the contaminated groundwater plumes at Berkeley Lab are also discrete, and do not interact hydrologically.

At least one of the three structurally lowest geologic units (rocks of the Great Valley Group, Orinda Formation and Mixed Unit) lies either at the surface or at depth beneath all of Berkeley Lab, and with few exceptions these units consist of fine-grained rock types with very low permeabilities. Well yields in these units are substantially lower than 200 gpd with the exception of a few locations where coarser-grained strata (e.g., sandstone, conglomerate) are present. Many wells installed into these units take a day or more to recharge after water stored in the well is removed.

In a number of locations, structurally and stratigraphically higher units (Moraga Formation, colluvium and artificial fill), generally with higher permeabilities, overlie the deeper units. The contacts between the lower units and upper units are highly undulatory surfaces, so that the upper units generally occupy bowl-shaped depressions in the upper bounding surface of the lower units. The Moraga Formation is relatively permeable, and therefore can produce more than 200 gpd in most areas where the water table lies within or above it. Wells screened entirely in the Moraga Formation were generally not tested because it is assumed that they can yield more than 200 gpd. In locations where the water table lies within colluvium or artificial fill, well yields depend on the properties of these units, which differ from location to location. A geologic map constructed at the water table lowstand (i.e., the seasonal lowest dry-season water table elevation) was constructed to illustrate where these units were present in the saturated zone (**Appendix I**, **Figure I-8**). This map primarily used groundwater elevation data collected during September and October 1999, prior to installation and operation of most groundwater extraction systems. In a few locations, data from other years (ranging from 1993 to 2003) were utilized either because the 1999 data were not representative (i.e., water levels had been perturbed due to pumping) or because wells in some areas had not been constructed until later.

As discussed in Section 3.2.2, a sustained yield of 200 gallons per day is one of the threshold criteria used by SWRCB for determining whether groundwater is considered a potential drinking water source. Short-term pumping tests were therefore conducted in selected groundwater monitoring wells and temporary groundwater sampling points located in areas of groundwater contamination to determine which areas would not constitute a potential drinking water source (i.e., could not yield 200 gallons per day [gpd]) by this criteria . Results of the testing are tabulated in **Appendix G. Figure. 2.2-1** shows areas of groundwater contamination exceeding Maximum Contaminant Levels (MCLs) for drinking water. These areas are divided into subareas that do not constitute potential sources of drinking water and areas that may constitute potential sources of drinking water (based on the short-term yield testing results and the distribution of permeable rock units below the water table). A map showing both the water table geology and these subareas of the groundwater plumes is shown in **Appendix I, Figure I-9.** Most of the well yield testing was conducted in March 2004, when groundwater elevations are at their highest annual levels and well yields are at a maximum. During the summer and fall when groundwater elevations decline, it is likely that additional wells would have yields less than 200 gpd, particularly in those areas where the water table drops into the less permeable horizons below the base of the Moraga formation. In addition, since only short-term tests were conducted, conclusions regarding which areas may constitute potential drinking water sources are considered conservative, because longer-term tests may show that sustainable yields are less than 200 gallons per day in areas where the short-term tests showed higher yields.

SECTION 3

METHODOLOGY FOR DEVELOPMENT OF CORRECTIVE ACTION OBJECTIVES, MEDIA CLEANUP STANDARDS (MCSs), POINTS OF COMPLIANCE, AND CORRECTIVE MEASURES ALTERNATIVES

The CMS Report provides the rationale for recommending the corrective measures that should be implemented at each soil and groundwater unit that requires remedial action. In order to accomplish this, Corrective Action Objectives and corresponding MCSs are first developed, which specify the required goals for protecting human health and the environment. The various corrective measures alternatives that have the potential for achieving the Corrective Action Objectives are then compiled and the alternatives recommended for implementation selected from the list of candidate alternatives through a formal evaluation process. To document that the Corrective Action Objectives have been achieved, compliance with MCSs will be demonstrated at prescribed locations in each environmental media requiring remediation.

3.1 CORRECTIVE ACTION OBJECTIVES

Corrective Action Objectives are the media-specific goals required to protect human health and the environment. Corrective Action Objectives were developed both to address potential risk and to address regulatory policy (i.e., the protection of the beneficial uses of groundwater). As described in Section 1.3.4, the ERA concluded that no hazards exist to plants or animals from exposure to chemicals in soil, groundwater, or surface water at Berkeley Lab (Berkeley Lab, 2002b). Therefore, no corrective action objectives were developed for ecological receptors. The human health exposure pathways and the corresponding receptors of potential concern were determined in the HHRA (Berkeley Lab, 2003a), and are listed in **Table 1.3.4-2** and **Table 1.3.4-3** for soil and groundwater units, respectively.

The primary Corrective Action Objective is to protect human health by reducing COC concentrations so that theoretical ILCRs are less than, or at the lowest reasonably achievable level within the USEPA target-risk range (between 10^{-4} and 10^{-6}) and HIs are less than 1. Based on the results of the HHRA (Berkeley Lab, 2003a), this objective is applicable to the following contaminant migration pathways.

- Inhalation of VOCs volatilizing from soil to indoor or outdoor air
- Inhalation of PCBs volatilizing from soil to indoor air
- Incidental ingestion and direct dermal contact with PCBs in soil
- Inhalation of VOCs volatilizing from groundwater to indoor air
- Dermal contact with VOCs in groundwater

The lowest reasonably achievable level within the risk management range was selected as the risk-based corrective action objective for the following reasons:

1. The USEPA has expressed a preference for cleanups achieving the more protective end of the risk management range (i.e., 10^{-6}) (USEPA, 1997).
2. The DTSC has also expressed a preference for the cleanup achieving the more protective end of the risk range (i.e., 10^{-6}), if reasonably achievable. The required cleanup levels will be specified by the Standardized Permits and Corrective Action Branch of the DTSC in a modification to Berkeley Lab's RCRA Hazardous Waste Handling Facility (HWHF) Permit.
3. Institutional controls will be required for those areas where the theoretical ILCR>10^{-6} and/or HI>1.

In addition, the DTSC could initiate enforcement actions against Berkeley Lab, if RCRA CAP requirements specified in a modified HWHF Permit (including required cleanup levels) are not followed. Additional compliance and legal costs would likely be incurred as a result of such enforcement actions.

The following Corrective Action Objectives were developed based on regulatory requirements:

- Protect and/or restore groundwater quality to levels that are protective of beneficial uses (i.e., COC concentrations less than or equal to Maximum Contaminant Levels [MCLs] for drinking water in areas where groundwater meets SWRCB criteria for potential drinking water sources under Resolution 88-63
- Control the migration of contaminated groundwater so that COCs do not migrate to groundwater in adjacent uncontaminated areas or to surface water.

- Control the migration of contaminated groundwater so that COCs above risk-based levels do not migrate to groundwater in adjacent areas where concentrations are below risk-based levels.

These objectives were selected for the following reasons:

1. They are California state legal requirements specified in Resolutions of the SWRCB under the Porter-Cologne Water Quality Control Act (Division 7 of the California Water Code).
2. Institutional controls will be required in areas considered a potential drinking water source and MCLs are exceeded.

There are various costs and benefits associated with compliance or non-compliance with the risk-based and regulatory-based objectives listed above. Cleanup to less stringent risk based levels (e.g., 10^{-4} or 10^{-5} rather than 10^{-6}) would be less expensive and would still be in the range that is considered safe and protective of public health. However, lower cleanup levels would result in added costs for new building construction and possibly preclude development in some areas. Less stringent risk based levels would also adversely affect the project schedule and incur additional costs since they would require negotiation with the regulatory agencies. Non-compliance with the regulatory-based objectives could result in enforcement actions and resultant legal costs. In addition, there could be a possible impact on private property values in neighborhoods adjacent to Berkeley Lab.

3.2 MEDIA CLEANUP STANDARDS

Media Cleanup Standards (MCSs) are media-specific concentrations that the corrective measures must achieve in areas that currently exceed these concentrations, in order to meet the corrective action objectives. As described in the RCRA Corrective Action Plan (USEPA, 1994), MCSs "*must be based on promulgated federal and state standards, risk derived standards, all data and information gathered during the corrective action process", and/or other applicable guidance documents)*…." The general methodology used to develop MCSs is described below. The specific MCSs proposed for COCs in soil and groundwater at Berkeley Lab are developed in Sections 4 (VOCs) and Section 5 (PCBs).

3.2.1 Risk-Based MCSs

Proposed Risk Levels

The proposed MCSs for Berkeley Lab are based on two criteria: 1) the USEPA-recommended target cancer-risk range for risk managers (i.e., a theoretical ILCR between 10^{-6} and 10^{-4}) also referred to as the "risk management range" and 2) a non-cancer hazard quotient (HQ) value (for individual chemicals) of 1.0. These ranges are consistent with the Corrective Measures Objectives described above. A target ILCR in the range of 10^{-4} to 10^{-6} is considered by the USEPA to be safe and protective of public health (Federal Register 56 [20]: 3535, Wednesday, January 30, 1991). An HI (sum of HQs) below 1.0 will likely not result in adverse non-cancer health effects over a lifetime of exposure.

An industrial/institutional land use scenario was used to develop risk-based MCSs, which is consistent with the current and potential future land use at Berkeley Lab. To help ensure that the corrective measures technologies selected are appropriate to the corrective measures objectives, and can result in the lowest reasonably achievable COC concentrations within the USEPA risk management range, DTSC has indicated that proposed target risk-based MCSs should be based on theoretical ILCRs of 10^{-6} (the lower bound of the risk management range).

Since the target risk-based MCSs may not be achievable at some groundwater units due to technical impracticability, upper-limit risk-based MCSs are also provided that represent the upper bound of the USEPA risk management range (i.e., a theoretical ILCR of 10^{-4}) and non-cancer HQ of 1.0. The upper-limit risk-based MCSs will be used to assess compliance with corrective measure objectives at locations where target risk-based MCSs cannot reasonably be achieved.

Modifications to the Human Health Risk Assessment Methodology

The proposed risk-based MCSs for Berkeley Lab were derived for an industrial/institutional land use scenario generally utilizing the same methodology and input parameters as were used to estimate risks in the HHRA (Berkeley Lab, 2003a). Toxicity values were first reviewed, however, to ensure that the most recently available toxicity data would be used in the MCS calculations. The following revisions in toxicity data were identified and incorporated into the risk-based MCS calculations:

1. Updates of the USEPA Integrated Risk Information System (IRIS) or National Center for Environmental Assessment (NCEA) toxicity values included:
    - Revision of the dermal reference doses (RfDds) for 1,1-DCE, 1,1,1-TCA, benzene, and TCE
    - Revision of the unit risk factor (URF) for ethylbenzene
    - Revision of the reference concentration (RfC) for n-butylbenzene.
2. USEPA IRIS or NCEA values were used for chronic reference exposure levels (RELs) in the HHRA since the California Environmental Protection Agency's (CalEPA's) RELs had not yet been adopted. RfCs for TCE, ethylbenzene, methyl tertbutyl ether, toluene, naphthalene, chloroform, methylene chloride and PCE were changed as a result of the newly adopted RELs.
3. The cancer risk factor for 1,1-DCE was withdrawn by USEPA, and 1,1-DCE is no longer considered to be a carcinogen by either the USEPA or Cal-EPA.

Although no revisions have been made to cancer risk factors for TCE, recent research on TCE carcinogenicity strongly suggests that the cancer risk factors used to estimate the risk-based MCSs for TCE are overly conservative by approximately a factor of 10. A discussion of this research is given in **Appendix A**.

The calculations used to determine the proposed risk-based MCSs are presented in **Appendix A.**

An additional modification to the risk assessment calculations was a change in the value for the building crack density parameter (η) used for indoor air modeling. The HHRA estimates for the risks to potential future indoor workers from the indoor air inhalation pathway were based on the American Society of Testing and Materials (ASTM) implementation of the Johnson and Ettinger (1991) vapor intrusion model (ASTM, 1995), using conservative ASTM default parameters to define soil and building physical characteristics. These default parameters are generally within the range of values possible for the physical properties of soil and overlying buildings at Berkeley Lab units, so they were also used for developing the risk-based MCSs for groundwater. However, for the potential future indoor worker pathway, the parameter (η) used to represent the proportion of floor area that consists of open cracks has a default value of 1%, which is considered to be unrealistically high for future buildings that might be located at the site. Based on this discrepancy, regulatory agencies using either the ASTM implementation, or subsequent implementations, of the Johnson and Ettinger model have adopted lower values for this parameter.

- The City of Oakland Urban Land Redevelopment (ULR) program assigned a value of 0.1% to η for application to their implementation of the ASTM vapor intrusion model, based on California data presented by the American Society of Heating, Refrigerating, and Air Conditioning Engineering (Spence and Gomez, 1999).
- The USEPA has assigned default values of 0.38% for slab-on-grade houses and 0.02% for houses with basements for the current implementation of the Johnson and Ettinger model (USEPA, 2003).
- The RWQCB uses a value of 0.04% for all scenarios for current implementation of the Johnson and Ettinger model (USEPA, 2003).
- A comparison of indoor air results with soil-gas concentrations at Berkeley Lab Building 7 using the Johnson and Ettinger 1991 model suggested that 0.2% was a reasonable site specific value.

Based on this information, Berkeley Lab has adopted a value of 0.2% for η, which is between the values provided by the California-specific City of Oakland ULR program value and the USEPA value for slab-on-grade construction.

3.2.2 Regulatory-Based MCSs

The principal regulatory standards that may be pertinent to the development of MCSs at Berkeley Lab are provided in **Table 3.2.2-1**. These standards contain specific numerical requirements for allowable chemical concentrations in the affected environmental media (groundwater and soil) at Berkeley Lab.

Table 3.2.2-1. Regulatory Standards Potentially Pertinent to MCSs at Berkeley Lab

Standard	Description
Federal	
Safe Drinking Water Act (CFR40.141)	Sets Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs) for drinking water.
Toxic Substance Control Act - PCB (40 CFR Part 761)	Sets cleanup requirements for PCBs.
State	
California Safe Drinking Water Act (CCR Title 22, Division 4, Chapter 15)	Sets California Maximum Contaminant Levels (MCLs) for drinking water.
Porter-Cologne Water Quality Control Act (California Water Code, Division 7)	Adopts Water Quality Control Plans (San Francisco Bay Basin Plan) that establish beneficial uses of state waters and sets water quality objectives for those uses.

The regulatory agencies that implement the laws and regulations commonly adopt policies that guide their applicability and implementation. Potentially applicable policies that have been adopted by the SWRCB, the agency created by the Porter-Cologne Water Quality Control Act include:

- Resolution 68-16 “Statement of Policy with Respect to Maintaining the High Quality of Waters in California” (non-degradation policy) requires that for waters for which water quality objectives are set by Basin Plans or the Porter-Cologne Water Quality Control Act, existing water quality must be maintained. This resolution implies that non-detect or background levels must be maintained except in specific circumstances.
- Resolution 88-63, “Sources of Drinking Water Policy,” specifies that, except under specifically detailed circumstances, all surface waters and groundwaters are to be protected as existing or potential sources of municipal and domestic supply.
- Resolution 92-49, “Policies and Procedures for Investigation and Cleanup Abatement of Discharges under Water Code 13304”, requires regional boards to meet the highest levels reasonably obtainable, where, at a minimum, water quality objectives established in the Basin Plans must be met. However, it does permit specification of case-by-case cleanup levels where restoration of background levels is not a reasonable objective.

In addition, the RWQCB has prepared the technical document “Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater” (RWQCB, 2003). The document presents “conservative” Environmental Screening Levels (ESLs), which were developed to address environmental protection goals presented in the Water Quality Control Plan for the San Francisco Bay Basin (RWQCB, 1995). The ESLs are based largely on risk assessment modeling, similar to that presented in the Berkeley Lab HHRA, and modeling of soil concentrations that might impact groundwater as a potential drinking water source.

The California RWQCB San Francisco Bay Region’s Water Quality Control Plan (Basin Plan) (RWQCB, 1995) establishes beneficial uses and water quality objectives (WQOs) for groundwater and surface water in the San Francisco Bay region. The Basin Plan identifies existing beneficial uses of East Bay Plain groundwater as: Municipal and Domestic water supply; Industrial Process water supply; Industrial Service water supply, Agricultural water supply; and possibly Freshwater replenishment supply. Although Berkeley Lab is not in the East Bay Plain, some groundwater beneath Berkeley Lab may be a source of recharge for the East Bay Plain basin, so these beneficial uses may be pertinent to Berkeley Lab groundwater.

However, according to the RWQCB's review of General Plans for several East Bay cities, including Oakland and Berkeley, there are no plans to develop local groundwater resources for drinking water purposes, because of existing or potential salt-water intrusion, contamination, or poor or limited quantity (RWQCB, 1999).

SWRCB Resolution No. 88-63 specifies that all groundwaters of the State are considered suitable, or potentially suitable, for municipal or domestic water supply, with the following exceptions: 1) the water source does not provide sufficient water to supply a well capable of producing an average sustained yield of 200 gpd, 2) total dissolved solids (TDS) exceed 3,000 mg/L, or 3) contamination that cannot reasonably be treated for domestic use by either Best Management Practices or best economically achievable treatment practices.

Although groundwater is not used for drinking water or other beneficial uses at Berkeley Lab and is not used for drinking water downgradient in the City of Berkeley or at UC Berkeley, potential beneficial uses of groundwater at Berkeley Lab would include domestic supply, except for those areas where the specific exceptions to SWRCB Resolution 88-63 apply. Under the Basin Plan, cleanup levels "for groundwaters with a beneficial use of municipal and domestic supply are set no higher than Maximum Contaminant Levels (MCLs) or secondary MCLs"…"whichever is more restrictive; or a more stringent level based on a site-specific risk assessment." In areas of Berkeley Lab where the well yield is greater than 200 gpd, and TDS concentrations are less than 3,000 mg/L, MCLs are the regulatory-based MCSs for groundwater COCs, providing that they are achievable through Best Management Practices or best economically achievable treatment practices. Most of Berkeley Lab is underlain by fine-grained, low permeability sedimentary rocks in which groundwater well yields are substantially lower than 200 gpd, although a few areas where undulations in the upper surface of these strata are filled with permeable volcanic rocks or surficial materials (colluvium and artificial fill) have wells where yields can exceed 200 gpd. In Section 2.2 and Section 4, figures are included showing the areas where the groundwater does not provide sufficient water to supply individual wells capable of producing an average sustained yield of 200 gpd.

As noted by RWQCB, "groundwater conditions directly underlying specific areas may limit potential use as a municipal or domestic drinking water supply" (**Appendix J**). Therefore for those areas of groundwater contamination where well yields are less than 200 gpd, risk-based levels are considered applicable and are proposed as MCSs, at least for the short term. However, it is acknowledged that the RWQCB designates all groundwater potentially suitable for municipal or domestic supply unless it has been formally de-designated. Therefore, the long-term goal for these areas would be to restore groundwater quality to the maximum beneficial use (MCLs), if practicable. Once the short-term goal is achieved, the long-term approach would be natural degradation within the framework of a long-term monitoring program to document the status of natural degradation and that migration of contaminated groundwater is under control. It is not possible to specify with a high level of confidence the timeframe when MCLs would be achieved in areas where the well yield is less than 200 gpd. Based on the very low rates of attenuation observed, it will likely take at least several decades to achieve MCLs in most of these areas. In the interim, groundwater will be monitored to document the status of natural degradation and assure that migration of contaminated groundwater is under control. Regulatory-based MCSs (MCLs) will not apply in those areas with insufficient well yield to be considered a potential drinking water source.

3.2.3 Regulatory-Based Compliance Levels

In addition to MCSs, a compliance level of non-detect was set for areas of groundwater and surface water that are not currently contaminated, but could potentially be impacted by migration of COCs. This compliance level addresses the SWRCB non-degradation policy under the Porter-Cologne Water Quality Control Act. In addition, the HHRA and ERA assumed that pathways from surface water to human and ecological receptors would remain incomplete, based on continued capture prior to the discharge of contaminated groundwater to surface water.

3.2.4 Costs Associated with MCS Levels and Compliance Levels

Cost estimates to achieve both risk-based cleanup levels and cleanup levels based on protection of potential future drinking-water sources are provided in Section 6.

3.3 DEMONSTRATION OF COMPLIANCE WITH MEDIA CLEANUP STANDARDS

Points of compliance are the site-specific locations at which the concentrations of individual COCs are measured and MCSs must be achieved. Points of compliance are established in each environmental media requiring remediation.

Groundwater

For groundwater, MCSs should be achieved throughout the area of contamination. This is referred to as throughout-the-plume/unit point of compliance (POC) for groundwater. Locations for demonstrating compliance with groundwater MCSs will consist of representative wells in the existing Berkeley Lab groundwater monitoring network. These wells will be located both in the area where groundwater MCSs are exceeded, and downgradient from those areas to monitor for downgradient plume migration. Some of these wells have been used to monitor the performance of ICMs or pilot tests, and will continue to monitor the performance of these systems if selected as a final remedy. New monitoring wells may be installed if required to monitor the performance of additional corrective measures that are implemented.

Groundwater monitoring at Berkeley Lab is currently based on a schedule (Berkeley Lab, 2001) that was approved by the RWQCB in 2002 (RWQCB, 2002). A revised monitoring schedule will be submitted to the RWQCB that establishes the requirements for compliance monitoring. Some wells that were installed for initial characterization purposes are now considered to be superfluous for monitoring compliance with MCSs or remedial system performance, and are recommended for abandonment. In addition, it is expected that the number of wells required for compliance monitoring and the required frequency of monitoring will decrease over time as more groundwater remediation progresses and the area where MCSs are exceeded becomes smaller. Groundwater monitoring wells that are considered superfluous will be identified as such in the Groundwater Monitoring and Management Plan or in other documentation submitted to the Water Board, and will be properly destroyed after receiving Water Board approval. Revised monitoring schedule requests will be periodically submitted to the RWQCB for approval.

When the concentrations of COCs in all compliance wells at a groundwater unit are lower than MCSs averaged over four consecutive quarters of monitoring, the corrective measure will be considered complete for that unit.

Soil

Compliance with MCSs at soil units will generally be demonstrated by collecting post-remediation samples representative of residual contamination. Prior to implementing a corrective measure at each soil unit, a workplan will be submitted to the DTSC that will include the requirements for collecting confirmation samples. The requirements will specify sampling locations for soil treated in place or provide the number of samples required per square foot of excavation wall and floor. For PCB remediation waste, a sampling grid of 1.5 meters, with a minimum of three sampling points is required (40 CFR §761.283). A smaller square grid interval can be used when the PCB-cleanup site is sufficiently small or irregularly shaped. For soils that are contaminated with VOCs, a larger-size sampling grid may be specified, with a minimum of one floor sample and one sample for each wall of excavation.

To demonstrate that remedial objectives have been attained, the MCSs will be compared to representative site chemical concentrations to which human receptors may be exposed (exposure point concentrations [EPCs]). In accordance with USEPA guidance (USEPA, 1989), the EPCs will be set for soil at the 95-percent upper confidence limit (UCL) on the arithmetic mean of the sample concentrations, unless the sample size is less than eight ($N < 8$) or the percentage of non-detect values is greater than 80%. In those cases where there are insufficient soil data to calculate a reliable UCL, the maximum concentration will be used. When MCSs are attained at the confirmation soil sampling locations, the corrective measure will be considered complete for that unit.

3.4 TECHNICAL IMPRACTICABILITY

Remediation of contaminated media to the prescribed MCS can in certain situations be technically impracticable from an engineering perspective. Technical impracticability (TI) for contaminated groundwater refers to a situation where achieving groundwater cleanup levels associated with final cleanup goals is not practicable from an engineering perspective (USEPA, 2001). The term engineering perspective refers to factors such as feasibility, reliability, scale or magnitude of a project, and safety.

The USEPA has noted that permanent reduction of VOC concentrations in groundwater below certain levels (e.g., to MCLs) cannot be achieved at many sites using currently available technology (USEPA, 2001). Currently, groundwater underlying approximately 3% of the total area of Berkeley Lab site exceeds MCLs, as illustrated on **Figure 2.2-1**. Reasons for the technical impracticability of groundwater cleanups are generally the result of hydrogeologic and/or contaminant-related factors, such as very low permeability soils and/or the presence of residual dense non-aqueous phase liquids (DNAPLs) (USEPA, 2001).

Low permeability rock and soil containing DNAPL or very high levels of dissolved VOCs are present at several of the Berkeley Lab groundwater units. These conditions limit the effectiveness of remedial technologies in attaining MCSs. The impact of these conditions is further compounded by geologic characteristics such as multiple layers, heterogeneities, and fractured rock, which are present over most of the site. In areas where DNAPL is present it constitutes a continuing source of dissolution of COCs into the groundwater that decreases the effectiveness of dissolved phase cleanup actions. The presence of low permeability rock and soil in the saturated zone results in very low rates of advection (flow) of contaminated groundwater, so that contaminant migration mechanisms may be dominated by diffusion (the movement of molecules from zones of high concentration to zones of low concentration due to the random motion of molecules and ions). Diffusion of contaminants is a relatively slow process that can limit the ability to achieve MCSs, and impact adjacent areas for many years. The inability to deliver treatment reagents or transport media (e.g., water) in low permeability soils is an additional factor that can prevent remedial technologies from being effective.

The time required to achieve MCSs in areas of low permeability rock and soil containing DNAPL or very high levels of dissolved VOCs is difficult to accurately estimate. This is because diffusion rates are difficult to estimate, and because cleanup rates also depend upon unknown factors such as the mass of contaminant released and the length of time the contaminant has been present in the subsurface. In addition, cleanup actions may result in contaminant removal rates that tail off (reach asymptotic levels) at concentrations that may be significantly above MCSs.

Based on the evaluation of site-specific factors contributing to TI provided above, it is likely that MCSs, particularly the regulatory-based MCSs (i.e., MCLs), will not be achievable at all groundwater units. The areas subject to corrective measures can generally be divided into the following three categories, based on potential to achieve MCSs:

1) Areas where MCSs are unlikely to be attained. These areas are characterized by low permeability rock and soil where DNAPL and/or very high levels of dissolved VOCs are present and excavation is not a feasible alternative (e.g., areas at or adjacent to the source zone of the Building 7 lobe of the Old Town Groundwater Solvent Plume).
2) Areas where attaining MCSs is likely. These areas fall into two subcategories:
    a) Areas with relatively high permeability rock and soil containing low to moderate concentrations of dissolved phase VOCs (e.g., the Building 52 lobe of the Old Town Groundwater Solvent Plume); and,
    b) Areas with relatively low permeability rock and soil containing low concentrations of dissolved phase VOCs (not significantly exceed MCSs) that are amenable to natural degradation processes (e.g., the Building 69A Area of Groundwater Contamination).
3) Areas where the ability to attain MCSs is uncertain. These areas are generally characterized by low permeability rock or soil, the absence of DNAPL, and moderate to high groundwater contaminant concentrations (e.g., much of the Building 7 lobe of the Old Town Groundwater Solvent Plume).

Whether MCSs will be attained at a groundwater unit cannot be determined until sufficient data have been collected to determine contaminant reduction rates resulting from the implemented corrective measures, and how those rates change over time. The effectiveness of the implemented remedial technologies in achieving the required MCSs will therefore be evaluated in 2011 after five years of operation, or when sufficient data have been collected to support a Determination of TI. A Determination of TI requires approval of the DTSC If the reviews show that groundwater concentrations are approaching an asymptotic level above the specified MCS (regulatory-based or target risk-based) and the mass of groundwater COCs being removed is not significant, then a Determination of TI will be requested from the DTSC. Each TI request will include the following components:

1. The specific groundwater MCSs, consistent with the groundwater use designations that are considered technically impracticable to achieve.
2. The area over which the TI decision will apply.
3. A conceptual model that describes the geology; hydrogeology; contamination sources, properties, and distribution; fate and transport processes; and current and potential receptors.
4. An evaluation of the restoration potential of the site, including data that support the conclusion that attainment of MCSs is technically impracticable from an engineering perspective.
5. Estimates of the cost of existing or proposed corrective measures.
6. A demonstration that no other corrective measures alternative would achieve the MCSs.
7. A proposed alternative remedial strategy protective of human health and the environment. The alternative remedial strategy would be considered protective of human health and the environment if the following criteria are met:
    - Concentrations of COCs are less than upper-limit risk-based MCSs or institutional controls are in place to block the exposure pathways of potential concern.
    - Institutional controls prohibiting future domestic use of groundwater are implemented for those areas where groundwater is a potential source of domestic supply.
    - If any remaining sources of contamination are still present, they are removed to the extent practicable.
    - The areal extent of the groundwater contamination is stable or decreasing.

3.5 SELECTION AND EVALUATION OF CORRECTIVE MEASURES ALTERNATIVES

3.5.1 Introduction

Corrective measures alternatives are intended to mitigate potential exposure to, control migration of, and/or remediate the COCs. A step-wise process was used to select and evaluate corrective measures alternatives for implementation at Berkeley Lab. The principal steps of the process were:

1. Identification of corrective measures alternatives that may be potentially applicable to specific classes of chemicals of concern (i.e., halogenated VOCs or PCBs) in the soil and groundwater at Berkeley Lab.
2. Preliminary screening of the potentially applicable alternatives, to reduce the large number of available technologies to a manageable number for more detailed evaluation

3. Evaluation of each corrective measures alternative using defined standards and selection factors
4. Recommendation of corrective measures for implementation.

3.5.2 Identification of Potentially Applicable Corrective Measures Alternatives

Corrective measures alternatives potentially applicable to each class of COCs chemicals-of-concern (solvent-related VOCs or PCBs) at Berkeley Lab were identified. For PCBs, potentially applicable remedial alternatives were developed primarily from USEPA guidance (USEPA, 1993a). For VOCs, the potentially applicable remedial alternatives were developed primarily from the Treatment Technologies Screening Matrix provided in the Federal Remediation Technologies Roundtable (FRTR) Remediation Technologies Screening Matrix and Reference Guide (http://www.frtr.gov/matrix2/section3/table3_2.html). In addition no action was included for both classes of COCs as a baseline for comparison.

The identified alternatives were classified into the following general corrective measure categories for both soils and groundwater:

- No Action
- Risk and Hazard Management
- Monitored Natural Attenuation
- Containment and Hydraulic Control
- Active Treatment/Disposal.

No Action

The no-action alternative includes no active remediation of COCs, but provides a basis for comparison with the other remedial alternatives. All previously implemented ICMs would be terminated, and no additional measures would be implemented except for institutional controls. Natural attenuation processes such as biodegradation, dispersion, adsorption, dilution, and volatilization would still occur; however, there would be no means to document the effectiveness of natural attenuation. The no-action alternative may be justified in some cases, especially where implementing a corrective measure will result in no significant reduction of risk to human health and the environment.

Risk and Hazard Management

Institutional controls are non-engineered instruments that help minimize the potential for human exposure to contamination and/or protect the integrity of a remedy by limiting land or resource (e.g., groundwater) use. They include administrative or legal controls, physical barriers or markers, and methods to preserve information and data and inform current and future workers of hazards and risks. Also included are operational safety requirements implemented to ensure worker safety and the proper handling of hazardous materials during remedial activities. Institutional controls are generally used when remedies are ongoing and when residual contamination is present at a level that does not allow for unrestricted use after cleanup. They are intended to supplement engineering controls and are rarely the sole remedy at a site.

Affected portions of Berkeley Lab land parcels subject to restricted use would be regulated through a Land Use Covenant (LUC) between UC and the DTSC, in accordance with California Code of Regulations (CCR), Title 22, Division 4.5, Section 67391.1. The LUC would not be a site-wide control, but would be placed on the individual parcels that are subject to land use restrictions. In areas where groundwater contaminant concentrations are less than regulatory-based groundwater MCSs (MCLs), no land use restrictions would be applicable based on groundwater contamination. In areas where groundwater contaminant concentrations exceed regulatory-based groundwater MCSs (MCLs), land use restrictions would be implemented as follows:

- Extraction of groundwater for domestic, industrial, or agricultural use would be prohibited unless it was treated to the required standards for domestic use; or groundwater concentrations could be demonstrated to be below levels of concern for industrial or agricultural use.

- Development of residential facilities would be prohibited unless subsequent site-specific studies documenting that risks to residential receptors were below levels of concern were submitted to, and approved by, the DTSC.

- Institutional land use would be permitted without restriction, except for areas where groundwater or soil contaminant concentrations exceed the upper-limit risk-based MCSs (i.e., theoretical ILCR>10-4, HI>1).

For areas exceeding the upper-limit risk-based MCSs (i.e., theoretical ILCR>10^{-4}, HI>1), development of institutional facilities would be prohibited unless a mitigation and monitoring plan was developed to ensure that COC exposures contributing to risks were below levels of concern. Mitigation and monitoring plans would be submitted to DTSC for review and approval.

Berkeley Lab will prepare a Groundwater Monitoring and Management Plan and a Soil Management Plan as part of the Corrective Measures Implementation (CMI) phase of the RCRA CAP. The groundwater monitoring and management plan will include: a description of the vertical and lateral extent of groundwater contamination; a listing of specific perimeter groundwater monitoring wells that will be used to monitor potential migration beyond current plume margins; a description of specific surface water monitoring requirements; and, a description of Berkeley Lab management controls that will be used to reduce potential risks from exposures associated with contaminated groundwater. The soil management plan will include a description of Berkeley Lab management controls that will be used to reduce potential risks from exposures associated with contaminated soil.

Monitored Natural Attenuation

The natural biodegradation of organic chemicals can occur when indigenous (naturally occurring) microorganisms capable of degrading the chemicals are present and sufficient concentrations of nutrients, electron acceptors, and electron donors are available to the microorganisms. Under favorable conditions, highly chlorinated hydrocarbons such as PCE, TCE, and 1,1,1-TCA will biodegrade to less chlorinated compounds (i.e., DCE, DCA and vinyl chloride) (**Figure 3.5-1**).

Microorganisms obtain energy for growth and activity from oxidation and reduction reactions (redox reactions). Redox reactions involve the transfer of electrons to produce chemical energy. Oxidation is a reaction where electrons are lost (from an electron donor) and reduction is the reaction where electrons are gained (by an electron acceptor). During natural biodegradation, a carbon source typically serves as the primary growth substrate (food) for the microorganisms, and is the electron donor that is oxidized. The carbon source can include natural organic carbon or anthropogenic (man-made) carbon such as fuel hydrocarbons. Electron acceptors can be elements or compounds occurring in relatively oxidized states such as oxygen, nitrate, sulfate, ferric iron, and carbon dioxide.

Natural biodegradation of organic compounds causes measurable changes in groundwater geochemistry. The indicator parameters of the redox reactions, including metabolic byproducts can be measured. The following factors indicate conditions favorable for biodegradation:

- Dissolved oxygen (DO) less than 0.5 mg/L
- Nitrate less than 1.0 mg/L
- Sulfate less than 20 mg/L
- Divalent manganese and ferrous iron greater than 1 mg/L
- Low values of the Oxidation-Reduction Potential (ORP).

Monitored natural attenuation (MNA) is the stabilization and long-term shrinking of a contaminant plume by natural processes such as microbial degradation. This alternative is generally applicable only to dissolved groundwater plumes. In order to implement this alternative, the source of the contamination must first be removed and the presence and rates of natural degradation processes must be documented. Natural attenuation processes can be demonstrated through a variety of lines of evidence, including static or retreating chemical isoconcentration contours over time, changes in the ratios of parent to breakdown products, the presence of bacteria capable of degrading the COCs, and/or the presence of geochemical indicators of naturally occurring biodegradation.

The major component of MNA as a remedial alternative would be the long-term monitoring program to provide initial and continuing confirmation that the predicted biological activity and/or reductions in COC concentrations occur and remain effective. Risk and hazard management measures may be required to protect human health and the environment during the long term until overall effectiveness can be achieved.

MNA is retained as a remedial alternative where natural degradation can be currently documented. MNA is also retained as an option for future consideration at other locations after the source has been removed and monitoring data indicate that natural degradation may be occurring.

Containment and Hydraulic Control

Containment and hydraulic control measures can be used to control the mobilization and migration of contaminants. For groundwater, this category primarily includes below-ground barriers constructed to prevent further migration of contaminants, such as groundwater extraction trenches and wells, slurry walls, grout curtains, and permeable reactive barriers. These measures can also be implemented to control the migration of groundwater contaminants from source areas. Above-ground engineered covers (capping) and other containment measures (solidification and stabilization) can be used to minimize the leaching of contaminants from soil to groundwater.

Engineering controls can be used to eliminate, or reduce to acceptable levels, the potential risk to human health from processes such as COCs volatilizing from groundwater and migrating into the indoor air of new buildings. These controls could include vapor barriers or ventilation controls. Engineering controls may also be used to eliminate or reduce the potential for cross-media COC transfers or migration of COCs into less contaminated areas.

Containment and hydraulic control measures may be protective of human health and the environment; however, the time frame for contaminant reduction within the containment zone (i.e., upgradient of a below-ground barrier, or below an above-ground cover) would be significantly longer than more active remedial alternatives.

Active Treatment/Disposal

Remedial technologies consist of the direct application of methods that can be used to achieve the corrective action objective (i.e., attain the MCS) in each affected media. Instead of restricting the application of a technology to the edge of a containment zone (as in Containment and Hydraulic Controls, above), these approaches involve more active measures within the contaminant mass to ultimately provide attainment of MCSs throughout the unit. These remedial technologies are potentially applicable to both soil and groundwater media, and were selected from the following categories:

- In situ treatment
- Extraction/excavation with ex-situ treatment
- Extraction/excavation and off-site disposal.

3.5.3 Preliminary Screening of Corrective Measures Alternatives

The preliminary screening process consisted of an evaluation of the potential effectiveness and implementability of the identified corrective measures alternatives. Screening was performed for each of the categories of alternatives described in Section 3.5.2, and for subset technologies within each category, for each of the contaminant classes at Berkeley Lab. The screening was based on two general criteria: effectiveness and implementability.

- Effectiveness pertains to chemical-specific characteristics of technologies in reducing contaminant concentrations given the physical and chemical properties of detected COCs.
- Implementability pertains to site-limiting characteristics of technologies given the physical constraints of the site such as topography, building locations, underground utilities, available space, and proximity to sensitive operations and the characteristics of the affected media such as depth to groundwater and hydraulic conductivity.

Alternatives that did not pass this initial screening process were eliminated from further consideration.

3.5.4 Evaluation of Corrective Measures Alternatives

Each of the corrective measures alternatives that passed the initial screening process was then evaluated to determine whether it could meet the following four corrective action standards:

- Protects human health and the environment
- Attain MCSs
- Provides source control (if applicable)
- Complies with applicable standards for the management of waste.

Preference was given to those alternatives that could meet all four standards, or three standards where source control was not pertinent. At a minimum the alternative was required to be protective of human health and the environment and comply with applicable standards for the management of waste.

Protect Human Health and the Environment

Each corrective measures alternative was evaluated to assess whether it could effectively protect human health and the environment from unacceptable short and long-term risks either by meeting risk-based MCSs, or by eliminating exposure pathways to COCs exceeding risk-based MCSs.

Attain Media Cleanup Standards

Each corrective measures alternative was evaluated to assess whether it could potentially meet the proposed target MCSs. An alternative was assumed to meet this standard if the technology had been used effectively under analogous site conditions, and/or if the results of bench-scale testing, pilot-scale testing or ICMs indicated that the technology would be able to meet one or more of the MCSs. Both remediation of media with COCs exceeding MCSs, and prevention of COC migration into media where COCs are currently less than MCSs, were considered in evaluating this standard.

Provide Source Control

Where continuing releases from sources pose a threat to human health or the environment, source control technologies were evaluated to assess if they could provide either removal or containment of COCs that are available for dissolution into groundwater. An alternative was assumed to meet this standard if the technology had been used effectively under analogous site conditions, and/or if the results of bench-scale testing, pilot-scale testing or ICMs indicated that the technology would be effective in controlling the sources of contaminants.

Comply With Applicable Standards for Management of Wastes

Each corrective measures alternative was evaluated to determine the potential to produce manageable wastes. The regulatory standards pertinent to the management of wastes at Berkeley Lab are listed in **Table 3.5.4-1**.

Table 3.5.4-1. Regulatory Standards Pertinent to Waste Management

Standard	Description
Federal	
Resource Conservation and Recovery Act (40 CFR Parts 261 to 268)	Regulates waste treatment, storage, and disposal facilities and defines waste types.
Toxic Substance Control Act - PCB (40 CFR Part 761)	Establishes disposal options for PCB remediation wastes.
State	
CCR Title 23, Division 3, Chapter 15	Regulates water quality aspects of waste discharge to land.
CCR Title 22, Division 4.5, Chapters 11 and 12	Provides standards for the management of hazardous waste. Applies to excavated contaminated soil and spent GAC.

In addition, corrective measures for groundwater and soil may result in discharges to air and the sanitary sewer that are regulated by permit requirements. Regulations for emissions of treated soil gas from vapor treatment systems are enforced by the Bay Area Air Quality Management District (BAAQMD). Limitations for air discharges are specified in BAAQMD Regulation 8 Rule 47 (Air Stripping and Soil Vapor Extraction Operations). Regulations for the discharge of wastewater from groundwater treatment systems into the sanitary sewer are enforced by EBMUD. Berkeley Lab’s Wastewater Discharge Permit provides the daily maximum allowable concentration for discharge to the sanitary sewer.

On-site reuse options were evaluated for treated groundwater when treatment systems were initially installed. Effluent from two treatment systems was used as makeup for cooling tower water at Building 88 and Building 37. The Building 88 reuse was halted when it was determined that the water was potentially damaging to cooling tower operations (total dissolved solids concentrations were too high). Reuse at the Building 37 cooling tower has continued. Currently, and according to the remedies proposed in this report, most of the treated groundwater will be recirculated as part of implemented corrective measures to flush contaminants from the subsurface. Other on-site reuse options for extracted groundwater will be reevaluated in the future, if the water is no longer needed for recirculation.

Corrective measures alternatives that meet the four corrective action standards listed above were also evaluated against the following five corrective measures selection factors:

- Long-term effectiveness and reliability
- Reduction of toxicity, migration potential, or volume of the COCs
- Short-term effectiveness, including the near-term risks associated with implementing the corrective measure
- Implementability
- Cost.

SECTION 4

DEVELOPMENT OF CORRECTIVE MEASURES FOR VOLATILE ORGANIC COMPOUNDS (VOCs)

The principal COCs that have impacted environmental media at Berkeley Lab are halogenated non-aromatic VOCs. These chemicals are primarily solvents such as TCE and PCE, and their byproducts resulting from the natural degradation of the original solvent chemicals. Aromatic VOCs are also present in the soil and groundwater, primarily as the result of fuel leaks from underground storage tanks.

The following subsections include a discussion of the selection of proposed cleanup criteria (Section 4.1); the evaluation of “global” issues that pertain to all of the sites where VOCs are the potential concern, including screening of corrective measure technologies and development of corrective measure alternatives (Section 4.2); and the site-specific detailed evaluations of corrective measures for VOC-impacted soil and groundwater (Section 4.3). The soil and groundwater units at which VOCs are the COCs are listed in **Table 4-1**.

Table 4-1. Soil and Groundwater Units with VOCs as Chemicals of Concern

Unit
Building 51/64 Groundwater Solvent Plume
Building 51L Groundwater Solvent Plume and Source Area
Building 71 Groundwater Solvent Plume Building 71B lobe
Building 7 Lobe of the Old Town Groundwater Solvent Plume and Source Area Former Building 7 Sump
Building 52 Lobe of the Old Town Groundwater Solvent Plume
Building 25A Lobe of the Old Town Groundwater Solvent Plume
Solvents in Groundwater South of Building 76
Building 69A Area of Groundwater Contamination
Building 75/75A Area of Groundwater Contamination
Building 77 Area of Groundwater Contamination
Benzene Detected in Wells East of Building 75A

4.1 MEDIA CLEANUP STANDARDS

4.1.1 Media Cleanup Standards for Groundwater

Media cleanup standards for groundwater were developed for the following VOCs that were detected at concentrations above MCLs during Fiscal Year 2003 (FY03) (October 1, 2002 through September 30, 2003).:

- benzene
- carbon tetrachloride
- chloroform
- 1,1-dichlorethane (1,1-DCA)
- 1,2-dichloroethane (1,2-DCA)
- 1,1-dichloroethene (1,1-DCE)
- cis-1,2- dichloroethene (cis-1,2-DCE)
- trans-1,2- dichloroethene (trans-1,2-DCE)
- 1,2 dichloropropane
- methylene chloride
- 1,1,1-trichloroethane (1,1,1-TCA)
- 1,1,2-trichloroethane (1,1,2-TCA)
- tetrachloroethene (PCE)
- trichloroethene (TCE)
- vinyl chloride.

4.1.1.1 Risk-Based MCSs

The proposed risk-based MCSs for COCs in groundwater are listed in **Table 4.1.1-1**, along with the maximum COC concentrations detected in FY03. The target MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-6} or an HQ of 1, for all potential exposure pathways. The upper-limit MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-4} or an HQ of 1, for all potential exposure pathways. The only COCs that exceeded the proposed risk-based MCSs in FY03 are carbon tetrachloride, PCE, TCE, and vinyl chloride. The risk drivers for these COCs are the volatilization of groundwater COCs and subsequent migration into indoor air, where potential future indoor workers might be exposed; and for TCE only, dermal contact with groundwater by intrusive construction workers. An additional MCS is therefore provided for TCE for units where the intrusive construction worker could potentially be exposed (i.e., the depth to groundwater is less than or equal to 20 feet). The risk calculations assumed a conservative depth to groundwater of 5-feet at all locations for the inhalation pathway, and used the same default parameters as were used in the HHRA, with the exceptions described in Section 3.

Table 4.1.1-1. Proposed Risk-Based MCSs for VOCs in Groundwater

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Proposed Risk-Based MCSs	
		Target Groundwater MCS Based on Theoretical ILCR=10^{-6} and HI = 1 (µg/L)	**Upper-Limit Groundwater MCS Based on Theoretical ILCR = 10^{-4} and HI = 1 (µg/L)**
benzene	47	175	17,514
carbon tetrachloride	**4,600**	27	1,004(c)
chloroform	196	1,206	120,582(a) 38,838(b) (c)
1,1-DCA	**15,800**	3,663	366,345
1,2-DCA	75	1,030	102,956
1,1-DCE	2,210	28,873(c)	28,873(c)
cis-1,2-DCE	1,240	98,405(c)	98,405(c)
trans-1,2-DCE	469	94,405(c)	94,405(c)
1,2-dichloropropane	9.4	1,071	15,302(c)
methylene chloride	1,600	10,381	1,038,071
1,1,1-TCA	277	1,570,783 (c)	1,570,783 (c)
1,1,2-TCA	37	1,905	190,489(a) 61,026(b) (c)
PCE	**76,035**	343	25,265(c)
TCE	**79,300**	1,594	1,159,365(a) 3,065(b) (c)
Vinyl chloride	**835**	12	1,213

(a) MCS is applicable where groundwater >20 feet.

(b) MCS is applicable where groundwater ≤ 20 feet (based on potential risk to intrusive construction worker).

(c) MCS is based on HI = 1; all other MCSs based on theoretical ILCR = 10^{-4}.

Note: Boldface concentration values indicate that the maximum detected concentration of the COC in FY03 was above the proposed target risk-based MCS.

To ensure that the presence of multiple chemicals at any unit would not result in unacceptable additive risks, maximum site-wide detected concentrations of chemicals were evaluated. As shown in **Table 4.1.1-1**, maximum detected concentrations of only five COCs exceeded risk-based MCSs. The maximum detected concentrations of other COCs were well below (generally at least an order of magnitude lower than) risk-based MCSs, so these COCs do not contribute significantly to risk. If all five chemicals that are currently present at concentrations exceeding the MCS were remediated to achieve their respective target MCSs, then the theoretical ILCR would be approximately 5×10^{-6}, which is within the USEPA risk management range. This “worst case” situation is considered to be very unlikely, since not all COCs are present at every soil unit, and the relative proportions of different COCs are sufficiently different that remediation to achieve MCSs would result in concentrations of all but the primary risk-driver COC being reduced to substantially less than their risk-based MCSs. The maximum site concentration of only one COC (TCE) exceeds the risk-based MCS based on the hazard index and all other COCs for which the risk-based MCS is based on the hazard index are present at concentrations several orders of magnitude lower than their hazard index. Therefore, the additive risks for these chemicals are not significant.

4.1.1.2 Regulatory-Based MCSs

MCLs are the proposed regulatory-based MCSs for VOCs in groundwater where the groundwater is a potential source for domestic water supply (i.e., source can provide sufficient water to supply a well capable of producing 200 gpd and they are achievable through Best Management Practices or best economically achievable treatment practices). Proposed regulatory-based MCSs (MCLs) for groundwater are listed in **Table 4.1.1-2**. Also listed in the table is the maximum concentration of each COC detected in groundwater during FY03.

Table 4.1.1-2. Proposed Regulatory-Based MCSs for VOCs in Groundwater

Groundwater COC	Maximum Concentration Detected in Groundwater in FY03 (μg/L)	Proposed Regulatory-Based Groundwater MCS (MCL) (μg/L)
benzene	47	1.0
carbon tetrachloride	4,600	0.5
chloroform	196	100
1,1-DCA	15,800	5
1,2-DCA	75	0.5
1,1-DCE	2,210	6
cis-1,2-DCE	1,240	6
trans-1,2-DCE	469	10
1,2-dichloropropane	9.4	5
methylene chloride	1,600	5
1,1,1-TCA	277	200
1,1,2-TCA	37	5
PCE	76,035	5
TCE	79,300	5
vinyl chloride	835	0.5

4.1.2 Media Cleanup Standards for Soil

Media cleanup standards for soil were developed for those VOCs that the HHRA (Berkeley Lab, 2003a) concluded were present in soil at concentrations above the de minimis level (i.e., theoretical ILCR > 10^{-6} or HI > 1), and for the groundwater COCs (Section 4.1.1) that have been detected in soil at Berkeley Lab. The later criterion was included so that the soil MCSs would be set at levels that are protective of groundwater MCSs (i.e., consider the cross-media transfer of contaminants).

Following is the list of the soil COCs. Except for 1,2-dichloropropane and 1,1,2-TCA, which are only groundwater COCs, the soil and groundwater COCs are the same.

- benzene
- carbon tetrachloride
- chloroform
- 1,1-dichlorethane (1,1-DCA)
- 1,2-dichloroethane (1,2-DCA)
- 1,1-dichloroethene (1,1-DCE)

- cis-1,2- dichloroethene (cis-1,2-DCE)
- trans-1,2- dichloroethene (trans-1,2-DCE)
- methylene chloride
- 1,1,1-trichloroethane (1,1,1-TCA)
- tetrachloroethene (PCE)
- trichloroethene (TCE)
- vinyl chloride.

4.1.2.1 Risk-Based MCSs

The proposed risk-based MCSs for soil are listed in **Table 4.1.2-1**. Also listed in the table is the maximum concentration of the COC that has been detected in soil at Berkeley Lab. The target MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-6} or an HQ of 1, for all potential exposure pathways. The upper-limit MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-4} or an HQ of 1, for all potential exposure pathways. The only COCs that exceed the proposed risk-based MCSs are benzene, carbon tetrachloride, PCE, and TCE. The l exposure pathway that drives these MCSs is the volatilization of soil COCs and subsequent migration into indoor air, where potential future indoor workers might be exposed.

To ensure that the presence of multiple chemicals at any one site would not result in unacceptable additive risks, maximum concentrations of chemicals detected at the site were evaluated. As shown in **Table 4.1.2-1**, the maximum detected concentrations of only five COCs benzene, carbon tetrachloride, PCE, TCE, and vinyl chloride) exceed the target risk-based MCS. Benzene exceeds the MCS at only one unit where no other COCs are present. Therefore, only four COCs are present at any one unit at concentrations that potentially contribute to risks at the unit. For COCs that are present at concentrations less than the risk-based target MCSs, the total of the theoretical ILCRs associated with the maximum concentrations is less than 1.4 x 10-6. In the unlikely event that all four chemicals that are currently present at concentrations exceeding the MCS were remediated to achieve their respective MCSs, the other COCs remained at their current concentrations, and maximum concentrations of all COCs were present at one location, the theoretical ILCR would therefore be less than 5.4 x 10-6, which is within the USEPA risk management range. This “worst case” situation is considered to be very unlikely, since not all COCs are present at every soil unit, and the relative proportions of different COCs are

Table 4.1.2-1. Proposed Risk-Based MCSs for VOCs in Soil

Soil COC	Maximum Concentration Detected in Soil (mg/kg)	Proposed Risk-Based MCS	
		Target Soil MCS Based on Theoretical ILCR=10^{-6} and HI = 1 (mg/kg)	Upper Limit Soil MCS Based on Theoretical ILCR = 10^{-4} and HI = 1 (mg/kg)
benzene	**1.2**	0.1	6(a)
carbon tetrachloride	**10**	0.05	1.8(a)
chloroform	0.092	0.28(a)	0.28(a)
1,1-DCA	0.8	1.3	127
1,2-DCA	0.029	0.23	9(a)
1,1-DCE	0.17	8(a)	8(a)
cis-1,2-DCE	3.1	38(a)	38(a)
trans-1,2-DCE	0.45	50(a)	50(a)
methylene chloride	0.3	1.8	184
1,1,1-TCA	11	690(a)	690(a)
PCE	**3,000**	0.45	45
TCE	**60**	2.3	225
Vinyl chloride	**0.016**	0.0035	0.35

Note: Boldface numbers indicate maximum soil concentrations that are above the proposed target risk-based soil MCS.
(a): Denotes MCS based on HI=1. All other MCSs are based on theoretical ILCR.

sufficiently different that remediation to achieve MCSs would result in concentrations of all but the primary risk-driver COC being reduced to substantially less than their risk-based MCSs. Similarly, the risk-based MCS is based on the HQ for only five COCs. Maximum site-wide concentrations of these five COCs are all less than 10% of the MCS with the exception of chloroform, which is present at a concentration of approximately 33% of the MCS. Therefore, additive risks for these chemicals would not result in an HI (sum of HQs) greater than 1.0, and are therefore insignificant.

Remediation of soil to concentrations below risk-based MCSs could be necessary in some cases, in order to meet risk-based groundwater MCSs. This would be the case where residual soil contamination is present at concentrations that are below risk-based MCSs, but could dissolve into groundwater at concentrations exceeding risk-based groundwater MCSs. In order to determine if this criteria is applicable to developing MCSs for soil, Berkeley Lab calculated the COC soil concentrations that could result in groundwater concentrations at the risk-based MCS level, according to USEPA soil screening guidance (USEPA, 1996b). The linear soil/water partitioning equation for saturated soil yields the soil COC concentrations (C_t) in equilibrium with its concentration in groundwater at the risk-based levels. The calculated C_t soil concentrations are listed in **Table 4.1.2-2** for each soil COC together with the corresponding risk-based MCSs for soil from **Table 4.1.2-1**. The equilibrium values of C_t are approximately one order of magnitude or more greater than the risk-based soil MCSs, and were therefore not considered any further for setting proposed soil MCSs.

Table 4.1.2-2. Estimated Soil Concentrations in Equilibrium with Risk-Based MCSs for Groundwater

Soil COC	Target Risk-Based Soil MCS[(a)] (mg/kg)	Soil Concentration (C_t) in Equilibrium with Risk-Based Groundwater MCS (mg/kg)
benzene	0.1	1.2
carbon tetrachloride	0.05	0.34
chloroform	0.28	7.2
1,1-DCA	1.3	20.5
1,2-DCA	0.23	5.0
1,1-DCE	8	201
cis-1,2-DCE	38	571
trans-1,2-DCE	50	628
methylene chloride	1.8	47.8
1,1,1-TCA	690	14,922
PCE	0.45	4.1
TCE	2.3	19.9
Vinyl chloride	0.0035	0.06

(a) Proposed risk based soil MCS from Table 4.1.2-1.

4.1.2.2 Regulatory-Based MCSs

Remediation of soil to concentrations below risk-based MCSs may be necessary in some cases, in order to meet regulatory-based groundwater MCSs. This would be the case where residual soil contamination is present at concentrations that are below risk-based MCSs, but could dissolve into groundwater at concentrations exceeding regulatory-based groundwater MCSs (MCLs). In order to determine if this criteria is applicable to developing MCSs for soil at Berkeley Lab, Berkeley Lab considered the guidance provided by the RWQCB in their technical document "Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater" (RWQCB, 2003). The document provides "conservative Environmental Screening Levels for over 100 chemicals commonly found at sites with contaminated soil and groundwater." The ESLs include a component that considers soil screening levels for groundwater protection. This component of the ESL soil screening levels addresses potential leaching of chemicals from vadose zone soils and subsequent impact on groundwater and were back calculated based on target groundwater screening levels (i.e., California Primary MCLs where available), and was adopted as the regulatory-based MCS for soil.

The soil screening levels for the protection of groundwater are listed in **Table 4.1.2-3**. Also listed in the table are the target risk-based soil MCSs from **Table 4.1.2-1**. The target risk-based soil MCSs are greater than the proposed regulatory-based soil MCSs for all COCs except for chloroform, carbon tetrachloride, PCE, and vinyl chloride. The soil screening levels are potentially applicable MCSs where the groundwater is a potential source for domestic water supply (i.e., source can provide sufficient water to supply a well capable of producing 200 gpd and they are achievable through Best Management Practices or best economically achievable treatment practices). In those areas, the lesser of the risk-based soil MCS or the soil screening level would be the applicable.

Table 4.1.2-3. Proposed Soil MCSs that are Protective of Regulatory-Based MCSs for Groundwater

Soil COC	Proposed Regulatory-Based Soil MCS for Protection of Beneficial Use of Groundwater[(a)] (mg/kg)	Target Risk-Based Soil MCS[(b)] (mg/kg)
benzene	**0.044**	0.1
carbon tetrachloride	0.11	0.05
chloroform	2.9	0.28
1,1-DCA	**0.2**	1.3
1,2-DCA	**0.0045**	0.23
1,1-DCE	**1.0**	8
cis-1,2-DCE	**0.19**	38
trans-1,2-DCE	**0.67**	50
methylene chloride	**0.077**	1.8
1,1,1-TCA	**7.8**	690
PCE	0.7	0.45
TCE	**0.46**	2.3
vinyl chloride	0.085	0.0035

(a) Soil screening level from RWQCB (2003).

(b) Target risk based soil MCS from Table 4.1.2-2.

Note: Boldface numbers indicate that regulatory based (protection of groundwater) soil MCS is less than the target risk-based soil MCS.

4.1.3 Summary of Media Cleanup Standards for VOCs

Groundwater

Two criteria were considered when developing MCSs for groundwater: potential risk to human health and the impact to the beneficial use of groundwater for domestic supply. The proposed target risk-based MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-6} or an HQ of 1, and are applicable in all areas of Berkeley Lab. The regulatory-based MCSs (MCLs) are based on potential future domestic use, and are applicable to the areas where groundwater constitutes a potential drinking water source based on SWRCB criteria (i.e., well yield is ≥ 200 gallons per day). Since MCLs are less than the risk-based MCSs for all COCs, the risk-based MCSs will apply only in those areas where groundwater is not considered a potential drinking water source. Proposed target MCSs for groundwater and the applicability of the MCSs are listed in **Table 4.1.3-1**.

As discussed in Section 3.4, it is likely that achievement of regulatory-based MCSs (MCLs) will be technically impracticable in many of the areas of groundwater contamination using currently available technology. The effectiveness of the implemented remedial systems in achieving the required MCSs will therefore be reviewed after five years of operation (in 2011). If at that time groundwater concentrations are approaching an asymptotic level above MCLs and the mass of groundwater contaminants that is being removed is not significant, a Determination of Technical Impracticability (TI) will be requested from the DTSC. If the Determination of TI is approved, the regulatory based MCSs will be replaced with the established risked-based MCSs, and the following actions will be implemented.

- Any remaining sources of contamination will be removed or contained
- A monitoring program will be established to demonstrate that containment of groundwater contamination is being maintained.

Soil

Two criteria were considered when developing MCSs for soil: potential risk to human health from the soil pathway and the cross-media transfer of soil COCs to groundwater at concentrations that could result in groundwater MCSs being exceeded. Risk-based soil MCSs are the lowest concentrations of each COC that would result in a theoretical ILCR of 10^{-6} or an HQ of 1, either through direct soil pathways or cross-media transfer, and are applicable in all areas of Berkeley Lab. Regulatory-based soil MCSs were developed based the potential to impact groundwater above regulatory-based MCSs (MCLs), and are applicable to areas where groundwater constitutes a potential drinking water source based on SWRCB criteria (i.e., well yield is ≥ 200 gallons per day). In those areas where groundwater is considered a potential drinking water source, the lesser of the risk-based soil concentration or regulatory-based soil concentration is proposed as the MCS. Proposed target MCSs for soil and the applicability of the MCSs are listed in **Table 4.1.3-1**. **Figure I-9** (**Appendix I**) shows areas where soil COC concentrations exceed the soil MCSs.

Table 4.1.3-1. Summary of Proposed Media Cleanup Standards (MCSs) for Groundwater and Soil

	Groundwater		**Soil**	
	Target Risk-Based Groundwater MCS (µg/L)	**Regulatory-Based Groundwater MCS (MCLs) (µg/L)**	**Target Risk-Based Soil MCS (mg/kg)**	**Regulatory-Based Soil MCS (a) (mg/kg)**
Applicability	Well yield is < 200 gpd	Well yield ≥ 200 gpd	Soil overlying areas where well yield is < 200 gpd	Soil overlying areas where well yield ≥ 200 gpd
COC				
benzene	175	1	0.1	0.044
carbon tetrachloride	27	0.5	0.05	0.05*
chloroform	1,206	100	0.28	0.28*
1,1-DCA	3,663	5	1.3	0.2
1,2-DCA	1,030	0.5	0.23	0.0045
1,1-DCE	28,873	6	8	1.0
cis-1,2-DCE	98,405	6	38	0.19
trans-1,2-DCE	94,405	10	50	0.67
1,2-dichloropropane	1,071	5	NA	NA
methylene chloride	10,381	5	1.8	0.077
1,1,1-TCA	1,570,783	200	690	7.8
1,1,2-TCA	1,905	5	NA	NA
PCE	343	5	0.45	0.45*
TCE	1,594	5	2.3	0.46
vinyl chloride	12	0.5	0.0035	0.0035*

(a) The lesser of the risk-based or regulatory based MCS. * indicates MCS is risk based; all other MCSs for soil in areas where well yield is ≥ 200 gpd are regulatory based.

NA: MCS is not applicable. Chemical is not a soil COC.

4.2 SELECTION AND EVALUATION OF CORRECTIVE MEASURES ALTERNATIVES FOR VOCs IN SOIL AND GROUNDWATER

4.2.1 Subdivision of Groundwater Units into Zones

For the purpose of selecting the appropriate corrective measures alternatives for VOCs, some of the Berkeley Lab groundwater units were divided into distinct zones. Different remedial strategies may be applicable to each defined zone in the same groundwater unit because of the relative concentrations and different phases of halogenated VOCs present.

- The plume source zone contains DNAPL and/or relatively high concentrations of COCs in the soil that constitute a continuing source of groundwater contamination.
- The plume core zone contains COCs in the groundwater at concentrations greater than risk-based MCSs, but data do not indicate the presence of DNAPL.
- The plume periphery zone contains COCs in the groundwater at concentrations below risk-based MCSs, but greater than regulatory-based MCSs [e.g., MCLs]).

The plume source zone is defined as the area that contains DNAPL and/or concentrations of VOCs in vadose zone soils that exceed the RWQCB soil screening levels for groundwater protection (RWQCB, 2003). Dissolved concentrations of groundwater COCs in the source zone are largely controlled by the balance between the original contaminant concentration in soil matrices, the continued dissolution of COCs into groundwater, and the removal of COCs by flushing of upgradient groundwater (or for existing systems, the flushing of injected water through the saturated zone). For some of the Berkeley Lab units, the source zone is no longer present due to low initial contaminant concentrations and/or the natural attenuation of residual soil contamination and DNAPL.

The plume core zone is defined as the area of the plume where dissolved concentrations of COCs in groundwater exceed risk-based MCSs, the analytical data do not indicate the presence of DNAPLs, and concentrations of VOCs in vadose zone soils do not exceed the RWQCB soil screening levels for groundwater protection (RWQCB, 2003). Dissolved concentrations of COCs in groundwater in the core zone are largely controlled by migration of contaminated groundwater from the upgradient source zone, if present, and the equilibrium partitioning of COCs between the groundwater and soil. Residual soil concentrations are largely controlled by the equilibrium partitioning of COCs between the groundwater and soil.

The plume periphery is the area of the plume with COC concentrations that are less than risk-based MCSs, but greater than regulatory-based MCSs (i.e., MCLs). Dissolved concentrations of COCs in groundwater in the periphery zone are largely controlled by migration of contaminated groundwater from the source and core zones, if present, and the equilibrium partitioning of COCs between the groundwater and soil. Any reductions in groundwater COC concentrations in the plume periphery would be ineffective unless 1) there is no core or source zone present, 2) concentrations in the core and source zones are first significantly reduced, or 3) hydraulic controls are installed to isolate the plume periphery zone. Cleanup of a plume periphery zone is therefore considered a lower priority than cleanup of the core or source zone, if present. However, as discussed in Section 3, a Corrective Action Objective is to contain contaminated groundwater, so that it does not degrade water quality in adjacent areas. Therefore, existing controls on the migration of groundwater from the plume periphery zone should be maintained to prevent the degradation of groundwater quality in adjacent areas.

Table 4.2.1-1 indicates which of the three zones is present at each of the groundwater units.

Table 4.2.1-1. Source Zone, Core Zone, and Periphery Zones at Groundwater Units

Unit	Plume Source Zone	Plume Core	Plume Periphery
Building 51/64 Groundwater Solvent Plume		√	√
Building 51L Groundwater Solvent Plume	√	√	√
Building 71 Groundwater Solvent Plume Building 71B lobe	√	√	√
Building 7 lobe of the Old Town Groundwater Solvent Plume	√	√	√
Building 52 lobe of the Old Town Groundwater Solvent Plume			√
Building 25A lobe of the Old Town Groundwater Solvent Plume		√	√
Solvents in Groundwater South of Building 76			√
Support Services Area (Building 69A Area)			√
Support Services Area (Building 75/75A Area)			√
Support Services Area (Building 77 Area)			
Benzene Detected in Wells East of Building 75A			√

4.2.2 Identification of the Presence of DNAPL

The ability of a corrective measure to effectively remediate contaminated groundwater is a function of a number of variables, one of the most important of which is whether DNAPLs are present. Therefore, it is important to identify where DNAPLs may be present, and, if possible, delineate their extent. Most DNAPL detection methods are subject to “false negatives” (i.e., lack of detection does not indicate absence of DNAPLs), particularly because DNAPL tends to migrate and collect along thin, irregular heterogeneities. In the absence of reliable detection methods, USEPA specifies use of various “rules of thumb” to assess whether DNAPLs are likely to be present (USEPA, 1992). Two of these “rules of thumb” applicable to Berkeley Lab are discussed below.

4.2.2.1 Method 1 -- Comparison of Soil Concentrations with Soil Saturation Concentrations

DNAPL can be presumed to be present in a soil sample when the concentration of a constituent in soil exceeds its soil saturation concentration (sat). The USEPA PRG table lists a default soil saturation concentration value of 230 mg/kg for PCE in vadose-zone soil based on the equation:

$$\text{sat (mg/kg)} = C_{w,sol} / \rho_b \left(\rho_b K_d + \theta_w + H' \theta_a \right)$$

where:

ρ_b = bulk density (dry mass of soil/volume of soil [kg/m^3]) (assumed value 1.5)
K_d = $K_{oc} f_{oc}$ = solid/aqueous partition coefficient (m^3/kg);
Where: K_{oc} = organic carbon/aqueous partition coefficient (m^3/kg); 160 cm^3/g
f_{oc} = mass fraction of organic carbon in soil (assumed value 0.006)
$C_{w,sol}$ = solubility limit of a particular chemical (mg/L)
θ_w = water-filled porosity
H' = Henry’s Law constant
θ_a = air-filled porosity.

Based on analyses of soil samples at Berkeley Lab, the mass fraction of organic carbon (f_{oc}) averages approximately 0.0025 and the bulk density is approximately 1.6 or greater. In addition, soils with elevated COC concentrations are primarily present in the saturated zone. For saturated soil, the above equation can be simplified to

$$\text{sat (mg/kg)} = (n + \rho_b K_d)\, C_{w,sol}, \quad \text{where } n = \text{porosity}$$

Using the site-specific values noted above, and assuming a porosity of 0.25, the soil saturation concentration for PCE in saturated soil would be 178 mg/kg, only slightly less than the default value provided in the PRG table. The estimated soil saturation concentrations for soil COCs are listed in **Table 4.2.2-1**, together with the maximum concentrations detected at the units discussed in this report:

Table 4.2.2-1 Soil Saturation Concentrations for Soil COCs

Soil COC	Maximum Concentration Detected (mg/kg)	Default USEPA Soil Saturation Concentration (mg/kg)	Estimated Berkeley Lab Soil Saturation Concentration (mg/kg)
benzene	1.2	1,100	735
carbon tetrachloride	10	1,100	735
chloroform	0.092	2,900	3,239
1,1-DCA	0.8	1,700	1,927
1,2-DCA	0.029	1,800	2,703
1,1-DCE	0.17	1,500	1,118
cis-1,2-DCE	3.1	1,200	1379
trans-1,2-DCE	0.45	3,100	2,911
methylene chloride	0.3	2,500	3,874
1,1,1-TCA	11	1,200	897
PCE	**3,071**	230	178
TCE	60	1,300	1,023
vinyl chloride	0.016	1,200	913

Note: Boldface number indicates concentration greater than soil saturation concentration.

Only one COC (PCE) has been detected at a concentration above the soil saturation concentration. The concentration exceeds this level only in the source area of the Building 7 Lobe of the Old Town Groundwater Plume, so only this area might have DNAPL present according to this criterion.

4.2.2.2 Method 2 -- Effective Volubility of Constituents in Groundwater

The USEPA (USEPA, 1992) recommends assessing the potential presence of DNAPLs by determining whether concentrations in groundwater exceed 1% of either the pure-phase volubility or the effective volubility (the theoretical upper-level dissolved-phase concentration of a constituent in ground water in equilibrium with a mixed DNAPL). Where multi-component mixtures are present, USEPA recommends that effective volubility (the solubility multiplied by the mole fraction) be calculated based on the mole fraction of each component in the DNAPL. However, insufficient data are available to allow accurate estimation of mole fractions in potential DNAPLs. Therefore, the potential presence of DNAPL is estimated by comparing the pure-phase volubility (equivalent to the solubility) of COCs with their measured groundwater concentrations. This simplification is unlikely to result in erroneous interpretations of the presence or absence of DNAPLs, although it cannot be used to predict the composition of multi-phase DNAPLs. **Table 4.2.2-2** lists pure-phase volubilities (solubilities) of the soil COCs at Berkeley Lab.

Table 4.2.2-2. Pure-Phase Volubilities of Soil COCs.

Soil COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Pure-Phase Volubility (Solubility) (µg/L)	1% of Solubility (µg/L)
benzene	47	1,800,000	1,800
carbon tetrachloride	4,600	790,000	7,900
1,1-DCA	15,800	7,900,000	79,000
1,2-DCA	75	8,500,000	85,000
1,1-DCE	2,210	2,300,000	23,000
cis-1,2-DCE	1,240	3,500,000	35,000
trans-1,2-DCE	469	6,300,000	63,000
methylene chloride	1,600	13,000,000	130,000
1,1,1-TCA	277	1,300,000	13,000
1,1,2-TCA	37	4,400,000	4,400
PCE	**76,035**	200,000	2,000
TCE	**79,300**	1,100,000	11,000
vinyl chloride	835	2,800,000	2,800

Note: Boldface number indicates concentration greater than 1% of solubility.

The data in **Table 4.2.2-2** indicate that only two COCs (PCE and TCE) are present at concentrations greater than 1% of their solubility. Concentrations of these COCs exceed 1% of their solubility only in the Building 7 Lobe of the Old Town Groundwater Plume and the

Building 71B lobe of the Building 71 Groundwater Solvent Plume, so only these areas might have DNAPL present according to this criterion.

4.2.3 Identification of Potentially Applicable Corrective Measures Alternatives

The corrective measures alternatives that are considered potentially applicable to halogenated VOCs in soil and groundwater are listed in **Table 4.2.3-1** and **Table 4.2.3-2**, respectively.

4.2.3.1 Preliminary Screening of Potentially Applicable Corrective Measures Alternatives

A step-wise screening process, as described in **Section 3.3,** was used to evaluate the corrective measures alternatives for VOCs in soil and groundwater at Berkeley Lab. The screening consisted of an evaluation as to whether the method was potentially effective and applicable. Each technology was screened based on a determination as to whether it could meet one or more of the following objectives:

- Remove the source of the groundwater plumes (potentially reduce COC concentrations in the source area where DNAPL and/or residual soil contamination is present)
- Remediate the groundwater plume (potentially achieve MCSs downgradient from the source area)
- Control the COCs in order to protect human health and the environment (e.g., restrict migration of COCs into areas with lower COC concentrations).

The results of the initial screening process are included in **Table 4.2.3-1** and **Table 4.2.3-2**. The retained technologies are discussed in more detail in the following section.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion	
No Action	No Action	No further action of any type	Is not effective in protecting human health.	Implementable	√	Retain for further consideration as a required alternative.
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation (MNA)	Natural subsurface processes - such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials - are allowed to reduce contaminant concentrations to acceptable levels.	Is not effective in protecting human health. Is not effective in reducing COC concentrations in soil over a reasonable time frame.	Implementable	X	Eliminate from current consideration based on effectiveness.
Risk and Hazard Management	Institutional Controls (physical barriers or markers)	Signs, fencing and/or other barriers designed to reduce or eliminate human exposure to COCs	May be effective in protecting human health. Is not effective in reducing COC concentrations.	Implementable.	√	Retain for further consideration
	Institutional Controls (legal or administrative)	Administrative or legal restrictions such as deed restrictions or permit requirements that limit activities (such as construction of buildings) that might result in human exposure to COCs	May be effective in protecting human health. Is not effective in reducing COC concentrations.	Implementable.	√	Retain for further consideration.
Containment	Capping Solidification Stabilization	A surface cover is placed over the contaminated soil (capping). Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Effective in protecting human health. Containment measures can also limit surface water infiltration and leaching of contaminants to groundwater. Not effective in reducing COC concentrations.	Implementable.	√	Retain for further consideration.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability		Conclusion
Remedial Technologies	**In situ treatment**					
	Enhanced bioremediation	The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance in situ biological degradation of organic contaminants. Nutrients, oxygen, or other amendments may be used.	May not be effective in reducing COC concentrations in low permeability or heterogeneous soils. Preferential flow paths may severely decrease contact between injected fluids and contaminants. Remediation times are often years, depending mainly on the degradation rates of specific contaminants, site characteristics, and climate.	Not implementable in low permeability and/or high moisture content soils such as the Mixed Unit. May be implementable in Moraga Formation or in surficial units, but soil COCs are generally sparse in those units.	X	Eliminate from consideration based on effectiveness.
	Phytoremediation	Phytoremediation is a set of processes that use plants to clean contamination in soil, ground water, surface water, sediment, and air.	Effective in reducing COC concentrations only in shallow contaminated soils. Can also transfer contamination cross media (soil to air). High concentrations of contaminants in plume source areas may be toxic to plants.	Not implementable in Berkeley Lab source areas because areas are developed and in some locations groundwater is too deep.	X	Eliminate from further consideration based on implementability.
	Bioventing	Air is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.	Not effective in reducing concentrations of VOCs.	Implementable	X	Eliminate from further consideration based on effectiveness.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion	
Remedial Technologies **(cont'd.)**	**In situ treatment (cont'd.)**					
	Chemical oxidation	Reduction/oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.	Limited effectiveness in reducing COC concentrations in heterogeneous and/or low permeability soil because it requires intimate contact of the reagent with the source solvent.	Pilot testing has indicated that the method is implementable.	√	Retain for consideration.
	Electrokinetic separation	Electrokinetic separation uses electrochemical and electrokinetic processes to desorb, and then remove, polar organics from low permeability soils	Limited effectiveness in reducing COC concentrations due to fractured, heterogeneous nature of the bedrock units. For organic compounds, the method is limited to the soluble fraction and will not remove residual non-aqueous-phase solvents.	Implementability may be limited in source area because of numerous underground utilities.	X	Eliminate from further consideration based on effectiveness.
	Extraction with ex-situ treatment					
	Soil vapor extraction (SVE)	Vacuum is applied through extraction wells to create a pressure gradient that induces advection of gas-phase volatiles through soil to extraction wells. The process includes a system for handling off-gases.	Not effective in reducing COC concentrations in low permeability and/or high moisture content soils, so effectiveness is variable, depending on site conditions.	An SVE system has been installed on-site as an ICM.	√	Retain for further consideration

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion	
Remedial Technologies **(cont'd.)**	**Extraction with ex-situ treatment (cont'd.)**					
	Thermally enhanced SVE/DPE	Heating and groundwater extraction is used to increase volatilization of VOCs and decrease vadose zone moisture content to facilitate vapor removal. The heating can be accomplished by conductive heating, electrical resistance/ electromagnetic/fiber optic/radio frequency heating; hot air or steam injection.	High moisture content is a limitation of standard SVE that thermal enhancement may help overcome. This method has been pilot tested in the source area of the Old Town Plume – Building 7 lobe and has proven effective in removing COCs.	This method has been implemented in the source area of the Old Town Plume – Building 7 lobe as a pilot test.	√	Retain for further consideration.
	Fracturing – enhanced SVE	Pressurized air or liquid is injected beneath the surface to develop cracks in low permeability and over-consolidated sediments, opening new passageways that increase the effectiveness of many in situ processes and enhance extraction efficiencies. Sand or granular reactive materials can be injected into the fractures or to keep them open and/or deliver in situ remediation agents.	Effectiveness in reducing COC concentrations at Berkeley Lab is unknown. Artificial fracturing may result in opening of new pathways that may cause the unwanted spread of contaminants into uncontaminated materials.	Not implementable in developed source areas and/or slope stability concerns in some core areas.	X	Eliminate from further consideration based on effectiveness and/or implementability.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability		Conclusion
Remedial Technologies **(cont'd.)**	**Extraction with ex-situ treatment (cont'd.)**					
	Soil flushing + Groundwater Extraction (water/ surfactant/co-solvent)	Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the ground water to raise the water table into the contaminated soil zone. Contaminants are leached into the ground water, which is then extracted and treated.	Soil flushing has low potential effectiveness in reducing COC concentrations in heterogeneous or fine grained/low permeability materials. At Berkeley Lab, flushing and recirculation of treated groundwater has been effective in removing contaminants from beneath the Building 7 sump excavation. Surfactants can adhere to soil and reduce effective soil porosity. Reactions of flushing fluids with soil can reduce contaminant mobility. Surfactant/co-solvent flushing is effective for relatively small and well-defined solvent targets, which have not been located at Berkeley Lab.	Soil flushing with treated groundwater has been implemented as ICMs/pilot tests at several locations at Berkeley Lab. Surfactant/co-solvent flushing should be used only where flushed contaminants and soil flushing fluid can be contained and recaptured.	√	Retain soil flushing with treated groundwater for further consideration. Eliminate surfactant/co-solvent flushing from further consideration based on effectiveness and implementability.
	Soil mixing	The soil is broken up and mixed by drilling, which increases the permeability. The contaminants can be extracted by SVE and/or destroyed by injection of chemical oxidants. Steam can also be simultaneously injected to volatilize the contaminants.	Effectiveness in reducing COC concentrations is not known.	Low permeability materials (e.g., the Mixed Unit) can be broken up and mixed with higher permeability materials (e.g., Moraga Formation or surficial units) to increase the permeability and allow flushing/extraction of the contaminants.	√	Retain for further consideration.

Table 4.2.3-1. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Soil (cont'd.)

Corrective Measures Category	Technology	Description	Effectiveness	Implementability	Conclusion	
Remedial Technologies **(cont'd.)**	**Extraction with ex-situ treatment (cont'd.)**					
	Excavation with ex-situ treatment: Biopiles, composting, fungal biodegradation, chemical extraction, chemical oxidation/reduction, dehalogenation, separation, soil washing, hot gas decontamination, incineration, open burn, pyrolysis, and thermal desorption.	Soil is excavated and treated on-site, then reused or transported off-site for disposal.	The methods would be effective in protecting human health and reducing COC concentrations.	Many of the alternatives would not be implementable because of limited area available for treatment.	X	Eliminate from further consideration based on implementability
	Excavation and offsite disposal	Contaminated material is removed and transported to permitted off-site treatment and disposal facilities. Pretreatment may be required.	Method has been used at Berkeley Lab and is effective in protecting human health and reducing COC concentrations.	This alternative has been implemented at several ICMs at Berkeley Lab.	√	Retain for further consideration.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
No Action	No Action	No further action of any type.	Is not effective in protecting human health.	Implementable.	Same as source zone.	Same as source zone.	Same as source zone	Same as source zone.	Retain for further consideration as a required alternative.
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation (MNA)	Natural subsurface processes—such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials are allowed to reduce contaminant concentrations to acceptable levels.	Not effective in protecting human health or reducing COC concentrations in areas where DNAPL or high residual soil concentrations are available for dissolution into groundwater	Implementable.	Is not effective in areas where high residual soil concentrations are available for dissolution into groundwater. May be effective in areas of lower contaminant concentrations where site data indicate that natural attenuation processes are occurring.	Implementable.	May be effective in areas where site data indicate that natural attenuation processes are occurring.	Implementable.	Eliminate from consideration in plume source areas and high concentration core area. Retain for further consideration in lower concentration plume core and periphery areas.
Risk and Hazard Management	Institutional Controls (physical barriers or markers)	Signs, fencing, and/or other barriers designed to reduce or eliminate human exposure to COCs.	May be effective in protecting human health. Is not effective in reducing COC concentrations.	Implementable.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Retain for further consideration.
	Institutional Controls (legal or administrative)	Administrative or legal restrictions such as deed restrictions or permit requirements that limit activities (such as construction of buildings) that might result in human exposure to COCs	May be effective in protecting human health Is not effective in reducing COC concentrations. Would likely be required to restrict ground water use prior to achieving regulatory-based MCSs.	Implementable.	Same as source zone.	Same as source zone.	Would be effective if plume migration is controlled. Would likely be required to restrict ground water use prior to achieving regulatory-based MCSs.	Implementable	Retain for further consideration.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Containment and Capture	Containment/ diversion (Slurry walls Sheet pile walls Grout curtains)	These methods stabilize groundwater COCs in place by preventing or reducing their migration. Slurry walls consist of trenches filled with a low permeability material., usually a mixture of bentonite and water. Grout curtains consist of the subsurface injection of a cement/bentonite and water mixture to decrease the subsurface permeability.	Not effective in protecting human health or reducing COC concentrations. These methods can be used to decrease the potential for migration of plume boundaries or of high concentration zones within plumes.	Implementable	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration as a remedial technology based on effectiveness. Retain as a plume control measure.
	Groundwater Capture (Drains, Trenches, Extraction wells)	Control measures to prevent further migration of groundwater contaminants by extracting groundwater within and at the downgradient edge of groundwater plumes.	Not effective in protecting human health. The effectiveness in reducing contaminant concentrations is limited by the continued presence of a residual source and the heterogeneity of the subsurface. However, capture is effective in controlling further migration of COCs.	Implementable. Subsurface drains, trenches and extraction wells are being used on site as plume control measures.	Is not protective of human health. Does not reduce COC concentrations except over very long time scales. However, capture is effective in controlling further migration of COCs.	Same as source zone.	Is not protective of human health. Does not reduce COC concentrations except over very long time scales. However, capture is effective in controlling further migration of COCs.	Same as source zone.	Eliminate from further consideration as a remedial technology based on effectiveness. Retain as a plume control measure.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies	**In Situ Treatment**								
	Permeable Reactive Barrier (PRB) and Funnel and Gate	A permeable wall, containing reactive substances such as sorbents or zero-valent metals, is installed across the flow path of the plume. Contaminants are chemically removed as groundwater flows through the wall. A funnel and gate system can be used to direct the groundwater towards the permeable wall	Not effective because of the relatively high concentrations of COCs in the source zone.	Implementable. Similar implementability to collection trenches which have been installed on site. The reactive element in the barrier would need frequent replacement due to reduced reactive capacity and/or loss in media porosity due to precipitation.	Not effective because of the relatively high concentrations of VOCs in the core zone.	Implementable	Could be effective as a migration control measure in the periphery zone of the plume.	Implementable	Eliminate from further consideration as a remedial technology based on effectiveness. Retain as a plume control measure.
	Chemical Oxidation	A chemical oxidant solution, such as hydrogen peroxide, is injected into the aquifer. The oxidant converts chlorinated VOCs to water, carbon dioxide, and chlorides.	Method has been pilot tested with inconclusive results of effectiveness in reducing COC concentrations. Injecting chemical over a wide area in low permeability soil would likely leave unreacted pockets of contamination. Permanganate could produce byproducts that degrade water quality. Other oxidants (ozone, hydrogen peroxide) would have limited stability in the subsurface, reducing the effective treatment radius.	Would require a significant number of injection wells in the low permeability Mixed Unit core area of the plume.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Retain for further consideration.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies **(cont'd.)**	**In situ treatment (cont'd.)**								
	Enhanced bioremediation	Aerobic Oxidation An oxygen release compound (ORC®) is injected into the aquifer to stimulate natural aerobic degradation of contaminants. The amendment could be added via direct injection or groundwater circulation.	Limited effectiveness in reducing COC concentrations because highly chlorinated VOCs (e.g., PCE, TCE) do not degrade well via direct aerobic degradation using ORC technology.	Low groundwater velocities at Berkeley Lab would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	Same as source zone.	Same as source zone.	May be effective in downgradient areas where highly chlorinated VOCs have been degraded to less chlorinated VOCs (e.g., DCE, vinyl chloride) that will not degrade further under site conditions	Low groundwater velocities at Berkeley Lab would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	Eliminate from further consideration based on effectiveness for source and core zones. Retain for further consideration for periphery zone.
		Anaerobic Reductive Dechlorination Contaminants are degraded by native microorganisms, enhanced through the addition of an amendment such as hydrogen release compound (HRC®). The amendment could be added via direct injection or groundwater circulation.	Not effective in reducing COC concentrations in source area due to continued dissolution of DNAPL and residual soil COCs into groundwater	Groundwater velocities at Berkeley Lab would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	May be effective in reducing COC concentrations if anaerobic conditions are present and can be maintained. Amendment might not adequately permeate low permeability or heterogeneous soils. Vinyl chloride could accumulate in some areas.	Groundwater velocities at Berkeley Lab would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	Same as core zone	Same as core zone.	Eliminate from current consideration based on effectiveness for source zones. Retain for further consideration for core and periphery zones.
		Cometabolism Injection of a dilute solution of liquids and/or gases (e.g., toluene, methane or oxygen) into the contaminated ground water zone to enhance the rate of methanotrophic biological degradation of organic contaminants.	Would not be effective in reducing COC concentrations based on results of methanotrophic treatment technology pilot test.	The extremely low groundwater velocity would necessitate numerous injection points. In addition, reapplication of amendment would likely be required.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on effectiveness.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont’d.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies (cont’d.)	**In situ treatment (cont’d.)**								
	Phytoremediation	Phytoremediation is a set of processes that uses plants to clean contamination, particularly organic substances, in ground water and surface water.	Effectiveness in reducing COC concentrations is limited to shallow depths (most contamination is at greater depths i.e.,10 ft or more).	Plume source areas are developed, so planting of appropriate vegetation would not be possible in most locations.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on effectiveness and implementablility.
	Extraction with ex-situ treatment								
	Soil Flushing + Groundwater Extraction	Inject treated groundwater and/or potable water to infiltration trenches or wells to alter hydraulic gradients and flush contaminated groundwater towards extraction trenches/wells. Remove VOCs from extracted water using methods such as granular activated carbon (GAC) absorption or air stripping. Method can be enhanced by increasing subsurface permeability using technologies listed for soil such as soil mixing or fracturing.	Can effectively limit downgradient plume migration and provide short-term COC concentration decreases, but rapid aquifer restoration will not occur because a very high number of pore volumes must be flushed though the saturated zone and the rate of flushing is severely limited in some areas of Berkeley Lab by low permeability materials in the saturated zone. May result in undesirable mobilization of DNAPL.	This technology has been implemented as ICMs/pilot tests at a number of locations	Can effectively limit downgradient plume migration and may result in long-term decreases in COC concentrations in some areas, but rapid aquifer restoration is unlikely to occur because a very high number of pore volumes must be flushed though the saturated zone and the rate of flushing is severely limited in some areas of Berkeley Lab by low permeability materials in the saturated zone.	Implementable.	Can effectively limit downgradient plume migration, and may result in long-term decreases in COC concentrations in some areas, although the rate of flushing is severely limited in some areas of Berkeley Lab by low permeability materials in the saturated zone.	Implementable.	Retain for further consideration.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies (cont'd.)	**Extraction with ex-situ treatment (cont'd.)**								
	Dual-Phase Extraction (DPE)	Extract VOCs in vapor and groundwater simultaneously under vacuum through dual-phase extraction wells. Lowered water table increases treatment zone volume for vapor extraction, which generally removes contaminant mass more quickly than groundwater extraction. Remove VOCs from vapor stream with a vapor treatment system such as GAC absorption, and from groundwater stream using water treatment system, such as a GAC system.	This method is most effective in relatively high permeability/low moisture content soils where soil concentrations are high or DNAPL is present. Lowering of water table and simultaneous removal of soil VOCs is likely to result in lowering of groundwater concentrations. However, if DNAPLs or residual soil contamination remains below the lowered water table, MCSs may not be achievable.	Implementable. This technology has been implemented as an ICM in the core area of the B7 lobe of the Old Town plume.	Effectiveness at Building 53/58 slope DPE system in core of Building 7 lobe is poor because of low permeability/high moisture content soils and low contaminant concentrations in soil. Similar results are expected in other plume core areas.	Implementable.	Effectiveness is expected to be similar to plume core areas.	Implementable.	Retain for further consideration for plume source areas. Eliminate from further consideration based on effectiveness for plume core and periphery areas.
	Air Sparging	Compressed air, injected into lower portion of affected aquifer, percolates up through saturated zone causing transfer of VOCs from aqueous to vapor phase, vapors migrate to the vadose zone to be collected with a soil vapor extraction system.	Since sparging requires intimate contact of the air with the source solvents, it is not effective in heterogeneous, low permeability soils.	Would require a large number of wells. Potential mobilization of VOC vapors is a potential health concern.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on implementation and effectiveness.

Table 4.2.3-2. Preliminary Screening Matrix for Potential Corrective Measures Technologies for Groundwater (cont'd.)

Corrective Measures Category	Technology	Description	Plume Source Zone		Plume Core Zone		Plume Periphery Zone		Conclusion
			Effectiveness	Implementability	Effectiveness	Implementability	Effectiveness	Implementability	
Remedial Technologies (cont'd.)	**Extraction with ex-situ treatment (cont'd.)**								
	In-Well Air Stripping	Air is injected into a double screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Once in the well, some of the VOCs in the contaminated ground water are transferred from the dissolved phase to the vapor phase by air bubbles. The contaminated air rises in the well to the water surface where vapors are drawn off and treated by a soil vapor extraction system.	Limited effectiveness in heterogeneous, low permeability saturated zone soils. Effectiveness is limited to the immediate area of the well.	Would require a large number of wells.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on effectiveness.
	Steam/hot water Injection	Steam or hot water is forced into an aquifer through injection wells to vaporize volatile contaminants. Vaporized components rise to the unsaturated zone where they are removed by vacuum extraction and then treated.	Limited effectiveness in heterogeneous, low permeability soils.	Potential mobilization of VOC vapors is a potential health concern.	Same as source zone.	Same as source zone.	Same as source zone.	Same as source zone.	Eliminate from further consideration based on effectiveness.

Based on the screening matrices presented above, the following corrective measures alternatives were retained for further evaluation:

Soil

- No Action
- Institutional Controls
- Containment (Capping, Solidification, Stabilization)
- Chemical Oxidation
- Soil Vapor Extraction
- Thermally Enhanced SVE/DPE
- Soil Flushing (with water) + Groundwater Extraction
- Soil Mixing
- Excavation with offsite disposal.

Groundwater

- No Action
- Monitored Natural Attenuation (plume core and periphery zones)
- Institutional Controls
- Containment and Capture (slurry walls, sheet pile walls, grout curtains drains, trenches, extraction wells)
- Permeable Reactive Barrier and Funnel & Gate (plume periphery zones)
- Chemical Oxidation
- Enhanced Bioremediation (plume core and periphery zones)
- Soil Flushing (with water) + Groundwater Extraction
- Dual-Phase Extraction (source zone).

A discussion of the unit-specific applicability of each of these technologies is provided in the following section. As discussed in Section 4.1.1.4, a tiered approach to meeting risk-based and regulatory-based groundwater MCSs is likely to be implemented at Berkeley Lab, therefore the effectiveness of each alternative in meeting each of these MCSs in the plume source area, plume core area, and plume periphery area was addressed individually.

4.3. SITE-SPECIFIC SELECTION AND EVALUATION OF CORRECTIVE MEASURES ALTERNATIVES FOR VOLATILE ORGANIC COMPOUNDS (VOCS) IN SOIL AND GROUNDWATER

This section describes the site-specific factors that affect the evaluation and selection of corrective measures alternatives, and includes discussions of the distribution of COCs, results of the human health risk assessment, concentration trends, previously implemented ICMs, and results of bench-scale and field-scale pilot tests. The data and other information presented in this section are derived primarily from the Draft Final RFI Report (Berkeley Lab, 2000a), Environmental Restoration Program Quarterly Progress Reports, and the Human Health Risk Assessment (Berkeley Lab, 2003a).

4.3.1. Building 51/64 Groundwater Solvent Plume

The Building 51/64 Groundwater Solvent Plume is located in the Bevalac Area of Berkeley Lab, which primarily includes the Building 51/64 complex (the decommissioned Bevatron particle accelerator and support facilities) and the Building 71 complex (the decommissioned Super Heavy Ion Linear Accelerator [Super HILAC]). Major development of the area began in the early 1950s, when construction started on the Bevatron and associated support facilities. The Bevatron operated for almost 40 years from 1954 to 1993.

The plume extends westward from the southeast corner of Building 64 (**Figure 4.3.1-1**). The principal plume constituents are halogenated VOCs that were used as cleaning solvents, including 1,1,1-TCA, TCE, PCE, and their associated degradation products (e.g., 1,1-DCE, 1,1-DCA, cis-1,2-DCE, and vinyl chloride). The principal source of the plume was likely the Building 51/64 Former Temporary Equipment Storage Area (AOC 9-12), although other sources in the Building 51/64 area may have contributed to the plume.

Contaminated source area soils were excavated as an ICM in August 2000 and a groundwater extraction system was installed in the backfilled excavation. In addition, an in situ soil flushing pilot test is being conducted in the source area to evaluate the implementability of the method and its potential effectiveness in achieving MCSs. Contaminated groundwater in the vicinity of Building 51 has the potential to enter the building’s subdrains, which originally were routed to the stormdrain system that discharges to North Fork Strawberry Creek. To avert discharges to the creek, an ICM was implemented in 1996 that routes water from the Building 51 subdrain system to a groundwater treatment system. The treated groundwater is then discharged to the sanitary sewer. The locations of the ICMs and pilot test are shown on **Figure 4.3.1-1**.

4.3.1.1. Current Conditions

Geology and Hydrogeology

The area of the Building 51/64 plume is underlain by sedimentary rocks of the Orinda Formation, which consist primarily of siltstones and fine-grained sandstones that strike approximately east-west and dip 25° to 60° to the north. The bedrock is overlain by a thin veneer of artificial fill that thickens substantially to the southwest towards the former location of Blackberry Canyon, a major east-west-trending drainage course that bisected the current Building 51/64 area prior to development. Artificial fill, in places greater than 100 feet thick, was placed in the drainages in the Bevalac area, and the ridges were cut by up to 40 feet to provide graded areas on which to construct buildings and parking lots.

The water table in the Building 51/64 Plume Area lies primarily within the Orinda Formation east of Building 51B, but is within the artificial fill to the west. Slug tests and pumping tests conducted on wells screened in the Orinda Formation in the Building 51/64 plume area indicate hydraulic conductivity values ranging from approximately 2×10^{-9} to 3×10^{-8} meters per second.

To the southwest of Building 64, the contact between artificial fill in Blackberry Canyon and the Orinda Formation cuts down across the water table. **Figure 4.3.1-2** shows the intersection between the water table and the predevelopment topographic surface, illustrating the area in which the water table lies within the artificial fill. Slug test data in this area indicate relatively high hydraulic conductivities for the artificial fill (typically 10^{-7} to 10^{-6} meters per second). Groundwater wells generally yield less than 200 gpd from wells screened solely in the Orinda Formation and have short-term yields greater than 200 gpd from wells screened wholly or partly in the artificial fill or colluvium (**Figure 4.3.1-2**).

The water level elevation contour map for the Bevalac Area is shown on **Figure 4.3.1-3**, and indicates that flow is approximately southwestwards. The map contours indicate that the horizontal component of the hydraulic gradient (dh/dl) is approximately 0.4 near Building 64. Assuming a hydraulic conductivity (K) of 1 x 10^{-8} meters per second, which is typical of the Orinda Formation in this area and an effective porosity (n_e) of approximately 0.2, Darcy's law ($v_x = K/n_e$ x dh/dl) results indicates an average linear groundwater velocity (v_x) of 0.6 meters per year (2 feet per year). For flow in the artificial fill, groundwater velocities would be expected to be approximately an order of magnitude greater.

Groundwater Contamination

The Building 51/64 plume contains a number of halogenated non-aromatic VOCs, most of which have been detected at concentrations above MCLs. The maximum concentrations of chemicals detected at concentrations above MCLs in FY03 are listed in **Table 4.3.1-1,** and are compared to the target risk-based MCSs. PCE, carbon tetrachloride, 1,1-DCA, and vinyl chloride were detected in the groundwater at concentrations above target risk-based MCSs in FY03.

Table 4.3.1-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 51/64 Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Regulatory-Based Groundwater MCS (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
TCE	1,590	5	1,594
PCE	**692**	5	343
carbon tetrachloride	**40.6**	0.5	27
cis-1,2-DCE	226	6	98,405
trans-1,2-DCE	25	10	94,405
1,1-DCE	2,210	6	28,873
methylene chloride	57.2	5	10,381
1,1-DCA	**15,800**	5	3,663
1,2-DCA	24.5	0.5	1,030
vinyl chloride	**835**	0.5	12
1,1,1-TCA	277	200	1,570,783
1,1,2-TCA	11.1	5	1,905

Note: Boldface concentration indicates that the maximum detected concentration of the COC in FY03 exceeds the target risk-based groundwater MCS.

Groundwater COC Trends

Before implementation of the source area ICM, halogenated VOCs were detected at total concentrations above 100,000 µg/L in groundwater samples collected in the source area, with 1,1,1-TCA comprising approximately 90% of the contaminant mass. The source area was excavated as an ICM and backfilled with gravel in 2000. Subsequent to the ICM, halogenated non-aromatic VOC concentrations have decreased to a total concentration of approximately 500 µg/L or less in the source area, with the primary COC detected 1,1-DCA.

Concentration trends for total halogenated non-aromatic VOCs in the Building 51/64 plume are shown on **Figure 4.3.1-4a, Figure 4.3.1-4b, and Figure 4.3.1-5**. Concentrations of VOCs detected in MW51-96-18, SB64-98-17, and SB64-98-8 near the plume source area have decreased significantly since the ICM was implemented. There has also been a decreasing trend in the concentrations of VOCs detected in MW51-96-16, in the plume core. Except for a decrease in the concentration of vinyl chloride in MW56-98-2, concentrations of VOCs detected in other wells monitoring the plume have remained relatively constant.

Most of the plume constituents comprise chemicals that represent primary or intermediate compounds in the PCE or 1,1,1-TCA degradation pathway. The relative proportions of plume constituents differ substantially with distance downgradient from the source area. The primary COC prior to the ICM (1,1,1-TCA) is generally detected only in the source area, with its daughter product, 1,1-DCA detected in the source area and also in downgradient areas.

A similar pattern is also observed for PCE and its daughter products. Well MW51-96-18, which is located close to the source area, contains a higher fraction of PCE and TCE and a lower fraction of DCE and vinyl chloride (**Figure 4.3.1-6**) than core area well MW51-96-16 (**Figure 4.3.1-7**), located about 100 feet downgradient from the source area. Well MW51-00-8, located in the downgradient area, contains only degradation products with no PCE or TCE (**Figure 4.3.1-8**). These three wells show consistent temporal trends in daughter/parent ratios. The source area well (MW51-96-16) shows an increase in the relative proportion of parent products through time, accompanied by a substantial decrease in concentrations (**Figure 4.3.1-6**). This appears to indicate that the rate of degradation is slower than the rate of advection of COCs derived from desorption of residual soil COCs into the plume. Proportions of parent/daughter products have remained relatively constant in the mid-plume well MW51-96-16) (**Figure 4.3.1-7**) indicating that equilibrium has been reached between advection of COCs and degradation. The downgradient well (MW51-00-8) has shown a relatively constant proportion of vinyl chloride to DCE over time, with the total concentration of VOCs also remaining relatively constant (**Figure 4.3.1-8**). This suggests that equilibrium has been reached between advection of COCs and degradation in the downgradient area. Since concentrations of COCs in the groundwater in the source area have been significantly reduced, the advection of COCs into the core and downgradient areas should decline over time.

Soil Contamination

The primary VOCs detected in soil samples collected in the source zone for the Building 51/64 Plume were 1,1,1-TCA, TCE, 1,1-DCA, and PCE. Relatively high concentrations of VOCs (i.e., maximum concentrations of 1,1,1-TCA and PCE were 2,800 mg/kg and 680 mg/kg, respectively) were detected in soil samples collected from the excavated plume source area prior to the ICM, with several COCs above target risk-based MCSs. Residual VOC concentrations, however, are relatively low (0.23 mg/kg total VOCs maximum).

Maximum concentrations of COCs detected in residual soil are listed in **Table 4.3.1-2**. All concentrations are below both target risk-based MCSs and regulatory-based MCSs (for protection of groundwater).

Evidence of DNAPL and Residual Soil Contamination

Prior to the ICM, the concentrations of 1,1,1-TCA and PCE detected in the Building 51/64 plume source area exceeded their soil saturation concentrations, indicating that free DNAPLs were probably present. However, post-ICM soil sample concentrations were substantially below those levels. Similarly, although concentrations of both carbon tetrachloride and 1,1,1-TCA in groundwater exceeded 1% of their solubilities and effective volubilities prior to the ICM, post-ICM concentrations were substantially below those levels. These comparisons provide evidence for past, but not current presence of DNAPLs.

Table 4.3.1-2. Maximum Concentrations of COCs Detected in Residual Soil in the Building 51/64 Groundwater Solvent Plume Source Area

COC	Maximum Concentration Detected (mg/kg)	Target Risk-Based Soil MCS (mg/kg)	Regulatory-Based Soil MCS[(a)] (mg/kg)
PCE	0.16	0.45	0.7
TCE	0.085	2.3	0.46
cis-1,2-DCE	0.022	38	0.19
1,1,1-TCA	0.11	690	7.8
1,1-DCA	0.047	1.3	0.2
1,1-DCE	0.006	8	1.0

(a) MCS for the protection of beneficial uses of groundwater.

4.3.1.2. Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 51/64 Groundwater Solvent Plume:

- Residual soil contamination is not present at concentrations that exceed either regulatory-based or target risk-based MCSs. However, soil containing high concentrations of COCs indicative of free DNAPLs was present prior to the source area soil excavation ICM. The potential for leaching and dissolution of COCs from soil in the source area was substantially reduced as a result of the ICM.
- Groundwater COC concentrations have generally shown gradual long-term declines over most of the plume area. A substantial decline in concentrations was observed in the ICM excavation area and immediately downgradient in post-ICM groundwater samples.
- Groundwater in the source area flows primarily through relatively low permeability rocks of the Orinda Formation. The estimated groundwater velocity is approximately 2 to 20 feet per year.
- Groundwater yields are less than 200 gpd from upgradient and source area wells where the contamination is in the Orinda Formation. Target risk-based MCSs are applicable to this area. Groundwater yields are greater than 200 gpd from downgradient wells where the contamination is in the artificial fill and colluvium. Regulatory-based MCSs are applicable to this area.
- Spatial variations in plume chemistry and two studies on the potential for biodegradation indicate that biodegradation has been occurring throughout the Building 51/64 plume. The lack of a temporal change in the relative proportions of COCs in the central plume area indicates that a relative state of equilibrium has been reached between degradation of dissolved COCs in this area and desorption and downgradient migration of COCs from the source area.

- Migration of COCs beyond the downgradient boundary of the plume does not appear to be occurring, with the downgradient limit of detectable COCs remaining static. Migration of COCs to North Fork Strawberry Creek via the Building 51 subdrain system is not occurring because water from the subdrain is conveyed to a treatment system then discharged to the sanitary sewer.
- Concentrations of COCs exceed target risk-based MCSs in groundwater near the source area, and vinyl chloride slightly exceeds target risk-based MCSs in the central part of the plume. The potential human receptor and risk-based exposure pathway of potential concern is exposure to COCs by a hypothetical future indoor worker breathing vapor migrating from the groundwater to indoor air (Berkeley Lab, 2003a).
- Concentrations of COCs throughout most of the plume exceed regulatory-based MCSs. However, regulatory-based MCSs are only applicable to the downgradient portion of the plume, where the water table is in the fill.

4.3.1.3. Evaluation of Retained Corrective Measures Alternatives

Concentrations of soil COCs in the Building 51/64 plume source area are less than both target risk-based and regulatory-based MCSs. Concentrations of several groundwater COCs exceed target risk-based MCSs in the plume source area beneath the southeast corner of Building 64. In addition, the concentration of vinyl chloride slightly exceeds target risk-based MCS in the central portion of the plume. Regulatory-based MCSs are not applicable to the source area of the plume, and the area immediately downgradient from the source area, since well yields are less than 200 gpd. However regulatory-based MCSs are probably applicable to the downgradient area of the plume, beneath and northwest of Building 51B. No migration of COCs is occurring beyond the plume margins, so migration control is not a concern.

The corrective measures alternatives that are evaluated for the Building 51/64 Groundwater Solvent Plume are those that were retained in **Table 4.2.3-1** and **Table 4.2.3-2** (for soil and groundwater, respectively). The results of the evaluation are provided in **Table 4.3.1-3** and discussed below.

No Action

No action for the Building 51/64 Groundwater Solvent Plume would consist of terminating all groundwater monitoring activities, stopping of the ongoing Building 64 soil flushing pilot test and groundwater extraction from the gravel-filled ICM excavation, and

Table 4.3.1-3. Evaluation of Corrective Measures Alternatives, Building 51/64 Groundwater Solvent Plume

Corrective Measures Alternative	**Corrective Action Standards (yes/no)**				**Decision Factors (a)**				**Other Factors (b)**	
	Protective of Human Health / Environment	**Attain MCSs**	**Control Migration**	**Comply with Waste Management Requirements**	**Long-Term Reliability and Effectiveness**	**Reduction in Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Cost (c)**	**Regulatory Agency Acceptance**	**Community Concerns**
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	yes	yes	4	3	2	4	1	1
Institutional Controls	yes/no	no	no	yes	2	1	3	4	2	2
Groundwater Containment/Capture	no/yes	no	yes	yes	2	2	2	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/yes	no	yes	yes	2	2	2	3	4	3
Chemical Oxidation	no/no	no	no	yes	2	2	2	2	5	5
Soil Vapor Extraction	no/no	no	no	yes	1	1	1	3	3	3
Thermally Enhanced SVE/DPE	no/no	no	no	yes	1	1	1	3	3	3
Enhanced bioremediation	yes/yes	yes	yes	yes	4	4	2	4	4	4
Soil Flushing and Groundwater Extraction	yes/no	yes	unknown	yes	3	3	4	3	4	4
Soil Mixing	yes/yes	yes	no	yes	3	3	4	5	3	3
Excavation with Offsite Disposal	yes/no	yes	yes	yes	4	4	4	4	4	4

(a) Level of Compliance Ranking
1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance
1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

allowing water in the Building 51 subdrain system to flow through the stormdrain system to North Fork Strawberry Creek. Concentrations of COCs in the groundwater would likely remain at levels greater than both target risk-based MCSs and regulatory-based MCSs, for the foreseeable future. These conditions would require establishment of Institutional Controls in order to protect future workers, and/or to designate groundwater as a non-drinking water source. In addition, this alternative would likely be unacceptable to the regulatory agencies and the community. The No Action alternative is not protective of human health and the environment and is therefore eliminated from further consideration.

Monitored Natural Attenuation

Studies of chemical (i.e., specific electron acceptors and metabolic byproducts) and biological parameters applicable to the potential for biodegradation of the Building 51/64 plume were conducted in both 1997 and 2003. Both studies concluded that the potential for biodegradation within the plume was high. A report discussing the results of the 2003 investigation is contained in **Appendix E**. In addition, concentrations of VOCs in the groundwater in the source area have been significantly reduced since the source area soil excavation ICM was completed. The lines of evidence that demonstrate that MNA would be an effective alternative for remediation of the Building 51/64 Groundwater Solvent Plume are as follows:

1. The source area has been removed.
2. The contaminants are biodegradable.
3. The plume is stable.
4. Biodegradation daughter products are present and increase in proportion downgradient from the source area.
5. Bacteria capable of degrading chlorinated solvents were identified as being present in the plume.
6. Isotopic analysis of parent and daughter products indicates that biodegradation is occurring and vinyl chloride is being converted to ethane.
7. pH, moisture, and organic carbon content are sufficient to support natural biodegradation.
8. Culturable bacteria densities indicated that microbial activity was normal and high enough to support significant biodegradation activity.

MNA is therefore the recommended alternative for the Building 51/64 Groundwater Solvent Plume. However, relatively high concentrations of halogenated VOCs still remain in the groundwater adjacent to the excavated source area. The effectiveness of MNA and the length of time required to attain the required MCSs may be significantly improved if this area were first isolated from the remainder of the plume and/or concentrations of COCs in groundwater in the source area are reduced. More aggressive remediation technologies are therefore recommended for the source area in combination with MNA, as described below.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The groundwater plume is stable so no containment or capture of the plume boundary is currently required or planned. However, containment of COCs in the source area of the plume would likely allow MNA to result in decreasing COC concentrations in downgradient areas. Therefore, containment of the source area using a groundwater extraction trench, or groundwater extraction wells, is a recommended alternative for the plume when used in conjunction with another method such as MNA.

An ICM that captures and treats water in the Building 51 subdrain system was installed to prevent COCs from flowing through the stormdrain system to North Fork Strawberry Creek. Continuing capture and treatment is required as a regulatory compliance measure until discharge to surface water is shown to be below detectable levels.

Permeable Reactive Barrier/Funnel and Gate

A permeable reactive barrier or funnel and gate system would serve a similar function to a groundwater capture system, and therefore could be applicable to source containment.

Therefore, this method could be used to minimize migration of COCs from the source area to downgradient areas, and is considered to be a recommended alternative when used in conjunction with MNA.

Chemical Oxidation

The effectiveness of chemical oxidation for remediation of the source area of the plume is not known and would require pilot testing prior to any full-scale implementation. In situ chemical oxidation is generally not effective in low permeability materials such as the Orinda Formation. As described in Section 4.3.2, pilot testing of this technology in the low permeability Building 51L Groundwater Solvent Plume source area was not effective, so this method is unlikely to be effective for the Building 51/64 plume, and is therefore not recommended.

Soil Vapor Extraction (SVE) and Thermally Enhanced Dual Phase Extraction (DPE)

The effectiveness of soil vapor extraction (SVE) systems is controlled by both contaminant volatility and subsurface vapor flow. The COCs detected at the Building 51/64 plume are highly volatile and can be easily removed from soil and groundwater if sufficient vapor flow through the soil can be established. Thermal heating, in combination with dewatering, dries the soil, thereby increasing the effectiveness of an SVE system. However, the method is not effective in low permeability materials (such as the Orinda Formation in the Building 51/64 area), which still retain excess moisture even with soil drying. In addition, due to the high capital and operating cost of treating a small area such as the Building 51/64 plume source area, this alternative is not recommended.

Soil Mixing

Since the remaining soil COCs at the Building 51/64 Plume source area lie beneath Building 51/64, soil mixing is not implementable at this unit. In addition, the shallow depth of soil contamination would lend itself readily to soil excavation for a similar cost to soil mixing, with a much greater potential effectiveness. Soil mixing is therefore not recommended.

Enhanced Bioremediation

Available data indicate that natural biodegradation of COCs is occurring within the Building 51/64 plume, and that enhancement could potentially interfere with the naturally occurring degradation processes. In addition, the relatively high dissolved oxygen (DO) concentrations in the plume core area indicate that the application of HRC® would not be an effective alternative. An additional concern with the use of HRC is that concentrations of metals dissolved in the groundwater can increase significantly due to the lowered pH. Enhanced bioremediation is therefore not recommended for consideration.

Soil Flushing and Groundwater Extraction

A soil flushing pilot test, consisting of a groundwater injection trench inside Building 64 and a groundwater extraction trench east of the building was initiated in the plume source zone in October 2003. The test was designed to target an inclined, relatively high permeability zone, which appeared to be a migration pathway for groundwater COCs. Although insufficient time has elapsed to assess the long-term effectiveness of the pilot test, initial data indicate that the method has been effective and that COCs are being mobilized toward the extraction trench. However, to increase the effectiveness of the test and reduce the potential for mobilization of COCs to the southwest of the test area, an additional extraction trench located downgradient from the injection trench is recommended.

Excavation with Offsite Disposal

Based on available sampling data, residual soil concentrations are below both target risk-based and regulatory-based MCSs. The highest concentrations of soil COCs are likely located at shallow depths under the southeast end of Building 64, where the residual COCs sorbed to soil are likely present due to equilibrium partitioning with the dissolved phase. The highest concentrations of groundwater contaminants are also present at shallow depths under the southeast corner of the building. Since Building 64 overlies the source area, excavation is not currently possible, but should be considered if the building were to be removed.

Summary of Building 51/64 Plume Corrective Measures Implementation Strategy

The remediation objectives for the Building 51/64 Plume are to: 1) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs do not migrate into areas where concentrations are less than MCLs; 2) reduce groundwater COCs concentrations in the source area below target risk-based MCSs; 3) reduce vinyl chloride concentrations in the area near Building 51B area to below the target risk-based MCS; 4) reduce groundwater COC concentrations in the downgradient area where well yields exceed 200 gpd to below regulatory-based MCSs; and, 5) ensure that groundwater COCs at detectable concentrations do not migrate to surface water through the storm drain system.

The pilot test results indicate that soil flushing may be effective in meeting remediation objective (2), reducing groundwater COC concentrations in the source area to below target risk-based MCSs. The pilot test would be continued as the proposed corrective measure; however, it would be enhanced with an additional groundwater collection trench extending along the south side of Building 64. This collection trench would both reduce the potential for hydraulic head changes caused by soil flushing to increase groundwater advection rates, and reduce the potential for COCs at concentrations above regulatory-based MCSs to migrate from the source area to downgradient areas (remediation objective [1]). Although a permeable reactive barrier or funnel and gate system could also reduce migration of COCs, it would not be effective in controlling hydraulic head changes caused by source area soil flushing, and so is not recommended. Excavation of source area soils would also be effective in meeting remediation objectives (1) and (2), but it should be considered only if Building 64 were to be removed.

Given that MNA has been documented to be a viable corrective measure for the plume, remediation objectives (1), (3), and (4) are likely to be met by MNA, as long as containment and remediation of the source zone is conducted, as described above.

Objective (5) should be met by continued capture and treatment of groundwater in the Building 51 subdrain system until it can be shown that COC concentrations at the point of compliance (the outfall to the creek) are below detectable levels.

4.3.2. Building 51L Groundwater Solvent Plume and Source Area

The Building 51L Groundwater Solvent Plume is centered near the southwest corner of Building 51L in the Bevalac Area of Berkeley Lab (**Figure 4.3.2-1**). The Bevalac Area is described in Section 4.3.1.

Building 51L was constructed in the early 1980's as a computer support facility for Bevatron operations. In the early 1990's, Building 51L was reconfigured for use as a computer training facility. The use of the building for conducting training classes was terminated at the end of 2003, and the building was demolished in March 2004 as part of the Bevatron decommissioning process. A machine/maintenance shop was located in the Building 51L area prior to the 1970's. Solvent drum racks were reportedly located at various times at the current Building 51L location, along the adjacent wall of Building 51A, and along a former retaining wall located approximately 20 feet west of Building 51L.

The principal plume constituents are halogenated VOCs that were used as cleaning solvents, including TCE, PCE, and associated degradation products (e.g., cis-1,2-DCE, trans-1,2-DCE, and vinyl chloride). Based on the results of soil and groundwater sampling, solvent spills that occurred at the location of Building 51L appear to be the primary source for the soil and groundwater contamination.

4.3.2.1 Current Conditions

Geology and Hydrogeology

Building 51L was constructed on artificial fill that lies within a former hillside swale (**Figure 4.3.2-2**). The locations of soil borings, groundwater monitoring wells, and temporary groundwater sampling points in the Building 51L area are shown on **Figure 4.3.2-3**. An east-west geologic cross section (A-A') immediately south of Building 51L is shown on **Figure 4.3.2-4**. The artificial fill underlying the Building 51L area consists of gravelly clay and sandy or clayey silt. The thickness of the fill increases from approximately 10 to 20 feet at the retaining wall west of Building 51L to 30 feet to the northeast of the building. The artificial fill overlies residual soil/colluvium consisting primarily of silty clay with some gravel that ranges from approximately 5 to 20 feet thick. Underlying the soil/colluvium is shale and siltstone of the Great Valley Group. The three geologic units (fill, soil/colluvium, and bedrock) beneath the site act as distinct hydrogeologic units.

Groundwater is extracted from two wells south of the former location of Building 51L as an ICM. Groundwater extraction has resulted in drawdown of the water table to depths as great as 20 to 35 feet bgs near the extraction wells. In the absence of groundwater extraction, the water table would be between approximately 13 and 15 feet bgs in this area.

Based on laboratory-wide slug tests, the hydraulic conductivity ranges from 10^{-5} to 10^{-7} meter per second for colluvium/alluvium, 10^{-5} to 10^{-8} meters per second for the Great Valley Group, and 10^{-6} to 10^{-8} meters per second for artificial fill. Based on the performance of the extraction wells, the long-term sustainable yield from the Great Valley Group bedrock in this area is less than 200 gpd. Groundwater yields measured in wells screened in the fill above the bedrock in the Building 51L area are also less than 200 gpd.

The water level elevation contour map for the Bevalac Area is shown on **Figure 4.3.1-3**, and indicates that regional flow is northward near Building 51L. The gradient has been locally modified by groundwater extraction at the south end of the building. On the west side of Building 51L, the gradient in the artificial fill appears to be directed toward the stormdrain backfill and/or storm drain catch basin.

The groundwater elevation map contours indicate that the horizontal component of the hydraulic gradient (dh/dl) is approximately 0.3 near Building 51L. Assuming a hydraulic conductivity (K) of 1×10^{-7} meters per second, which is typical of artificial fill and an effective porosity (n_e) of approximately 0.2, Darcy's law ($v_x = K/n_e \times dh/dl$) results indicates an average linear groundwater velocity (v_x) of 4.5 meters per year (15 feet per year).

Groundwater Contamination

The Building 51L Groundwater Solvent Plume contains a number of halogenated non-aromatic VOCs, most of which have been detected at concentrations above MCLs (**Table 4.3.2-1)**. The maximum concentrations of chemicals detected at concentrations above MCLs in FY03 are listed in **Table 4.3.2-1**, and are compared to the target risk-based MCSs. Vinyl chloride was detected at concentrations exceeding the target risk-based MCS.

The highest total VOC concentrations in groundwater are present in a northwest-trending zone (**Figure 4.3.2-5**) whose west edge lies close to the active stormdrain west of Building 51L (Berkeley Lab, 2002c). The area in which the maximum concentrations of primary solvent products (i.e., PCE and TCE) in groundwater have been detected is apparently offset to the northeast of the locus of maximum concentrations of daughter (degradation) products (cis-1,2-DCE, trans-1,2-DCE, and vinyl chloride). This suggests either that groundwater flow has generally been directed westward toward the stormdrain or that conditions favorable for degradation occur to the west (Berkeley Lab, 2002c).

Table 4.3.2-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 51L Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
carbon tetrachloride	2.7	0.5	27
1,1-DCA	245	5	3,663
1,1-DCE	71	6	1,030
cis-1,2-DCE	1,100	6	98,405
trans-1,2-DCE	469	10	94,405
PCE	40	5	343
TCE	1,373	5	1,594
vinyl chloride	**542**	0.5	12

Note: boldface concentration indicates that the maximum detected concentration of the COC in FY03 exceeds the target risk-based groundwater MCS.

The plume covers a relatively small area approximately 100 feet wide by 70 feet long centered under the southwest corner of Building 51L (**Figure 4.3.2-5**). Groundwater contaminants have generally not been detected in wells screened in bedrock, indicating that the vertical extent of groundwater contamination is limited to the overlying fill and colluvium.

Groundwater COC Trends

Concentrations of the individual halogenated VOCs detected in temporary groundwater sampling points SB51L-98-1A and SB51L-02-3 located near the southwest corner of Building 51L have been increasing (**Figure 4.3.2-6**). The increases in concentrations appear to be related to groundwater extraction from EW51L-00-1, located approximately 10 to 15 feet from the sampling points.

Soil Contamination

Maximum concentrations of COCs detected in the soil in the source area of the Building 51L Groundwater Solvent Plume are listed in **Table 4.3.2-2**. The concentrations of soil COCs are less than the target risk-based MCSs, except for PCE, TCE, chloroform and vinyl chloride. However, the detection frequency of chloroform and vinyl chloride was less than 1% so the inclusion of these analytes as COCs is considered to be a statistical artifact, and not to represent risks to human health. The maximum concentrations of PCE and TCE were detected under Building 51L, at approximately 6.5 to 12 feet below the building (**Figure 4.3.2-7**). PCE was either the primary contaminant detected or it was detected at approximately the same concentration as TCE in this area. At almost all other locations, TCE was the primary contaminant detected. Total concentrations of VOCs above 1 mg/kg extend to a maximum depth of approximately 20 feet. The contamination is restricted primarily to the fill and underlying colluvium.

Table 4.3.2-2. Maximum Concentrations of COCs Detected in Soil in the Building 51L Groundwater Solvent Plume

COC	Maximum Concentration Detected (mg/kg)	Target Risk-Based Soil MCS (mg/kg)
PCE	**21**	0.45
TCE	**24**	2.3
1,1,1-TCA	0.019	690
1,1-DCA	0.8	1.3
1,1-DCE	0.074	7.9
benzene	0.0053	0.1
chloroform	**0.31**	0.28
cis-1,2-DCE	3.1	38
trans-1,2-DCE	0.45	50
vinyl chloride	**0.012**	0.0035

Note: boldface concentration indicates that the concentration exceeds the target risk-based soil MCS.

Evidence of DNAPL

Since the maximum concentrations of COCs detected in the soil are substantially lower than their soil saturation concentrations, the soil data provide no evidence for the presence of DNAPL. Similarly, concentrations of COCs in groundwater are low relative to their solubilities and effective volubilities, again providing no evidence for the presence of DNAPL.

4.3.2.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 51L Groundwater Solvent Plume and source area:

- No evidence is available suggesting the presence of free-phase DNAPL in soil or groundwater.
- Soil and groundwater contamination is limited to the upper 20 to 25 feet in the artificial fill and colluvium.
- Artificial fill and colluvium/residual soil beneath the Building 51L area have relatively low permeabilities. Groundwater wells screened in these units yield less than 200 gpd. In addition, based on the performance of the groundwater extraction wells, the long-term sustainable yield from the underlying Great Valley Group bedrock in this area is less than 200 gpd. Target risk-based MCSs are therefore applicable.
- The COCs appear to have undergone some natural biodegradation. Byproducts of PCE and TCE degradation, including cis-1,2 DCE and vinyl chloride have been detected in the soil and groundwater.
- Vinyl chloride is the only COC that exceeds the target risk-based MCS for groundwater. PCE and TCE concentrations exceed the target risk-based MCSs for soil. The potential human receptor and risk-based exposure pathway of potential concern is exposure to COCs by a hypothetical future indoor worker breathing vapor migrating from the groundwater or from soil to indoor air (Berkeley Lab, 2003a).
- Migration of COCs beyond the downgradient boundary of the plume does not appear to be occurring, with the downgradient limit of detectable COCs remaining static.

4.3.2.3 Evaluation of Retained Corrective Measures Alternatives

Concentrations of both soil and groundwater COCs in the Building 51L plume and source area exceed target risk-based MCSs. Regulatory-based MCSs are not applicable. Available data indicate that DNAPLs are not present. No migration of COCs is occurring beyond the plume margins, so migration control is not a concern. Transfer of COCs to surface water could potentially occur through the storm drain system, if the groundwater level were not maintained beneath the base of the storm drain by pumping. However, as a result of dilution and volatilization of COCs, the chemical concentrations should be below detectable levels at the outflow to the creek, as shown by the absence of detectable Building 51L plume COCs in surface water samples collected from North Fork Strawberry Creek prior to groundwater extraction.

The corrective measures alternatives that are evaluated for the Building 51L Groundwater Solvent Plume and source area are those that were retained in **Table 4.2.3-1** and **Table 4.2.3-2** (for soil and groundwater, respectively). The results of the evaluation are provided in **Table 4.3.2-3** and discussed below.

No Action

No action for the Building 51L Groundwater Solvent Plume would consist of termination of all groundwater monitoring activities and stopping of extraction and treatment of groundwater. Under this alternative, once extraction was halted, contaminated groundwater could enter the storm drain system and then flow into North Fork Strawberry Creek, although as described above, the COC concentrations would likely remain below levels of concern at the creek outfall. Since there is no evidence that COC concentrations are declining, groundwater concentrations would likely remain above target risk-based MCSs for the foreseeable future. These conditions would require establishment of Institutional Controls to protect future workers. In addition, this alternative would likely be unacceptable to the regulatory agencies and the community. The No Action alternative is not protective of human health and the environment and is therefore eliminated from further consideration.

Table 4.3.2-3. Evaluation of Corrective Measures Alternatives, Building 51L Groundwater Solvent Plume and Source Area

Corrective Measures Alternative	**Corrective Action Standards (yes/no)**				**Decision Factors (a)**				**Other Factors (b)**	
	Protective of Human Health / Environment	**Attain MCSs**	**Control Migration**	**Comply with Waste Management Requirements**	**Long-Term Reliability and Effectiveness**	**Reduction in Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Cost (c)**	**Regulatory Agency Acceptance**	**Community Concerns**
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	no/no	no	no	yes	1	1	1	4	1	1
Institutional Controls	yes/no	no	no	yes	2	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	yes	Yes	3	2	3	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/no	no	no	yes	1	1	1	3	4	3
Chemical Oxidation	no/no	unknown	yes	yes	1	1	2	3	5	5
Enhanced bioremediation	yes/yes	unknown	yes	yes	2	2	2	3	4	4
Soil Flushing and Groundwater Capture	yes/yes	yes	yes	yes	3	3	2	4	4	4
Thermally Enhanced Dual Phase Extraction	yes/yes	unknown	yes	yes	1	3	1	2	5	5
Soil Mixing	yes/yes	yes	Yes	yes	3	3	3	2	4	4
Excavation and Offsite Disposal	yes/yes	yes	yes	yes	5	5	5	3	5	4

(a) Level of Compliance Ranking
1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance
1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997, including the Building 51L plume area. Geochemical parameters measured in well MW51-97-16, located near the core of the plume indicated conditions favorable for natural degradation processes. In particular, the dissolved oxygen concentration was very low (0.13 mg/L), nitrate and nitrite were not detected, manganese (Mn^{2+}) concentrations were low, and ferrous iron (Fe^{2+}) was present. These are favorable redox conditions under which reductive dechlorination of PCE and TCE by microorganisms can occur.

MNA, however, is considered not to be a potentially effective alternative under current plume conditions based on the relatively stable COC concentrations observed in the groundwater over the past several years. These observations indicate that MNA would not be an effective alternative unless the source area is first isolated from the remainder of the plume and/or concentrations of COCs in groundwater in the source area are significantly reduced. Therefore, MNA should only be considered in combination with more aggressive remediation technologies.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The groundwater plume is stable, so no containment or capture of the plume boundary is currently required or planned.

An ICM consisting of a temporary groundwater pump-and-treat system was installed to lower the groundwater table and prevent infiltration of impacted groundwater into the storm drain system, and subsequent migration to surface water (North Fork Strawberry Creek). Continuing capture and treatment is required as a regulatory compliance measure until discharge to surface water is shown to be below detectable levels. Lining or rerouting the storm drain line so that it does not traverse the plume area is recommended to achieve this objective and would allow discontinuing of groundwater capture.

Permeable Reactive Barrier/Funnel and Gate

The groundwater plume is stable, so rates of advection are low, so a permeable reactive barrier or funnel and gate system is not required to capture the plume boundary or control releases from the plume core area.

Chemical Oxidation

An in situ chemical oxidation pilot test was completed in the Building 51L Groundwater Solvent Plume source area in 2002. The purpose of the test was to determine the implementability and effectiveness of chemical oxidation to treat impacted groundwater at the unit. The report describing the test methodology and results is included in **Appendix B**. The test consisted of the injection of hydrogen peroxide (H_2O_2), combined with citric acid. Subsequent monitoring in nearby observation wells (e.g., **Figure 4.3.2-8** showing results for SB51L-03-1) indicated that the effect of chemical oxidation on contaminant levels was immediate, but short lived. Concentration levels rebounded quickly exceeding baseline and historical levels within a month in some cases (i.e., cis-1,2-DCE, **Figure 4.3.2-8**). Based on the results of the pilot test, chemical oxidation is not a recommended alternative.

Enhanced Bioremediation

A pilot test would need to be performed to evaluate the feasibility of enhanced bioremediation. However, because enhanced bioremediation requires the delivery of the enhancing agent to the source solvents, it is generally not effective in low permeability materials such as the fill/colluvium where the COCs are present at the unit, and is therefore not recommended.

Soil Flushing and Groundwater Extraction

Soil flushing using injection trenches constructed in the unsaturated zone could be used to flush contaminants from the vadose zone into the underlying saturated zone where contaminants could be pumped and treated. This alternative is not recommended, however because the low permeability of the artificial fill, where most of the soil contamination is present, and the heterogeneous nature of the fill and colluvium limit the effectiveness of the method.

Soil Vapor Extraction (SVE) and Thermally Enhanced Dual Phase Extraction (DPE)

The effectiveness of SVE systems is controlled by both contaminant volatility and subsurface vapor flow. The COCs detected at the Building 51L plume are highly volatile and can be easily removed from soil and groundwater if sufficient vapor flow through the soil can be established. Thermal heating, in combination with dewatering, dries the soil, thereby increasing the effectiveness of an SVE system. However, the method is not effective in low permeability materials (such as the silt and clay material comprising the artificial fill at Building 51L), which still retain sufficient moisture even with soil drying. In addition, due to the high capital and operating cost of treating such a small area as the Building 51L plume, this alternative is not recommended.

Soil Mixing

Soil mixing is an implementable technology for the plume source area, but the effectiveness of this technology is not known. Excavation is preferred to soil mixing since excavation would be effective, and the cost of soil mixing would be higher than the costs of excavation, given the small source area and the need for pilot testing soil mixing prior to implementation. Soil mixing is therefore not recommended.

Excavation and Offsite Soil Disposal

Concentrations of both soil and groundwater COCs are above target risk-based MCSs. The highest concentrations of COCs are present at relatively shallow depths (approximately 20 to 25 feet bgs maximum) beneath the area where the southwest end of Building 51L was formerly located. Since the building was removed, excavation is now an implementable alternative. Excavation of the low permeability fill along with the contaminated groundwater would likely reduce contaminant concentrations below target risk-based MCSs. Excavation can be completed using either a long-armed excavator or closely-spaced, large diameter, soil-auger borings.

Summary of Building 51L Corrective Measures Implementation Strategy

The remediation objectives for the Building 51L Groundwater Solvent Plume and source area are to: 1) ensure that groundwater COCs at detectable concentrations do not migrate to surface water through the storm drain system; 2) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs do not migrate into areas where concentrations are less than MCSs; 3) reduce groundwater COC concentrations below target risk-based MCSs; and 4) reduce soil COC concentrations below target risk-based MCSs.

Lining or rerouting the storm drain line so that it does not traverse the plume area is the recommended alternative to meet remediation objective (1). Groundwater extraction will continue until this is accomplished, or until it can be shown that COC concentrations at the point of compliance (the outfall to the creek) are below detectable levels.

No action is needed to meet objective (2) since migration of the plume has not been occurring.

Given the small size of the impacted area, soil excavation and offsite disposal is the recommended alternative to remove contaminated material in both the saturated and unsaturated zones. This measure will meet both objective (3) and objective (4). After excavation has reduced COC concentrations below risk-based levels in the central plume area it is likely that natural attenuation processes will further reduce COC concentrations in the groundwater.

4.3.3 Building 71 Groundwater Solvent Plume (Building 71B Lobe)

The Building 71 Groundwater Solvent Plume extends southwestward from Building 71 and 71B in the Bevalac Area of Berkeley Lab (**Figure 4.3.2-1**). The plume consists of two distinct lobes that have different sources, based on contaminant chemistry, plume geometry, and hydraulic gradient information. The Building 71B and Building 71 lobes extend southwestward from Building 71B and Building 71, respectively, and lobes commingle just north of Building 46A (**Figure 4.3.3-1**). The Building 71 lobe is not discussed further in this document, since VOC concentrations have been decreasing and were below MCLs when wells monitoring the plume were last sampled in July 2003.

The Bevalac Area is described in Section 4.3.1. The Building 71 complex housed the former Super Heavy Ion Linear Accelerator (Super HILAC) and associated support facilities. The Super HILAC is no longer in operation. Building 71B houses a machine shop.

The principal Building 71B lobe constituents are halogenated VOCs that were used as cleaning solvents, including TCE, PCE, and associated degradation products (e.g., cis-1,2-DCE, and vinyl chloride). Based on the results of soil and groundwater sampling, solvent spills that occurred at the location of Building 71B appear to be the primary source for the soil and groundwater contamination.

Two pilot tests and an ICM were conducted to evaluate potential corrective measures alternatives for the Building 71B lobe. The pilot tests consisted of in situ chemical oxidation (ISCO) and enhanced bioremediation using HRC. Reports describing the methodology and results of the pilot tests are included in **Appendix B**. The ICM consisted of excavation of contaminated source area soil from beneath and south of Building 71B.

4.3.3.1 Current Conditions

Geology and Hydrogeology

Bedrock in the Building 71B lobe area is composed of fractured silty sandstone and sandy siltstone of the Orinda Formation. Prior to building construction, the main branch of North Fork Strawberry Creek flowed southwestward from the east end of Building 71 beneath the west end of Building 71B towards Building 51. During development, a 48-inch concrete pipe was placed in the bottom of the creek to convey surface water, and the channel was filled with artificial fill consisting of clay, gravelly clay, and silty sand. The Building 71B lobe is oriented approximately along the former creek alignment. The surface topography near Buildings 71 and 71B now slopes steeply to the south and southwest toward the Bevatron complex (Building 51).

Groundwater is present in both the Orinda Formation and the surficial fill units, with the depth to groundwater ranging from approximately 10 to 40 feet bgs. Water level fluctuations of more than 10 feet are observed between winter and summer in well MW71B-99-3R in the Building 71B lobe source area.

Based on results of slug tests conducted in monitoring wells, the Orinda Formation has a hydraulic conductivity ranging from approximately 10^{-7} to 10^{-9} meters per second. Based on data from elsewhere at Berkeley Lab, hydraulic conductivities in the artificial fill are expected to be higher (10^{-6} to 10^{-8} meters per second≤). As shown on **Figure 4.3.3-1**, groundwater monitoring well MW71B-99-3R in the source area can produce more than 200 gpd, whereas groundwater monitoring well MW71B-98-13 in the core area cannot.

The water level elevation contour map for the Bevalac Area is shown on **Figure 4.3.1-3**, and indicates that groundwater flow in the Building 71/71B area is southwestward toward Building 51 (**Figure 4.3.1-3**). The map contours that the horizontal component of the hydraulic gradient (dh/dl) is approximately 0.2 and 0.3 near Building 71B. Assuming a hydraulic conductivity (K) of 1 x 10^{-7} meters per second for the artificial fill, a gradient of 0.3, and an effective porosity (n_e) of approximately 0.25, Darcy's law ($v_x = K/n_e$ x dh/dl) indicates that the average linear groundwater velocity (v_x) would be 4 meters per year (13 feet per year). For flow in the underlying Orinda Formation bedrock, groundwater velocities would be expected to be approximately an order of magnitude lower.

Groundwater Contamination

The Building 71B lobe contains halogenated non-aromatic VOCs, most of which have been detected at concentrations above MCLs. Chemicals that were detected at concentrations above

MCLs in FY03 are listed in **Table 4.3.3-1**, where the maximum detected concentrations are compared to the target risk-based MCSs. This table includes groundwater samples collected in 2004 from temporary groundwater sampling points installed for the chemical oxidation pilot test. PCE has been detected in the groundwater at concentrations exceeding the target risk-based MCS.

Table 4.3.3-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 71B Lobe of the Building 71 Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03[(a)] (µg/L)	Regulatory-Based Groundwater MCS (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
TCE	277	5	1,594
PCE	**5,620**	5	343
cis-1,2-DCE	324	6	98,405
vinyl chloride	5.2	0.5	12

(a) Table also includes groundwater samples collected in 2004 from temporary groundwater sampling points installed for the chemical oxidation pilot test at building 71B.

Note: boldface concentration indicates that the maximum detected concentration of the COC exceeds the target risk-based groundwater MCS.

Groundwater COC Trends

Concentration trends for total halogenated non-aromatic VOCs in the Building 71B lobe are shown on **Figures 4.3.3-2a and 4.3.3-2b**. A long-term decline in groundwater concentrations has been observed from approximately 1992 to the present in wells MW90-3, MW90-4 and MW90-5, monitoring the downgradient portion of the lobe; and the downgradient boundary of the lobe has apparently retreated over the same period. Concentrations of COCs in wells monitoring the upgradient part of the lobe have remained relatively stable over 6 years of monitoring, except for recent changes in the source area that are the result of pilot test operations. Seasonal oscillations in COC concentrations in source area well MW71B-99-3R correlate with oscillations in the water table elevation. These corresponding variations indicate dissolution and leaching of soil contaminants during the rainy season, either when the water table rises into contaminated soils, or from flushing of contaminated soil by surface water infiltration. Leaking storm drain lines in the source area were repaired during the soil excavation ICM to prevent them from being an uncontrolled source of soil flushing.

All of the plume constituents comprise chemicals that represent primary or intermediate compounds in the primary PCE degradation pathway. The relative proportions of plume constituents differ substantially with distance downgradient from the source area. Well MW71B-99-3R, which is located close to the source area, contains more than 90% PCE (**Figure 4.3.3-3**). Well MW71B-98-13, located about 50 feet crossgradient from the source area, and well MW90-3, located approximately 180 feet downgradient, contain approximately 30 to 40% PCE, with the remainder consisting of PCE-degradation products (**Figure 4.3.3-4 and Figure 4.3.3-5**). The changes in the proportions of plume constituents away from the source area indicate that degradation has occurred during plume migration. The proportions of constituents, however, are similar in both MW71B-98-13 and MW90-3, indicating that degradation may be significant process only close to the source zone, and may not be occurring at a significant rate further downgradient. Excluding the effects of recent pilot tests, the relative proportions of lobe constituents have not changed significantly over time in these wells. This indicates that the rate of degradation does not greatly exceed the rate of COC migration from the upgradient source area.

A chemical oxidation pilot test was conducted in 2003 in the source area. A report describing the test methodology and results is included in **Appendix B**. Reagents (hydrogen peroxide and citric acid) were injected beneath and south of Building 71B, immediately adjacent to MW71B-99-3R. Results of post-pilot test groundwater sampling indicated that although total VOC concentrations decreased during the test, they rebounded to pre-pilot test levels within two months. However, the proportion of PCE dropped substantially relative to the proportion of degradation products (i.e., TCE, cis-1,2-DCE and vinyl chloride) as shown on **Figure 4.3.3-3**. The results suggested that that a reaction (possibly due to bacterial growth stimulated by the presence of carbon in citric acid, a test reagent,) favoring dechlorination was produced by the test. The results of the pilot test indicated that reagents could be delivered with some success to the pore space of the targeted soil volume, and that PCE concentrations could be reduced. However, the method has not been effective in reducing total VOC concentrations in groundwater, either because reagents were not delivered to a sufficient volume of COCs to affect groundwater concentrations, or because advection of COCs into the area occurred after completion of the test.

An enhanced bioremediation pilot test was conducted upgradient from well MW71B-98-13. A pumping test was conducted prior to implementation of the pilot test to assess the feasibility of reagent injection. The pumping test had the unexpected result of both substantially decreasing PCE concentrations in the pilot test area, and altering the relative proportions of constituents (**Figure 4.3.3-4**). After initiation of the pilot test, PCE and total VOC concentrations continued to decline, and the proportions of degradation products increased. In addition, important indicator parameters such as methane, volatile fatty acid and dissolved hydrogen concentrations also increased. These observations suggest that respiration of microbes associated with reductive dechlorination of COCs had occurred, and that the test was effective in the degradation of COCs. A caveat to this finding is that odor and taste impacts from the use of this technology are significant, and have degraded water quality. In addition, the concentrations of dissolved metals increased substantially in the groundwater.

Soil Contamination

The maximum VOC concentrations detected at the unit were 110 mg/kg PCE, 1.4 mg/kg TCE, and 0.8 mg/kg cis-1,2-DCE. The maximum total VOC concentration detected was in a sample collected at 3.5 feet bgs immediately adjacent to Building 71B (**Figure 4.3.3-6**). To address this contamination, two ICMs were conducted, consisting of excavation of contaminated soil in the areas shown on **Figure 4.3.3-6**.

Concentrations of COCs in residual (post ICM) soil samples are listed in **Table 4.3.3-2**. Also listed in the table are the corresponding target risk-based and regulatory-based soil MCSs. PCE is the only COC detected at a concentration that exceeds target risk-based MCSs for soil. The regulatory-based MCSs would apply to the soil COCs since the well yield is greater than 200 gpd in the source area, where the soil COCs have been detected.

Table 4.3.3-2. Maximum Concentrations of COCs Detected in Soil in the Building 71B Lobe of the Building 71 Solvent Plume Source Area

COC	Maximum Concentration Detected (mg/kg)	Target Risk-Based Soil MCS (mg/kg)	Regulatory-Based Soil MCS (mg/kg)
PCE	**47**	0.45	0.45
TCE	0.46	2.3	0.46
cis-1,2-DCE	0.45	38	0.19
trans-1,2-DCE	0.039	50	0.67
methylene chloride	0.24	1.8	0.077

Note: boldface concentration indicates that the concentration exceeds the target risk-based soil MCS.

Residual contamination exceeding the MCSs lies along the east side of the excavation and in localized areas where soil could not be safely removed due to building stability concerns. The residual soil contamination constitutes a continuing source of VOCs that dissolve into groundwater.

Surface Water

The hillside beneath Building 71B is drained by several hydraugers (subhorizontal drains) which intercept the Building 71B lobe in the subsurface. Concentrations of COCs in monthly samples of hydrauger effluent have been below or at MCLs, with the exception of hydrauger 51-01-3 and 51-01-3A, which contained cis-1,2-DCE at a maximum concentration of approximately three times the MCL of 6 ug/L. These hydraugers have had a long-term decreasing trend in concentrations. The hydrauger effluent is currently intercepted and piped to a treatment system and discharged to the sanitary sewer. However, if interception of the effluent were discontinued, the groundwater from the hydraugers would be conveyed to the storm drain system and then to surface water in Blackberry Creek. As a result of dilution and volatilization of COCs; and given the relatively low concentrations in the effluent, untreated water conveyed by the storm drain should be below compliance levels (i.e., detectable levels) once it reaches the creek.

Evidence of DNAPL and Residual Soil Contamination

The relatively low concentrations of COCs observed in post-ICM soil samples indicate that free DNAPLs are probably not present at the unit. PCE concentrations detected prior to the ICMs were only slightly below the PCE soil saturation concentration, indicating that DNAPL may have previously been present at the unit. Similarly, PCE concentrations located at the source zone are greater than 1% of solubility, suggesting the presence of DNAPL, although these concentrations may reflect DNAPLs that were removed as a result of the ICMs.

The lack of declining concentration trends or changes in relative proportions of COCs in groundwater (prior to startup of the pilot tests) indicates that residual soil contamination and DNAPL has probably been present within or adjacent to the saturated zone in the vicinity of the source area. During the soil excavation ICMs, soil contaminated with VOCs at concentrations exceeding target risk-based MCSs was found beneath and adjacent to Building 71B, and residual concentrations exceeding these levels remain in place along the margin of the ICM excavation. However, the mass of contaminants has been significantly reduced by the two ICMs.

4.3.3.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 71B lobe Of the Building 71 Groundwater Solvent Plume:

- Residual soil contamination that exceeds target risk-based MCSs is present beneath Building 71B in the source area of the Building 71B lobe. DNAPLs were likely present in this area in the past, but may have been removed as a result of ICMs. Past rapid increases in groundwater COC concentrations coincident with increased rainfall and groundwater elevation rises suggest that this residual soil contamination resulted in direct impacts to groundwater. The potential for leaching and dissolution of COCs from soil has been substantially reduced as a result of excavation of a significant mass of contaminated soil and diversion of leaking storm drains, although the long-term impact of these actions has not yet been established. Corrective measures at the unit should therefore be based on the remediation of vadose zone soil contamination, and low-level saturated zone residual soil contamination.
- Groundwater flows primarily through relatively low permeability rocks of the Orinda Formation and through surficial units along the former course of Blackberry Creek. The estimated groundwater velocity is roughly 13 feet per year or less.
- Groundwater well yield in the source area is greater than 200 gpd so that regulatory-MCSs are applicable, whereas target risk-based MCSs are applicable to the remaining area of the lobe since well yields are less than 200 gpd.
- Spatial variations in plume chemistry suggest that degradation of COCs in the groundwater has been occurring in near Building 71B during migration, although evidence for degradation in the downgradient portion of the plume is less certain. The lack of a temporal change in the relative proportions of COCs throughout most of the area of the lobe indicates that a state of equilibrium has been reached where degradation rates are similar to rates of desorption and dissolution of soil contaminants and downgradient migration of dissolved COCs. However, concentrations trends indicate that degradation rates may slightly exceed migration rates in the downgradient portion of the lobe.
- Initial results of the ISCO pilot test in the source area indicate that this method was partially effective at delivering reagents in the subsurface, but results were ambiguous in regard to impacts on groundwater COC concentrations.
- Initial results of the enhanced bioremediation HRC pilot test indicate that this method was effective at both delivering reagents in the subsurface, and promoting degradation of COCs in groundwater.

- Migration of COCs beyond the downgradient boundary of the plume does not appear to be occurring, and the decreasing concentration trends observed in wells monitoring this area suggest that the lobe has been retreating.
- Concentrations of COCs are above target risk-based MCSs and regulatory MCSs in both soil and groundwater. The potential human receptor and risk-based exposure pathway of potential concern is exposure to COCs by a hypothetical future indoor worker breathing vapor migrating from the groundwater or soil to indoor air (Berkeley Lab, 2003a).
- Hydrauger effluent derived from the Building 71B lobe contains COCs at concentrations greater than compliance levels. The effluent is currently diverted from storm water discharge and treated at a groundwater treatment system.

4.3.3.3 Evaluation of Retained Corrective Measures Alternatives

Concentrations of soil and groundwater COCs in the Building 71B lobe exceed regulatory-based MCSs for a number of COCs, and exceed target risk-based MCSs for PCE. Since well yield in the source area is greater than 200 gpd, regulatory-based MCSs are applicable in this area. No migration of COCs beyond the lobe margins is occurring, so migration control is not a concern. Transfer of COCs to surface water could potentially occur via hydraugers that drain the area, so corrective measures for groundwater should consider this potential impact.

The corrective measures alternatives that are evaluated for the Building 71B lobe and source area are those that were retained in **Table 4.2.3-1** and **Table 4.2.3-2** (for soil and groundwater, respectively). The results of the evaluation are provided in **Table 4.3.3-3** and discussed below.

<u>No Action</u>

No action for the Building 71B lobe would consist of terminating all groundwater monitoring activities and stopping the collection and treatment of hydrauger effluent. Groundwater concentrations of several COCs would likely result in continued impacts to hydrauger discharges above detectable levels for the foreseeable future. As described above; however, concentrations of COCs in hydrauger effluent have been declining and the COC concentrations should be below levels of concern at the creek. Since COC concentrations in groundwater monitoring wells do not show declining trends, the concentration of PCE would likely remain above target risk-based MCSs for the foreseeable future. These conditions would

Table 4.3.3-3. Evaluation of Corrective Measures Alternatives, Building 71B Lobe of the Building 71 Solvent Plume and Source Area

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (c)	Regulatory Agency Acceptance	Community Concerns
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	yes/no	yes	no	yes	2	2	2	4	1	1
Institutional Controls	yes/no	no	no	yes	3	1	3	4	4	2
Groundwater Containment/Capture	no/no	no	no	yes	3	2	3	3	4	4
Surface Water Capture	no/yes	no	yes	yes	4	1	5	4	3	4
Permeable Reactive Barrier	no/no	no	no	yes	3	2	3	3	4	3
Chemical Oxidation	yes/yes	unknown	yes	yes	2	2	2	2	5	5
Soil Vapor Extraction	no/no	no	yes	yes	2	2	2	3	4	4
Thermally Enhanced SVE/DPE	no/no	no	no	yes	3	3	3	4	4	4
Soil Mixing	yes/yes	Yes	Yes	Yes	3	3	3	4	4	4
Enhanced bioremediation	yes/yes	yes	no	yes	4	4	4	4	4	4
Soil Flushing and Groundwater Extraction	yes/no	yes	yes	yes	3	3	4	3	4	4
Excavation with Offsite Disposal	yes/yes	yes	yes	yes	5	5	5	2	5	4

(a) Level of Compliance Ranking
1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance
1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

require establishment of Institutional Controls to protect future indoor workers. In addition, this alternative would likely be unacceptable to the regulator agencies and the community. The No Action alternative is not protective of human health and the environment and is therefore eliminated from further consideration.

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997. As part of this study, geochemical parameters were measured in well MW90-3, located in the downgradient portion of the Building 71B lobe. Concentrations of geochemical indicator parameters, particularly the relatively high dissolved oxygen concentration, measured in this area were not favorable for natural degradation processes. However, observed ratios of parent-daughter compounds within the plume strongly suggest that degradation occurs in the upgradient portion of the plume during migration, and results of the enhanced biodegradation HRC pilot test indicated that biodegradation can be successfully enhanced in this area. Since a large fraction of the soil COCs in the plume source area have been removed, natural attenuation through biodegradation may be a favorable method for the upgradient portion of the lobe, and the reduction in COC concentrations in the upgradient area would lead to declining concentrations in the downgradient portion of the lobe where conditions suitable for biodegradation do not appear to be present. These observations indicate that MNA could be an effective alternative if the residual soil COCs in the source area that constitute a continuing source of groundwater contamination can be significantly reduced.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The groundwater plume is stable so no containment or capture of the plume boundary is currently required or planned. However, contaminated hydrauger effluent is currently collected and treated to prevent discharge of contaminated water to surface water, so continuing capture and treatment is required as a regulatory compliance measure until discharge to surface water is shown to be below detectable levels.

For the source area soil contamination, containment through capping would reduce the risk to human health; however, it is not recommended since it would likely be unacceptable to the community and its long-term effectiveness would be uncertain without continued maintenance.

Permeable Reactive Barrier/Funnel and Gate

A permeable reactive barrier or funnel and gate system would serve a similar function to a groundwater capture system. Therefore, as noted above, no capture of the plume boundary is currently required or planned. This alternative is therefore not recommended.

Chemical Oxidation

The pilot test indicated that chemical oxidants could be delivered to subsurface soils at the unit, but that the effectiveness of the method for remediating groundwater is questionable as indicated by the short-lived nature of the observed concentration changes. However, the method may be effective at treating localized areas of soil contamination that are inaccessible to other technologies, such as the small zones of contaminated soil that remain adjacent to foundation members beneath Building 71B, although this application of the method was not pilot-tested, so its effectiveness is unknown. Since few other technologies could be implemented in these small zones of soil contamination, and the scale of a pilot test would be similar to full-scale application, it is recommended that this technology be implemented for “hot spot” cleanup of residual soil COCs at the unit.

Soil Vapor Extraction (SVE) and Thermally Enhanced Dual Phase Extraction (DPE)

The effectiveness of SVE systems is controlled by both contaminant volatility and subsurface vapor flow. The solvents detected at the Building 71B lobe source area are highly volatile and can be easily removed from soil and groundwater if sufficient vapor flow through the soil can be established. Thermal heating, in combination with dewatering, dries the soil thereby increasing the effectiveness of an SVE system. However, the method is not effective in low permeability materials (such as the silt and clay material comprising the artificial fill at Building 71B), which still retain excess moisture even with soil drying. In addition, due to the high capital and operating cost of treating a small area such as the Building 71B lobe source area, this alternative is not recommended.

Soil Mixing

Since the remaining soil COCs at the Building 71B lobe source area lie beneath Building 71B, it is not feasible to implement soil mixing at this unit.

Enhanced Bioremediation

Pilot-test data indicate that enhanced bioremediation is an implementable and potentially effective technology in the upgradient portion of the Building 71B lobe. Resultant reductions in groundwater COC concentrations would contribute to attenuation of COC concentrations in downgradient areas. A possible negative effect of HRC is that HRC reagents cause declines in groundwater taste and odor quality and increases in dissolved metals concentrations in the groundwater. However, these declines in groundwater quality should be fairly localized and short term. Enhanced bioremediation is therefore recommended.

Soil Flushing and Groundwater Extraction

During implementation of the ICMs, leaking storm drains that probably contributed to leaching of COCs from the soil to groundwater were found to be located within the Building 71B lobe source area. Since a significant quantity of COCs is still sorbed to the soil matrix in this area, soil flushing could possibly result in increased mobilization of contaminants into the dissolved phase in that area. Clean water from the storm drain effluent could be injected into the gravel-backfilled ICM excavation located at the upgradient edge of the source area soil contamination, and captured by downgradient extraction well(s) or an extraction trench. Application of this technology has been effective in reducing COC concentration levels at the Former Building 7 sump, the source of the Building 7 lobe of the Old Town Groundwater Plume.

Prior to implementing this alternative, however, testing should be completed to assure that the injected water would be captured. This technology is recommended for the Building 71B lobe.

Excavation with Offsite Disposal

Excavation has been effective in removing the contaminated source area soil that is accessible. However, the degree of source removal has been limited due to engineering concerns regarding the stability of the foundation of Building 71B. Most of the contaminated soil that remains is adjacent to foundation members beneath the building, and is not accessible for excavation. Additional excavation is therefore not recommended as a final corrective measure, except for limited areas that are accessible.

Summary of Building 71 Lobe Corrective Measures Implementation Strategy

The remediation objectives for the Building 71B lobe are to: 1) ensure that groundwater COCs above compliance levels (i.e., detectable concentrations) do not migrate to surface water; 2) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs (MCLs) do not migrate into areas where concentrations are less than MCLs; 3) reduce groundwater COC concentrations in the source area where well yield is greater than 200 gpd to below regulatory-based MCSs and target risk-based MCSs; and, 4) reduce soil COC concentrations below target risk-based MCSs. Continuation of surface water capture of hydrauger effluent is required to address objective (1) above, until it can be shown that COC concentrations at the point of compliance (the outfall to the creek) are below levels of detection.

Alternatives recommended to meet objectives (3) and (4) will also help meet objective (2). In addition, after the source area has been remediated and or migration from the source area has been controlled, enhanced bioremediation using HRC can be used to further reduce COC concentrations in the area downgradient from the source.

Soil flushing, chemical oxidation (for unsaturated zone soils only) and excavation with offsite disposal have been identified as potentially effective corrective measures alternatives to meet remediation objectives (3) and (4). A combination of these technologies is recommended for the source zone of the Building 71B lobe. Additional excavation beyond the existing ICM excavations should be conducted to remove soils that are accessible. Despite somewhat ambiguous results pertaining to groundwater COCs, chemical oxidation may potentially be effective in targeting soil in areas not accessible to excavation, and is the only screened technology that could potentially be applied to areas of contamination surrounding foundation members in the source area. Therefore, this technology is proposed for targeting areas not accessible to excavation.

4.3.4 Building 7 Lobe of the Building 7 Groundwater Solvent Plume (AOC 2-4) and the Former Building 7 Sump (AOC 2-5)

Berkeley Lab (at that time known as the Radiation Lab) moved from the UC Berkeley campus to its present location in 1940 in order to construct the 184-Inch Cyclotron, a historic facility used to accelerate atomic particles for use in nuclear physics experiments. The area of the cyclotron building (the original Building 6) and adjacent support shops and laboratories to the north and east of Building 6 formed the core of Berkeley Lab operations throughout the 1940s, and therefore is commonly referred to as "Old Town". Redevelopment of the Old Town Area in the late 1980's resulted in replacement of the 184-Inch Cyclotron building (the original Building 6) with the Advanced Light Source building (the present Building 6) and construction of Building 2, which houses the Advanced Materials Laboratory.

The Old Town Groundwater Solvent Plume is a broad, multi-lobed groundwater plume, composed primarily of halogenated non-aromatic VOCs, which underlies much of the Old Town area. The geometry and distribution of chemicals in the plume indicate that it consists of three coalescing lobes that were originally discrete plumes derived from distinct sources (**Figure 4.3.4-1**). The Building 7 lobe (AOC 2-4) contains significantly higher VOC concentrations than the other two plume lobes, and extends northwestward from the northwest corner of Building 7 to the parking area downslope from Building 58.

Leaks and/or overflows of halogenated non-aromatic hydrocarbons (primarily PCE) from an abandoned sump (the Former Building 7 Sump ([AOC 2-5]) that was located north of Building 7 were the source of the contamination. The COCs were initially released as free product to the soil around the sump and then migrated as DNAPLs into the saturated zone. A sufficient mass of either residual or free-phase DNAPLs remains in the source area to constitute a continuing source of groundwater contamination.

Continuing dissolution of COCs from the soil and westward to northwestward flow of the groundwater from the sump area has resulted in the development of the Building 7 lobe. Originally, the Building 7 lobe was most likely a distinct groundwater plume, but it has coalesced with other plumes (the current Building 52 lobe and Building 25A lobe) associated with other discrete sources in the Old Town Area. The coalesced plumes now constitute the three main lobes of the Old Town Groundwater Solvent Plume.

Extensive sampling of the soil and groundwater was conducted between approximately 1992 and 2003 to characterize the magnitude and extent of COCs in both the area of the former Building 7 Sump, the source area, and in the core areas of the Building 7 lobe. During this period, ICMs were implemented where they were determined to be necessary to protect human health and the environment. In addition, pilot testing was conducted to evaluate the effectiveness and implementability of potential remedial technologies. The ICMs and pilot tests are listed in **Table 4.3.4-1**. The locations of these ICMs and pilot tests are shown on **Figure 4.3.4-2**.

4.3.4.1 Current Conditions

Physiography and Surface Water Hydrology

Most of the developed portion of the Old Town Area lies atop a roughly triangular topographic bench bounded on the west by the Building 6 complex and the west-facing Building 53/58 slope, on the south by the south-facing slope above Strawberry Creek, and on the east by Building 26 and a southeast-facing slope (**Figure 4.3.4-3**). Prior to development, a drainage course flowed from the Building 6 area through the current location of Building 58, continuing northwestward to a confluence with North Fork Strawberry Creek in Blackberry Canyon. This drainage was filled during site development. Downgradient (west) of Building 58, the Building 7 lobe is approximately coincident with the former drainage course.

Surface runoff consists of overland flow off paved and unpaved areas, which is directed to storm drains (**Figure 4.3.4-4**) which discharge into North Fork Strawberry Creek. Storm drain inspections have shown breaks in some of the lines, indicating that water may leak both out of and into the storm drain system at some locations. Known breaks were identified just west of the former Building 7 sump, and were repaired in 2003. Prior to repair, these breaks probably constituted sources of artificial groundwater recharge during the rainy season.

Table 4.3.4-1. Summary of ICMs and Pilot Tests Conducted for the Former Building 7 Sump and the Building 7 Lobe

Date	Location	Comments
Excavation and Removals		
1992	Source location	Removal of the contents (free product) in the Building 7 Sump, the source of the Building 7 lobe.
1995	Source location	Removal of the Building 7 Sump and excavation of source area soil to a depth of 17 feet to remove highly contaminated soil and free product.
In-Situ Soil and/or Saturated Zone Flushing		
1996 ongoing	Source zone immediately downgradient from the Former Building 7 Sump location	Groundwater extraction from the Building 7 Groundwater Collection Trench. Treatment of extracted groundwater with a Granular Activated Carbon (GAC) treatment system, and recirculation of the treated water into the 17-feet deep (approximate top of saturated zone) gravel-filled sump excavation. Method has been effective in reducing concentrations of COCs in the groundwater and soil in the source zone and controlling downgradient migration of groundwater COCs.
1998 ongoing	Leading edge	Extraction of groundwater from the Building 58 West Groundwater Collection Trench at the downgradient edge of Building 7 lobe. Installed to control migration of the downgradient edge of the Building 7 lobe. Method has been effective in controlling migration of the leading edge of the Building 7 lobe.
1999 ongoing	Core zone	Extraction of groundwater and soil gas from the Building 58/58 Slope Groundwater Collection Trench. Starting in October 2003, treated groundwater was discharged on the slope above the collection trench to flush the downslope core zone. Method has been effective in controlling downgradient migration of the core zone. Effectiveness in reducing contaminant mass has not been determined.
2002 ongoing	Downgradient edge of the core zone	Extraction of groundwater from Building 58 East Groundwater Collection Trench. Starting in October 2003, treated groundwater was discharged on the slope above the collection trench to flush the downslope core zone. Method has been effective in controlling downgradient migration of the core zone. Effectiveness in reducing contaminant mass has not been determined.
2002-ongoing	Core zone downgradient from the Building 7 Groundwater Collection Trench.	Injection of treated groundwater into six injection wells. Capture of the injected water at three downgradient extraction wells and from the upgradient collection trench. Effectiveness in reducing COC concentrations in groundwater in core zone has not been determined.

Thermally Enhanced Soil Vapor Extraction Pilot Test		
2001 ongoing	Source zone immediately downgradient from the Former Building 7 Sump	Conductive electrical heating of soil in three boreholes combined with extraction of both soil vapor and groundwater from one central and three peripheral extraction wells. Method has been effective in removing contaminant mass from the source zone
In Situ Methanotrophic Treatment Technology (MTT) Pilot Test		
2000	Building 7 lobe core zone downgradient from the Building 7 Groundwater Collection Trench	A mixture of air, methane, nitrous oxide, and triethylphosphate was injected into the subsurface to stimulate the growth of microorganisms. Method was not effective in reducing contaminant mass in the groundwater in the core zone
Migration Control Compliance Measure		
1998	Building 7 lobe periphery zone	A drain line was plugged and a sump was installed to capture contaminated effluent to prevent migration of contaminated water through the drain system to surface water. Method has been effective in controlling migration of contaminated water to surface water.

Geology

The Building 7 lobe area is underlain at relatively shallow depth by three main bedrock units (**Figure 4.3.4-5**). The Orinda Formation is the deepest-encountered rock unit, and extends to a depth greater than 190 feet near Building 53. The Orinda Formation is overlain by volcanic and volcaniclastic rocks of the Moraga Formation over much of the northwestern part of the Old Town Area. Although some outcrops of Moraga Formation appear to be relatively undisturbed, most outcrops consist of loosely consolidated, poorly sorted, angular blocks composed of Moraga Formation rock types (andesitic volcanic breccia, andesite, thin sandy siltstone layers, volcaniclastic gravelly sandstone, and minor basalt).

In many places, rocks found along the contact between the Moraga and Orinda Formations comprise a mixture of rock types common to both formations, and are mapped as the “Mixed Unit”. The Mixed Unit appears to represent structurally interleaved portions of the Moraga and Orinda Formations. Rocks of both the Moraga Formation and Mixed Unit in the Building 7 Area are interpreted to represent ancient landslide deposits emplaced before development of the current topography.

Overlying the bedrock, a thick section of colluvium is present in the lower part of the former drainage course immediately beneath and west of Building 58. The colluvium is overlain by up to 40 feet of artificial fill that was placed in the drainage course that flowed from the vicinity of Building 6 through the current location of Building 58. Alluvium and colluvium are relatively thin in other parts of the Building 7 Area.

As shown on **Figures 4.3.4-6 and 4.3.4-7**, the contacts between these units dip northward to northwestward in the Building 7 lobe area. In general, the upper contact of the Orinda Formation has high relief, forming bowl-shaped depressions that are occupied by the Mixed Unit, Moraga Formation, colluvium, and artificial fill (**Figure 4.3.4-8**).

Hydrogeology

The surficial units (i.e., alluvium, colluvium and artificial fill) are generally above the water table, except for colluvium within the former drainage course that trends northwestward beneath Building 58 (**Figures 4.3.4-8**). Slug tests and pumping tests of wells have shown that both the Orinda Formation and the Mixed Unit have relatively low hydraulic conductivities, typically on the order of 10^{-8} to 10^{-9} meters per second. Deep horizons of the Orinda Formation (>130 feet bgs) intercepted by a four-level well cluster (MW53-92-21) immediately north of the Building 7 lobe have even lower hydraulic conductivities, on the order of 10^{-12} to 10^{-13} meters per second. These data indicate that groundwater flow in the Orinda Formation in this area is insignificant, which is verified by the negligible to nondetectable levels of contamination observed in wells screened within the Orinda Formation.

The Moraga Formation volcanic rocks that occupy depressions in the undulatory upper contact of the Orinda Formation have relatively high hydraulic conductivities (typically on the order of 10^{-4} to 10^{-6} meters per second) in comparison to the underlying units, and therefore constitute preferential flow pathways. For this reason, the structure of this undulatory contact between the Orinda Formation and the overlying units has a strong influence on groundwater flow. The contact is illustrated on cross-section A-A’ (**Figure 4.3.4-8**). The hydraulic conductivity of colluvium below Building 58 along the downgradient portion of the Building 7 lobe is unknown, but is expected to be intermediate between those measured for the Moraga and Orinda Formations.

Water level elevation contours (**Figure 4.3.4-9**) show that groundwater generally flows northwestwards in the Building 7 Area, although, flow is locally deflected to the north in the vicinity of Building 53, to the north of Building 7. This local northward-directed flow is due to the geometry of contacts between relatively low hydraulic conductivity Orinda Formation rocks and higher hydraulic conductivity Moraga Formation and Mixed Unit rocks. **Figure 4.3.4-10** shows the distribution of geologic units at the water table in the Old Town Area, which affect the groundwater flow pathways. Groundwater flow directions are also locally influenced by groundwater extraction and reinjection associated with ongoing pilot tests and ICMs located primarily west and northwest of Building 7.

Groundwater flow modeling has been conducted for the Old Town Plume, including the Building 7 lobe, using the ITOUGH2 code (Zhou and others, 2004; Preuss and others, 1999). The modeling, along with slug test data, was used to estimate rock physical characteristics (i.e., hydraulic conductivity and effective porosity) based on matching of seasonal variations in groundwater elevations. Modeled flow velocities are typically between 0.1 and 1 feet per day (37 to 365 feet per year) within the core of the Building 7 lobe, although velocities in the downgradient periphery are somewhat greater (**Appendix D**), indicating that groundwater at the head of the Building 7 lobe would take several years to reach the toe of the lobe.

Groundwater wells in the Building 7 lobe central core zone generally yield less than 200 gpd, whereas wells in the area immediately surrounding the central core zone have short-term yields greater than 200 gpd (**Figure 4.3.4-11a**).

Groundwater Contamination

The principal Building 7 lobe constituents are halogenated non-aromatic VOCs that were used as cleaning solvents, including PCE and carbon tetrachloride, and their associated degradation products (e.g., TCE 1,1-DCE, cis-1,2-DCE, and vinyl chloride), most of which have been detected at concentrations above MCLs. In addition, benzene, an aromatic VOC, has been detected in one deep well in the vicinity of the lobe, but does not appear to be associated with the Building 7 lobe and may be naturally occurring. Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.4-2,** where the maximum detected concentrations are compared to the target risk-based MCSs.

Table 4.3.4-2. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 7 Lobe of the Old Town Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Regulatory-Based Groundwater MCS (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
TCE	**79,300**	5	1,594
PCE	**76,035**	5	343
carbon tetrachloride	**4,600**	0.5	27
cis-1,2-DCE	1,240	6	98,405
trans-1,2-DCE	13	10	94,405
1,1-DCE	550	6	28,873
chloroform	150	100	1,206
methylene chloride	1,600	5	10,381
1,1-DCA	44.6	5	3,663
1,2-DCA	6.6	0.5	1,030
1,2-dichloropropane	7.2	5	1,071
vinyl chloride	75	0.5	12
1,1,2-TCA	8.1	5	1,905
Benzene	8.9	1	175

Note: boldface concentration indicates that the maximum detected concentration of the COC exceeds the target risk-based groundwater MCS.

Distribution of COCs

The highest contaminant concentrations are found in wells along the elongate core of the Building 7 lobe northwest (downgradient) of the former Building 7 sump (**Figure 4.3.4-11a and Figure 4.3.4-11b**). The vertical distribution of total halogenated non-aromatic VOCs in the Building 7 lobe is depicted on cross section A-A’ (**Figure 4.3.4-12**). Isoconcentration contours on the cross section depict a steep concentration gradient across the contact between the Moraga Formation and the underlying Orinda Formation below the core of the Building 7 lobe. This observation is commonly observed in other areas of the Old Town plume where closely located wells are screened at multiple depth horizons (Berkeley Lab, 2000).

Prior to 1997, the highest concentrations were detected in the source area immediately adjacent to the Former Building 7 Sump in monitoring well MW7B-95-21. Concentrations have declined in that well due to extraction and treatment of groundwater from the Building 7 Groundwater Collection Trench. The highest VOC concentrations are now detected in the core area in wells MP7-99-1B and MW58-00-12, both of which contain approximately 90,000 µg/L of halogenated VOCs, composed primarily of nearly equal concentrations of PCE and TCE.

Groundwater COC Trends

Concentration trends for total halogenated non-aromatic VOCs in the Building 7 lobe are shown on **Figures 4.3.4-13a**, **4.3.4-13b**, **4.3.4-13c**, **4.3.4-13d** and **4.3.4-13e**. The concentrations of VOCs detected in most of the wells monitoring the lobe have been relatively stable or have declined. The declining trends, particularly in the source area, are primarily the result of the ICMs and pilot tests that have been implemented. The most marked long-term decline in concentrations has been observed in monitoring well MW7B-95-21, which is located between the Former Building 7 Sump and the Building 7 Groundwater Collection Trench. The concentration of total halogenated VOCs detected in MW7B-95-21 has declined from approximately 300,000 µg/L to 10,000 µg/L or less. This decline is attributed primarily to the effects of soil flushing. Concentrations have remained low since soil flushing was halted at the beginning of 2003.

In situ soil flushing has had mixed results in reducing COC concentrations in the Mixed Unit. The Building 7 soil flushing pilot test consists of injection of treated-groundwater into six injection wells in the lobe core area, with the saturated screen intervals of the wells within the Mixed Unit. The test has resulted in significant declines in COC concentrations in MW7-95-23, which is screened in the Mixed Unit and Orinda Formation **(Figure 4.3.4-13b)**. However, flushing has not resulted in observable effects on COC concentrations measured in core area wells screened solely within low permeability rocks of the Mixed Unit (e.g., wells MP7-99-1B and MP7-99-2B). The soil flushing pilot test was expanded in 2003 to include discharge of treated-groundwater to surface soil at the top of the Building 53/58 slope and into well MW53-93-16. As a result of this action, groundwater COC concentrations have declined to approximately

50% of the pre-injection levels in well MW58-00-12. MW58-00-12 is screened in the Mixed Unit and Orinda Formation, indicating that flushing of the Mixed Unit may be effective in some areas.

The proportion of dissolved PCE degradation products (e.g., TCE and cis-1,2-DCE) relative to PCE increases with distance downgradient from the source area, indicating that Building 7 lobe constituents have degraded as they have migrated. This is illustrated by comparing the relative proportions of parent to daughter products in wells MW7-92-19 (source area well), MW58-93-3, and MW58A-94-14 (downgradient well) (**Figure 4.3.4-14a, Figure 4.3.4-14b, and Figure 4.3.4-14c**).

The general downgradient decrease in the ratio of parent to daughter products indicates that degradation of constituents occurred during initial migration of the plume; however, recent data indicate that for the lobe core area, migration has superseded degradation as the dominant fate process. This is illustrated in well MW58-93-3, located at the downgradient edge of the core where the proportion of PCE has increased relative to its degradation products (**Figure 4.3.4-14b**). However, the available data suggest that natural degradation is the dominant fate process downgradient (west) of Building 58. This is illustrated in well MW58A-94-14, at the leading edge of the lobe, where long-term decreases in both the total concentration of halogenated VOCs and the parent to daughter ratio are observed (**Figure 4.3.4-14c**). These conclusions are supported by the site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs that was conducted in 1997. The data collected were generally not indicative of conditions favorable for natural degradation throughout most of the Building 7 lobe, except for the downgradient area (MW58A-94-14) where a relatively low dissolved oxygen concentration was measured.

Soil Contamination

Pre-Remediation Soil Contamination

In 1992, an abandoned concrete sump was discovered between Buildings 7 and 7B (**Figure 4.3.4-15**). The sediment and liquid within the sump and soil covering the ditch were sampled and removed. PCE (free product) was detected in the sump. Soil investigations conducted between 1992 and 1995 showed that PCE was the primary contaminant, with TCE, 1,1,1-TCA, cis-1,2-DCE, and 1,1-DCE also detected at relatively high concentrations. The maximum PCE concentration in soil (14,000 mg/kg) was detected at a depth of 2.8 feet, within a few feet of the sump. Elevated PCE concentrations (>100 mg/kg) were generally restricted to the upper 20 feet of soil within a few feet south and west of the sump. The PCE concentrations measured in soil below the water table were generally less than 100 mg/kg. A zone of elevated concentrations exceeding 1 mg/kg was detected within the Mixed Unit in an area extending westward from the sump (**Figure 4.3.4-16**).

Post-Remediation Residual Soil Contamination

ICMs and Pilot Tests

In 1992, the concrete slab covering the sump was removed, and the sediment and liquid in the sump, and soil filling the adjacent concrete ditch, were removed and disposed. In 1995, the sump was removed and approximately 70 cubic yards of the surrounding contaminated soil was excavated to a depth of 17 feet from an area approximately 10 feet long by 7 feet wide (**Figure 4.3.4-15**). These ICMs resulted in the removal of a large fraction of the highly contaminated vadose zone soil from the site, although soil remaining at the base of the excavation contained up to 1,000 mg/kg PCE.

Subsequent to the soil-removal ICMs, the contaminant mass immediately downgradient from the former sump location has been reduced by: 1) groundwater injection and soil flushing between the Building 7 sump ICM excavation and the Building 7 Groundwater Collection Trench; and 2) operation of the thermally enhanced DPE pilot test.

Groundwater infiltration into the gravel-filled ICM excavation was initiated in 1997, using treated groundwater extracted from the Building 7 collection trench. The infiltrating groundwater has leached downward to the saturated zone and then flowed northwestwards and been recaptured by the Building 7 Groundwater Collection Trench. This process was been generally continuous from May 1997 through June 2001, at which time infiltration was discontinued to help improve the effectiveness of the thermally enhanced DPE pilot test. Almost two million gallons of treated water was pumped into the remedial excavation and approximately 50 kg of VOCs were removed from the groundwater during this period, indicating an average removal rate of slightly less than 1 kg/month, which declined asymptotically to very low levels.

Confirmation soil samples collected from the floor of the ICM excavation prior to groundwater infiltration had concentrations between 300 and 1,000 mg/kg total VOCs (**Figure 4.3.4-17**). Soil sampling conducted through the excavation backfill in 2002 (SB7HTC-02-1) and 2003 (SB7-03-2), approximately five years after injection of treated groundwater was initiated, indicated that VOCs in soil beneath the central part of the ICM excavation had been significantly reduced by flushing (0.09 mg/kg total VOCs maximum). However, concentrations of VOCs in soil at the west edge of the excavation were essentially unchanged (720 mg/kg total VOCs maximum), indicating that the effects of flushing were localized.

The thermally enhanced DPE pilot test started operating in July 2001, and has operated primarily during the summer and fall seasons since that time. The system consists of three heater wells, four DPE wells, and two instrument wells **(Figure 4.3.4-17**). Starting in October 2003, the system was enhanced by injection of hot air under pressure. Approximately 700 kg of contaminant mass have been removed from the extracted soil gas during this period, indicating an average removal rate greater than 1 kg/day.

Residual Soil COC Concentrations

Residual contamination primarily consists of PCE, which was present at a maximum concentration of 3,000 mg/kg in heater instrument well HI7-00-1. As shown on **Figure 4.3.4-17** and **Figure 4.3.4-18**, most of the soil near the former Building 7 sump contains relatively low concentrations of VOCs (<1 mg/kg), and soil containing elevated VOC concentrations is confined to relatively thin zones that are generally less than 5 feet thick. Maximum detected concentrations of VOCs in soil remaining after excavation are shown in **Table 4.3.4-3**.

Table 4.3.4-3. Maximum Concentrations of COCs Detected in Soil at the Former Building 7 Sump

COC	Maximum Concentration Detected (mg/kg)	Target Risk-Based Soil MCS (mg/kg)	Regulatory-Based Soil MCS (mg/kg)
PCE	**3,000**	0.45	0.7
TCE	**60**	2.3	0.46
cis-1,2-DCE	0.043	38	0.19
1,1,1-TCA	11	690	7.8
1,1-DCA	0.024	1.3	0.2
1,1-DCE	0.16	8	1.0
Benzene	0.0091	0.1	0.044
Carbon tetrachloride	**10**	0.05	0.11
Chloroform	0.092	0.28	2.9
Vinyl chloride	**0.0049**	0.0035	0.085

Note: boldface numbers indicate concentrations above target risk-based MCS.

Most of the VOC concentration data depicted on the figures were collected prior to startup of the thermally enhanced SVE pilot test. Removal of VOCs by the pilot test has occurred approximately within the heated zone shown on the figures, and VOC concentrations within the zone have likely decreased significantly below those shown.

Soil samples have been collected from a number of borings located west of the Building 7 collection trench. Halogenated VOC concentrations in these borings are generally orders of magnitude lower than those detected east of the collection trench, with the maximum concentrations (4.1 mg/kg PCE and 2.4 mg/kg TCE) detected in boring SB7B-95-7, located approximately 50 feet west of the collection trench. Both PCE and TCE concentrations in groundwater samples from wells (MP7-99-1B and MP7-99-2B) near this boring are approximately 40,000 µg/L. Assuming a soil porosity of approximately 25%, and a bulk density of approximately 1.6, the mass of TCE or PCE dissolved in groundwater alone would be sufficient to result in soil concentrations of approximately 6 mg/kg. This observation indicates that the soil results west of the Building 7 collection trench are likely indicative of groundwater contamination, rather than residual soil contamination in the soil samples.

Evidence of DNAPL

PCE was detected at concentrations substantially above its estimated Berkeley Lab soil saturation concentration of 178 mg/kg **(Table 4.2.2-1)** in a number of samples collected between the Former Building 7 Sump and the Building 7 Groundwater Collection Trench (**Figure 4.3.4-17 and Figure 4.3.4-18)**. These relatively high concentrations indicative of the presence of free-phase DNAPL were present in several relatively thin zones within the Mixed Unit, extending to a maximum depth of approximately 35 feet. Given the large mass of VOCs that has been extracted during operation of the thermally enhanced SVE pilot test, it is likely that the volume of DNAPL has been reduced in the pilot test area; however, some DNAPL probably still remains based on the PCE concentration of 720 mg/kg (above the soil saturation level) detected in a soil sample collected from boring SB7HTC-02-1 in 2002.

In addition to inferences drawn from soil concentration data, groundwater samples collected from MW7B-95-21 located between the Former Building 7 Sump and the groundwater collection trench exceeded 1% of effective pure-phase volubility criteria for PCE and TCE, indicating that free-phase DNAPL was likely present. Although concentrations have declined in MW7B-95-21 to well below the solubility criteria, samples collected from lysimeters at several depth horizons in the heater test instrument wells have groundwater concentrations close to or in excess of 100% of PCE solubility, indicating the presence of DNAPL within the samples.

The presence of DNAPL in the area downgradient from the Building 7 Groundwater Collection Trench, is uncertain. PCE concentrations have been below soil saturation levels in all of the samples collected west of (downgradient) from the Building 7 Groundwater Collection Trench. The soil data, however, cannot rule out the presence of DNAPL since the sampling intervals were primarily 5 feet or greater, generally insufficient to delineate DNAPL-impacted zones, and sampling depths may have been too shallow to detect DNAPL that migrated downdip within the Mixed Unit.

Groundwater COC concentrations exceed 1% of their solubilities in several wells downgradient from the Building 7 Groundwater Collection Trench. The area of the Building 7 lobe where concentrations of PCE exceed 1% of solubility (i.e., approximately 2,000 ug/L) coincides with the Building 7 lobe core area shown on **Figure 4.3.4-19**. However, the area in which DNAPL might be present would likely to be smaller, since the groundwater concentrations are controlled by the hydraulic and chemical characteristics of the plume (i.e., dispersion, diffusion, retardation, etc), in addition to the rate of dissolution of DNAPL into the groundwater.

The Building 7 Groundwater Collection Trench penetrates into the relatively low permeability Orinda Formation, below the deepest levels where elevated soil VOC concentrations have been detected in soil samples. Therefore, it is assumed that the collection trench intercepts essentially all groundwater contamination and DNAPL migrating from the source area. If this is the case, and if DNAPL is not present downgradient from the collection trench, then groundwater COC concentrations should have declined in the downgradient area as the cut-off portion of the lobe migrated downgradient away from the trench. For wells located approximately 10 feet or more downgradient from the collection trench (e.g., MP7-99-1B, MP7-99-2B, and MW7B-95-24), COC concentrations have remained relatively stable at concentrations greater than 10% of solubility. This suggests either that DNAPL is present west of the collection trench, or that groundwater velocities are so low that the lobe is essentially stagnant in this area.

4.3.4.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 7 lobe of the Old Town Groundwater Solvent Plume and the Former Building 7 Sump source area:

- The only known DNAPL in the Building 7 area lies in thin, generally westward-dipping zones of fractured rock of the Mixed Unit in the area between the Former Building 7 Sump and the Building 7 Groundwater Collection Trench. The DNAPL is present in the saturated zone in thin layers between approximately 20 and 35 feet bgs, and continues to provide a source for dissolution of contaminants into groundwater. Migration of COCs from the source area is prevented by continuing operation of the Building 7 Groundwater Collection Trench.
- No definitive evidence exists for the presence of residual or free-phase DNAPL west of the trench, so contamination consist primarily of dissolved-phase COCs in groundwater equilibrium with sorbed COCs derived from the migration of dissolved contaminants. However, it is possible that some undetected DNAPL may be present in this area. Operation of two additional groundwater collection trenches prevents further migration of the core area.

- Within the core of the Building 7 lobe, relatively permeable rocks of the Moraga Formation are thin or absent at the water table. Groundwater contaminants are primarily present in lower permeability rocks of the Mixed Unit because groundwater flow flushes contaminants from the higher permeability Moraga Formation. The low permeability of the Mixed Unit hinders flushing and results in retention of contaminants.
- The Building 7 lobe is elongated along the direction of groundwater flow, consistent with advection being the predominant contaminant transport mechanism, as would be expected given the relatively steep groundwater gradients and moderate permeabilities of the upper portion of the saturated zone. Estimated groundwater velocities are relatively slow, less than 1 meter per year in the Mixed Unit and Orinda Formation.
- Wells within the core of the Building 7 lobe generally have sustainable yields of less than 200 gpd, so target risk-based MCSs are applicable in this area. However, most wells in the lobe periphery have short-term yields exceeding the 200 gpd criteria, so regulatory-based MCSs (MCLs) are applicable in that area.
- Contaminant concentrations and hydraulic conductivity values decrease with depth, as indicated by analytical data from multi-well clusters and hydraulic test data. Advective transport downward into, and laterally within, the deeper horizons of the Orinda Formation, is insignificant.
- Spatial and temporal concentration trends suggest that degradation of VOCs occurred during initial migration of the Building 7 lobe to its present configuration. However, evidence of continued degradation is lacking except in one well located at the downgradient edge of the lobe.
- Concentrations of COCs exceed target risk-based MCSs in groundwater in the source and core areas, and PCE and TCE exceed target risk-based soil MCSs in the source area. The potential human receptors and risk-based exposure pathways of potential concern are exposure to COCs by hypothetical future indoor workers breathing vapor migrating to indoor air from soil or from groundwater, by landscape maintenance workers breathing vapor migrating to outdoor air from soil, and by intrusive construction workers contacting groundwater (Berkeley Lab, 2003a).

4.3.4.3 Evaluation of Retained Corrective Measures Alternatives

For the purpose of evaluating corrective measures alternatives and recommending the technology to implement, the Building 7 lobe was divided into the following three discrete areas, based on different remediation objectives (**Figure 4.3.4-19**).

1) The lobe *source area* contains both soil and groundwater COCs at concentrations exceeding target risk-based MCSs. In addition, DNAPL is known to be present.

2) The lobe *core area* comprises an elongate zone of dissolved groundwater COCs at concentrations that exceed target risk-based MCSs. The presence of DNAPL in this area is uncertain; however, given the relatively high concentrations of some COCs in the groundwater, this area may also contain some DNAPL that migrated from the source area prior to construction of the Building 7 Groundwater Collection Trench. It is also likely that COCs are sorbed to the soil in this area as the result of sorption of COCs from the groundwater.
3) The *lobe periphery area* surrounds the core area and comprises an extensive zone of dissolved groundwater COCs at concentrations exceeding regulatory-based MCSs (MCLs). Since COC concentrations in the groundwater in the periphery are below target risk-based MCSs, cleanup of this area is considered a lower priority than cleanup of the source and core areas. In addition, remediation of the periphery area would likely not be effective until cleanup of the core is sufficient to prevent the migration of groundwater COCs into the periphery at concentrations above the applicable MCSs.

Alternatives Applicable to the Former Building 7 Sump and Building 7 Lobe Source Area

The source area contains thin zones of residual and free-phase DNAPL that are primarily present in relatively deep (20 to 35 feet bgs) horizons of the Mixed Unit. Dissolved groundwater concentrations have been controlled in recent years by the balance between continued dissolution of COCs into groundwater, flushing of treated groundwater through the saturated zone, and changes in operations of the thermally enhanced SVE pilot test. Since COCs are present both in the dissolved phase in the groundwater and as residual and/or free-phase DNAPL, all retained alternatives listed in **Tables 4.2.3-1 and 4.2.3-2** (for soil and groundwater, respectively) were evaluated. The results of the evaluation are provided in **Table 4.3.4-4** and discussed below.

No Action

No action for the Building 7 lobe source area would consist of termination of all groundwater monitoring activities and stopping extraction and recirculation of groundwater from the Building 7 Groundwater Collection Trench. Soil and groundwater COC concentrations would remain above both target risk-based and regulatory-based MCSs for the foreseeable future. These conditions would require establishment of Institutional Controls to protect human health. Dissolution of COCs into groundwater would increase the rate of migration of dissolved COCs from the source area into the core area. In addition, this alternative would likely be

Table 4.3.4-4. Evaluation of Corrective Measures Alternatives, Former Building 7 Sump and Building 7 Lobe Source Area

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protective of Human Health / Environment	Attain MCSs	Control Migration (c)	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (d)	Regulatory Agency Acceptance	Community Concerns
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	no/no	no	no	yes	1	1	1	4	1	1
Institutional Controls	yes/no	no	no	yes	2	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	yes	yes	4	2	4	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/no	no	no	yes	1	1	1	3	4	3
Chemical Oxidation	yes/yes	unknown	na	yes	3	3	3	3	5	5
Enhanced bioremediation	yes/yes	no	no	yes	1	1	1	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	no	na	yes	3	2	2	3	4	4
Thermally Enhanced Dual Phase Extraction	yes/yes	unknown	yes	yes	3	4	2	3	5	5
Soil Containment – Capping, Solidification, Stabilization	yes/no	no	no	no	1	1	1	3	1	1
Excavation and Offsite Disposal	yes/yes	yes	yes	yes	5	5	5	2	5	4
Soil Mixing	yes/yes	unknown	yes	yes	3	3	2	2	5	5
Soil Mixing and Chemical Oxidation	yes/yes	yes	yes	yes	4	4	4	2	5	5

(a) Level of Compliance Ranking
1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance
1. None
2. Low
3. Partial
4. Moderate
5. High

(c) na; not applicable

(d) relative cost from 1 (high) to 5 (low)

unacceptable to the regulator agencies and the community. This alternative is not protective of human health and the environment and is therefore not recommended.

Monitored Natural Attenuation

COCs are present in the source area both as DNAPL and sorbed to the soil matrix at concentrations that will result in continued dissolution of COCs into groundwater. Until continued dissolution of COCs into the groundwater can be prevented, MNA would not be effective. In addition, even if dissolution were prevented, a considerable amount of time would be required for MNA to be effective, if it could be effective at all, given the high concentrations of COCs in the groundwater. MNA is not protective of human health and the environment and is therefore not recommended.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

Groundwater capture by itself is not an effective technology for reducing groundwater COC concentrations in the source area, primarily because of the presence of DNAPL in the saturated zone. However, containment of source area COCs would likely help expedite remediation of the downgradient core area. This alternative is not effective by itself in protecting human health or attaining MCSs and is therefore not recommended, except if used in combination with groundwater flushing, as described below.

Permeable Reactive Barrier/Funnel & Gate

This alternative is not effective in protecting human health or attaining MCSs in the source area due to the high concentrations of COCs currently present in the groundwater, and is therefore not recommended.

Chemical Oxidation

The effectiveness of in situ chemical oxidation for remediation of the source area is not known and would require pilot testing prior to any full-scale implementation. It was not possible to pilot-test this technology due to the ongoing thermally enhanced SVE pilot test being conducted in the small source area. In situ chemical oxidation is generally not effective in low permeability materials such as the Mixed Unit where the COCs are primarily present in the source area. Pilot testing of this technology in the low permeability Building 51L Groundwater Solvent Plume source area and Building 71B plume source area was not effective. For these reasons, chemical oxidation is not recommended.

Enhanced Bioremediation

Based on the results of an enhanced bioremediation pilot test (methanotrophic treatment technology pilot test) that was conducted in the Building 7 lobe core area, enhanced bioremediation would not be an effective technology in the source area. The pilot test was not effective in delivery of the enhancing agents to the source solvents in the low permeability/heterogeneous Mixed Unit where it was tested. Similar results would be expected in the source area, where the COCs are also primarily present in the Mixed Unit. Enhanced bioremediation is therefore not recommended.

Soil Flushing and Groundwater Extraction

Treated groundwater has been extracted from the Building 7 Groundwater Collection Trench and periodically injected into the Former Building 7 sump excavation since 1997. This source area flushing has resulted in decreases in soil COC concentrations in soil beneath the injection area, and decreases in groundwater concentrations to levels below target risk-based MCSs. Although groundwater concentrations have remained below target risk-based MCSs without flushing for almost a year, the data are insufficient to assess whether the groundwater concentration reductions will be permanent. Given the presence of DNAPL in the saturated zone, COC concentrations in groundwater would likely rebound to levels well above the target risk-based MCSs if groundwater capture and flushing were terminated. Therefore, although this technology can temporarily reduce concentrations below target risk-based MCSs, it is reliant on continued operation to maintain these levels. Therefore, this technology is recommended only as a temporary control measure until other alternative(s) can permanently reduce COC concentrations to the required levels.

Soil Vapor Extraction and Thermally Enhanced Dual Phase Extraction (DPE)

The effectiveness of soil vapor extraction (SVE) is controlled by both contaminant volatility and subsurface vapor flow. In low permeability soils and in soils with high moisture contents, such as the Mixed Unit, flow rates adequate to remove contaminants cannot be achieved by SVE alone. Thermal heating, in combination with dewatering, dries the soil, thereby increasing the effectiveness of an SVE system. This technology has been effectively pilot-tested in the Mixed Unit in the Building 7 lobe source area, where over 700 kg of contaminant mass have been removed from the extracted soil vapor.

Although the system was installed as a pilot test, it is appropriately designed and located to continue removing contaminant mass from the source area; however, it is not known whether continued operation of this system will reduce COC concentrations below target risk-based MCSs. Once the contaminant mass removed by the system approaches an asymptotic level, the need for further corrective measures would be assessed by 1) collecting confirmation soil samples to compare to the MCSs and 2) comparing groundwater concentrations to the MCSs after any rebound has occurred. If further corrective measures are required to attain MCSs, either the system could be modified or expanded (e.g., installing additional heater or DPE wells), or an alternate technology (i.e., excavation and offsite disposal) could be implemented. A benefit of this alternative is that except for any system expansion costs, there would be no added cost for installation. Thermally enhanced DPE is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe source area using the decision factors shown in **Table 4.3.4-4**.

Soil Containment

Containment can be somewhat effective in protecting human health in the short term, but less effective in the long-term. Capping would not prevent the continued dissolution of COCs into the groundwater and subsequent downgradient migration. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies or the community. For these reasons containment is not recommended.

Excavation and Offsite Disposal

Excavation of soil beneath and adjacent to the Former Building 7 Sump was conducted as an ICM in 1995. The excavation was completed by drilling large-diameter borings. A similar method is proposed for any additional source removal, because of the depth of excavation that would be required. Since relatively small volumes of residual soil contamination can result in continuing impacts to groundwater, this method would be modified to provide sufficient overlap of the auger holes so that all of the contaminated soil could be removed. Such a modification would likely involve drilling an initial set of spaced auger holes, backfilling them with a cement grout mixture, then drilling a second set of intervening auger holes, which partially overlapped the original holes.

The extent of any excavation would not be determined until post-pilot test soil samples are collected and compared to MCSs. Therefore, prior to excavation, soil samples will be collected to determine the extent of excavation that would be required. Post-excavation groundwater concentrations would likely decline to levels below target risk-based MCSs, but would probably remain above regulatory-based MCSs, since low levels of soil contamination in equilibrium with dissolved groundwater COCs would continue to be present in groundwater adjacent to the excavated area. Excavation and offsite disposal is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe source area using the decision factors shown in **Table 4.3.4-4**.

Soil Mixing

Soil mixing consists of using drilling equipment to break up the soil and increase the permeability, generally simultaneously with vapor extraction to remove volatilized contaminants. The method has been used in conjunction with injection of chemical reagents (e.g., oxidants), to destroy contaminants, or chemical reagents combined with grouts to stabilize contaminants. Injection of chemical oxidants, as described under Chemical Oxidation above, would likely increase the reliability and effectiveness of this method.

If implemented in the plume source area, this method would be used to break up and mix the low permeability Mixed Unit with the overlying higher permeability Moraga Formation. This would increase the permeability and allow flushing/extraction of the contaminants. Since thermally enhanced SVE was being pilot tested in the relatively small plume source area, it was not possible to pilot test this technology. Soil mixing is an implementable technology for the plume source area, but the effectiveness of this technology is not known. Excavation is preferred to soil mixing in the source area since excavation would be effective and the cost of soil mixing would be higher than the costs of excavation, given the small source area and the need for pilot testing soil mixing prior to implementation. Soil mixing is therefore not recommended.

Summary of Former Building 7 Sump and Building 7 Lobe Source Area Corrective Measures Implementation Strategy

The initial remediation objectives for the source area of the Building 7 lobe of the Old Town Groundwater Plume source area are to: 1) remove any residual or free-phase DNAPLs that continue to result in dissolution of COCs into groundwater; 2) decrease vadose zone soil COC concentrations below target risk-based MCSs; and, 3) decrease groundwater COC concentrations below target risk-based MCSs. The corrective measures alternatives that were identified as likely to meet these objectives are thermally enhanced DPE and excavation with offsite disposal.

A cost comparison of the two alternatives under consideration (thermally enhanced DPE and excavation and offsite disposal) is provided in **Appendix C**. Expansion of the thermally enhanced DPE system, assuming the need for two additional heater wells and two additional DPE wells, would cost approximately $94,700. Operation and maintenance costs of the system would be approximately $118,500 per year. The estimated cost and net present value for excavation, offsite disposal, and restoration of an area of 200 square feet to a depth of 60 feet bgs (444 cubic yards) is approximately $569,200.

The estimated cost of expansion and continued operation of the thermally enhanced DPE system would exceed the cost of excavation with offsite disposal within approximately 5 years of DPE operation. Based on the operational history of the thermally enhanced DPE pilot-test system, 5 years would not be sufficient time to meet target risk-based MCSs. In addition, the level of compliance ranking of the other decision factors listed in **Table 4.3.4-4** (long-term reliability and effectiveness, the short term effectiveness, and the reduction in toxicity, mobility, or volume) for excavation and offsite disposal are greater than those for thermally enhanced DPE. Therefore, excavation with offsite disposal is recommended as the preferred alternative.

After confirmation sampling shows that the three initial source area remediation objectives have been met, the plume source area will be managed in accordance with the strategy described below for the plume periphery. After completion of the excavation, operation of the Building 7 groundwater collection trench would be discontinued, except as necessary to remediate the plume core. If the objectives have not been met, then the source zone will be managed in accordance with the strategy described below for the plume core.

Alternatives Applicable to the Building 7 Lobe Core Area

The core area contains COCs primarily dissolved in the groundwater. In addition, COCs sorbed to low permeability soils as a result of equilibrium partitioning with the groundwater constitute a continuing source of groundwater contamination. Wells in the core area generally cannot produce more than 200 gpd and therefore risk-based MCSs are the applicable cleanup levels. The presence of DNAPL is uncertain; however, the evidence indicates that some DNAPL may be present, particularly in the upgradient core area near the source. Therefore, retained alternatives listed in both **Tables 4.2.3-1 and 4.2.3-2** (for soil and groundwater, respectively) were evaluated. The results of the evaluation are provided in **Table 4.3.4-5** and discussed below.

No Action

No action in the Building 7 lobe core would consist of termination of all groundwater monitoring activities, stopping operation of the Building 53/58 slope DPE system and the Building 58 east groundwater collection trench, and terminating injection and extraction of groundwater from wells in the core area. Groundwater concentrations would remain at levels above target risk-based

Table 4.3.4-5. Evaluation of Corrective Measures Alternatives, Building 7 Lobe Core

	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
Corrective Measures Alternative	**Protective of Human Health / Environment**	**Attain MCSs**	**Control Migration**	**Comply with Waste Management Requirements**	**Long-Term Reliability and Effectiveness**	**Reduction in Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Cost (c)**	**Regulatory Agency Acceptance**	**Community Concerns**
No Action	no/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	no/no	no	no	yes	1	1	1	4	1	1
Institutional Controls	yes/no	no	no	yes	2	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	yes	Yes	3	2	3	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/no	no	no	yes	1	1	1	3	4	3
Chemical Oxidation	yes/yes	unknown	yes	yes	3	3	3	3	5	5
Enhanced bioremediation	yes/yes	no	no	yes	1	1	1	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	yes	yes	yes	3	4	4	4	4	4
Thermally Enhanced Dual Phase Extraction	yes/yes	unknown	yes	Yes	3	4	2	2	5	5
Excavation and Offsite Disposal	yes/yes	yes	yes	yes	5	5	5	1	5	4
Soil Mixing	yes/yes	unknown	yes	Yes	2	2	2	1	5	5
Soil Mixing and Chemical Oxidation	yes/yes	yes	yes	yes	3	4	3	1	4	4

(a) Level of Compliance Ranking
1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance
1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

and regulatory-based MCSs for the foreseeable future. These conditions would require establishment of Institutional Controls to protect human health. Migration of dissolved COCs from the plume core into the plume periphery might result in concentrations of groundwater COCs in the periphery exceeding risk-based levels. This alternative is not protective of human health and the environment and would likely be unacceptable to the regulators and the community, and is therefore not recommended.

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997. As part of this study, geochemical parameters were measured in several wells located in the Building 7 lobe core area. Concentrations of geochemical indicator parameters, particularly the relatively high dissolved oxygen concentration, were not favorable for natural degradation processes. MNA is not protective of human health and the environment and is therefore not recommended.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies or the community, and is therefore not recommended.

G*roundwater Containment/Capture*

Groundwater capture by itself is not an effective technology for reducing groundwater COC concentrations in the core area, primarily because of the extremely long time required for contaminants to diffuse from the low permeability Mixed Unit and the low groundwater velocities. This technology has been implemented within the plume core to effectively control migration of COCs from high concentration areas in the core into lower concentration areas of the core and periphery. This alternative is not effective by itself in protecting human health or attaining MCSs and is therefore not recommended as a corrective measures alternative, unless it is used in combination with groundwater flushing, as described below.

Permeable Reactive Barrier/Funnel & Gate

This alternative is not effective in protecting human health or attaining MCSs in the source area due to the high concentrations of COCs currently present in the groundwater, and is therefore not recommended.

Chemical Oxidation

The effectiveness of chemical oxidation for remediation of the core area is not known and would require pilot testing prior to any full-scale implementation. In situ chemical oxidation is generally not effective in low permeability and/or heterogeneous materials such as the Mixed Unit, so the likelihood that it would be effective is considered to be low. However, if pilot testing showed that delivery of reagents to the impacted pore space could be ensured, then this technology could potentially be effective. Therefore, the method it is retained for further evaluation in the summary section below because of the limited number of technologies potentially effective in the core area. Implementation of this method would require numerous closely spaced injection points (typically on the order of 3 to 5 feet spacing). Chemical oxidation is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe core area using the decision factors shown in **Table 4.3.4-5**.

Enhanced Bioremediation

Based on the results of an enhanced bioremediation pilot test (methanotrophic treatment technology pilot test), enhanced bioremediation is not an effective technology. The pilot test was not effective in delivery of the enhancing agents to the source solvents in the low permeability/heterogeneous Mixed Unit in the score area where it was tested. Enhanced bioremediation is therefore not recommended. The technology may be effective as part of a long-term strategy for the plume core once concentrations have been reduced to levels that are more conducive to natural attenuation processes.

Soil Flushing and Groundwater Extraction

Given the high concentrations of dissolved COCs in the plume core, and the tendency of clay-rich units such as the Mixed Unit to adsorb COCs from the groundwater, flushing of a large number of pore volumes of clean groundwater would be needed to reduce groundwater COC concentrations below the target risk- based MCSs. The soil flushing pilot test being conducted in the core area has resulted in decreased concentrations of COCs in several wells, indicating that this method may be effective in reducing concentrations below risk-based levels. The rate of concentration reduction is highly dependent on the permeability of the rocks, however, and insufficient data are currently available to estimates the time required for compliance with target risk-based MCSs. Groundwater extraction and flushing is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe core area using the decision factors shown in **Table 4.3.4-5**.

Thermally Enhanced Dual Phase Extraction (Heater Test)

Thermally enhanced dual phase extraction is primarily suitable for unsaturated soils with high concentrations of residual or free-phase DNAPL. Therefore, this method has poor applicability to the core of the Building 7 lobe, where contamination is primarily associated with groundwater flowing in the saturated zone. In addition, the capital, operations and maintenance costs for the relatively small-scale system in the source area was estimated at $629,800 for expansion of a preexisting system and the initial five years of operation. This cost does not include the primary capital costs that would be associated with installation of a new system. The operations and maintenance costs for the much larger core area would be at least an order of magnitude greater, and capital costs would also need to be applied to this area. Thermally enhanced DPE is not recommended due to both the poor applicability of the method and the large costs of implementation.

Excavation and Offsite Disposal

Excavation of the low permeability rocks of the Mixed Unit along with the contaminated groundwater contained within them would likely reduce contaminant concentrations below target risk-based MCSs. However, the required extent of excavation adjacent to the Advanced Light

Source (ALS) could have severe impacts on of ALS operations. Excavation and offsite disposal is retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe source area using the decision factors shown in **Table 4.3.4-4**. The relatively steep slope requiring excavation, the depth of excavation required, and the sensitive structures at both the top and base of the slope would require extremely costly excavation measures.

Soil Mixing

Soil mixing would be used to break-up and mix the low permeability Mixed Unit with the overlying higher permeability Moraga Formation. This would increase the permeability and enhance flushing/extraction of groundwater COCs or enhance injection of chemical oxidant reagents. The method has been used in conjunction with injection of chemical reagents (e.g., oxidants), to destroy contaminants, or chemical reagents combined with grouts to stabilize contaminants. Injection of chemical oxidants, as described under Chemical Oxidation above, would likely increase the reliability and effectiveness of this method. Prior to implementing soil mixing, pilot testing would be required to assess its effectiveness and evaluate whether injection of chemical reagents would increase its effectiveness.

Since soil mixing reduces the density of the subsurface materials, a concern with the technology would be its impact on the stability of the slope below the ALS and mitigation measures that might be required after the mixing is completed. The cost of implementing soil mixing would be considerably less than the cost for either chemical oxidation or excavation, since it would basically consist of a combination of those two technologies (less disposal costs). Soil mixing is therefore not recommended because of implementability concerns and cost. However, if it can be shown that small “hot spots” of low permeability, highly impacted zones within the core remain after implementation of another technology, such an approach may be viable for locally increasing the permeability of those areas to enhance soil flushing.

Summary of Building 7 Lobe Core Corrective Measures Implementation Strategy

The initial remediation objectives for the core area of the Building 7 lobe of the Old Town Groundwater Solvent Plume are to: 1) decrease groundwater COC concentrations below target risk-based MCSs; and, 2) prevent migration of COCs in groundwater at concentrations above risk-based levels into the periphery. The alternatives that were identified as likely to meet these objectives are chemical oxidation, excavation with offsite disposal, and groundwater extraction/flushing. In addition, soil mixing was considered but rejected because of slope stability concerns and since the cost would be considerably higher than the other three technologies under consideration.

A cost comparison of the three alternatives under consideration (chemical oxidation, excavation with offsite disposal, and groundwater extraction/flushing) is provided in **Appendix C**. The cost for application of chemical oxidation is estimated at $4,150,000. The cost for groundwater extraction and flushing is estimated as $22,000 in capital costs for system expansion and $62,000 per year for operation and maintenance. Net present value for capital, operation, and maintenance costs is estimated at $1,193,400, assuming 30 years of operation. The base cost for excavation and offsite disposal is estimated at $6,180,000.

Based only on cost, groundwater extraction and flushing would be the recommended alternative. In addition, the level of compliance rankings of the other decision factors listed in **Table 4.3.4-5** (long-term reliability and effectiveness, the short-term effectiveness, and the reduction in toxicity, mobility, or volume) for groundwater extraction and soil flushing are higher than those for chemical oxidation. Although the level of compliance rankings for excavation and offsite disposal are somewhat higher than those for groundwater extraction and flushing, the estimated $5,000,000 cost differential outweighs the other factors. Groundwater extraction and flushing is therefore recommended as the preferred alternative, particularly since the estimated cost for excavation does not consider potentially significant impacts on ALS operations.

If groundwater COC concentrations in part or the entire plume core are reduced to levels below target risk-based MCSs, then those areas will be managed according to the strategy described below for the plume periphery.

Alternatives Applicable to the Building 7 Lobe Periphery Area

The periphery area contains groundwater COCs at concentrations below target risk-based MCSs but above regulatory-based MCSs (i.e., MCLs), and includes areas that are primarily downgradient or crossgradient from the core area. Many of the wells in the periphery area can produce more than 200 gpd and therefore regulatory-based MCSs are the applicable cleanup levels. As a result of natural attenuation, the hydrogeologic setting, and/or ongoing groundwater capture, groundwater containing COCs at detectable concentrations has not been migrating beyond the currently defined plume boundary. As corrective measures reduce groundwater concentrations in the Building 7 lobe source and core areas to levels below target risk-based MCSs, those areas will be controlled using the same strategy for the periphery area described in this section.

Since COCs in the periphery area are present primarily in groundwater, with only a negligible fraction present as sorbed soil COCs in equilibrium with groundwater, only retained alternatives listed in **Table 4.2.3-2** (potential corrective measures alternatives for groundwater) are evaluated. The results of the evaluation are provided in **Table 4.3.4-6** and discussed below.

No Action

No-action in the Building 7 lobe periphery would consist of terminating all groundwater monitoring activities and stopping operation of the Building 58 West and Building 58 East Groundwater Collection Trenches and the Building 53/58 Slope Dual Phase (groundwater and soil vapor) Extraction System. Groundwater concentrations would remain at levels above regulatory-based MCSs for the foreseeable future, although natural degradation processes would likely result in continued decreases in COC concentrations at some locations. In addition, termination of groundwater extraction at the leading edge of the lobe east of Building 58 could degrade downgradient groundwater quality. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community. It also does not comply with regulatory requirements and is therefore not recommended.

Monitored Natural Attenuation

Studies of geochemical and biological parameters indicative of the potential for natural degradation of COCs were conducted within the plume area in 1997 and 2003. Data from wells monitoring the downgradient portion of this area (MW58A-94-14 and MW58-95-18) suggest that ongoing natural attenuation is occurring. The rate of natural attenuation is expected to

Table 4.3.4-6. Evaluation of Corrective Measures Alternatives, Building 7 Lobe Periphery

	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
Corrective Measures Alternative	**Protective of Human Health / Environment**	**Attain MCSs**	**Control Migration**	**Comply with Waste Management Requirements**	**Long-Term Reliability and Effectiveness**	**Reduction in Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Cost (c)**	**Regulatory Agency Acceptance**	**Community Concerns**
No Action	yes/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	no	yes	3	3	2	4	3	1
Institutional Controls	yes/no	no	no	yes	3	1	3	4	4	2
Groundwater Containment/Capture	yes/yes	no	yes	yes	3	2	3	3	4	4
Permeable Reactive Barrier/Funnel & Gate	yes/yes	no	yes	yes	3	2	3	2	4	3
Chemical Oxidation	yes/yes	unknown	yes	yes	3	3	3	1	5	5
Enhanced bioremediation	yes/yes	unknown	no	yes	1	1	1	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	yes	yes	yes	3	3	3	4	4	4

(a) Level of Compliance Ranking
1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance
1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

increase in most areas of the periphery as corrective measures in the source and core areas reduce COC concentrations in the upgradient groundwater.

MNA is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe periphery area using the decision factors shown in **Table 4.3.4-6**.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

Groundwater containment/capture can effectively control migration of COCs from the periphery into uncontaminated areas downgradient from the Building 7 lobe to comply with regulatory requirements. Groundwater capture has been effective at controlling downgradient migration of the leading edge of the Building 7 lobe, and should continue until it can be shown that termination of the technology does not result in detectable concentrations of COCs in downgradient compliance wells.

Permeable Reactive Barrier /Funnel & Gate

A permeable reactive barrier or funnel and gate might also control migration of COCs from the periphery into uncontaminated areas to comply with regulatory requirements in areas downgradient from the Building 7 lobe. However, since the groundwater collection trench has been installed as an ICM and groundwater treatment systems are already in place, this alternative would have added costs. In addition, the effectiveness of a permeable reactive barrier is not known. This alternative is therefore not recommended.

Chemical Oxidation

The effectiveness of in situ chemical oxidation for remediation of the periphery is not known and would require pilot testing prior to any full-scale implementation. In situ chemical oxidation is generally not effective in low permeability and/or heterogeneous materials such as the Mixed Unit and Orinda Formation. Generally, chemical oxidation is applied to areas that have high COC concentrations, and is not applicable to broad areas of low level contamination, such as the Building 7 lobe periphery, due to the high costs of reagent injection, the need for close spacing of injection points, and because reagent chemistry does not persist during groundwater migration. The cost for conducting chemical oxidation of the plume core was estimated to be approximately $4,150,000 (**Appendix C**), and would be higher for the plume periphery due to the larger area that would require treatment. For these reasons, chemical oxidation is not recommended.

Enhanced Bioremediation

Available data indicate that natural biodegradation of COCs is occurring in the periphery area, and that enhancement of bioremediation may not be necessary. However, it is possible that some enhanced bioremediation methods may be effective for expediting the process in some parts of the periphery. Enhanced bioremediation is recommended for consideration only if MNA by itself becomes ineffective.

Soil Flushing and Groundwater Extraction

Available data indicate that DNAPL is not present in the plume periphery, although very low concentrations of sorbed COCs in equilibrium with dissolved groundwater COCs are likely to be present. Therefore, groundwater flushing may result in permanent reductions of COC concentrations that are maintained with minimal “rebound” after cessation of flushing.

As described above, a soil flushing pilot test is currently being conducted in the plume core, and results indicate that this technology has been effective in decreasing COC concentrations. This technology would likely be even more effective in the plume periphery, which has even lower initial dissolved COC concentrations. Additional injection/extraction wells/trenches could be installed to flush the plume periphery. Soil flushing with groundwater extraction is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 7 lobe periphery area using the decision factors shown in **Table 4.3.4-6**.

Summary of Building 7 Lobe Periphery Corrective Measures Implementation Strategy

The remediation objectives at the Building 7 lobe periphery are to: 1) ensure that groundwater COCs do not migrate into uncontaminated areas; and, 2) decrease groundwater COC concentrations below regulatory-based MCSs. The corrective measures alternatives that were identified as likely to meet these objectives are MNA, groundwater capture, enhanced bioremediation, and soil flushing with groundwater extraction.

Groundwater capture should continue at the leading edge of the Building 7 lobe to meet remediation objective (1) above until it can be shown that termination of groundwater extraction does not result in detectable concentrations of COCs in downgradient compliance wells.

A combination of MNA and soil flushing and groundwater capture is recommended to meet objective (2) above. The level of compliance rankings for the decision factors listed in **Table 4.3.4-5** (long-term reliability and effectiveness; the short-term effectiveness; the reduction in toxicity, mobility, or volume; and cost) for these two alternatives are similar. Since available data indicate that natural attenuation is resulting in concentration reductions at the downgradient edge of the Building 7 lobe, MNA is the recommended alternative for this area. Soil flushing is the recommended alternative for the other areas of the periphery where evidence for MNA is currently absent.

4.3.5. Building 52 Lobe of the Old Town Groundwater Solvent Plume

A general description of the Old Town Groundwater Solvent Plume is given in **Section 4.3.3**. As described in that section, the Old Town plume consists of three coalescing lobes (Building 7 lobe, Building 25A lobe, and Building 52 lobe) of halogenated non-aromatic hydrocarbons derived from distinct sources **(Figure 4.3.4.-1)**. The Building 52 lobe extends northwestward from the area east of Building 52 to Building 46, where the contaminated groundwater is captured by the Building 46 subdrain (**Figure 4.3.5-1**).

The distribution of elevated VOC concentrations in the Building 52 lobe indicates that the source of groundwater contamination was located east of Building 52A. Groundwater and soil sampling conducted in 1998 and 2000 to characterize the location, and magnitude and extent of COCs in this area indicated that a source of the lobe was likely spills in the vicinity of the paved area east of Building 52A. An ICM was conducted in 2001 that consisted of excavation of contaminated soil from this area. In addition, a soil flushing pilot test was initiated near the source area in May 2003.

4.3.5.1 Current Conditions

Geology and Hydrogeology

Bedrock consists primarily of relatively permeable volcanic rocks of the Moraga Formation, up to 80 feet thick, overlying the low permeability Orinda Formation. The water table lies at approximately 50 to 70 feet below ground surface throughout most of the lobe, although it shallows to approximately 7 feet bgs at the base of the steep slope east of Building 46, where the toe of the lobe is intercepted by the Building 46 subdrain. The groundwater gradient is westward to northwestward (**Figure 4.3.4-9**). Wells screened within the Moraga Formation in the Building 52 lobe are generally able to produce more than 200 gpd (**Figure 4.3.5-1**).Groundwater flow modeling has been conducted for the Old Town Plume, including the Building 52 Lobe using the ITOUGH2 code (Zhou and others, 2003; Preuss and others, 1999). The modeling, along with slug test data, was used to estimate rock physical characteristics (i.e., hydraulic conductivity and effective porosity) based on matching of seasonal variations in groundwater elevations. The model results indicate hydraulic conductivity values of approximately 10^{-5} meters per second and effective porosity values of approximately 0.04 within the Moraga Formation of the Building 52 lobe. Modeled flow velocities based on these values are typically in the range of 3 to 6 meters per day (10 to 20 feet per day), which are substantially greater than velocities estimated for other parts of Berkeley Lab. Modeled travel time estimates indicate that particles located at the head of the Building 52 lobe would reach the toe of the lobe in 28 to 65 days (**Appendix D**). Modeling results also suggest that groundwater generally flows westwards towards Building 53, and then turns northwestwards towards Building 46

Groundwater Contamination

The principal Building 52 lobe constituents are halogenated non-aromatic VOCs that were used as cleaning solvents, including PCE and carbon tetrachloride, and their degradation products (e.g., TCE 1,1-DCE, cis-1,2-DCE, and chloroform). Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.5-1,** where the maximum detected concentrations are compared to the target risk-based MCSs.

Groundwater COC Trends

Concentration trends for total halogenated non-aromatic VOCs detected in wells monitoring the Building 52 lobe are shown on **Figure 4.3.5-2**. An overall long-term decline in concentrations was observed from approximately 1995 through 1999 in the core of the lobe (MW52-95-2B), but concentrations have since remained relatively stable. A decreasing trend was also observed in wells monitoring the downgradient area of the lobe (MW27-92-20 and MW46-93-12), primarily between 1995 and 1997.

Table 4.3.5-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 52 Lobe of the Old Town Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (μg/L)	Maximum Contaminant Level (MCL) (μg/L)	Target Risk-Based Groundwater MCS (μg/L)
TCE	87.8	5	1,594
PCE	34*	5	343
carbon tetrachloride	13.9	0.5	27
cis-1,2-DCE	44.3	6	98,405

* In August 2003, PCE concentrations of 537 and 410 μg/L were detected in two wells within the plume, but are inconsistent with all other results from these wells and are therefore not considered to be representative of groundwater conditions.

The relative proportions of plume constituents vary with distance downgradient from the source area, with PCE becoming less abundant in comparison to TCE and DCE, indicating that degradation occurs during plume migration. The relative proportions of the primary COCs in the PCE degradation pathway (PCE, TCE, cis-1,2-DCE, and 1,1-DCE) are shown on **Figure 4.3.5-3** (source area well), **Figure 4.3.5-4** (midplume well), and **Figure 4.3.5-5** (downgradient well). As shown on the figures, the relative proportions of these constituents at each well location have changed relatively little over time. This indicates that the rate of degradation in the downgradient areas does not greatly exceed the rate of dissolution of COCs from residual soil contamination and migration from the source area.

The relative proportions of COCs in the carbon tetrachloride degradation pathway (carbon tetrachloride and chloroform) are shown on **Figure 4.3.5-6** (source area well), **Figure 4.3.5-7** (midplume well), and **Figure 4.3.5-8** (downgradient well). Although the total concentration of carbon tetrachloride and chloroform has gradually declined, their relative proportions have shown no consistent trend, suggesting that degradation is not an important factor in reducing concentrations of these COCs within the lobe.

An ICM using soil flushing technology was initiated for the Building 52 Lobe in May 2003. This ICM has comprised injection of treated groundwater into groundwater monitoring wells MW52-98-8B and MW52-98-9 in the upgradient portion of the lobe. An approximately 50% reduction in COC concentrations was observed in monitoring well MW52-95-2B, located downgradient from the injection wells, over three months of pilot test operation (**Figure 4.3.5-2**). The decrease indicates that flushing is an effective method for reducing groundwater COC concentrations, at least in the short-term.

Soil Contamination

Soil samples were collected in 2000 from twenty shallow (approximately 10-feet deep) borings to help locate the source of the contamination detected in groundwater east of Building 52A. Up to 5 mg/kg total halogenated VOCs, consisting predominantly of PCE with lesser amounts of TCE and cis-1,2-DCE, were detected in soil samples collected from borings close to the monitoring wells with the highest groundwater concentrations. In 2001, the area of soil contamination east of Building 52A was excavated to a depth of approximately 9 feet as an ICM (**Figure 4.3.5-9a** and **Figure 4.3.5-9b**). The maximum concentrations of halogenated VOCs detected in residual soil from the excavation area were below the target risk-based MCSs except for two samples that contained PCE exceeding its MCS and one sample that contained cis-1,2-DCE exceeding its MCS. However, the 95% UCLs for both PCE and cis-1,2-DCE in this area were less than the target risk-based MCSs (**Appendix H**) indicating that representative COC concentrations are lower than levels of concern.

Evidence of DNAPL and Residual Soil Contamination

Maximum concentrations of COCs detected in soil samples collected in the Building 52 lobe area are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**, . Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs. This lack of evidence for the presence of DNAPLs is corroborated by the decline in total concentrations of halogenated VOCs in upgradient areas of the lobe observed from approximately 1995 to 1999.

The lack of continuing declining concentration trends (excluding declines that have been a direct result of soil flushing) and the absence of changes in relative proportions of COCs in groundwater indicate that residual soil contamination is probably present at the upgradient edge the lobe.

4.3.5.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 52 lobe of the Old Town Groundwater Solvent Plume:

- There is no evidence suggesting the presence of DNAPL. The only residual soil contamination detected in the vadose zone consists of relatively low concentrations of contamination beneath the ICM excavation that are less than regulatory-based soil MCSs.
- Past declining concentration trends in groundwater in the upgradient area of the lobe suggest that the mass of residual soil contamination available to impact groundwater has declined in the past. However, the cessation of significant concentration declines and the lack of evidence for degradation of COCs at the head of the lobe indicate that low levels of residual contamination in equilibrium with dissolved groundwater COCs probably remain within the saturated zone. Therefore, corrective measures for the lobe should be based on the remediation of dissolved-phase COCs and low level saturated zone residual soil contamination.
- The Building 52 lobe lies within an area where groundwater flows primarily through the relatively permeable rocks of the Moraga Formation. Continued groundwater flow may result in flushing of contaminants from the pore space of the Moraga Formation.
- Wells within the Moraga Formation in the Building 52 lobe are expected to have sustainable yields greater than 200 gpd, so regulatory-based MCSs are applicable.
- The Building 52 lobe is elongated along the direction of groundwater flow, consistent with advection being the predominant contaminant transport mechanism. The estimated groundwater velocity is roughly 10 to 20 feet per day in the Moraga Formation in this area.
- Spatial variations in plume chemistry suggest that degradation has been occurring during migration of constituents that are part of the PCE degradation pathway. The lack of temporal change in the relative proportions of COCs indicates that the plume has apparently reached a state of equilibrium where degradation rates are similar to rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. No evidence for degradation of carbon tetrachloride has been observed.
- Concentrations of COCs are above regulatory-based MCSs for groundwater, but are less than regulatory-based MCSs for soil and less than target risk-based MCSs for soil and groundwater.
- Initial results of the soil flushing pilot test indicate that this method may be effective at decreasing COC concentrations within the lobe.

4.3.5.3 Evaluation of Retained Corrective Measures Alternatives

Concentrations of groundwater COCs in the Building 52 lobe exceed regulatory-based MCSs for a number of COCs, but are well below target risk-based MCSs. Since well yield is greater than 200 gpd, regulatory-based MCSs are applicable.

As a result of ongoing capture of groundwater at a subdrain located east of Building 46 at the leading edge of the lobe, groundwater containing COCs at detectable concentrations has not been migrating beyond the currently defined plume boundary. Transfer of COCs to surface water could potentially occur through the storm drain system, if the extraction of water from the Building 46 subdrain were terminated. However, as a result of dilution and volatilization of COCs, the chemical concentrations would likely be below detectable levels at the outflow to the creek.

Since COCs are present primarily in groundwater, with only a negligible fraction present as sorbed soil COCs in equilibrium with groundwater and there is no indication of the presence of DNAPL, only retained technologies listed in **Table 4.2.3-2** (potential corrective measures technologies for groundwater) are evaluated. The results of the evaluation are provided in **Table 4.3.5-2** and discussed below.

Table 4.3.5-2. Evaluation of Corrective Measures Alternatives, Building 52 Lobe

Corrective Measures Alternative	**Corrective Action Standards (yes/no)**				**Decision Factors (a)**				**Other Factors (b)**	
	Protective of Human Health / Environment	**Attain MCSs**	**Control Migration**	**Comply with Waste Management Requirements**	**Long-Term Reliability and Effectiveness**	**Reduction in Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Cost (c)**	**Regulatory Agency Acceptance**	**Community Concerns**
No Action	yes/no	no	no	yes	1	1	1	5	1	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	no	yes	2	2	1	4	1	1
Institutional Controls	yes/no	no	no	yes	3	1	3	4	4	2
Groundwater Containment/Capture	yes/yes	no	yes	yes	3	2	3	4	4	4
Permeable Reactive Barrier/Funnel & Gate	yes/yes	no	yes	yes	3	2	3	3	4	3
Chemical Oxidation	yes/yes	unknown	yes	yes	2	3	3	1	5	5
Enhanced bioremediation	yes/yes	unknown	no	yes	3	3	2	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	yes	yes	yes	3	3	4	3	4	4

(a) Level of Compliance Ranking
1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance
1. None
2. Low
3. Partial
4. Moderate
5. High

(c) relative cost from 1 (high) to 5 (low)

No Action

No action for the Building 52 lobe would consist of terminating all groundwater monitoring activities and stopping extraction and treatment of water from the Building 46 subdrain, which intercepts the downgradient edge of the 52 lobe. Under this alternative, once extraction from the subdrain was halted, contaminated groundwater could enter the storm drain system and flow into North Fork Strawberry Creek, although as described above, the COC concentrations would likely be below levels of concern at the creek outfall. Groundwater concentrations would remain at levels above regulatory-based MCSs for the foreseeable future, although natural degradation processes would likely result in decreases in COC concentrations at some locations. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community. It also does not comply with regulatory requirements and is therefore not recommended.

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997. Geochemical parameters measured in well MW52-95-2B, located in the upgradient portion of the Building 52 lobe were not favorable for natural degradation processes. In particular, the dissolved oxygen concentration was substantially greater than the minimum concentration that is considered indicative of conditions under which reductive dechlorination of COCs can occur. However, observed ratios of parent-daughter compounds within the plume strongly suggest that degradation occurs during downgradient migration. As described above, the lobe has apparently reached a state of equilibrium where the degradation rates are similar to the rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. These observations indicate that MNA would not be an effective alternative unless concentrations of COCs in groundwater in the upgradient area were to be significantly reduced. Therefore, MNA should only be considered in combination with more aggressive remediation technologies.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

Groundwater capture has been effective at controlling downgradient migration of the leading edge of the Building 52 lobe and preventing the flow of contaminated water through the stormdrain system to North Fork Strawberry Creek. This technology should continue until it can be shown that termination of the technology does not result in detectable concentrations of COCs in downgradient compliance wells and it can be shown that COCs would not be detected at the outfall to North Fork Strawberry Creek.

Permeable Reactive Barrier /Funnel & Gate

A permeable reactive barrier or funnel and gate system might control migration of COCs into uncontaminated areas to comply with regulatory requirements in areas downgradient from the Building 52 lobe. However, since the subdrain and groundwater treatment systems are already in place, this alternative would have added costs. In addition, the effectiveness of these types of systems is not known. This alternative is therefore not recommended.

Chemical Oxidation

Generally, the chemical oxidation method is applied in areas that have high COC concentrations and is not applicable to broad areas of low-level contamination due to the high costs of reagent injection, the need for close spacing of injection points, and because reagent chemistry does not persist during groundwater migration. High COC concentrations or “hot spots” are not present in the Building 52 lobe area, so the technology is unlikely to be cost effective. In addition, the effectiveness of the technology for remediation of the Building 52 lobe is not known and would require pilot testing prior to any full-scale implementation. The cost for conducting chemical oxidation for the Building 52 lobe would be greater than that estimated for the smaller area

Building 7 lobe core, which was estimated to be approximately $4,150,000 (**Appendix C**). Based on the high cost and unlikely effectiveness of this technology, it is not recommended.

Enhanced Bioremediation

Available data suggest that natural degradation is occurring in the Building 52 lobe area during downgradient migration of dissolved COCs. Therefore, the addition of enhancements might be effective in stimulating bioremediation of groundwater COCs, although the method would probably not be effective in the upgradient area of the lobe where high dissolved oxygen concentrations were measured. The technology may be effective as part of a long-term strategy for the Building 52 lobe; however, pilot test would need to be performed to evaluate its effectiveness. Enhanced bioremediation would not be implemented until groundwater COC concentrations in the upgradient lobe area have been reduced to levels that do not migrate to the downgradient area at concentrations above regulatory-based levels.

Soil Flushing and Groundwater Extraction

Available data indicate that DNAPL is not present in the Building 52 lobe, groundwater COC concentrations are relatively low, and the contamination is present in relatively permeable rocks. These characteristics indicate that soil flushing and groundwater extraction may be effective in reducing COC concentrations in the groundwater with minimal "rebound" after flushing is terminated.

After the first three months of operation of the soil flushing pilot test in the upgradient area of the Building 52 lobe, groundwater COC concentrations in MW52-95-2B, located close to the injection points, have been reduced by approximately 50%. Additional injection/extraction wells/trenches could be installed to remediate the areas of the Building 52 lobe beyond the pilot test area.

Summary of Building 52 Lobe Corrective Measures Implementation Strategy

The remediation objectives for the Building 52 lobe are to: 1) ensure that groundwater COCs at detectable concentrations do not migrate to surface water; 2) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs do not migrate into areas where concentrations are less than MCSs; and, 3) decrease groundwater COC concentrations below regulatory-based MCSs. The remedial technologies that have been identified that may meet these objectives are groundwater capture, MNA, enhanced bioremediation, and soil flushing.

Groundwater capture using the Building 46 subdrain addresses remediation objectives (1) and (2) above. This technology should continue until it can be shown that termination of the technology does not result in detectable concentrations of COCs in downgradient compliance wells and at the outfall to North Fork Strawberry Creek. The system (Building 46 subdrain and groundwater treatment system) is already in place and operation and maintenance costs are relatively low.

In situ soil flushing has been identified as a potentially effective alternative to address remediation objective (3) above. Based on the initial soil flushing pilot test results, this technology may permanently reduce COC concentrations to regulatory-based MCSs, and therefore is recommended for full-scale implementation. If in situ soil flushing results in COC concentrations above the regulatory-based MCSs, MNA should be considered to further reduce the concentrations. As described above, the Building 52 lobe has apparently reached a state of equilibrium where the degradation rates are similar to the rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. Soil flushing may reduce COC concentrations sufficiently so that MNA becomes an effective alternative (i.e., the rate of degradation exceeds the rate of dissolution in the upgradient lobe area and migration). Enhanced bioremediation should be considered if MNA becomes ineffective.

4.3.6 Building 25A Lobe

The Old Town Groundwater Solvent Plume is discussed in **Section 4.3.3**. As described in that section, the Old Town plume consists of three coalescing lobes (Building 7 lobe, Building 25A lobe, and Building 52 lobe) of halogenated non-aromatic hydrocarbons derived from distinct sources **(Figure 4.3.4.-1)**. The Building 25A Lobe encompasses two subplumes of groundwater contamination, containing different suites of COCs, which are likely derived from different sources. The primary subplume contains TCE, 1,1-DCE and minor amounts of cis-1,2-DCE, and extends from the western portion of Building 25A westward to the eastern edge of Building 6 (**Figure 4.3.6-1**). This subplume contains over 200 ug/L total VOCs and is primarily present in rocks of the relatively low permeability Orinda Formation. The second subplume contains primarily PCE (approximately 20 µg/L maximum concentration), with lower concentrations of TCE and carbon tetrachloride. This subplume extends from east of Building 25A to south of Building 25 (**Figure 4.3.6-2**), roughly coincident with the body of permeable Moraga Formation rocks that underlies that area

Based on the concentrations of COCs in the groundwater, the source area for the western subplume is located near the western end of Building 25A. From approximately 1996 to 1998, soil and soil gas sampling were conducted in that area; however, no specific source was located. An ICM was started in 2002 to flush contaminants from the soil in the source area. The ICM consists of injection of treated groundwater into a shallow infiltration trench located between Building 25A and Building 44A and extraction of the injected water from a downgradient trench west of Building 25A and from well MW25A-98-3 north of Building 25A. Extraction, treatment, and recirculation of water from the trench were started in April 2002.

4.3.6.1 Current Conditions

<u>Geology and Hydrogeology</u>

The Building 25A lobe extends both southwards and westwards from Building 25A, with the highest COC concentrations detected in wells at the west end of the building. Bedrock beneath the Building 25 lobe area consists of relatively permeable volcanic rocks of the Moraga

Formation overlying low permeability rocks of the Orinda Formation. Two large bodies of Moraga Formation rocks occupy depressions in the upper contact of the Orinda Formation. One is oriented north-south beneath Building 25 and the eastern part of Building 25A, while the other is located beneath Buildings 5 and 16. Due to the large contrast in hydraulic conductivity between these two units, the geometry of these bodies has a significant effect on groundwater flow in the lobe. Groundwater is present in both the Moraga Formation and Orinda Formation. As shown on **Figure 4.3.6-3,** wells screened within the Moraga Formation, and within a zone of relatively permeable Orinda Formation rocks in the area north of Building 25A are generally able to produce more than 200 gpd. However wells screened within the Orinda Formation are generally unable to produce more than 200 gpd.

The water table is generally 20 to 30 feet bgs in the vicinity of Buildings 25A, 5 and 16, but deepens to approximately 80 feet bgs south of Building 25. Groundwater gradient and flow directions are generally westward southward and eastward, radially away from Building 25A (**Figure 4.3.4-9**).

Groundwater flow modeling has been conducted for the Old Town Plume, including the Building 25A lobe using the ITOUGH2 code (Zhou and others, 2003; Preuss and others, 1999). The modeling, along with slug test data, was used to estimate rock physical characteristics (i.e., hydraulic conductivity and effective porosity) based on matching of seasonal variations in groundwater elevations. Modeled flow velocities based on these values are typically in the range of 0.03 to 0.3 meters per day (0.1 to 1 feet per day) throughout most of the lobe, although rainy season model velocities within the Moraga Formation rocks beneath Building 25 were as high as 3 meters per day (10 feet per day), reflecting the rise of water levels into high permeability rocks of the Moraga Formation (**Appendix D**).

Groundwater Contamination

The principal Building 25A lobe constituents are halogenated non-aromatic VOCs that were used as cleaning solvents including TCE, PCE, and carbon tetrachloride and their degradation products (e.g., 1,1-DCE, cis-1,2-DCE, and chloroform). Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.6-1** where the maximum detected concentrations are compared to the target risk-based MCSs. None of the COCs was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.6-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 25A Lobe of the Old Town Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (μg/L)	Maximum Contaminant Level (MCL) (μg/L)	Target Risk-Based Groundwater MCS (μg/L)
TCE	304	5	1,594
PCE	37.5	5	343
Carbon tetrachloride	2	0.5	27
1,1-DCE	67.5	6	28,873

Groundwater COC Trends

Concentration trends for total halogenated non-aromatic VOCs detected in wells monitoring the Building 25A lobe (western subplume) are shown on **Figure 4.3.6-4a and 4.3.6-4b**. Groundwater COC concentrations were relatively constant in the source area at Building 25A until initiation of the soil flushing pilot test. Since startup of the pilot test, groundwater COC concentrations have dropped substantially in the wells immediately adjacent to the test, but have not shown consistent trends in other source area wells. Downgradient wells to the west of the source area (i.e., wells MW5-93-10 and MW6-92-17 have shown slow long-term concentration declines over the past 10 years.

The relative proportions of TCE and 1,1-DCE vary with distance downgradient (westward) from the source area. As shown on **Figure 4.3.6-5** and **Figure 4.3.6-6**, the proportion of 1,1-DCE relative to TCE increases significantly with distance downgradient from well MW25A-99-2, located close to the source area, and well MW25A-95-15, located approximately 50 feet downgradient from the source area. However, this relationship cannot be verified in wells further downgradient because parent product concentrations decrease significantly, and degradation product concentrations are below detection levels. The 1,1-DCE may originate either directly as a product spill or from degradation of TCE. If 1,1-DCE is derived from the degradation of TCE, then the downgradient increase in the relative proportion of 1,1-DCE indicates that degradation is occurring during plume migration. The relative proportions of these constituents have not changed markedly over time, and a slight increase is apparent in the proportion of parent product (TCE) to daughter product (1,1-DCE) in well MW25A-95-15. This indicates that the rate of degradation does not greatly exceed the rate of COC migration from the upgradient source area or dissolution of COCs from residual soil contamination. Based on approximately eight years of monitoring the downgradient edge of the subplume, no downgradient migration of COCs beyond the toe of the plume has been occurring, although this relation is uncertain in the area where the subplume coalesces with the Building 7 lobe.

For the eastern PCE/TCE/carbon tetrachloride subplume, COC concentrations have been essentially constant throughout the monitoring period. Based on approximately eight years of monitoring the downgradient edge of the subplume, no downgradient migration of COCs beyond the toe of the plume has been occurring.

Soil Contamination

Soil samples have been collected in the source area near Building 25A, but only sporadic samples contained detectable VOCs. No PCE was detected, and the maximum detected concentrations of TCE and 1,1-DCE were 0.052 and 0.0058 mg/kg, respectively. These levels are substantially lower than the regulatory-based MCSs. In 1998, soil gas probes were installed west, north, and beneath Building 25A to help locate the source of the groundwater contamination, but no contaminant source was located.

Distribution of DNAPL and Residual Soil Contamination

Maximum concentrations of COCs detected in soil samples collected in the Building 25A lobe area are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**. Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs in the lobe.

The lack of declining concentration trends or changes in relative proportions of COCs in groundwater (prior to startup of the soil flushing pilot test) indicate that residual soil contamination is probably present within or adjacent to the saturated zone in the vicinity of the source area, although COCs were not detected in saturated zone samples collected during installation of monitoring wells in this area.

4.3.6.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 25A lobe of the Old Town Groundwater Solvent Plume:

- There is no evidence suggesting the presence of DNAPL. The absence of declining trends in COC concentrations combined with the lack of evidence for degradation of COCs in the source area of the western subplume and throughout the eastern subplume indicate that low levels of residual contamination in equilibrium with dissolved groundwater COCs probably remain within the saturated zone. Therefore, corrective measures for the lobe should be based on the remediation of dissolved-phase COCs and low level saturated zone residual soil contamination.
- Concentrations of COCs for both subplumes are at levels significantly lower than target risk-based MCSs.
- Since well yield is generally greater than 200 gpd, regulatory-based MCSs are applicable.

<u>Western Subplume (TCE and 1,1-DCE)</u>

- The western subplume lies within an area where groundwater flows primarily through relatively low permeability rocks of the Orinda Formation close to the source area, and through higher permeability rocks downgradient (west) and crossgradient (north) of this area. Groundwater wells near the source area yield less than 200 gpd, whereas those downgradient and crossgradient yield more than 200 gpd. The estimated groundwater velocity is roughly 0.1 to 1 feet per day.
- Spatial variations in plume chemistry suggest that degradation has been occurring during migration of constituents that are part of the TCE degradation pathway. The lack of temporal change in the relative proportions of COCs indicates that a state of equilibrium has been reached where degradation rates are similar to rates of dissolution of soil contaminants and downgradient migration of dissolved COCs.
- Initial results of the soil flushing pilot test indicate that this method may be effective at decreasing COC concentrations, although no data are available to determine whether permanent concentration reductions are attainable in the absence of continued flushing.

- Migration of COCs beyond the toe of the subplume does not appear to be occurring, and the decreasing concentration trends observed in wells monitoring this area suggest that the subplume may be retreating.

<u>Eastern Subplume (PCE, TCE, and Carbon Tetrachloride)</u>

- The eastern subplume lies within an area where groundwater flows primarily through permeable rocks of the Moraga Formation. This indicates that continued groundwater flow may result in flushing of contaminants from the pore space of the Moraga Formation. Due to the relatively high permeabilities, groundwater extraction wells installed within the plume would be expected to yield more than 200 gpd. The estimated groundwater velocity is up to 9 feet per day in the Moraga Formation. Migration of COCs beyond the toe of the subplume does not appear to be occurring.
- Groundwater COC concentrations are too low to draw conclusions regarding degradation in the eastern subplume. The lack of temporal change in the relative proportions of COCs indicates that a state of equilibrium has been reached where if any degradation is occurring, its rate is similar to rates of dissolution of soil contaminants and downgradient migration of dissolved COCs.

4.3.6.3 Evaluation of Retained Corrective Measures Alternatives

Concentrations of groundwater COCs in the Building 25A lobe exceed regulatory-based MCSs for a number of COCs, but are well below target risk-based MCSs. Since well yield is generally greater than 200 gpd, regulatory-based MCSs are applicable.

Groundwater containing COCs at detectable concentrations has not been migrating beyond the currently defined plume boundary (except possibly where the plume coalesces with the higher concentration Building 7 lobe), so migration control is not a concern. Since COCs are present primarily in groundwater, with only a negligible fraction present as sorbed soil COCs in equilibrium with groundwater, only retained technologies listed in **Table 4.2.3-2** (potential corrective measures technologies for groundwater) are evaluated. The results of the evaluation are provided in **Table 4.3.6-2** and discussed below.

<u>**No Action**</u>

No action for the Building 25A lobe would consist of terminating all groundwater-monitoring activities and stopping the soil flushing pilot testing the source area. Currently, groundwater concentrations of several COCs (carbon tetrachloride, cis-1,2-DCE, PCE, and TCE)

Table 4.3.6-2. Evaluation of Corrective Measures Alternatives, Building 25A Lobe

	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
Corrective Measures Alternative	**Protective of Human Health / Environment**	**Attain MCSs**	**Control Migration (c)**	**Comply with Waste Management Requirements**	**Long-Term Reliability and Effectiveness**	**Reduction in Toxicity, Mobility, or Volume**	**Short-Term Effectiveness**	**Cost (d)**	**Regulatory Agency Acceptance**	**Community Concerns**
No Action	yes/no	no	no	yes	2	1	2	5	1	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	yes	yes	3	2	2	4	1	1
Institutional Controls	yes/yes	yes	no	yes	3	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	yes	yes	3	3	3	3	4	4
Permeable Reactive Barrier/Funnel & Gate	no/yes	no	yes	yes	3	3	3	3	3	3
Chemical Oxidation	yes/yes	unknown	no	yes	2	3	3	1	5	5
Enhanced bioremediation	yes/yes	unknown	no	yes	3	3	2	3	4	4
Soil Flushing and Groundwater Extraction	yes/yes	yes	yes	yes	3	3	4	3	4	4

(a) Level of Compliance Ranking
1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance
1. None
2. Low
3. Partial
4. Moderate
5. High

(c) na; not applicable
(d) relative cost from 1 (high) to 5 (low)

are well above regulatory-based MCSs (MCLs). Groundwater concentrations would remain at levels greater than regulatory-based MCSs for the foreseeable future. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community. It also does not comply with regulatory requirements and is therefore not recommended.

Monitored Natural Attenuation

A site-wide evaluation of geochemical parameters indicative of the potential for natural degradation of COCs was conducted in 1997. Geochemical parameters measured in well MW25-95-15, located a short distance downgradient from the Building 25A groundwater collection trench, were not favorable for natural degradation processes. In particular, the dissolved oxygen concentration was substantially greater than the minimum concentration that is considered indicative of conditions under which reductive dechlorination of COCs can occur. However, observed ratios of parent-daughter compounds within the western subplume suggest that degradation occurs during downgradient migration. In addition, there is no evidence that natural attenuation is occurring in the eastern subplume. As described above, the lobe has apparently reached a state of equilibrium where the degradation rates are similar to the rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. These observations indicate that MNA would not be an effective alternative unless concentrations of COCs in groundwater in the source area are significantly reduced. Therefore, MNA should only be considered in combination with more aggressive remediation technologies.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The Building 25A lobe is generally stable and no containment or capture is required. Some migration of COCs above regulatory-based MCSs may be occurring where the Building 25A lobe coalesces with the Building 7 lobe; however, at these locations concentrations of

Building 25A lobe constituents are only slightly above MCLs. Continuation of soil flushing and groundwater capture (or implementation of other corrective measures) in the western subplume source area should reduce COC concentrations in the downgradient areas to levels below MCSs. This alternative is therefore not recommended.

Permeable Reactive Barrier /Funnel & Gate

A permeable reactive barrier or funnel and gate system might control migration of COCs into uncontaminated areas to comply with regulatory requirements in areas downgradient from the Building 25A lobe. However, the Building 25A lobe is stable, except possibly where it coalesces with the Building 7 lobe where Building 7 lobe COC concentrations are well above MCLs. This alternative is therefore not recommended.

Chemical Oxidation

Generally, in situ chemical oxidation is applied in areas that have high COC concentrations and is not applicable to broad areas of low level contamination due to the high costs of reagent injection, the need for close spacing of injection points, and because reagent chemistry does not persist during groundwater migration. High COC concentrations or “hot spots” are not present in the Building 25A Lobe, indicating that the technology is unlikely to be cost effective. In addition, the effectiveness of the technology for remediation of the Building 25A lobe is not known and would require pilot testing prior to any full-scale implementation. The method would require numerous closely spaced injection points (typically on the order of 3 to 5 feet spacing). In addition, implementation of this technology would be difficult because for the Building 25A lobe source area is located under Building 25A. For these reasons, chemical oxidation is not recommended.

Enhanced Bioremediation

Available data suggest that natural degradation is only occurring in the downgradient portion of the western subplume. Therefore, the addition of enhancements might be effective in stimulating bioremediation of groundwater COCs in the downgradient portion of the lobe. Hydrogen Releasing Compound (HRC) could be injected to enhance reductive dechlorination of groundwater COCs in both the western and eastern subplumes. However, although pilot testing of this technology at the Building 71B lobe of the Building 71 Groundwater Solvent Plume has indicated that this method may be effective, its effectiveness at the Building 25A lobe is unknown. Enhanced bioremediation would not be implemented until groundwater COC concentrations in the upgradient lobe area have been reduced to levels that do not migrate to the downgradient area at concentrations above regulatory-based levels.

Soil Flushing and Groundwater Extraction

Available data indicate that DNAPL is not present in the Building 25A lobe and groundwater COC concentrations are relatively low. These characteristics indicate that soil flushing and groundwater extraction may be effective in reducing COC concentrations in the groundwater with minimal "rebound" after flushing is terminated.

After two years of operation of the soil flushing pilot test in the source area, groundwater COC concentrations in wells immediately adjacent to the pilot test area and well MW25A-95-15 have been substantially reduced. However, "rebound" following cessation of flushing has not been evaluated, so it is not yet certain whether concentration declines will be permanent. Based on results of pilot testing, this technology is recommended for full-scale implementation.

Summary of Building 25A Lobe Corrective Measures Implementation Strategy

The remediation objectives for the Building 25A lobe are to: 1) ensure that groundwater COCs at concentrations exceeding regulatory-based MCSs do not migrate into areas where concentrations are less than MCSs; and, 2) decrease groundwater COC concentrations below regulatory-based MCSs. The remedial technologies that have been identified that may meet these objectives are MNA, enhanced bioremediation, and soil flushing.

No remediation technologies are needed to address objective (1) above, since long-term groundwater monitoring data have established that the downgradient boundaries of the two subplumes of the Building 25A lobe are not migrating, except possibly where the western subplume coalesces with the Building 7 lobe.

In situ soil flushing has been identified as a potentially effective alternative to address remediation objective (2) above. Based on soil flushing pilot test results, this technology may permanently reduce COC concentrations to regulatory-based MCSs, and therefore is recommended for full-scale implementation. If in situ soil flushing results in COC concentrations above the regulatory-based MCSs, MNA should be considered to further reduce the concentrations. As described above, the Building 25A lobe has apparently reached a state of equilibrium where the degradation rates are similar to the rates of dissolution of soil contaminants and downgradient migration of dissolved COCs. Soil flushing may reduce COC concentrations sufficiently so that MNA becomes an effective alternative (i.e., the rate of degradation exceeds the rate of dissolution in the upgradient lobe area and migration). Enhanced bioremediation should be considered if MNA becomes ineffective.

4.3.7 Building 69A Area of Groundwater Contamination

The location of the Building 69A Area of Groundwater Contamination is shown on **Figure 4.3.7-1**. The most likely source of the contamination was leakage from a pipeline in the Building 69A Hazardous Materials Storage and Delivery Area (AOC 3-1) that drains to the Building 69A Storage Area Sump (SWMU 3-5). A dislocation was observed in one of the sump drainpipes and repaired in 1987.

4.3.7.1 Current Conditions

Geology and Hydrogeology

Prior to development of the site, the topography of the Building 69A area was generally dominated by relatively steep southward facing slopes. Chicken Creek Canyon, a major north-south-trending drainage course, and its tributaries, occupied the area west of the current location of Building 69A, and flowed downslope towards Building 77. Colluvium greater than 10 feet thick overlies bedrock in the former drainage area. During development, hillside cuts and canyon filling resulted in placement of artificial fill from 25 to 50 feet thick within the canyon in the vicinity of Building 69A. This created the relatively flat site on which Building 69A and adjacent buildings and parking areas are currently located. The main bedrock unit underlying the artificial fill and colluvium in the Building 69A area is the Orinda Formation, which consists of nonmarine siltstones and fine-grained sandstones. The Orinda Formation is overlain in some areas by volcanic and sedimentary rocks of the Mixed Unit.

Shallow groundwater in the Building 69A area is present in both the Orinda Formation and the surficial units (i.e., alluvium, colluvium, and artificial fill). However, groundwater flow within the Orinda Formation is of minor importance, as indicated by the relatively low values of hydraulic conductivity that have been measured in the unit. Depth to groundwater is approximately 25 feet to 45 feet bgs. Assuming a hydraulic conductivity value (K) of 2.6×10^{-7} meters per second for the Orinda Formation (estimated from a slug test in MW69A-92-22) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity (v_x) would be approximately 18 meters per year (45 feet per year) in the Building 69A area. Groundwater velocities in the surficial units are likely to be greater than this estimate. As shown on **Figure 4.3.7-1**, yields from wells in this area are all less than 200 gpd.

Groundwater Contamination

The principal Building 69A Area of Groundwater Contamination constituents are degradation products of halogenated non-aromatic VOCs that were used as cleaning solvents (e.g., cis-1,2-DCE and vinyl chloride). Lower concentrations of trans-1,2-DCE, PCE, 1,1,1-TCA, and other VOCs, including aromatic hydrocarbons, have also been occasionally detected. Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.7-1** where the maximum detected concentrations are compared to the target risk-based MCSs. Vinyl chloride was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.7-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 69A Area of Groundwater Contamination

COC	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
cis-1,2-DCE	28	6	98,405
vinyl chloride	**43**	0.5	12
PCE	11	5	343

Note: boldface concentration indicates that the maximum detected concentration of the COC in FY03 exceeds the target risk-based groundwater MCS.

The lateral extent of contamination appears to be confined to a relatively small area west and southwest of Building 69A. The extent of vinyl chloride, which is apparently restricted to the area of temporary groundwater sampling point SB69A-99-1, is much more limited than that of cis-1,2-DCE. Based on the low hydraulic conductivity of the Orinda Formation, the vertical extent of contamination is likely restricted to the colluvium and the upper few feet of the Orinda Formation. No COCs have been detected in downgradient temporary groundwater sampling point SB77-02-1.

Groundwater COC Trends

Concentration variations for cis-1,2-DCE and vinyl chloride in wells monitoring the area of groundwater contamination over time are shown on **Figure 4.3.7-2**. The concentration of cis-1,2-DCE has been decreasing in groundwater samples collected from the three wells monitoring the area of groundwater contamination the and is approaching the MCL. However, the concentration of vinyl chloride detected in SB69A-99-1 increased from nondetectable levels to approximately 30 to 40 µg/L in early 2001, coincident with a significant decrease in cis-1,2-DCE concentrations, and has remained relatively constant since that time. The lateral extent of the Building 69A Area of Groundwater Contamination does not appear to have changed over several years of monitoring. However, the observed decrease in cis-1,2-DCE concentrations, in conjunction with an increase in vinyl chloride concentrations strongly suggests that natural degradation processes are occurring (vinyl chloride is a degradation product of cis-1,2-DCE), and that COC concentrations will likely decline to levels below MCLs.

Soil Contamination

Shallow soil samples (2-foot depth) were collected in 1991 in the area west of the groundwater unit to help assess whether chemicals had been released from the likely source, the pipe dislocation described above. The highest VOC concentrations were detected adjacent to the repaired dislocation of the pipe (PCE maximum 2 mg/kg and TCE maximum 0.008 mg/kg), indicating that the pipe was the probable source of the contamination. Soil samples collected in 1992 and 1993 near the repaired pipe dislocation contained PCE at a maximum concentration of 1.4 mg/kg. However, no VOCs were detected in soil samples collected in the same area in September 2000, suggesting that the previously detected PCE and TCE may have degraded to nondetectable levels.

The only other location where halogenated VOCs have been detected in soil samples collected in the area of groundwater contamination was cis-1,2-DCE (0.008 mg/kg maximum) in soil boring SB69A-99-1. However, these soil samples were collected from below the water table, indicating that they may represent groundwater contamination rather than soil contamination.

Presence of DNAPL

Maximum concentrations of COCs detected in soil samples collected in the Building 69A Area of Groundwater Contamination are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**. Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs. The absence of DNAPLs is further substantiated by the decline in total concentrations of halogenated VOCs in groundwater.

4.3.7.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Building 69A Area of Groundwater Contamination:

- There is no evidence suggesting the presence of DNAPL or of residual soil contamination at levels likely to leach into groundwater. Declines in COC concentrations in groundwater corroborate this finding.
- Groundwater flows primarily through surficial units and low permeability rocks of the Orinda Formation at velocities estimated to be approximately 18 feet per year or greater.
- Due to the relatively low permeability of the Orinda Formation, well yields are less than 200 gpd, so target risk-based MCSs are applicable.
- Spatial and temporal concentration trends suggest that cis-1,2-DCE has been degrading, but this process has apparently resulted in local increases in vinyl chloride concentrations. It is anticipated that vinyl chloride levels will not decrease until after the remaining cis-1,2-DCE has degraded further.
- Concentrations of vinyl chloride exceed target risk-based MCSs in groundwater in temporary groundwater sampling point SB69A-99-1. The potential human receptors and risk-based exposure pathways of potential concern are exposure to COCs by hypothetical future indoor workers breathing vapor migrating to indoor air from groundwater (Berkeley Lab, 2003a).

4.3.7.3 Evaluation of Retained Corrective Measures Alternatives

Concentrations of groundwater COCs (vinyl chloride) in the Building 69A Area of Groundwater Contamination exceed target risk-based MCSs. Regulatory-based MCSs are not applicable. Available data indicate that DNAPLs are not present. No migration of COCs beyond the plume margins is occurring, so migration control is not a concern.

The corrective measures alternatives that are evaluated for the Building 69A Groundwater Solvent Plume and source area are those that were retained in **Table 4.2.3-2** for groundwater). The results of the evaluation are provided in **Table 4.3.7-2** and discussed below.

No Action

No action for the Building 69A Area of Groundwater Contamination would consist of termination of all groundwater monitoring activities. The concentration of vinyl chloride should eventually decrease to below the risk-based level; however, the timeframe for this to happen is unknown. These conditions would require establishment of Institutional Controls to protect future workers. In addition, this alternative would likely be unacceptable to the regulatory agencies and the community. The No Action alternative is not protective of human health and the environment and is therefore eliminated from further consideration.

Monitored Natural Attenuation

The site groundwater monitoring data indicate that biodegradation of halogenated VOCs by reductive dechlorination is occurring. The lines of evidence for this conclusion include:

- The contaminant mass currently consists almost entirely of cis-1,2-DCE and vinyl chloride. The presence of these degradation products suggests biodegradation of PCE and/or TCE. In addition, groundwater samples collected from SB69A-99-1 showed consistent decreases in cis-1,2-DCE concentrations, while concentrations of vinyl chloride have increased.
- Dissolved oxygen (DO) concentrations measured in groundwater indicate that groundwater conditions are anaerobic (DO<1).
- Aromatic hydrocarbons have been detected in groundwater samples. These fuel hydrocarbons could be a carbon source for indigenous microorganisms.

Table 4.3.7-2. Evaluation of Corrective Measures Alternatives, Building 69A Area of Groundwater Contamination

Corrective Measures Alternative	Corrective Action Standards (yes/no)				Decision Factors (a)				Other Factors (b)	
	Protection of Human Health and the Environment	Attain MCSs	Control Migration (c)	Comply with Waste Management Requirements	Long-Term Reliability and Effectiveness	Reduction in Toxicity, Mobility, or Volume	Short-Term Effectiveness	Cost (d)	Regulatory Agency Acceptance	Community Concerns
No Action	no/no	no	na	yes	4	4	3	5	2	1
Monitored Natural Attenuation (MNA)	yes/yes	yes	na	yes	4	4	3	4	5	4
Institutional Controls	yes/no	no	na	yes	3	1	3	4	4	2
Groundwater Containment/Capture	no/yes	no	na	yes	2	2	2	3	3	2
Permeable Reactive Barrier/Funnel & Gate	no/yes	no	no	yes	2	2	2	3	3	3
Chemical Oxidation	no/no	unknown	na	yes	3	3	3	3	5	5
Enhanced bioremediation	yes/yes	unknown	na	yes	4	4	4	3	5	5
Soil Flushing and Groundwater Extraction	yes/yes	yes	na	yes	3	3	4	3	4	4

(a) Level of Compliance Ranking
1. None
2. Low
3. Partial
4. Moderate
5. High

(b) Level of Acceptance
1. None
2. Low
3. Partial
4. Moderate
5. High

(c) na; not applicable
(d) relative cost from 1 (high) to 5 (low)

MNA would include a program to monitor the effectiveness of the alternative. The monitoring program would be based on the existing monitoring well network. Periodic groundwater sampling would provide confirmation that degradation of COCs is continuing, and that vinyl chloride concentrations remain below risk-based levels. MNA is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 69A Area of Groundwater Contamination using the decision factors shown in **Table 4.3.7-2**.

Institutional Controls

The evaluation of Institutional Controls is similar to that for the No Action alternative discussed above; however, institutional controls can be somewhat effective in protecting human health in the short term, but less effective in the long-term. This alternative would not achieve MCSs and would likely be unacceptable to the regulatory agencies and the community, and is therefore not recommended.

Groundwater Containment/Capture

The plume is stable and no containment or capture of the plume boundary is currently required or planned. This alternative is therefore not recommended.

Permeable Reactive Barrier/Funnel & Gate

A permeable reactive barrier or funnel & gate system would have a similar effect to a groundwater capture system. Since the plume is stable and no containment or capture is currently required or planned for the future, this technology is not recommended.

Chemical Oxidation

The effectiveness of chemical oxidation for remediation of the Building 69A Area of Groundwater Contamination plume is not known and would require pilot testing prior to any full-scale implementation. In situ chemical oxidation is generally not effective in low permeability materials such as the Orinda Formation, and as described in Section 4.3.2, pilot testing of this technology in the Building 51L and Building 71B Groundwater Solvent Plume source areas was not effective, so the likelihood that it would be effective is considered to be low. However, due to the very small size of this unit, this technology could potentially be effective if pilot testing showed that delivery of reagents to the impacted pore space could be ensured. In situ chemical oxidation is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 69A Area of Groundwater Contamination using the decision factors shown in **Table 4.3.7-2**.

Enhanced Bioremediation

Enhanced bioremediation for the Building 69A Area of Groundwater Contamination would consist of the controlled release of Oxygen Release Compounds (ORC®) into the groundwater to enhance natural biodegradation of vinyl chloride. A pilot test of HRC injection was conducted at Building 75/75A Area of Groundwater Contamination, under similar site-specific hydrogeologic conditions to those found in the Building 69A area. The results were not favorable, suggesting that enhanced bioremediation is not effective under the hydrogeologic conditions that are present. However, since HRC was the technology that was tested, the effectiveness of ORC is not known. Enhanced bioremediation using ORC is therefore retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 69A Area of Groundwater Contamination using the decision factors shown in **Table 4.3.7-2**.

Soil Flushing and Groundwater Capture

Available data indicate that DNAPL and COCs sorbed to the soil matrix in the vadose zone are not present in the Building 69A Area of Groundwater Contamination, except for sorbed COCs in equilibrium with dissolved groundwater COCs. Therefore, groundwater flushing may result in permanent reductions of COC concentrations that are maintained with minimal “rebound” after cessation of flushing. However, the very low permeability of saturated zone materials at the unit would likely limit the effectiveness of this remedy due to the long period of time needed for implementation. In addition, introduction of treated water might result in halting the apparently on-going natural degradation processes. Based on this evaluation, soil flushing is retained for further evaluation in the summary section below, where it is compared to other alternatives retained for the Building 69A Area of Groundwater Contamination using the decision factors shown in **Table 4.3.7-2**.

Summary of Corrective Measures Implementation Strategy

The remediation objective for the Building 69A Area of Groundwater Contamination is to reduce groundwater COC (vinyl chloride) concentrations below target risk-based MCSs. The remedial technologies that have been identified that may meet these objectives are MNA, enhanced bioremediation, chemical oxidation, and in situ soil flushing. Except for MNA, the effectiveness of these technologies would be severely limited by the low permeabilities of subsurface materials. The cost of MNA would be less than the other alternatives that can meet the remediation objective, and except for the short-term effectiveness of soil flushing and enhanced bioremediation, ranked at least as high in the other decision factors listed in **Table 4.3.7-2**. Therefore, based on its ranking in the decision factors and the fact that there is strong evidence that MNA is currently effective, MNA is the recommended alternative.

4.3.8 Solvents in Groundwater South of Building 76 (AOC 4-5)

The location of the Solvents in Groundwater South of Building 76 (Building 76 Groundwater Solvent Plume) is shown on **Figure 4.3.7-1**. The area of maximum VOC concentrations in groundwater south of Building 76 suggests that the primary source of the plume was related to Building 76 operations; however, the specific source has not been located. The Building 76 Motor Pool Collection Trenches and Sump (SWMU 4-3) are suspected to be the primary source of contamination, due to their close proximity to the plume and potential for past releases. The Former Building 76 Gasoline and Diesel Underground Storage Tanks (USTs) (AOCs 4-1 and 4-2) are the likely sources for fuel hydrocarbons that have also been detected in the groundwater south of Building 76.

4.3.8.1 Current Conditions

Geology and Hydrogeology

The Building 76 area lies on a relatively flat graded building pad that interrupts a relatively steep southwest-facing slope. The main bedrock in the Building 76 area is the Orinda Formation, which consists of nonmarine siltstones and fine-grained sandstones. Approximately 10 to 20 feet of fill overlies the bedrock south of the building.

Depth to groundwater is approximately 13 feet to 25 feet bgs. The groundwater is generally in the Orinda Formation and does not extend into the overlying fill. Assuming a hydraulic conductivity value (K) of 3×10^{-8} meters per second for the Orinda Formation (estimated from a slug test in MW76-1) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity (v_x) would be approximately 1.5 meters per year (5 feet per year) in the Building 76 area. As shown on **Figure 4.3.7-1**, yields from wells in this area are all less than 200 gpd.

Groundwater Contamination

The principal Building 76 Groundwater Solvent Plume constituents are halogenated non-aromatic VOCs that were used as cleaning solvents (PCE and TCE) and their degradation products (e.g., cis-1,2-DCE). In addition, diesel- and gasoline-range hydrocarbons and aromatic (fuel-related) VOCs have been occasionally detected in wells in this area. Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.8-1** where the maximum detected concentrations are compared to the target risk-based MCSs. None of the COCs was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.8-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 76 Groundwater Solvent Plume

COC	Maximum Concentration Detected in Groundwater in FY03 (μg/L)	Maximum Contaminant Level (MCL) (μg/L)	Target Risk-Based Groundwater MCS (μg/L)
cis-1,2-DCE	9.8	6	98,405
TCE	20	5	3,065

The plume extends approximately 100 feet southwards from the motor pool area on the south side of Building 76. Groundwater containing COCs lies beneath the existing motor pool gasoline and diesel underground storage tanks and also likely extends beneath Building 76. The lateral (transgradient) extent of halogenated non-aromatic VOCs in the groundwater is characterized by the absence of VOCs in wells to the west and east of the plume (**Figure 4.3.7-1**). The lateral (downgradient) extent of the plume is indicated by only sporadic detections of VOCs in monitoring well MW76-98-22, with no VOCs detected in the well since March 2001. Based on the low hydraulic conductivity of the Orinda Formation, the vertical extent of contamination is likely restricted to relatively shallow depths in the Orinda Formation.

Groundwater COC Trends

VOC concentrations in wells south of Building 76 have remained relatively constant since 1993, as indicated by measurements in monitoring well MW76-1. In addition, COCs have not been detected in downgradient monitoring well MW76-98-22 since March 2001.

Soil Contamination

Soil samples were collected near the Building 76 motor pool collection trenches and garage area sump during several rounds of sampling from 1992 to 1997. In addition, soil samples were collected in 1990 during removal operations for the former Building 76 underground gasoline and diesel storage tanks and in 1997 during subsequent investigations of soil contamination associated with the former USTs. The sampling locations partially overlie the area of groundwater contamination. Relatively low concentrations (well below MCSs) of PCE, TCE, 1,1,1-TCA, Freon compounds, and chloroform were the only halogenated VOCs detected.

Soil Gas and Indoor Air Data

The maximum theoretical ILCR (2.1×10^{-5}) estimated for the unit was within the USEPA target risk range (10^{-4} to 10^{-6}) for current indoor workers, based on indoor air concentrations measured inside Building 76, which partly overlies the area of groundwater contamination (Berkeley Lab, 2003). Benzene, PCE, and TCE were the primary risk drivers. Since benzene was not detected in the groundwater, the source of the benzene is likely the adjacent gasoline fuelling operations. The major source of the halogenated VOCs detected in indoor air may be surface (e.g., concrete) contamination from historical motor pool degreasing activities, and not contaminated soil or groundwater. Soil gas sampling was conducted to assess whether or not VOCs were present beneath the concrete floor of the Building. Soil gas VOC concentrations in the vicinity of the previously collected indoor air sampling data were several orders of magnitude lower than RWQCB ESLs for soil gas. However, two soil gas sampling points at the west end of Building 76 contained elevated levels of PCE (maximum concentration 4,200 $\mu g/m^3$) that exceed the ESL (1,400 $\mu g/m^3$).

Presence of DNAPL

Maximum concentrations of COCs detected in soil samples collected in the Building 76 Groundwater Solvent Plume area are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**. Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs.

4.3.8.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Building 76 Groundwater Solvent Plume:

- There is no evidence suggesting the presence of DNAPL at the unit.
- Groundwater flows primarily through surficial units and low permeability rocks of the Orinda Formation at velocities estimated to be approximately 18 feet per year or greater.
- Due to the relatively low permeability of the Orinda Formation, well yields are less than 200 gpd, so target risk-based MCSs are applicable.
- No data are available to assess whether natural degradation of COCs is occurring.
- Concentrations of COCs are at levels several orders of magnitude lower than target risk-based MCSs.

4.3.8.3 Evaluation of Retained Corrective Measures Alternatives

Groundwater well yields at the unit are substantially less than 200 gpd and therefore only target risk-based MCSs are applicable. Since COC concentrations are several orders-of-magnitude less than target risk-based MCSs (**Table 4.3.8-1**) no action is required to attain MCSs. No migration of COCs beyond the plume margins is occurring, so migration control is not a concern. Therefore, No Further Action is recommended for the Building 76 Area of Groundwater Contamination. Since MCSs have been achieved, no comprehensive evaluation of other corrective measures alternatives was completed for this unit.

4.3.9 Building 77 Area of Groundwater Contamination

The location of the Building 77 Area of Groundwater Contamination is shown on **Figure 4.3.7-1**. The Building 77 Sanitary Sewer System (AOC 5-4) was considered the most likely source of the groundwater contamination, based on its location relative to the contamination. Soil and soil-gas sampling conducted along the sewer line, however, could not identify a source area.

4.3.9.1 Current Conditions

Geology and Hydrogeology

Prior to development of the site, the topography of the Building 77 area was generally dominated by relatively steep southward facing slopes. Chicken Creek Canyon, a major north-south-trending drainage course, and its tributaries, bisected the area and flowed beneath the current location of Building 77. During development, hillside cuts and canyon filling resulted in placement of up to 45 feet of artificial fill within the canyon, creating the relatively flat site on which Building 77 is located. The creek has been diverted into stormdrains and emerges just downslope from the road south of Building 77.

Bedrock in the Building 77 area consists of nonmarine claystone, siltstone, and fine-grained sandstones of the Orinda Formation. Several feet of colluvium overlie the bedrock at the base of the former tributary of Chicken Creek. Approximately 40 to 45 feet of fill overlies the colluvium or directly overlies the bedrock where the colluvium is not present.

Shallow groundwater in the Building 77A area is present in both the Orinda Formation and the surficial units (i.e., alluvium, colluvium, and artificial fill). Depth to groundwater is approximately 40 feet to 45 feet bgs. Assuming a hydraulic conductivity value (K) of 4×10^{-9} meters per second for the Orinda Formation (estimated from slug tests south of Building 77) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity (v_x) would be approximately 0.4 meters per year (1.5 feet per year) near the southwest end of Building 77. As shown on **Figure 4.3.7-1**, yields from wells in this area are less than 200 gpd.

Groundwater Contamination

The principal Building 77 Area of Groundwater Contamination constituents are degradation products of halogenated non-aromatic VOCs that were used as cleaning solvents, including cis-1,2-DCE, trans-1,2-DCE, 1,1-DCE, and 1,1-DCA. Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.9-1** where the maximum detected concentrations are compared to the target risk-based MCSs. None of the COCs was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.9-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 77 Area of Groundwater Contamination

COC	Maximum Concentration Detected in Groundwater in FY03 (μg/L)	Maximum Contaminant Level (MCL) (μg/L)	Target Risk-Based Groundwater MCS (μg/L)
cis-1,2-DCE	6.1	6	98,405
PCE	9.5(a)	5	343

(a)Except for an anomalous detection of PCE in August 2003, which was attributed to cross contamination during sampling, concentrations of PCE in MW91-2 have been 1 μg/L or less since 1996.

The lateral extent of contamination appears to be confined to a small area at the southwest corner of Building 77 near MW91-2. Contaminants have not been detected in downgradient, upgradient, or crossgradient wells. Based on the low hydraulic conductivity of the Orinda Formation, the vertical extent of contamination is likely restricted to the fill and the upper few feet of the Orinda Formation.

Groundwater COC Trends

The variations in the concentrations of halogenated VOCs detected MW91-2 over time are shown on **Figure 4.3.9-1**. Concentrations of both total VOCs and the individual chemicals detected in MW91-2 have consistently declined since 1992, with concentrations decreasing to levels below MCLs (trans-1,2-DCE, 1,1-DCE, and 1,1-DCA); or ranging from slightly above to below MCLs (cis-1,2-DCE).

The presence of degradation products and the observed decreases in VOC concentrations strongly suggest that natural degradation is occurring and that concentrations of COCs will continue to decline. Cis-1,2-DCE, trans-1,2-DCE, and possibly 1,1-DCE are probably present as the result of biodegradation of PCE and/or TCE. The presence of 1,1-DCA, and possibly 1,1-DCE, is probably the result of biodegradation of 1,1,1-TCA.

Soil Contamination

In 1996, five shallow soil-gas probes were installed inside the southwest wall of Building 77 to help identify the source of the groundwater contamination. No source area was indicated since only low levels of photoionizable compounds were detected.

Presence of DNAPL

Maximum concentrations of COCs detected in soil samples collected in the Building 77 Area of Groundwater Contamination are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**. Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs. The absence of DNAPLs is further substantiated by the decline in concentrations of both total and individual halogenated VOCs in the groundwater.

4.3.9.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Building 77 Area of Groundwater Contamination:

- There is no evidence suggesting the presence of DNAPL or of residual soil contamination at levels likely to leach into groundwater.
- Groundwater flows primarily through surficial units and low permeability rocks of the Orinda Formation at velocities estimated to be approximately 1.5 feet per year.
- Due to the relatively low permeability of the Orinda Formation, well yields are less than 200 gpd, so target risk-based MCSs are applicable.
- Declining concentration trends and the presence of degradation products indicate that natural attenuation of COCs is occurring at the unit.

- Concentrations of COCs are several orders of magnitude less than target risk-based MCSs. Concentrations of COCs have declined to levels below or only slightly above MCLs, with all concentrations below MCLs some quarters.

4.3.9.3 Evaluation of Retained Corrective Measures Alternatives

Groundwater well yield at the unit is less than 200 gpd and therefore, only target risk-based MCSs are applicable. The groundwater concentration data indicate that natural attenuation processes have been effective in reducing concentrations of COCs in the Building 77 area to several orders-of-magnitude below target risk-based MCSs and also below MCLs. Concentrations of the four VOCs consistently detected, trans-1,2-DCE, 1,2-DCE, cis-1,2-DCE, and 1,1-DCA, were below MCLs three of the five quarters MW91-2 was sampled from September 2001 through August 2003. No migration of COCs beyond the plume margins is occurring, so migration control is not a concern for the unit. Therefore, No Further Action is recommended for the Building 77 Area of Groundwater Contamination. Since MCSs have been achieved, no comprehensive evaluation of the other corrective measures alternatives was completed for this unit.

4.3.10 Building 75/75A Area of Groundwater Contamination

There are two relatively small areas where halogenated VOCs have been detected in the groundwater near Buildings 75 and 75A (**Figure 4.3.7-1**). The first area extends southward from the east side of Building 75A toward Building 75. The second area is located between Building 75 and 75A. The two areas may commingle near the northeast corner of Building 75. Collectively these areas have been designated the Building 75/75A Area of Groundwater Contamination. The different suites of chemicals detected in groundwater east and south of Building 75A indicate separate sources for the contamination. The contamination may be related to operations of the Building 75 Former Hazardous Waste Handling and Storage Facility; however, the source has not been confirmed since only relatively low concentrations of COCs have been detected in the soil in the area.

4.3.10.1 Current Conditions

Geology and Hydrogeology

The main bedrock unit that underlies the Building 75/75A area is the Orinda Formation, which consists of nonmarine siltstones and fine-grained sandstones. Overlying the bedrock is approximately 20 feet of colluvium, consisting of clay, which is in turn overlain by approximately 12 feet of sandy-clay fill material.

Depth to groundwater varies from approximately 15 to 28 feet bgs. Assuming a hydraulic conductivity value (K) of 4×10^{-7} meters per second for the Orinda Formation (estimated from a slug test in MW75-98-15) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity (v_x) would be approximately 9 meters per year (30 feet per year) in the Building 75/75A area. As shown on **Figure 4.3.7-1**, yields from wells in this area are all less than 200 gpd.

Groundwater Contamination

The principal Building 75/75A Area of Groundwater Contamination constituents are halogenated non-aromatic VOCs that were used as cleaning solvents, including TCE and degradation products (e.g., 1,1-DCE, and cis-1,2-DCE). Chemicals detected in the groundwater at concentrations above MCLs in FY03 are listed in **Table 4.3.10-1** where the maximum detected concentrations are compared to the target risk-based MCSs. None of the COCs was detected at a concentration exceeding the target risk-based MCS.

Table 4.3.10-1. Maximum Concentrations of COCs Exceeding MCLs in FY03 in the Building 75/75A Area of Groundwater Contamination

COC	Maximum Concentration Detected in Groundwater in FY03 (μg/L)	Maximum Contaminant Level (MCL) (μg/L)	Target Risk-Based Groundwater MCS (μg/L)
Contamination East of Building 75A			
TCE	16.0	5	1,594
cis-1,2-DCE	52	6	98,405
PCE	15.2[(a)]	5	343
Contamination South of Building 75A			
PCE	46[(a)]	5	343

[(a)] Anomalous detections of PCE and TCE in 2003 may have been the result of cross contamination during sampling. PCE has generally not been detected in wells in this area

The upgradient and transgradient extent of the groundwater contamination is characterized by the absence of COCs in monitoring wells to the north and west of Building 75A, and wells further east and southeast of the unit (**Figure 4.3.7-1**). Based on the low hydraulic conductivity of the Orinda Formation, the vertical extent of contamination is likely restricted to the fill and the upper few feet of the Orinda Formation.

Groundwater COC Trends

Concentrations of cis-1,2-DCE have declined somewhat in MW75-96-20, while concentrations in SB75-02-1 appear to be increasing. Both of these wells monitor the area of groundwater contamination east of Building 75A. The relatively high concentration of cis-1,2-DCE in SB75-02-1 suggests that biodegradation of PCE and/or TCE is occurring.

Soil Contamination

Halogenated VOCs were detected in soil samples collected between Building 75 and Building 75A in 1997 during closure activities associated with the former Building 75 Former Hazardous Waste Handling Facility, and in 2002 east of Building 75A as part of a groundwater contamination source investigation. Maximum concentrations of COCs detected are listed in **Table 4.3.10-2**. All concentrations are well below the target risk-based MCSs. Regulatory-based MCSs for soil are not applicable since well yields are less than 200 gpd.

Table 4.3.10-2. Maximum Concentration of VOCs Detected in Soil Samples, Building 75/75A Area of Groundwater Contamination

COC	Maximum Concentration (mg/kg)	Target Risk-Based MCS (mg/kg)
PCE	0.31	0.45
TCE	0.061	2.3
cis-1,2-DCE	0.43	38
trans-1,2-DCE	0.021	50
1,1,1-TCA	0.015	690
1,1-DCE	0.006	8
Methylene chloride	0.02	1.8

The maximum concentrations of the detected VOCs were generally found in the samples collected east of Building 75A. This is the location that is considered the primary source area for the VOCs detected in the groundwater east of the building.

Presence of DNAPL

Maximum concentrations of COCs detected in soil samples collected in the Building 75/75 Area of Groundwater Contamination are substantially lower than the soil saturation concentrations shown in **Table 4.2.2-1**, . Similarly, concentrations of COCs in groundwater are very low relative to their solubilities and effective volubilities. These comparisons do not provide any evidence for the presence of DNAPLs.

4.3.10.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Building 75/75A Area of Groundwater Contamination:

- There is no evidence suggesting the presence of DNAPL.
- Groundwater flows primarily through surficial units and low permeability rocks of the Orinda Formation at velocities estimated to be approximately 30 feet per year.
- Due to the relatively low permeability of the Orinda Formation, well yields are less than 200 gpd, so target risk-based MCSs are applicable.
- The presence of degradation products indicate that natural attenuation of COCs is occurring at the unit.
- Concentrations of COCs in groundwater are several orders of magnitude less than target risk-based MCSs.

4.3.10.3 Evaluation of Retained Corrective Measures Alternatives

Groundwater well yields at the unit are substantially less than 200 gpd. Therefore, only target risk-based MCSs are applicable, and COC concentrations are all several orders-of-magnitude less than target risk-based MCSs (**Table 4.3.10-1**). No migration of COCs beyond the plume margins is occurring, so migration control is not a concern. Therefore, No Further Action is recommended for the Building 75/75A Area of Groundwater Contamination. Since MCSs have been achieved, no comprehensive evaluation of other corrective measures alternatives was completed for this unit.

4.3.11 Benzene Detected in Groundwater in Wells East of Building 75A

Benzene has been detected in two relatively deep monitoring wells (MW91-4 and MW75A-00-7) on the east side of Building 75A. The locations of the wells are shown on **Figure 4.3.7-1**. The wells are screened within the Orinda Formation from approximately 115 to 145 feet below ground surface. The source of the benzene is not known; however, given the fact that benzene has also been detected in other deep wells screened in the Orinda Formation, there is a possibility that the benzene could be naturally occurring.

4.3.11.1 Current Conditions

Geology and Hydrogeology

The main bedrock unit that underlies the Building 75/75A area is the Orinda Formation, which consists of nonmarine siltstones and fine-grained sandstones. Overlying the bedrock is approximately 20 feet of colluvium, consisting of clay, which is in turn overlain by approximately 12 feet of sandy-clay fill material.

Depth to groundwater varies from approximately 15 to 28 feet bgs. Assuming a hydraulic conductivity value (K) of 4 x 10^{-7} meters per second for the Orinda Formation (estimated from a slug test in MW75-98-15) and an estimated effective porosity (n_e) of 0.1, Darcy's law ($v_x = K/n_e \times dh/dl$) indicates that the average linear groundwater velocity for the shallower section of the Orinda Formation (v_x) would be approximately 9 meters per year (30 feet per year) in the Building 75/75A area. The velocity in the deeper section where the benzene has been detected would be much less. Well yields from both MW91-4 and MW75A-00-7 are much less than 200 gpd and therefore risk-based MCSs are applicable.

Groundwater Contamination

Benzene has been detected in MW91-4 and MW75A-00-7 most quarters the wells have been sampled. Benzene is generally the only VOC detected in either well. Benzene has not been detected in two monitoring wells (MW75-99-7 and MW75-96-20), which are within approximately 14 feet of the deeper wells, but screened above a depth of 50 feet. The maximum concentration of benzene detected in each well in FY03 is listed in **Table 4.3.11-1** where the maximum detected concentrations are compared to the target risk-based MCS. Benzene has not been detected at a concentration above the target risk-based MCS.

Table 4.3.11-1. Maximum Concentrations of Benzene Detected in Groundwater in FY03 in the Building 75A Area

Well Number	Maximum Concentration Detected in Groundwater in FY03 (µg/L)	Maximum Contaminant Level (MCL) (µg/L)	Target Risk-Based Groundwater MCS (µg/L)
MW91-4	11	1	175
MW75A-00-7	47	1	175

<u>Groundwater COC Trends</u>

The detected concentration of benzene in MW91-4 has ranged from 3.6 µg/L to 98 µg/L, with no apparent trend in the data. Concentrations in MW75A-00-7 have ranged from 10 and 47 µg/L, also with no apparent trend in the data.

<u>Soil Contamination</u>

The only location where benzene has been detected in soil samples near Building 75A was at a depth of 140 feet at MW75A-00-7.

<u>Presence of DNAPL</u>

The concentration of benzene in groundwater is very low relative to its solubility and effective volubility, providing no evidence for the presence of DNAPL.

4.3.11.2 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Benzene Detected in Two Wells East of Building 75A:

- There is no evidence suggesting the presence of DNAPL.
- Groundwater wells in which the benzene has been detected yield less than 200 gpd, so target risk-based MCSs are applicable.

4.3.11.3 Evaluation of Retained Corrective Measures Alternatives

Groundwater well yields at the unit are substantially less than 200 gpd. Therefore, only target risk-based MCSs are applicable, and benzene concentrations are several orders-of-magnitude less than target risk-based MCS (**Table 4.3.11-1**). Therefore, No Further Action is recommended for the Benzene Detected in Groundwater in Two Wells East of Building 75A. Since MCSs have been achieved, no comprehensive evaluation of other corrective measures alternatives was completed for this unit.

SECTION 5

DEVELOPMENT OF CORRECTIVE MEASURES FOR POLYCHLORINATED BIPHENYLS (PCBs)

The primary COCs present at two Berkeley Lab units are polychlorinated biphenyls (PCBs). These chemicals were primarily present as components of oils that were used in pumps and electrical devices at Berkeley Lab. PCBs are not COCs at any groundwater units. The soil units at which PCBs are COCs are:

- Building 88 Hydraulic Gate Unit (AOC 6-3)
- Building 75 Former Hazardous Waste Handling and Storage Facility (SWMU 3-6)

5.1 MEDIA CLEANUP STANDARDS FOR PCBs

Risk and Regulatory-Based MCS

On June 29, 1998, the Disposal Amendments to the Toxic Substances Control Act (TSCA) (dubbed the Megarule by industry) were published in the Federal Register (63 FR 3584). The Megarule provides cleanup options for PCBs in bulk remediation waste, including soil. The self-implementing cleanup level (i.e., the ‘‘walk-away’’ level) for soil in “high occupancy” areas is ≤1 part per million (ppm), or ≤10 ppm if the soil is capped (40 CFR §761.61(a)(4)(i)(A). The codified text uses (ppm) for concentration measurement of non-liquids as an equivalent to milligrams per kilogram (mg/kg). The TSCA cleanup level is based on an evaluation of potential risk assuming an unprotected exposure 24 hours a day, 7 days a week, and 50 weeks per year for the “high occupancy” scenario.

To ensure that the TSCA cleanup level addressed risks calculated for Berkeley Lab units, risks associated with pathways identified for the Berkeley Lab HHRA were examined. **Table 5.1-1** lists estimates of the lowest soil PCB concentrations for any PCB Aroclor that would result in a theoretical ILCR of 10^{-6} or an HI equal to 1.0 for these critical pathways and receptors, using the same methodology as was used in the HHRA (Berkeley Lab, 2003a). The minimum soil

PCB concentration that met this criterion was 0.8 mg/kg, only slightly below the TSCA cleanup level. Since PCB-contaminated soil at Berkeley Lab consists of a mixture of Aroclors, this slight discrepancy would not result in risks exceeding the USEPA target risk range.

Table 5.1-1. Derivation of Risk-Based Target MCS for PCBs in Soil

Receptor	Theoretical ILCR or HI	PCB Concentration
Landscape Maintenance Worker	Theoretical ILCR=1x10^{-6} Hazard Index=1	0.8 mg/kg 1.2 mg/kg
Construction Worker	Theoretical ILCR=1x10^{-6}	31.8 mg/kg
	Hazard Index=1	1.8 mg/kg

To assess whether the TSCA cleanup level could potentially result in impacts to groundwater, it was compared to the groundwater protection component of the RWQCB Environmental Screening Levels (RWQCB, 2003). That component is 6.3 mg/kg for all Aroclors, indicating that the 1 mg/kg TSCA level is protective of groundwater.

Proposed MCS for PCBs and Points of Compliance

The proposed MCS for PCBs in soil is 1 mg/kg, the self-implementing cleanup level for soil in “high” occupancy areas under TSCA. Post-remediation confirmation soil samples were collected to verify compliance with the self-implementing cleanup level.

5.2 SELECTION AND EVALUATION OF CORRECTIVE MEASURES ALTERNATIVES FOR PCBs IN SOIL

Subsequent to completion of the Berkeley Lab HHRA, which identified the two units for which PCBs are the COCs, Berkeley Lab conducted ICMs that resulted in reduction of residual PCB concentrations to less than the proposed MCS of 1 mg/kg at both the Building 88 Hydraulic Gate Unit and the Building 75 Former hazardous Waste Handling and Storage Facility. For this reason, no further evaluations of corrective measures alternatives are needed. A description of the two units, including the ICMS that were conducted, is provided in the following sections.

5.3 BUILDING 88 HYDRAULIC GATE UNIT (AOC 6-3)

The 88-Inch Cyclotron located in Building 88 is operated as a national facility in support of DOE programs in basic nuclear science. The central component is a sector-focused, variable-energy cyclotron that produces heavy-ion beams of elements throughout the periodic table. A hydraulic pump in Room 181 of Building 88 is used to operate the building's hydraulic main vault doors. The pump has probably been used since the building was constructed in 1960. A PCB-containing oil was used in the pump from 1962 to 1976. The oil was changed to a non-PCB oil in 1976. During the RFA, an oil stain approximately 10 feet long was observed on the concrete floor around the pump. The stain was probably the result of occasional drips of oil from the pump over the period of pump operation. Cleanup of the PCB stain and retrofilling and cleaning of the pump were conducted in 1991. The location of the hydraulic gate pump is shown on **Figure 5.3-1**.

5.3.1 Physiography and Geology

Building 88 is constructed on a bench cut into a steep westward and northwestward facing slope. The northwestward facing slope forms the south side of Blackberry Canyon, through which the North Fork of Strawberry Creek flows. The bedrock underlying Building 88 consists of northerly dipping marine mudstones, sandstones, and shales of the Great Valley Group. Bedrock is present at relatively shallow depths (within approximately 2 feet at some locations) under the building. Colluvium is present in scattered locations around Building 88, with the thickest deposit (approximately 25-feet thick) on the slope above the north end of Building 88. Depth to groundwater ranges from approximately 40 feet at the north end of Building 88 to more than 100 feet at the south end.

5.3.2 Contamination

Soil Contamination

Initial soil samples collected during the RFI from beneath the concrete floor near the hydraulic gate pump contained PCBs (10,000 mg/kg maximum concentration) and oil & grease (28,000 mg/kg maximum concentration). An ICM was conducted in February 1995, in which the concrete floor slab was removed from an area of approximately 12 square feet near the pump

(**Figure 5.3-1**), and additional soil samples were collected. Accessible contaminated sand was removed and the concrete slab was repaired. Additional samples were subsequently collected to assess the lateral extent of contamination, and indicated the presence of PCB concentrations of several thousand mg/kg, primarily in the base sand beneath the concrete, in an area extending from the pump area toward the southwest (**Figure 5.3-1**), where excavation could not be conducted because the presence of numerous subsurface live electrical utility lines restricted access to the contaminated soil. The HHRA indicated potential risks to human health based on the residual PCB concentrations.

In June and July 2004, a temporary shutdown of Building 88 operations allowed rerouting of electrical utility lines in the area of contaminated soil. After rerouting these lines, a second ICM was conducted that consisted of removal of PCB-contaminated soil to depths of up to 11.5 feet. Confirmation sample results from the ICM excavation had PCB concentrations less than the 1 mg/kg MCS except for two adjacent samples near the southern corner of the excavation. Three samples subsequently collected from within 1 foot of this location contained less than 1 mg/kg PCBs. An additional 0.5 feet of soil was then excavated from the area containing more than 1 mg/kg PCBs. The ICM excavation area and analytical results for confirmation samples are shown on **Figure 5.3-2**.

Groundwater Contamination

Groundwater monitoring well MW88-93-13, which is located at the southwest corner of Building 88, was sampled for PCBs in 2000. No PCBs were detected.

5.3.3 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants in the Building 88 Hydraulic Gate Unit:

- The only COCs were PCBs
- No PCBs have been detected in groundwater, so soil is the only media of concern.
- ICMs that removed PCB-contaminated soil have reduced PCB concentrations in residual soil to levels below the 1 mg/kg MCS.

Evaluation of Retained Corrective Measures Alternatives

No Further Action is recommended for the Building 88 Hydraulic Gate unit. Since MCSs have been achieved, no comprehensive evaluation of the other corrective measures alternatives was completed for this unit.

5.4 BUILDING 75 FORMER HAZARDOUS WASTE HANDLING AND STORAGE FACILITY (SWMU 3-6)

The former Hazardous Waste Handling Facility (HWHF) at Building 75 was used from about 1962 until 1998 to store wastes generated at Berkeley Lab, pending disposal offsite (**Figure 5.4-1**). Wastes included waste oils (both PCB-containing and non-PCB-containing), asbestos, acids, tritium, chlorides, nitrites, organic and inorganic solvents, empty hazardous chemical or waste drums, and other materials. The facility was also used to handle, store, package, and solidify radioactive waste. During operation, drums containing waste acids were kept on pallets with secondary containment. Lockers within the area were used for storing hazardous materials on shelves. PCB-containing oils were stored within a diked, fenced area outside the building.

A closure investigation conducted during 1997 and 1998 resulted in closure certification for the facility from the DTSC in July 1998, conditional on the unit being included in the Corrective Measures Study Process. Numerous soil samples were collected from borings drilled both inside the boundaries of the former HWHF and immediately outside its perimeter. An ICM has been conducted at the unit that consisted of excavating soil with concentrations of PCBs above 1 mg/kg from the “J pad” area west of Building 75A.

5.4.1 Physiography and Geology

Prior to development of the site, the Building 75 area was situated on the west edge of Chicken Creek Canyon, a major north-south-trending drainage course, which flowed downslope towards Building 77. During development, hillside cuts and canyon filling resulted in placement of artificial fill from 25 to 50 feet thick within the canyon in the vicinity of Building 69A. This created the relatively flat site on which Building 75 and adjacent buildings and parking areas are currently located. Artificial fill is absent just west of Building 75 and thickens eastwards towards the former canyon. The main bedrock unit underlying the artificial fill and colluvium in the Building 75 area is the Orinda Formation, which consists of nonmarine siltstones and fine-grained sandstones. The Orinda Formation is overlain in the area upslope from Building 75 by volcanic rocks of the Moraga Formation.

Shallow groundwater in the Building 75 area is present in both the Orinda Formation and the surficial units (i.e., alluvium, colluvium, and artificial fill and the groundwater flows generally southeastwards.

5.4.2 Contamination

Soil Contamination

The principal contaminants in soil at the unit were PCBs (in association with crude/waste oil), which were detected primarily the vicinity of the “J pad” west of Building 75A and at the southeast corner of Building 75A. Several other site COCs (1,1,1-TCA, 1,1-DCE, cis-1,2-DCE, methylene chloride, PCE and TCE) were detected sporadically at the unit, but are only present at concentrations less than MCSs and, as described in the HHRA, were only present at concentrations below de minimis risk levels. Therefore, these chemicals are not considered to be COCs for this unit.

A series of ICMs were conducted in the PCB-contaminated areas in the Building 75 area. These ICMs were completed subsequent to completion of the HHRA. The ICMs consisted of removal and offsite disposal of soil containing PCBs at concentrations exceeding the 1 mg/kg MCS. The excavation areas and analytical results for both confirmation samples and samples from borings drilled adjacent to the ICM excavations are shown on **Figure 5.4-1**.

Groundwater Contamination

PCBs have not been detected in groundwater in the vicinity of Building 75.

5.4.3 Conceptual Model

The information given above is the basis for the following conceptual model describing the distribution and fate of contaminants for the Building 75 Former HWHF:

- The only COCs are PCBs
- No PCBs have been detected in groundwater, so soil is the only media of concern.
- ICMs that removed PCB-contaminated soil have reduced PCB concentrations in residual soil to levels below the 1 mg/kg MCS.

5.4.4 Evaluation of Retained Corrective Measures Alternatives

No Further Action is recommended for the Building 75 Former HWHF. Since MCSs have been achieved, no comprehensive evaluation of the other corrective measures alternatives was completed for this unit.

SECTION 6

COST ANALYSES

Cost estimates to achieve both risk-based cleanup levels and cleanup levels based on protection of potential future drinking water sources are provided in **Table 6-1** for each soil and groundwater unit. Although the target risk-based MCS has been set at the 10^{-6} theoretical ILCR level, estimated costs for cleanup to the 10^{-4} and 10^{-5} levels are also provided for comparison. Where cleanup protective of potential drinking water sources is not required, cost is shown as $0; however, risk-based cleanup and the associated costs shown will still be required for those areas. In addition, the incremental costs associated with controlling migration of contaminated groundwater are also provided, where applicable. These regulatory compliance costs are associated with the SWRCB non-degradation policy under the Porter-Cologne Water Quality Control Act. However, although these costs are indicated under regulatory compliance, if current migration control measures were terminated, there could also be a potential risk to the environment. The total costs for conducting recommended corrective measures are based on risk-based cleanup using a 10^{-6} theoretical ILCR level, cleanup to MCLs in areas where protection of potential future drinking water sources is applicable (i.e., well yields > 200 gpd), and the costs of continued migration control.

Table 6-1. Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units

Soil and Groundwater Units	**Risk-Based Cleanup Costs**			**Potential Future Drinking Water Source Cleanup Costs[(a)]**	**Regulatory Compliance Costs[(b)]**	**Total Costs[(d)] of Recommended Corrective Measures**
	Risk = 10^{-4}	**Risk = 10^{-5}**	**Risk = 10^{-6}**	**MCS = MCLs[(c)]**	**Incremental Cost of Migration Control**	
Building 51/64 Groundwater Solvent Plume						
Corrective Measure	No Action	Soil Flushing and Extraction Trench and MNA.	Soil Flushing and Extraction Trench and MNA	Soil Flushing and Extraction Trench and MNA.	Capture and Treat Groundwater from Building 51 Subdrain	
Assumed End Date	N/A	Soil Flushing = 2011 MNA = indeterminate	Soil Flushing = 2011 MNA = indeterminate	Soil Flushing = 2011 MNA = indeterminate	indeterminate	
Capital Cost	$0	$29,000	$29,000	$29,000	$0	$29,000
Annual O&M Cost	$0	$106,000	$106,000	$106,000	$20,000	$126,000
Total Cost (NPV) through 2011	$0	$682,000	$682,000	$682,000	$124,000	$806,000
Annual Cost After 2011	$0	$26,000	$26,000	$26,000	$20,000	$46,000
Building 51L Groundwater Solvent Plume and Building 51L Source Area						
Corrective Measure	No Action	Soil Excavation and MNA.	Soil Excavation and MNA.	No Action	Reroute/line storm drain	
Assumed End Date	N/A	Excavation = 2006 MNA = indeterminate	Excavation = 2006 MNA = indeterminate	N/A	2006	
Capital Cost	$0	$569,000	$569,000	$0	$147,000	$716,000
Annual O&M Cost	$0	$26,000	$26,000	$0	$0	$26,000
Total Cost (NPV) through 2011	$0	$730,000	$730,000	$0	$138,000	$868,000
Annual Cost After 2011	$0	$26,000	$26,000	$0	$0	$26,000

Table 6-1. Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	**Risk-Based Cleanup Costs**			**Potential Future Drinking Water Source Cleanup Costs(a)**	**Regulatory Compliance Costs(b)**	**Total Costs(d) of Recommended Corrective Measures**
	Risk = 10^{-4}	**Risk = 10^{-5}**	**Risk = 10^{-6}**	**MCS = MCLs(c)**	**Incremental Cost of Migration Control**	
Building 71 Groundwater Solvent Plume						
Corrective Measure	No Action	Chemical Oxidation (source area) and Soil Flushing	Chemical Oxidation (source area) and Soil Flushing	Chemical Oxidation (source area) and Soil Flushing	Capture and Treat Hydrauger Effluent	
Assumed End Date	N/A	Soil Flushing = 2011 Chemical Oxidation = 2006	Soil Flushing = 2011 Chemical Oxidation = 2006	Soil Flushing = 2011 Chemical Oxidation = 2006	indeterminate	
Capital Cost	$0	$380,000	$380,000	$380,000	$0	$380,000
Annual O&M Cost	$0	$80,000	$80,000	$80,000	$20,000	$100,000
Total Cost (NPV) through 2011	$0	$959,000	$959,000	$959,000	$124,000	$1,083,000
Annual Cost After 2011	$0	$0	$0	$0	$20,000	$20,000
Old Town Groundwater Solvent Plume Building 7 Lobe and Former Building 7 Sump						
Corrective Measure	Source Excavation, Soil Flushing and Groundwater Extraction,	Source Excavation, Soil Flushing and Groundwater Extraction	Source Excavation, Soil Flushing and Groundwater Extraction	Source Excavation, Soil Flushing and Groundwater Extraction, MNA in Downgradient Area	Capture and Treat Groundwater from Trenches	
Assumed End Date	2011	indeterminate	indeterminate	indeterminate	indeterminate	
Capital Cost	$591,000	$591,000	$591,000	$591,000	$0	$591,000
Annual O&M Cost	$62,000	$62,000	$62,000	$62,000	$20,000	$82,000
Total Cost (NPV) through 2011	$970,000	$970,000	$970,000	$970,000	$124,000	$1,094,000
Annual Cost After 2011	$0	$62,000	$62,000	$62,000	$20,000	$82,000

Table 6-1. Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	**Risk-Based Cleanup Costs**			**Potential Future Drinking Water Source Cleanup Costs[(a)]**	**Regulatory Compliance Costs[(b)]**	**Total Costs[(d)] of Recommended Corrective Measures**
	Risk = 10^{-4}	**Risk = 10^{-5}**	**Risk = 10^{-6}**	**MCS = MCLs[(c)]**	**Incremental Cost of Migration Control**	
Old Town Groundwater Solvent Plume Building 52 Lobe						
Corrective Measure	No Action	No Action	No Action	Soil Flushing with 4 New Injection Wells	Capture and Treat Groundwater from B46 Subdrain	
Assumed End Date	N/A	N/A	N/A	indeterminate	indeterminate	
Capital Cost	$0	$0	$0	$66,000	$0	$66,000
Annual O&M Cost	$0	$0	$0	$49,000	$20,000	$69,000
Total Cost (NPV) through 2011	$0	$0	$0	$364,000	$124,000	$488,000
Annual Cost After 2011	$0	$0	$0	$49,000	$20,000	$69,000
Old Town Groundwater Solvent Plume Building 25A Lobe						
Corrective Measure	No Action	No Action	No Action	Soil Flushing and Groundwater. Extraction, MNA in Downgradient Area	No Action	
Assumed End Date	N/A	N/A	N/A	indeterminate	N/A	
Capital Cost	$0	$0	$0	$0	$0	$0
Annual O&M Cost	$0	$0	$0	$51,000	$0	$51,000
Total Cost (NPV) through 2011	$0	$0	$0	$318,000	$0	$318,000
Annual Cost After 2011	$0	$0	$0	$51,000	$0	$51,000

Table 6-1. Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	Risk-Based Cleanup Costs			Potential Future Drinking Water Source Cleanup Costs[(a)]	Regulatory Compliance Costs[(b)]	Total Costs[(d)] of Recommended Corrective Measures
	Risk = 10^{-4}	Risk = 10^{-5}	Risk = 10^{-6}	MCS = MCLs[(c)]	Incremental Cost of Migration Control	
Solvents in Groundwater South of Building 76						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	$0	$0	$0
Annual O&M Cost	$0	$0	$0	$0	$0	$0
Total Cost (NPV)	$0	$0	$0	$0	$0	$0
Building 75/75A Area of Groundwater Contamination						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	$0	$0	$0
Annual O&M Cost	$0	$0	$0	$0	$0	$0
Total Cost (NPV)	$0	$0	$0	$0	$0	$0
Building 69A Area of Groundwater Contamination						
Corrective Measure	No Action	No Action	MNA	No Action	No Action	
Assumed End Date	N/A	N/A	indeterminate	N/A	N/A	
Capital Cost	$0	$0	$0	$0	$0	$0
Annual O&M Cost	$0	$0	$26,000	$0	$0	$26,000
Total Cost (NPV) through 2011	$0	$0	$160,000	$0	$0	$160,000
Annual Cost After 2011	$0	$0	$26,000	$0	$0	$26,000

Table 6-1. Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	Risk-Based Cleanup Costs			Potential Future Drinking Water Source Cleanup Costs[(a)]	Regulatory Compliance Costs[(b)]	Total Costs[(d)] of Recommended Corrective Measures
	Risk = 10^{-4}	Risk = 10^{-5}	Risk = 10^{-6}	MCS = MCLs[(c)]	Incremental Cost of Migration Control	
Building 77 Area of Groundwater Contamination						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	$0	$0	$0
Annual O&M Cost	$0	$0	$0	$0	$0	$0
Total Cost (NPV)	$0	$0	$0	$0	$0	
Benzene in Wells East of Building 75A						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	$0	$0	$0
Annual O&M Cost	$0	$0	$0	$0	$0	$0
Total Cost (NPV)	$0	$0	$0	$0	$0	
Building 88 Hydraulic Gate Unit						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	N/A	$0	$0
Annual O&M Cost	$0	$0	$0	N/A	$0	$0
Total Cost (NPV) through Assumed End Date	$0	$0	$0	$0	$0	$0

Table 6-1. Cost Estimates for Specific Corrective Measures Alternatives Proposed for Soil and Groundwater Units (cont'd.)

Soil and Groundwater Units	**Risk-Based Cleanup Costs**			**Potential Future Drinking Water Source Cleanup Costs[(a)]**	**Regulatory Compliance Costs[(b)]**	**Total Costs[(d)] of Recommended Corrective Measures**
	Risk = 10^{-4}	**Risk = 10^{-5}**	**Risk = 10^{-6}**	**MCS = MCLs[(c)]**	**Incremental Cost of Migration Control**	
Building 75 Former Hazardous Waste Handling and Storage Facility						
Corrective Measure	No Action	No Action	No Action	No Action	No Action	
Assumed End Date	N/A	N/A	N/A	N/A	N/A	
Capital Cost	$0	$0	$0	N/A	$0	$0
Annual O&M Cost	$0	$0	$0	N/A	$0	$0
Total Cost (NPV) through Assumed End Date	$0	$0	$0	$0	$0	$0
Grand Total (NPV) through 2011	$970,000	$3,341,000	$3,501,000	$3,293,000	$634,000	$4,817,000[(e)]
Grand Total (Annual Cost After 2011)	$0	$114,000	$140,000	$188,000	$80,000	$320,000[(e)]

(a) Where regulatory-based cleanup is not required, the cost for regulatory-based cleanup is shown as $0.00; however, risk-based cleanup and the associated costs shown will still be required for those areas.

(b) Control the migration of contaminated groundwater so that COCs do not migrate to groundwater in adjacent uncontaminated areas or to surface water.

(c) Regulatory-based MCSs apply in plume areas where well yield ≥ 200 gallons per days

(d) Total costs only include estimated direct costs associated with task scopes described in the CMS report. General compliance costs and program administration/management costs are not included.

(e) The Total Costs of Recommended Corrective Measures (column 7) is the sum of either the Risk Based Cleanup Cost (column 4) or the Potential Drinking Water Source Cleanup Cost (column 5), whichever is applicable at each unit, and the Regulatory Compliance Cost (column 6). Therefore the Total Costs of Recommended Corrective Measures does not sum across each row.

SECTION 7

NATIONAL ENVIRONMENTAL POLICY ACT REVIEW

7.1 INTRODUCTION

It is DOE's policy with respect to compliance with National Environmental Policy Act (NEPA) requirements to incorporate NEPA values into documents prepared for Resource Conservation and Recovery Act (RCRA) corrective actions whenever allowed by the RCRA regulatory oversight agency. Hence, with the approval of the DTSC, this chapter provides the required NEPA documentation, which includes a discussion of the proposed RCRA corrective actions at Berkeley Lab and their consequences. Further, when state agencies must comply with a state environmental policy act (in this case, the California Environmental Quality Act or CEQA), it is DOE's policy to reduce duplication between the NEPA and comparable state requirements (pursuant to the Council on Environmental Quality regulation at 40 CFR Section 1506.2(c)). Therefore, to the extent possible, this NEPA values review incorporates by reference the relevant information contained in the California Environmental Protection Agency Department of Toxic Substances Control's (DTSC's) Initial Study and Tiered Negative Declaration (IS/ND) for the Corrective Measures Project at Lawrence Berkeley National Laboratory (DTSC, 2005).

The IS/ND was prepared by the DTSC in accordance with requirements of CEQA (Section 21000 et seq., California Public Resources Code) and Guidelines for Implementation (Section 15000 et seq., Title 14, California Code of Regulations). The IS/ND describes the environment affected by the proposed actions and analyzes the potential impacts with regard to the following environmental topic areas: (1) aesthetics; (2) agricultural resources; (3) air quality; (4) biological resources; (5) cultural resources; (6) geology and soils; (7) hazards and hazardous materials; (8) hydrology and water quality; (9) land use and planning; (10) mineral resources; (11) noise; (12) population and housing; (13) public services; (14) recreation; (15) transportation and traffic; (16) utilities and service systems; and (17) cumulative impacts. The document was tiered from Berkeley Lab's 1987 Long Range Development

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Plan Environmental Impact Report (1987 LRDP EIR), as amended in 1992 and 1997 (Berkeley Lab, 1987, 1992, 1997).

The IS/ND is being published concurrently with this CMS Report and is available for public review and comment. The IS/ND, along with programmatic tiering documents, is available for review at the following location:

Berkeley Public Library
2nd floor Reference Desk
2090 Kittredge Street
Berkeley, California.

In addition, the IS/ND is available for review on-line at:

http://www.dtsc.ca.gov/HazardousWaste/LBNL/index.html

The following sections briefly describe the purpose and need of the proposed action, alternatives considered, the affected environment, and the potential impacts of the proposed action. More detailed descriptions of the affected environment and potential impacts are contained in the IS/ND. More detailed discussions of the proposed RCRA corrective actions are provided in previous sections of this CMS Report.

7.2 PURPOSE AND NEED

The purpose of the proposed action is to implement (construct or complete) the corrective measures (clean-up activities) recommended in the CMS Report. These activities would be implemented to reduce or eliminate the potentially adverse effects to human health or the environment caused by historic releases of chemicals to soil and groundwater at Berkeley Lab, and would be conducted as part of the Corrective Measures Implementation (CMI) phase of the project. A NEPA review of this proposed action is required because in addition to extending the corrective measures that are currently in place, the CMI phase of the project will implement additional corrective measures.

7.3 PROPOSED ACTION AND ALTERNATIVES

Berkeley Lab has identified, evaluated, and recommended clean-up measures in accordance with requirements of the RCRA Corrective Action Process. This process is described in detail in Section 3 and Section 4 of this report. The first step in the process consisted of compiling a list of alternatives potentially applicable to clean-up of volatile organic compound (VOC) contaminated soil and groundwater at Berkeley Lab. The categories of alternatives and the specific technologies identified are listed in Table 7.3-1 and Table 7.3-2 for areas of VOC-contaminated soil and groundwater, respectively.

Table 7.3-1. Potentially Applicable Cleanup Alternatives for VOC-Contaminated Soil

Corrective Measures Category	Technology
No Action	No Action [1]
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation (MNA)
Risk and Hazard Management	Institutional Controls (physical barriers or markers) Institutional Controls (legal or administrative)
Containment	Capping, Solidification, Stabilization
In situ treatment	Enhanced bioremediation Phytoremediation Bioventing Chemical oxidation Electrokinetic separation
Extraction with ex situ treatment	Soil vapor extraction (SVE) Thermally enhanced SVE/dual phase extraction Fracturing, enhanced SVE Soil flushing (water/ surfactant/co-solvent) with groundwater extraction Soil mixing Excavation with *ex situ* treatment: Biopiles, composting, fungal biodegradation, chemical extraction, chemical oxidation/reduction, dehalogenation, separation, soil washing, hot gas decontamination, incineration, open burn, pyrolysis, and thermal desorption. Excavation and off-site disposal

[1] Under the No Action alternative, all previously implemented Interim Corrective Measures (ICMs) and pilot tests would be terminated, and no additional active measures would be implemented.

Table 7.3-2. Potentially Applicable Cleanup Alternatives for VOC-Contaminated Groundwater

Corrective Measures Category	Technology
No Action	No Action[1]
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation (MNA)
Risk and Hazard Management	Institutional Controls (physical barriers or markers) Institutional Controls (legal or administrative)
Containment and Capture	Containment/diversion (Slurry walls, Sheet pile walls, Grout curtains) Groundwater Capture (Drains, Trenches, Extraction wells)
In situ treatment	Permeable Reactive Barrier (PRB) and Funnel and Gate Chemical Oxidation Enhanced bioremediation Phytoremediation
Extraction with ex-situ treatment	Soil Flushing with Groundwater Extraction Dual-Phase Extraction (DPE) Air Sparging In-Well Air Stripping Steam/hot water Injection

[1] Under the No Action alternative, all previously implemented Interim Corrective Measures (ICM) and pilot tests would be terminated, and no additional active measures would be implemented.

The potentially applicable clean-up alternatives listed in Table 7.3-1 and Table 7.3-2 were screened to eliminate those alternatives that were considered ineffective or not applicable under site-specific conditions. Based on the screening process, the following technologies were retained for the site-specific evaluations applied to each of the areas of soil and groundwater contamination.

Soil

- No Action
- Institutional Controls
- Containment (Capping, Solidification, Stabilization)
- In Situ Chemical Oxidation
- Soil Vapor Extraction (SVE) or Dual Phase Extraction (DPE)
- Thermally Enhanced SVE/DPE
- In Situ Soil Flushing (with water)
- Soil Mixing
- Excavation with offsite disposal

Groundwater

- No Action
- Monitored Natural Attenuation (MNA)
- Institutional Controls
- Containment (slurry walls, sheet pile walls, grout curtains)
- Groundwater capture (drains, trenches, extraction wells)
- Permeable Reactive Barrier and Funnel and Gate
- Chemical Oxidation
- Enhanced Bioremediation
- Groundwater Extraction/Flushing
- Dual-Phase (groundwater and soil-vapor) Extraction

The retained alternatives were subjected to a formal evaluation process for each area of soil and groundwater contamination where further action was required. The process considered whether the alternative would comply with the following four standards:

- Protect human health and the environment
- Attain the required clean-up levels
- Control sources of releases to reduce or eliminate, to the maximum extent practicable further releases that might pose a threat to human health or the environment
- Meet all applicable waste management requirements

In addition, the alternatives were evaluated against the following five selection factors:

- Long-term reliability and effectiveness
- Reduction in the toxicity, mobility, or volume of waste
- Short-term effectiveness
- Implementability, including consideration of site-specific factors as well as community and state acceptance
- Cost

The clean-up alternative(s) that best met the four standards and five selection factors listed above for each area of soil or groundwater contamination were recommended for implementation. The recommended alternatives were as follows:

Soil

- Excavation with offsite disposal

Groundwater

- Monitored Natural Attenuation (MNA)
- Institutional Controls
- Groundwater capture (drains, trenches, extraction wells)
- Enhanced Bioremediation
- Groundwater Extraction/Flushing
- Dual-Phase (groundwater and soil-vapor) Extraction

As noted in the preceding chapters of this CMS Report, corrective measures are required for two areas of soil contamination and seven areas of groundwater contamination. A specific clean-up technology/technologies is recommended for each of these areas on a media- (groundwater or soil) and site-specific basis. The technology recommended for soil clean-up is excavation and off-site disposal of contaminated soil. The primary technologies recommended for groundwater clean-up are in situ soil flushing and monitored natural attenuation (MNA). Localized application of chemical oxidants and Hydrogen Release Compounds® (HRC®) is also proposed.

Excavation and off-site disposal are recommended for the cleanup of contaminated soil near Buildings 7 and 51L. Contaminated soil in these areas would be excavated and placed in covered storage bins until the bins could be shipped off site for disposal in accordance with applicable local, state, and federal laws and regulations.

Soil flushing and/or MNA are recommended for the cleanup of contaminated groundwater near Buildings 51/64, 51L, 69A, and 71B, and in the "Old Town Area" near Buildings 7, 25A, and 52. Soil flushing consists of the simultaneous injection of clean water into, and extraction of contaminated water from, the subsurface. The purpose of soil flushing is to promote flow of contaminated groundwater towards extraction locations (e.g., wells or trenches) and to increase the rate that residual soil contaminants desorb into the flowing groundwater. The extracted groundwater would be treated on site using granular activated carbon (GAC) canisters, and then reinjected to continually flush contaminants from the subsurface or, if the water is not needed for flushing, discharged to the sanitary sewer under a permit issued by the East Bay Municipal Utility District (EBMUD).

The initial construction or installation phases for most of the soil flushing systems have already been completed as part of pilot tests or Interim Corrective Measures (ICMs) conducted over the past few years. The corrective measures in most cases consist of adoption or expansion of these pilot tests and ICMs. MNA would be applied in areas where hydrochemical data indicate that natural processes (e.g., biodegradation) are reducing the mass of contaminants, and consists of continued monitoring of the effectiveness of these processes.

7.4 AFFECTED ENVIRONMENT

The affected environment for each NEPA value (air quality, biological resources, geology, soils, etc.) is described below. No Agricultural Resources or Mineral Resources are known to occur on the site. Therefore, these two values have been excluded from further review.

Aesthetics

Berkeley Lab has an aesthetic that is sometimes described as "buildings in nature" as site structures are, for the most part, scattered amid trees and other vegetation. Although Berkeley Lab manages on-site vegetation to reduce the risk of wildland fire, vegetated areas are typically dense enough to visually separate the built environment from adjacent residential properties and to serve as a transitional element between the Lab and the parklands and open space to the east. Many buildings in the central built area display an industrial look and utilitarian quality due to the type of building materials (e.g., poured-in-place concrete, corrugated metal siding) and the visible mechanical equipment (exposed pipes, vents, panels, and tanks) related to the activities occurring in the buildings. Activities associated with the implementation of corrective measures would occur within the central built environment of Berkeley Lab (e.g., in parking lots and/or adjacent to buildings).

Air Quality

The site is located in the cities of Berkeley and Oakland, within the boundaries of the San Francisco Bay Area Air Basin. Berkeley's proximity to the onshore breezes stimulated by the Pacific Ocean provide for generally very good air quality at Berkeley Lab. However, during the summer and fall emissions generated in Oakland and Berkeley are often blown to the east and south, where they contribute to the formation of photochemical smog. In the winter, reduced solar energy and cooler temperatures diminish ozone smog formation, but increase the likelihood of carbon monoxide formation.

The federal Clean Air Act of 1970 established maximum allowable concentration criteria standards for six ambient air pollutants: ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter, and lead. Each of these standards was set to meet specific public health and welfare criteria. California has adopted more stringent state standards for these and other pollutants. These ambient air pollutants and their state and federal standards are listed in Table 7.4-1.

The Bay Area Air Basin is currently designated as nonattainment for state and federal ozone standards, although ozone levels measured in the Berkeley and Oakland area have not exceeded the standards in the past four years. Ozone and ozone precursors are the pollutants of greatest concern in the Air Basin. The Air Basin is also designated as nonattainment for the state Respirable Particulate Matter (PM_{10}) standard. The Air Basin is designated as either attainment or unclassified for all other pollutants.

State law requires that air districts create an inventory of facilities with potential to emit specified Toxic Air Contaminants (TAC), and make this information available to the public upon request. In 2000, the local air district calculated that the annual excess cancer risk in the Bay Area is about 167 per million people from stationary sources, and about 450 in a million from diesel exhaust. Thus, diesel emissions create about 70% of toxic and cancer-causing emissions found in ambient air.

Biological Resources

Berkeley Lab is situated on approximately 200 acres on the western slopes of the Oakland-Berkeley Hills, within a mixture of low to moderate density residential neighborhoods and open space of various vegetation types and wildlife habitats. The proposed action would be implemented within developed areas of Berkeley Lab that are generally paved or occupied by other infrastructure and do not provide wildlife resources. No mature trees or water bodies are present in the areas where actions would be taken.

Berkeley Lab is located within the Briones Valley and Richmond USGS (United States Geological Survey) 7.5 Minute Quads. Potential special status species listed by the California Department of Fish and Game Natural Diversity database (CNDDB), U.S. Fish and Wildlife Service (USFWS), and the California Native Plant Society (CNPS) for these Quads are tabulated

Table 7.4-1. Federal and State Ambient Air Quality Standards

Pollutant	Averaging Time	California Standards	Federal Standards	
		Concentration	Primary	Secondary
Ozone (O_3)	1 Hour	0.09 ppm (180 µg/m^3)	0.12 ppm (235 µg/m^3)	Same as Primary Standard
	8 Hour	---	0.08 ppm (157 µg/m^3)	
Respirable Particulate Matter (PM_{10})	24 Hour	50 µg/m^3	150 µg/m^3	Same as Primary Standard
	Annual Arithmetic Mean	20 µg/m^3	50 µg/m^3	
Fine Particulate Matter ($PM_{2.5}$)	24 Hour	No Separate State Standard	65 µg/m^3	Same as Primary Standard
	Annual Arithmetic Mean	12 µg/m^3	15 µg/m^3	
Carbon Monoxide (CO)	8 Hour	9.0 ppm (10 mg/m^3)	9.0 ppm (10 mg/m^3)	---
	1 Hour	20 ppm (23 mg/m^3)	35 ppm (40 mg/m^3)	
	8 Hour (Lake Tahoe)	6 ppm (7 mg/m^3)	---	
Nitrogen Dioxide (NO_2)	Annual Arithmetic Mean	---	0.053 ppm(100 µg/m^3)	Same as Primary Standard
	1 Hour	0.25 ppm (470 µg/m^3)	---	
Lead	30 Day Average	1.5 µg/m^3	---	---
	Calendar Quarter	---	1.5 µg/m^3	Same as Primary Standard
Sulfur Dioxide (SO_2)	Annual Arithmetic Mean	---	0.030 ppm (80 µg/m^3)	---
	24 Hour	0.04 ppm (105 µg/m^3)	0.14 ppm (365 µg/m^3)	---
	3 Hour	---	---	0.5 ppm (1300 µg/m^3)
	1 Hour	0.25 ppm (655 µg/m^3)	---	---

Source: California Air Resources Board, July 2003

ppm=parts per million
mg/m^3=milligrams per cubic meter
µg/m^3=micrograms per cubic meter

in the IS/ND (DTSC, 2005). The Quads contain many habitats (from salt marshes to upland oak woodland), only a few of which occur in the less disturbed areas of Berkeley Lab. No action is proposed in these less disturbed areas of Berkeley Lab. In addition, no state or federally listed rare, threatened or endangered plant or animal species have been located or are expected to appear on the site, based on biological surveys conducted previously for the LRDP EIR, as amended in 1992 and 1997 (Berkeley Lab, 1987, 1992, 1997).

State and federal laws related to biological resources that are potentially relevant to the site include the Federal Endangered Species Act of 1973 (ESA), the Migratory Bird Treaty Act of 1918, the California Endangered Species Act (CESA) and the California Native Plant Protection Act of 1977. The U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) enforce the provisions of the ESA and Migratory Bird Treaty Act. The California Department of Fish and Game is responsible for the enforcement of the state laws.

State and federal laws related to biological resources that are potentially relevant to the site include the Federal Endangered Species Act of 1973 (ESA), the Migratory Bird Treaty Act of 1918, the California Endangered Species Act (CESA) and the California Native Plant Protection Act of 1977. The U.S. Fish and Wildlife Service and National Oceanic and Atmospheric Administration enforce the provisions of the ESA and Migratory Bird Treaty Act. The California Department of Fish and Game is responsible for the enforcement of the state laws.

Cultural Resources

An archaeological resources survey conducted for the LRDP EIR found no indications of historic or prehistoric archaeological resources at Berkeley Lab. A team is systematically investigating and reporting on the historic value of all buildings and structures at the Lab. Their reports are submitted to the State Historic Preservation Officer for concurrence. The State Historic Preservation Officer is responsible for administrating federally and state mandated historic preservation programs in California, including Section 106 of the National Historic Preservation Act. Thus far, only Building 51 is considered eligible for listing in the National Register of Historic Places.

Geology and Soils

Berkeley Lab is located in a region of seismic activity caused by the San Andreas Fault System. The United States Geological Survey (USGS) estimates a 70 percent likelihood of a Richter magnitude 6.7 or greater earthquake in the Bay Area within the next 30 years. Groundshaking from such an earthquake can cause landslides, surface rupture, structural damage, and other ground failures. Within the San Andreas fault system, the active Hayward fault is located within a mile of Berkeley Lab. A major earthquake on the Hayward fault could cause violent groundshaking at Berkeley Lab.

Native soils at Berkeley Lab are typically loams or silty loams with a moderate permeability and a low shrink-swell potential. Natural rock outcrops are few, although there are many rock exposures in cut slopes. At least one major and several minor historical landslide masses are present at Berkeley Lab.

Hazards and Hazardous Materials

Berkeley Lab's Environment, Health and Safety Division's Waste Management Group is responsible for ensuring compliance with hazardous waste regulations and for determining the Berkeley Lab Hazardous Waste Handling Facility's storage and labeling requirements, selecting an offsite disposal site, and manifesting and maintaining disposal records. Hazardous wastes are handled, stored, and disposed of in accordance with applicable DOE and Berkeley Lab policies, and state and federal regulations.

Hydrology and Water Quality

Berkeley Lab is located in the Strawberry Creek watershed, an area characterized by steep slopes underlain by bedrock with a shallow soil surface. Groundwater flow through bedrock is typically characterized by fracture flow that has slow recharge and low yield, while groundwater flow in the drainages is unconfined flow and fluctuates with seasonal precipitation. Berkeley Lab is not underlain by an easily accessible, high-yield, confined aquifer system that is capable of supplying many users; however, some minor recharge to the alluvial aquifer underlying the East Bay Plain may occur. There are no production wells at Berkeley Lab or downgradient of the facility in the City of Berkeley. The Berkeley Lab and surrounding communities receive their water from EBMUD.

Storm water generated within the Berkeley Lab facility is currently managed in accordance with Berkeley Lab's National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges Associated with Industrial Activity. The San Francisco Bay Regional Water Quality Control Board (RWQCB) and the City of Berkeley provide oversight and enforcement of this permit. Implementation of the permit requirements is detailed in Berkeley Lab's Storm Water Pollution Prevention Plan (SWPPP) and Storm Water Monitoring Plan (SWMP).

Land Use and Planning

The corrective measures will be implemented within the Berkeley Lab site, which is owned by the University of California (UC) and mostly leased to DOE. This land and a larger surrounding area belonging to the University are within the boundaries of the cities of Berkeley and Oakland. Adjacent land use includes residential areas to the north, UC Berkeley athletic fields and recreational facilities to the south, residential areas and UC Berkeley student housing, amphitheater, and classrooms to the west, and the UC Berkeley Lawrence Hall of Science Museum to the east.

Berkeley Lab is a federal facility conducting work within the University of California's mission and as such is generally exempted by the federal and state constitutions from compliance with local land use regulations, including general plans and zoning. However, Berkeley Lab seeks to cooperate with local jurisdictions to reduce any physical consequences of potential land use conflicts to the extent feasible. The City of Berkeley's Zoning Code designates the entire Berkeley Lab Hill site as High Density Residential. As the purpose of Berkeley Lab is research rather than residential use, this designation does not accurately reflect the existing land uses on the site. The Berkeley General Plan designates the area as Institutional, which correctly reflects the existing uses on the site. Areas adjacent to Berkeley Lab are designated as open space.

The Land Use and Transportation Element of the Oakland General Plan designates land use at Berkeley Lab as Institutional. A portion of Berkeley Lab is also designated as a Resource

Conservation Area, where future buildings are not permitted except as required to facilitate the maintenance of conservation areas.

Noise

The topography in the Berkeley Lab area is hilly, which has a substantial effect on the propagation of noise. Noise-sensitive land uses exist to the north, east, and west of Berkeley Lab. There are no sensitive land uses in the southerly direction that are close enough to be potentially impacted by excavation or drilling noise. The nearest noise sensitive land use areas are shown on **Figure 7-1**. A description of each area is provided below:

> **Area 1** – This area to the west consists of the Nyingma Institute (Buddhist facility) and single- and multi-family residences. The average background sound levels in this area were measured at 44 to 54 dBA.
>
> **Area 2** – This area to the north consists of single-family residences along Campus Drive, Olympus Avenue, and Summit Road. Average background sound levels in this area were measured at 52 to 54 dBA.
>
> **Area 3** – To the east is the UC Berkeley Lawrence Hall of Science Museum. Average background sound levels at the Museum site were measured at 53 to 54 dBA.

Population and Housing

Berkeley Lab currently has 4,375 employees, which is over 90% of what the 1987 LRDP anticipated at buildout. Employees live in various parts of the Bay Area and commute to work. No housing is located on site.

Public Services and Recreation

Fire protection is provided on site by the Alameda County Fire Department. The station is located at Berkeley Lab Building 48 and staffed 24 hours per day. At least four firefighters, including officers, are on duty at all times. Equipment includes one fire engine, one reserve fire engine, a hazardous materials vehicle, and a light duty four-wheel drive “brush rig” that can be used for wildland fires.

Security services at Berkeley Lab include contract, non-sworn security officers and sworn police provided by UC Berkeley. Contracted personnel staff the Berkeley Lab entry gate kiosks.

The Berkeley and Oakland Unified School Districts serve the cities that adjoin Berkeley Lab. They operate approximately 100 schools with enrollments totaling about 60,000 elementary and secondary students for the 2002-2003 academic year. The UC Berkeley campus is adjacent to Berkeley Lab.

Berkeley Lab's open space is not accessible to the public. The cities of Berkeley and Oakland have numerous parks. Near Berkeley Lab, regional open space resources include the 2,077-acre Tilden Park and the 205-acre Claremont Canyon Preserve, which border the eastern Berkeley City limits and are used extensively by Berkeley residents. These parks provide open space and recreation facilities, including picnic areas, bicycle trails, swim areas, and environmental education centers. Also bordering the city's eastern limits is University of California property, including the central campus, Strawberry Canyon and the Ecological Study Area that serve as popular open space resources.

Transportation and Traffic

Commuter routes serving the Lab and the much larger University are often congested during commute hours. The roadways within or near the Berkeley Lab site that might be affected by corrective measures activities include:

- *Cyclotron Road*, *McMillan Road*, and *Lawrence Road*, which are located within the boundaries of Berkeley Lab.
- *Hearst Avenue*, an east-west street that extends from West Berkeley to the Northwest corner of the UC Berkeley Core Campus near the entrance to Berkeley Lab. Hearst Avenue is not a designated truck route within the City of Berkeley. The intersections of Hearst Avenue near Berkeley Lab operate at acceptable levels of traffic service during both morning and afternoon peak hours.
- *Shattuck Avenue,* a north-south roadway, classified as a Principal Arterial in the Metropolitan Transportation System and the Congestion Management Program. Shattuck Avenue is the most heavily used north-south roadway in the Berkeley area. Shattuck Avenue is a designated truck route between Adeline Street and Shattuck Place. The intersections of Shattuck Avenue with Hearst Avenue and University Avenue operate at acceptable levels of traffic service during both the morning and afternoon peak hours.
- *University Avenue,* a four lane east-west street, classified as a Principal Arterial in the MTS and CMP. The intersections of University Avenue with Martin Luther King Way, Milvia Street, Shattuck Avenue (East), Shattuck Avenue (West), and Oxford

Street are operating at acceptable levels of traffic service during both the morning and afternoon peak hours; however, the intersections of University Avenue with Sixth Street and San Pablo Avenue operate at unacceptable levels of traffic service during both the morning and afternoon peak hours.

- *Interstate 80 (I-80),* which connects the San Francisco Bay Area with the Sacramento region and continues east. Interstate 80 and the nearby I-80/I-580 interchange operate at capacity during peak commute hours. I-80 operates at unacceptable levels of traffic service during both the morning and afternoon peak hours westbound between University Avenue and the I-80/580 split and eastbound from the Emeryville city limits to the Albany city limits.

Berkeley Lab is served by the Bay Area Rapid Transit (BART), Alameda-Contra Costa Transit (AC Transit) bus routes, and a Berkeley Lab operated shuttle service, which includes service to Berkeley Lab.

The BART station closest to the Berkeley Lab is the Downtown Berkeley station at Center Street/Shattuck Avenue. AC Transit provides relatively direct travel to and from neighboring cities such as Oakland, Richmond, El Cerrito, San Francisco, and local Berkeley neighborhoods. A Berkeley Lab shuttle bus operates between the Downtown Berkeley BART station and the Laboratory. Another shuttle bus operates between the Laboratory and the Rockridge BART station during morning and evening commute hours. On-site shuttle bus service is provided.

Bicycle and pedestrian routes can be found on or along most roadways within and surrounding the Berkeley campus.

Utilities and Services Systems

EBMUD provides water to Berkeley Lab and has a storage capacity of 3.1 million gallons in the area, which is available in part to serve the Lab. Water is used for both daily laboratory work and facility operations as well as for fire protection. In addition, Berkeley Lab operates and maintains three 200,000-gallon storage tanks on site for emergency supplies.

Wastewater services are provided by EBMUD. Wastewater is carried by a gravity flow system through two monitoring stations at Hearst Avenue and Centennial Drive, which connect to the UC and City of Berkeley sewer systems, ending at the EBMUD intercepting sewer.

Berkeley Lab also has a storm drainage system that empties into North Fork Strawberry Creek and Strawberry Creek.

Non-hazardous solid waste is disposed at the West Contra Costa Landfill in Richmond. The landfill is projected to close in January 2006, at which time solid waste would be disposed at the Altamont Landfill.

Electricity is provided by Pacific Gas and Electric Company through existing on-site infrastructure and the Grizzly Peak substation. Many facilities with Berkeley Lab also have emergency generators for emergency back-up and on-site utility plants.

Environmental Justice

Environmental justice was an area not analyzed in the IS/ND. Environmental justice refers to the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws and policies. Analysis of the impacts associated with environmental justice is required under NEPA pursuant to Executive Order (EO) 12898. No specific low-income or minority population as defined under EO 12898 is present in the census tract that includes Berkeley Lab or in adjacent census tracts although commuter and truck traffic will pass through or near minority/low income neighborhoods.

7.5 PROBABLE ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION AND ALTERNATIVES

The probable environmental impacts that would result from implementation of the proposed corrective measures are summarized in Table 7.5-1. As noted in the IS/ND, the proposed action would not have significant direct, indirect, or cumulative effects on the human environment. The proposed action would have the beneficial effect of improving soil and water quality by removing soil and groundwater contamination at the Berkeley Lab.

Table 7.5-1. Summary of Probable Environmental Impacts[a]

Direct Effects

NEPA Value	Summary of Impact Analysis for the Proposed Action
Aesthetics	Most actions would have no impact on the visual characteristics of Berkeley Lab. Those that would, such as excavations, would cause only temporary changes in the visual environment and would be visible only to on-site personnel or from a very few vantage points off site. Excavation sites would be returned to their previous condition (i.e., repaved) when work is complete.
Agricultural Resources	There are no agricultural resources on site or in the vicinity of Berkeley Lab and thus no impacts were identified for this NEPA value.
Air Quality	Corrective measures would not conflict with or obstruct implementation of any air quality plan (*e.g.*, the Ozone Attainment Plan, Clean Air Plan, or Carbon Monoxide Maintenance Plan). The actions would not violate any applicable air quality standard or contribute substantially to any existing or projected air quality violations. Applicable and appropriate BAAQMD measures would be implemented to reduce construction-period air impacts from excavation actions. The actions would create few or no toxic air contaminant emissions.
Biological Resources	Corrective measures would be conducted in areas of Berkeley Lab that are occupied by buildings, parking lots, and other infrastructure. In these areas, there are no natural vegetation associations, wildlife habitat, marshes, vernal pools, wetlands, or riparian areas. Hence, it is unlikely that listed or special status species would be affected by the corrective measures.
Cultural Resources	Corrective measures would not make changes to or remove historical buildings. The cleanup sites are located in previously disturbed areas of cut and fill that are not believed to contain paleontological or archaeological resources.
Environmental Justice	No specific low-income, minority or Native American population adjoins Berkeley Lab. Commuter and truck traffic will pass through or near minority/low income neighborhoods, but the impact due to CMS activity would be negligible.
Geology and Soils	Although Berkeley Lab is located in a seismically active region, implementing the corrective measures would not expose people or structures to substantial hazards from earthquakes. Excavations would be temporary and properly shored. Areas to be excavated are currently paved and would be repaved when excavation is complete. Most remediation facilities would be below ground (e.g., wells, trenches, piping) or relatively small (e.g., pumps, GAC canisters, drums) and thus not particularly susceptible to earthquake damage. None of the actions would occur in areas that are prone to landslides, liquefaction, tsunamis, or seiche waves. No structures would be constructed that would have foundations subject to deformation or damage by shrink/swell soils.

Direct Effects

NEPA Value	Summary of Impact Analysis for the Proposed Action
Hazards and Hazardous Materials	The corrective measures would not require bulk storage of flammable or combustible liquids or gases, corrosive, caustic, or otherwise reactive or toxic chemical substances. Any waste generated, such as spent GAC or contaminated soil, would be handled, stored and disposed of or recycled (GAC) in accordance with applicable DOE, local, state and federal laws, regulations and policies. Waste soil would be transported in covered bins and thus the possibility of a spill during transport would be small.
Hydrology and Water Quality	The corrective measures would remove contaminants from soil and groundwater, which would have the beneficial effect of improving water quality. No discharges of contaminated groundwater to surface water would occur. No streams or rivers would be altered. No new impervious surfaces or sources of pollutants would be created. The site is not subject to flooding and the measures would not increase the risk of flooding at downstream locations.
Land Use and Planning	The corrective measures would be implemented within the developed portion of Berkeley Lab near existing buildings and paved lots. The measures would not divide an existing community; conflict with existing or proposed land uses; convert open space; conflict with local general plans, zoning, or local adopted environmental plans and goals; or create a nuisance as a result of incompatible land use.
Mineral Resources	There are no mineral resources on site or in the vicinity of Berkeley Lab and thus no impacts were identified for this NEPA value.
Noise	Excavation, drilling, and trucking activities may temporarily increase noise levels nearby. However, they would not expose people off site to noise levels in excess of applicable local standards, including the City of Berkeley's Noise Ordinance, which specifies restrictions for construction activities
Population and Housing (Socioeconomics)	Workers needed to implement the corrective measures would be Berkeley Lab employees or local contractors, which would be a minor positive short-term socioeconomic impact. The small number of workers required to implement the proposed action would not create demand for new homes, employment, or infrastructure. No housing would be demolished by the proposed actions.
Public Services and Recreation	Berkeley Lab has on-site fire and security services, which can accommodate the proposed action. The corrective measures would not create increased demand for police or fire protection, schools, parks, or other public facilities in the surrounding communities because the action would not cause an increase in the local population.
Transportation and Traffic	Travel demand management procedures are incorporated as part of the proposed action. Truck traffic would be scheduled to avoid peak hours. With the incorporation of the traffic demand procedures, vehicle trips generated by implementation of the corrective measures (primarily truck trips during the excavation and removal of soil) would add very little to traffic congestion. Because the number of projected truck trips is small there would be only a very small increased probability of vehicle accidents. There would be very little effect on the demand for public transportation.

Direct Effects

NEPA Value	Summary of Impact Analysis for the Proposed Action
Utilities and Service Systems	The corrective measures would extract contaminated groundwater, use GAC filters to remove VOCs, and then reinject clean water back into the ground to remove additional contaminants in a process known as soil flushing. Because groundwater is recycled in the process, no loss of groundwater would occur and the process would have the beneficial effect of removing contaminants. Some water would be discharged to the sanitary sewer under a permit issued by EBMUD. The volume and quality of water discharged to the sewer due to these corrective measures would alter negligibly the volume and quality currently discharged. If extracted and treated groundwater were no longer needed for recirculation, other reuse options would then be evaluated. Landfills in the area have adequate capacity to accommodate the approximately 1,400 cubic yards of waste soil that would be generated by the excavation of contaminated soil. Spent carbon from the GAC canisters would be collected and recycled off site. The proposed action would not impair stormwater quality or increase the volume of stormwater generated because no new impervious surfaces would be created.

Cumulative Effects

Cumulative effects arise from the proposed action's incremental impacts, when added to the impacts of all existing and reasonably foreseeable future impacts. The Initial Study examined the potential for cumulative impacts. No issues arose from cumulative effects.

Indirect Effects

Indirect effects are reasonably foreseeable effects caused by the proposed action, but occur later in time or are further removed from the project site than direct effects. Growth inducement, which could have adverse effects due to increased traffic, reduced air quality, or loss of open space, is an example of an indirect effect. The corrective measures are not expected to produce adverse indirect effects.

[a] Source: DTSC 2005

Alternatives (i.e., alternative technologies) to the proposed action were summarized previously in this section and discussed in detail in Sections 3 and 4 of this CMS Report. These alternatives were compared using the formal RCRA evaluation process described in Section 4 and summarized at the beginning of this section. Some alternative technologies were rejected as ineffective or not applicable under site-specific conditions (e.g., phytoremediation and air sparging). Among the remaining potentially effective and applicable technologies, the cleanup alternatives that best met the evaluation criteria were selected for the proposed action while the remaining technologies (e.g., capping, slurry wall, sheet pile wall, soil mixing, and permeable reactive barrier) were rejected. In addition, the rejected technologies would have environmental effects similar to the proposed action because they would involve similar activities, such as excavation, operation of heavy equipment, and hauling of soil and materials to and from the site. Thus, the rejected alternative technologies do not present an environmentally superior alternative to the proposed action.

In addition to the use of alternative technologies, one of the alternatives considered was a “No Action” Alternative. Under the No Action Alternative, the currently operating ICMs would be turned off and additional corrective measures would not be implemented. If the No Action Alternative were implemented, cleanup goals would not be achieved at some locations or it might take substantially longer to achieve the goals. If the goals are not achieved, institutional controls would be required to protect future workers and/or to designate groundwater as a non-drinking water source. This alternative would likely be unacceptable to regulatory agencies.

SECTION 8

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Appendix A

Calculation of Risk-Based Media Cleanup Standards

Appendix A-1: Media Cleanup Standards Calculations for Theoretical ILCR = 10^{-6} and HI = 1

APPENDIX A: GROUNDWATER AND SOIL MEDIA CLEANUP STANDARD CALCULATION SUMMARY

LAWRENCE BERKELEY NATIONAL LABORATORY HHRA

Input Parameters for all MCS Calculations	
Cancer Risk	1.00E-06
Hazard Quotient	1
η*	0.002
Depth to Groundwater (feet)	5
Depth to Soil Source (feet)	5

Risk Estimates

	Groundwater					Soil	
Groundwater COPCs	Indoor Workers		Intrusive Workers		Soil COPCs	Indoor Workers	
Compound	Calculated Target Cancer Risk Cw (µg/L)	Calculated Target Non-Cancer Risk Cw (µg/L)	cancer Cw (µg/L) $^{a/}$	Non-cancer Cw (µg/L) $^{a/}$		Calculated Target Cancer Risk Cs (mg/kg)	Calculated Target Non-Cancer Risk Cs (mg/kg)
Organic Compounds							
1,1,1-Trichloroethane	--	1,570,783	--	2,596,355	1,1,1-Trichloroethane	--	690
1,1,2-Trichloroethane	1,905	--	14,833	61,026			
1,1-Dichloroethane	3,663	1,025,767	277,640	2,260,781	1,1-Dichloroethane	1.3	364
1,1-Dichloroethene	--	28,873	--	639,607	1,1-Dichloroethene	--	7.9
1,2-Dichloroethane	1,030	3,088,688	53,714	1,081,945	1,2-Dichloroethane	0.23	8.5
1,2-Dichloroethene, cis-	--	98,405	--	199,358	1,2-Dichloroethene, cis-	--	38.1
1,2-Dichloroethene, trans-	--	94,405	--	320,269	1,2-Dichloroethene, trans-	--	49.6
1,2-Dichloropropane	1,071	15,302	27,688	--			
Benzene	175	108,838	8,092	46,238	Benzene	0.10	6.0
Carbon tetrachloride	27	1,004	3,084	4,625	Carbon tetrachloride	0.05	1.7
Chloroform	1,206	684,732	8,770	38,838	Chloroform	0.49	0.28
Methylene chloride	10,381	1,482,958	235,804	2,829,653	Methylene Chloride	1.8	1974
Tetrachloroethene	343	25,265	384	29,661	Tetrachloroethene	0.45	380
Trichloroethene	1,594	682,956	55,015	3,065	Trichloroethene	2.3	966
Vinyl chloride	12	33,798	7,236	83,736	Vinyl chloride	0.0035	9.7

*Areal fraction of cracks in foundations/walls (cm^2-cracks/cm^2-total area)

$^{a/}$ Refer to the Model Unit Definition table for all associated unit definitions.

Risk-Based MCS ☐

APPENDIX A: GROUNDWATER RISK CALCULATIONS
MODELING VOLATILIZATION FROM GROUNDWATER INTO INDUSTRIAL/COMMERCIAL INDOOR AIR (ASTM MODEL)

LAWRENCE BERKELEY NATIONAL LABORATORY CMS

Equations

1i) Enclosed Space (Indoor) Air Concentration Due to Volatilization from Ground Water

Cair-indoor = CwVFwesp

2i) Cross-Media Groundwater-to-Enclosed (Indoor) Space Air Volatilization Factor

$$VF_{wesp} = \frac{H\left[\frac{D^{eff}_{ws}/L_{GW}}{ER\,L_B}\right]}{1+\left[\frac{D^{eff}_{ws}/L_{GW}}{ER\,L_B}\right]+\left[\frac{D^{eff}_{ws}/L_{GW}}{\left(D^{eff}_{crack}/L_{crack}\right)\eta}\right]} \times 10^3 \frac{L}{m^3}$$

3i) Effective Diffusion Through Foundation Cracks

$$D^{eff}_{crack} = D^{air}\frac{\theta^{3.33}_{acrack}}{\theta^2_T} + D^{wat}\frac{1}{H}\frac{\theta^{3.33}_{wcrac}}{\theta^2_T}$$

Input Parameter Definition[a]		Commercial Input Parameters
Cair-indoor	Modeled COPC indoor air concentration (µg/m3)	Calculated (Eq. 1i)
Cw	Groundwater COPC concentration (µg/L)	Measured
VFwesp	Cross-media groundwater-to-enclosed (indoor) space volatilization factor(mg/m3-air)/(mg/L-water)	Calculated (Eq. 2i)
H	Henry's law constant (cm3-water)/(cm3-air)	Chemical-specific
Deffws	Effective diffusion coefficient between ground water and soil surface (cm2/s)	Calculated (Eq 3 on Page: Cair-gw outdoor)
LGW	Depth to ground water = hcap + hv (cm)	152
ER	Enclosed-space air exchange rate (1/sec)	0.00023
LB	Enclosed-space volume/infiltration area ratio (cm)	300
Deffcrack	Effective diffusion coefficient through foundation cracks (cm2/s)	Calculated (Eq. 3i)
Lcrack	Enclosed-space foundation or wall thickness (cm)	15
η	Areal fraction of cracks in foundations/walls (cm2-cracks/cm2-total area)	0.002
Dair	Diffusion coefficient in air (cm2/s)	Chemical-specific
θ acrack	Volumetric air content in foundation/wall cracks (cm3-air/cm3 total volume)	0.26
θ T	Total soil porosity (cm3/cm3-soil)	0.38
θ wcrack	Volumetric water content in foundation/wall cracks (cm3-water/cm3 total volume)	0.12
Dwat	Diffusion coefficient in water (cm2/s)	Chemical-specific
	Target Cancer Risk (user defined)	1.00E-06

Compound	Calculated Cw based on Target Cancer Risk (µg/L)	Calculated Cw based on Target Non-Cancer Risk (µg/L)	H	Dair (cm^2/s)	Dwat (cm^2/s)	Deffcrack (cm^2/s)	Deffws (cm^2/s)	VFwesp	Target Cancer Risk Cair-indoor ($\mu g/m^3$)	Target Non-Cancer Risk Cair-indoor ($\mu g/m^3$)
Organic Compounds										
1,1,1-Trichloroethane	--	1,570,783	7.05E-01	7.80E-02	8 80E-06	6.09E-03	3.59E-04	6.17E-03	--	9.69E+03
1,1,2-Trichloroethane	1,905	--	3.74E-02	7.80E-02	8.80E-06	6.09E-03	1.34E-03	4.03E-04	7.67E-01	--
1,1-Dichloroethane	3,663	1,025,767	2.30E-01	7.42E-02	1.05E-05	5.79E-03	5.14E-04	2 09E-03	7.67E+00	2.15E+03
1,1-Dichloroethene	--	28,873	1.07E+00	9 00E-02	1 04E-05	7.02E-03	3.90E-04	1 06E-02	--	3.07E+02
1,2-Dichloroethane	1,030	3,088,688	4.01E-02	1.04E-01	9.90E-06	8.12E-03	1.53E-03	5 68E-04	5.85E-01	1.75E+03
1,2-Dichloroethene, cis-	--	98,405	1.67E-01	7 36E-02	1 13E-05	5.74E-03	6 19E-04	1.56E-03	--	1.53E+02
1,2-Dichloroethene, trans-	--	94,405	3.85E-01	7.07E-02	1.19E-05	5.52E-03	4.27E-04	3.25E-03	--	3.07E+02
1,2-Dichloropropane	1,071	15,302	1.15E-01	7.82E-02	8 73E-06	6.10E-03	6.76E-04	1.15E-03	1.23E+00	1.75E+01
Benzene	175	108,838	2.28E-01	8.80E-02	9.80E-06	6.87E-03	5.54E-04	2.42E-03	4.23E-01	2.63E+02
Carbon tetrachloride	27	1,004	1.25E+00	7.80E-02	8.80E-06	6.09E-03	3 30E-04	1.07E-02	2.92E-01	1.07E+01
Chloroform	1,206	684,732	1.50E-01	1.04E-01	1.00E-05	8.12E-03	7.34E-04	1 92E-03	2.32E+00	1.32E+03
Methylene chloride	10,381	1,482,958	8.98E-02	1 01E-01	1.17E-05	7.88E-03	1.02E-03	1.18E-03	1.23E+01	1.75E+03
Tetrachloroethene	343	25,265	7.54E-01	7.20E-02	8.20E-06	5.62E-03	3 28E-04	6.07E-03	2.08E+00	1.53E+02
Trichloroethene	1,594	682,956	4.22E-01	7 90E-02	9.10E-06	6.16E-03	4.11E-04	3.85E-03	6.14E+00	2.63E+03
Vinyl chloride	12	33,798	1.11E+00	1.06E-01	1.23E-05	8.27E-03	4.57E-04	1.30E-02	1.57E-01	4.38E+02

[a] Refer to the Model Unit Definition table for all associated unit definitions.

APPENDIX A: GROUNDWATER RISK CALCULATIONS
INDOOR WORKER -- RME SCENARIO
CARCINOGENIC AND NONCARCINOGENIC RISK ESTIMATES - INHALATION OF VOLATILE COPCS IN INDOOR AIR FROM GROUNDWATER

LAWRENCE BERKELEY NATIONAL LABORATORY CMS

Exposure Assumptions		
Receptor	Indoor Office Worker,	RME Scenario
COPC Ambient Air Concentration (Cair-indoor)	chemical-specific	μg/m^3
Exposure Frequency (EF)	250	days/yr
Exposure Duration (ED)	25	yrs
Fraction of EF breathing air at the site (ET)	0.333	unitless
Averaging Time, Carcinogens (ATC)	70	yrs
Averaging Time, Noncarcinogens (ATNC)	25	yrs
Inhalation Unit Risk Factor (URF)	chemical-specific	(μg/m3)-1
Inhalation Reference Concentration (RfC)	chemical-specific	μg/m3

Risk and Hazard Equations

Carcinogenic:

$$Risk = \frac{(C_{air-indoor})(EF)(ED)(ET)(URF)}{(AT_c)(365 days/year)}$$

Noncarcinogenic:

$$HQ = \frac{(C_{air-indoor})(EF)(ED)(ET)}{(RfC)(AT_{nc})(365 days/year)}$$

COPC [a]	CAS Number [b]	Indoor Air Concentration for Target Cancer Risk (μg/m^3) [c]	Indoor Air Concentration for Target Non-Cancer Risk (μg/m^3) [c]	URF (μg/m^3)$^{-1}$	HHRA URF (if different)	RfC (μg/m^3)	Cancer Risk	Hazard Quotient
Organic Compounds								
1,1,1-Trichloroethane	71-55-6	--	9.69E+03	--		2.21E+03	1.00E-06	1.0
1,1,2-Trichloroethane	79-00-5	7.67E-01	--	1.60E-05		--	1.00E-06	1.0
1,1-Dichloroethane	75-34-3	7.67E+00	2.15E+03	1.60E-06		4.90E+02	1.00E-06	1.0
1,1-Dichloroethene	75-35-4	--	3.07E+02	--	5.00E-05	7.00E+01	1.00E-06	1.0
1,2-Dichloroethane	107-06-2	5.85E-01	1.75E+03	2.10E-05		4.00E+02	1.00E-06	1.0
1,2-Dichloroethene, cis-	156-59-2	--	1.53E+02	--		3.50E+01	1.00E-06	1.0
1,2-Dichloroethene, trans-	156-60-5	--	3.07E+02	--		7.00E+01	1.00E-06	1.0
1,2-Dichloropropane	78-87-5	1.23E+00	1.75E+01	1.00E-05		4.00E+00	1.00E-06	1.0
Benzene	71-43-2	4.23E-01	2.63E+02	2.90E-05		6.00E+01	1.00E-06	1.0
Carbon tetrachloride	56-23-5	2.92E-01	1.07E+01	4.20E-05		2.45E+00	1.00E-06	1.0
Chloroform	67-66-3	2.32E+00	1.32E+03	5.30E-06		3.00E+02	1.00E-06	1.0
Methylene chloride	75-09-2	1.23E+01	1.75E+03	1.00E-06		4.00E+02	1.00E-06	1.0
Tetrachloroethene	127-18-4	2.08E+00	1.53E+02	5.90E-06	5.80E-07	3.50E+01	1.00E-06	1.0
Trichloroethene	79-01-6	6.14E+00	2.63E+03	2.00E-06	1.70E-06	6.00E+02	1.00E-06	1.0
Vinyl chloride	75-1-4	1.57E-01	4.38E+02	7.80E-05		1.00E+02	1.00E-06	1.0

[a] COPC = chemical of potential concern.

[b] CAS = Chemical Abstracts Service number.

[c] Modeled indoor air concentrations are based on the COPC-specific cancer risk and hazard quotient

[d] μg/m^3 = micrograms per cubic meter.

-- = data not available

APPENDIX A: GROUNDWATER RISK CALCULATIONS
MODELING VOLATILIZATION FROM GROUNDWATER TO SOIL SURFACE (ASTM MODEL)
LAWRENCE BERKELEY NATIONAL LABORATORY CMS

3) Effective Diffusion Coefficient Between Ground Water and Soil Surface

$$D_{ws}^{eff} = (h_{cap} + h_v)\left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}}\right]^{-1}$$

$$D_{cap}^{eff} = D^{air}\frac{\theta_{acap}^{3.33}}{\theta_T^2} + D^{wat}\frac{1}{H}\frac{\theta_{wcap}^{3.33}}{\theta_T^2}$$

5) Effective Diffusion Coefficient in Soil Based on Vapor-Phase Concentration

$$D_s^{eff} = D^{air}\frac{\theta_{as}^{3.33}}{\theta_T^2} + D^{wat}\frac{1}{H}\frac{\theta_{ws}^{3.33}}{\theta_T^2}$$

Input Parameter Definition[a]		Input Parameters
H	Henry's law constant (cm3-water)/(cm3-air)	Chemical-specific
Deffws	Effective diffusion coefficient between ground water and soil surface (cm2/s)	Calculated (Eq. 3)
hcap	Thickness of capillary fringe (cm)	5
hv	Thickness of vadose zone (cm)	147
Deffcap	Effective diffusion coefficient through capillary fringe (cm2/s)	Calculated (Eq. 4)
Deffs	Effective diffusion coefficient in soil based on vapor-phase concentration (cm2/s)	Calculated (Eq. 5)
Dair	Diffusion coefficient in air (cm2/s)	Chemical-specific
θ acap	Volumetric air content in capillary fringe soils (cm3-air/cm3 total volume)	0.038
θ T	Total soil porosity (cm3/cm3-soil)	0.38
θ wcap	Volumetric water content in capillary fringe soils (cm3-water/cm3-soil)	0.342
Dwat	Diffusion coefficient in water (cm2/s)	Chemical-specific
θ as	Volumetric air content in vadose zone soils (cm3-air/cm3-soil)	0.26
θ ws	Volumetric water content in vadose zone soils (cm3-water/cm3-soil)	0.12

Compound	H	Dair (cm^2/s)	Dwat (cm^2/s)	Deffs (cm^2/s)	Deffcap (cm^2/s)	Deffws (cm^2/s)	VFwamb
1,1,1-Trichloroethane	7.05E-01	7.80E-02	8.80E-06	6.09E-03	1.25E-05	3.59E-04	4.32E-05
1,1,2-Trichloroethane	3.74E-02	7.80E-02	8.80E-06	6.09E-03	5.58E-05	1.34E-03	5.34E-06
1,1-Dichloroethane	2.30E-01	7.42E-02	1.05E-05	5.79E-03	1.85E-05	5.14E-04	1.82E-05
1,1-Dichloroethene	1.07E+00	9.00E-02	1.04E-05	7.02E-03	1.35E-05	3.90E-04	7.21E-05
1,2-Dichloroethane	4.01E-02	1.04E-01	9.90E-06	8.12E-03	6.14E-05	1.53E-03	7.06E-06
1,2-Dichloroethene, cis-	1.67E-01	7.36E-02	1.13E-05	5.74E-03	2.27E-05	6.19E-04	1.49E-05
1,2-Dichloroethene, trans-	3.85E-01	7.07E-02	1.19E-05	5.52E-03	1.51E-05	4.27E-04	2.62E-05
1,2-Dichloropropane	1.15E-01	7.82E-02	8.73E-06	6.10E-03	2.49E-05	6.76E-04	
Benzene	2.28E-01	8.80E-02	9.80E-06	6.87E-03	1.97E-05	5.54E-04	1.99E-05
Carbon tetrachloride	1.25E+00	7.80E-02	8.80E-06	6.09E-03	1.14E-05	3.30E-04	7.17E-05
Chloroform	1.50E-01	1.04E-01	1.00E-05	8.12E-03	2.64E-05	7.34E-04	1.68E-05
Methylene chloride	8.98E-02	1.01E-01	1.17E-05	7.88E-03	3.84E-05	1.02E-03	1.24E-05
Tetrachloroethene	7.54E-01	7.20E-02	8.20E-06	5.62E-03	1.14E-05	3.28E-04	4.23E-05
Trichloroethene	4.22E-01	7.90E-02	9.10E-06	6.16E-03	1.44E-05	4.11E-04	2.87E-05
Vinyl chloride	1.11E+00	1.06E-01	1.23E-05	8.27E-03	1.58E-05	4.57E-04	8.78E-05

[a] Refer to the Model Unit Definition table for all associated unit definitions.

APPENDIX A: GROUNDWATER RISK CALCULATIONS
CALCULATION OF DOSE ABSORBED PER UNIT AREA PER EVENT (DAevent)
INTRUSIVE WORKER -- RME SCENARIO

LAWRENCE BERKELEY NATIONAL LABORATORY HHRA

Equations	Input Parameter Definition		Input Parameters
	tevent	Duration of event (hr/event) [a]	0.25
	t*	Time it takes to reach steady state (hr/event)	Chemical-specific
	DAevent	Dose absorbed per unit area per event (mg/cm²-event) [b]	Calculated
	Kp	Permeability coefficient from water (cm/hr) [c]	Chemical-specific
	Cw	Concentration of chemical in water (mg/cm³) [d]	Measured
	τevent	Lag time per event (hr/event)	Chemical-specific
	B	Relative contribution of permeability coefficients in strateium corneum and viable epidermis (unitless)	Chemical-specific
	pi		3.141592654
		Target Cancer Risk (user defined)	1.00E-06

Organics:

If tevent < t*, then:

$$DA_{event} = 2K_pC_w\sqrt{\frac{6\tau_{event}\,t_{event}}{\pi}}$$

If tevent > t*, then:

$$DA_{event} = K_pC_w\left[\frac{t_{event}}{1+B} + 2\tau_{event}\left(\frac{1+3B+3B^2}{(1+B)^2}\right)\right]$$

Inorganics:

$$DA_{event} = K_pC_wt_{event}$$

Preliminary COPC [e]	Type [f]	t*	Kp	cancer Cw (µg/L) [g]	cancer Cw (mg/cm³) [h]	non-cancer Cw (µg/L) [g]	non-cancer Cw (mg/cm³) [h]	τevent	B	cancer DAevent (organics)	non-cancer DAevent (organics)	DAevent (inorganics)	DAevent (all)
1,1,1-Trichloroethane	o	1.43E+00	1.30E-02	--	--	2,596,355.04	2 60E+00	6.00E-01	1.00E-01	--	3.61E-02		
1,1,2-Trichloroethane	o	1.43E+00	6 40E-03	14,833	1 48E-02	61,025.93	6.10E-02	6.00E-01	1.12E-02	1.02E-04	4.18E-04		
1,1-Dichloroethane	o	9 20E-01	6 70E-03	277,640	2.78E-01	2,260,780.63	2.26E+00	3.80E-01	6.17E-03	1.58E-03	1 29E-02		
1,1-Dichloroethene	o	8.90E-01	1.20E-02	--	--	639,606.58	6.40E-01	3.70E-01	1.35E-02	--	6.45E-03		
1,2-Dichloroethane	o	9 20E-01	4.20E-03	53,714	5 37E-02	1,081,945.02	1.08E+00	3.80E-01	3.02E-03	1.92E-04	3.87E-03		
1,2-Dichloroethene, cis-	o	8 90E-01	7 70E-03	--	--	199,357.89	1.99E-01	3 70E-01	7.24E-03	--	1 29E-03		5.93E-07
1,2-Dichloroethene, trans-	o	8.20E-01	1.00E-02	--	--	320,269 49	3 20E-01	3.40E-01	7.20E-03	--	2 58E-03		
1,2-Dichloropropane	o	1 00E+00	1.00E-02	27,688	2 77E-02	--	--	4.30E-01	1.00E-02	2.51E-04	--		
Benzene	o	7.00E-01	1.50E-02	8,092	8.09E-03	46,237.54	4.62E-02	2.90E-01	1.00E-01	9.03E-05	5 16E-04		1 34E-08
Carbon tetrachloride	o	1.86E+00	1 60E-02	3,084	3.08E-03	4,625.47	4.63E-03	7 80E-01	1.00E-01	6.02E-05	9.03E-05		
Chloroform	o	1.19E+00	6.80E-03	8,770	8.77E-03	38,838.38	3.88E-02	5 00E-01	9.33E-03	5.83E-05	2.58E-04		
Methylene chloride	o	7.60E-01	3 50E-03	235,804	2.36E-01	2,829,653.40	2.83E+00	3.20E-01	1.78E-03	6.45E-04	7.74E-03		
Tetrachloroethene	o	2.18E+00	3.30E-02	384	3.84E-04	29,661.31	2.97E-02	9.10E-01	2.00E-01	1.67E-05	1.29E-03		
Trichloroethene	o	1.39E+00	1 20E-02	55,015	5.50E-02	3,065.15	3.07E-03	5.80E-01	1.00E-01	6.95E-04	3.87E-05		
Vinyl chloride	o	5.10E-01	7.30E-03	7,236	7.24E-03	83,736.30	8 37E-02	2.10E-01	2.30E-03	3.35E-05	3.87E-04		1.38E-07

[a] hr/event = hours per event

[b] mg/cm²-event = milligrams per centimeter-event

[c] cm/hr = centimeters per hour

[d] mg/cm³ = milligrams per cubic centimeter

[e] Preliminary COPC = preliminary chemical of potential concern

[f] "o" indicates an organic compound, "i" indicates an inorganic compound

[g] Cw is the maximum detected contaminant concentration, mg/L = micrograms per liter

[h] mg/cm³ = milligrams per cubic centimeter

APPENDIX A: GROUNDWATER RISK CALCULATIONS
INTRUSIVE WORKER -- RME SCENARIO
CARCINOGENIC AND NONCARCINOGENIC RISK ESTIMATES -- DERMAL CONTACT WITH GROUNDWATER

LAWRENCE BERKELEY NATIONAL LABORATORY HHRA

Exposure Assumptions		
Receptor	Intrusive Worker: RME Scenario	
COPC Absorbed Dose per Event (DAevent)	chemical-specific	mg/cm2-event
Event Frequency (EV)	1	events/day
Exposure Frequency (EF)	60	days/yr
Fraction of EF in Contact with Ground Water (EC)	1.0	unitless
Exposure Duration (ED)	1	yrs
Exposed Body Surface Area (SA)	3300	cm2
Averaging Time, Carcinogens (ATC)	70	yrs
Averaging Time, Noncarcinogens (ATN)	1	yrs
Oral Slope Factor Adjusted for GI Absorption (SFd)	chemical-specific	(mg/kg-day)-1
Body Weight (BW)	70	kg
Oral Reference Dose Adjusted for GI Absorption (RfDd) where: RfDd = RfDoral*OAF	chemical-specific	µg/m3
Gastrointestinal (oral) Absorption Fraction (OAF)	chemical-specific	unitless

Risk and Hazard Equations

Carcinogenic:

$$Risk = \frac{(DA_{event})(EV)(EF)(EC)(ED)(SA)(SF_d)}{(BW)(AT_c)(365 days/year)}$$

Noncarcinogenic:

$$HQ = \frac{(DA_{event})(EV)(EF)(EC)(ED)(SA)}{(RfD_d)(BW)(AT_{nc})(365 days/year)}$$

Preliminary COPC [a/]	CAS Number [b/]	Cancer DAevent (mg/cm^2-event) [c/]	Non-cancer DAevent (mg/cm^2-event) [c/]	SFd (mg/kg-day)$^{-1}$ [d/]	RfDd (mg/kg-day)	Cancer Risk	Hazard Quotient
1,1,1-Trichloroethane	71-55-6	--	3.61E-02	--	2.80E-01	1.00E-06	1.00E+00
1,1,2-Trichloroethane	79-00-5	1.02E-04	4.18E-04	8.89E-02	3.24E-03	1.00E-06	1.00E+00
1,1-Dichloroethane	75-34-3	1.58E-03	1.29E-02	5.70E-03	1.00E-01	1.00E-06	1.00E+00
1,1-Dichloroethene	75-35-4	--	6.45E-03	--	5.00E-02	1.00E-06	1.00E+00
1,2-Dichloroethane	107-06-2	1.92E-04	3.87E-03	4.70E-02	3.00E-02	1.00E-06	1.00E+00
1,2-Dichloroethene, cis-	156-59-2	--	1.29E-03	--	1.00E-02	1.00E-06	1.00E+00
1,2-Dichloroethene, trans-	156-60-5	--	2.58E-03	--	2.00E-02	1.00E-06	1.00E+00
1,2-Dichloropropane	78-87-5	2.51E-04	--	3.60E-02	--	1.00E-06	1.00E+00
Benzene	71-43-2	9.03E-05	5.16E-04	1.00E-01	4.00E-03	1.00E-06	1.00E+00
Carbon tetrachloride	56-23-5	6.02E-05	9.03E-05	1.50E-01	7.00E-04	1.00E-06	1.00E+00
Chloroform	67-66-3	5.83E-05	2.58E-04	1.55E-01	2.00E-03	1.00E-06	1.00E+00
Chloromethane	74-87-3	5.56E-04	--	1.63E-02	--	1.00E-06	1.00E+00
Methylene chloride	75-09-2	6.45E-04	7.74E-03	1.40E-02	6.00E-02	1.00E-06	1.00E+00
Tetrachloroethene	127-18-4	1.67E-05	1.29E-03	5.40E-01	1.00E-02	1.00E-06	1.00E+00
Trichloroethene	79-01-6	6.95E-04	3.87E-05	1.30E-02	3.00E-04	1.00E-06	1.00E+00
Vinyl chloride	75-1-4	3.35E-05	3.87E-04	2.70E-01	3.00E-03	1.00E-06	1.00E+00

[a/] Preliminary COPC = preliminary chemical of potential concern.

[b/] CAS = Chemical Abstracts Service number

[c/] mg/cm^2-event = milligram per square centimeter per event.

[d/] mg/kg-day = milligram per kilogram per day.

"--" = Data unavailable.

APPENDIX A: SOIL RISK CALCULATIONS
MODELING VOLATILIZATION FROM SOILS (0 - 20 FT BGS) INTO INDOOR AIR (ASTM MODEL)

Equations

1i) Enclosed Space (Indoor) Air Concentration Due to Volatilization from Subsurface Soil

$C_{air\text{-}indoor} = C_s VF_{sesp} \times 10^3$

2i) Cross-Media Subsurface Soil-to-Enclosed (Indoor) Space Air Volatilization Factor

$$VF_{sesp} = \frac{\left[\dfrac{Hp_s}{\theta ws + k_s p_s + H\theta_{as}}\right]\left[\dfrac{D_s^{eff}/L_s}{ER\,L_B}\right]}{1+\left[\dfrac{D_s^{eff}/L_s}{ER\,L_B}\right]+\left[\dfrac{D_s^{eff}/L_s}{(D_{crack}^{eff}/L_{crack})\eta}\right]} x10^3 \frac{cm3-kg}{m^3-g}$$

3i) Effective Diffusion Through Foundation Cracks

$$D_{crack}^{eff} = D^{air}\frac{\theta_{acrack}^{3.33}}{\theta_T^2} + D^{wat}\frac{1}{H}\frac{\theta_{wcrack}^{3.33}}{\theta_T^2}$$

Input Parameter Definition[a]		Residential Input Parameters
P_s	Soil bulk density (g-soil/cm³-soil)	1.7
$C_{air\text{-}indoor}$	Modeled COPC indoor air concentration (µg/m³)	Calculated (Eq. 1i)
C_s	Soil COPC concentration (mg/kg)	Measured
VF_{sesp}	Cross-media subsurface soil-to-enclosed (indoor) space volatilization factor (mg/m3-air)/(mg/kg-soil)	Calculated (Eq. 2i)
H	Henry's law constant (cm³-water)/(cm³-air)	Chemical-specific
θ_{ws}	Volumetric	0.12
θ_{as}	Volumetric air content in vadose zone soils (cm³-air/cm³-soil)	0.26
Ls	Depth to subsurface soil source (cm)	152 4
ER	Enclosed-space air exchange rate (1/sec)	0.00023
L_B	Enclosed-space volume/infiltration area ratio (cm)	300
D^{eff}_{crack}	Effective diffusion coefficient through foundation cracks (cm²/s)	Calculated (Eq. 3i)
L_{crack}	Enclosed-space foundation or wall thickness (cm)	15
η	Areal fraction of cracks in foundations/walls (cm²-cracks/cm²-total area)	0.002
D^{air}	Diffusion coefficient in air (cm²/s)	Chemical-specific
θ_{acrack}	Volumetric air content in foundation/wall cracks (cm³-air/cm³ total volume)	0.26
θ_T	Total soil porosity (cm³/cm³-soil)	0.38
θ_{wcrack}	Volumetric water content in foundation/wall cracks (cm³-water/cm³ total volume)	0.12
D^{wat}	Diffusion	Chemical-specific
K_s	coefficient in	Ks = K_{oc} X f_{oc}
K_{oc}	water (cm²/s) Soil-water	Chemical-specific
F_{oc}	fraction of organic carbon	0.01
	Target Cancer Risk	1.00E-06

Compound	Koc (cm³water-g-carbon)	Ks (cm³-water/cm³-soil)	Calculated Target Cancer Risk Cs (mg/kg)	Calculated Target Non-Cancer Risk Cs (mg/kg)	H	D^{air} (cm²/s)	D^{wat} (cm²/s)	D^{eff}_{crack} (cm²/s)	D^{eff}_s (cm²/s)	VF_{sesp}	Cair-indoor (µg/m³) for Target Cancer Risk	Cair-indoor (µg/m³) for Target Non-Cancer Risk
1,1,1-Trichloroethane	1.10E+02	1 10E+00	--	690.17	7.05E-01	7 80E-02	8 80E-06	6.09E-03	6.09E-03	6.35E-03	--	4.38E+03
1,1-Dichloroethane	3.13E+01	3.13E-01	1.27	364.20	2.30E-01	7 42E-02	1.05E-05	5.79E-03	5.79E-03	6.03E-03	7.67E+00	2.19E+03
1,1-Dichloroethene	5.82E+01	5.82E-01	--	7.92	1 07E+00	9 00E-02	1.04E-05	7.02E-03	7.02E-03	1.74E-02	--	1.38E+02
1,2-Dichloroethane	1.68E+01	1.68E-01	0.23	8.54	4.01E-02	1.04E-01	9 90E-06	8.12E-03	8.12E-03	2.52E-03	5.85E-01	2.15E+01
1,2-Dichloroethene, cis-	3.55E+01	3 55E-01	--	38.15	1 67E-01	7 36E-02	1.13E-05	5.74E-03	5.74E-03	4.02E-03	--	1.53E+02
1,2-Dichloroethene, trans-	5.21E+01	5.21E-01	--	49.65	3 85E-01	7.07E-02	1.19E-05	5.52E-03	5.52E-03	6.18E-03	--	3.07E+02
Benzene	5 82E+01	5.82E-01	0 10	6.04	2.28E-01	8.80E-02	9.80E-06	6.87E-03	6.87E-03	4.32E-03	4.23E-01	2.61E+01
Carbon tetrachloride	2.08E+02	2 08E+00	0 05	1.75	1.25E+00	7.80E-02	8.80E-06	6.09E-03	6.09E-03	6.14E-03	2.92E-01	1 07E+01
Chloroform	3 97E+01	3.97E-01	0.49	0.28	1.50E-01	1 04E-01	1.00E-05	8.12E-03	8.12E-03	4.70E-03	2.32E+00	1.32E+00
Methylene Chloride	1 17E+01	1.17E-01	1.84	1,974.09	8.98E-02	1.01E-01	1.17E-05	7.88E-03	7.88E-03	6.66E-03	1.23E+01	1.32E+04
Tetrachloroethene	1.56E+02	1.56E+00	0.45	379.96	7.54E-01	7.20E-02	8 20E-06	5.62E-03	5.62E-03	4.60E-03	2.08E+00	1.75E+03
Trichloroethene	1 67E+02	1.67E+00	2.25	966.19	4.22E-01	7 90E-02	9.10E-06	6.16E-03	6.16E-03	2.72E-03	6.14E+00	2.63E+03
Vinyl chloride	1 43E+01	1.43E-01	0 00	9 66	1 11E+00	1.06E-01	1 23E-06	8.27E-03	8.27E-03	4.54E-02	1.57E-01	4.38E+02

[a] Refer to the Model Unit Definition table for all associated unit definitions.

APPENDIX A: SOIL RISK CALCULATIONS
INDOOR WORKER -- RME SCENARIO
CARCINOGENIC AND NONCARCINOGENIC RISK ESTIMATES - INHALATION OF VOLATILE COPCS IN INDOOR AIR FROM SOILS (0-20 FT BGS)

LAWRENCE BERKELEY NATIONAL LABORATORY, CALIFORNIA

Exposure Assumptions	
Receptor	Indoor Office Worker: RME Scenario
COPC Ambient Air Concentration ($C_{air-indoor}$)	chemical-specific μg/m^3
Exposure Frequency (EF)	250 days/yr
Exposure Duration (ED)	25 yrs
Fraction of EF breathing air at the site (ET)	0.333 unitless
Averging Time, Carcinogens (AT_C)	70 yrs
Averging Time, Noncarcinogens (AT_{NC})	25 yrs
Inhalation Unit Risk Factor (URF)	chemical-specific (μg/m^3)$^{-1}$
Inhalation Reference Concentration (RfC)	chemical-specific μg/m^3

Risk and Hazard Equations

Carcinogenic:

$$Risk = \frac{(C_{air-indoor})(EF)(ED)(ET)(URF)}{(AT_c)(365 days/year)}$$

Noncarcinogenic:

$$HQ = \frac{(C_{air-indoor})(EF)(ED)(ET)}{(RfC)(AT_{nc})(365 days/year)}$$

Preliminary COPC [a/]	CAS Number [b/]	Indoor Air Concentration for Target Cancer Risk (μg/m^3) [c/]	Indoor Air Concentration for Target Non-Cancer Risk (μg/m^3) [c/]	URF (μg/m^3)$^{-1}$	RfC (μg/m^3)	Cancer Risk	Hazard Quotient
1,1,1-Trichloroethane	71-55-6	--	4.38E+03	--	1.00E+03	1.00E-06	1.00
1,1-Dichloroethane	75-34-3	7.67E+00	2.19E+03	1.60E-06	5.01E+02	1.00E-06	1.00
1,1-Dichloroethene	75-35-4	--	1.38E+02	--	3.15E+01	1.00E-06	1.00
1,2-Dichloroethane	107-06-2	5.85E-01	2.15E+01	2.10E-05	4.90E+00	1.00E-06	1.00
1,2-Dichloroethene, cis-	156-59-2	--	1.53E+02	--	3.50E+01	1.00E-06	1.00
1,2-Dichloroethene, trans-	156-60-5	--	3.07E+02	--	7.00E+01	1.00E-06	1.00
Benzene	71-43-2	4.23E-01	2.61E+01	2.90E-05	5.95E+00	1.00E-06	1.00
Carbon tetrachloride	56-23-5	2.92E-01	1.07E+01	4.20E-05	2.45E+00	1.00E-06	1.00
Chloroform	67-66-3	2.32E+00	1.32E+00	5.30E-06	3.01E-01	1.00E-06	1.00
Methylene Chloride	75-09-2	1.23E+01	1.32E+04	1.00E-06	3.00E+03	1.00E-06	1.00
Tetrachloroethene	127-18-4	2.08E+00	1.75E+03	5.90E-06	3.99E+02	1.00E-06	1.00
Trichloroethene	79-01-6	6.14E+00	2.63E+03	2.00E-06	6.00E+02	1.00E-06	1.00
Vinyl chloride	75-1-4	1.57E-01	4.38E+02	7.80E-05	1.00E+02	1.00E-06	1.00

[a/] Preliminary COPC = preliminary chemical of potential concern.

[b/] CAS = Chemical Abstracts Service number.

[c/] Modeled indoor air concentrations (ASTM vapor intrusion model) were based on the exposure-point concentration of each COPC detected at the evaluated area.

[d/] μg/m^3 = micrograms per cubic meter

-- = data not available.

Appendix B

Pilot Test Summary Reports

- Building 71B Bioremediation Pilot Test (March 2004)
- Building 71B In-Situ Chemical Oxidation Pilot Test (May 2004)
- Building 51L In-Situ Chemical Oxidation Pilot Test (August 2004)

E.O. Lawrence Berkeley National Laboratory
University of California
Environmental Restoration Program

United States Department of Energy

BUILDING 71B BIOREMEDIATION PILOT TEST

for the
Lawrence Berkeley National Laboratory
Environmental Restoration Program

March 2004

BUILDING 71B BIOREMEDIATION PILOT TEST

for the
Lawrence Berkeley National Laboratory
Environmental Restoration Program

A Joint Effort of
Environment, Health and Safety Division and
Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

March 2004

Owner: United States Department of Energy
1301 Clay St., Rm. 700N
Oakland, California 94612-5208

Operator: University of California Lawrence Berkeley National Laboratory
and United States Department of Energy
1 Cyclotron Road
Berkeley, CA 94720

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SECTION 1

INTRODUCTION

The Ernest Orlando Lawrence Berkeley National Laboratory (Berkeley Lab) is currently in the Corrective Measures Study (CMS) phase of the Resource Conservation and Recovery Act (RCRA) Corrective Actions Process (CAP). The Berkeley Lab Environmental Restoration Program (ERP) implements the CAP at Berkeley Lab.

As part of the CMS process, Berkeley Lab proposed in consultation with the regulatory agencies, various pilot-scale tests designed to evaluate different remedial technologies. Pilot-scale testing involves operation of potential remedial technologies on a small-scale to assess their applicability and potential effectiveness under site-specific Berkeley Lab conditions. Pilot test results can be used to optimize the design and operation of the full-scale corrective measure, should it be implemented.

A work plan titled “Work Plan for Pilot Testing Hydrogen Release Compounds (HRC®) in the Core Area of the Building 71b Lobe of the Building 71 Groundwater Solvent Plume” was prepared describing the proposed pilot-scale test. The work plan describes the rationale and procedures for injecting HRC® into the core area of the Building 71B lobe of the Building 71 groundwater contaminant plume (Figure 1) to degrade chlorinated aliphatic hydrocarbons (CAHs), including tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE) and vinyl chloride (VC), using enhanced *in situ* bioremediation techniques. Addition of HRC® enhances natural bioremediation by supplying electron acceptors that accelerate the metabolic activity of indigenous microorganisms that transform or destroy contaminants.

Most organisms obtain energy for growth and activity by physiologically coupling oxidation and reduction reactions and harvesting the resulting chemical energy. When molecular oxygen is available (aerobic conditions), many organisms including humans couple the oxidation of the organic compounds (primary growth substrate or food) to the reduction of oxygen. (Oxygen is the electron acceptor and is reduced and the organic compound is the electron donor and is oxidized). Many microorganisms can still oxidize organic compounds when oxygen is absent (anaerobic conditions) by using other electron acceptors including nitrate (NO_3^-), manganese (Mn^{4+}), ferric iron (Fe^{3+}), sulfate (SO_4^-), and carbon dioxide (CO_2). The oxidation process, however, extracts smaller amounts of energy, and is therefore less effective, as the oxidation-reduction reactions progress from nitrate to carbon dioxide. Microorganism use petroleum hydrocarbons and some chlorinated aliphatic hydrocarbons (CAHs), like vinyl chloride, as the primary growth substrate.

In comparison, very little evidence is available suggesting that the highly chlorinated CAHs including tetrachloroethene (PCE), trichloroethene (TCE), DCEs, trichloroethenes (TCAs), dichloroethanes (DCAs), and polychlorinated benzenes undergo biodegradation by either aerobic or anaerobic oxidation. This is due to the fact that these compounds are already highly oxidized. In addition, these compounds are not amenable for use as a primary growth substrate because they may be toxic to the bacteria. Instead, the CAHs are used as electron acceptors in reactions that rely on other sources of carbon as the primary growth substrate. Other sources of carbon can include low molecular weight organic compounds (e.g., lactate, acetate, methanol, glucose, etc.), petroleum hydrocarbons, volatile fatty acids (e.g., lactic, acetic, pyruvic, and butyric acid) or naturally occurring organic matter.

Biodegradation of CAHs generally occurs under reducing (i.e., anaerobic) conditions and is referred to as reductive dechlorination. During this process, the CAH is reduced and a chlorine atom is removed and replaced with a hydrogen atom. In general, the success of reductive dechlorination is limited to the existence of a reducing environment, the availability of primary growth substrate and hydrogen, both of which may be consumed by other bacteria competing for these constituents, and the presence of the microorganisms that degrade these compounds.

HRC® is formulated by the manufacturer to serve as both a source of carbon and hydrogen, thus enhancing redox conditions and microbial populations that favor bioremediation. HRC® contains a sugar base that acts as a growth substrate for the microorganisms and, when hydrated in water, slowly releases lactic acid. Lactic acid degrades to lower molecular weight volatile fatty acids (i.e., pyruvic and acetic acid), producing hydrogen that the bacteria substitute in the CAH structure for chlorine, yielding energy for their metabolism and a biodegraded CAH. If full dechlorination of the CAH occurs, then the end product is typically ethene, ethane, methane, carbon dioxide and/or water.

The sections that follow describe the results of the pilot-scale study.

SECTION 2

PUMPING WELL TEST

A 96-hour long pumping well test was performed at Building 71B to characterize the water-bearing zone penetrated by the pumping well MW71b-98-13 (Figure 2) and to determine the feasibility of injecting HRC® into the zone. The pumping well test was performed from August 7 to August 11, 2003, prior to injecting HRC® on September 26, 2003 (Section III).

During the test, monitoring wells SB71b-99-1, SB71b-99-2 and MW71B-00-2 were utilized as observation wells for measuring water level changes caused by pumping. Water pumped from MW71b-98-13 was also sampled and analyzed for wellhead parameters (dissolved oxygen, specific conductance and temperature) and volatile organic compounds (VOCs by EPA method 8260). A complete description of the pumping well test and results can be found in Appendix A.

Data collected during the pumping well test were evaluated and interpreted as follows:

- The water levels and pumping rate did not stabilize during the test making it difficult to estimate formation properties (hydraulic conductivity and storativity) using standard transient well analysis techniques;

- A best estimate of the hydraulic conductivity (K) equal to 4.0E-07 m/s was determined using a steady-state analytical solution. The estimate for K is believed to be too low given that drawdown was observed in a monitoring well located 26 feet from the pumping well, yet the linear velocity determined using the estimated K and site hydraulic gradient would not have predicted such a quick water level response. This implies that the entire thickness of the water-bearing zone may not be contributing substantially to the total flow to the well. Rather, preferential flow paths through thin water-bearing layers having much greater hydraulic conductivity is more plausible;

- Wellhead parameters including dissolved oxygen, temperature, specific conductance and pH stabilized early during the pumping well test suggesting samples collected and analyzed were representative of *in situ* conditions;

- Dissolved oxygen levels measured in groundwater samples collected from the pumping well were at or below 1 mg/L signifying reducing conditions. Anaerobic bacteria that degrade VOCs by reductive dechlorination favor such conditions;
- Groundwater samples collected during the test and analyzed for VOCs contained PCE and TCE that have been shown in the literature to be degraded by reductive dechlorination;

Analyses and observations resulting from the pumping well test indicated that injection of HRC® into the artificial fill was feasible. The quick hydraulic response observed during the test provided confidence that HRC® would disperse in the groundwater and travel within a reasonable time period to a downgradient observation point where the effects of biodegradation could be detected, if it occurred. Therefore, it was proposed to inject HRC® within 6-feet and upgradient from MW71b-98-13 where it would dissolve and travel with the groundwater degrading contaminants along the way. Samples collected from monitoring well MW71b-98-13 would be used to establish a baseline against which future analyses could be compared and the effectiveness of the bioremediation technology could be assessed.

SECTION 3

BASELINE SAMPLING

Groundwater samples were collected from monitoring well MW71b-98-13 prior to injection on Sept. 24, 2003 and Sept. 26, 2003. A peristaltic pump was used to extract groundwater from the monitoring well and to pump it through a flow-through cell where wellhead parameters were measured. A portable meter was used to measure the wellhead parameters including dissolved oxygen, temperature, pH and specific conductance. Groundwater samples were taken after the wellhead parameters stabilized and after a minimum of three-casing volumes were purged from the well. Samples were also collected and analyzed on site for dissolved carbon dioxide, ferrous iron, and total sulfide using field test kits.

The samples were analyzed for the chemical constituents summarized in Table 1 and the volatile organic compounds (VOCs) listed for EPA method 8260 summarized in Table 2. (Note that Table 2 only summarizes the EPA method 8260 constituents detected in the samples). Wellhead parameters are reported in Table 3. The following laboratories or field test kits were used to analyze the samples:

- Microseeps, Inc. (Pittsburgh, PA) analyzed the samples for total organic carbon (TOC), total inorganic carbon (TIC), volatile fatty acids (VFA), hydrogen, and light hydrocarbon gases (LHG including ethene, ethane, and methane).

- Berkeley Lab analyzed the samples for EPA method 8260 parameters.

- BC Laboratories, Inc. (Bakersfield, CA) analyzed the samples for the remaining constituents excluding carbon dioxide and ferrous iron.

- Dissolved carbon dioxide, ferrous iron, and sulfide were measured by field personnel on site during sampling using a Chemetrics K-1910 test kit and Hach test kits 26672-00 and 223801, respectively.

Unfortunately, the baseline VFA sample sent to Microseeps broke during shipping and the nitrate/nitrite sample sent to BC Laboratories exceeded their hold time. Therefore, a second round of samples were collected from monitoring well SB71b-99-1 on Sept. 30, 2003 after HRC® was injected. The sample was collected from SB71b-99-1 because it was believed that HRC® had already reached well MW71b-98-13 and would, therefore, influence the baseline results had MW71b-98-13 been sample instead. Well SB71b-99-1 is located immediately upgradient from the HRC® injection location (Figure 2) and is connected hydraulically to MW71b-98-1 based on the pumping test results.

SECTION 4

HYDROGEN RELEASE COMPOUND (HRC®) INJECTION

Injection of HRC® into the formation was accomplished using a Geoprobe® rig, push rods, water bath, and a high-pressure pump. Vironex, Inc., located in San Leandro, California, was the contractor who provided the equipment and operators needed to perform the work. On-site LBNL personnel supervised the contractor. The injection process took about 5 hours and was started and completed on September 26, 2003.

Site preparation consisted of locating underground utilities including construction of a shallow 1.7 ft. wide, 8.4 ft. long, 4 ft. deep trench used to visually locate a 6-inch water main (Figure 3). Two nearby stormwater drains were covered with plastic and sand bags to prevent accidental spills of HRC® or drilling fluids from entering the drain. No spills occurred. Approximately 330 pounds of HRC® was purchased for the pilot study from Regenesis, Inc. headquartered in San Clemente, California and delivered to LBNL.

A Geoprobe® rig was used to advance push rods to a total depth of 25 to 30 ft. below ground level where the injection process began. Thirty pound plastic buckets containing HRC® were pre-heated in a water bath to about 130ºF prior to injection to lower the viscosity of the honey-like material, allowing it to be easily pumped down hole through the hollow push rods. A high-pressure pump was used to inject the HRC® and was calibrated prior to use by counting the number of strokes required to pump about 4 pounds of HRC® into an empty bucket. Warm HRC® was then injected under pressure (240-300 pounds per square inch) through the push rods, out the open jets of the injection tool located at the bottom of the push rods and into the formation. The injection rods were pulled back one foot at a time and approximately 4 pounds of HRC® was injected per linear foot of boring. Injection was intentionally halted once the injection interval reached the top of the water table.

Table 4 summarizes the total amount of HRC® injected into each of the four Geoprobe® borings shown on Figure 3. The borings were installed in the order that they are numbered. As noted in the comment column of Table 4, a small quantity of HRC® was observed flowing out of the top of boring #2 into the trench when injecting into borings #3 and #4. This implies that a preferential flow path or short circuit through the formation developed between boring #2 and #3 and between #2 and #4. The short circuit between borings was observed when the injection interval reached a depth of 20 ft. in boring #3 and 15 ft. in boring #4. Broad vertical coverage of HRC® is still believed to have taken place given the relatively constant pressure observed during injection into individual one foot intervals.

SECTION 5

POST-INJECTION GROUNDWATER SAMPLING

Post-injection groundwater sampling was initiated after HRC® injection to determine the effectiveness of the treatment technology. Groundwater samples were collected from monitoring well MW71b-98-13 on a weekly to biweekly schedule for a period of 3 months, and monthly thereafter. Wellhead parameters including dissolved oxygen, temperature, and specific conductance were collected using a portable meter when the well was purged to ensure that representative groundwater samples were obtained Weekly and biweekly samples were collected using a peristaltic pump and analyzed for VOCs (i.e., EPA method 8260 parameters). Summaries of the VOC analyses and wellhead parameters are summarized in Table 2 and 3, respectively. (Note that Table 2 summarizes only the VOCs detected in the samples).

An expanded list of analyses was performed on groundwater samples taken from MW71b-98-13 on a bimonthly schedule (Table 1). These analyses were conducted to supplement and enhance the information provided by the VOC analyses. The VOC analyses provide an overall view of the effectiveness of the treatment technology, while the expanded list provides a more detailed look at the hydrochemical conditions controlling the bioremediation process.

The following laboratories and field test kits were used to analyze the samples:

a. Microseeps, Inc. (Pittsburgh, PA) analyzed the samples for total organic carbon (TOC), total inorganic carbon (TIC), volatile fatty acids (VFA), hydrogen, and light hydrocarbon gases (LHG including ethene, ethane, and methane).

b. Berkeley Lab analyzed the samples for EPA method 8260 parameters; and

c. BC Laboratories, Inc. (Bakersfield, CA) analyzed the samples for the remaining constituents (excluding carbon dioxide and ferrous iron) and some of the EPA method 8260 samples.

d. Dissolved carbon dioxide, ferrous iron, and sulfide were measured by field personnel on site during sampling using a Chemetrics K-1910 test kit and Hach test kits 26672-00 and 223801, respectively.

SECTION 6

INTERPRETATION OF PILOT TEST RESULTS

The baseline samples, historical results from previous quarterly and annual sampling events, and post-injection analytical results (Tables 1 through 3) provide the basis for evaluating the pilot test results and assessing the continued effectiveness of enhanced bioremediation. The criteria given in Table 5 provide the basis for interpreting the analytical results.

The electron acceptors and geochemical parameters listed in Table 1 provide the basis for measuring the potential success of CAHs degradation by reductive dechlorination and monitoring of site-specific conditions that can lead to its arrest. Based on thermodynamic theory, reductive dechlorination of PCE, TCE and cis-1,2-DCE will not proceed until electron acceptors including oxygen, nitrate, manganese (IV), and ferric iron have been reduced (or are not present). Microorganisms who utilize these electron acceptors during respiration will flourish and dominate over species that would otherwise utilize the CAHs as their primary electron acceptors. Oxygen, nitrate, and dissolved manganese concentration levels are nondetect or very low (Table 1) implying these electron acceptors are not available to compete with the CAHs. Ferric iron (Fe^{3+}) is perhaps the most important of the natural electron acceptors to be considered when evaluating the redox potential and microbial respiration processes that can lead to reductive dechlorination of CAHs. The detection of ferrous iron (Fe^{2+}, the reduced form of ferric iron, Fe^{3+}) reported in Table 1 is a very strong indicator that redox conditions, which promote reductive dechlorination of CAHs, exist in the core of the groundwater plume at Building 71b. Post-injection electron acceptor data (Table 1) and the interpretation of these data (based on the criteria in Table 5), indicates that redox conditions that support reductive dechlorination have not changed significantly throughout the 6-month pilot test following HRC® injection.

Even though redox conditions that favor CAH degradation may be present, hydrogen ions must also be readily available as a substitute for chlorine in the CAH structure. In addition, a carbon source must be available to act as the electron donor (i.e., food). HRC® provides both of these components. Groundwater pH (Table 3) dropped dramatically within a few days of injecting HRC® signifying that the HRC® had begun to hydrate and release volatile fatty acids in the groundwater, as expected. This was confirmed later on December 4, 2003 when volatile fatty acids (lactic, pyruvic, acetic acids, etc.) were detected in the first scheduled round of groundwater samples collected for this purpose (Table 1). Analytical data from this same round of samples also provide ample evidence that dissolved hydrogen and total organic carbon levels rose dramatically above background levels (Table 1) within 2 months of injecting HRC® into the water-bearing zone. The latest round of analyses from the February 19, 2004 sampling indicates that dissolved hydrogen and total organic carbon levels have since decreased and the relative abundance of volatile fatty acids has shifted from lactic acid to acetic acid as hydrogen is released. This may imply that the HRC® is "aging" and will become less effective over time as volatile fatty acids decrease (releasing smaller amounts of hydrogen) and as carbon is consumed.

The data described above demonstrates that redox conditions are favorable, and that sufficient electron donors (in the form of total organic carbon and volatile fatty acids) are present, to support microbial respiration. In addition, indicator parameters including pH, volatile fatty acids, and dissolved hydrogen, show that hydrogen ions are present in the groundwater and potentially available to support substitution for chlorine in the CAH structure. The question that remains is whether microorganisms that degrade the CAHs are present, or whether they are competing with other organisms that utilize more readily available electron acceptors in the respiration process? Indirect evidence that these bacteria are present can be concluded from the observed decrease in contaminant concentration data reported in Table 2 and large increase in metabolic byproducts of microbial respiration (i.e., ethene, ethane, and methane) reported in Table 1. The PCE and TCE concentrations detected in samples from monitoring well MW71b-98-13 decreased immediately following HRC®injection on September 26, 2003 as shown on

Figure 4 to levels approaching the cleanup standard for drinking water. In contrast, cis-DCE, and to a lesser extent, VC concentrations have increased. Cis-DCE and VC are known byproducts of the reductive dechlorination process and may increase as PCE and TCE are biodegraded to cis-DCE, VC and eventually ethene, ethane, methane, carbon dioxide and water.

Approximately 3 to 5 weeks after HRC® injection, both the cis-DCE and VC concentrations began to drop and were at or below historical concentrations by mid December 2003 (Table 2). Starting in mid January 2004, cis-DCE concentrations began to climb. This is attributed to seasonal rainfall and subsequent recharge that has flushed PCE and TCE out of soils causing contaminant levels to rise in groundwater samples collected from the upgradient source area (near well MW71B-99-3R, Figure 2). This leads us to believe that higher concentrations of PCE and TCE, flowing downgradient from the source with the groundwater, are being swept through the treatment area and degraded by the HRC® increasing the cis-DCE levels at MW71b-98-13. Meanwhile, PCE and TCE concentrations have remained relatively constant at MW71b-98-13 implying that enhanced bioremediation of these compounds is quite effective. Reductive dechlorination of cis-DCE and VC appears to be less effective in the short-term, but given time they also appear to degrade.

SECTION 7

CONCLUSIONS

The degradation of PCE and TCE, and to a lesser extent cis-DCE and VC, using HRC®-enhanced natural bioremediation is a feasible remedial technology for the Building 71b core groundwater contaminant plume. Natural conditions appear to favor the use of this technology, producing a 10-fold reduction in PCE and TCE to levels meeting regulatory standards (Table 3, maximum contaminant level [MCL]) and 3-fold decrease in cis-DCE contaminant concentrations within 6 months. Vinyl chloride, which is known to be more recalcitrant to biodegradation under anaerobic conditions, has remained relatively stable within its historical range of concentration values.

The introduction of HRC® into the water-bearing zone at Building 71b has not been without negative consequences. The groundwater has developed a strong septic-like odor that is likely caused by the decaying sugar and organic acids found in the HRC®. Introduction of large amounts of organic material has created conditions similar to a shallow house-hold septic field, where biological degradation of the organic waste can impart an odor and impact the taste of shallow groundwater. Unlike a septic system, however, HRC® does not introduce pathogens found in human or animal wastes, but simply promotes the growth of indigenous microorganisms that can degrade the contaminants. Given the likelihood that the shallow water-bearing zone beneath Building 71b will not be used as a potable water supply, quick and effective mitigation of site contaminants using enhanced bioremediation is clearly protective of public health and safety; whereas, the impact on taste and odor should be viewed as a tradeoff, or cost, of obtaining this benefit, should this technology be used as the final remedy.

LIST OF FIGURES

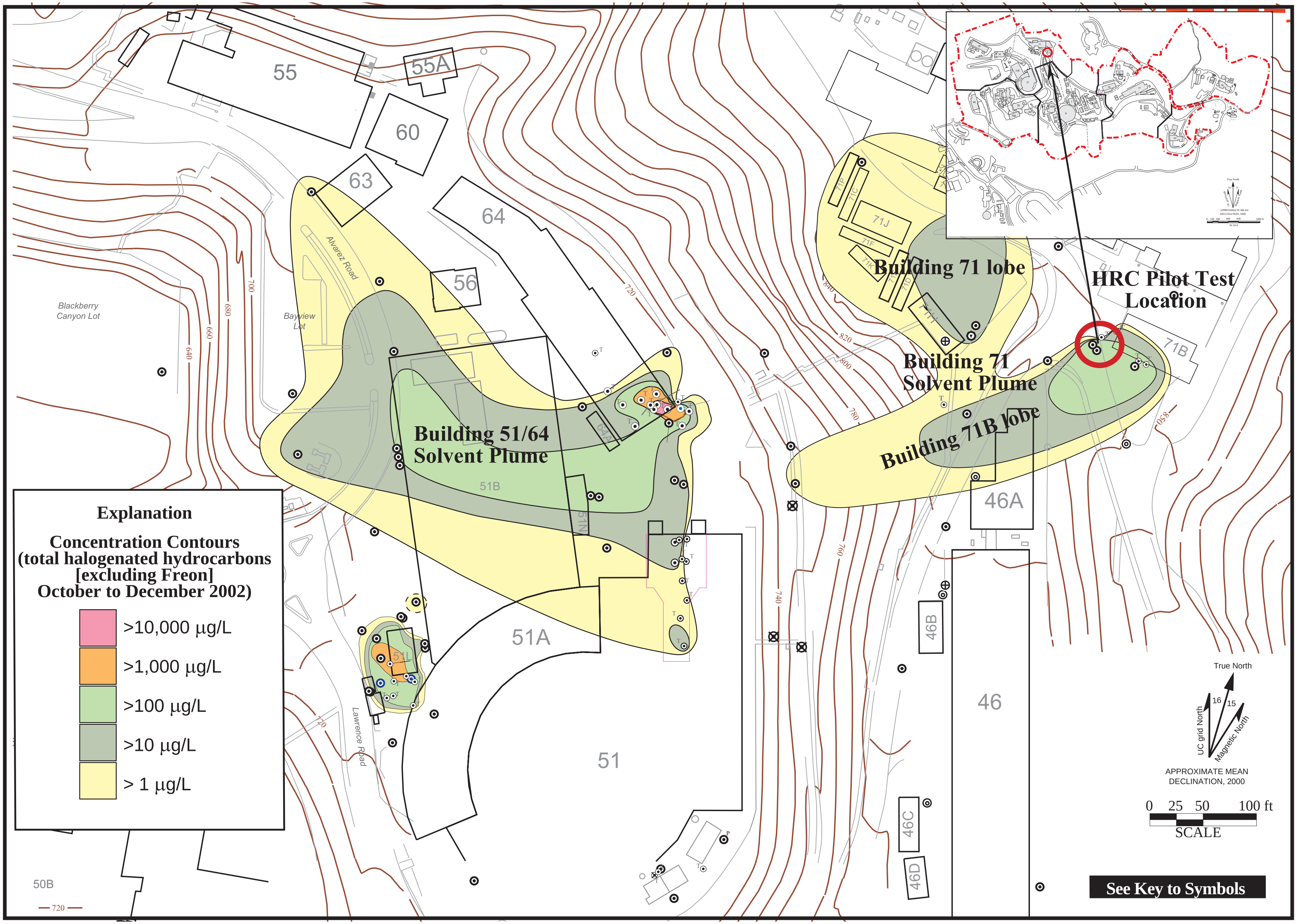

Figure 1. Location of Building 71b HRC Pilot Test.

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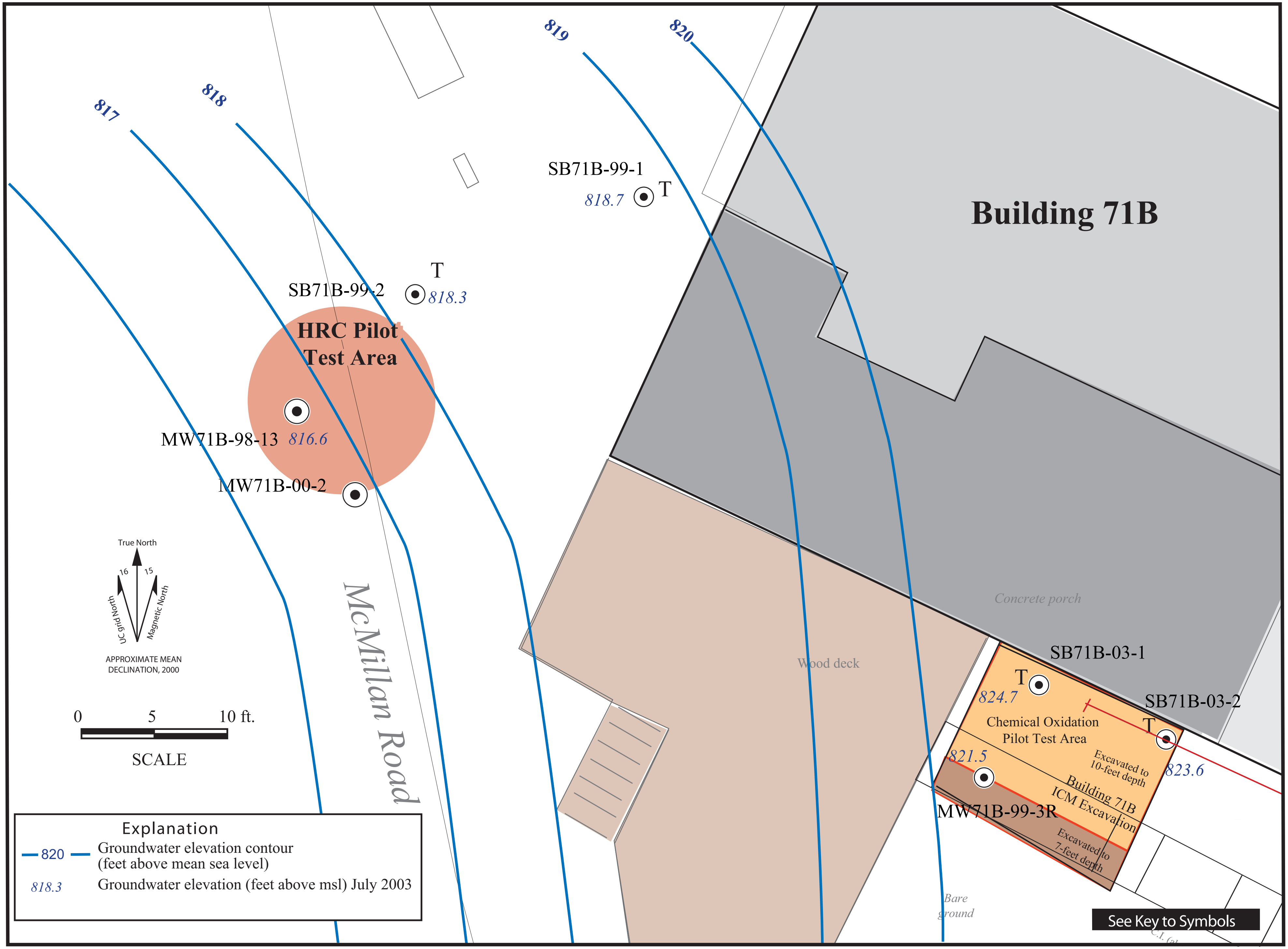

Figure 2. Site Map Building 71b HRC Pilot Test.

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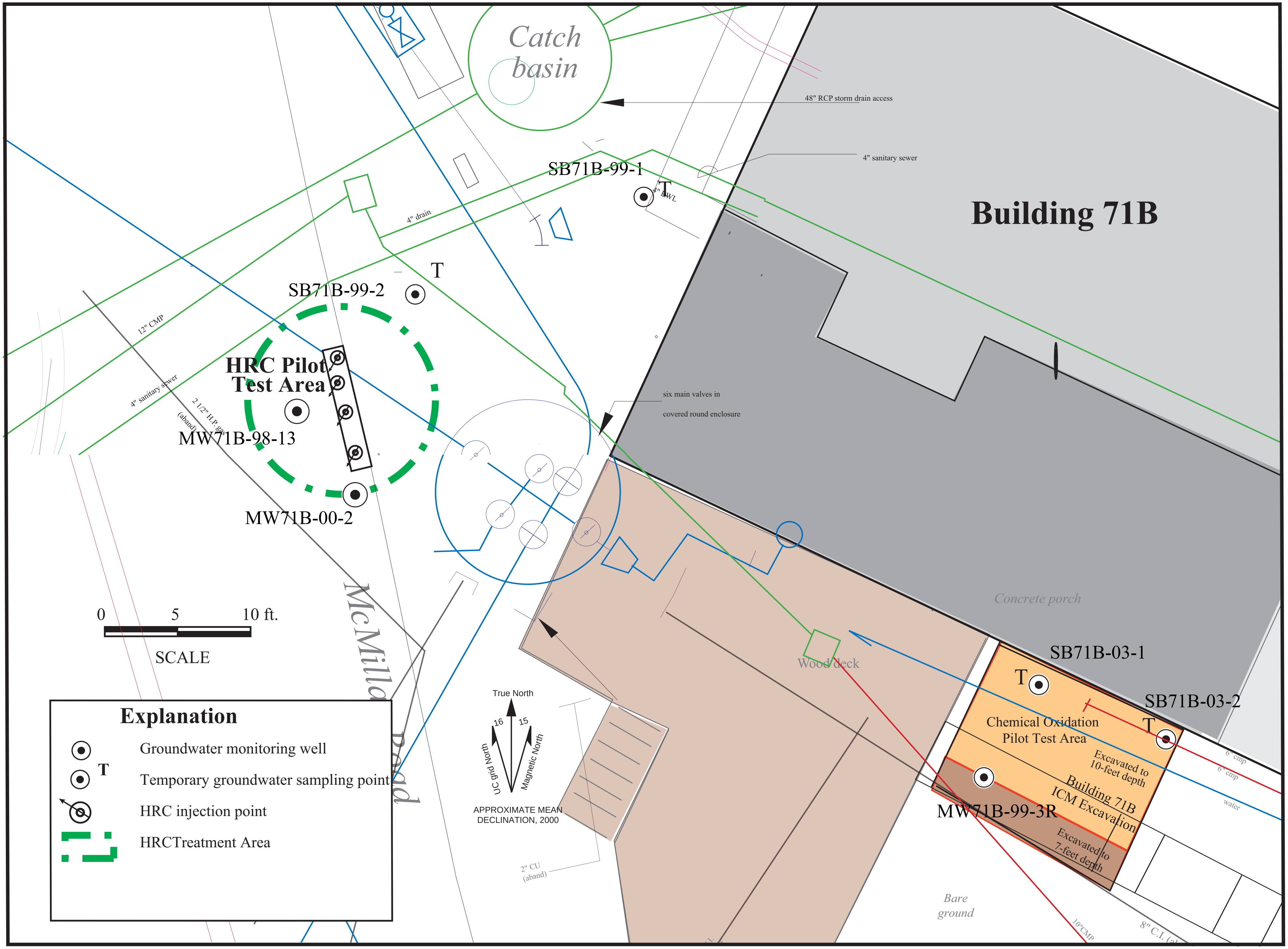

Figure 3. HRC Injection Points.

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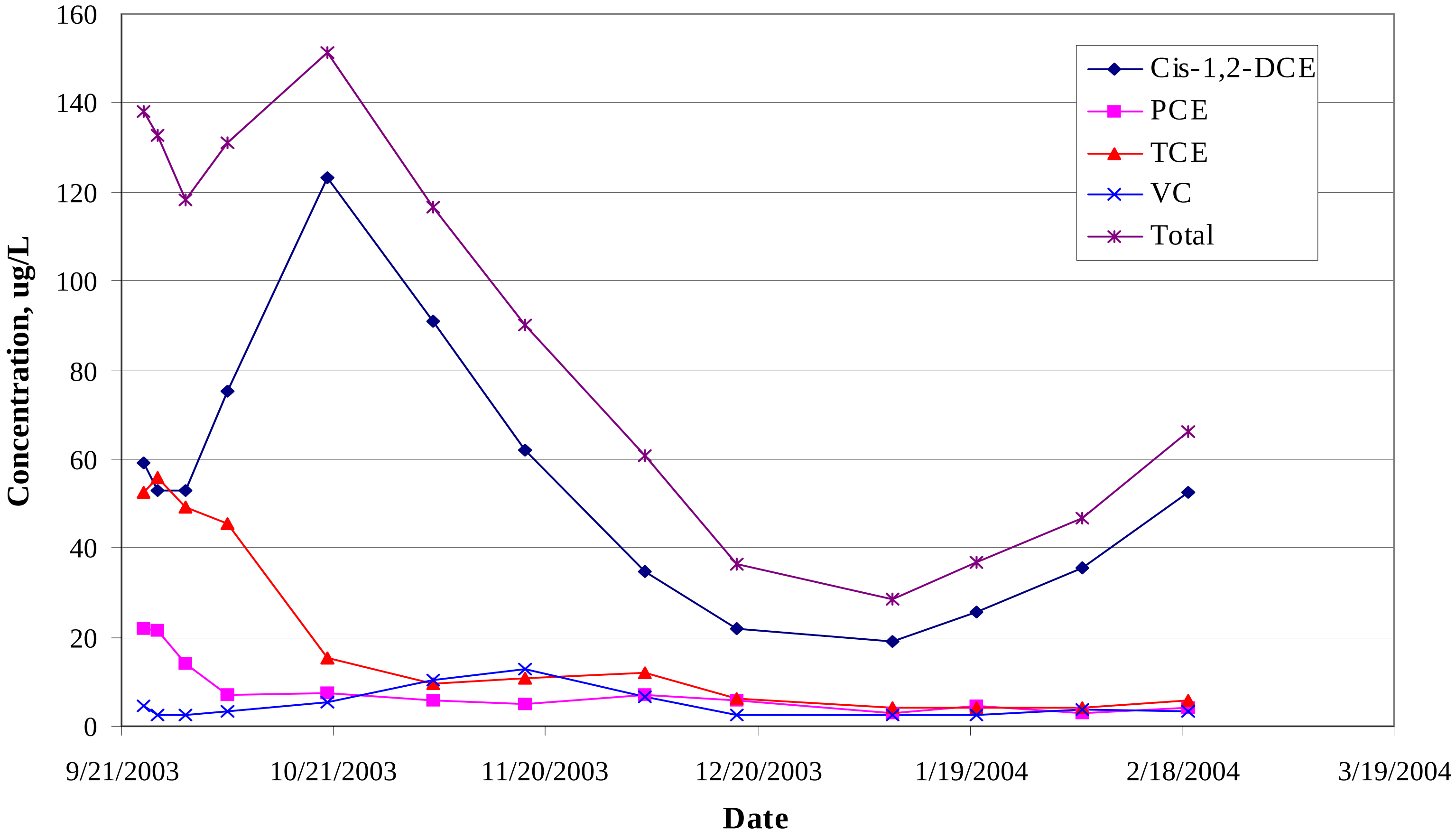

Figure 4. VOC Concentrations in Response to HRC® Injection.

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Table 1. Analytical Results for Electron Acceptors, Metaboloic Byproducts, and Other Indicator Parameters

Analyte	Baseline		4-Dec-03	19-Feb-04	Unit
	MW71b-98-13[a]	SB71b-99-1[b]	MW71b-98-13	MW71b-98-13	
DO	0.3	0.97	0.50	0.50	mg/L
Nitrate as NO_3^-	–	<1.0	<0.88	<0.88	mg/L
Nitrite as NO_2	–	<1.0	0.11	<0.065	mg/L
Total Manganese	–	–	25	44	mg/L
Dissolved Mn	2.4	2.5	–	–	mg/L
Ferrous Iron (Fe^{2+})	4.0 [c]	–	5.2	4.8	mg/L
Sulfate as SO_4^{2-}	17	18	34	5.0	mg/L
Total Sulfide	<0.1	–	<0.1	<0.1	mg/L
Ethene	89	–	3600	2000	ng/L
Ethane	72	–	220	44	ng/L
Methane (CH_4)	53	–	1100	3600	µg/L
Carbon Dioxide (CO_2)	<10	–	<10	<10	mg/L
Alkalinity as $CaCO_3$	240	260	1400	2000	mg/L
TIC (as CaC O_3)	790	–	3400	2700	mg/L
TOC	<5.0	–	7200	2100	mg/L
Hydrogen	0.79	–	20000	36	nM
Acetic Acid	–	<0.070	187	415	mg/L
Butyric Acid	–	<0.070	< 70	5300	
Lactic Acid and HIBA	–	<0.070	1930	860	mg/L
Pentanoic Acid	–	<1.0	109	216	mg/L
Propionic Acid	–	<0.070	870	1370	mg/L
Pyruvic Acid	–	<0.070	3100	< 70	mg/L
Chloride (Cl)	12	11	74	38	mg/L
Total Iron	–	–	25	100	mg/L
Dissolved Iron	0.74	–	–	–	mg/L

[a] Sample was collected on 9/24/03 prior to HRC® injection.

[b] Sample was collected on 9/30/03 from upgradient well SB71b-99-1 after HRC® injection because original baseline sample was broken during transport or exceeded hold time.

[c] Sampled and analyzed for Fe^{2+} on 10/6/03.

"– " Indicates sample was not analyzed for this constituent.

Table 2. Summary of Analytical Results for Volatile Organic Compounds (concentrations in µg/L).

Constituent	MCL	6/25/99	(D)	9/15/99	11/16/99	3/7/00	5/18/00	6/20/00	9/11/00
1,1 Dichloroethene	6	<1	1.1	<1	<1	<1	<1	1.0	
Cis-1,2-Dichloroethene	6	58.0	45.0	47.5	61.1	51.6	65.8	43.0	53.4
Trans-1,2-Dichloroethene	10	<1	0.57	<1	<1	<1	<1	1.5	
Tetrachloroethene	5	146.0	180.0	90.1	112.0	36.1	104.0	210.0	171.9
Trichloroethene	5	86.4	91.0	81.4	79.6	50.4	120.0	100.0	119.3
Vinyl Chloride	0.5	2.6	4.0	3.9	3.7	7.7	3.8	2.9	3.0
Total Halogenated Hydrocarbons		293	322	223	256	146	294	358	347.6

Constituent	MCL	11/29/00	3/19/01	(D)	5/22/01	9/6/01	11/20/01	2/28/02	5/16/02
1,1 Dichloroethene	6	<1	1.1	0.98	<1	<1	1.2	<1	<1
Cis-1,2-Dichloroethene	6	89.2	91.1	71.0	68.0	65.5	46.9	58.7	81.0
Trans-1,2-Dichloroethene	10	<1	<1	1.8	<1	<1	<1	<1	<1
Tetrachloroethene	5	68.8	131.8	120.0	149.7	106.8	102.8	121.9	130.1
Trichloroethene	5	128.4	85.1	77.0	71.8	88.0	68.0	90.5	88.7
Vinyl Chloride	0.5	6.5	5.8	3.4	16.0	5.3	2.8	5.9	5.3
Total Halogenated Hydrocarbons		293	315	274	306	266	222	277	305

Constituent	MCL	9/3/02	2/12/03	8/5/03[b] 11:07	8/7/03[b] 11:07	8/7/03[b] 12:07	8/7/03[b] 15:00	8/8/03[b] 11:00	8/11/03[b] 11:00
1,1 Dichloroethene	6	<1	<1	<1	<1	<1	<1	<1	<1
Cis-1,2-Dichloroethene	6	74.9	63.8	57.3	50.5	55.9	76.7	80.1	84.1
Trans-1,2-Dichloroethene	10	<1	<1	<1	<1	<1	<1	<1	<1
Tetrachloroethene	5	75.3	115.0	143.0	49.1	42.1	39.1	72.8	50.0
Trichloroethene	5	71.0	89.8	78.1	54.7	70.2	79.1	89.0	79.8
Vinyl Chloride	0.5	4.1	5.2	2.9	2.2	2.0	3.6	3.6	4.3
Total Halogenated Hydrocarbons		225.3	274	281.3	156.5	170.2	198.5	245.5	218.2

Table 2. Summary of Analytical Results for Volatile Organic Compounds (concentrations in μg/L) (cont'd.)

Constituent	MCL	9/24/03[a]	9/26/03[a]	9/30/03	10/6/03	10/20/03	11/4/03	11/17/03	12/4/03
1,1 Dichloroethene	6	<1	<1	<1	<1	<1	<1	<1	<1
Cis-1,2-Dichloroethene	6	59	53.1	53	75.2	123	91	61.9	34.6
Trans-1,2-Dichloroethene	10	<1	<1	<1	<1	<1	<1	<1	<1
Tetrachloroethene	5	21.8	21.4	14	7.2	7.6	5.6	4.8	7.2
Trichloroethene	5	52.7	55.7	49	45.4	15.4	9.6	10.6	12
Vinyl Chloride	0.5	4.4	2.5	2.4	3.3	5.3	10.3	12.9	6.8
Total Halogenated Hydrocarbons		137.9	132.7	118.4	131.1	151.3	116.5	90.2	60.6

Constituent	MCL	12/17/03	1/8/04	1/20/04	2/4/04	2/19/04			
1,1 Dichloroethene	6	<1	<1	<1	<1	<1			
Cis-1,2-Dichloroethene	6	22	19.2	25.8	35.6	52.7			
Trans-1,2-Dichloroethene	10	<1	<1	<1	<1	<1			
Tetrachloroethene	5	5.8	2.8	4.6	2.8	4.1			
Trichloroethene	5	6.4	4.1	4.2	4.3	5.9			
Vinyl Chloride	0.5	2.3	2.5	2.3	3.9	3.4			
Total Halogenated Hydrocarbons		36.5	28.6	36.9	46.6	66.1			

[a] Baseline Samples – treatment with HRC® began on 9/26/03 after the 9/26/03 sample was collected.

[b] 8/7 – 8/11/03 samples were collected during pumping well test.

(D) = duplicate sample.

Table 3. Summary for Wellhead Parameters.

Wellhead Parameter	**Baseline 9/24/03**	**9/29/03**	**9/30/03**	**10/1/03**	**10/2/03**	**10/4/03**	**10/6/03**	**10/14/03**	**10/20/03**
DO (mg/L)	0.3	0.37	0.22	0.48	0.22	0.23	0.26	0.31	0.71
Temperature (ºC)	17.4	19.1	16.3	17.9	16.8	15.9	17.8	17.2	17.0
pH	6.01	2.63	5.12	4.92	5.66	5.42	5.47	4.24	5.19
Specific conductance (µmhos)	698	1310	1100	1180	1180	2370	1446	2050	2330
Wellhead Parameter	**10/27/03**	**11/12/03**	**11/17/03**	**12/4/03**	**12/11/03**	**12/17/03**	**1/8/04**	**1/20/04**	**2/4/04**
DO (mg/L)	0.33	0.14	0.33	0.50	0.58	0.53	0.45	0.46	0.45
Temperature (ºC)	22.7	19.5	17.4	14.5	14.1	14.7	16.8	13.9	18.4
pH	4.62	5.05	5.23	4.8	5.36	5.23	5.24	5.26	5.30
Specific conductance (µmhos)	2460	3010	2850	3280	2920	2630	2190	2680	3310
Wellhead Parameter	**2/19/04**								
DO (mg/L)	0.50								
Temperature (ºC)	14.8								
pH	5.34								
Specific conductance (µmhos)	3110								

Table 4. Summary of HRC® Injection

Boring No.	Injection Depth Below Ground Level (ft)	Total HRC® Injected (lbs.)	Comment
1	12-30	80	HRC® returned to surface
2	12-30	110	No return
3	12-30	80	Injection into #3 forced HRC® out of boring #2
4	15-25	30	Injection into #4 forced HRC® out of boring #2
Total HRC Injected (lbs.):		**300**	

Table 5. Analytical Parameters and Trends in Concentrations During Natural Biodegradation.

Analysis	Terminal Electron Accepting Process	Trend in Analyte Concentration During Natural Biodegradation	Possible Concentration in Most Contaminated Zone	Significance
Electron Acceptors and Metabolic Byproducts				
Dissolved Oxygen (DO)	Aerobic Respiration	Decreases	> 0.5 mg/L	Aerobic conditions; suppresses the reductive dechlorination pathway at higher concentration.
			> 1.0 mg/L	Vinyl Chloride may be oxidized aerobically
Nitrate (NO_3^-)	Denitrification	Decreases	< 1.0 mg/L	At higher concentrations, may compete with reductive dechlorination pathways.
Nitrite (NO_2^-)	Denitrification	Increases		Produced as an intermediate byproduct during denitrification.
Manganese (Mn^{2+})	Manganese IV Reduction	Increases	> 1.0 mg/L	Reductive dechlorination pathway possible
Ferrous (II) Iron (Fe^{2+})	Ferric (III) Iron (Fe^{3+}) Reduction	Increases	> 1.0 mg/L	Reductive dechlorination pathway possible
Sulfate (SO_4^{2-})	Sulfate Reduction	Decreases	< 20 mg/L	At higher concentrations, may compete with reductive dechlorination pathways.
Sulfide (H_2S/HS^-)	Sulfate Reduction	Increases	> 1 mg/L	Reductive dechlorination pathway possible
Methane (CH_4)	Methanogenesis	Increases	> 0.5 mg/L	Ultimate reductive daughter produce; vinyl chloride may accumulate.
			< 0.5 mg/L	Vinyl choride may be oxidized aerobically
Other Indicator Parameters				
Alkalinity	All processes listed above	Increases	> 2 times background	Results from interaction of carbon dioxide with aquifer materials.
Carbon Dioxide (CO_2)	All processes listed above	Increases	> 2 times background	Ultimate oxidative daughter product
Chloride (Cl)	Reductive dechlorination or direct oxidation of chlorinated compounds	Increases	> 2 times background	Daughter product of reductive dechlorination pathways.

Table 5. Analytical Parameters and Trends in Concentrations During Natural Biodegradation (cont'd.)

Analysis	Terminal Electron Accepting Process	Trend in Analyte Concentration During Natural Biodegradation	Possible Concentration in Most Contaminated Zone	Significance
***Other Indicator Parameters* (cont'd.)**				
Hydrogen	Denitrication, ferric iron reduction, sulfate reduction	Increases	> 1 nM/L	Reductive pathway possible: vinyl chloride may accumulate.
			< 1 nM/L	Vinyl chloride oxidized.
Oxidation-Reduction Potential (ORP)	All processes listed above	Decreases	< 50 mV	Reductive dechlorination pathway or anaerobic biodegradation possible.
			< -100 mV	Reductive dechlorination pathway likely
pH	—		5 < pH < 9	Optimal range for reductive pathway.
			< 5 or > 9	Outside optimal range for reductive pathway.
Temperature (ºC)	—		> 20ºC	Biochemical process is accelerated.
Total Dissolved Inorganic Carbon (DIC)	—	—	—	Primary end product of aerobic microbial activity – measure of total microbial activity.
Total Organic Carbon (TOC)	—		> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic.
Volatile Fatty Acids	Source of H used in reductive dechlorination	Increases	> 0.1 mg/L	Intermediate products resulting from biodegradation of aromatic compounds; serve as a carbon and energy source.

Appendix A

MW71b98-13 Pumping Well Test

Building 71B Pumping Well Test

A short duration pumping well test was performed at Building 71B to characterize the water-bearing zone penetrated by monitoring well MW71b-98-13. This short report summarizes and interprets the results of hydraulic data, wellhead measurements, and water quality results obtained during the test.

Hydraulic Response

Groundwater was pumped from 98-13, a 2-inch diameter monitoring well that is completed in artificial fill with an open sand-pack interval lying 15 to 30 feet below ground level (bgl). Initial static water levels in 98-13 prior to pumping were 14.14 ft below top of casing (TOC). In comparison, the pre-pumping static water level in adjacent monitoring well MW71B-00-2, completed in the underlying Orinda formation, was 46.05 ft below TOC, which is below the fill. The sand pack for well 00-2 is from 45 to 60 ft. bgl.

A peristaltic pump was used to extract groundwater from monitoring 98-13 starting on 8/7/03 at 11:02 A.M. and ending 4 days later on 8/11/03 at 11:02 A.M. The cumulative volume of water produced from the well was periodically recorded during the test and was used to calculate the pumping rate. The pumping rate did not stabilize during the test (Figure 1), which is typical of low yield formations.

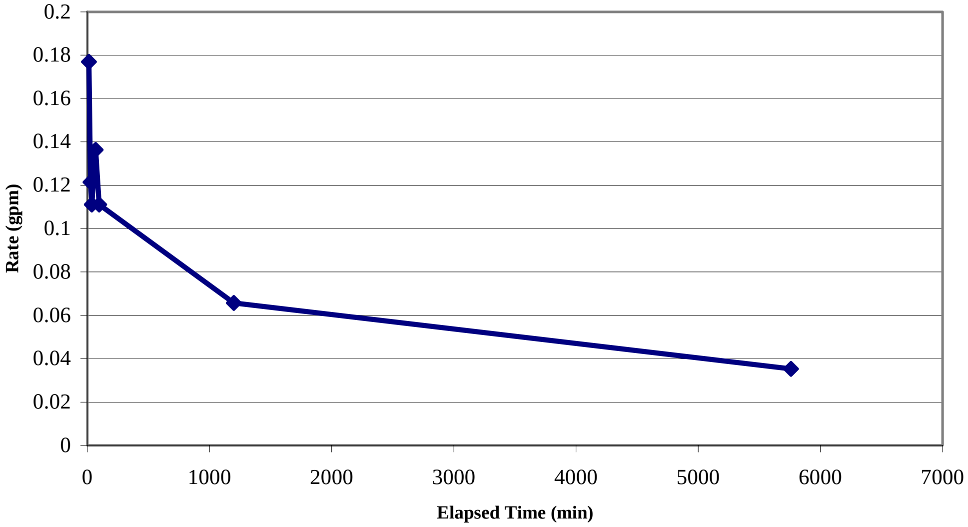


Figure 1. Extraction rate from pumped well MW71b-98-13

Water levels were measured in the pumping well and nearby observation wells 00-2, SB71b-99-1 and SB71b-99-2 using Omega MicroDAQ dataloggers and Druck pressure transducers. Depth to water level measurements were also periodically made by hand using an electric water level tape or probe. Temporary monitoring wells 99-1 and 99-2 are both completed in the fill with sand pack intervals ranging from 13-25 ft. and 8-20 ft. bgl, respectively.

Water level measurements in the pumping and observation wells were converted to hydraulic head elevations above mean sea level (Figure 2). The initial heads measured in monitoring wells 98-13, 99-1, and 99-2 were within 0.5 ft. of each other (818.19 to 818.69 ft.) prior to groundwater extraction. In comparison, the head measured in 00-2 was 32 feet, much lower than the other wells implying the two groups of wells (98-13, 99-1, and 99-2 versus 00-2) represent hydraulic responses from two different water-bearing zones – one zone being in the fill and the other in the Orinda formation. Further evidence leading to this conclusion is established by the fact that the water levels in monitoring wells 99-1 and 99-2 (Figure 3 and 4) decreased in response to pumping 98-13 (Figure 5) as expected, whereas water levels increased in 00-2 (Figure 6) during groundwater extraction. The very large difference in heads exhibited by the two water bearing-zones may also signify that the water in the upper fill layer may be perched.

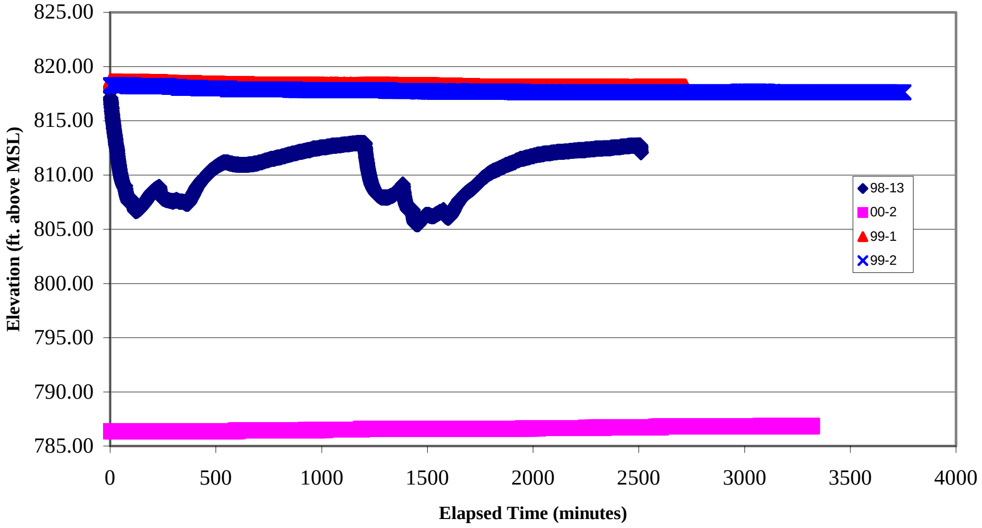


Figure 2. Water elevations in wells from start of pumping

Drawdown responses in the water table caused by pumping (Figure 3 through 5) were examined for obvious trends that would be amenable to evaluation using standard type-curve data matching techniques. However, given that the rates and heads were changing throughout the test (Figure 1 and 2), it was decided that the boundary conditions were not suitable for this type of analysis. In addition, sufficient data were not collected in order for the drawdown curves to developed a unique or distinct shape (i.e., signature typical of a Theis or delayed yield response) before the batteries powering the pressure tranducers drained 2 to 3 days into the test. Instead, a simple first order estimate of the hydraulic conductivity (K) of the fill was calculated using the final pumping rate and heads measured in wells 99-1 and 99-2 and the steady-state solution for an confined aquifer given below:

$$K = \frac{Q}{2b\pi(h_2 - h_1)} \ln \frac{r_2}{r_1} \qquad (1)$$

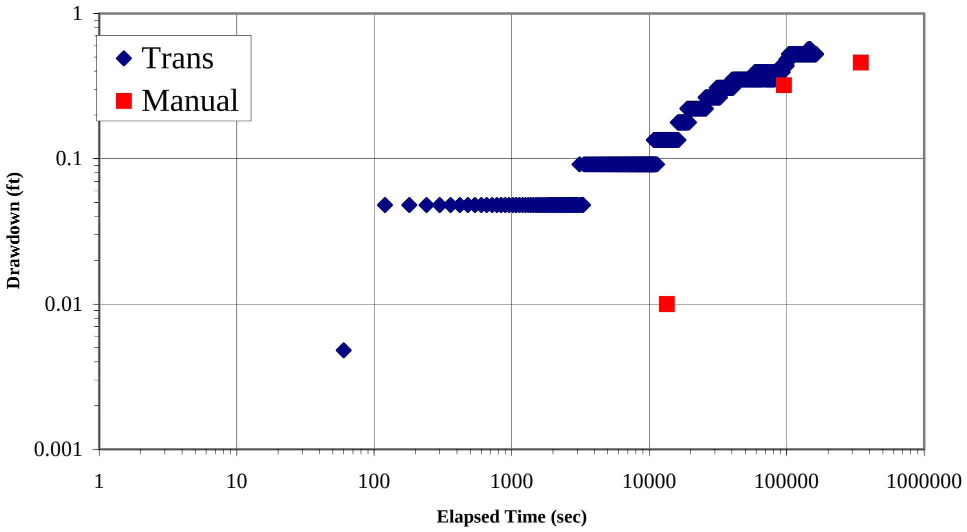


Figure 3. Drawdwon response in monitoring well SB71b-99-1.

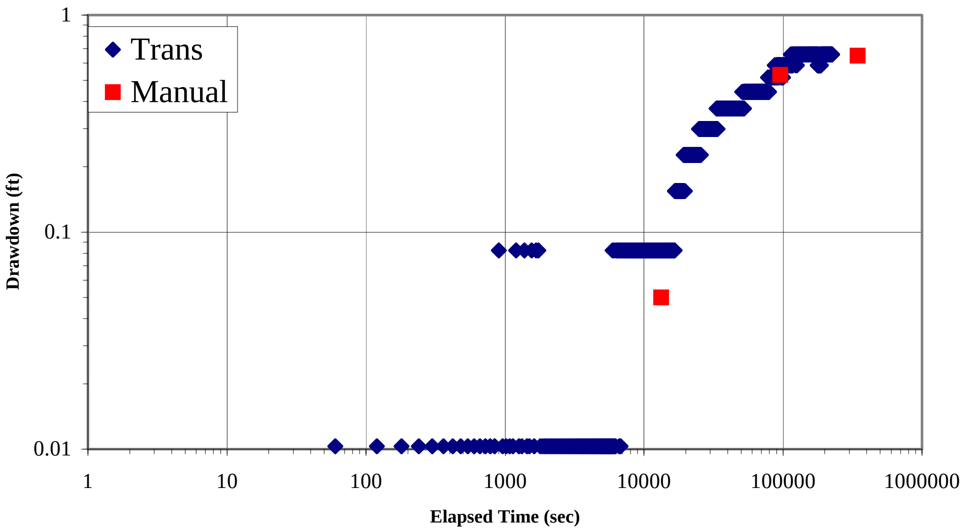


Figure 4. Drawdown response in monitoring well SB71b-99-2.

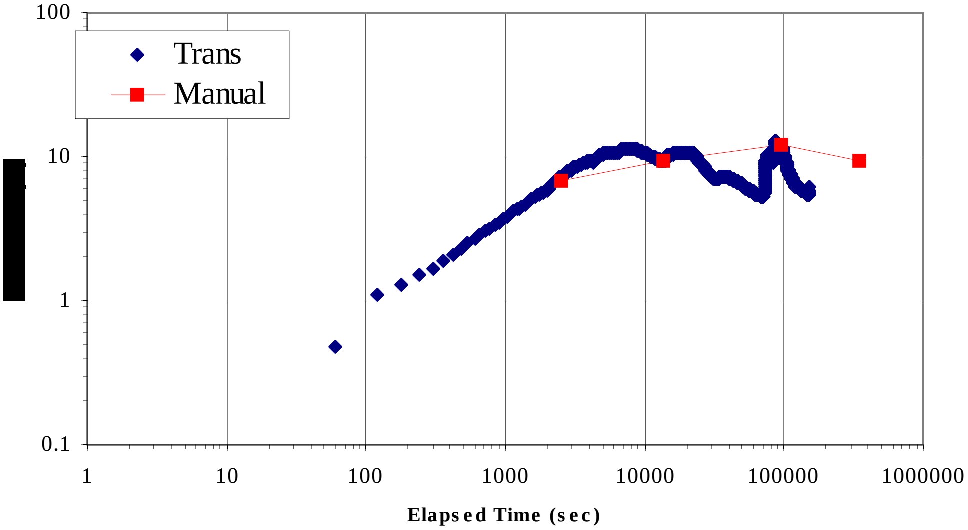


Figure 5. Drawdown response in pumping well MW71b-98-13.

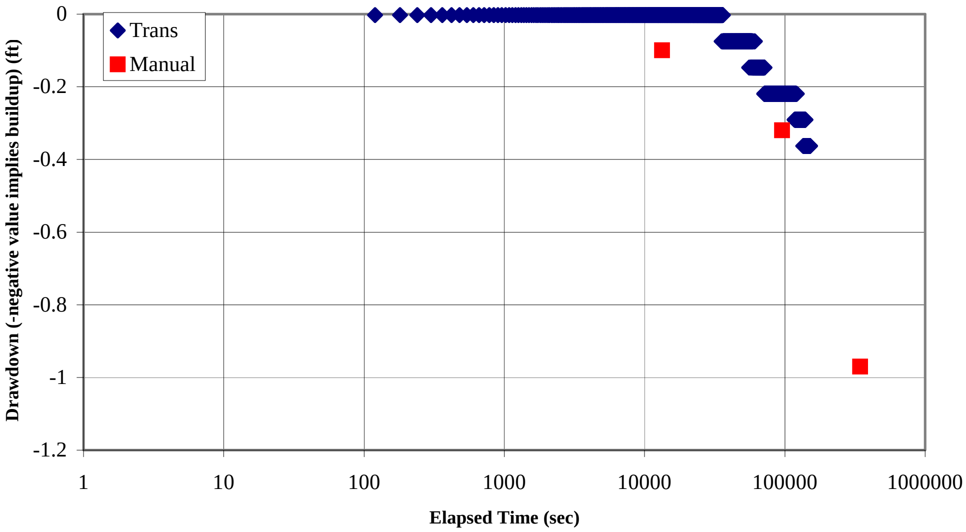


Figure 6. Buildup in well MW71b-00-2 during pumping.

where Q is the volumetric pumping rate (0.0353 gpm), b is the saturated thickness of the confined interval (assumed to be equal the sand-pack interval, i.e., ~12 ft.), r_1 and r_2 are the radial distances from the pumping well to observation well 99-2 (~12 ft.) and 99-1 (~26 ft.), and h_1 and h_2 are the head values at well 99-2 (817.62 ft.) and 99-1 (818.23 ft.), respectively. Using the values observed from the pumping test, K was estimated to be 0.85 gal/day/ft^2 (4.0E-07 m/s), which is within the hydraulic conductivity range for a silty sand (Freeze and Cherry, 1979, Table 2.3).

The derived K-value (i.e., 4.0E-07 m/s) is much smaller than would be expected to affect a drawdown response in the two nearby observation wells. Using an estimate of formation porosity of 20% and a steep hydraulic gradient of 0.1 m/m, the background linear groundwater velocity (without pumping) would only be on the order of 0.02 m (2 cm) per day. This estimate for velocity would only be marginally improved by increasing the gradient due to pumping to 1 m/m. Either the approach used to derive K underestimates its value by 1 to 2 orders of magnitude, implying that the entire sand pack thickness may not be contributing to flow to the well (i.e., preferential flow paths exist), or the porosity is much smaller than 20%. Given the extent and age of the contaminant plume, the contaminant velocity would suggest that the approach used to derive K is the source of error rather than the porosity.

Wellhead Parameters

Wellhead parameters including dissolved oxygen (DO), specific conductance, temperature and pH were measured in groundwater samples periodically collected during the test. A flow-through cell was placed in-line on the discharge line from the well and a calibrated YSI multi-purpose probe was used to measure the wellhead parameters in real time (Figure 7).

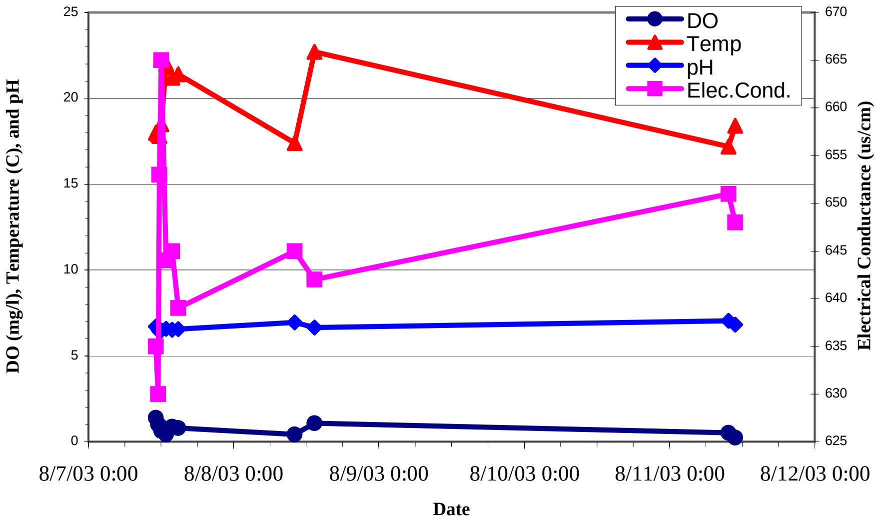


Figure 7. Wellhead parameters including DO, specific conductance, temperature and pH.

The wellhead parameters are normally collected during groundwater sampling events to determine how effective the well purging process is in obtaining groundwater samples from the formation that are representative of true aquifer conditions. The wellhead parameters typically stabilize after stagnant water in the well is purged and replaced by “fresh” groundwater flowing into the well from the formation. The DO and pH were found to be quite stable throughout the entire pumping test (Figure 7, Table 1). The specific conductance stabilized within an hour of the start of pumping and, in general, exhibited a small increase (10-12 µs/cm) thereafter through the end of the test. The groundwater temperature changed by 4 to 5ºC, which is unusual and significant; however, the time of measurement appears to have influence the temperature readings more than any likely variation in temperature attributed to the formation. Note that the large groundwater temperatures (Figure 7, Table 1) occur in the afternoon when ambient air temperatures are also expected to be highest suggesting that the afternoon water temperatures were likely influenced by the heat and corresponding temperature of the test equipment (i.e., discharge line, flow through cell, and probe) used to make the measurement. Comparison of the temperature data collected only in the morning (Table 1) suggests that the temperatures were very stable throughout the pumping test (17.2 to 18.4ºC). Note that the electrical conductance also exhibits an inverse correlation with temperature presumably because the probe is temperature compensated.

Table 1. Wellhead parameters measured during pumping well test.

Date/Time	Dissolved Oxygen (mg/L)	Specific Conductance (µs/cm)	Temperature (ºC)	pH
8/7/2003 11:10:00 AM	1.4	635	18	6.70
8/7/2003 11:30:00 AM	1.0	630	17.9	6.55
8/7/2003 11:45:00 AM	0.95	653	17.8	6.42
8/7/2003 12:02:00 PM	0.63	665	18.5	6.48
8/7/2003 12:50:00 PM	0.42	644	22	6.57
8/7/2003 1:50:00 PM	0.88	645	21.2	6.52
8/7/2003 2:50:00 PM	0.80	639	21.4	6.55
8/8/2003 10:05:00 AM	0.43	645	17.4	6.95
8/8/2003 1:20:00 PM	1.08	642	22.7	6.65
8/11/2003 9:45:00 AM	0.52	651	17.2	7.05
8/11/2003 10:50:00 AM	0.25	648	18.4	6.81

In addition to being a general wellhead parameter, dissolved oxygen is the most thermodynamically favored electron acceptor used by microorganisms for the biodegradation of organic carbon, whether natural or anthropogenic (including some chlorinated aliphatic hydrocarbons [CAHs] of concern at the Building 71b site). Anaerobic bacteria, which favor the reductive dechlorination of CAHs, generally, cannot function at DO concentrations greater than about 1.0 mg/L. The majority of DO concentrations reported in Table 1 are at or below 1.0 mg/L suggesting that reducing conditions probably exist in the water-bearing zone penetrated by well

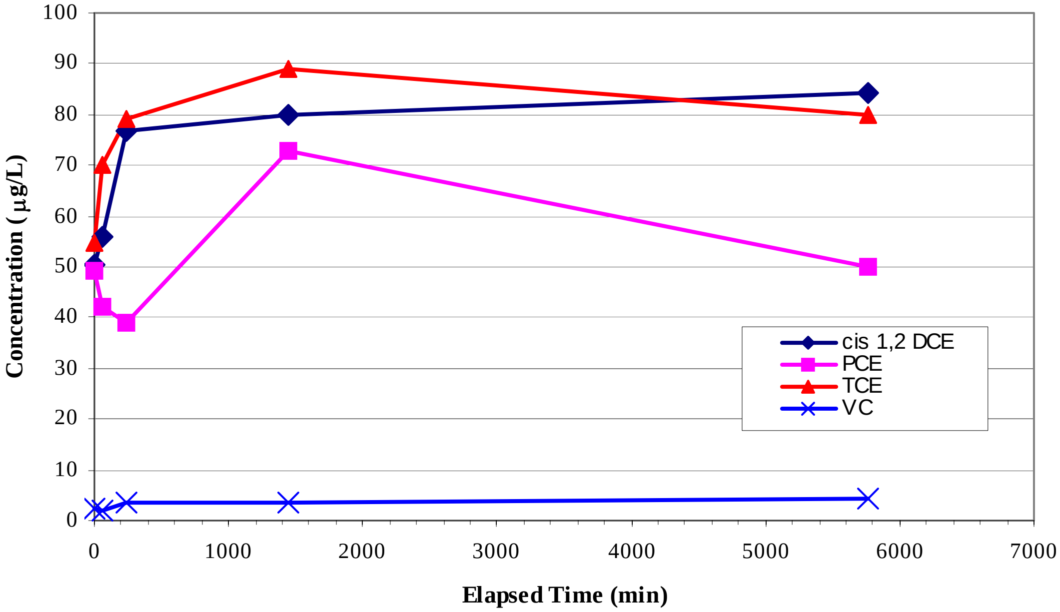
98-13 and that conditions favoring reductive dechlorination of CAHs by anaerobic bacteria potentially exist.

Water Quality Results

Groundwater samples were collected from the discharge water pumped from 98-13 during the test and subsequently analyzed to determine the type and concentration of CAHs present. In addition, samples were taken over time to determine the effect that pumping had on CAH concentrations. Five samples was collected and analyzed for CAHs using USEPA Method 8260B performed by LBNL’s Environmental Measurements Laboratory.

Four volatile organic compounds were detected in the five groundwater samples including cis 1,2-dichloroethene (DCE), trichloroethene (TCE), tetrachloroethene (PCE) and vinyl chloride (Figure 8). Detection of these constituents is consistent with previous sample results. The detection of the parent product TCE and PCE and their degradation by products including DCE and VC is encouraging. These results coupled with the low DO values reported earlier suggests that reductive dechlorination by anaerobic bacteria may be taking place or that, at a minimum, conditions potentially exist that favor these processes.

The CAH concentrations were found to increase with time and then stabilize with the exception of PCE, which showed mixed results (Figure 8). A stable or increasing trend in the concentration levels is favored over a decreasing trend if a pumping well is used to enhance the hydraulic gradient and speed the movement of water and dissolved CAHs through the saturated zone during the pilot test. Hydrogen release compounds (HRC®) will be injected into the water-bearing zone



upgradient from the pumping well during the pilot test to enhance biodegradation and decrease the concentration levels of CAH accordingly. Thus, if a decrease in CAHs levels is observed during the pilot test in direct contradiction to the observations made during this pumping well test, then one can safely assume that HRC® enhanced biodegradation is likely taking place. Had the concentration levels decreased during the pumping well test (because of dilution of contaminated water with fresh water drawn in by the well outside the impacted area) then it would be more difficult to draw a definitive conclusion regarding degradation.

Summary

Data collected during this pumping well test were evaluated and interpreted as follows:

- The drawdown data collected during the test were not of sufficient quality (i.e., constant rate and/or constant head conditions did not materialize during the test) or quantity (i.e., duration) to provide an estimate of formation properties using transient well analysis techniques;
- A initial estimate of the hydraulic conductivity (K) equal to 4.0E-07 m/s was determined from the test data using an analytical solution describing steady flow to a well pumped at a constant rate and fully penetrating a confined aquifer. The estimate for K is believed to be too low given the fact that drawdown occurred in a monitoring well located 26 feet from the pumping well and the estimated linear velocity (determined using K) would not have predicted this observation. This suggests that either the steady-state solution is inappropriate for use or the input parameter values, especially the saturated thickness (b), were not adequately defined. Preferential flow paths through the water-bearing layer to the well would reduce b and increase K producing a more realistic value of K;
- Wellhead parameters including dissolved oxygen, temperature, specific conductance and pH stabilized early during the pumping well test suggesting samples collected and analyzed were representative of *in situ* conditions;
- Dissolved oxygen levels measured in groundwater samples collected from the pumping well were at or below 1 mg/L signifying reducing conditions. Anaerobic bacteria that degrade CAHs by reductive dechlorination favor these conditions;
- Groundwater samples collected during the test and analyzed for CAHs contained PCE and TCE that have been shown in the literature to be degraded by reductive dechlorinators;
- With the exception of PCE, the concentration levels of the four CAHs detected in the groundwater samples increased and/or stabilized during 4 days of pumping. An increase in concentration is preferred over a decrease. This is because the introduction of HRC® during the pilot test is expected to enhance biodegradation and reduce contaminant levels. This trend is opposite of the increase observed during this pumping well test and, therefore, will provide credible evidence that the HRC® is working should a decrease in CAH concentrations be observed during the pilot study.

Recommendation

Preliminary analyses and conditions reported herein favor the use of HRC® to enhance biodegradation at the Building 71b well MW71b-98-13 location. The pilot study should proceed to determine if the application of HRC® enhances biodegradation of CAHs at this site.

E.O. Lawrence Berkeley National Laboratory
University of California
Environmental Restoration Program

United States Department of Energy

BUILDING 71B *IN-SITU* CHEMICAL OXIDATION PILOT TEST

for the

Lawrence Berkeley National Laboratory

Environmental Restoration Program

May 2004

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A Joint Effort of
Environment, Health and Safety Division and
Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

May 2004

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SECTION 1

SUMMARY

During the weeks of June 16th, 2003, and October 13th, 2003, pilot tests of the in-situ chemical oxidation (ISCO) of chlorinated volatile aliphatic hydrocarbons contaminants (VOCs) consisting primarily of tetrachloroethylene (PCE) in groundwater within the soil and Orinda Formation in the vicinity of Building 71B were performed via injection of citric acid and hydrogen peroxide according to the “Workplan for In-Situ Chemical Oxidation Pilot Test” dated May 2003 (“workplan”). The injection events at Building 71B carried out the pilot test design specified in the workplan to the extent possible given the low permeabilities encountered at the site.

The reagents were injected into the medium and deep intervals during both the June and October injection events. The first event entailed injection into 9 wells and the second into 6 wells. In both events, the wells were arranged in a hexagonal array with a 4 to 5-foot spacing. These arrays enclosed three groundwater wells in the first event and two groundwater wells in the second event.

The injection was performed by Rejuvenate under the supervision of personnel from Lawrence Berkeley National Laboratory’s (LBNL’s) Environmental Restoration Program (ERP) and Parsons Engineering. Concentrations and volumes of reagents injected into each group of wells were recorded along with the injection pressures at each well. The effect of the injection was monitored in real time via measurements of pH in the groundwater wells and observations of the seepage patterns.

Injection pressures were successfully limited to avoid hydraulic fracturing with one exception each in the deep and middle intervals. The pH measurements in the groundwater wells indicate that a radius of influence greater than 2 feet was achieved around the injection wells in the deep interval and less than 2 feet around the wells in the middle interval. This resulted from injection of 90% of the acid mass and 40% of the hydrogen peroxide mass specified in the workplan in the deep injection interval, and 41% of the acid mass and 14% of the hydrogen peroxide mass specified in the workplan in the middle interval. Low permeabilities encountered in the pilot test area made it unfeasible to inject larger amounts of reagent in an economically-viable time frame.

The reagent solutions injected would occupy a maximum of 14% and 5% of the total pore volume around each well in the deep and middle intervals, respectively, if all of the reagents flowed away from the injection wells via pore flow. However, a significant portion of the reagent volume injected in the deep interval entered a hydraulic fracture and likely advected to positions outside the target pilot test volume. Nonetheless, the injected volume in the deep interval likely occupied a half of the effective pore volume within the target volume. This was sufficient to achieve the desired radius of influence in the more permeable portions of the subsurface.

The VOC concentration changes in response to the two injection events varied with increases in one groundwater well and no change or decreases in the other two in the week following the injection. Total VOC concentration changes were less than a factor of 2. During the two weeks to two months following the injection events, total VOC concentrations returned to near pre-injection levels typically, particularly when examined on a molar rather than a mass basis.

The most significant concentration changes were increases in the concentrations of trichloroethylene (TCE), cis-1,2 dichloroethylene (cis-1,2 DCE), and/or vinyl chloride (VC) to levels above the pre-test concentrations during the one to two months after each injection event. These changes indicate that some reductive dechlorination process was instantiated by the reagent injection. This may be a biotic process using the citrate as a growth substrate, or an abiotic process of some undetermined type. Given these results, a technology to enhance/instantiate reductive dechlorination is probably more likely than ISCO to successfully remediate the site.

SECTION 2

INTRODUCTION

During the weeks of June 16th, 2003, and October 13th, 2003, personnel from Rejuvenate conducted a pilot test of the *in-situ* chemical oxidation (ISCO) of VOCs in the subsurface adjacent to and beneath the southern side of Building 71B as shown in Figure 1. The objectives of this test, as stated in the workplan, were to determine if ISCO could effectively reduce the contaminant mass in soil and groundwater in the vicinity of Building 71B. This work was performed under the direction of personnel from Parsons Engineering and LBNL's ERP.

As described in the workplan, the pilot test location was selected to focus ISCO in the volume beneath the highest VOC concentrations in soil measured at the time. While the majority of these soils were previously excavated during a source removal interim corrective measure (ICM), VOC concentrations in groundwater beneath this excavation, and time variation of these concentrations, suggested that residual contaminants within the zone of water table fluctuation continued to impact groundwater. Therefore the workplan called for injection of reagents into the upper portion of the saturated zone. Soil sampling during the pilot test indicated that VOC concentrations in soil similar to those excavated during the source removal ICM continue to exist beneath the concrete deck to the north of the source ICM area. Therefore the pilot test area was situated at the edge of an area of significant soil contamination in the unsaturated zone as well as at a location of suspected residual contamination in the zone of seasonal saturation.

The volume selected for ISCO contained a mix of soil and underlying Orinda Formation material. No specification to inject iron was made based upon analysis of the iron content of the colluvium at the site. No analysis of the iron content in the Orinda Formation was carried out however. Prior to the conduct of the pilot test, an iron concentration measured in the groundwater from MW71B-99-3R within the pilot test area was considered with the conclusion that groundwater in this formation likely had sufficient iron to allow for ISCO without the addition of iron.

SECTION 3

HYDROGEOLOGIC BACKGROUND

Estimating the average linear velocity of flow in the pilot test area is useful to interpreting the ISCO results. The gradient between wells MW71B-99-3R, and SB71B-03-1 and -2 varied from a low of 0.19 in September, 2003 (the “dry season”) directed to the south to southwest, to a high of 0.26 in February, 2004 (the “wet season”) directed to the southwest. The water table in September, 2003 was located in the Orinda Formation and the water table in February, 2004 was located in colluvium.

The gradient at the pilot test site is approximately perpendicular to the west to northwest strike of the Orinda Formation in the vicinity of the pilot test. The dip of the Orinda Formation in the vicinity of the pilot test is 30 to 40 degrees to the northeast. Geologic logs in the pilot test area indicate the Orinda Formation consists of interbedded siltstone and sandstone as is typical of this formation at LBNL. The relationship of the gradient to the bedding suggests that the bulk hydraulic conductivity should be the harmonic average of the hydraulic conductivities of the individual strata. However, due to the fluvial deposition of the Orinda Formation, the different lithologies occur in a three-dimensional structure which would likely allow the more conductive lithologies to have a greater influence on the bulk conductivity. Therefore the logarithmic average conductivity, which yields a higher estimate than the harmonic average, will be used to estimate the linear velocities in the pilot test area.

The logarithmic average of the hydraulic conductivities inverted from slug test data collected from wells installed in the Orinda Formation throughout LBNL is $1*10^{-7}$ meters/second (m/s). The log average hydraulic conductivity from wells screened exclusively in fine-grained sandstones and finer-grained rocks is $4*10^{-8}$ m/, and in wells with some exposure to medium-grained sandstones and coarser-grained rocks is $4*10^{-6}$ m/s. This latter group includes approximately one quarter of the wells screened in the Orinda Formation at LBNL.

One of the five logged borings in the pilot test area encountered medium-grained sandstone. Lithologies encountered in the other borings were finer grained. Therefore the ratio of borings at the pilot test area which encountered medium-grained sandstone or coarser lithologies to those borings which did not is approximately the same as that in the entire set of slug-tested wells screened in the Orinda Formation at LBNL. Therefore application of the log average hydraulic conductivity from the entire set of slug test results to the pilot test site is warranted.

The colluvium at the pilot test site consists of clay. The log average hydraulic conductivity from slug tests in wells screened in colluvium at LBNL is $2*10^{-8}$ m/s, which is one-fifth of the log average hydraulic conductivity of the Orinda Formation. The colluvium at these wells screens consists of clay and gravelly clay.

A review of dry density and moisture content measurements on samples from the Orinda Formation recorded on geotechnical bore logs indicates the porosity of the Orinda Formation rocks averages 25%. Numerical modelling of the groundwater flow in the Old Town area of LBNL indicates that the effective porosity of the Orinda Formation is 3% to 5%. This appears to be a reasonable estimate as flow through any porous rock typically occurs primarily through a fraction of the total pore volume, and in the Orinda Formation flow occurs primarily through the coarser-grained rocks, which make up half or less of the total rock mass.

Using the gradients and hydraulic conductivity from above, an effective porosity of 5%, and assuming groundwater flow follows the hydraulic gradient, the average linear velocity in the pilot test area under background conditions is $3.8*10^{-7}$ m/s, or 0.11 feet/day (ft/d), and $5.2*10^{-7}$ m/s, or 0.15 ft/d, at the time of the June and October injection events, respectively.

SECTION 4

JUNE INJECTION EVENT

4.1 SCHEDULE OF ACTIVITIES

On June 12 and 13, 2003, Ofiaro Drilling bored and Rejuvenate installed injection wells SB71B-03-R1 to R9. On June 16th, Rejuvenate connected the well heads and injection lines and commenced injection. Injection in the deepest interval continued on June 17th. On June 18th, the injection wells were raised and the middle and deepest intervals were injected. This work was conducted under the supervision of Parsons Engineering.

4.2 INJECTION WELLS

The June injection was conducted in 9 wells consisting of SB71B-03-R1 through R9. These wells were arranged in a nearly hexagonal grid with a 4 to 5-foot spacing, and surrounded three groundwater wells as shown on Figure 1. The injection wells were installed to depths greater than well screens in SB71B-03-1 and -2 and a depth overlapping with the upper portion of the screened interval in MW71B-99-3R.

The injection wells consisted of ¾-inch internal-diameter, stainless-steel pipe with external threaded couplings. The screen sections consisted of the same pipe with three, approximately 3/16-inch holes drilled at equal angles around the pipe. A set of these holes was drilled at approximately 4-inch intervals along the screen. Chemical resistant rubber packers could variously be attached above the screen or above and below the screen. The outer diameter of the packers was approximately 1.5 inches when deflated. The packers were wrapped around the injection casing and designed to be inflated by the injectate itself via holes drilled through the casing. A typical well configuration is shown on Figure 2.

The injection wells were installed in 3.5-inch diameter open borings advanced to 26 feet below ground surface (bgs) by a portable hydraulic drill rig using continuous flight augers. A 2-inch internal diameter PVC casing was grouted into the upper few feet of each boring. The annulus between the PVC casing and the injection casing was sealed at the top of the PVC casing by a compression fitting in order to minimize exposure to the injectate if a packer failed in the boring during injection.

4.3 INJECTION INTERVALS

On June 16th and 17th, the packers were placed to restrict injection to the interval below 18 feet. On June 18th, the injection wells were raised to restrict injection to the interval below 10 feet.

4.4 INJECTION PRESSURES

Injection pressures were generally 10 psi or less during injection of the both the deep interval and the middle and deep interval. The injection pressure was selected by Rejuvenate.

4.5 REAGENT QUANTITIES INJECTED AND REAL-TIME RESPONSES OBSERVED

Approximately 1,060 gallons of reagent were injected. This consisted of 740 gallons of 11% hydrogen peroxide solution, on average, and 320 gallons of 13% citric acid, on average. Approximately 650 gallons were injected into the deep interval and 410 gallons into the middle and deep interval over the course of three days as listed in Table 1. The total elapsed injection time to the deep interval was 2 hours and 25 minutes, and to the middle and deep interval was 1 hour and 5 minutes. Therefore the average injection rate to the deep interval was 4.5 gallons per minute (gpm), or 0.65 gpm per well, and to the middle and deep interval was 6.3 gpm, or 0.9 gpm per well.

Table 1. Injection Periods During the June Injection Event.

injection			**SB71B-03 wells injected during period**
No.	**period**	**interval**	
1	6/16 afternoon	deep	R2, R3, R4, R5, R6, R7, R9
2	6/17 morning	deep	R2, R3, R4, R5, R6, R7, R9
3	6/17 afternoon	deep	R1, R2, R3, R4, R5, R6, R8
4	6/18 morning	middle and deep	R2, R3, R4, R5, R6, R7, R9
5	6/18 afternoon	middle and deep	R2, R3, R4, R5, R6, R7, R9

Approximately 650 gallons were vacuumed into drums as seepage from the ground surface. The seepage was concentrated at the margins of a low-strength concrete backfill through which several of the injection wells were installed. The backfill was placed in an approximately 10 foot deep source removal excavation in 2000. The pH of the seepage was 3 to 4. Some small quantity of seepage (approximately 20 gallons) in addition to this amount ran down a slope away from the site and may have entered a storm drain catch basin. Monitoring of flow in a nearby downstream catch basin shortly after this event showed neutral pH.

Table 2 lists pH measurements taken from MW71B-99-3R and SB71B-03-1 after some of the injection periods. SB71B-03-2 was dry prior to injection and remained so during injection.

Table 2. Summary of pH Measurements During the June Injection Period.

injection period			**well**	
			MW71B-99-3R	**SB71B-03-1**
No.	**time**	**interval**	**after**	**after**
1	6/16 afternoon	deep		
2	6/17 morning	deep		6.0
3	6/17 afternoon	deep	7.0	6.0
4	6/18 morning	middle and deep		6.0
5	6/18 afternoon	middle and deep		

4.6 PACKER FAILURE

The high ratio of the seepage volume (>670 gallons) to the injectate volume (approximately 1060 gallons), and the spatial distribution of the seepage led to the hypothesis that Rejuvenate's packer system was failing to seal properly against the borehole walls. Such a failure would allow the injectate to occupy the entire well bore and would not be noticed at the ground surface due to the compression fitting at the top of each well. Having occupied the entire well bore, the injectate would enter the least resistive location along the entire borehole wall. It was hypothesized that this location would be the interface between the low-strength concrete backfill and the underlying *in-situ* material.

Review of Rejuvenate's packer system, which had previously been utilized at a number of other non-LBNL sites under the supervision of other consultants, revealed that the inflation of the packers by the pressurized injectate inside the well casing would not be sufficient to inflate the packers against the borehole wall under low flow conditions, such as are likely at the 71B pilot test site due to the low permeabilities of the surrounding hydrogeologic materials. Under low flow conditions, pressures outside the injection screen would tend to match pressures inside the screen due to little head loss across the screen. Due to the material characteristics of the packers, they require pressure inside the packer to exceed the pressure outside the packer by approximately 15 pounds per square inch (psi) to begin inflation. Therefore the packers would not inflate under low-flow conditions.

Based upon this review, Rejuvenate agreed to fabricate packers with a separate pressure line and reinject the site. This was carried out during the October injection event reported on below. The difference in flow rates between the June injection event with the original packer system, and the October injection event with the independently pressurized packers provides further evidence of the failure of Rejuvenate's packer system to properly seal. The June flow rates were 0.65 gpm into a supposed 8-foot long interval and 0.9 gpm into a supposed 16-foot long interval, both at 10 psi. The October flow rates were 0.15 gpm at 10 psi and 0.35 gpm at 20 psi into 5-foot long intervals. If the original packer system had sealed properly, this would imply the October flow rates should have been 0.3 to 0.4 gpm at 10 psi and 0.6 to 0.8 gpm at 20 psi into 5-foot long intervals, or approximately twice the actual flow rates achieved in the October injection event.

After the review of the packer system, Rejuvenate contended that their packer system worked as designed in more permeable settings which allowed higher flow rates. However as the system is based fundamentally upon dynamic pressures developed during injection, there is significant uncertainty whether the head loss across the screen in high-flow conditions would be enough to produce the pressure differential required for this packer system to seal the borehole. Rejuvenate's claim would have to be proven on a site by site basis, perhaps by installing pressure instrumentation outside the injection screen, in order to assure that the injectate pushed in at high flow rates was actually going into the intended formation interval.

4.7 DISCUSSION OF RESULTS

The workplan called for injection of 7.3 kg of citric acid in 9 gallons of solution and 37 kg of hydrogen peroxide in 97 gallons of solution per 5-foot interval for injection wells spaced 5 feet apart. Assuming that the quantity of injectate which was not collected as seepage remained in the subsurface, the average quantities injected in each approximately 22-foot long (the entire well depth less the average thickness of concrete) interval were 7.0 kg of citric acid and 12.2 kg of hydrogen peroxide in 46 gallons of solution. Taking the well spacing as 4.5 feet, 27% of the acid mass, 9% of the hydrogen peroxide mass, and 14% of the total reagent volume specified in the workplan were injected throughout the entire well depth. The pH measurements during the injection event indicate that the maximum radius of influence from the injection wells was less than the typical two-foot minimum distance from an injection to a monitoring well.

The VOCs repeatedly detected in the three wells within the pilot test area consist of PCE, TCE, cis-1,2 DCE, and VC. Of the three wells enclosed in the pilot test area, MW71B-99-3R has the longest concentration history prior to the pilot test. One baseline sample was collected from SB71B-03-1 prior to the test and SB71B-03-2 was dry prior to the test.

The VOC concentrations in MW71B-99-3R during the month after the June injection event were similar to concentrations at this time of year prior to the injection event as shown on Figures 3 and 4. This indicates that on the timescale of the activity of hydrogen peroxide, typically believed to be hours in the subsurface, no significant oxidation of the contaminant mass occurred at the position of this well. Two months after the injection event, the total concentration of VOCs on a mass basis decreased slightly and the VOC ratios changed significantly. The fraction of PCE decreased, and the fraction of cis-1,2 DCE, and to a lesser extent TCE, increased to ratios which have not been measured in this well previously.

The month time-scale of the change in VOC ratios in MW71B-99-3R indicates that a process other than chemical oxidation was induced by the injection. Based upon the change in VOC ratios, it appears that a biotic or abiotic reductive dechlorination process occurred. A biotic process may have been triggered by the presence of citrate, which is an organic compound which potentially could have been utilized as a growth substrate.

No significant changes clearly attributable to the injection of chemical oxidants are observed in the VOC concentrations in SB71B-03-1 as shown on Figure 5. The concentration of PCE immediately after the injection was less than half that prior to the injection, however the concentration of the other VOCs remained approximately constant. After the initial decline following the June injection event, the PCE concentration remained relatively constant for more than two months after the June injection event. From the average linear velocity of 0.11 ft/day, the average distance of groundwater advection during the two months following the June injection event is approximately 7 feet under ambient conditions. As SB71B-03-1 was at the upgradient edge of the injection grid, and the radius of influence was apparently less than 2 feet, the initial PCE concentration decrease and following stabilization is therefore probably due to well equilibration.

After the injection, groundwater was present henceforth in SB71B-03-2. The initial PCE concentration of approximately 900 ug/L after injection decreased to approximately 200 ug/L during the following month and stabilized at this concentration. This is likely due to mobilization of contaminants residing in the vadose zone just north of the well as discussed below in the October injection results section. From the average linear velocity estimate, the average groundwater advection distance following injection is approximately 3 feet. As SB71B-03-2 is also at the upgradient edge of the injection grid, the decrease in concentrations is probably due to advection of injected water contaminated by residual contaminants in the vadose zone away from the well, and advection of relatively cleaner groundwater from upgradient of the injection zone of influence to the well.

SECTION 5

OCTOBER INJECTION EVENT

5.1 SCHEDULE OF ACTIVITIES

On September 16th, Ofiaro Drilling bored and sampled SB71B-03-R10 and R11. Also on this date, injection wells SB71B-03-R1 to R2 were removed and the associated borings examined with a downhole video camera to determine their suitability for reuse in the second injection period. This examination revealed that the borings were filled with slough below 13 feet bgs and therefore were inappropriate for reuse. Therefore Ofiaro Drilling overdrilled SB71B-03-R1 to R4 and subsequently sealed the borings with bentonite chip on September 16th and 18th to prevent vertical migration of injectants during the second injection period. Replacement borings SB71B-03-R12 to R15 were drilled by Ofiaro Drilling on September 18th.

Installation of the injection wells in SB71B-03-R10 to R15 by Rejuvenate on October 7th failed due to significant leakage between the packer line and injection line inside the well heads. The injection well heads were retooled at Rejuvenate's shop and the injection wells were installed into the borings SB71B-03-R10 to R15 on October 14th. The well pattern utilized for the October injection event consisted of SB71B-03-R12 to R15 which were arranged 4 to 5 feet apart in a nearly hexagonal grid enclosing two observation wells, SB71B-03-1 and SB71B-03-2, as shown on Figure 1. Injection in the deep interval occurred on October 15th. On October 16th the injection wells were removed, reconfigured for injection in the middle interval, and reinstalled. The middle interval was injected on October 17th. This work was conducted under the supervision of LBNL's ERP and Parsons Engineering.

5.2 INJECTION WELLS

The October injection was conducted in 6 wells consisting of SB71B-03-R10 to R15. These wells injection wells were arranged in a nearly hexagonal grid with a 4 to 5-foot spacing, and surrounded two groundwater wells as shown on Figure 1. The injection wells were installed to similar depths greater than groundwater wells SB71B-03-1 and -2

The packers utilized during the October injection event utilized packers fabricated by Rejuvenate which were inflated with water independent from the injectate line. The outside diameter of these packers was approximately 2.5 inches. Due to the size of these packers, the near-surface PVC casings installed prior to the June event were not installed in the borings prior to the October event. In other respects the wells were the same as those used in the June injection.

The wells were again installed in 3.5-inch diameter open borings. Borings SB71B-03-R10 and R11 were advanced to 27 feet bgs, while borings SB71B-03-R12 to R15 were advanced to 25 feet bgs. This difference accounted for the difference in ground surface elevation between the borings such that the bases of the borings were at approximately the same elevation.

5.3 INJECTION INTERVALS

Table 3 below lists the injection intervals in each well along with the estimated depth to the base of concrete and top of the Orinda Formation at each well.

Table 3. Geologic Contacts and Injection Intervals.

well name	depths ft)					
	base of concrete	**top of Orinda Formation**	**bottom of hole**	**deep interval**	**middle interval**	**shallow interval†**
SB71B-03-R10	1.5	9.5	27	22-27	11-17*	4-10
SB71B-03-R11	1.5	17	27	22-27	11-19	4-10
SB71B-03-R12	2.5	5	25	20-25	14-19	7-12
SB71B-03-R13	8	9	25	20-25	13-18	9-14
SB71B-03-R14	4	13	25	20-25	12-17	6-11
SB71B-03-R15	2	16	25	20-25	12-17	6-11

*not injected due to packer failure, †not injected due to time constraints

Due to concerns about the inability of the packers to seal against a previously injected borehole wall, the depths of the each interval were selected such that the top of the packer below the screen would inflate against an uninjected section of borehole wall. This decision resulted in an uninjected interval ranging from 1 to 3 feet in length between the intervals. The top of the shallowest interval was selected to minimize interaction of the injectate with the overlying concrete structural slab at R10 and R11 and low-strength backfill at the remainder of the wells). Within these constraints, the boundary between the shallow and middle injection intervals was selected to minimize exposure of more than one hydrogeologic unit within an interval.

Due to the low injection rates, the time scheduled for injection did not allow for injection of all three intervals. Therefore a decision was made not to inject the shallow interval as it was in the unsaturated zone, and the metric of success for this pilot test, according to the workplan, was the concentration of VOCs in groundwater. The middle interval in SB71B-03-R10 could not be injected due to failure of the lower packer during reinstallation of the well. The failure of this packer led to the introduction of 10s of gallons of water into this boring. Water was observed exiting the top of the boring following both attempts to set this well at the middle injection interval and inflate the well.

5.4 INJECTION PRESSURES

Based upon the instability of the hydrogen peroxide, chemical oxidation using this reagent is generally believed to be effective for only a matter of hours after injection. Therefore, advection driven by injection pressure must bring the reagents into contact with the target contaminants to be oxidized within a very short time period. This is unlike more persistent *in-situ* treatment technologies where natural groundwater advection may be relied upon to bring the reagents, or their byproducts, into contact with the target molecules. The above suggests that injection pressures must be controlled carefully to prevent hydraulic fracturing of the formation that would cause the reagents to bypass most of the pore volume containing the target contaminants.

Hydraulic fracturing from vertical wells in the shallow subsurface is generally related the vertical stress in the material around the well, which is typically equal to the overburden pressure. The minimum overburden pressure in each injection interval occurs at the shallowest portion of the interval. Review of dry density and moisture content measurements for engineered fill, colluvium, and the Orinda Formation at other locations at LBNL indicates a total density of 120 pounds per cubic foot (lbs/ft3) is a conservative approximation for the average total density above the water table at the 71B pilot test site. This value equates to a minimum overburden pressure of 17 psi in the deep injection interval and 9 psi in the middle interval. The maximum injection pressures were set to slightly above these values to account for the higher than overburden pressures typically required to initiate a hydraulic fracture. Therefore the maximum target injection pressure for the deep interval was 20 psi and for the shallow interval was 10 psi.

Significant expansion of the packers occurs at approximately 15 psi. This conclusion was based upon discussions with Rejuvenate as well as direct observation of partial inflations of packers laid out on the ground surface. This suggests only the increment of packer pressure above 15 psi is effective at resisting passage of injected reagents. During injection, the target packer pressure was set at 15 psi higher than the maximum target injection pressures, or approximately 35 psi for the deep interval and 25 psi for the shallow interval. With exceptions detailed below, the injection pressures and packer pressures were maintained according to the specifications described above.

5.5 INJECTION INTERVAL PERMEABILITY

The permeability of each interval in each well was qualitatively gauged by injecting acid at equal to or less than the maximum injection pressure for fifteen minutes or until approximately 4 gallons of acid had been injected. The first 2 gallons injected were sufficient to fill the 5 foot-long boring interval with reagent. Fifteen minutes to inject an additional 2 gallons into the formation (equivalent to 0.15 gpm) was selected as it is a lower bound for the economic feasibility of *in-situ* treatment via reagent injection. At this rate, approximately 70% of the reagent volume specified in the workplan could be injected in an 8-hour period.

Injection pressures at the truck manifold and the well head provided secondary confirmation of the permeability around well. A well head pressure less than or equal to the manifold pressure on the same injection line indicated flow to the well (the manifold pressure gauges were typically positioned approximately 14 feet above the well head pressure gauges). A well head pressure less than the maximum injection pressure was also taken as indicating flow to the well. Relative differences in the flow rate to each well during multiwell injection, as measured qualitatively by flow meters on the injection manifold, provided a tertiary confirmation of differences in the permeability around each well.

Based upon data accumulated via the three methods outlined above, approximately half of the injection intervals were sufficiently permeable to accept 2 gallons of reagent within 15 minutes. The deep intervals in SB71B-03-R11, R12, and -R14 passed this test, and the middle interval in SB71B-03-R11 and -R15 passed this test, There was no discernible pattern or cause for which deep injection intervals passed the test. The middle injection intervals which passed the test had the greatest exposure of soil above the Orinda Formation suggesting that the soil at the site is relatively more permeable than the underlying rock, which is the reverse of the application of site-wide slug test results to this site as discussed in Section 2: Hydrogeologic Background.

5.6 REAGENT QUANTITIES INJECTED AND REAL-TIME RESPONSES OBSERVED

Approximately 256 gallons of reagent were injected. No seepage from the ground surface, the top of the injection wells (no compression fitting was present on the wells during this event), or surrounding injection wells was observed during injection, except as described below. These observations confirmed that the independently pressure-controlled packers, in combination with the specified pressure differential, were successful at restricting injection to the intended interval.

The reagents injected consisted of 102 gallons of 12% citric acid, on average, and 154 gallons of 17% hydrogen peroxide solution, on average. Of these totals, 70 gallons of citric acid and 115 gallons of hydrogen peroxide were injected in the deep interval and the remainder was injected in the middle interval. The total elapsed injection times for the deep and middle interval were 3 hours and 2 hours 35 minutes, respectively. Therefore the average injection rate to three wells at a time (the maximum number injected at once) in the deep interval was 1 gpm, or 0.35 gpm per well. The average injection rate to three wells at a time in the middle interval was 0.45 gpm, or 0.15 gpm per well.

During deep interval injection of hydrogen peroxide, the pressure in SB71B-03-R14 spiked, apparently due to offgassing from reactions in the boring. Following this pressure spike, the pressure dropped below pre-spike levels, the flow rate increased, turbid water was observed in SB71B-03-1, and seepage and offgassing were observed at the ground surface and from SB71B-03-R7 and –R8 to the south. All of these observations are consistent with the development of a hydraulic fracture. Injection to this well was subsequently shut off. Largely as a result of the hydraulic fracture, the majority of the reagents injected in the deep interval were injected in the SB71B-R11, R14 and R15 triangle of wells.

Due to the low injection rate in the middle interval of SB71B-03-R12 and R13, it was decided to initiate hydraulic fractures from SB71B-03-R12 toward the end of the injection event in order to maximize the opportunity for reagents to enter the formation. The injection pressure was increased to 20 psi and subsequent observations indicated a fracture was initiated.

Table 4 lists pH measurements taken from MW71B-99-3R and SB71B-03-1 before, during and after some of the injection periods.

Table 4. Summary of pH Measurements During the October Injection Period.

injection period			**well**						
			MW71B-99-3R		**SB71B-03-1**			**SB71B-03-2**	
No.	**time**	**interval**	**before**	**after**	**before**	**during**	**after**	**before**	**after**
1	10/15 morning	deep	7.0		7.0			7.0	4.5
2	10/15 afternoon	deep				5.5, 4.5, 6.0			
3	10/17 afternoon	middle	6.0	6.0	6.0		6.0	7.0	7.0

5.7 DISCUSSION OF RESULTS

The workplan called for injection of 7.3 kg of citric acid in 9 gallons of solution and 37 kg of hydrogen peroxide in 97 gallons of solution per 5-foot interval for injection wells spaced 5 feet apart. The average quantities injected in each, 5-foot long deep interval were 5.3 kg of citric acid in 12 gallons of solution and 12.3 kg of hydrogen peroxide in 19 gallons of solution. Taking the well spacing as 4.5 feet, 90% of the acid mass, 40% of the hydrogen peroxide mass, and 36% of the volume specified in the workplan were injected. The average quantities injected in each, 5-foot long (on average) middle interval were 2.4 kg of citric acid in 6 gallons of solution and 4.2 kg of hydrogen peroxide in 8 gallons of solution. Taking the well spacing as 4.5 feet, 41% of the acid mass, 14% of the hydrogen peroxide mass, and 16% of the total volume specified in the workplan were injected. As previously described, however, the distribution of these reagents is highly non-uniform due to differences in permeability between the wells, and hydraulic fracturing of the interval in some wells. These totals do not account for losses due to seepage, which comprised only a small fraction of the total volume of reagents injected during the October injection event.

The pH measurements during the injection event indicate that the maximum radius of influence from the injection wells was more than the two-foot minimum distance from an injection to a monitoring well during the deep interval injection, and less than the two-foot minimum distance from an injection to a monitoring well during the middle interval injection. A small reduction in pH in MW71B-99-3R from prior to after injection indicates that reagents reached this well suggesting an overall radius of injection influence of greater than 6 feet. However, seepage from injection wells SB71B-03-R7 and R8 during the hydraulic fracturing of SB71B-03-R14 indicates reagents probably reached MW71B-99-3R through the hydraulic fracture.

Analysis of dry densities of engineered fill, colluvium, and the Orinda Formation from other sites at LBNL indicates the porosity of the soils as approximately 38% and of the Orinda Formation as 25%. Based upon this porosity, the void space in the 2.5-foot radius cylinder around each 5-foot long injection interval in the soil and the Orinda Formation is 26 and 37 cubic feet for the deep and middle intervals, respectively. Therefore the reagent solution volumes injected are 14% and 5% of the total pore volumes for the deep and middle intervals, respectively. Note that due to hydraulic fracturing, some of the reagents did not flow away from the injection wells via pore flow, however, and so the actual fraction of the pore volume occupied by reagents within the target volume is somewhat less. Nonetheless comparison of the reagent volumes to the pH observations suggest the radius of influence was due to flow through pathways which were more permeable than the average, and which occupied perhaps a half of the total volume if the effective porosity is taken as approximately a quarter of the total porosity.

The hydraulic heterogeneity at the site indicated above by comparison of the pH responses to the reagent volumes injected is further confirmed by consideration of the injection flow rates. Half of the injection intervals were unable to accept a flow rate of 0.15 gpm or greater during the single well injections, yet the average flow rates were 0.35 gpm and 0.15 gpm per well in the deep and middle interval, respectively. Therefore the variation in flow rate to the deep interval must have been at least a factor of 3 from the minimum flow rate to the maximum flow rate.

The total VOC concentrations in MW71B-99-3R decreased significantly the day after the pilot test as shown in Figure 4, and the concentrations of individual VOCs decreased in proportion to the total decrease. The total concentration rebounded significantly in the following sample collected three days later. If the total concentration decline had been due to oxidation of a significant portion of the contaminant mass between the injection wells and this monitoring well, the reduction should have persisted for a length of time suggested by the linear velocity and the flow direction. As the injection wells were 6 to 10 feet upgradient from MW71B-99-3R, the post-injection average linear velocity of 0.15 ft/day suggests the concentration reductions due to oxidation should have persisted for a month or more. The much shorter duration of the concentration decrease indicates the decrease is more likely indicative of dilution of groundwater in the well by reagents flowing along a preferential flow path. This path probably consists of the hydraulic fracture which developed during injection in the deep interval in SB71B-03-R14 and propagated into the region around MW71B-99-3R as evidenced by offgassing and seepage at SB71B-03-R7 and –R8 to either side of the monitoring well during injection. Surprisingly, a similar total concentration decrease due to dilution by reagent intrusion was not observed in SB71B-03-1 after hydraulic fracturing at SB71B-03-R14 despite a turbidity spike in this well. This may be because the sample was taken after completion of all injection activities, including the injection of the middle interval near this well.

During the week after the injection, the concentration of TCE and cis-1,2 DCE rebounded to the upper limit of the pre-injection concentration range and the concentration of PCE remained below pre-injection concentrations in MW71B-99-3R. In the month to month and a half after the injection, the concentrations of cis-1,2 DCE and VC increased to levels in excess of pre-injection concentrations, the concentration of TCE decreased to the lower limit of the pre-injection concentration range, and the concentration of PCE decreased further. On a mass basis (milligrams/litre), the total VOC concentration during this period decreased by approximately one quarter as compared to the total concentrations during the same month in previous years as shown on Figure 4. However, the total concentration on a molar basis (mols/liter) remained the same or slightly above previous years, as shown on Figure 7, indicating that none of the contaminant mass was completely oxidized.

The total VOC concentration in SB71B-03-1 decreased by approximately 40% in the week after the injection as shown on Figure 5. The concentration of each individual VOC decreased as well with the concentration of cis-1,2 DCE decreasing the most and the concentration of PCE decreasing the least. Within two to three weeks after the injection, the total VOC concentration rebounded to 90% of pre-injection levels with the ratio of cis-1,2 DCE to PCE significantly increased. Within four weeks, the total VOC concentration rebounded fully. Significant precipitation did not commence until mid-December, so using the dry season average linear velocity of 0.11 ft/d, the total average advection distance under ambient conditions would have been 2.3 feet in the three weeks after the injection. The actual advection distance would have been somewhat less due to dissipation of the injection pressures. As SB71B-03-1 is centered on the downgradient side of an injection well triangle approximately 4 feet across, and there was some radius of influence around this triangle, the time to rebound is significantly shorter than would be commensurate with uniform oxidation of the contaminant within the cylindrical volume around each injection well. Therefore the time to rebound likely reflects advection and diffusion of untreated groundwater from lower permeability zones not accessed by reagents within the treatment area.

The total VOC concentration in SB71B-03-1 increased by more than 50% in the week after the injection with relative increases in PCE and TCE as shown in Figure 6. This was likely due to mobilization of contaminant from the area north of the well where high concentrations of VOCs were measured in the soil above 10 feet bgs in SB71B-03-R10 prior to the ISCO test. Contaminants from this depth were probably mobilized by water introduced into this boring due to packer failures. Within two months after the injection the total VOC concentration declined to 25% greater than pre-injection levels with a significant increase in cis-1,2 DCE and TCE relative to PCE.

Groundwater from all of the sites had increases in the concentration of cis-1,2 DCE, and MW71B-99-3R also had an increase in VC, indicating again that injection of the chemical oxidation reagents likely initiated a reductive dechlorination process.

SECTION 6

CONCLUSIONS

The workplan was followed to the extent practicable and economical given the low permeabilities encountered at the Building 71B pilot test site. No concentration changes measured in the three wells monitoring the June injection event are apparently due to chemical oxidation. The concentration changes in SB71B-03-1 after the October injection event are apparently due to chemical oxidation. The magnitude of the VOC concentration decrease (40%) and the time to full concentration rebound relative to that predicted under ambient groundwater flow conditions (0.5 month versus 2 to 3 months) indicates the injection was not able to overcome the significant heterogeneity which exists in the Orinda Formation. The concentration increase in SB71B-03-2 after the October injection event is apparently due to mobilization of VOC contaminants residing in the vadose zone to the north.

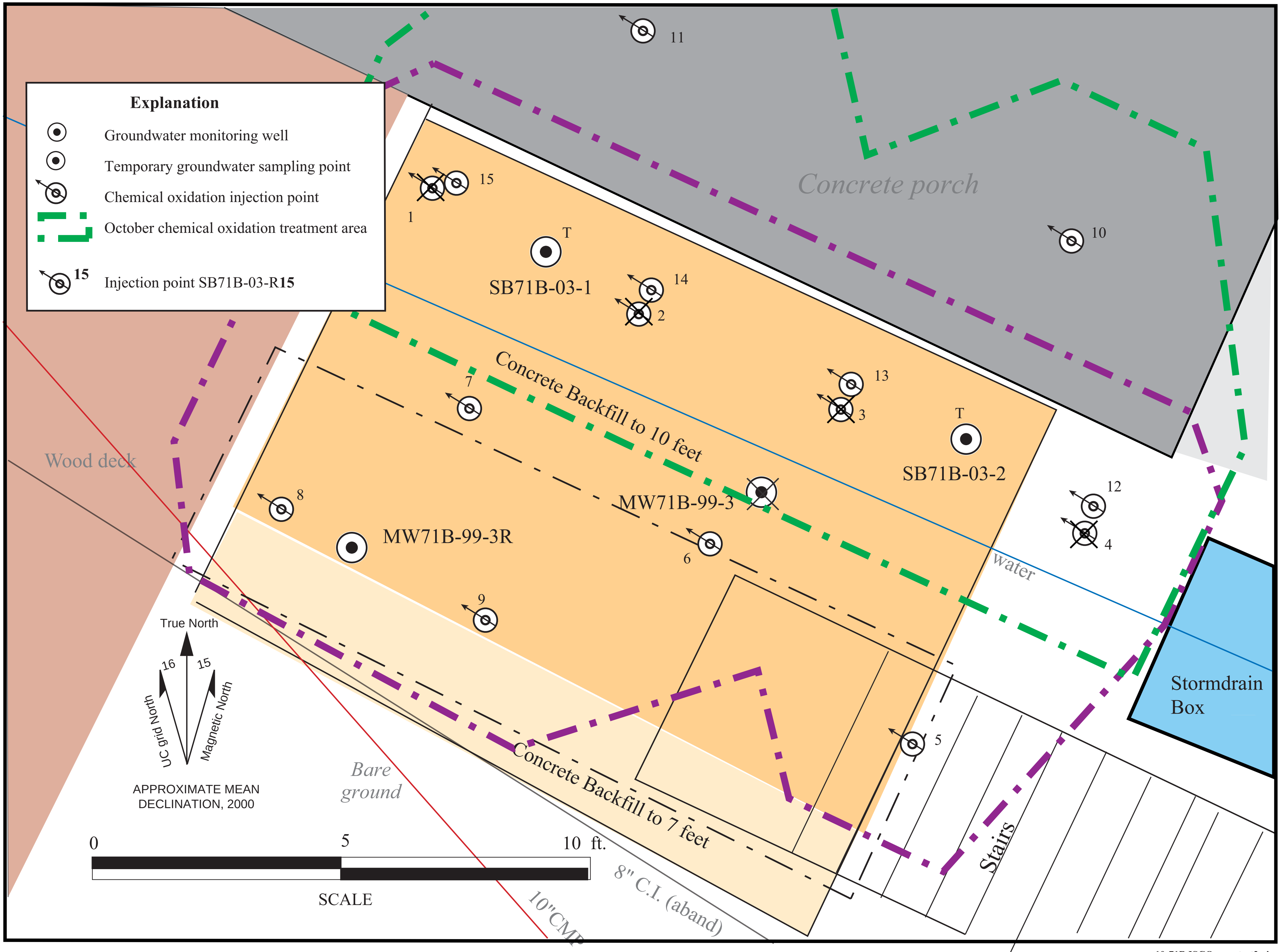
Based upon these results, full-scale ISCO implemented with the technology used for the pilot test would likely not be successful at permanently lowering VOC concentrations to the likely regulatory limits for the LBNL site. It is likely that ISCO implemented using a technology which allowed for narrower injection intervals, such as sleeve-port injection, would overcome the heterogeneity at the site. This would be predicated upon remediation of the contaminants in the vadose zone to the north of the pilot test area. Remediation of this zone could be by excavation, or some in-situ technology such as chemical oxidation. The pilot test reported on in this document does not provide any data regarding the effectiveness of ISCO to remediate contaminants in the vadose zone.

The observed concentration changes (increased concentrations of less chlorinated relative to more chlorinated compounds) suggest that ISCO as implemented in this pilot test fomented reductive dechlorination. The results from MW71B-99-3R indicate this most clearly as shown on Figure 7 by the decline in the average number of chlorine atoms per VOC molecule from nearly 4 (PCE dominant) prior to the June injection event to 2 (DCE dominant) a month after the October injection event.

One hypothesis is that the injected citrate was utilized as a growth substrate by the endogynous microbial community. However, this is an unexpected result as the degradation of hydrogen peroxide would possibly sterilize the injection area as well as elevate the dissolved oxygen concentrations in the subsurface, neither of which is conducive to reductive chlorination. Unfortunately, measurements of dissolved oxygen and the concentrations of different dissolved iron and manganese cations are not available to further analyze this hypothesis.

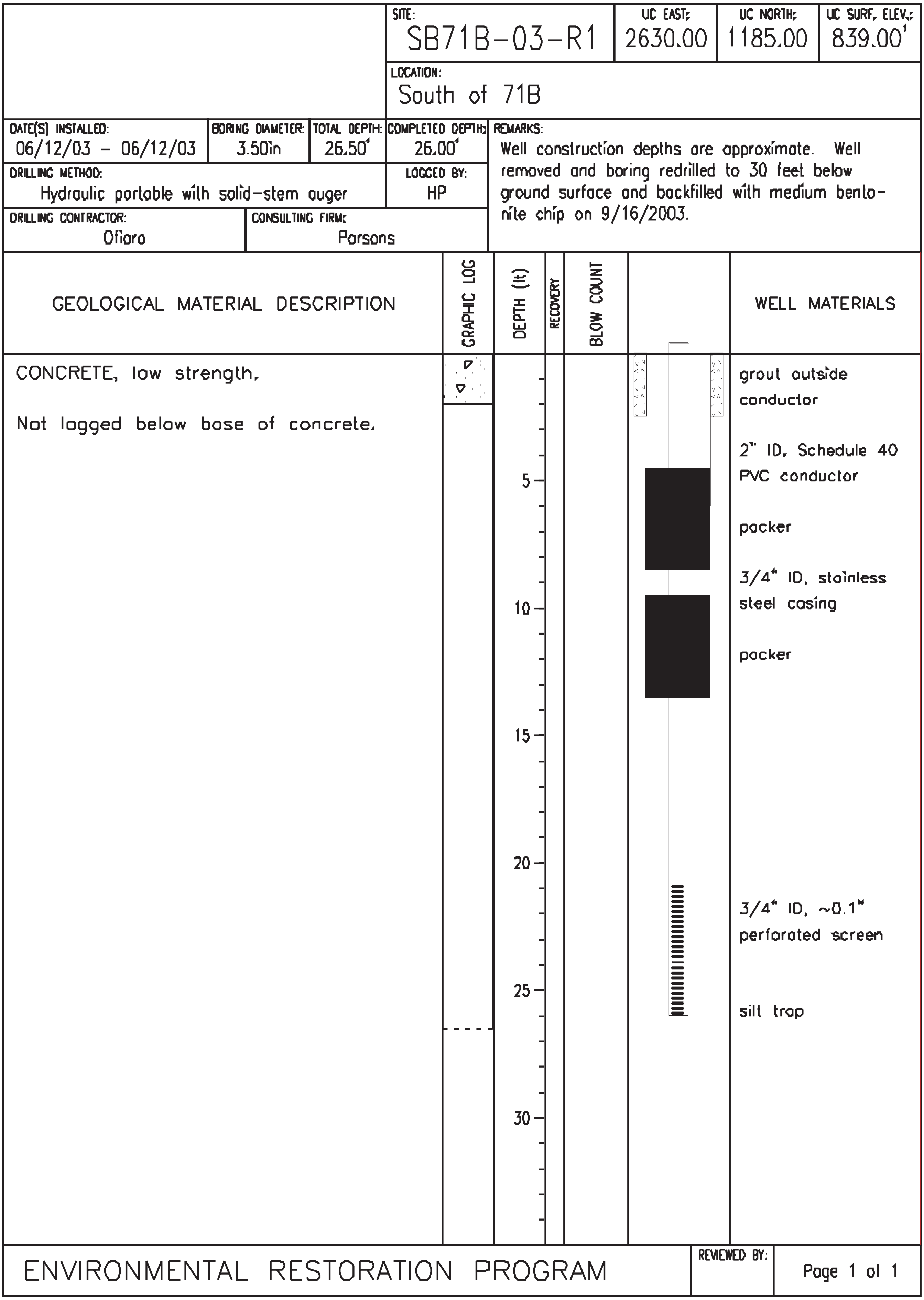
The apparent occurrence of reductive dechlorination following the ISCO injection suggests that a remedial technique designed to enhance reductive dechlorination would be a successful alternative to ISCO at the subject site.

LIST OF FIGURES



10-71B ISCO map test2.ai
10/03

Figure 1 . Locations of in-situ chemical oxidation injection points (Sept. 2003) and temporary groundwater sampling points SB71B-03-1 and SB71B-03-2.



	SITE: SB71B-03-R1	UC EAST: 2630.00	UC NORTH: 1185.00	UC SURF. ELEV.: 839.00'
	LOCATION: South of 71B			

DATE(S) INSTALLED: 06/12/03 - 06/12/03	BORING DIAMETER: 3.50in	TOTAL DEPTH: 26.50'	COMPLETED DEPTH: 26.00'	REMARKS: Well construction depths are approximate. Well removed and boring redrilled to 30 feet below ground surface and backfilled with medium bentonite chip on 9/16/2003.
DRILLING METHOD: Hydraulic portable with solid-stem auger			LOGGED BY: HP	
DRILLING CONTRACTOR: Ofiara	CONSULTING FIRM: Parsons			

GEOLOGICAL MATERIAL DESCRIPTION	GRAPHIC LOG	DEPTH (ft)	RECOVERY	BLOW COUNT		WELL MATERIALS
CONCRETE, low strength. Not logged below base of concrete.						grout outside conductor 2" ID, Schedule 40 PVC conductor packer 3/4" ID, stainless steel casing packer 3/4" ID, ~0.1" perforated screen silt trap

ENVIRONMENTAL RESTORATION PROGRAM

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Figure 2. Typical injection well log .

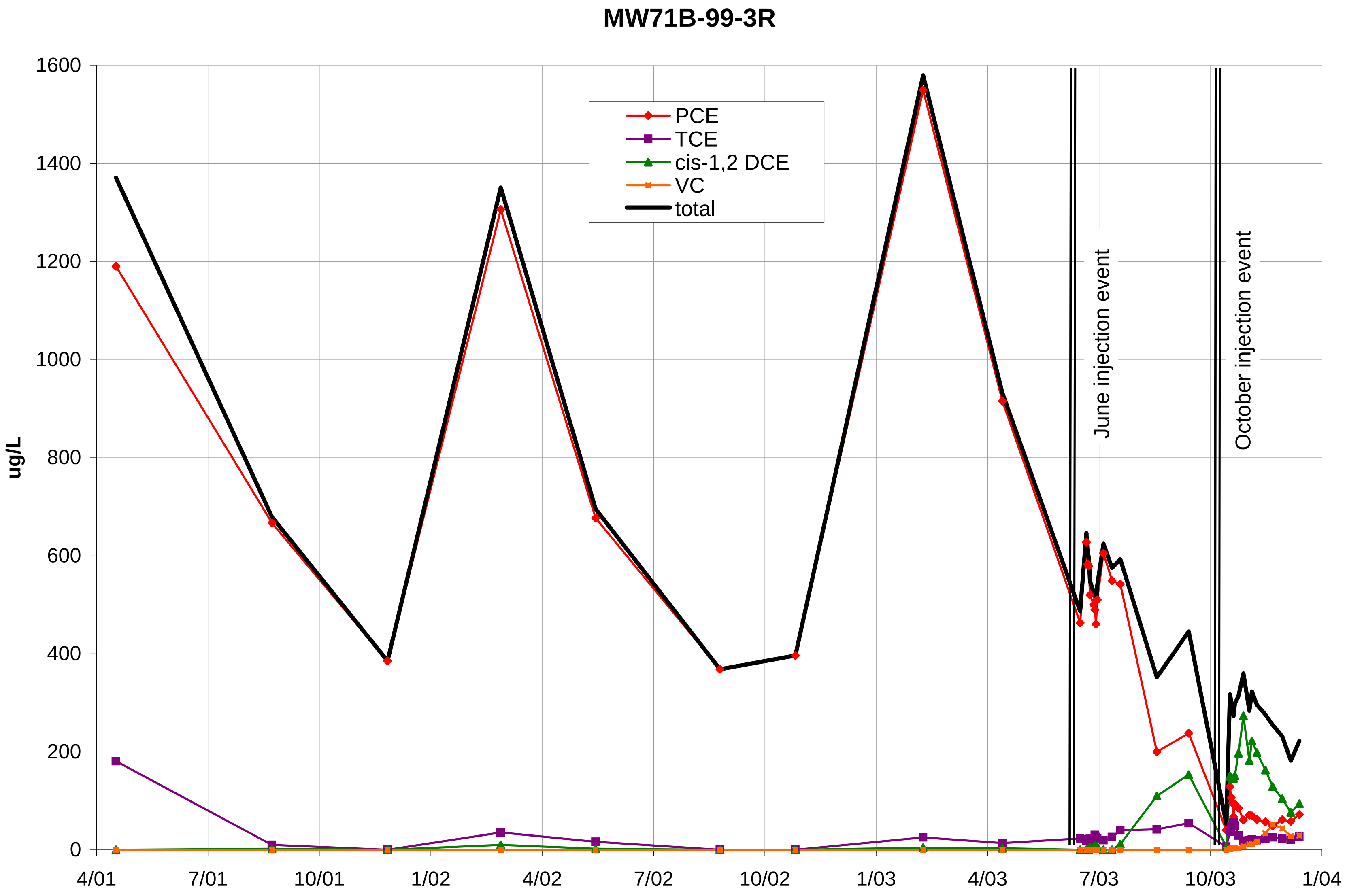

Figure 3. Long-term VOC concentration changes in MW71B-99-3R.

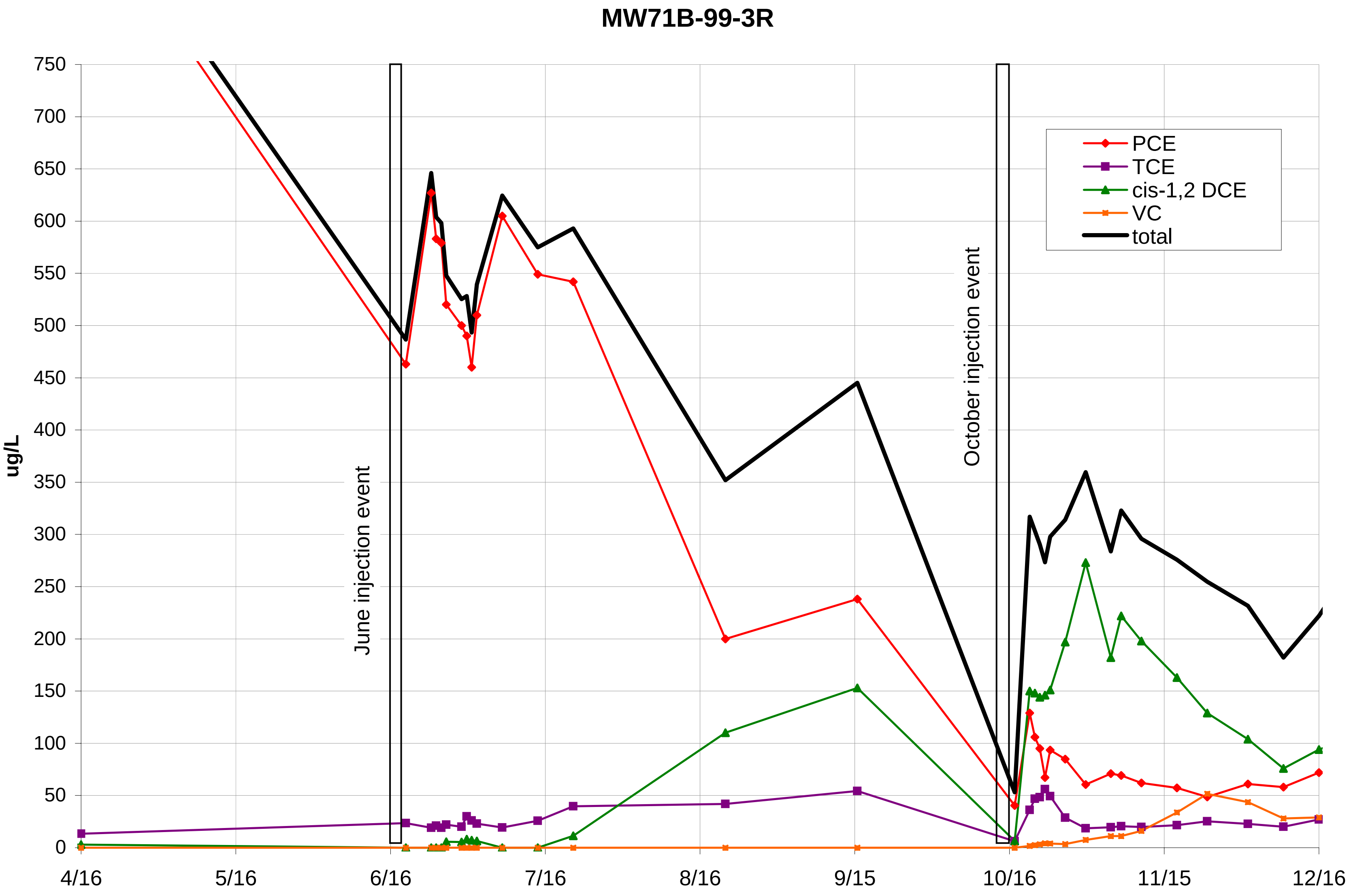

Figure 4. Short-term VOC concentration changes in MW71B-99-3R.

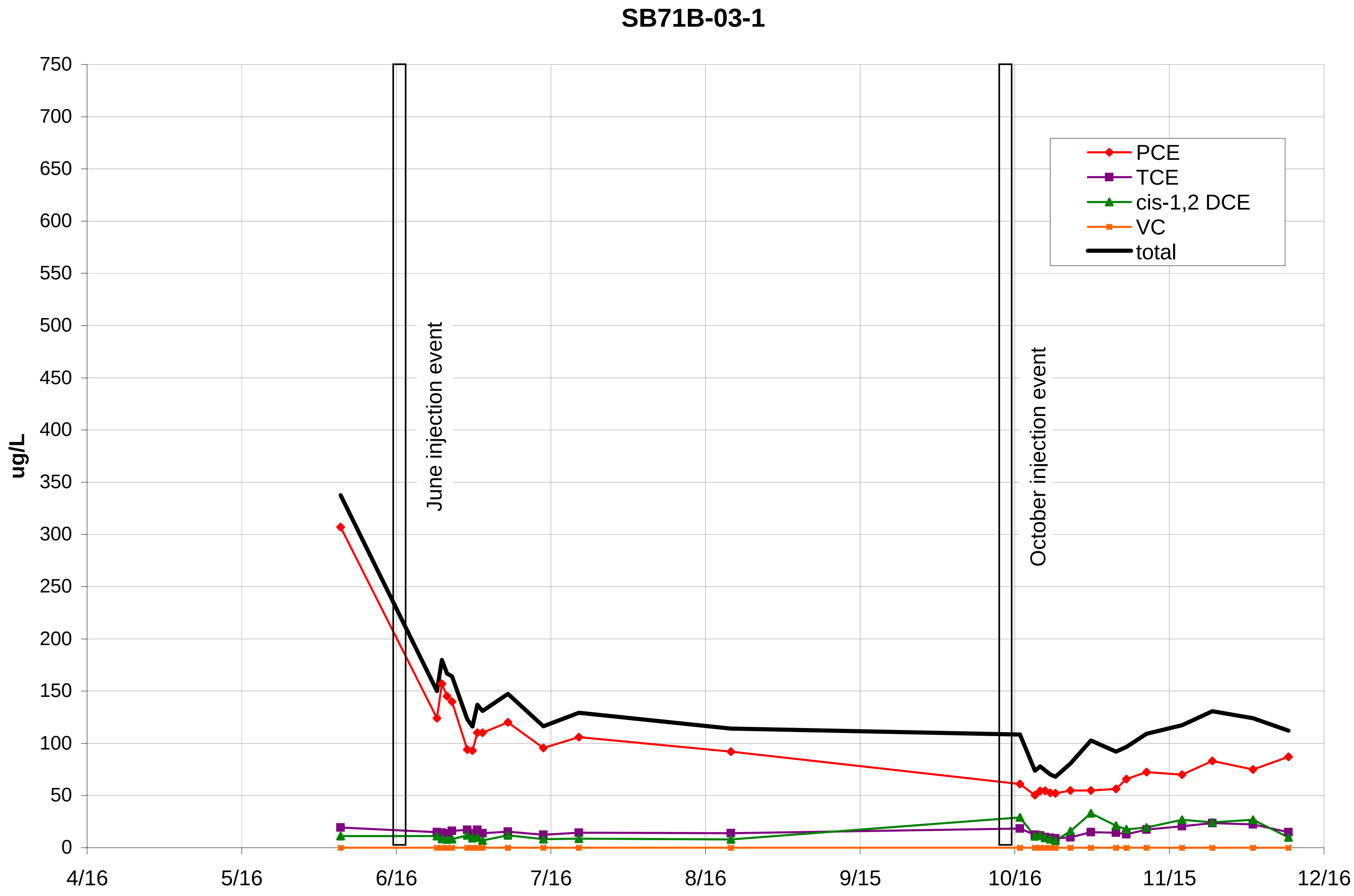

Figure 5. Changes in VOC concentrations in SB71B-03-1.

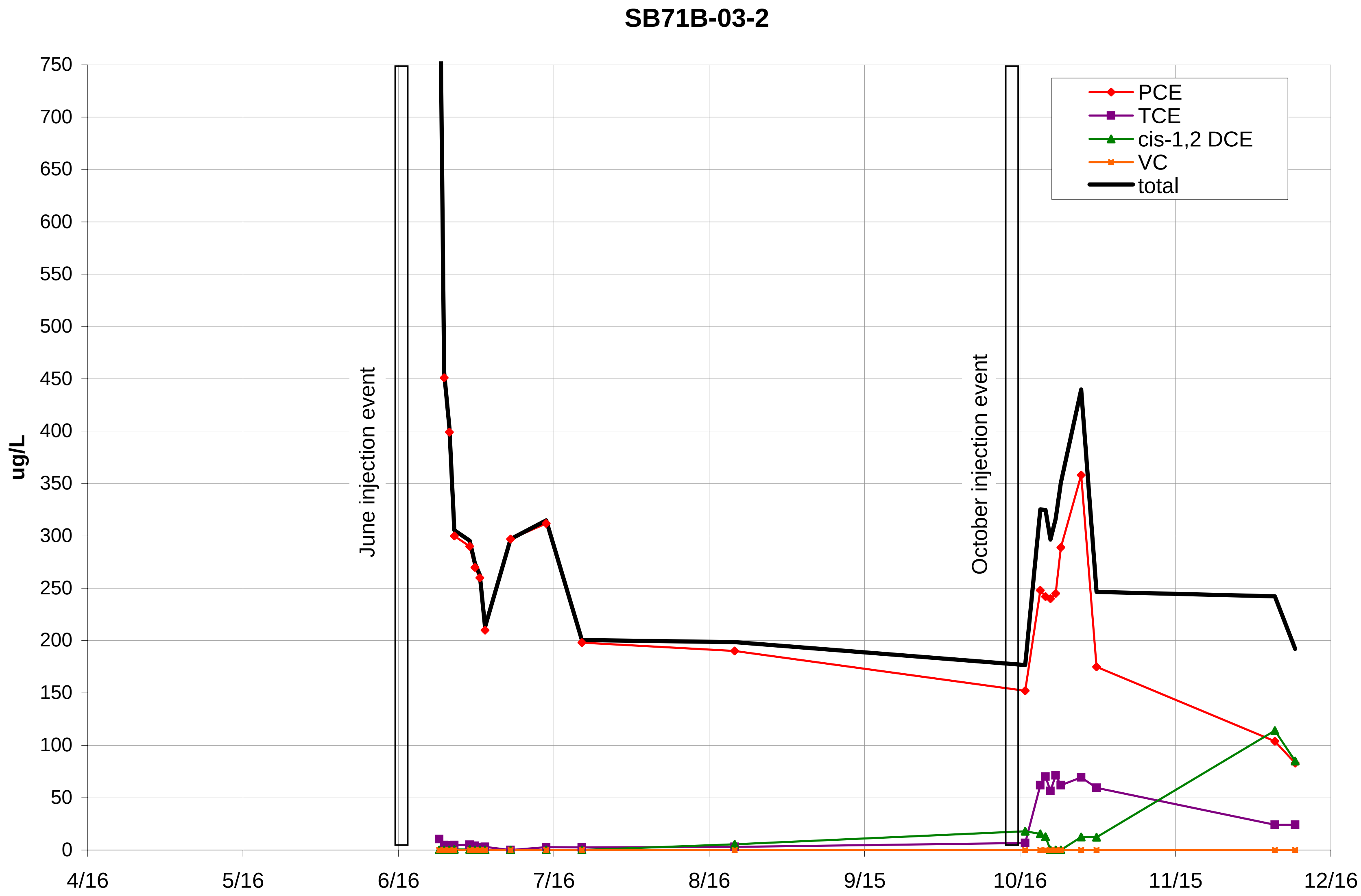

Figure 6. Changes in VOC concentrations in SB71B-03-2.

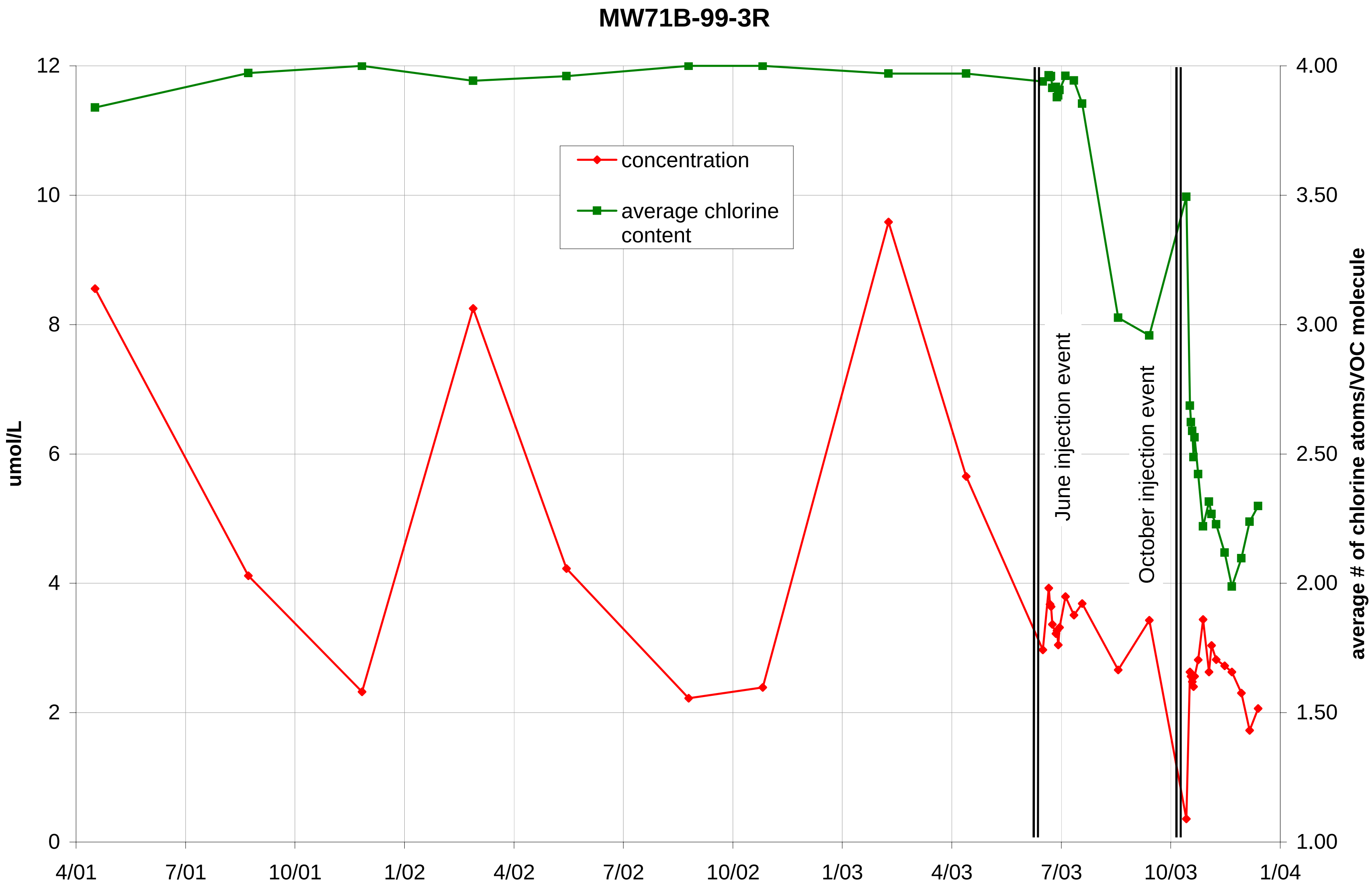

Figure 7. Long-term, molar VOC concentration changes in MW71B-99-3R.

E.O. Lawrence Berkeley National Laboratory
University of California
Environmental Restoration Program

United States Department of Energy

BUILDING 51L *IN-SITU* CHEMICAL OXIDATION PILOT TEST

for the

Lawrence Berkeley National Laboratory

Environmental Restoration Program

August 2004

BUILDING 51L *IN-SITU* CHEMICAL OXIDATION PILOT TEST

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Environmental Restoration Program

A Joint Effort of
Environment, Health and Safety Division and
Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

August 2004

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SECTION 1

SUMMARY

During the weeks of September 22, 2003 and December 8, 2003, a pilot test of *in-situ* chemical oxidation (ISCO) of chlorinated volatile aliphatic hydrocarbon contaminants (VOCs) in the engineered fill in the vicinity of Building 51L was performed via injection of citric acid and hydrogen peroxide according to the "Workplan for *In-Situ* Chemical Oxidation Pilot Test" dated May 2003 ("workplan"). The contaminants at the site consist primarily of tetrachloroethylene (PCE) and trichloroethylene (TCE) in the unsaturated zone and cis-1,2 dichloroethylene (cis-1,2 DCE) in the saturated zone.

The reagents were injected into a deep interval in two wells during the September event, and into shallow and deep intervals in 12 wells in the December injection event. The 12 injection wells in the second event were arranged in a hexagonal array with a 5-foot spacing. This array enclosed three groundwater wells.

The injection was performed by Rejuvenate under the supervision of personnel from Lawrence Berkeley National Laboratory's (LBNL's) Environmental Restoration Program (ERP) and Parsons Engineering. Concentrations and volumes of reagents injected into each group of wells were recorded along with the injection pressures at each well. The effect of the injection was monitored in real time via measurements of pH in the groundwater wells and observations of the seepage patterns.

Injection pressures were successfully limited to avoid hydraulic fracturing. Reagents did not seep into an adjacent storm drain or migrate into a shallow, laterally extensive sand layer at the site. Seepage during the test was primarily from open wells and the drain in the well box of monitoring well MW51L-01-4. All of this seepage was contained on the ground surface and transferred to 55-gallon drums by vacuum. No seepage migrated overland to outside the pilot test area, and no seepage entered the storm drain catch basin in the vicinity of the pilot test.

The pattern of seepage and the pH measurements indicate that a radius of influence of at least 3 feet was achieved around each well. However, this only required injection of 13% of the total reagent volume containing 15% of the acid mass and 30% of the hydrogen peroxide mass, and 26% of the total reagent volume containing 35% of the acid mass and 40% of the hydrogen peroxide mass specified in the workplan for the shallow and deep injections intervals, respectively. Based upon the response data collected, continued injection during the pilot test would likely have resulted in the additional injected volume either migrating away from the pilot test area laterally and/or seeping to the ground surface, rather than increased filling of the pore space immediately around the wells. Therefore the reagent volumes specified in the workplan were not injected due to achieving the desired radius of influence with the smaller reagent quantities, and due to the low flow rates which made injecting the workplan-specified volumes economically unfeasible.

Injection of the reagent volumes specified in the workplan would theoretically have occupied a maximum of 26% of the total pore volume around each well, which is reasonably equivalent to the likely effective porosity. The actual reagent volumes injected occupied a maximum of 3.5%, or 1/28th, and 7.5%, or 1/13th, of the total pore volume around each well in the shallow and deep intervals, respectively. The changes in pH during injection of these volumes indicate that only a small fraction of the total pore volume was accessed by the reagents. Therefore, it appears the vast majority of reagents infiltrated into and advected through significantly more permeable pathways comprising a small portion of the total soil mass. This is in accord with the distribution of soil types in the engineered fill. Well- and poorly-sorted sand make up 3% of the fill, while silty sand and gravel make up 21%. The remainder of the fill consists of silt and clay. The VOC concentration changes in the post-ISCO test soil samples support the conclusion that reagents primarily advected along coarse-grained pathways with the VOC concentration changes in the only post-ISCO soil sample containing clean, coarse-grained soil significantly more altered from the pre-ISCO concentrations than in any other sample.

Significant decreases (35% to 100%) of all volatile aliphatic hydrocarbon contaminants (VOCs) detected prior to the pilot test were measured in wells monitoring the artificial fill following the December injection event. The pattern and duration of the decreases, as well as the detection of new VOCs following the injection events and the low ratio of reagent volume to total pore volume, strongly suggest that the decreases were due to chemical oxidation rather than dilution or some other process. As soil contamination occurs in both the coarse- and fine-grained soils, the post-test rebound is likely due to advection and diffusion of contaminants from the fine-grained soils. Therefore injection methods which could further discretize the injection interval in a full-scale ISCO relative to the pilot test could be explored. One possible method of achieving this goal is sleeve-port injection. However, injection of the necessary reagent volumes into the finer-grained soils through greater discretization is likely to be economically unfeasible due to the low injection flow rates.

SECTION 2

INTRODUCTION

During the weeks of September 22nd and December 8th, 2003, personnel from Rejuvenate conducted a pilot test of the in-situ chemical oxidation (ISCO) of chlorinated volatile aliphatic hydrocarbon contaminants (VOCs) in the subsurface adjacent to and beneath the western side of Building 51L. The objectives of this test, as stated in the workplan, were to determine if ISCO could effectively reduce the contaminant mass in soil and groundwater in the vicinity of Building 51L. This work was performed under the direction of personnel from LBNL's ERP and Parsons Engineering.

Note that the pilot test described in the workplan did not specify injection of iron along with the other reagents. Analysis of the iron content of a drill-cutting sample of the artificial fill in the vicinity of Building 51L and of several liner samples of artificial fill and colluvium in the vicinity of Building 71B indicated that the artificial fill at Building 51L had sufficient iron to allow for ISCO without the addition of iron.

SECTION 3

INJECTION WELLS

The September and December injection events were conducted in the same hexagonal, three-row array of 12 injection wells on a 5-foot spacing that enclosed a soil volume containing three temporary groundwater monitoring wells as shown on Figure 1. The eastern row consisted of four injection wells plunging 60 degrees from horizontal beneath the western edge of Building 51L. These wells are numbered IW51L-03-1 to -4 from north to south. The southern two of the declined wells bracketed temporary groundwater monitoring well SB51L-02-3. The remaining injection wells were vertical. Temporary groundwater monitoring well SB51L-03-1 and -2 were approximately centered in the northernmost and southernmost triangles of vertical injection wells, respectively.

The injection wells consisted of ¾-inch internal-diameter, stainless-steel pipe with external threaded couplings. The screen sections consisted of the same pipe with three, approximately 3/16-inch holes drilled at equal angles around the pipe. A set of these holes was drilled at approximately 4-inch intervals along the screen. Hydraulic pressure was supplied to packers above and, where necessary, below the screen via a separate line. The outside diameter of the packers was approximately 1.7 inches. The packers consisted of a heat- and chemical-resistant rubber tube clamped to the stainless steel casing.

The injection wells were installed in 2.5-inch diameter open borings advanced by direct-push. A 2-inch internal diameter PVC casing was grouted into the upper few feet of each boring. The annulus between the PVC casing and the injection casing was sealed at the top of the PVC casing by a compression fitting in order to minimize exposure to the injectate if a packer failed in the boring during injection.

SECTION 4

SEPTEMBER INJECTION EVENT

4.1 SCHEDULE OF ACTIVITIES

On Thursday and Friday, September 25th and 26th, Rejuvenate and its direct push subcontractor, Vironex, installed injection wells IW51L-03-1 to -12 at Building 51L. Injection into only wells IW51L-03-2 and -10 occurred on September 27th during this injection event.

4.2 INSTALLATION OF INJECTION WELLS

The injection wells were installed by Rejuvenate in 2.5-inch diameter borings advanced by Vironex using direct-push methods. Borings were typically advanced by hydraulic pressure on the push rod alone. Occasional hydraulic percussion was necessary to advance the rod.

4.3 INJECTION INTERVALS

During the September injection event, the packers would not hold pressure without continual flow indicating a leak somewhere in the packer system. With continual flow of 5 gpm, the pressure could be maintained at approximately 20 pounds per square inch (psi). This leak was later determined to be occurring at the well casing joints. As a consequence of this equipment failure, it was decided to maintain pressure in the packers of just two injection wells through continual flow to allow injection of some quantity of acid and hydrogen peroxide solution. This decision was taken with the realization that water leaking from the packer system would be injected somewhere into the subsurface during this process, but this was deemed acceptable in order to gather at least some data on the impact of injecting acid and hydrogen peroxide reagents into the subsurface.

Well IW51L-03-10 was chosen for injection due to its proximity to temporary monitoring well SB51L-03-1, respectively. Well IW51L-03-2 was chosen for injection as it was the closest, out of the six wells initially connected to the injection truck, to temporary monitoring well SB51L-02-3.

Well IW51L-03-2 plunged 60 degrees beneath Building 51L. The total declined depth of this well was 24 feet below ground surface (bgs; 21 feet bgs vertically). The declined depth to the artificial fill/colluvium contact was estimated as 26.5 feet bgs (23 feet bgs vertically), and the declined depth to the colluvium/Great Valley Group contact was estimated as 39 feet bgs (34 feet bgs vertically). The packers in well IW51L-03-2 were positioned for injection of the entire borehole interval below 19 feet bgs (16 feet bgs vertically).

Well IW51L-03-2 was a vertical well with a total depth of 23 feet bgs. The artificial fill/colluvium contact was estimated as 21.5 feet bgs and the colluvium/Great Valley Group contact was estimated as 28 feet bgs at the location of this well. The packers in well IW51L-03-10 were positioned for injection of the entire borehole interval below 15 feet bgs.

4.4 INJECTION PRESSURES

Prior to injection of any chemical solution, the packers were pressurized to 20 psi. Injection pressures were approximately 10 psi.

4.5 REAGENT QUANTITIES INJECTED AND REAL-TIME RESPONSES OBSERVED

Injection to well IW51L-03-10 occurred first, followed by injection to well IW51L-03-2. The depth to water (DTW) and pH prior to the commencement of injection were measured in temporary monitoring wells SB51L-02-3, SB51L-03-1 and -2, and in monitoring well MW51L-01-3. Table 1 lists the pH measurements taken during the September injection event.

Table 1. Summary of pH measurements during September injection event.

injection to well	**well**										
	SB51L-02-3			**SB51L-03-1**		**SB51L-03-2**			**MW51L-01-3**		
	before	**during**	**after**	**before**	**after**	**before**	**during**	**after**	**before**	**during**	**after**
IW51L-03-10	7.0			7.0	3.0	7.0		7.0	7.0		7.0
IW51L-03-2		6.5	6.5		3.0		6.5			6.5	

Approximately 55 gallons of reagent, consisting of 20 gallons of ~10% citric acid and 35 gallons of 17.5% hydrogen peroxide, were injected into well IW51L-03-10. The DTW was

14.35 feet below ground surface (bgs). The pH changed to 3 and the DTW rose to 1.2 feet bgs during or shortly after injection to this well. SB51L-03-1 was subsequently purged continuously throughout the injection activities with the final DTW in this well below the initial DTW.

Shortly after ceasing flow to the packers in IW51L-03-10, low pH seepage to the ground surface commenced, primarily from the drain hole inside the well box for MW51L-01-4. The timing, location and quantity of seepage indicates that the packers in the injection well were sealing the boring during the continuous flow phase, and that when flow was ceased the reagents pushed up the boring due to the off-gassing reaction, and followed a shallow lateral pathway, consisting possibly of the base rock, to MW51L-01-4 13 feet away.

Injection next took place in IW51L-03-2 with continual flow to the packers. 25 gallons of ~10% citric acid were injected. After injection of approximately 15 gallons of acid, the first pH measurement in temporary wells SB51L-02-3 and SB51L-03-2, and in monitoring well MW51L-01-3 indicated the pH had dropped 0.5 standard units. The pH in SB51L-03-2 did not change throughout the remainder of the injection. Hydrogen peroxide was not injected into this well due to concerns about the amount of water leaking from the packers.

After the injection of reagents into IW51L-03-2 and depressurization of the packers in this well, seepage was again observed from the drain hole in the MW51L-01-4 well box. 30 gallons of water were subsequently injected into IW51L-03-2 with the packers depressurized to check the connection to drain hole in MW51L-01-4 well box. Seepage from this location was found to correlate with injection. The casing in MW51L-01-4 was checked for damage and found to be intact and the DTW was measured at 22 feet bgs, indicating no intrusion of seepage into this well casing.

The effluent in the storm drain adjacent to the pilot test site was periodically monitored at a location downflow. No changes in flow rate, pH, or turbidity were observed during or after the injection event, indicating that no seepage to the storm drain occurred during injection.

4.6 DISCUSSION OF RESULTS

The workplan called for injection of 7.3 kg of citric acid in 9 gallons of solution and 37 kg of hydrogen peroxide in 97 gallons of solution per 5-foot interval for injection wells spaced 5 feet apart. 7.7 kilograms (kg) of citric acid in 25 gallons of solution and 23.7 kg of hydrogen peroxide in 35 gallons of solution were injected into the 8-foot long interval in well IW51L-03-10. Therefore, 66% of the acid mass, 40% of the hydrogen peroxide mass, and 32% of the reagent volume specified in the workplan were injected in this interval. 9.7 kg of citric acid in 25 gallons of solution were injected into the 5-foot long interval in well IW51L-03-2. This is 133% of the acid mass, 280% of the acid reagent volume, and 24% of the total reagent volume specified in the workplan. Injection was stopped short of the workplan targets due to concerns about water leaking from the packers.

The pH decrease in temporary monitoring well SB51L-03-1 during injection into well IW51L-03-10 indicates that the radius of influence in the most conductive layers during this injection was greater than 3 feet, the shortest distance from the injection well to a monitoring well.

The timing, magnitude, and position of the pH decreases during injection into IW51L-03-2 suggest that no pH response occurred during this injection. Rather the decrease of 0.5 standard pH units was due to the uncertainty of the monitoring method (pH paper). In particular, note that the pH apparently decreased in MW51L-01-3, which is screened across 15 feet of Great Valley Sequence bedrock below an aquitard consisting of colluvium. This aquitard separates VOC-contaminated groundwater in the artificial fill from groundwater with concentrations of VOCs below detection limits in the Great Valley Group below. Therefore it is unlikely that acid injected into well IW51L-03-2 reached monitoring well MW51L-01-3.

If the conclusion of no pH response during injection into well SB51L-03-2 is correct, it indicates that the radius of influence in the most conductive layers during this injection was less than 9 feet, which is the shortest distance from this injection well to a monitoring well.

The VOCs repeatedly detected in the three wells screened in the artificial fill in the pilot test area prior to injection consist of tetrachloroethylene (PCE), trichloroethylene (TCE), cis-1,2 dichloroethylene (cis-1,2 DCE), trans-1,2 dichloroethylene (trans-1,2 DCE), 1,1 dichloroethylene

(DCE), vinyl chloride (VC), and 1,1-dichloroethane (1,1 DCA) as shown in Figures 2, 3, and 4. The dominant DCE isomer in all the wells is cis-1,2 DCE. Chloroethane (CE) was consistently detected in well SB51L-03-1 after injection as shown on Figure 3. The VOCs detected in the three wells screened in the artificial fill in the pilot test area only after the injection events are chloroform, methylene chloride, methyl chloride, and methyl bromide as shown on Figures 5, 6, and 7.

One groundwater sample was collected from each of wells SB51L-02-3 and SB51L-03-1 in the week following the September injection event. Following the injection, the concentration of total DCE in SB51L-03-1, which was closest to the wells injected during this event, declined approximately 80% as shown on Figure 3. In well SB51L-02-3, the concentration of total DCE declined approximately 25% and the concentration of PCE declined 70% as shown on Figure 2. The majority of the decrease in the concentration of total DCE in this well was due to a decrease in the concentration of trans-1,2 DCE. The concentration of other VOCs, most notably 1,1 DCA in well SB51L-03-1, remained approximately constant.

The decline in concentrations of some VOCs and not others in wells SB51L-02-3 and SB51L-03-1 following the September injection event suggests the declines are due to chemical oxidation rather than dilution (which is a significant possibility owing to the unknown large quantity of water injected during this event due to leakage from the packer lines). This is additionally suggested by the presence of previously undetected VOCs in well SB51L-03-1 following the injection event, as shown on Figure 6. Three of these VOCs are only detected in the first post-injection groundwater sample collected a week from this well after the injection. This timing strongly suggests these VOCs were created by a chemical reaction resulting from the injection.

The total VOC concentration in well SB51L-03-1 increased to near background levels two months after the September injection as shown on Figure 3. The only notable change is the decrease in 1,1 DCA and the increase in CE, which is a degradation product of 1,1 DCA. This suggests the instantiation of a long-term degradation process. As shown on Figure 2, the total VOC concentration in well SB51L-02-3 decreased significantly compared to background levels after the September injection, particularly when consideration is given to the typical pre-injection pattern of increased concentrations in the dry season. Significant precipitation did not begin until mid-December in the July 1, 2003 to June 30, 2004 rain year. The total VOC concentration decrease in SB51L-02-3 may be due to advection of treated groundwater into the vicinity of well SB51L-02-3 due to a groundwater flow towards extraction well EW51L-00-1 to the south.

During the two years prior to the September injection event, no VOCs were repeatedly detected in quarterly groundwater samples from monitoring wells MW51L-01-3 and -4, which are screened in the Great Valley Group beneath and near to the pilot test site, respectively. No VOCs were detected in the quarterly groundwater samples from monitoring wells MW51L-01-3 and -4 a month and a half after the September injection event. This indicates the September injection did not induce leakage of groundwater from the artificial fill to the Great Valley Group through the intervening colluvial aquitard.

SECTION 5

DECEMBER INJECTION EVENT

5.1 SCHEDULE OF ACTIVITIES

On Tuesday, December 9th, a direct-push rig and operator from Gregg Drilling was mobilized to the Building 51L site to assist with removing injection wells previously installed by Rejuvenate on September 25th and 26th. These wells had proven faulty during an attempt to the conduct the ISCO pilot test on September 27th. After removal of these wells by Gregg Drilling, Rejuvenate installed new wells configured for injection into the deeper interval at the site. On Wednesday, December 10th Rejuvenate connected well heads and injection lines and commenced injection. Injection in the deep interval continued on Thursday and Friday, December 11th and 12th. On the afternoon of Friday, December 12th and the morning of Saturday, December 13th, Rejuvenate pulled the injection wells, and reconfigured and reinstalled them for injection in the shallow interval. Injection of this interval was completed during the afternoon of Saturday, December 13th.

5.2 INJECTION INTERVALS

The ISCO pilot test injection was targeted to treat the engineered fill in the pilot test area at Building 51L, as described in the workplan. As previously mentioned, the injection wells were initially configured and installed for injection into the deeper interval in the engineered fill. The injection wells were subsequently reconfigured and reinstalled for injection into a shallower interval. Table 2 below lists the deeper and shallower injection intervals at each well along with the estimated depth to the engineered fill/colluvium contact and the colluvium/Great Valley Sequence contact.

Table 2. Geologic contacts and injection intervals.

well name	depths (ft)*				
	Qf/Qu contact	Qu/Kgv contact	bottom of hole	deep interval	shallow interval
IW51L-03-1	27.5 (24)	44 (38)	24 (21)	16-24 (14-21)	6-13 (5-11)
IW51L-03-2	26.5 (23)	39 (34)	24 (21)	16.5-24 (14-21)	6-13 (5-11)
IW51L-03-3	23.5 (20.5)	34 (29.5)	24 (21)	16.5-24 (14-21)	7-14 (6-12)
IW51L-03-4	21 (18)	28.5 (24.5)	24 (21)	16.5-24 (14-21)	7-14 (6-12)
IW51L-03-5	22.5	27	23	16.5-23	6-13
IW51L-03-6	21.5	26	23	16.5-23	6-13
IW51L-03-7	20	25	20	NA	6-20
IW51L-03-8	18	24	20	12.5-20	7-20
IW51L-03-9	16.5	23	18	11-18	NA
IW51L-03-10	21	28	23	16.5-23	6-13
IW51L-03-11	19.5	27	20	13-20	5-12
IW51L-03-12	18	25	20	13-20	5-12

* depths in parentheses are vertical equivalents of declined depths

The bottom depth of each boring was selected so as to penetrate the colluvium beneath the engineered fill in order to assure the entire base of the fill section was treated. The base of each injection boring was also selected so as to separate it from the top of the relatively permeable Great Valley Sequence beneath by at least three feet of relatively lower permeability colluvium. This was done in an effort to prevent the injected solutions from preferentially flowing into the Great Valley Sequence.

The workplan for the ISCO pilot test specified 5-foot long injection intervals. Despite repeated communication with Rejuvenate regarding this requirement, the contractor arrived on site with 6-foot long injection screens. When combined with blank casing stubs on either side of the screen associated with either a packer unit or an end cap, the minimum length of an injection interval was 6.5 feet. Due to the necessity to complete the pilot test at the appointed time, the decision was made in the field to accept this length of injection interval.

Due to concerns about the inability of the packers to seal against a previously injected borehole wall, the depths of the shallow injection intervals were selected such that the top of the packer below the screen would inflate against an uninjected section of borehole wall. This decision resulted in an uninjected interval ranging from 1 to 3.5 feet in length between the deep and shallow intervals. Further, this decision, combined with the greater than expected length of the injection intervals, led to selection of two 7-foot long intervals rather than the three 5-foot intervals originally envisioned based upon the workplan.

Packers could not be placed below a depth of approximately 12 feet in IW51L-03-7 due to the presence of a piece of packer torn off from the previously installed well. Therefore both the shallow and deep intervals were injected simultaneously during injection of the shallow intervals in the other wells. This was achieved by placing a packer above the shallow interval in IW51L-03-7 with no packer below.

A clean sand layer exists between 2 and 5 feet deep at injection wells IW51L-03-4 and -9. Based upon previous borings, the lateral margins of this sand layer lie approximately 10 feet to the east, 20 feet to the west and 80 feet to the south. This layer potentially has significantly higher permeability than the underlying, predominantly fine-grained soils. As such, this layer had the capacity to absorb a large amount of reagent and transmit these reagents a significant distance from the pilot test site. In addition to absorbing and transmitting reagents away from the target volume, reagents migrating through this layer could potentially contact a cast-iron storm drain passing beneath Building 51L causing increased corrosion of this pipe. Due to these concerns, the following measures were taken to forestall the entry of reagents to this layer.

The top of the shallow injection interval in IW51L-03-8 was set to a depth of 7 feet to assure at least two feet of relatively less permeable fine-grained engineered fill between the top of the injection interval and the base of the nearby sand layer. It was not possible to inflate a packer against uninjected borehole wall below the shallow interval in this well as the top of the deeper interval was 12.5 feet. Therefore, as with IW51L-03-7, only a single packer was placed above the shallow interval and the shallow and deep intervals were injected simultaneously during injection of the shallow intervals in the other wells. The shallow interval in IW51L-03-9 was not injected due to the small additional borehole length which could potentially be injected above the deep interval (7 to 11 feet deep), and the risk that reagents injected in this interval might migrate into the clean sand layer. Finally, a 6-foot deep boring was installed through the sand layer 4 feet south of IW51L-03-9. This boring was left open during the injection activities to monitor for migration of reagents into and through the sand layer.

5.3 INJECTION PRESSURES

Based upon the instability of the hydrogen peroxide, chemical oxidation using this reagent is generally believed to be effective for only a matter of hours after injection. Therefore, advection driven by injection pressure must bring the reagents into contact with the target contaminants to be oxidized within a very short time period. This is unlike more persistent in-situ treatment technologies where natural groundwater advection may be relied upon to bring the reagents, or their byproducts, into contact with the target molecules. The above suggests that injection pressures must be controlled carefully to prevent hydraulic fracturing of the formation that would cause the reagents to bypass most of the pore volume containing the target contaminants.

Hydraulic fracturing from vertical wells in the shallow subsurface is generally related the vertical stress in the material around the well, which is typically equal to the overburden pressure. The minimum overburden pressure in each injection interval occurs at the shallowest portion of the interval. This pressure was calculated based upon a review of dry densities and moisture contents from geotechnical reports and water level measurements from ERP wells in the engineered fill near Building 51L.

The average dry density of the engineered fill was 103 pounds per cubic foot. The average moisture content was 17% above a depth of approximately 8 feet, which equates to a saturation of 80% (assuming a specific density for the solids of 2.65). Below approximately 8 feet the saturation is 100%. The average water level in the area is 13 to 14 feet deep, indicating a five to six foot capillary fringe. Using the numbers above, the minimum overburden pressure was calculated as 10 to 11 pounds per square inch (psi) in the deep interval and 5 to 6 psi in the shallow interval. The maximum injection pressures were set at 2 to 2.5 times the minimum overburden pressures in order to maximize injection pressure-driven advection within safe limits. This multiplier is based upon the general field experience pressures to initiate hydraulic fractures are significantly greater than overburden pressures, in part due to soil cohesion. Therefore the maximum target injection pressure for the deep interval was 24 psi and for the shallow interval was 12 psi.

Significant expansion of the packers occurs at approximately 15 psi. This conclusion was based upon discussions with Rejuvenate as well as direct observation of partial inflations of packers laid out on the ground surface. This suggests only the increment of packer pressure above 15 psi is effective at resisting passage of injected reagents. During injection, the target packer pressure was set at 15 psi higher than the maximum target injection pressures, or approximately 40 psi for the deep interval and 25 psi for the shallow interval. Other than the one instance described below, the injection pressures and packer pressures were maintained according to the specifications described above.

The effectiveness of the 15 psi pressure differential between the packer and injection pressures was confirmed during the first round of deep interval injection. During this injection there was no seepage at the ground surface when the pressure differential was greater than 15 psi. At the end of the injection the differential decreased to less than 5 psi due to a decision by Rejuvenate to increase the injection pressure without increasing the packer pressure. Rejuvenate took this action without prior discussion with ERP personnel in an attempt to increase the injection rate. Shortly thereafter seepage commenced from the nearby drain inside the MW51L-01-4 well box, indicating migration of reagents up to and through the shallow subsurface. ERP personnel recommended a reduction in injection pressure as soon as the pressure increase was observed. However, the injection was complete at this time. Approximately 5 gallons of reagent were injected at the higher pressure.

5.4 INJECTION INTERVAL PERMEABILITY

Rejuvenate’s injection truck includes two approximately 100 gallon tanks for acid and water and an approximately 200 gallon tank for hydrogen peroxide solution. These tanks are connected via valved piping to a single pump. Fluid exiting the pump can be directed to circulate back to the originating tank or to a manifold with three valved ports which afford independent pressure control to three external hoses. Each external hose can connect to one or two injection wells. The injection truck also includes a separate pump for inflating and maintaining pressure in the packers.

The pump truck includes various types of flow meters between the injection pump and manifold and within the manifold. None of these flow meters could be shown to be quantitatively accurate to the satisfaction of the ERP personnel supervising the pilot test. Therefore direct readings of reagent tank fluid levels combined with elapsed times were employed to gauge injection rates.

The lack of quantitatively reliable flow meters on each injection line made it necessary to initially inject each well interval singly in order to qualitatively gauge permeability. Each interval in each well was injected at equal to or less than the maximum injection pressure for fifteen minutes or until approximately 4 gallons of acid had been injected. The first 2 gallons injected were sufficient to fill the 6 to 7 foot-long boring interval with reagent. Fifteen minutes to inject an additional 2 gallons into the formation (equivalent to 0.15 gpm) was selected as it is a lower bound for the economic feasibility of *in-situ* treatment via reagent injection. At this rate, approximately 70% of the reagent volume specified in the workplan could be injected in an 8-hour period.

Injection pressures at the truck manifold and the well head provided secondary confirmation of the permeability around well. A well head pressure less than or equal to the manifold pressure on the same injection line indicated flow to the well (the manifold pressure gauges were typically positioned approximately 4 feet above the well head pressure gauges). A well head pressure less than the maximum injection pressure also typically indicated flow to the well. Relative differences in the flow rate to each well during multiwell injection, as measured qualitatively by flow meters on the injection manifold, provided a tertiary confirmation of differences in the permeability around each well.

Based upon data accumulated via the three methods outlined above, the deep injection intervals in IW51L-03-2, -4, -5, -8, -10, and -12, or approximately half all the wells, were sufficiently permeable to accept 2 gallons of reagent within 15 minutes. Intervals which passed this test were not distributed according to any discernible pattern; rather they were randomly distributed among the intervals which failed this test. All of the shallow injection intervals were sufficiently permeable to accept 2 gallons of reagent within 15 minutes. The permeability difference between shallow and deep intervals could perhaps be due to differences in consolidation of the fill and/or differences in saturation. Geologic logs in the area do not indicate significant differences in grain-size in the shallow injection interval versus the deep injection interval.

5.5 REAGENT QUANTITIES INJECTED AND REAL-TIME RESPONSES OBSERVED

Approximately 430 gallons of reagent were injected in the deep interval. This consisted of 95 gallons of 10% citric acid, 75 gallons of 12.5% hydrogen peroxide solution, and 260 gallons of 17.5% hydrogen peroxide solution. These reagents were injected in approximately four equal volumes during four periods over the course of three days, as listed in Table 3. The total elapsed injection time was 5 hours, and therefore the average injection rate to six wells at a time was 1.5 gallons per minute (gpm), or 0.25 gpm per well.

Table 3. Wells injected during each injection period

Injection			IW51L-03 wells injected during period
No.	**period**	**interval**	
1	12/10 afternoon	northern wells - deep	1, 2, 5, 6, 10
2	12/11 morning	northern wells - deep	1, 2, 3, 5, 6, 10
3	12/11 afternoon	southern wells - deep	11, 3, 4, 8, 9, 12
4	12/12 morning	southern wells - deep	11, 3, 4, 8, 9, 12
5	12/13 afternoon	southern wells - shallow	7, 8, 3, 4, 11, 12
6	12/13 evening	northern wells - shallow	1, 2, 5, 6, 10, 11

Approximately 210 gallons of reagent were injected in the shallow interval. This consisted of 30 gallons of 10% citric acid and 180 gallons of 17.5% hydrogen peroxide solution. These reagents were injected in approximately two equal volumes during two periods in one day, as listed in Table 2. The total elapsed injection time was 1 ½ hours, and therefore the average injection rate to six wells at a time was 2.3 gallons per minute (gpm), or 0.4 gpm per well.

Packer failures occurred four times during injection. These failures were observed as a precipitous drop in the well head injection pressure. Both the packer and reagent feed lines to the well were shut off at the wellhead in these instances. A packer failed in IW51L-03-5 near the midpoint of the second injection period and in IW51L-03-10 at the end of the second injection period. A packer in an undiagnosed position failed at the end of the fourth injection period. A packer in IW51L-03-2 failed near the beginning of the sixth injection period. The only failed packer observed upon well removal was in IW51L-03-10. The upper packer failed by splitting longitudinal along most of its length. The shape of a notch/dimple along the split edge suggested that the packer had impinged on something sharp in the borehole, such as a gravel grain.

The pH in three temporary monitoring wells area screened in the engineered fill in the pilot test area was measured prior to commencement of injection and periodically throughout the injection. These measurements are summarized in Table 4. The pH of the effluent in a storm drain passing near the pilot test area was also measured to monitor for potential seepage of injected reagents into the storm drain. This storm drain consists of a 24-inch diameter, reinforced concrete pipe whose invert is located approximately 4 feet west of the pilot test area and at a depth of approximately 15 feet.

Table 4. Summary of pH measurements during injection.

Injection			**Well**						**Storm Drain below pilot test site**
			SB51L-02-3		**SB51L-03-1**		**SB51L-03-2**		
No.	**period**	**interval**	**before**	**after**	**before**	**after**	**before**	**after**	
1	12/10 afternoon	northern wells - deep	6.5	6.5	6.5	6	6.5		6.5
2	12/11 morning	northern wells - deep	6.5	6.5	5	3.5	6.5		7
3	12/11 afternoon	southern wells - deep	2				3.5		7
4	12/12 morning	southern wells - deep	3		3		2		7
5	12/13 afternoon	southern wells - shallow	3.5	5	3	3	4	3	7
6	12/13 evening	northern wells - shallow	3		3		3		

The pH of the storm drain effluent was measured at the closest access to the storm drain downflow of the pilot test area. This location is approximately 230 feet northwest of the pilot test area where the storm drain emerges on the slope and transitions to an 18-inch diameter corrugated metal pipe. Access to the effluent consists of a hinged hatch in the top of the pipe. The pH of the effluent indicated no seepage occurred into the storm drain during the pilot test.

Seepage of reagents was observed at a variety of locations during injection. This seepage was typically contained on the surface with sand-filled rubber socks, if necessary, and then vacuumed into 55-gallon drums. The timing and location of the seepage is listed below in Table 5, as well as any actions taken to minimize the seepage. In addition to those actions listed, the packers were pressurized in IW51L-03-2 during the fourth injection period, in IW51L-03-9 during the fifth injection period, and in IW51L-03-3 during the sixth injection period in order to minimize potential seepage from these wells.

Table 5. Summary of seepage timing and location.

injection			seepage			
No.	**period**	**interval**	**location**	**time**	**amount**	**action**
1	12/10 afternoon	northern wells - deep	drain in MW51L-01-4 well box	end	5 gallons	lower injection pressure
2	12/11 morning	northern wells - deep	pavement joints near MW51L-01-4	end	gas	
3	12/11 afternoon	southern wells - deep	IW51L-03-2	mid	25 gallons	shut off IW3, 11, 12
4	12/12 morning	southern wells - deep	IW51L-03-1	mid	15 gallons	reduced IW3, 11, 12
			SB51L-03-2	mid	foam	
5	12/13 afternoon	southern wells - shallow	IW51L-03-1	mid	minimal	shut off IW3, 7, 11
			IW51L-03-2	mid	continuous	shut off IW3, 7, 11
6	12/13 evening	northern wells - shallow	drain in MW51L-01-4 well box	mid	minimal	
			SB51L-03-1	end	minimal	

No seepage was observed into the 6-foot deep boring through the sand layer south of IW51L-03-9 indicating reagents did not enter this layer in significant quantities.

5.6 DISCUSSION OF RESULTS

The seepage and injection pressure data do not indicate that hydraulic fracturing occurred, with one possible exception. The seepage pattern from IW51L-03-1 and -2 during deep interval injection suggests hydraulic fracturing may have occurred in this area. The pressure data from these wells and the surrounding wells IW51L-03-3, -5 and –6, however, do not record any decrease in the injection pressures during the first and second injection periods.

Such a pressure drop would be expected if one or more hydraulic fractures were initiated from these wells. Therefore it appears unlikely that hydraulic fracturing occurred, and the pattern of seepage was likely due to some pre-existing "fast path."

The workplan called for injection of 7.3 kg of citric acid in 9 gallons of solution and 37 kg of hydrogen peroxide in 97 gallons of solution per 5-foot interval. The average quantities injected in each, approximately 7-foot long, deep interval were 3.5 kg of citric acid in 8.5 gallons of solution and 19.5 kg of hydrogen peroxide in 30.5 gallons of solution. Therefore 35% of the acid mass, 40% of the hydrogen peroxide mass, and 26% of the total reagent volume specified in the workplan was injected in the deep interval. The average quantities injected in each, approximately 7-foot long, shallow interval were 1.0 kg of citric acid in 2.5 gallons of solution and 11 kg of hydrogen peroxide in 16.5 gallons of solution. Therefore 15% of the acid mass, 30% of the hydrogen peroxide mass, and 13% of the reagent volume specified in the workplan was injected in the shallow interval.

The masses and volumes specified in the workplan were not achieved due to the low flow rates at the maximum allowable injection pressures. At these flow rates, injection of the workplan specified volumes would have taken 109 hours and 68 hours of elapsed injection time in the deep and shallow intervals. This length of time was not economically feasible for the pilot test, and indicates that full-scale treatment would not be economical either.

Based upon dry density and moisture content measurements in geotechnical reports and water level measurements, the engineered fill in the vicinity of Building 51L has an average dry density is 102.5 pounds/cubic foot (lbs/ft^3) and an average total porosity of 38%. Therefore the pore space within a 3-foot diameter cylinder around each 7-foot long injection interval is 75 cubic feet. However, the pH measurements and seepage patterns indicate that only 5.5 and 2.5 cubic feet of reagent injected per well in the deep and shallow injection intervals, respectively, were required to reach a radius of influence of 3 feet or more. As these reagent solution volumes are only 7.5% and 3.5% of the total pore volumes respectively, this suggests the radius of influence was due to flow through pathways which were significantly more permeable than the average, and which occupied only a small percent of the total soil volume.

Detailed logging of the engineered fill in the vicinity of Building 51L was only performed on the one core from SB51L-01-9. This log indicates that the engineered fill consists of 3% well and poorly sorted sand (SW and SP) and 21% silty sand and gravel (SM and GM) by volume. The remaining volume consists of clay and silt (predominantly CL and ML). Based upon the inferred radius of influence, the total volumes injected, and the proportion of the engineered fill consisting of coarse-grained soil, it is reasonable to presume that the majority of the reagents infiltrated and advected through the coarse-grained soils with only minimal infiltration into the fine-grained soils.

Comparison of the reagent to soil mass ratios specified in the workplan (1:1000 for citric acid, 1:200 for hydrogen peroxide) with the ratio of injected reagent mass to coarse-grained soil mass within 3 feet of each injection interval (1:4300 for citric acid and 1:390 for hydrogen peroxide in the shallow interval, 1:1220 for citric acid and 1:230 for hydrogen peroxide in the deep interval) suggests contaminants residing in the coarse-grained soils were not completely oxidized in the shallow interval and were not completely oxidized in the deep interval during the pilot test. The unsaturated zone approximately coincides with shallow interval and the deep interval approximately coincides with the saturated zone. Therefore, significant, short-term declines in groundwater contaminant concentrations should be observed as the coarse-grained soils are more permeable and provide the majority of the water in any well sample. Significant rebound of groundwater contaminant concentrations should follow due to a lack of oxidation of contaminants in the less permeable, fine-grained soils within which soil sample results indicate contaminants are also present.

Following the December injection event, the VOC concentrations in all three wells screened in the artificial fill within the pilot test area decreased significantly as shown on Figures 2, 3, and 4. The total VOC concentration decreased approximately 80%, 35% and 100% in wells SB51L-02-3, SB51L-03-1 and SB51L-03-2, respectively. The concentrations remain significantly decreased for almost two weeks following injection in wells SB51L-03-1 and -2, and for almost four weeks in well SB51L-02-3. Following these periods, concentrations rapidly return to pre-injection levels.

Three previously undetected VOCs are measured in the first post-injection groundwater sample (collected three days after injection) from wells SB51L-02-3 and SB51L-03-2, as shown on Figure 5 and 7. This timing strongly suggests these VOCs were created by a chemical reaction resulting from the injection. Additionally, these VOCs are the same as those detected in SB51L-03-1 after the September injection.

The VOC concentration decreases in all three wells following the December injection indicate that either dilution or oxidation of these contaminants occurred. The persistence of the concentration decreases and the generation of new VOC constituents indicate that oxidation was probably the dominant process. The magnitude of the decreases relative to the low ratio of reagent volume to total pore volume further suggests that oxidation rather than dilution was the dominant process. The rapid rebound of concentrations following the December injection is probably due in part to the beginning of significant precipitation in mid-December. Water level measurements in 2001 from an extensive temporary well array in the area indicated precipitation infiltrated through pavement cracks in the vicinity of Building 51L and recharged the saturated zone.

The concentration decrease in SB51L-03-1 is less than in the other two wells following the December event, and there were no new VOC constituents in this well after the December event. The concentration decline and new VOC generation in SB51L-03-1 after the September injection were as significant as those in the other two wells after the December injection, suggesting the chemistry around this well was altered by the September injection event. The availability of endogenous iron may have been significantly reduced following the September event by citrate chelation and subsequent advection away from the well. Reduction in the available iron would have reduced the effectiveness of the December injection, particularly as no iron was injected. Calculation of the average linear velocity could provide some perspective on the likelihood of these hypotheses, however this velocity cannot be estimated from the available water level data. The hydrographs from wells SB51L-02-3 and SB51L-03-1 and -2 are too irregular to confidently ascertaine the water table position within a few months of the injection events. Additionally, the coverage provided by these wells may not be sufficient to determine the gradient within the pilot test area accurately, as demonstrated by the spatial variability of water levels in a denser array of temporary wells in 2001.

No VOCs were detected in the quarterly groundwater samples from monitoring wells MW51L-01-3 and -4 a month and a half after the December injection event. This indicates the December injection did not induce leakage of groundwater from the artificial fill to the Great Valley Group through the intervening colluvial aquitard.

SECTION 6

SOIL RESULTS

Soil samples were collected from soil borings SB51L-04-1 and -2 within the ISCO test area on March 5th, 2004 as shown on Figure 8. Soil samples of the artificial fill from borings SB51L-04-1 and -2 were collected from within half a foot of the depth of pre-ISCO test soil samples from adjacent borings SB51L-01-9 and -3, respectively, as shown on Figure 9. All of these samples were collected by direct-push coring using plastic liners. Comparisons of the most commonly detected VOCs in the soil samples (PCE, TCE, and cis-1,2 DCE) are shown on Table 6 and Figure 10.

The total mass of PCE and TCE after the ISCO test compared to prior to the test was approximately the same while the total mass of cis-1,2 DCE doubled as shown by the sums in Table 6. The ratio of post- to pre-ISCO concentrations for each compound for each sample pair is shown on Figure 11 (only sample pairs with no non-detects are shown). For all sample pairs, the TCE concentration ratio is either within or near the range of the PCE and cis-1,2 DCE ratios.

All of the sample pairs taken at exactly the same depth have a cis-1,2 DCE concentration ratio higher than the PCE and TCE ratios, which is consistent with reductive dechlorination of either in-situ, or mobilized, PCE and TCE. Sample pairs with mismatched depths have the reverse: a cis-1,2 DCE concentration ratio lower than the PCE and TCE ratios. The coincidental probability of this correlation is 1:84, therefore it is likely the cause of the reverse ratios is the sample depth difference. The pre-test concentrations may not have been equivalent at the different depths and/or there might have been differing responses to the ISCO test at different depths.

Sums of the same-depth sample pair results indicate significant reduction in PCE, some reduction in TCE, and more than a doubling in cis-1,2 DCE by mass. Due to the elapsed time between the sample dates, it is difficult to discern if the concentration differences observed are due to naturally occurring reductive dechlorination or due to reductive dechlorination initiated by injection of the chemical oxidation reagents, as was observed at the Building 71B ISCO test. However, the observed concentration changes appear too large to occur naturally during the approximately 3 years between sample collection, as back extrapolation from this rate would imply there was free-phase solvent at the site decades ago, which is not in accord with the groundwater plume shape or concentrations. Therefore, it is more likely that the changes are due to reductive dechlorination initiated by injection of the chemical oxidation reagents, as was observed after the ISCO test at Building 71B. One hypothesis is that the injected citrate was utilized as a growth substrate by the endogenous microbial community.

The sample pair at 5 ft bgs from SB51L-01-9 and -04-1 has the second largest absolute decrease in PCE, the largest absolute decrease in TCE, the largest absolute increase in cis-1,2 DCE, and the smallest post- to pre-test PCE and TCE ratios as shown on Figure 11. This sample pair accounts for most of the TCE mass reduction and most of the cis-1,2 DCE mass increase in the same depth sample pair set. The post- to pre-test cis-1,2 DCE ratio to PCE ratio is also larger than for any other sample pair by almost an order of magnitude, as suggested by the steeper slope for this sample pair on Figure 11. Therefore this sample pair appears to have experienced the most reductive dechlorination of any of the sample pairs. This sample pair was also the only pair to include clean, coarse-grained soil. As previously mentioned, the results of the Building 71B ISCO test indicated that ISCO could induce reductive dechlorination. The results from this sample pair therefore tend to confirm the conjecture that the injected reagents preferentially advected through the coarse-grained soils.

Table 6. Soil sample results from prior and after the ISCO test.

		concentration (mg/kg)											
		PCE				TCE				Cis-1,2-DCE			
Sample Sites	**Depth(s)**	**pre**	**post**	**delta**	**%delta**	**pre**	**post**	**delta**	**%delta**	**pre**	**post**	**delta**	**%delta**
SB51L-01-9 & -04-1	2	0.19	0.0086	-0.181	-95%	0.59	0.14	-0.45	-76%	0.041	0.027	-0.014	-34%
SB51L-01-9 & -04-1	5	0.25	0.0083	-0.242	-97%	3.6	0.79	-2.81	-78%	0.55	1.9	1.35	245%
SB51L-01-9 & -04-1	8.5 & 8.9	0.29	0.37	0.08	28%	0.73	0.67	-0.06	-8%	0.18	0.1	-0.08	-44%
SB51L-01-9 & -04-1	12.5 & 12.2	0.18	1.1	0.92	511%	0.51	1.8	1.3	253%	0.028	0.13	0.1	364%
SB51L-01-9 & -04-1	16.5	0.009	0.06	0.051	567%	0.24	1.3	1.1	442%	0.012	0.34	0.33	2733%
SB51L-01-3 & -04-2	2.3	<0.005	<0.005	0	0%	0.023	0.1	0.1	335%	0.032	0.019	-0.013	-41%
SB51L-01-3 & -04-2	5	<0.005	<0.005	0	0%	0.55	0.12	-0.43	-78%	0.036	0.012	-0.024	-67%
SB51L-01-3 & -04-2	8.5 & 8.8	0.015	0.025	0.01	67%	0.79	1.3	0.5	65%	0.11	0.051	-0.059	-54%
SB51L-01-3 & -04-2	12.5	0.34	0.048	-0.292	-86%	0.34	0.65	0.3	91%	0.066	0.08	0.01	21%
SB51L-01-3 & -04-2	16.5	0.005	<0.005	0	0%	0.49	1.3	0.8	165%	0.04	0.14	0.1	250%
SB51L-01-3 & -04-2	20.5	0.021	<0.005	-0.016	-76%	0.83	0.25	-0.58	-70%	0.37	0.16	-0.21	-57%
Sum		1.31	1.6399	0.33	25%	8.693	8.42	-0.27	-3%	1.465	2.959	1.49	102%
Sum of same depth pair results		0.825	0.145	-0.680	-82%	6.66	4.65	-2.01	-30%	1.15	2.68	1.53	133%

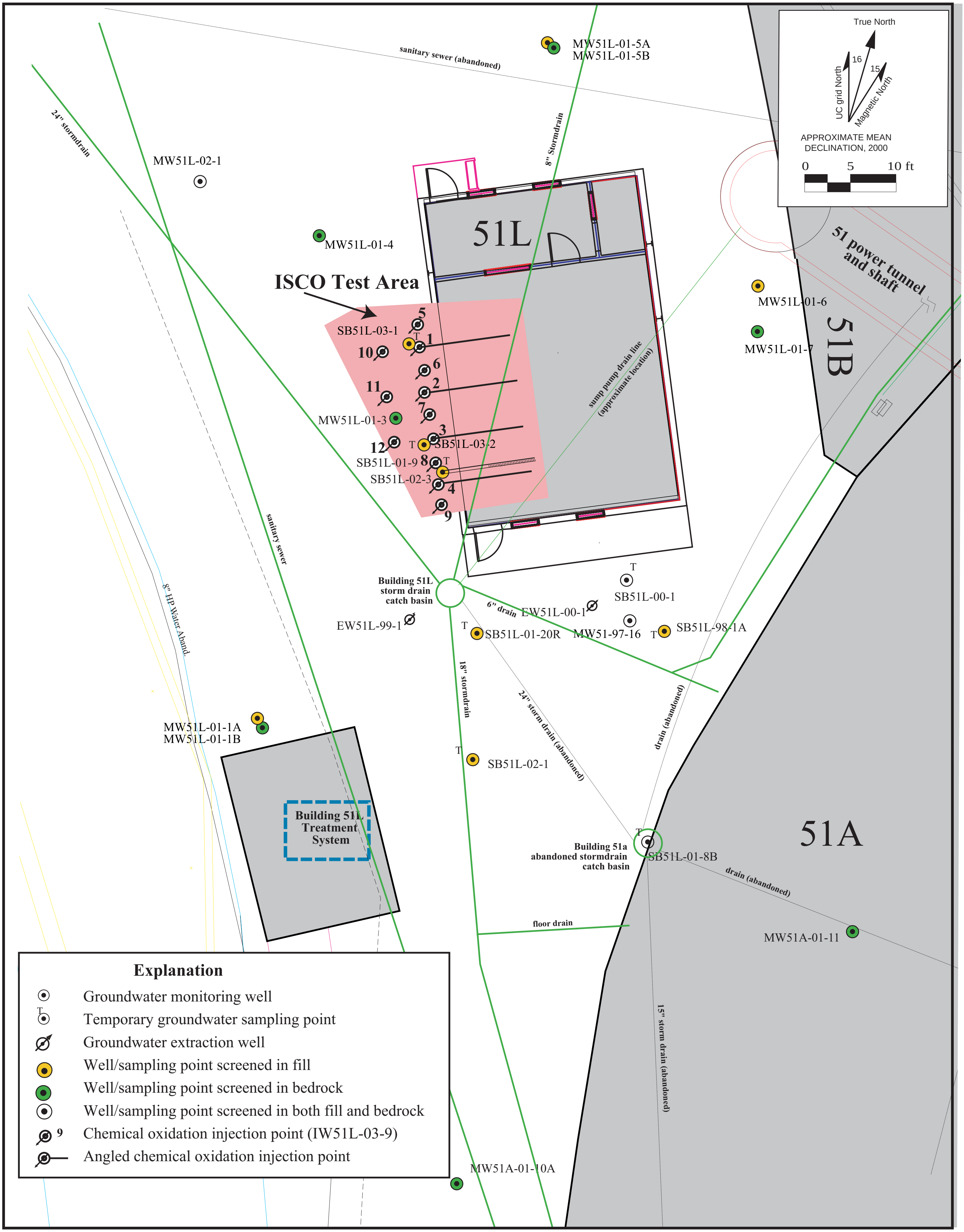
SECTION 7

CONCLUSIONS

The workplan was followed to the extent practicable and economical given the low permeabilities encountered at the Building 51L pilot test site. Based upon changes in the concentrations of VOCs in the wells monitoring the artificial fill within the pilot test area, and the low ratio of reagent volume to total pore volume, ISCO significantly reduced VOC concentrations through oxidation rather than dilution.

The volumes injected represented a small fraction of the total pore space within the pilot test area. These volumes are consistent with injection primarily into the coarser-grained soils in the pilot test volume. Observations of the pH changes during injection are consistent with the hypothesis that reagents primarily infiltrated these “fast paths.” The results of pre- and post-ISCO soil sampling are also generally consistent with this hypothesis. As significant VOC contaminant mass resides within both the coarse- and fine-grained soils, rebound of VOC concentrations after a full-scale ISCO due to advection and diffusion of untreated contaminants residing in fine-grained soils is probably a significant limitation on the success of this remedial method. Discretizing the contaminated zone into a greater number of injection intervals during full-scale ISCO as compared to the two intervals used during the pilot test might increase the effectiveness of ISCO. However, ISCO would probably still fail to reduce contaminant concentrations in the long term even with increased discretization due to the even lower permeabilities, and therefore flow rates, that would be encountered in fine-grained-only injection intervals.

LIST OF FIGURES



12-51L ISCO mapr1.ai
10/03

Figure 1. Locations of in-situ chemical oxidation (ISCO) pilot test area at Building 51L.

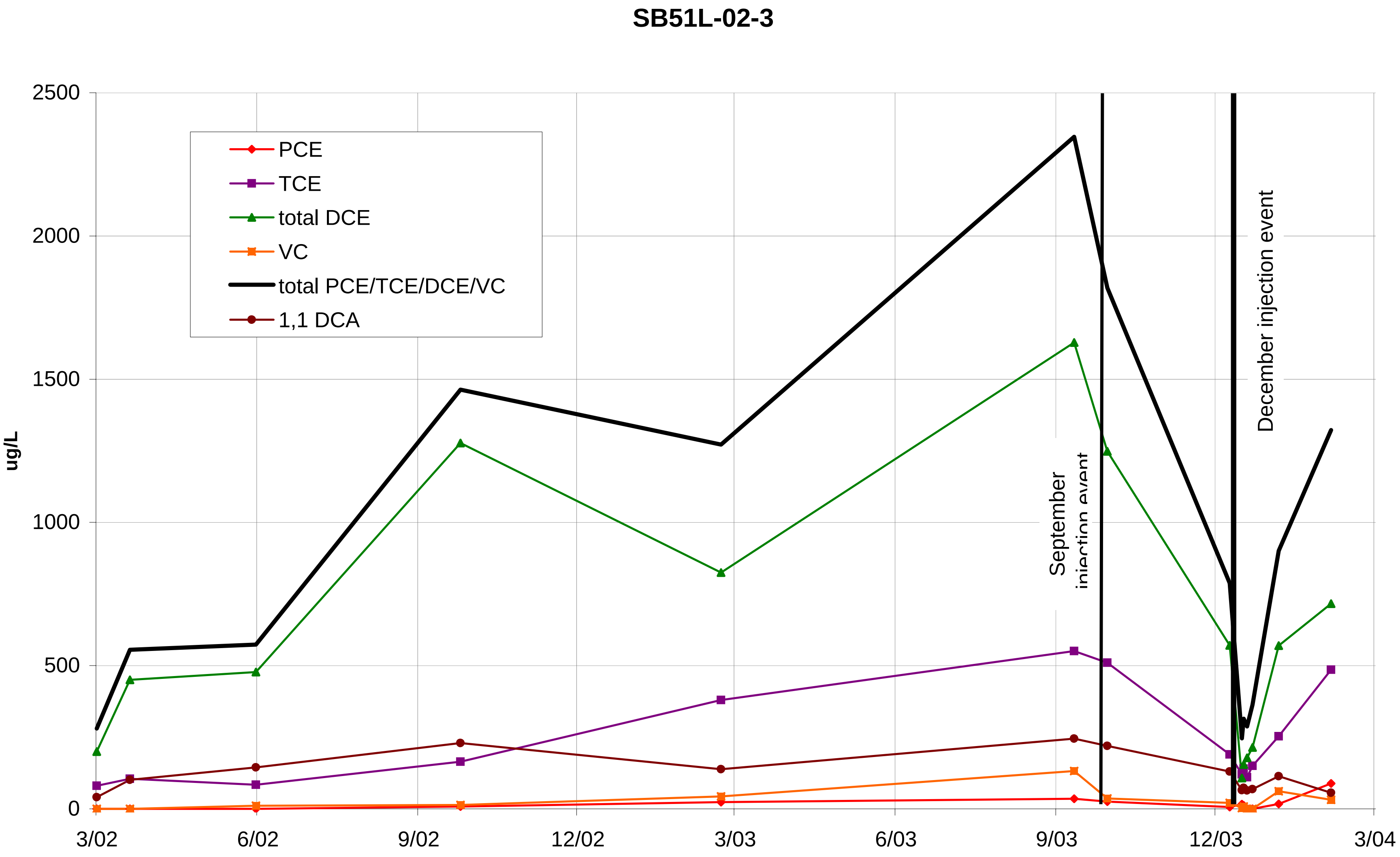


Figure 2. Concentrations of consistently detected VOCs in SB51L-02-3.

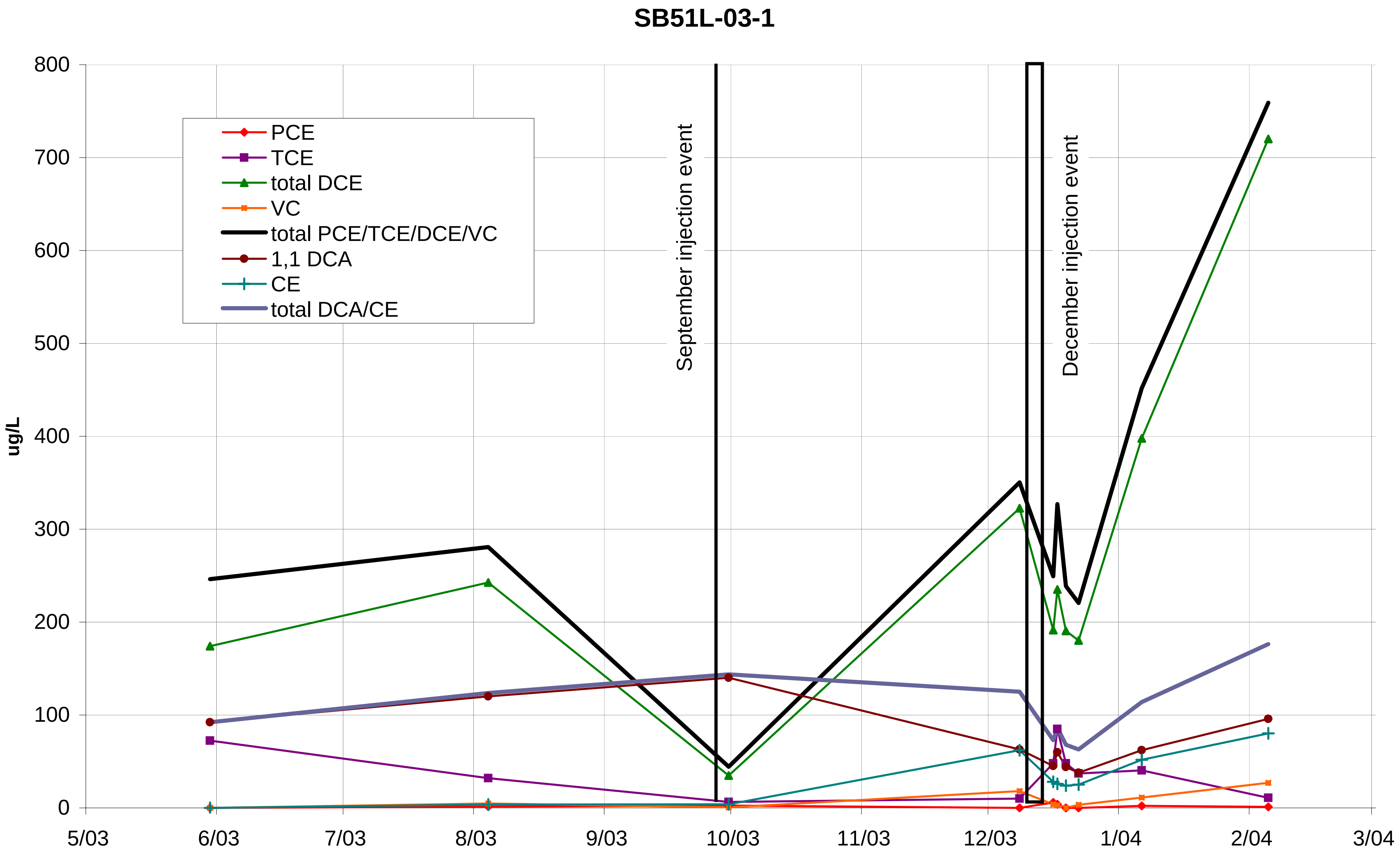


Figure 3. Concentrations of consistently detected VOCs in SB51L-03-1.

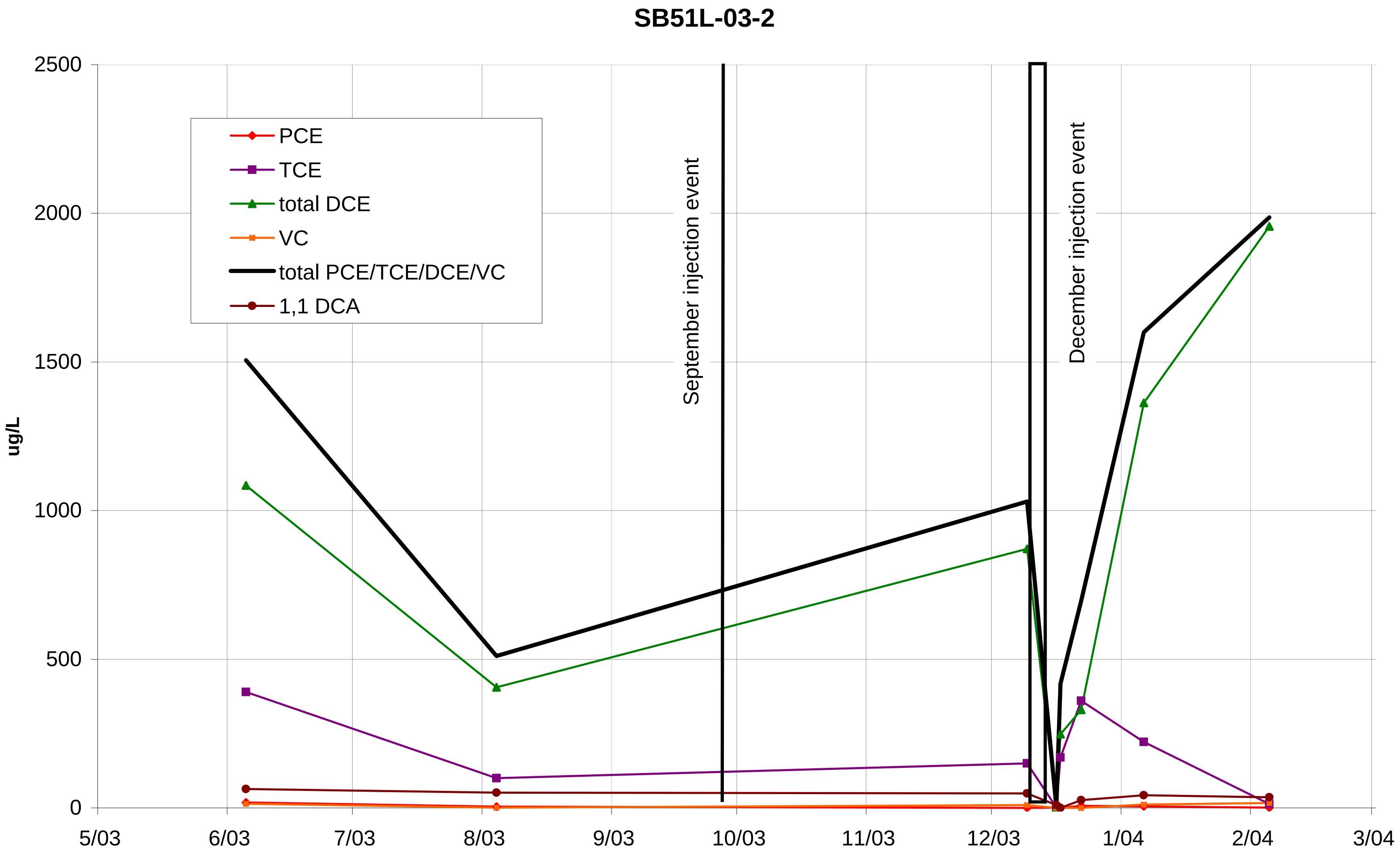


Figure 4. Concentrations of consistently detected VOCs in SB51L-03-2.

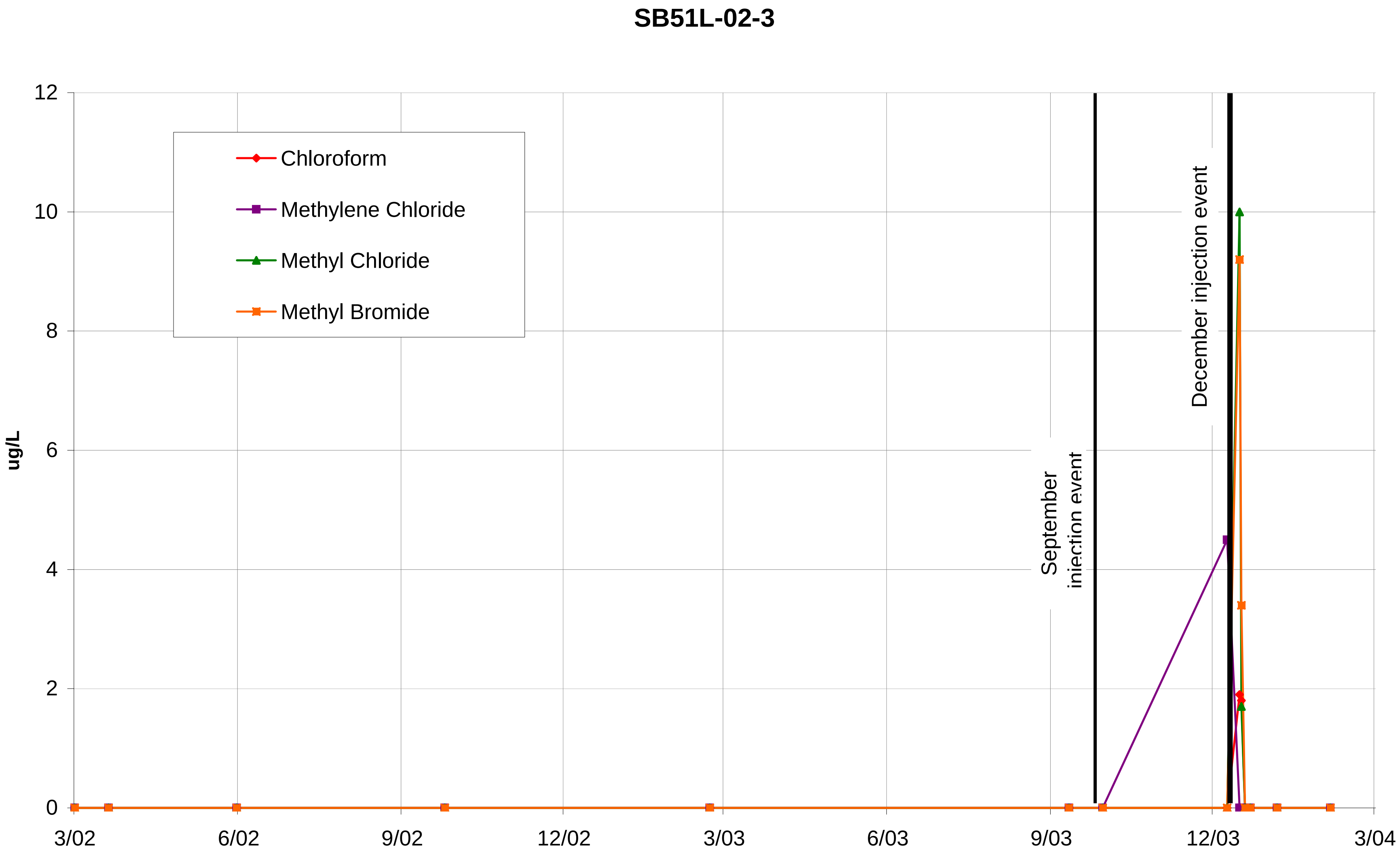


Figure 5. Concentrations of sporadically detected VOCs in SB51L-02-3.

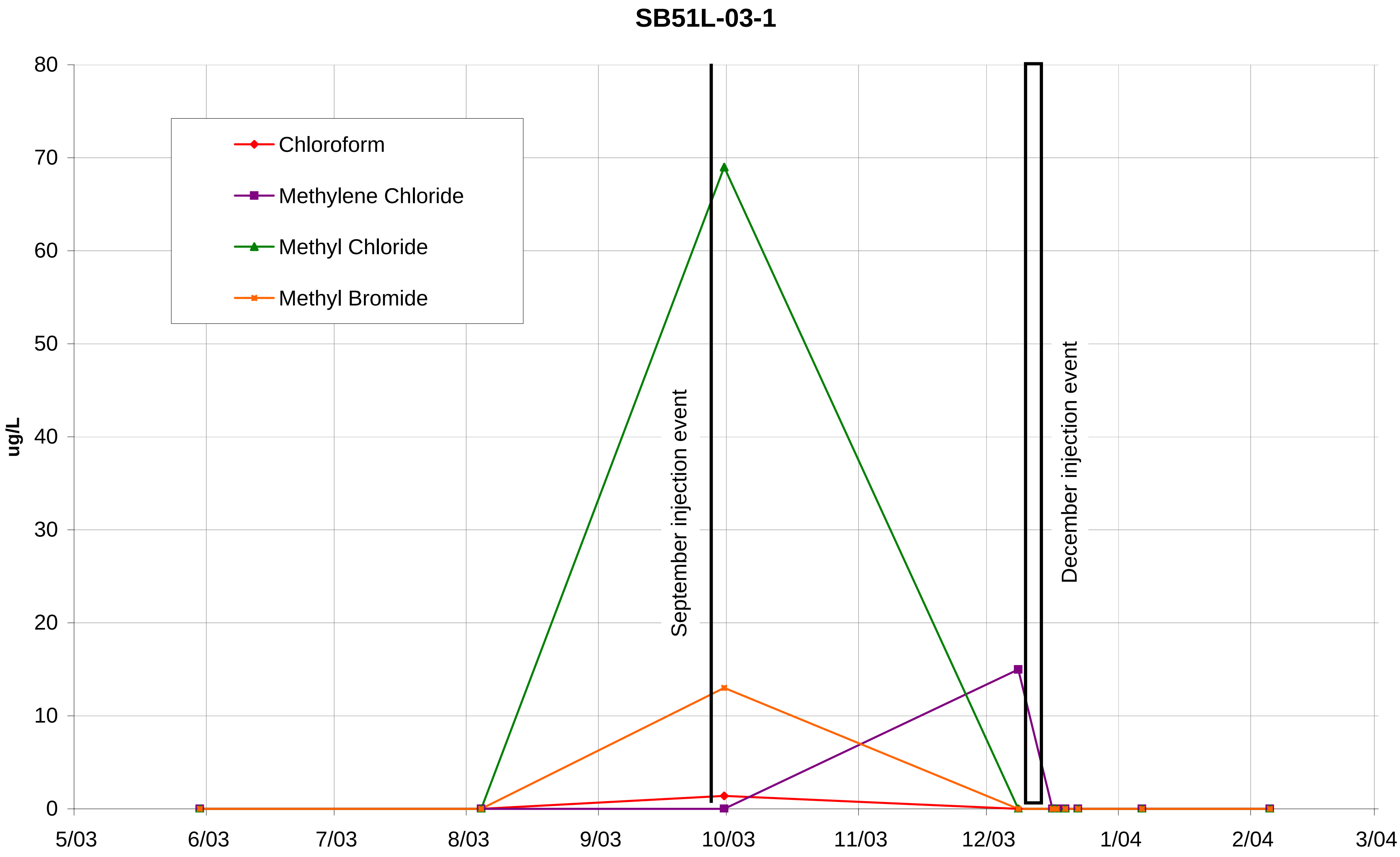


Figure 6. Concentrations of sporadically detected VOCs in SB51L-03-1.

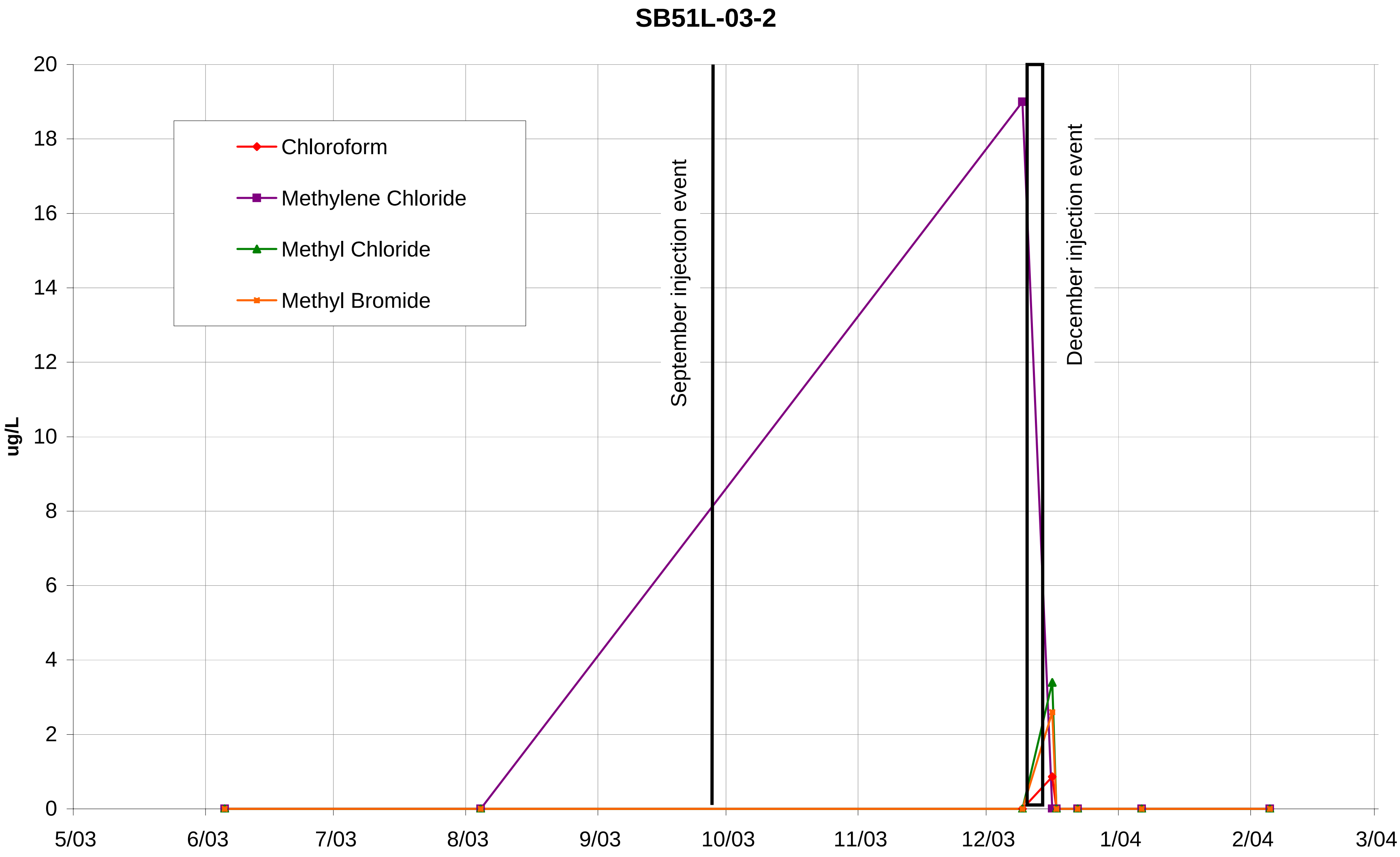
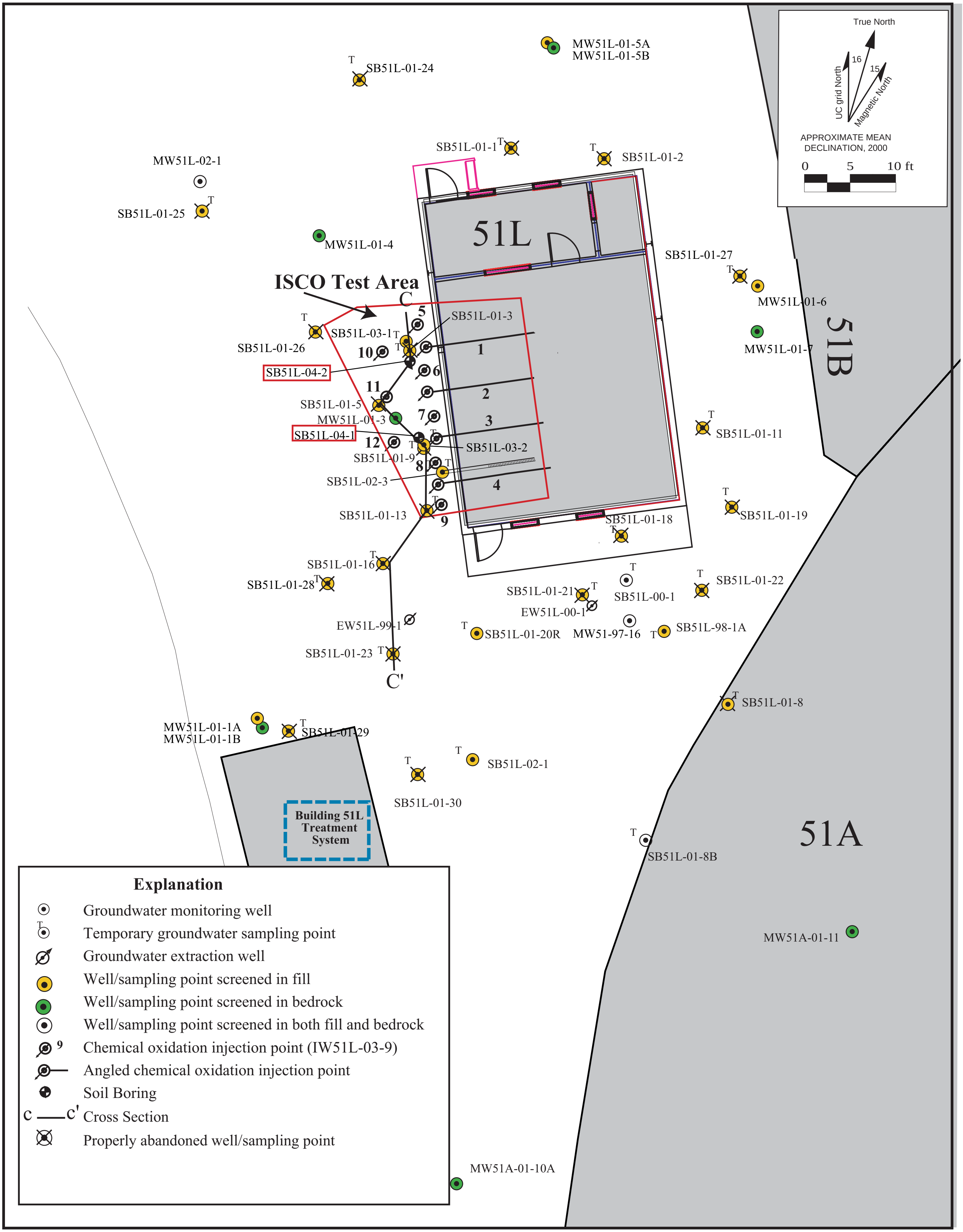


Figure 7. Concentrations of sporadically detected VOCs in SB51L-03-2.



8-51L ISCO.ai
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Figure 8. Locations of cross section C-C' and new borings SB51L-04-1 and SB51L-04-2.

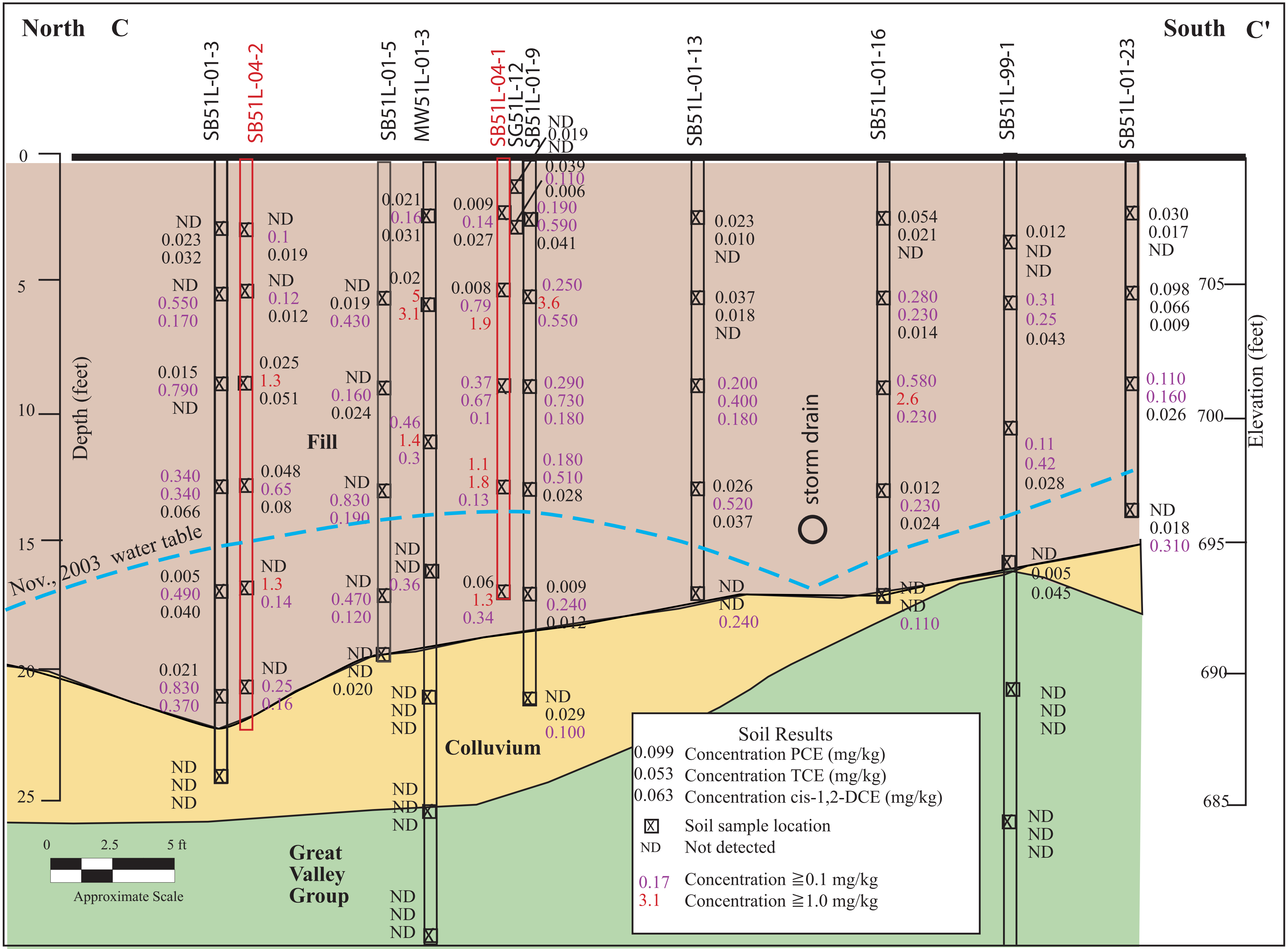

Figure 9. Cross section C-C', Building 51L area, showing concentrations of PCE, TCE and cis-1,2-DCE in soil (mg/kg).

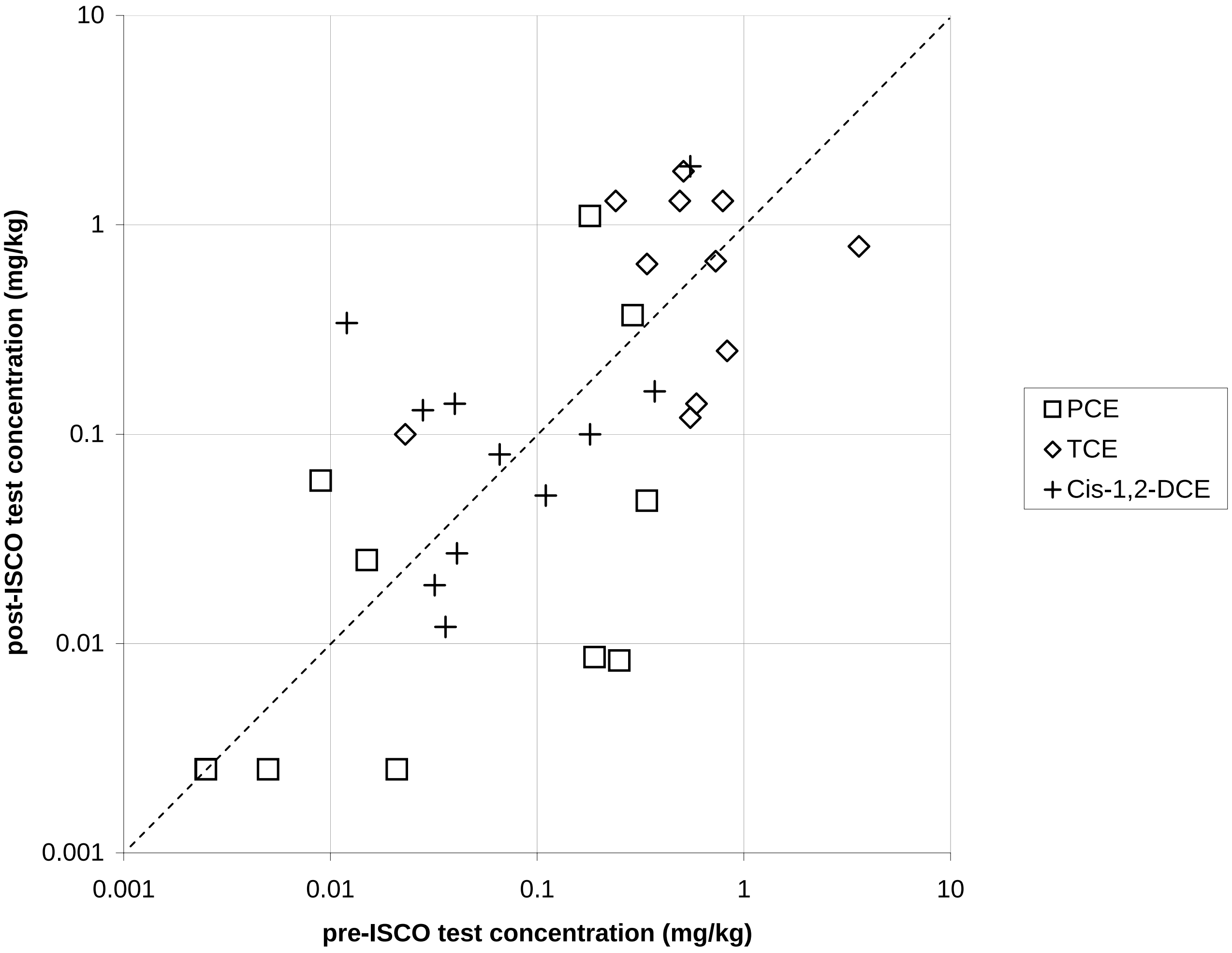

Figure 10. Comparison of the concentrations in soil of the most commonly detected VOCs prior to and after the ISCO test.

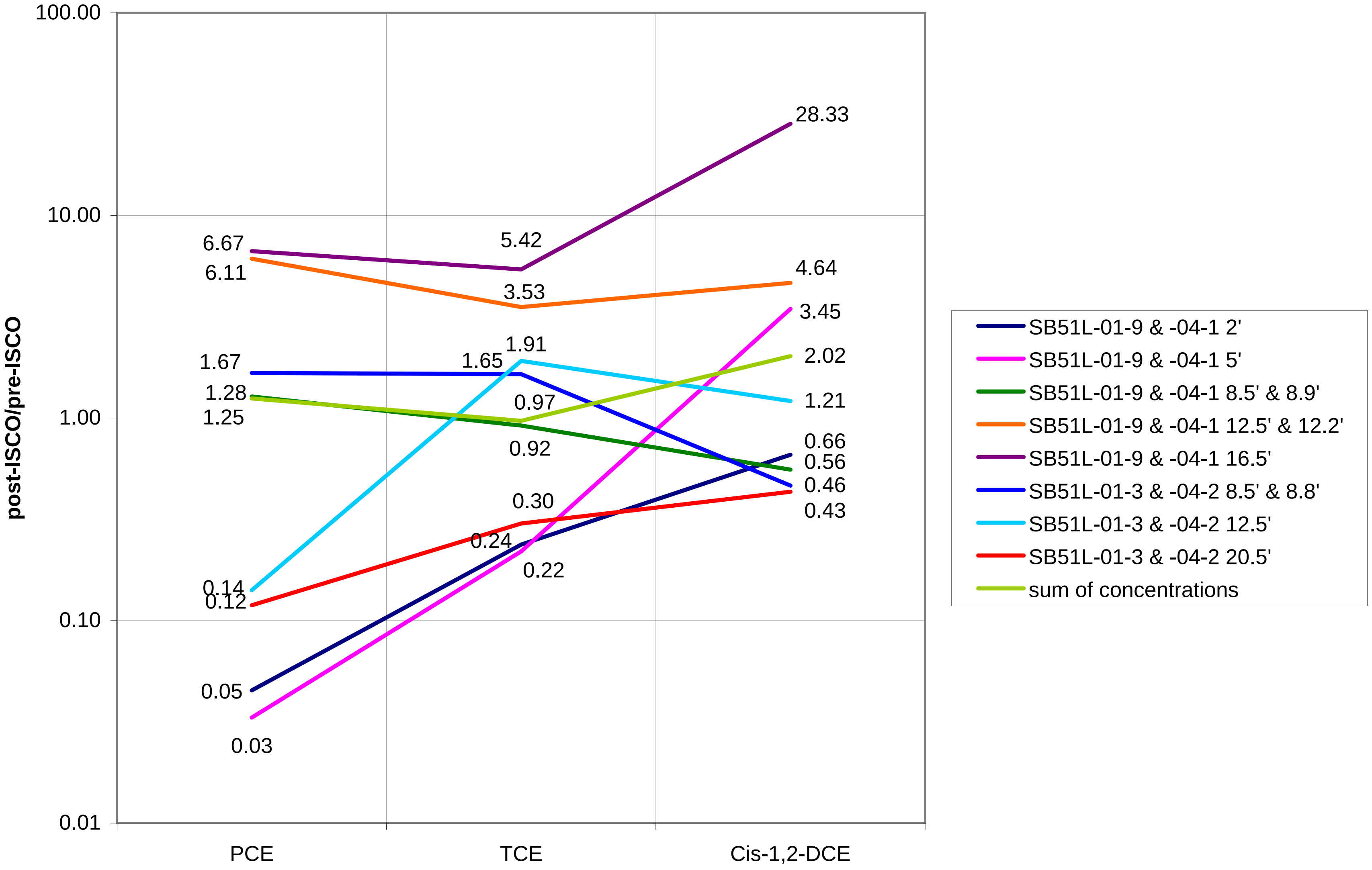

Figure 11. Comparison of PCE, TCE, and Cis 1,2-DCE concentration ratios for each pre- and post-ISCO test soil sample pair. Sample sets with nondetects are not shown.

Appendix C

Cost Estimates for Corrective Measures Alternatives

Appendix C

Cost Estimate Summary for Site-Specific Technology Comparisons
Corrective Measures Study - Berkeley Lab

Hazard Area	**Plume**	**Technology Description**	**Cost Estimate (Constant $)**	**Net Present Value**					
			Operations Period:	**5**	**10**	**15**	**20**	**25**	**30**
Old Town Groundwater Solvent Plume Bldg. 7 Lobe	Source	Expand DPE treatment system	Cap. =$94,700 O&M = $118,500/yr	$629,800	$1,088,900	$1,479,700	$1,812,300	$2,098,900	$2,342,500
Old Town Groundwater Solvent Plume Bldg. 7 Lobe	Source	Excavate soil	Cap. = $569,200	$569,200	$569,200	$569,200	$569,200	$569,200	$569,200
Old Town Groundwater Solvent Plume Bldg. 7 Lobe	Core	O&M of soil flushing treatment system	Cap. = $22,000 O&M= $62,000/yr	$300,800	$540,100	$743,700	$917,100	$1,066,400	$1,193,400
Old Town Groundwater Solvent Plume Bldg. 7 Lobe	Core	Install In Situ Chem. Ox. Treatment system	Cap. = $4,150,000	$4,150,000	$4,150,000	$4,150,000	$4,150,000	$4,150,000	$4,150,000
Old Town Groundwater Solvent Plume Bldg. 7 Lobe	Core	Excavate soil	Cap. = $6,180,000	$6,180,000	$6,180,000	$6,180,000	$6,180,000	$6,180,000	$6,180,000

OLD TOWN GROUNDWATER SOLVENT PLUME BLDG. 7 LOBE SOURCE AREA
EXPAND DUAL PHASE EXTRACTION with SOIL HEATING and HOT AIR INJECTION COST ESTIMATE

ASSUMPTIONS:

A. Develop work plan for expansion.
B. Expand DPE by adding two additional extraction wells with equipment and heaters.
C. Add two monitoring wells.
D. Dispose of cuttings as hazardous.
E. Perform O&M of treatment system for 30 years.
F. Decommission treatment system at end of project.
G. New construction work will be done in FY04.
H. Decommissioning will be done in FY2034.
I. NPV calculated using EPA method and a discount factor of 3.2%

CAPITAL COST

1.	Work plan	$ 9,700
2.	Expand DPE	$ 51,700
3.	Decommissioning	$ 24,700
4.	Contingency	$ 8,600
	Total Capital Cost	$ 94,700

ANNUAL OPERATIONS AND MAINTENANCE COST (30 YEARS)

1.	O&M DPE	$ 107,700
2.	Contingency	$ 10,800
	Total Annual O&M	$ 118,500

TOTAL PRESENT VALUE COSTS $ 2,342,500

OLD TOWN GROUNDWATER SOLVENT PLUME BLDG. 7 LOBE SOURCE AREA
EXCAVATION COST ESTIMATE

ASSUMPTIONS:

J. Develop engineering/design for excavation.
K. Excavate area that is 200 sf by 60 ft. deep.
L. Excavate by drilling 3ft. dia. Holes (40 ea.).
M. Assume that half of waste is hazardous and half is non-hazardous.
N. Sample soil for VOC and metal.
O. Install two monitoring wells.
P. Remove and replace concrete slabs at the site.
Q. Assume relocate a moderate amount of utilities that are in the work area.
R. Work will be done in FY04.
S. NPV calculated using EPA method and a discount factor of 3.2%

<u>CAPITAL COST</u>

5. Engineering/Design		$ 40,000
6. Excavation		$ 434,300
7. Contingency		$ 94,900
	Total Capital Cost	$ 569,200

<u>TOTAL PRESENT VALUE COSTS</u>	$ 569,200

OLD TOWN GROUNDWATER SOLVENT PLUME BLDG. 7 LOBE CORE AREA
O&M of EXISTING SOIL FLUSHING TREATMENT SYSTEM

ASSUMPTIONS:

T. Perform O&M of treatment system for 30 years.
U. Decommission treatment system at end of project.
V. Decommissioning will be done in FY2034.
W. NPV calculated using EPA method and a discount factor of 3.2%

<u>CAPITAL COST</u>

8.	Decommissioning		$ 20,000
9.	Contingency		$ 2,000
		Total Capital Cost	$ 22,000

<u>ANNUAL OPERATIONS AND MAINTENANCE COST (30 YEARS)</u>

3.	O&M Soil Flushing System		$ 56,000
4.	Contingency		$ 6,000
		Total Annual O&M	$ 62,000

<u>TOTAL PRESENT VALUE COSTS</u>	$ 1,193,400

OLD TOWN GROUNDWATER SOLVENT PLUME BLDG. 7 LOBE CORE AREA
INSTALL a CHEM. OX. TREATMENT SYSTEM

ASSUMPTIONS:

X. Much of installation is on a steep side slope.
Y. Develop engineering/design for new construction.
Z. Install a Chem. Ox. Treatment system for an area of 9,100 sf. by 50 ft. deep. (364 wells)
AA. Figure moderate utility relocation.
BB. Remove asphalt and replace.
CC. Remove stairs and replace.
DD. Install road and cut benches to access slope.
EE. Slope will require shoring.
FF. Soil cuttings from well drilling are considered as hazardous waste disposal, all other excavation is considered non-hazardous disposal.
GG. New construction work will be done in FY04.
HH. Decommission treatment system at end of project.
II. NPV calculated using EPA method and a discount factor of 3.2%

CAPITAL COST

10. Engineering/Design		$ 420,000
11. In Situ Chem. Ox. System		$ 2,100,000
12. Decommissioning		$ 940,000
13. Contingency		$ 690,000
	Total Capital Cost	$ 4,150,000

TOTAL PRESENT VALUE COSTS $ 4,150,000

OLD TOWN GROUNDWATER SOLVENT PLUME BLDG. 7 LOBE CORE AREA
EXCAVATE CONTAMINATED SOIL

ASSUMPTIONS:

JJ. Much of installation is on a steep side slope.
KK. Develop engineering/design for new construction.
LL. Excavate core plume area of approximately 7,700 sf by 50 ft. deep.
MM. Figure two areas of the above excavation, each approx. 700 sf will be excavated by drilling 3 ft. dia. Boreholes. The rest will be excavated with long reach excavators.
NN. Figure moderate utility relocation.
OO. Remove asphalt and replace.
PP. Remove stairs and replace.
QQ. Install road to access slope for excavation.
RR. Excavation will require shoring.
SS. Half of excavation spoils will be reused as backfill and half disposed offsite.
TT. Soil disposal is considered as hazardous waste.
UU. Remove and relocate an existing liquid nitrogen tank.
VV. Backfill area of excavation and return to pre construction conditions.
WW. Install five monitoring wells.
XX. New construction work will be done in FY04.
YY. NPV calculated using EPA method and a discount factor of 3.2%

CAPITAL COST

14.	Engineering/Design	$ 860,000
15.	Excavation	$ 4,290,000
16.	Contingency	$ 1,030,000
	Total Capital Cost	$ 6,180,000

TOTAL PRESENT VALUE COSTS $ 6,180,000

Appendix D

Numerical Simulation of Groundwater Flow in the LBNL Old Town System

Numerical Simulation of Groundwater Flow at the LBNL Old Town Site in Support of Remediation Strategies

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May 2004

ABSTRACT

A calibrated groundwater flow model for a contaminated site can provide substantial information for assessing and improving hydraulic measures implemented for remediation. We developed a three-dimensional transient groundwater flow model for a contaminated mountainous site at which interim corrective measures were initiated to limit further spreading of contaminants. This flow model accounts for complex geologic units that vary considerably in thickness, slope, and hydrogeologic properties, as well as large seasonal fluctuations of the groundwater table and flow rates. Other significant factors are local recharge from leaking underground storm drains and recharge from steep uphill areas. The zonation method was employed to account for the clustering of high and low hydraulic conductivities measured in a geologic unit. A composite model was used to represent the bulk effect of thin layers of relatively high hydraulic conductivity found within bedrock of otherwise low conductivity. The inverse simulator ITOUGH2 was used to calibrate the model for the distribution of rock properties. The model was initially calibrated using data collected between 1994 and 1996. To check the validity of the model, it was subsequently applied to predicting groundwater level fluctuation and groundwater flux between 1996 and 1998. Comparison of simulated and measured data demonstrated that the model is capable of predicting the complex flow reasonably well. Advective transport was approximated using pathways of particles originating from source areas of the plumes. The advective transport approximation was in good agreement with the trend of contaminant plumes observed over the years. The validated model was then refined to focus on a subsection of the large system. The refined model showed that most of the hydraulic measures implemented for remediation are effective.

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1. Introduction

The LBNL Environmental Restoration Program started in the late 1980s. The program deals with the identification and remediation of a variety of so-called Solid Waste Management Units (SWMU) and Areas of Concern (AOC) within Lawrence Berkeley National Laboratory (LBNL), some of which have caused significant groundwater contamination. Detailed investigation and monitoring, regarding the location and origin of hazardous wastes, groundwater plumes, vapor phases in soil, surface water and air, etc., have been conducted since the 1990s. During the last decade, Javandel and his coworkers (Javandel, 1990; LBNL, 2000, 2003) have accumulated a vast amount of data, including geologic profiles, hydrogeologic properties, groundwater levels, contaminant concentrations, and potential degradation. At the same time, interim corrective measures have been initiated toward removing the sources of contamination, excavating contaminated soils, limiting further spreading of contaminants, and cleaning up contaminated groundwater using suitable methods. As a result, most SWMU's and AOC's are of no further concern to regulators, with the exception of some groundwater plumes that are still being monitored, hydraulically contained, or treated (LBNL, 2000, 2003).

Of these plumes, the three plumes at the so-called Old Town site, the earliest developed part of the LBNL, are the most significant ones (see Figure 1). Originating from several sources, these groundwater plumes have a maximum concentration of more than 50,000 μg/L as of 2002. Presently, the contaminant sources have been removed, and several cleanup and containment measures have been initiated. Four groundwater collection trenches have been installed downstream from the plumes. One of them, the Building 7 trench, was installed in August 1996 as a source control measure. Contaminated groundwater has been pumped, treated, and re-injected into upstream wells to flush contaminated soils. Monitored contaminant concentrations in downstream wells are relatively stable, if not declining, because further movement of contaminants is limited by pumping contaminated groundwater from the trenches. However, pumping and treatment is expensive. Prediction of future concentration levels would help control this expense by indicating how long the cleanup and hydraulic containment activities will have to last. To that end, a numerical model was developed for simulating transient groundwater flow at the Old Town site, as a first step toward development of a transport model.

This report describes the development and validation of a transient groundwater flow model for the Old Town site. The groundwater flow model is based on a conceptual model which Javandel and his team developed from the large amount of gathered data (LBNL, 2000). The conceptual model included estimated locations and boundaries of hydrogeologic units, groundwater flow directions, and interpretation of piezometric measurements. In this study, we updated the conceptual model to incorporate new information.

This report consists of five sections: (1) the development of a hydrogeologic model to represent five hydrogeologic units; (2) the development of a transient groundwater flow model, including determination of model domain and boundary conditions, interpolation of initial conditions, and estimation of net areal recharge and local recharge resulting from storm drain leakage; (3) the calibration of heterogeneous rock properties within the Moraga Formation, the Mixed unit, and the Orinda Formation, using the measured water levels at a number of monitoring wells and the measured flow rates at two trenches between July 1, 1994, and June 30, 1996; (4) model validation using a "blind" prediction for the groundwater flow during the period between July 1, 1996, and June 30, 1998; and (5) the assessment of hydraulic measures implemented for remediation using a refined smaller-scale model.

The modeling challenges involved in this study include complex geological conditions, steep hydraulic gradients, strong heterogeneity, complex boundary conditions at the mountainous site, and recharge through the unpaved ground surface and leaking underground storm drains. This report focuses on the development and validation of the groundwater flow model and the understanding of groundwater flow at the Old Town site. A smaller-scale transport model in the focused area of contaminant plumes around Building 7 will be developed in the future.

2. Development of Hydrogeologic Model

The morphological, geologic, and hydrological situations at the Old Town site are complex. Morphology is accentuated by steep hills, deep ravines, and large gradients. The Old Town geologic setting is complicated, consisting of several units with vastly different hydrological properties. The near-surface has been modified by landslides and man-made cuts and fills (see Figure 2).

To capture this complexity, we developed a hydrogeologic model for the Old Town site. The geological data used for model development include geologic profiles of 711 boreholes and wells, cross-sections, and outcrop maps. The uppermost five hydrogeologic units contributing to groundwater flow were considered in this hydrogeologic model. These five hydrogeologic units, in descending order from the ground surface, are the Artificial Fill unit, the Colluvium unit, the Moraga Formation, the Mixed unit, and the Orinda Formation. The Orinda Formation is deep and less conductive of groundwater; only the top portion of the entire unit was considered in numerical simulations. Full descriptions of these units may be found in LBNL (2000).

The hydrogeologic model was developed in three steps: first, all borehole data stored in different formats were assembled; second, a consistency analysis was conducted using borehole-bottom elevations and zero-thickness data points obtained from outcrop maps; and finally, Kriging interpolation was used to generate unavailable information on thickness of hydrogeologic units and elevations of top and bottom of each unit. The data analysis of the three steps aimed to construct the top elevations of the five hydrogeologic units and the thickness of the top four units in a uniform fine grid. Note that some units are not continuous at the site. In cases where a unit is absent, its top elevation is indicated by the bottom elevation of the overlying unit.

2.1. Available Data

Two borehole datasets for the elevation and thickness of different hydrogeologic units were used as the basis for geostatistical interpolation. The first dataset, which was used in the previous hydrogeologic conceptual model, consists of boreholes and wells drilled before 1997. The second dataset consists of 82 boreholes drilled after 1997. In addition, the geologic data on cross-section and outcrop maps are combined with the borehole data to refine the current hydrogeologic model.

The first dataset (pre-1997) consists of geologic depth-sections for 537 boreholes/wells, 15 excavations, 47 outcrops, and 30 roadcuts (for brevity, we referred to each type as a "borehole"). The data record of a borehole consists of UC coordinates, elevation of the ground surface (top of the Artificial Fill unit), depth from the ground surface to the top of each hydrogeologic unit (or the thickness of units), and the elevation of borehole bottom. Of the 629 boreholes, 458 are "full" boreholes, at which the measured top elevation of each hydrogeologic unit is available. There are 171 "partial" boreholes with unavailable thickness/elevations of at least one or more units (usually because boreholes were not drilled deep enough to penetrate into the Orinda Formation).

The second dataset (post-1997) consists of geologic profiles in 82 additional boreholes/wells. The data are in the format of the depth from the ground surface to the bottom of a measured core interval and the corresponding hydrogeologic unit. A unit may consist of a number of intervals. The thickness of each unit is extracted from this dataset and transformed into the data format of the pre-1997 dataset. For a "partial" borehole, in which drilling ended within a hydrogeologic unit, the full thickness of the unit is unknown; in this case, the bottom elevation of the borehole was used in the following consistency analysis.

The pre-1997 and post-1997 data sets were combined to yield a full dataset of 711 vertical geologic boreholes. Of these boreholes, 508 are "full" boreholes and 203 are "partial" boreholes. Each borehole may consist of the geological data for nine parameters: the top elevations of the Artificial Fill unit, Colluvium unit, Moraga Formation, Mixed unit, and Orinda Formation, and the thickness of the Artificial Fill unit, Colluvium unit, Moraga Formation, and Mixed unit. For each of the nine parameters, the total number of data points available is different; the number of available data points for the above nine parameters (in the order) is 708, 691, 671, 576, 511, 691, 671, 576, and 510, respectively. The top elevation of the Orinda Formation is more uncertain than that of the ground surface because fewer measurements are available. The hydrogeologic model requires interpolation of the nine parameters when they are not available at boreholes.

In addition to the 711-borehole dataset, seven cross-sectional maps and one outcrop map are available to better constrain the hydrogeologic model. Each of the cross sections provides detailed information about the elevation/thickness of hydrogeologic units and the location and bottom of monitoring wells and boreholes. The outcrop map provides zero-thickness points for the Moraga Formation and the Mixed unit. These were used to better constraint the thickness of the two hydrogeologic units. A total of 596 data points with zero thickness are available along the edge of the Moraga Formation bowls (see Figure 9), and 483 points are available for the Mixed unit (see Figure 10).

2.2. Consistency Analysis

As the second step of developing the hydrogeologic model, we conducted a consistency analysis to check and improve the hydrogeologic model using all available data. The unavailable data (elevation/thickness) at each of the "partial" boreholes were first interpolated using all other borehole data available. The interpolated data were then modified using the borehole-bottom elevations and information obtained in the geologic cross-sectional maps. Then, the zero-thickness data points for the Moraga Formation and Mixed unit obtained from the outcrop map were finally used to adjust the thickness of these two units.

In the first step, the unavailable data at each of the "partial" boreholes were interpolated using all available borehole data. The unavailable data points for each of the nine parameters were interpolated. For example, we simultaneously interpolated the top elevation of the Orinda Formation at the remaining 200 boreholes using the data in the 511 boreholes with this parameter available. Tecplot 8.0 (AmTec Inc., 1998) was used for this interpolation, based on the kriging algorithm. The same parameters of the interpolation were used for interpolating the elevation and thickness of each hydrogeologic unit.

For each borehole, the first five parameters (i.e., top elevation of each unit) can be used to determine the last four parameters (i.e., thickness of each unit), or the first elevation and the last four thickness parameters can be used to determine the hydrogeologic model. In other words, there is a redundancy in the measured borehole data that can be used for consistency analysis. Ideally, if all nine parameters have been measured at one borehole location, the two methods must give identical stratigraphy. However, if some of the parameters have to be interpolated because certain parameters were not measured, there may be an inconsistency between the thickness directly interpolated and the thickness obtained by the difference between the interpolated top and bottom elevations of a unit. For example, the interpolated thickness of the Moraga Formation may be different from the value obtained using the interpolated top elevations of the Moraga Formation and Mixed units. In general, interpolated thickness is considered less uncertain than interpolated elevations. Therefore, in this study, we used interpolated thickness to develop the hydrogeologic model. These values were compared with the thickness calculated from interpolated elevations (i.e., top elevation minus bottom elevation). If the thickness at a "partial" borehole obtained by the two different interpolation methods was significantly different, geological judgement was applied to make the dataset consistent. Because the Moraga Formation is the most important unit for conducting groundwater, and the top elevation of the Moraga Formation is slightly less certain than the elevation of the ground surface, we used the top of the Moraga Formation as the reference surface. The top elevations of the other four units were determined using this reference surface and the thickness of the top four units.

In the second step, the uncertainty of interpolated thickness values was reduced using the geological information on the cross-sectional maps and our knowledge about the drilling depth of "partial" boreholes. The bottom of a hydrogeologic unit that was only partially penetrated by a borehole must be lower than the borehole bottom. Therefore, in case the interpolated thickness is more than the value obtained using the borehole bottom, the former was assigned to the thickness. Otherwise, the interpolated thickness was corrected and the thickness from the top of this unit to the borehole bottom was assigned. For example, at Borehole HLA:1.169, the boring bottom is 50 ft below the ground surface within the Mixed unit; the top of the Mixed unit is at a depth of 29 ft, indicating that the thickness of the Mixed unit is at least 21 ft; the interpolated thickness was only 0.3 ft because a steep gradient of geologic surface exists in this region. The interpolated thickness was also modified using the cross-sectional maps with information about wells/boreholes.

In the third step, a large number of data points with zero thickness for the Moraga Formation and Mixed unit (available in the outcrop map) were used to better constrain the lateral extent of the two units. For example, the 596 zero-thickness data points of the Moraga Formation were combined with the 711 borehole data points with measured or interpolated thickness, to interpolate the thickness at all locations in a uniform fine grid. This grid area ranges from 2,100 ft to 3,600 ft in the UC easting direction and –400 ft to 900 ft in the UC northing direction; and the discretization in the UC coordinates is 3.75 ft by 3.25 ft. Tecplot, with the kriging algorithm and its parameter values given above, was used for such an interpolation. For the Mixed unit, both zero-thickness data points and the borehole data points were used for the interpolation of its thickness. Only borehole data points were used in interpolating the thickness of the Artificial Fill and Colluvium units and the top elevation of the Moraga Formation, because no additional information about these parameters is available.

From the consistency analysis, we obtained all five parameters (one elevation value and four thickness values) for the 711 boreholes, either available from measurements or from interpolation. The top elevations of the other four units were calculated directly because all unavailable data in "partial" boreholes have been generated. The completed hydrogeologic model at the Old Town site thus consists of the nine parameters in each of the grid nodes in a uniform grid of [2,100, 3,600] by [-400, 900] ft.

2.3. Results and Discussion

Figures 3 through 6 show the top elevations of the Artificial Fill unit, Moraga Formation, Mixed unit, and Orinda Formation, respectively. "Full" boreholes are indicated by red squares; "partial" boreholes are indicated by black squares. Figures 7 through 10 show the thickness of the Artificial Fill unit, Colluvium unit, Moraga Formation, and Mixed unit, respectively. The purple squares in Figure 9 indicate the zero-thickness data points for the Moraga Formation obtained from the outcrop map, and those in Figure 10 indicate the zero-thickness data points in the Mixed unit. Note that the interpolation outside of the model boundary (to be discussed in Section 3) is not reliable, because few boreholes are available.

Figure 3 shows that the center of the Old Town area is located in a relatively flat part of the sloping LBNL site. The ground surface slopes steeply east of the Old Town area as well as downward to the west and south. The gradient of the ground surface in the north portion of the Old Town area is in the east-west direction; in the central portion, the gradient is from northeast to the southwest; in the south portion, from the north to the south. Two platforms of the ground surface can be defined: the first is the one located around Building 25 and along Buildings 6, 7, and 27; the second is the lower one located in the area of Buildings 46, 47, and 58, with a large gradient connected to the first platform. Figure 4 indicates that with a few exceptions, the top surface of the Moraga Formation follows the ground surface. However, this is not the case for the top surface of the Mixed unit (or the bottom surface of the Moraga Formation) shown in Figure 5. One can see three areas (within the boundary of this study) where the bottom of the Moraga Formation forms deep bowls. Moreover, steep gradients can be seen along the edge of the three Moraga bowls, in particular along the south edge of Large Bowl in the north area. These steep gradients on geologic contact surfaces make it difficult to numerically capture the strong spatial variability in the groundwater flow (in terms of water table and velocity). Figure 6 shows the elevation contour of the bottom of the Mixed unit or the top surface of the Orinda Formation.

Figure 7 demonstrates that certain parts of the Old Town area have been artificially filled to create a flat ground surface. The maximum thickness (about 37 ft) of the Artificial Fill unit is located north of Building 6 and west of Building 7. This fill zone was established for the construction of Building 6. This fill zone is hydraulically important because the water table is located within this Artificial Fill unit. The other fill zones are not hydraulically important because the groundwater table is below this unit.

Figure 8 shows a thin layer of the Colluvium unit of less than 10 ft in most of the Old Town area. This soil layer does not conduct saturated groundwater in most of the area, where the water table fluctuates within underlying units. However, the Colluvium unit underlying Building 58 and west of Building 58 (with thickness of about 10 ft) does contribute to saturated groundwater flow under conditions of a stable water table.

Figure 9 clearly identifies the three major Moraga bowls at the Old Town site. The first one (Large Bowl) is located in the area of Buildings 52, 53, and 27; the maximum thickness is approximately 85 ft, and the saturated groundwater flows within the highly permeable zone from the upstream boundary downward to Building 46. The second Moraga bowl (Small Bowl) underlies Building 6, with a maximum thickness of 35 ft; this bowl is smaller, but may be important for transport because contaminants may spread within this bowl. In the south, the third Moraga bowl (South Bowl) underlies Building 25; groundwater flows mainly within the Orinda Formation underlying the Moraga bowl. These discontinuous bowls are important parts of the hydrogeologic model in that they may fill during the wet winter months, resulting in outflow if the water levels reach a critical level.

Figure 10 shows that the maximum thickness of the Mixed unit exists at the north edge of Building 7. Permeability in this area is very small; this low permeability helps maintain high water levels monitored in a cluster of monitoring wells in the area of Building 7. The major contaminant plume originated from this area. Note that no thickness plot was available for the Orinda unit because this unit is very deep.

As indicated in Figures 2 and 5, a geologic divide exists between Large Bowl and the area downstream of Building 58. This divide is formed by the low-permeability Mixed unit and Orinda Formation. To the east of the divide is the thick, water-bearing Moraga Formation. To the west there is a steep downhill slope to the ground surface. This divide prevents groundwater flow in the east-west direction and forms the constrained channel for groundwater flow within Large Bowl. It may explain the co-existence of two separate trends of the contaminant plume originating along the north edge of Building 7. As shown in Figure 1, the main plume forms within the Mixed unit toward Building 58, while a smaller plume exists in Large Bowl towards Building 46. Note also that a saddle at the lower top elevation of the Mixed or Orinda Formation exists within this divide east of Building 47. This saddle is overlain by a thin layer of the Moraga Formation. It may provide a pathway for groundwater flow from Large Bowl to the west when the groundwater level is high enough (e.g., in winter seasons).

3. Development of the Groundwater Flow Model

Based on the developed hydrogeologic model, we developed a numerical model to simulate the variably saturated groundwater flow at the Old Town site. The saturated flow below the water table and the unsaturated flow above the water table were simulated simultaneously, because the time-dependent water table level was unknown until the solution was obtained. Flow model development includes determination of model domain and boundary conditions, initial conditions, net recharge, storm drain leakage, and mesh generation. Model calibration and validation are presented in Sections 4 and 5, respectively.

3.1. Software Used

The TOUGH2 code with module EOS9 is used for the forward simulation of saturated-unsaturated groundwater flow (Pruess et. al., 1999). The module EOS9 accounts for pressure distributions in the saturated zone and saturation distributions in the unsaturated zone. While TOUGH2-EOS9 is designed specifically to simulate unsaturated and saturated flow, the main focus of this report is on saturated flow. A preprocessor and postprocessor are developed in C++ to construct the input files for TOUGH2 forward runs and to analyze simulation results for the complicated groundwater system.

Within the Old Town, an unsaturated zone of relatively small thickness exists in the top portion of the groundwater system. Since the detailed flow processes in the unsaturated zone are not the main focus of this report, a simple (linear) constitutive model is used for the relative permeability and capillary pressure functions. The residual saturation used is 0.1, and the saturation value for the relative permeability of 1.0 and the capillary pressure of 0.0 is 0.8 (Pruess et. al., 1999). The maximum capillary pressure used at the residual saturation is 980 Pa. Initially, all mesh elements above the water table are considered dry, and their saturation is at the residual value. Residual saturation is also assigned to all boundary elements above the water table specified in boundary conditions. This specification of residual saturation ensures that there is little or no boundary flux through the unsaturated zone along the model boundary, a valid assumption because the flow in the unsaturated zone is mainly vertical.

The elevation of the water table was directly obtained from the pressure and saturation distributions obtained in TOUGH2 simulations. An element is considered saturated when its calculated pressure is larger than the reference air pressure and when saturation is close to or equals 1.0. The elevation of the water table is calculated using the elevation and simulated pressure of the first (top) saturated element in a vertical column, as follows

$$Z_{wt} = Z + \frac{P - P_{air}}{\rho_w g},$$

where Z_{wt} is the water table elevation (in meters), Z and P is the elevation and simulated pressure of the top saturated element, P_{air} is the reference pressure in Pa, ρ_w is the density of water, and g is the gravitational acceleration.

3.2. Model Domain

Several factors were taken into account in determining the extent of the model domain. First of all, the groundwater model was intended to provide a basis for understanding the contaminant transport at the Old Town site and was designed as a first step in the development of a full transport model. Therefore, the three major contaminant plumes at the site were included within the flow model system: the Building 7 plume (B7 lobe), the Building 52 plume (B52 lobe), and the Building 25A plume (B25A lobe). Second, the groundwater flow in the main water-bearing unit, the Moraga Formation, needs to be adequately described. Consequently, all three Moraga bowls defined in Section 2 need to be included. Finally, it is difficult to define appropriate boundary conditions for the system because the water table varies significantly in time and space. Therefore, the model boundaries were placed along monitoring wells so that the measured water levels could be used as boundary conditions. At some locations where monitoring wells are not available, flow paths were used to define no-flow boundaries.

Figure 11 shows the model domain in a plan view. The model boundary consists of four boundary-segment groups, with the water table prescribed and four no-flow boundary segments connecting these groups. The four groups are the upstream McMillan Road group, the Building 46 (B46) group, the Building 58 (B58) group, and the Building 6-Lawrence Road (B6) group. A boundary segment group may consist of one or more boundary segments, which in turn contain a number of boundary points (or columns in three dimensions). All boundary points share the same boundary conditions or the same interpolation scheme for boundary conditions. Figure 12 shows the hydrogeologic units in a vertical cross section along the model boundary. The cross section starts at the northwestern corner (Point A) at the UC coordinate (2530, 790) ft, and follows the boundary in a counterclockwise direction. The figure also shows the minimum and maximum water levels measured from 1994 to 1996.

The upstream boundary on the east is along McMillan Road from Point J at the UC northing of 800 ft down to Point G around Building 76 (see Figure 11). On the eastern side of the boundary group, few boreholes are available and the geology is unknown. Groundwater flowing from the uphill region into the model domain is a major water source for the Old Town groundwater system. On the upstream boundary, four monitoring wells were used to determine first-type boundary conditions. The water table changes from about 830 ft in the north up to 920 ft in the southeast. Of the several upstream segments, the segment between Points H and I in Figure 11 is the most important to the groundwater system. This is because most of the system inflow through the model boundary is through this segment, with groundwater flowing within the permeable Moraga Formation into Large Bowl (see Figure 12). This segment was referred to as “B52 influx” segment.

The downstream boundary consists of three boundary segment groups: the B46 group between Points A and B, the B58 group between Points C and D, and the B6 group between Points E and F. The B46 group is located at the east edge of Building 46. A groundwater collection trench extends along this boundary, where contaminated water has been collected for remediation. The water table is maintained at 800 ft in the trench, as observed in well MW46-93-12, and the uniform-constant-head condition can be specified along this boundary. As shown in Figure 12, a small cross-sectional area of the Moraga Formation below the water table accounts for almost all outflow through this boundary segment, through which most of the system outflow moves.

The B58 group (between C and D) was determined based on the groundwater collection trench and the measured water table contours. Contaminated groundwater has been collected in the trench since 1998. The measured flow rate in the trench was used for calibrating the groundwater model. Monitoring wells MW46-92-10 and MW58-95-14 were used to determine the first-type condition on the three boundary segments. Note that these wells have small seasonal fluctuations. Groundwater flows out of the system through the small cross-sectional area of the Artificial Fill unit, Colluvium unit, and Moraga Formation under the water table (see Figure 12).

In the B6 group, four boundary segments exist with first-type conditions. For the first segment along Building 6, few monitoring wells are available to determine the boundary conditions. Because the boundary segment is comprised mainly of the low permeable Orinda Formation, the flow rate crossing this boundary segment is small. The water table contour was drawn using the measured water levels at all monitoring wells, and was corrected by means of the measured water levels at MW37-92-18 and the additional information from the developed hydrogeologic model. The boundary was determined based on the estimated iso-water-level contour line through MW37-92-18. The remaining boundary segments were determined using MW37-92-18, MWP-8, and MW25-95-27. East of MW25-95-27, the boundary stretches along the measured-water table contour line through MW25-95-27.

No-flow boundary segments connect the above four boundary-segment groups. These segments were defined using water table contours measured in about 70 monitoring wells at the Old Town site. No-flow boundary segments are appropriate where (1) contours of the water table are approximately parallel to contours of the ground surface and main hydrogeologic units, and (2) where this behavior is independent of seasonal fluctuations. The definition of these no-flow boundaries was confirmed below by the simulation results in Sections 4 and 5. Note that there are significant head drops along these model boundaries. For example, along the no-flow boundary between the B58 and B6 groups, the head drops from 830 to 780 ft. In such a mountainous system, steep gradients and significant head drops along and across model boundaries provide formidable modeling challenges.

The ground surface shown in Figure 3 defined the top boundary. The bottom boundary was set approximately 60 ft below the top surface of the Orinda Formation. The exact location of the bottom boundary is not important, as long as there is a sufficient vertical distance from the bottom boundary to the water table. Figure 13 shows the elevation of the bottom boundary, which give a domain thickness that varies from 60 ft to 110 ft.

3.3. Mesh Generation

WinGridder 2.0 (Pan, 2001) was used to generate a three-dimensional mesh for the TOUGH2 simulations. The hydrogeologic model and the model-domain boundary were used as input to WinGridder. Figure 14 shows the centroids of vertical columns in the three-dimensional TOUGH2 mesh. Four regions with different mesh resolutions were defined. The first region (Region 1) was defined so as to capture the flow in Large Bowl where groundwater flows toward Building 46. Here the discretization was 18 ft by 18 ft. In the second region (Region 2), the mesh was refined to capture the flow and contaminant plume starting from Building 7 and extending toward Building 58; the cell dimensions were 22 ft by 22 ft. In the northern region (Region 3), groundwater flows primarily from east to west; the discretization was 35 ft by 35 ft. In the southern section (Region 4), groundwater flow occurs mostly within the Orinda Formation, which has low hydraulic conductivity; the discretization was 35 ft by 35 ft. In addition, the mesh was oriented based on flow directions obtained from the measured and simulated water table data. For example, in Large Bowl, the mesh was generated in the direction of 140° with respect to the UC east-west direction and along the main flow direction toward Building 46.

With respect to the vertical direction, the maximum discretization for the Artificial Fill unit, Colluvium unit, Moraga Formation, Mixed unit, and Orinda Formation were 6, 6, 6, 7, and 10 ft, respectively. The minimum discretization for each hydrogeologic unit was 0.1 ft. If the thickness of a unit is less than the minimum discretization, then this unit does not appear in the generated mesh, and the thickness was added to the upper or lower unit.

For the mesh we have 931 vertical columns, including 107 boundary ones, 12,994 elements, and 41,319 connections. This relatively coarse mesh was generated because a large number of forward runs were needed in the calibration to be discussed in Section 4. A refined mesh was used for later model validation, in which only a forward run was needed.

3.4. Boundary Conditions

Boundary conditions for the numerical model were determined using the measured water levels at a number of monitoring wells located on or close to the model boundary. These boundary wells include MW46-93-12, MW46-92-9, SB58-98-17, MW58-95-18, MW37-92-18, MWP-8, MW25-95-27, MW26-92-11, and MW52-94-10 (see Figure 11). In addition, MW91-9 and MW52-95-2B, located within the model domain away from the boundary, were used to project the measured water levels to the upstream boundary. There are three kinds of conditions for boundary segments: no-flow condition, spatially uniform head condition, and spatially varying head condition. All boundary conditions with specified heads are time dependent, because of the strong seasonal changes in the groundwater system.

There are six no-flow boundary segments, marked in black in Figure 11. Of the six no-flow boundary segments, two segments are located in the upstream boundary group. These two segments are located next to the “B52 influx” boundary segment. The determination of the two segments was based on the observation that the water table remains time independent at the interface between the upper, permeable Moraga Formation and the lower, much-less-permeable Mixed unit and/or the Orinda Formation. Because flow through these less permeable units is negligible, a no-flow boundary was used. Groundwater flow in all other four no-flow segments is along the boundary, which is perpendicular to water table contour lines.

There are six boundary segments marked in red in Figure 11. On each of these boundary segments the water levels are spatially uniform, but vary in time to represent seasonal fluctuations. Uniform head condition was specified using the measured water level at a representative well. For example, the measured water level at MW46-93-12 was used to specify hydraulic head on the segment for the B46 group.

There are six boundary segments with spatially varying head conditions, so specified, because the water level varies significantly along their boundary segments. The condition in each boundary column located within a boundary segment was determined by linearly interpolating the measured water levels at two representative wells. For example, the water levels in the boundary segment between MW37-92-18 and MWP-8 were determined by spatial interpolation of the measured water levels in the two wells.

In some cases, boundary wells started to measure after the onset of simulation. When the starting time of measurements of the water level is later than the initial time of simulation (July 1, 1994), an extrapolation of water level was calculated using a representative well, close to the boundary well. For example, there are two representative wells for the “B52 influx” boundary segment: MW52-94-10 and MW52-95-2B. The water level at MW52-95-2B was interpolated for the first simulation time period using the measured water level at MW53-93-9. Extrapolation was conducted using the minimum water level and the ratio of seasonal changes between the two wells. The measured water level at MW46-92-9 is not reliable; the water level at this well was interpolated using the levels at MW46-93-12 and MW51-94-15. At SB58-98-7, which is located in the Building 58 collection trench, the water level fluctuates between 778 ft in the summer and 780 ft in the winter. Linear interpolation in a year at the well was used, and the same pattern was used for each year.

Note that seasonal water level changes in the upstream boundary group are significantly larger than those in the downstream boundary groups. For example, the measured water-level fluctuates between 913.9 ft in the summer to 926.5 ft in the winter at MW26-92-11; the measured water level at MW52-95-2B ranges from 837.1 ft to 859.2 ft. In the B58 boundary group, the seasonal change in water level is less than 4.0 ft (see Figures 22 and 23).

Figure 12 shows the maximum and minimum water levels specified along the model boundary with hydrogeologic information. Along the downstream boundary, there are two segments with significant groundwater flow resulting from large hydraulic conductivity. The first is along Building 46 (Section Segment A–B), where groundwater flow leaves the model domain through a small saturated cross-sectional area of the Moraga Formation. This area accounts for most of the outflow from the groundwater system. The second most significant outflow is located in the B58 group (Section Segment C–D), with a small cross-sectional area of the Artificial Fill and Colluvium units. This small area may account for 10-20% of the total outflow of the system. Most segments of the downstream boundary are located within the Orinda Formation of low hydraulic conductivity, so that these boundary segments account for a small fraction of the total outflow.

On the upstream boundary, the most important boundary segment is the so-called “B52 influx” segment (H–I). In the winter, when the water table is higher, a large influx occurs within the large saturated cross-sectional area of the Moraga Formation. In the summer, when the water table is lower, influx is much smaller, as can be inferred from Figure 12.

3.5. Initial Conditions

The initial condition for the transient simulation runs was interpolated based on the measured water levels at a number of monitoring wells. The starting time for the simulation was selected at June 30, 1994, which is in the dry, summer season. The groundwater system can adjust to the specified initial conditions for a few months prior to the first rainfall in September 1994.

The measured water levels at 47 monitoring wells and the interpolated water level along the boundary were used to interpolate the water table for the 931 columns (in the numerical mesh for model calibration). For the monitoring wells completed after June 1994, we used the measured water levels at June 30, 1995 or 1996 to approximate the initial water levels at June 30, 1994.

Figure 15 shows the interpolated initial water table at June 30, 1994 and the wells used for interpolation. Because the interpolation does not reflect the effect of rock-property heterogeneity, the effect of South Bowl on the water table was not represented. In addition, the sharp change in the water table at the southern edge of Large Bowl was also not accounted for. A better representation of the buildup of the water table was achieved at the northern edge of Building 7, where a cluster of monitoring wells were available.

3.6. Recharge and Storm Drain Leakage

Groundwater flow at the site is strongly affected by direct infiltration from rainfall, as well as from leakage from storm drains and other underground utilities, such as domestic water lines and drains. Careful estimate of the infiltration from these water recharge sources is essential for the model, because the seasonal fluctuations of the groundwater table are strong in most of the system, indicating that recharge is an important contribution to water balance.

The areal net recharge through the unpaved areas of the model domain was calculated from the rainfall intensity, the size of the unpaved areas, and a recharge factor (fraction of rainfall infiltrating into groundwater). Appropriate recharge factors were estimated from the slope of the topography and the properties of the surficial soil. Some buildings also contribute to direct infiltration because the rainfall on their roofs directly drains into neighboring unpaved areas. For all paved areas, like parking lots or streets, we used a small recharge factor of 0.02 to represent unaccounted infiltration through small flower beds and pavement joints and cracks, which are too small to be included individually. Figure 16 shows the four types of infiltration areas defined on the basis of the types of land surface coverage and topographic slopes. In each type of infiltration area, further classification was conducted based on the properties of the surface geology.

Table 1. Recharge factor for different kinds of topography

	Paved		Unpaved	
	Building roofs	Others	Steep Slope	Gentle Slope
Soil/Fill	0.07	0.02	0.01	0.07
Moraga	0.40		0.01	0.40
Orinda	0.07		0.01	0.07

Evidence of corroded metal pipes and ruptured concrete pipes has been observed in the field (Zhou et al., 2004). While leakage through such storm drains is critical to the local groundwater system, estimating the amount of leaking water is difficult because it depends on many parameters, such as catchment area, type of damage, and soil type. In the model, storm-drain leakage was calibrated in a systematic manner. First, subsurface utility maps were employed to locate zones of potential leakage from corroded storm drains. Second, for each of the corroded storm drains, the number of pipe segments contributing to leakage and their corresponding discharge catchments were determined. Third, a simple pipe model was developed, based on water balance, without considering changes in mass storage inside a pipe segment. Finally, the recharge factor for each segment was calibrated (with rock properties) using the measured groundwater level at monitoring wells.

In the Old Town area, three locations were confirmed to have a significant amount of water leaking out of storm drains or other underground utilities, as shown in Figure 17. The first one is in the north edge of Building 7. This storm drain consists of four pipe segments with different catchment areas; the first segment at the upstream end receives discharge from the purple catchment of 5,991 sq ft; the catchment directly discharging to the second segment covers 49,745 sq ft; the catchment to the third segment covers 17,534 sq ft; no catchment exists for the fourth segment. The total flow rate into a segment depends on its catchment area, the flow rate coming from the upstream pipe, a recharge factor defining the relative amount of leakage into the underlying volume, and the rainfall rate. It was assumed that 98% rainfall in the catchment areas discharges into the inlet of the pipe, because most of the catchments are paved with a small recharge factor. The total flow rate effectively leaking into the groundwater system, R_i, in the *i*th segment was calculated as:

$$R_i = F_i\left(A_i I + Q_{i-1}\right) \text{ and } Q_i = \left(1 - F_i\right)\left(A_i I + Q_{i-1}\right)$$

where *F* is the recharge factor for the pipe segment, *A* is the area of catchment discharging directly into the pipeline, *I* is net rainfall rate, the Q_{i-1} is the discharge flow rate into the *i*th pipe segment from the upstream segment, and Q_i is the discharge flow rate away from the *i*th segment into the $i+1$ segment. As mentioned above, the catchment areas for the four segments in the B7 storm drain are 5,991, 49,745, 17,534, and 0 sq ft, respectively. The recharge factor for the four segments was 2, 4, 2, and 2%, respectively.

In the TOUGH2 model, each storm-drain segment was represented by a specific element that was added to the mesh. The connections between a storm-drain element and the underlying elements were included within the connection block. Since the lateral spread of the leaked water within the unsaturated zone cannot be appropriately modeled using the mesh selected, we elected to approximate the infiltration by assuming that water was introduced into an effective area around the drains that is three mesh-elements wide.

Storm-drain leakage was also believed to occur in the north edge of Building 14 and in a narrow strip between Buildings 6 and 7 as shown in Figure 17. The recharge from the two storm drains was estimated using a recharge factor. The recharge areas for the two storm drains were 1856 and 2420 sq ft, and the recharge factors were 0.4 and 0.6, respectively.

4. Calibration of Rock Properties

The hydraulic conductivity and “effective” porosity in the five hydrogeologic units were calibrated using the iTOUGH2 code (Finsterle, 1999). In the three-step process, we first defined rock zones of different rock properties for each hydrogeologic unit to capture the heterogeneity of rock properties; the zonation was based on measured hydraulic conductivity values obtained by slug and pumping tests. Second, we calculated the geometric mean and standard deviation of log hydraulic conductivity in each rock zone using the hydraulic conductivity measurements. Finally, we calibrated rock properties for each rock zone by matching the simulated and measured water levels in a number of monitoring wells and by matching the simulated and measured flow rates in the trenches at

Buildings 46 and 58. The time period for the transient calibration is from July 1, 1994, to June 30, 1996.

4.1. Hydraulic Conductivity Measurements

Three methods were used for measuring hydraulic conductivity at the LBNL site: slug tests, pumping tests, and tracer tests (LBNL, 2000). Slug tests were conducted in 105 wells. Test data were analyzed using a computer curve-matching program based on the method of Cooper and others (Cooper et al., 1967) and assuming radial flow away from a fully penetrating well in a confined aquifer. The calculated hydraulic conductivities range from approximately 10^{-10} to 10^{-4} m/s for the five hydrogeologic units. The slug-test calculations for a four-level well cluster indicated extremely low hydraulic conductivity, on the order of 10^{-12} to 10^{-13} m/s, in the Orinda Formation. Pumping tests were conducted in a limited number of wells, primarily in the area of the Old Town groundwater plumes where a sufficient drawdown could be generated. Hydraulic conductivity and storativity were computed using the computer program AQTESOLV, employing a modified Theis solution (Neuman, 1975).

In the entire Old Town area, there are 17, 9, 39, 6, and 37 measured hydraulic conductivity values available for the Artificial Fill unit, Colluvium unit, Moraga Formation, Mixed unit, and upper Orinda Formation, respectively. However, many of these measurements are located outside of the model domain. In the model domain, there are 1, 1, 30, 6, and 13 measured hydraulic conductivities assigned to the five units, respectively. We combined the measurements obtained from slug tests and pumping tests. When both tests were conducted at a well, the results from pumping tests were used. Figures 18–20 show the measured hydraulic conductivity values available for the Moraga Formation, Mixed unit, and Orinda Formation in the model domain, respectively.

In the Artificial Fill unit, the one measured hydraulic conductivity in the model domain is 1.58×10^{-8} m/s. This measurement is located in a large artificial fill zone in the north edge of Building 6. In the entire Old Town area, the measured hydraulic conductivity ranges from 2.24×10^{-9} to 4.00×10^{-6} m/s, with a geometric mean of 2.75×10^{-7} m/s. There is one measured hydraulic conductivity of 3.98×10^{-6} m/s available for the Colluvium unit in the model domain. The nine measurements in the entire Old Town area range from 5.01×10^{-10} to 3.98×10^{-6} m/s, with a geometric mean of 1.12×10^{-7} m/s.

For the Moraga Formation, the 39 measurements in the entire Old Town area have a geometric mean of 2.81×10^{-6} m/s. The 30 measured hydraulic conductivity values in the model domain indicates that the Moraga Formation is strongly heterogeneous (see Figure 18). Three major zones of hydraulic conductivity within the model domain can be defined. The most permeable zone is located in Large Bowl. Small Bowl along Building 6 and South Bowl have intermediate values of hydraulic conductivity. The least permeable zone is located in the north edge of Building 7 at the edge of Large

Bowl. The largest value of measured hydraulic conductivity occurs in the east edge of Building 46, with a value of 3.98×10^{-4} m/s; the smallest value is located in the north edge of Building 7, with a value of 1.26×10^{-9} m/s.

The six measured hydraulic conductivity values for the Mixed unit are available around Building 7 within the model domain (see Figure 19). Apparently, there are three zones of hydraulic conductivity. In the east edge of Building 6, the Mixed unit is most permeable, with a geometric mean value of 1.58×10^{-6} m/s. In the west of Building 7, the Mixed unit is the least permeable, with a geometric mean of 3.55×10^{-9} m/s. To the east of Building 7, the mean hydraulic conductivity is 1.58×10^{-7} m/s.

Figure 20 shows that the Orinda Formation is very permeable to the north of Buildings 5 and 25. The two permeable areas are connected through a narrow area to form a highly permeable zone, with a (geometric) mean hydraulic conductivity of 3.69×10^{-5} m/s. In the northwest portion of the model area, one measurement of hydraulic conductivity is available, with a value of 1.0×10^{-11} m/s. In the south of the model domain, the hydraulic conductivity in the Orinda Formation is on the order of 10^{-7} m/s with strong variability. In the Old Town area, the geometric mean of the 37 measured hydraulic conductivities of the Orinda Formation is 4.27×10^{-8} m/s.

4.2. Zonation of Rock Properties

It can be seen in Figures 18-20 that the Moraga Formation, Mixed unit, and Orinda Formation are strongly heterogeneous in the model domain. Therefore, it is necessary to define rock zones of different rock properties in each of the three units to accurately simulate groundwater flow for both global and local characteristics. Heterogeneity plays an important role in affecting the local groundwater features, particularly beneath the north edge of Building 7. In the Artificial Fill and Colluvium units, few measurements of hydraulic conductivity in the model domain are available to define the heterogeneity of rock properties. However, the major fraction of these units lies above the water table and therefore they do not contribute to the saturated groundwater flow. For this reason, we assumed uniform rock properties within each of the two units.

The zonation of the three major groundwater-bearing units (the Moraga Formation, the Mixed unit, and the Orinda Formation) was based on the analysis of the measured hydraulic conductivity values and the availability of monitoring wells in each of the zones. It was also based on our understanding of local features of the groundwater system. Rezonation was needed for some zones based on the match between measured and simulated water levels at a number of monitoring wells.

Figures 18–20 show the zonation of rock zones of different rock properties for the Moraga Formation, the Mixed unit, and the Orinda Formation, respectively. There are nine rock zones for the Moraga Formation, five zones for the Mixed unit, and four zones for the Orinda Formation. Within some of the rock zones, the values of measured hydraulic conductivity are very close to each other, exhibiting the clustering feature of similar hydraulic conductivity.

Tables 2–4 list the definition of rock zones, available hydraulic conductivity measurements, the geometric mean and standard deviation, and available monitoring wells for the Moraga Formation, the Mixed unit, and the Orinda Formation, respectively. In each zone, the geometric mean of measured hydraulic conductivity values was calculated when one or more measurements are available; when there is no measurements for a particular zone, the geometric mean of all measurements in the model domain was used. The standard deviation was calculated directly using the measurements in a zone when three or more measurements are available; otherwise, the standard deviation calculated for the entire model domain was used. The geometric mean of hydraulic conductivity in a zone was used as prior information to the optimal rock properties to be calibrated; the standard deviation was used as the weighting factor in iTOUGH2.

The appropriate zonation of rock properties is particularly important in the area north of Building 7. In this area, the local groundwater system is very complicated because of the interaction between the different hydrogeologic units and the strong heterogeneity of rock properties. The water table builds up at the steep slope of the interface between the Moraga Formation and the Mixed or Orinda Formation. To improve the initial zonation, we found it necessary to make the following changes: (1) extend the Moraga zone 7 (mrg37) to the east to include MW16-94-13; (2) extend the Mixed zone 3 (mix43) east to the upstream boundary; and extend the Orinda zone 3 (ord53) south to be in contact with Orinda zone 2 (ord52). This rezonation increased the water table in the B7 area and improved the match between the measured and the simulated water table in this area. The other important zone is the Orinda zone 2 (ord52), located close to the upstream boundary in the north of Buildings 5 and 25. Unlike other zones of the Orinda Formation, this zone is highly permeable, conducting groundwater from the upstream boundary downstream to Small Bowl underlying Building 6. This zone supplies a stable discharge to the Building 58 boundary.

One rock zone was used for the Artificial Fill and Colluvium unit. The geometric mean and standard deviation of the measured hydraulic conductivity in the entire Old Town area for the two units was calculated and used to represent those in the model domain. The mean log conductivity is –6.6 for the Artificial Fill unit and –6.9 for the Colluvium unit. The standard deviation is 0.9 and 1.31 for the two units, respectively, as shown in Table 4.

Table 2. Rock zones of different rock properties for the Moraga Formation, with available hydraulic conductivity measurements and monitoring wells

Zone name	Log hydraulic conductivity			Monitoring wells
	Measurements (log m/s)	Mean	Standard deviation	
Zone 1 (mrg31) (base case)	-6.0	-6.0	1.15*	
Zone 2 (mrg32) (upstream boundary)	-5.7, -5.8, -5.9	-5.8	1.15*	B46 Boundary flux
Zone 3 (mrg33) (large Moraga bowl)	-4.8, -4.4, -4.2, -4.5, -4.7	-4.5	0.24	MW91-8, MW53-93-17, MW53-93-9, MW52-95-2B, MW91-7, MW53-93-16B
Zone 4 (mrg34) (B46 boundary)	-3.4, -4.9	-4.1	1.15	MW27-92-20, MW46-93-12
Zone 5 (mrg35) (B6 Moraga bowl)	-6.1, -6.3, -6.5, -6.4, -5.9, -5.7, -6.0, -5.6, -5.5	-6.0	0.32	MW6-92-17, MW16-95-3, MW6-95-14, MW7-92-16, MW58-95-11, MW58-93-3
Zone 6 (mrg36) (B25 Moraga bowl)	-5.2, -6.3	-5.8	1.15*	MW25-95-5, MW25-93-15, MW25-94-12
Zone 7 (mrg37) (B7 low K edge)	-6.6, -8.0, -8.9, -5.9	-7.4	1.35	MW7B-95-21, MW7-95-22, MW7-95-23, MW7B-95-24, MW7B-95-25, MW90-2, MW7-92-19, MW52B-95-13, MW16-94-13, MW7-94-3
Zone 8 (mrg38) (B58 bowl)	-7.8, -5.3	-6.6	1.15*	MW58A-94-14
Zone98 (mrg39) (B25 North)	-4.4, -6.0	-5.2	1.15*	

*Note: for a rock zone with less than four measurements, the standard deviation calculated using all the measurements in the Moraga Formation is used.

Table 3. Rock zones of different rock properties for the Mixed unit with available hydraulic conductivity measurements and monitoring wells

Zone name	Log hydraulic conductivity			Monitoring wells
	Measurements (log m/s)	Mean	Standard Deviation	
Zone 1 (mix41) (base case)		-7.0	1.25*	
Zone 2 (mix42) (B6)	-5.5, -6.1	-5.8	1.25*	MW6-92-17, MW16-95-3
Zone 3 (mix43) (B7 east)	-6.6, -7.0	-6.8	1.25*	MW52B-95-13, MW16-94-13, MW7-94-3, MW52-93-14
Zone 4 (mix44) (B7 west)	-8.0, -8.9	-8.5	1.25*	MW7B-95-21, MW7-95-22, MW7-95-23, MW7B-95-24, MW7B-95-25, MW7-92-19, MW90-2
Zone 5(mix45) (B25 mixed bowl)		-7.0	1.25*	MW25-95-5, MW25-93-15, MW25-94-12

*Note: for a rock zone with less than four measurements, the standard deviation calculated using all the measurements in the Mixed unit is used.

Table 4. Rock zones of different rock properties for the Orinda Formation, with available hydraulic conductivity measurements and monitoring wells, and rock zones of the Artificial Fill and Colluvium units

Zone name	Log hydraulic conductivity			Monitoring wells
	Measurements	Mean	Standard deviation	
Zone 1 (ord51) (base case)	-6.7, -6.7, -7.1, -8.1, -10.5	-7.8	1.42	MW25A-95-4, MW37-92-5, MW25A-95-15
Zone 2 (ord52) (B25 high K)	-4.0, -4.6, -4.7, -6.2	-4.9	0.38	MW91-9, MW5-93-10
Zone 3 (ord53) (North Low K)	-10.9	-10.9	2.07*	
Zone 4(ord54) (South Low K)	-6.1, -7.6, -7.9	-7.2	2.07	
Artificial Fill (fil11) (the Old Town area)	-7.3, -6.5, -6.4, -6.2, -6.1, -6.1, -5.7, -7.8, -7.5, -7.3, -7.0, -8.6, -6.3, -6.0, -5.6, -5.6, -5.4	-6.6	0.90	
Colluvium (quu21) (the Old Town area)	-9.3, -8.9, -6.5 -5.9, -7.0, -6.7 -6.5, -6.2, -5.4	-6.9	1.31	

*Note: for a rock zone with less than four measurements, the standard deviation calculated using all the measurements in the Orinda Formation is used.

4.3. Groundwater Subsystems

To better understand and describe the Old Town groundwater system, we divided the entire system into four subsystems, based on the heterogeneity of rock properties and local characteristics of groundwater flow and the water table (see Figure 26). The first subsystem (called the Large Bowl subsystem) is located in Large Bowl, where flow occurs in the highly permeable and thick Moraga Formation. The water table is flat with large seasonal fluctuations. This subsystem is recharged by the influx from the upstream boundary and by rainfall. Groundwater flows toward Building 46 within Large Bowl confined by the interface between the Moraga Formation and the underlying Mixed or Orinda Formation (see Figure 5).

The second subsystem (called the B7 subsystem) is located at the north edge of Building 7, between the first and the third (or the fourth) subsystem. There are several wells installed for monitoring the water table and the contaminant transport in the Building 7 area. The heterogeneous rock properties and the steep slope of the bottom of the Moraga Formation make it difficult to accurately simulate the local features of water table and groundwater flow.

The third subsystem (called the Small Bowl subsystem) is in Small Bowl underlying Building 6. This subsystem is recharged by groundwater from the upstream Orinda Formation and two possible leaking storm drains located at the north of Building 14 and between Buildings 6 and 7. Groundwater in this subsystem supplies stable discharge to the Building 58 area, where groundwater has been collected in the B58 trench at a rate of about 10,000 gal/month.

The fourth subsystem (called the South Orinda subsystem) is located in the south of the Old Town area. The saturated groundwater flow occurs primarily within the Orinda Formation with low hydraulic conductivity. The water table changes from above 900 ft on the upstream boundary down to about 830 along the downstream boundary (the B6 boundary group).

4.4. Inverse Modeling

We applied the iTOUGH2 code (Finsterle, 1999) to the calibration of rock properties in the defined 20 rock zones within the five hydrogeologic units. The most important properties are the rock hydraulic conductivity and "effective" porosity. The "effective" porosity was defined for the modeling purposes as the mean continuum porosity of a rock zone, possibly representing the composition of the complicated rock porosity. For example, in the Mixed unit, thin layers of higher hydraulic conductivity have been found within the bedrock of very low conductivity, leading to a fast response in water table changes with seasonal fluctuations (Zhou et al., 2004). The "effective" porosity may be less than the actual physical porosity calculated using rock cores. "Effective" porosity and hydraulic conductivity in each zone were calibrated as model parameters. The measurement inputs to iTOUGH2 are the measured water-level series at 37 monitoring wells, and the flow-rate series collected in the Building 46 trench and Building 58 trench.

In addition, the geometric mean of measured hydraulic conductivity described in Section 4.2 was used as prior information for the parameters to be calibrated. For the three different kinds of measurements (measurements of hydraulic conductivities, water levels, and boundary flow rates), the weighting factors of each measurement in the objective function were selected based on its standard deviation. The standard deviation of 2,000 Pa (0.2 m) was used for the measured water level at each monitoring well. The values of 4,000 gallon/month were used for the standard deviation of flow rates measured in the B46 and B58 trenches. The standard deviations shown in Tables 2–4 were used for the measured hydraulic conductivities in different rock zones.

Because the four groundwater subsystems are separated yet interconnected. We conducted the calibration in two steps. In the first step, rock properties specific to a subsystem were calibrated independently, using the measurements within the subsystem. For example, the hydraulic conductivity of Moraga Zones 2, 3, and 4 (see Table 2 and Figure 18) was calibrated in the Large Bowl subsystem. The measurements used are the measured water levels at the monitoring wells: MW27-92-20, MW91-

8, MW53-93-17, MW53-93-9, and MW53-95-12, and the flow rates collected in the B46 trench. In the second step, the rock properties common to two or more subsystems were calibrated using all measurements in the entire groundwater system. This calibration method was used to avoid unphysical results obtained using the do-it-all-at-once method, which produces very small seasonal fluctuations around the mean water levels at some wells.

4.5. Calibration Results

Table 5 shows the calibrated values of hydraulic conductivity and "effective" porosity for the 20 rock zones in the five hydrogeologic units. Figure 21 shows the comparison between the calibrated hydraulic conductivity values and their prior ones.

The calibrated hydraulic conductivity for Moraga Zone 3 (mrg33) in Large Bowl is close to the geometric mean of the measured values in this zone. The measurements, obtained using pumping tests at five monitoring wells (MW91-7, MW91-8, MW27-92-20, MW53-93-9, and MW53-93-17) within the rock zone, are reliable, with a small standard deviation of 0.24.

The calibrated hydraulic conductivity for Moraga Zone 2 (mrg32) on the upstream boundary may not be the physical conductivity there. This is because on this boundary segment, where the most inflow occurs, uncertainties exist in determining the boundary conditions (water table) using linear interpolation between Well MW52-94-10 and MW52-95-2B, and in the development of the hydrogeologic model. This calibrated value represents the optimal value obtained under the given assumptions. The calibrated hydraulic conductivity in Moraga Zone 4 (mrg34) may be influenced by various uncertainties in the estimation of recharge and upstream inflow rates. The calibrated hydraulic conductivities for mrg32 and mrg34 are also close to their prior values, indicating that the measured hydraulic conductivities in the two rock zones are reliable.

For Moraga Zone 5 (mrg35) in the Small Bowl subsystem, the calibrated and the measured hydraulic conductivities are in close agreement, indicating that the measured hydraulic conductivities are reliable. Of the nine measurements listed in Table 2, four were obtained using pumping tests and the others were obtained using slug tests. All nine measured hydraulic conductivities are very close, with a small standard deviation of 0.32. It can be seen that Small Bowl is less permeable than Large Bowl.

The rock zone of mrg39 was used to control the flow rate from the north high-permeability zone of the Orinda Formation to the high-permeability zone of the Moraga Formation in South Bowl. As the flow rate largely depends on the calibrated hydraulic conductivity of mrg39, we see in Figure 21 that the small calibrated hydraulic conductivity results in a small flow rate recharging South Bowl from the upstream boundary. The calibration of mrdg39's hydraulic conductivity was based mainly on the match between the simulated and measured water-level series for three monitoring wells (MW25-94-12, MW25-93-15, and MW25-95-5) in South Bowl. In dry, summer seasons, the measured water levels are at the interface between the Moraga Formation and the underlying Mixed unit or Orinda

Formation, indicating that the flow rate is low. In wet, winter seasons, there is saturated groundwater flow within South Bowl, because the water level is within the Moraga Formation (see Figure 37).

The largest difference between prior and calibrated hydraulic conductivity occurs for the rock zone (ord53) in the north Orinda Formation. This difference may result from the lowest measured hydraulic conductivity, on the order of 3.5×10^{-11} m/s, which was used as the prior value for calibration. The significant difference may show that the single measured hydraulic conductivity is not reliable.

At the north edge of Building 7, the calibrated hydraulic conductivities for the Moraga Formation (Zone 7), Mixed unit (Zones 3 and 4), and Orinda Formation (Zone 3) units are smaller than in any other locations. This is consistent with what can be seen from measured hydraulic conductivities in Figures 18–20. The water table is located mainly within the Moraga Formation or the Mixed unit in the B7 subsystem. The Orinda Formation has very small hydraulic conductivity, and forces upstream groundwater to flow within the Moraga Formation or the Mixed unit. The low hydraulic conductivity of the Moraga Formation and Mixed units makes it possible to maintain the water table at a relatively high elevation.

Table 5. Calibrated hydraulic conductivities (m/s) and "effective" porosity for the 20 rock zones

Hydrogeologic unit	Zone name	Hydraulic conductivity		Effective porosity
		Prior	Calibrated	
Artificial Fill Unit	fil11	2.5e-7	4.0e-7	0.30
Colluvium Unit	quu21	1.3e-7	4.0e-7	0.30
Moraga Formation	Zone 1, mrg31	1.0e-6	9.7e-6	0.05
	Zone 2, mrg32	1.6e-6	7.0e-6	0.05
	Zone 3, mrg33	3.2e-5	1.9e-5	0.04
	Zone 4, mrg34	7.9e-5	3.7e-5	0.04
	Zone 5, mrg35	1.0e-6	6.3e-7	0.02
	Zone 6, mrg36	1.6e-6	9.7e-6	0.10
	Zone 7, mrg37	4.0e-8	5.0e-8	0.05
	Zone 8, mrg38	2.5e-7	2.5e-6	0.05
	Zone 9, mrg39	6.3e-6	4.0e-8	0.05
Mixed Unit	Zone 1, mix41	1.0e-7	4.3e-8	0.02
	Zone 2, mix42	1.6e-6	2.2e-8	0.07
	Zone 3, mix43	1.6e-7	5.0e-9	0.02
	Zone 4, mix44	3.2e-9	3.0e-8	0.02
	Zone 5, mix45	1.0e-7	4.3e-8	0.02
Orinda Formation	Zone 1, ord51	2.5e-8	1.5e-8	0.03
	Zone 2, ord52	1.3e-5	1.5e-6	0.05
	Zone 3, ord53	1.3e-11	7.0e-9	0.03
	Zone 4, ord54	1.3e-7	2.5e-8	0.03

The match between the calibrated and measured water levels at a number of monitoring wells and the match between the calibrated and measured flow rates at two groundwater trenches for the calibration period from July 1, 1994, to June 30, 1996, will be discussed in the next section, together with the model validation for the time period between July 1, 1996 and June 30, 1998.

5. Model Validation

The development of the conceptual and numerical models has been described in previous sections. The developed model was validated using the "blind" prediction of groundwater flow at the Old Town site for the period from July 1, 1996, to June 30, 1998. During this period, some facilities were established for the remediation of contaminated groundwater. Using these facilities, the contaminated groundwater was extracted by pumping, treated, and then reinjected into the groundwater system to help flush the contaminated groundwater. The effects of the remediation facilities on the local flow were neglected in the model validation, because the model validation was intended to investigate the general picture of groundwater flow. These effects were taken into account in a smaller-scale flow model focusing on the groundwater plume in the north of Building 7, as described in Section 6.

The coarse mesh used for model calibration, described in Section 4, was intended to reduce the computational burden of single forward run on model calibration. The coarse mesh was refined to reduce the inaccuracy of simulation results caused by low mesh resolution. The horizontal discretization in the refined mesh was 18 ft. To match the measured water table at a number of monitoring wells, TOUGH2 nodes were introduced at most of these wells, because the gradients of interfaces between different hydrogeologic units is very large at some locations. The refined mesh consists of 1,901 vertical columns, 39,211 elements, and 118,048 connections. To check the trend of the simulated water table in the entire groundwater system, we simulated the groundwater flow from July 1, 1994, to June 30, 1998, a four-year period that includes both the calibration and validation periods.

Figures 22 and 23 show the measured water-level series at boundary wells in the downstream and upstream boundary groups. The water level in most of the downstream boundary groups is within the Orinda Formation, except for a small cross-sectional area within the Moraga Formation and Artificial Fill/ Colluvium units, as shown in Figure 12. The seasonal fluctuations of the water level are less than 10 ft in the B6 group and less than 4 ft in the B58 group. There are no seasonal fluctuations along the B46 group, because the groundwater collection trench maintains a stable water level of 800 ft. Figure 23 shows the measured water levels at four boundary wells along the upstream boundary. MW26-92-11 and MW52-94-10 are located exactly at the boundary, whereas MW91-9 and MW52-95-2B, which are away from the boundary, were projected to the boundary to represent the water level on the boundary. At MW26-92-11, the seasonal fluctuation of the water level is about 12-14 ft, within the permeable Orinda Formation. At MW52-94-10, the water level is affected by the interface between the permeable Moraga Formation and the underlying Mixed unit of low permeability. This means that the water level at this well is always above this interface (in the winter) or exactly at this interface (in the summer).

5.1. Groundwater Budget

Sources of the Old Town groundwater system are (1) recharge by rainfall on unpaved areas, (2) recharge from leaking storm drains and other underground facilities located in the areas of Buildings 6, 7, and 14, and (3) the inflow from the upstream boundary with a water table higher than the downstream boundary segments. The most important boundary inflow is from the saturated cross-sectional area of the Moraga Formation on the northeast side of Building 52 (Boundary Segment H–I). The outflow through the B46 and B58 groups is the most significant outflow from the system. The annual average values of the rainfall, net areal recharge, storm-drain recharge, boundary influx and outflux, and the change in the groundwater storage in the system, are listed in Table 6. Note that the annual water budget was calculated from July 1 of a given year to June 30 of the next year, because June and July are in dry, summer seasons. Figure 24 shows the monthly rainfall, net areal recharge through unpaved areas, recharge through storm drains at Buildings 14 and 6, and recharge through the storm drain at Building 7. Figure 25 shows the total inflow through upstream boundary segments, total outflow through downstream boundary segments, and water-storage change in comparison with initial water storage in the groundwater system.

As shown in Figure 25a, we obtained good matches between the predicted flow rate at the B46 boundary group and the measured flow rate at the B46 trench, both in terms of transient patterns and minimum/maximum fluxes. For all winter season high flow rates, the matches between predicted and measured processes are very good. However, the matches are not as good for the dry, summer seasons. The reason for the summer-time discrepancies is because the bottom-surface elevation of the Moraga Formation in the north area was possibly underestimated in the hydrogeologic model because of the limited number of boreholes that penetrate into the Orinda Formation in this area. Hence, the simulation overestimated the groundwater flow rates through this permeable unit in summer months. Accurate description of the hydrogeology in the channel near the B46 boundary is critical for an accurate prediction of the minimum flow rates.

As shown in Table 6, the most important boundary inflow is from the saturated cross-sectional area of the Moraga Formation on the northeast side of Building 52, although the net areal recharge through unpaved areas and the recharge through leaking underground facilities are also important. The outflow through the B46 boundary segment accounts for 81% of the total outflow of the system, while that through the B58 boundary-segment group accounts for 12%. We can see a large mass storage obtained at the end of the validation period (June 30, 1998) because a high water table was still maintained on the boundary and within the model domain. The mass-balance error is small for the system, because TOUGH2 is locally and globally mass conservative.

Table 6. Water budget of the Old Town groundwater system during the period of 1994-1998. Note that the unit for flow rates is gallon/year

		1994–1995	1995–1996	1996–1997	1997–1998
Rainfall (inch/year)		45.1	34.24	31.61	60.78
System Input	Net areal recharge	576,475	437,661	404,044	776,900
	B7 storm drain recharge	129,876	98,602	91,029	175,031
	B14 storm drain recharge	27,060	20,544	18,966	36,468
	B6 storm-drain recharge	45,151	34,279	31,646	60,849
	B52 boundary flux	1054,000	738,425	887,825	759,303
	B25 boundary flux	375,049	324,177	288,551	300,078
	Influx on other upstream boundary segments	40,808	39,689	38,904	39,470
System Output	Outflow through the B46 boundary segment group	1536,000	1354,660	1426,590	1455,600
	Outflow through the B58 boundary segment group	133,702	207,836	222,926	210,196
	Outflow through other downstream boundaries	100,641	114,296	110,442	122,328
Change in storage (gallons)		455,500	62,900	-11,400	414,800

5.2. Water Table and Velocity Fields

Figures 26–29 show the water table contours and the two-dimensional velocity-vector fields for different seasons and different years. In winter seasons, the water table rises to a higher level because of recharge and the higher water table on the upstream boundary. The two-dimensional velocity field was defined using the velocity field on the water table. The water table contours and velocity fields show distinct difference between four groundwater subsystems.

The velocity in Large Bowl subsystem is large in comparison to the velocities in the other three subsystems. In dry, summer seasons, the recharge to Large Bowl is from inflow through the upstream boundary and from the South Orinda subsystem because of the large hydraulic gradients. The flow goes via a narrow channel of the saturated Moraga Formation from the southeast to the northwest. The water table is lower, and the total flow-bearing area of the channel is small in comparison with wet winter seasons. This area varies from the southeast to the northwest. The smallest area occurs at the

Building 46 boundary (see Figure 9), resulting in the maximum velocity in the subsystem. In wet, winter seasons, the groundwater flow results primarily from the areal recharge caused by rainfall, the inflow from the upstream boundary, and from the South Orinda subsystem. The flow-bearing cross-sectional area of the saturated Moraga Formation on the upstream boundary is much larger than in summer seasons, and more inflow occurs through the boundary. As a result, the water table rises to a higher level, producing larger capacity of discharge of the channel resulting from its larger flow-bearing cross-sectional area. More water goes through the channel from the upstream boundary to the downstream boundary. The outflow rate through the B46 boundary group is also much larger.

A smaller amount of flow goes through Small Bowl in the Small Bowl subsystem. This system is recharged from (1) the upstream flow in the permeable Orinda area around MW91-9 and MW5-93-10, and (2) recharge on the unpaved areas and storm-drain leaks. The flow rate is relatively stable downstream from the subsystem. In addition, the effect of recharge resulting from the storm-drain leakage can be seen in wet winter seasons.

In the B7 subsystem, the water table remains at a high level, within the Moraga Formation or the Mixed unit. In this subsystem, all hydrogeologic units are much less permeable than elsewhere. As a result, the velocity or flux is small. This subsystem receives recharge (1) from the South Orinda subsystem, (2) from unpaved areas by rainfall, and (3) from the leaking storm drains. Groundwater flows into the Large Bowl subsystem because of large hydraulic gradients. In the winter, the leakage of the storm drains in the north edge of Building 7 results in significant flow into the Large Bowl subsystem. The groundwater flowing away from the Building 7 area extends to the northwest and then is divided by the geological divide of the Mixed and Orinda Formation (see Figure 5). This groundwater feature explains the two co-existing contamination plumes, one toward Building 46 along the west edge of Large Bowl, and the other toward Building 58. The latter contains much higher concentrations of contaminants than the former plume, because concentrations in the former plume have decreased, diluted by clean groundwater flow from the upstream boundary.

In most of the South Orinda subsystem, flow rate is very small because of the small hydraulic conductivity of the Orinda Formation. In the area of Orinda zone 2 (ord52) with higher hydraulic conductivity, we can see noticeable velocities from the boundary around MW26-92-11 down to the area around MW91-9 and MW5-93-10. It is this flow rate that recharges Small Bowl underlying Building 6. In South Bowl, the noticeable velocity results from the high hydraulic conductivity of the Moraga Formation in South Bowl.

In addition, local water mounds arise during the wet, winter seasons, as shown in Figures 27 and 29. All water mounts occur in unpaved areas, where the underlying rock has low hydraulic conductivity (the water table builds up locally as a result of infiltration). In the summer, the water table is smooth, and lower than in winter seasons.

Figures 30 and 31 show very good agreement between the simulated and the measured water table at eight monitoring wells (MW27-92-20, MW91-8, MW53-93-17, MW53-93-9, MW52-95-2B, MW91-7, MW53-93-16B, and MW53-95-12) in the Large Bowl subsystem. The first seven wells are located within the core of Large Bowl, which has a thickness of more than 60 ft. The saturated groundwater flows within the Moraga Formation, with the (saturated Moraga) thickness of 15–30 ft in the summer, and 30–36 in the winter. The seasonal fluctuations in the water table range from 12 ft in the upstream side down to 10 ft in the downstream side. As seen in the water table patterns in these wells, as well as those in the boundary wells, the groundwater is recharged mainly from the upstream boundary and flows northwesterly towards Building 46 in the confined channel of the saturated Moraga Formation. MW53-95-12 is located on the west edge of Large Bowl, and on the geological divide of the Mixed unit and Orinda Formation; the simulated water table within the permeable Moraga Formation is higher than the measured one.

For the B7 subsystem, the simulation and calibration of groundwater flow is difficult, because of the strong heterogeneity of rock properties and the steep gradients at the bottom surface of the Moraga Formation. Figure 32 shows the reasonable match in four monitoring wells in the central area of Building 7: MW7B-95-21, MW7-95-22, MW7B-95-24, and MW7B-95-25. The most important feature for comparison is the average elevation of the water table. The water table in this area is within the Moraga Formation or Mixed unit of low hydraulic conductivity. Note that the water table at MW7B-95-21 was affected by the established facilities for remediation; the measured water table in the summer of 1997 is higher, and stays at a high level afterwards. Figure 33 shows the match at four wells away from the central area of Building 7. Good matches are also found in MW7-94-3 and MW16-94-13, where the water table is within either the Mixed unit or both the Moraga Formation and the Mixed unit. At MW52B-95-13, differences of only 2-4 ft are obtained between the simulated and measured water table. At MW7-92-19, the difference is more than 5 ft, because this well is a “partial” borehole with the boring bottom ending within the Moraga Formation, and the inaccurately interpolated bottom elevation was used in the hydrogeologic model. The interpolated bottom elevation of the Moraga Formation at this well is very similar to that in the four monitoring wells shown in Figure 32, resulting in a simulated water level very similar to that in the four wells. However, the measured water level at MW7-92-19 is 10 ft less than that in the four wells.

For the Small Bowl subsystem, good to excellent agreements were obtained between the simulated and measured water levels at eight monitoring wells (MW16-95-3, MW6-92-17, MW7-92-16, MW6-93-4, MW90-2, MW58-95-11, MW58-93-3, and MW58A-94-14) (Figures 34 and 35). Excellent agreements were found at the two upstream wells: MW16-95-3 and MW6-92-17. At MW6-93-4, the simulated water level is smaller than the measured one by 10 ft, indicating that there may be some local recharge of groundwater into this area. Downstream from Small Bowl, the water level in the Moraga Formation moves into the Artificial Fill and Colluvium units of high porosity, which produce a relatively stable water level with time. This stable water level in turn produces a stable boundary flow rate, as measured in the B58 trench.

Figure 36 shows a reasonable match between the simulated and the measured water level at four wells (MW91-9, MW5-93-10, MW25A-95-4, and MW25A-95-15) in the South Orinda subsystem. MW91-9 and MW5-93-10 are located in the permeable Orinda Formation (Orinda Zone 2), which exhibits seasonal water level changes of more than 10 ft. The simulated water level at MW91-9 is higher than the measured one. At MW5-93-10, the match is very good; groundwater flows downstream within the permeable Moraga Formation. It can be seen from the water table patterns that MW25A-95-4 and MW25A-95-15 are hydraulically disconnected because of the embedded highly permeable Orinda Formation between them. Figure 37 shows the match in three wells (MW25-94-12, MW25-93-15 and MW25-95-5) located in South Bowl. The water level at MW25-94-12 is within the Moraga Formation and has the seasonal fluctuations of 5 ft (and above the top of the Orinda Formation). At MW25-93-15, the water level is exactly at the top of the Mixed unit for most of the years, with a small seasonal rise in the winter. At MW25-95-5, the water level is within the Moraga Formation about 15 ft above the bottom of the Moraga Formation, but its seasonal change is small (less than 5 ft).

In summary, the model prediction of the groundwater flow at the Old Town site using the calibrated rock properties with our conceptual model is reasonable, as shown in comparison with the extensive measured water levels in a number of monitoring wells and the groundwater flow rates measured at two trenches. The numerical model helps us understand groundwater flow in this strongly heterogeneous system. It can also be used to accurately predict groundwater flow in the future. Meanwhile, it can be used with a transport model (to be developed) to predict the transport processes of the contaminants in the two plumes in the Old Town area. The simulation of flow and transport can be used to determine how long the current remediation measures will have to last.

5.3. Advective Contaminant Transport

As a first step toward understanding contaminant transport, particle trajectories have been analyzed and calculated (Zhou et al., 2003) and are discussed in this section. A more comprehensive transport model, including advective and dispersive transport, as well as degradation processes, will be developed in the future. The particles move with the transient groundwater flow, featuring seasonal fluctuations in the water table and strong variations in groundwater velocity (as shown in Figures 26 to 29). For the purpose of demonstration, we show the trajectories of particles originating from the source area of contaminants in the B7 lobe, B52 lobe, and B25A lobe, using steady-state pore velocity fields at July 1997, October 1997, January 1998, and April 1998. Figures 38 to 41 show the steady-state trajectories of particles at these particular times, respectively.

Particles originating from the B7 lobe migrate in two different directions in any season: northwesterly to the B58 boundary, and northerly to the B46 boundary. However, some particles may change their directions in different seasons, depending on the local flow field. In July 1997, the particles originating in the southwest of the major plume move toward the B58 boundary, whereas the particles originating in the northeast side of the major plume move northward along the geological barrier to the B46 boundary. Particles originating from the center of the major plume move downgradient northwesterly until they reach an area where the velocity field is very complex. South of

B53, the flow stagnants, and the particles cannot go further toward the model boundary. Here, the regional flow in Large Bowl encounters the flow moving northward from the geological barrier. In July 1997, no flow occurs at the saddle of the geological barrier, and no particles are found to go through the barrier saddle toward the B58 boundary. In October 1997, recharge from the 9-inch rainfall event elevated the water table, and some water flowed through the barrier's saddle toward the B58 boundary. This flow results in some particles from the major plume migrating through the saddle toward the B58 boundary. There is no stagnant area around the major plume, and particles originating in the center of the plume migrate northward along the geological barrier. In January 1998, the rainfall was very heavy, 19 inches for that month. As a result, the water table in Large Bowl became very high, and the velocity became very large. On the other hand, the water table at the geological barrier was elevated because of the large recharge through the overlying unpaved areas. As a result, no flow occurs at the barrier's saddle, and no particles migrate westward to the B58 boundary through the saddle. By April 1998, the velocity in Large Bowl remained very large, but the water mound in the geological barrier area had disappeared. As a result, a large amount of water flowed through the saddle to the B58 boundary. Most particles originating from the center and the north edge of the major plume migrate northward and turn westward at the saddle to the B58 boundary.

Overall, the calculated pathways of particles originating from the B7 plume lobe are in good agreement with the measured contaminant plumes. The particles originating immediately south of the core plume and all particles from the core area in winter seasons move towards the B58 boundary. This is consistent with the trend of the main B7 plume because the plume is elongated primarily in the northwest direction. Particles originating north of the core plume move northward in summer seasons along the western edge of Large Bowl and the eastern edge of the geologic divide. This is consistent with the elongated plume of low concentrations in the north direction. Note that this part of the plume has smaller concentrations than the core plume. This is because clean groundwater flows into Large Bowl from the upstream boundary, thus diluting the contaminant plume. The other reason is that particles from the north portion of the core area of the B7 lobe move in northerly only in summer seasons with small travel velocity. As a consequence, more contaminants are expected to migrate in a northwesterly direction, primarily because of larger velocity in winter seasons. The consistency between the measured plumes and the particle pathways indicates that the groundwater flow model can reproduce the flow fields reasonably well.

In July 1997, all particles from the area east of Building 52 migrated along the Moraga Channel downstream to the B46 boundary. Some particles originating south of the B52 lobe moved northwesterly passing the plume of the B7 lobe contaminants. Once the water table rose, owing to recharge from rainfall and the higher water table at the upstream boundary, particles from the B52 lobe moved directly toward the B46 boundary, bypassing the B7 plume. Later, with an elevated water table in Large Bowl, the particles originating from the south end of the B52 lobe move westward, combining with those from the B7 lobe and moving further westward to the B58 boundary. The measured plume is elongated toward the B46 boundary, similar to the main particle flow direction. Therefore, the pathways of the particles and the elongated plume are in good agreement. In addition, the mingling of particles originating from the B52 and B7 plume lobes in winter seasons is also consistent with the formation of a large contaminant plume for the low-concentration contour line.

For particles originating in the B25A lobe, the trajectories show less time dependent. All particles originating from the northeast area of Building 25A migrate northward to the B46 boundary. In the south area of the B25A lobe, particles move southward. Some particles may change directions from northwesterly in the summer to southerly in the winter.

6. Assessment of Hydraulic Measures for Remediation

The site-scale groundwater flow model developed was refined to assess the efficiency of existing hydraulic measures in restoring the contaminated site. The refinement was conducted with a focus on the main contaminant plume (the B7 lobe), therefore excluding the large area in the south of the site-scale model (see Figure 42). The refined model covers the northern area of the site-scale model, incorporating the B7 lobe and the B52 lobe. All perturbations to the groundwater system, including pumping and injection, were considered in the refined model. The efficiencies of two trenches located within the model area (for source control) and two trenches located on the model boundaries (for avoiding contamination of the surrounding environment) were assessed using this refined model. Conditions at the external boundary and initial conditions at June 1, 1996, were based on the simulated groundwater level of the site-scale model. The simulation time is from June 1, 1996 to June 30, 2000.

Perturbations to the global flow fields caused by the operation of two internal trenches were considered in the refined model. Groundwater was pumped at the B7 trench, treated, and continuously reinjected at the upstream sump, which is represented by six vertical columns in the model that are maintained at the measured water table of 975.40 ft (see Figure 42). The B7 trench is composed of two trench segments of filled gravel that are separated by a short segment of bedrock, each of which is represented by six vertical columns in the computational mesh. The boundary conditions in the two segments were specified using the measured groundwater level at two extraction wells within the trench. At the B53-58 trench, groundwater was also pumped, treated, and re-injected into the system. This trench is composed of eight gravel-filled columns, and the groundwater level at each column is specified at constant values, varying from 810 ft to 821.78 ft.

Figure 43 shows the simulated groundwater level contours and velocity vectors on the water table in October 1999, which represents a dry season. The elevated groundwater level upstream from the B7 trench is caused by the re-injection of treated groundwater at the former sump. Downstream from the B7 trench, the groundwater level decreases as a result of the pumping in the B7 trench. The groundwater from the sump to the trench flows mainly within the permeable Moraga Formation, resulting in large recirculation fluxes. The bottom of the trench is 57.4 ft below the groundwater surface, and in the Orinda Formation. Thus, in the vertical direction, the trench controls almost the entire contaminated groundwater flow. A mass balance indicates that the trench is capable of capturing about 70% of the groundwater injected at the sump.

The B53-B58 trench was installed in May 1999, based on the observed concentration contour measured at that time. This trench was expected to control the B7 plume at the downstream end of the high concentration portion. It is about 36 ft below the ground surface, penetrating the Mixed unit (24.6 ft thick) and ending in the Orinda unit. The water level imposed at the B53-B58 trench is lower than that in the surrounding area, resulting in convergent groundwater flow toward the trench. However, since the trench is located at the geologic divide and within the Mixed or Orinda unit of low hydraulic conductivity, the amount of groundwater flowing toward the trench is less significant than that in the B7 trench. The simulated flow field and the concentration field recently observed indicate that this trench may not be as effective as hoped, because a major fraction of the contaminants migrate south of the trench (Figure 43c).

At the B58 trench, the large flow velocities indicate that the trench is effective in preventing contaminated groundwater from leaving the model area and contaminating the downgradient environment. The concentration field suggests that the trench can be used to collect most of the advective flux of contaminants flowing through the B58 boundary. The same conclusion can be drawn for the B46 trench, which collects large amounts of contaminated groundwater for further treatment. However, in light of the differences between dry summer and wet winter conditions observed in Figures 38 through 41, there is the possibility during wet seasons that contaminants may migrate through the saddle toward the B58 boundary instead of proceeding towards the B46 trench. Further investigation is needed to evaluate whether these contaminants are being captured in the B58 trench.

7. Conclusions

In the late 1980s groundwater contamination was detected at the LBNL Old Town site. Since then, a large amount of data was collected on stratigraphy, hydogeologic properties, groundwater levels, and contaminant concentrations. Interim corrective measures were initiated to prevent further spreading of contaminants. This report describes the development of and simulation results from a three-dimensional transient groundwater flow model designed to (1) improve our basic understanding of the flow and contaminant transport patterns and (2) support the decision-making process for remediation measures.

A detailed hydrogeologic model was developed to describe the complex hydrogeology at the mountainous site, featuring several geologic units with strongly varying thickness and steep slopes. Based on detailed information from several hundred boreholes, a unique geologic setting was identified, with three isolated bowl-shaped rock masses of the Moraga Formation embedded in heterogeneous bedrock of much lower permeability (i.e., the Mixed unit and the Orinda Formation). Another modeling challenge was the strong seasonal patterns of groundwater flow, mainly affected by significant water recharge from upstream steep hills. In such a setting, the definition of appropriate model domain and boundary conditions is complicated, but essential to model development. In the model, the relevant model boundary passes through a number of groundwater monitoring wells, and the measured transient groundwater levels in these wells were used for boundary conditions.

The groundwater model was calibrated using groundwater levels and fluxes collected between 1994 and 1996. The rock zone method was used to deterministically define the spatial variability of rock properties within the same hydrogeologic unit, based on the observed clustering characteristics of measured hydraulic conductivities. A composite model was used to account for the internal heterogeneity of the rock, with thin permeable sand layers located within solid rock of low hydraulic conductivity. Transient inverse modeling was conducted to obtain the effective hydraulic conductivity and porosity for each of the 20 defined rock zones. Also calibrated were recharge factors for areal infiltration through rainfall and local infiltration through leaking underground utilities. It was found that modeling the local recharge from confirmed leaking storm drains is critical for accurate simulations because this recharge significantly affects the groundwater levels measured in low-permeability areas. Also note that the calibrated effective-porosity values are considerably smaller than the actual physical porosity of the rocks. Such small effective porosities demonstrate that only the thin sandstone layers embedded in the bedrock of low hydraulic conductivity are hydraulically important. These small porosities explain the rapid groundwater-level changes observed in response to precipitation events.

The calibrated groundwater flow model was validated using a blind model prediction conducted for the period between July 1996 and June 1998. The calibrated model produced good matches between the simulated and measured groundwater level in a large number of monitoring wells, and also captures the trend observed in the flow rates measured at two groundwater collection trenches. In addition, the simulated advective transport based on particle tracking is in good agreement with the measured extent of contaminant plumes. The validation results indicate that the developed model can accurately predict the complex groundwater flow at the LBNL site.

Finally, the calibrated and validated model was refined to focus on the main contaminant plume and on the effects of the perturbations caused by hydraulic measures for remediation. The assessment of hydraulic measures concluded that most of the hydraulic measures are effective in controlling the contaminant sources and in collecting contaminated groundwater to prevent further contamination from entering the surrounding environment. However, one trench may need to be relocated to control the high-concentration area of the main plume. In any case, the groundwater flow model provides a valuable tool for improving the decision-making process with respect to site remediation, and can be used as the basis for further development of a contaminant transport model.

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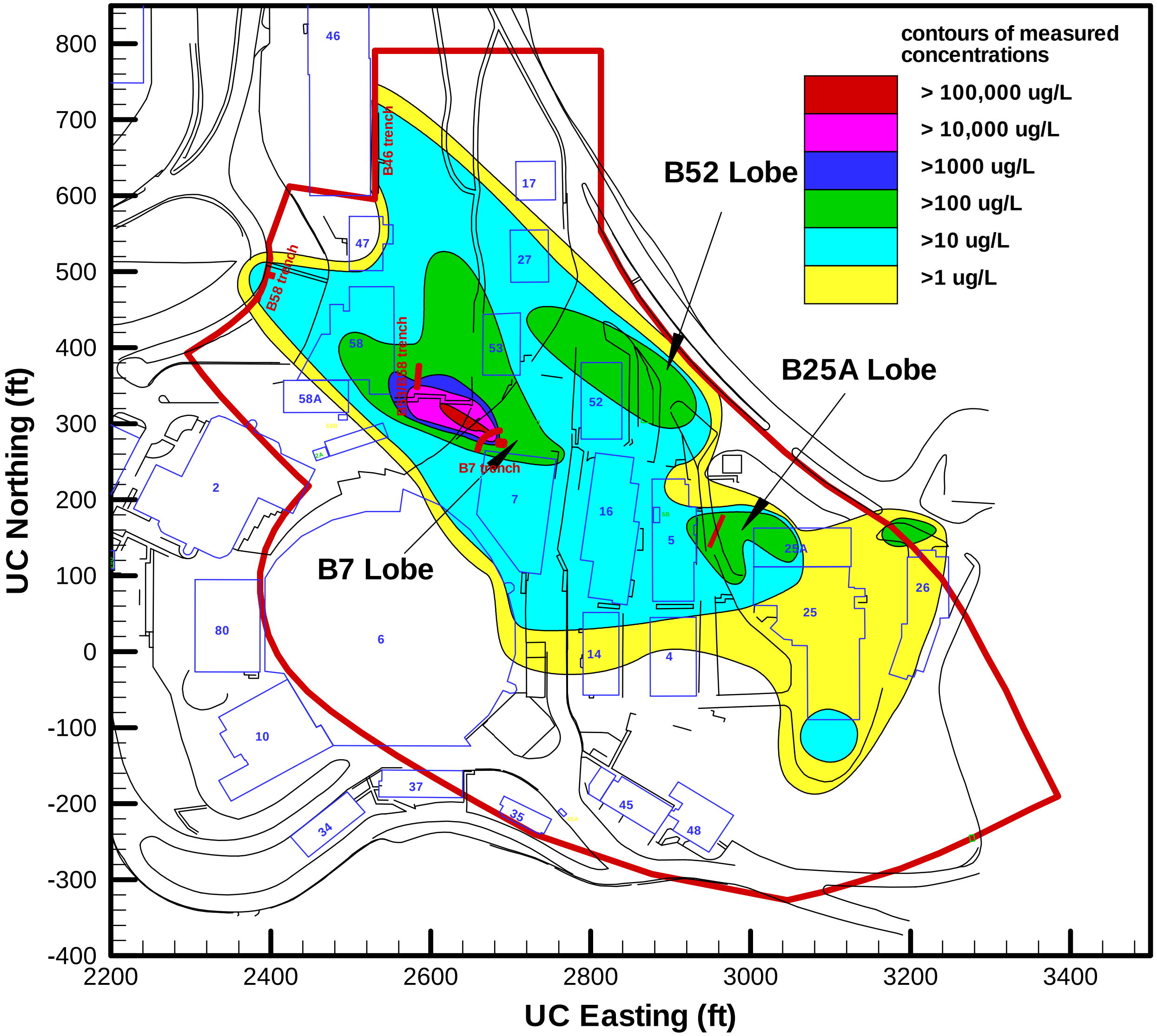

Figure 1. The Old Town map with buildings and their numbers in blue polygons and roads in black lines, and contaminant plumes measured in 1999 and groundwater collection trenches.

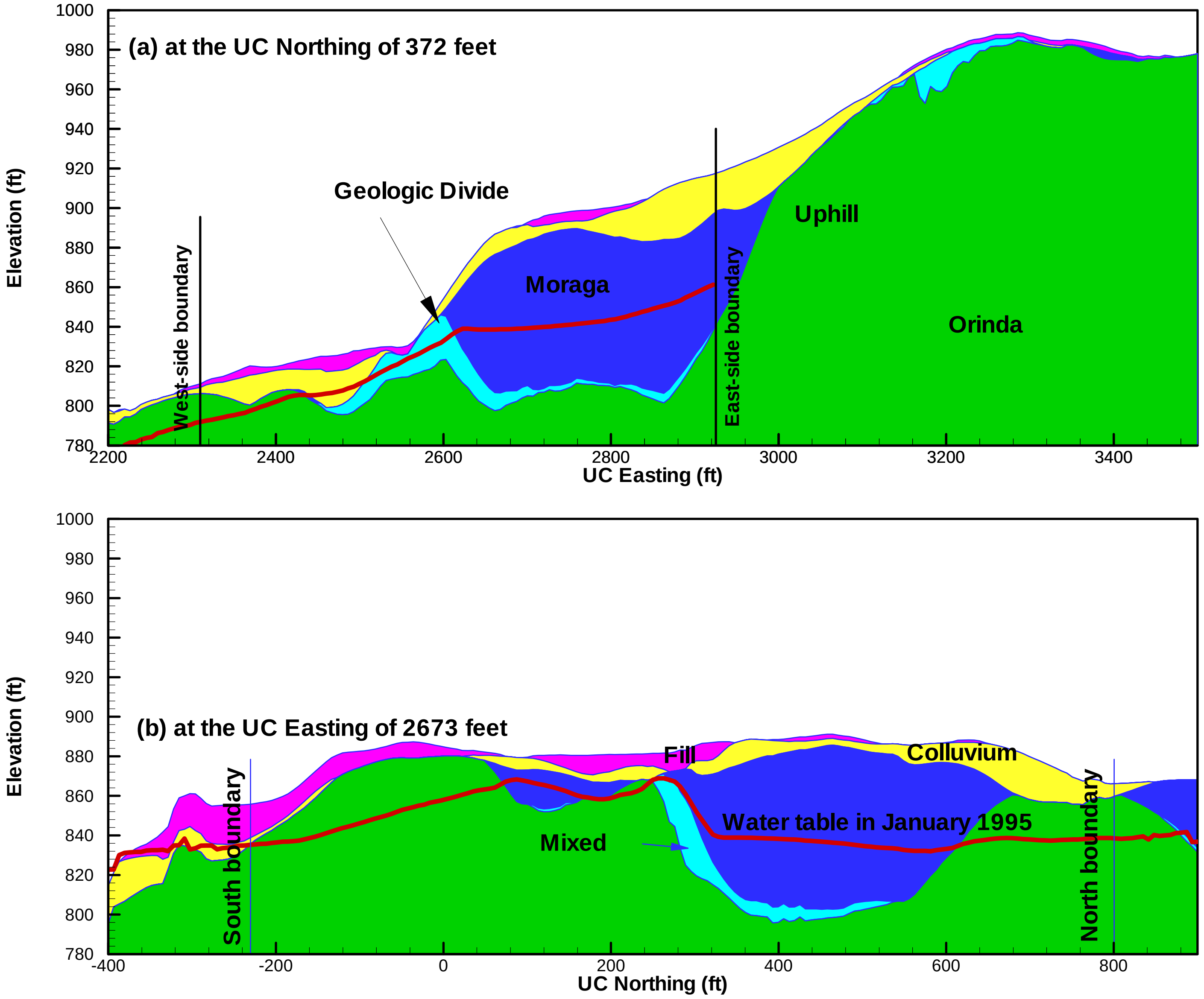

Figure 2. Geological profiles in vertical cross sections (a) in the UC Easting direction and (b) in the UC Northing direction, with representative water table.

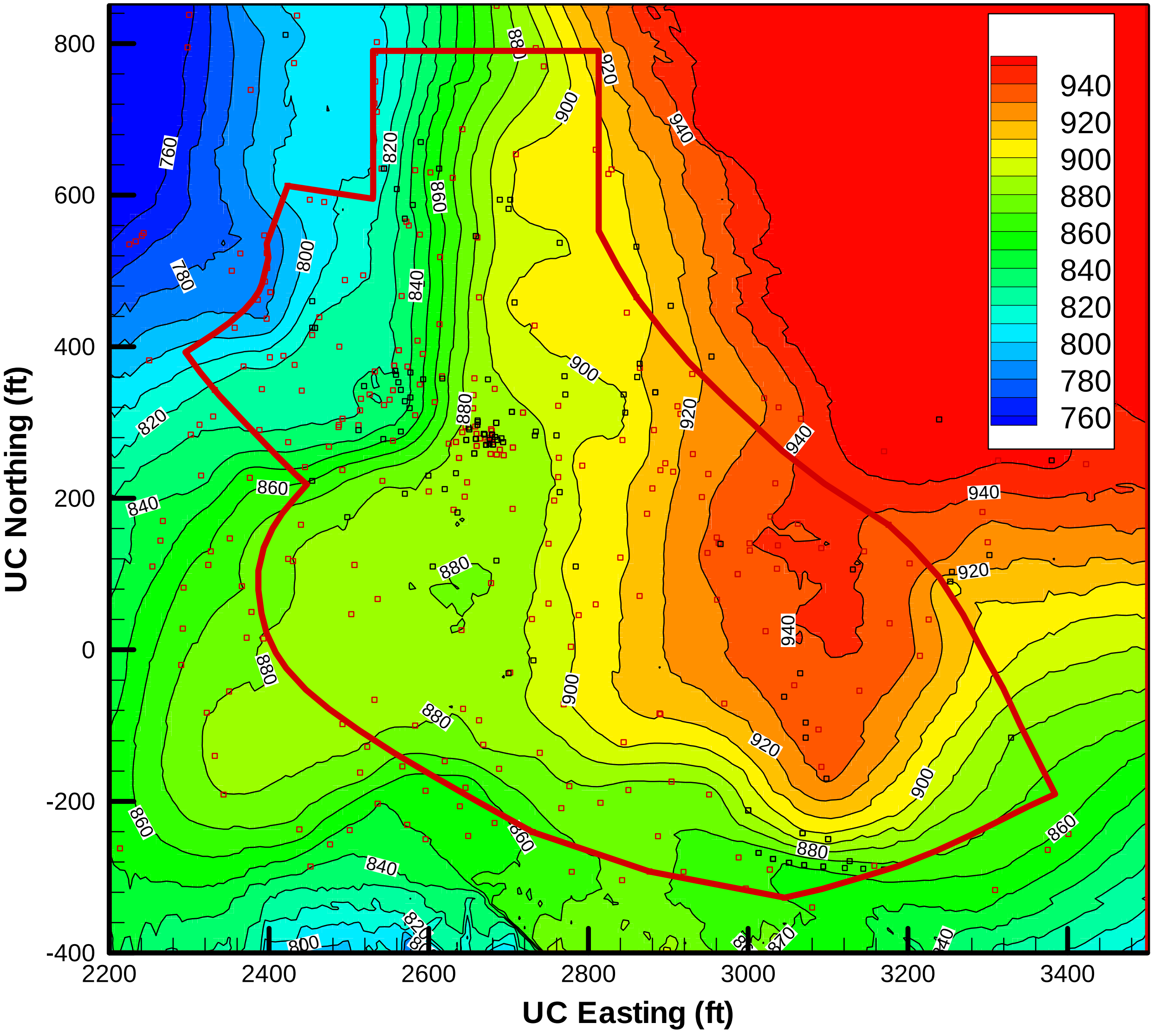

Figure 3. Surface elevation contours (ft) (the top of the Artificial Fill unit). Red squares indicate “full” boreholes and black squares indicate “partial” boreholes.

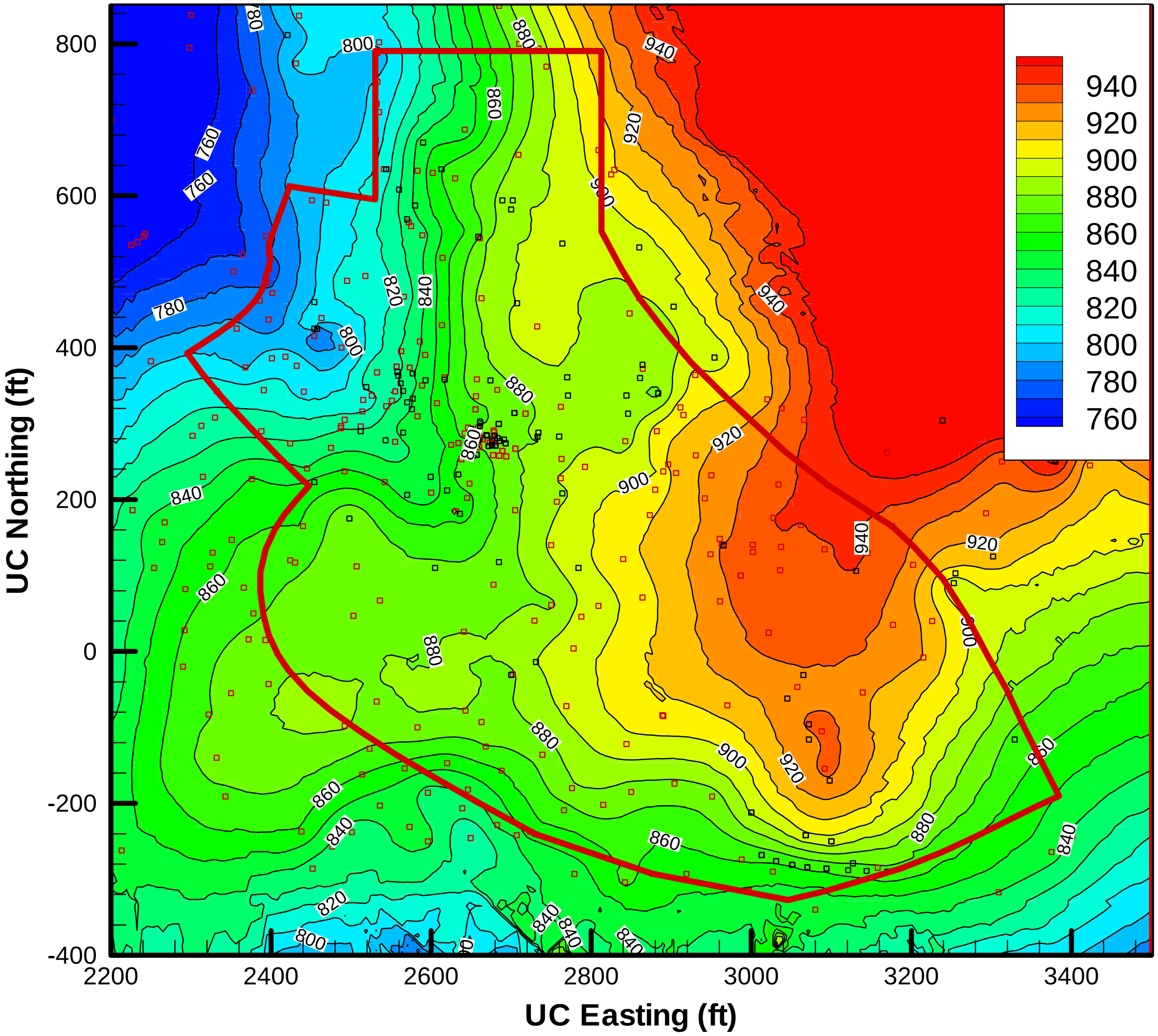

Figure 4. Structural contours of the top elevation (ft) of the Moraga Formation unit. Red squares indicate “full” boreholes and black squares indicate “partial” boreholes.

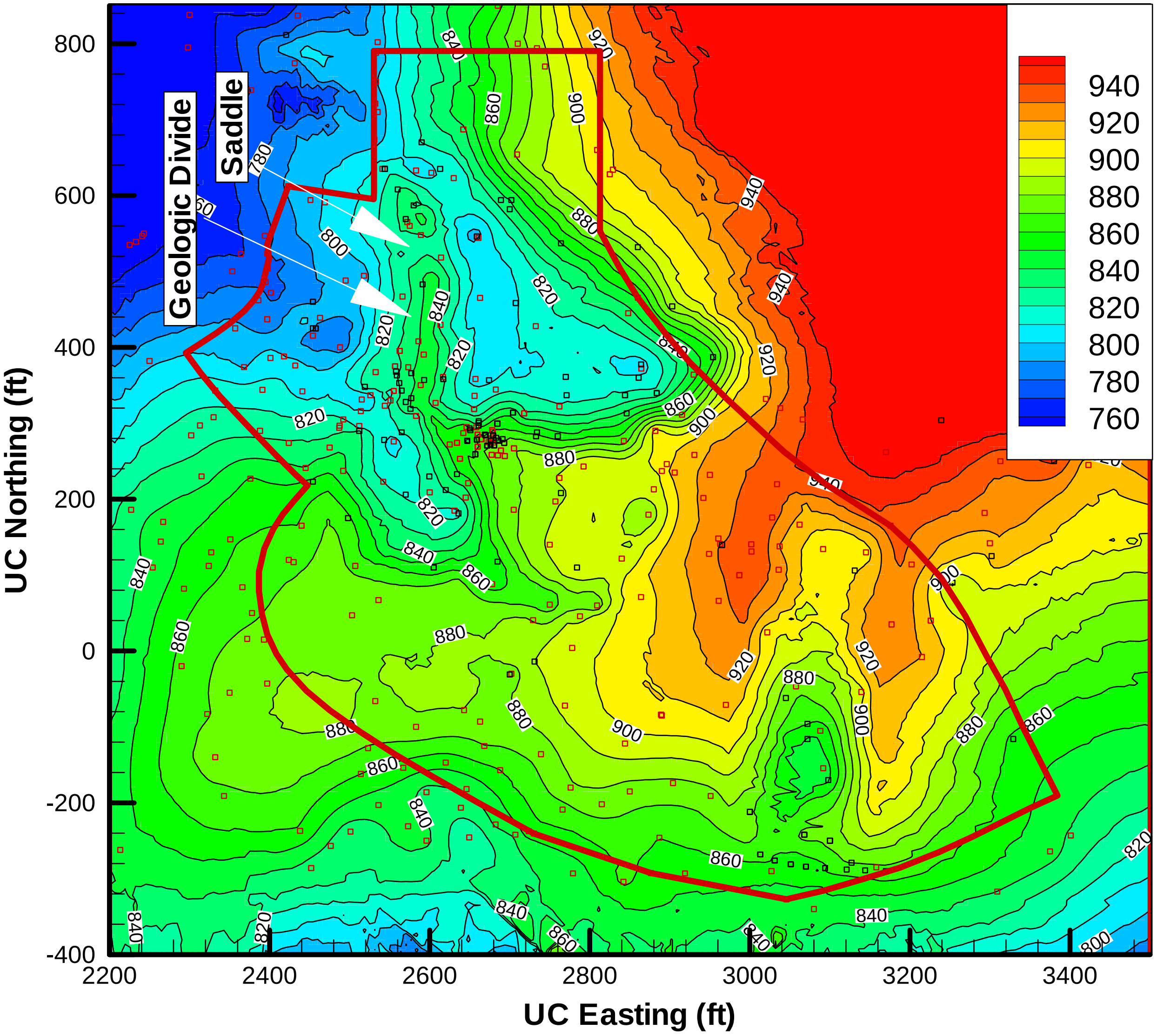

Figure 5. Structure contours of the top elevation (ft) of the Mixed unit. Red squares indicate “full” boreholes and black squares indicate “partial” boreholes.

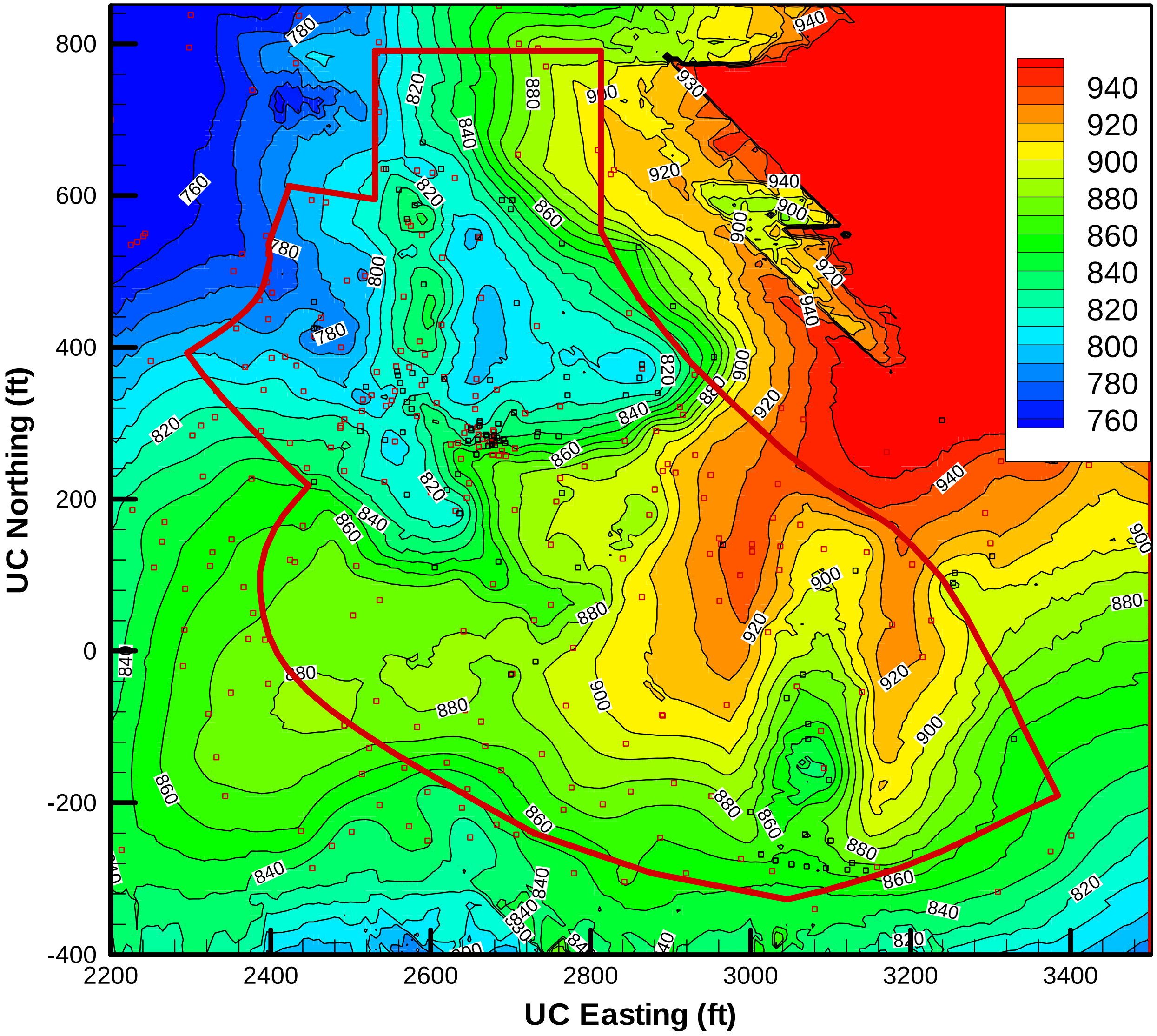

Figure 6. Structure contours of the top elevation (ft) of the Orinda Formation. Red squares indicate “full” boreholes and black squares indicate the interpolated top of the Orinda Formation for “partial” boreholes. Note that poor quality of interpolation can be seen in the east of the model domain.

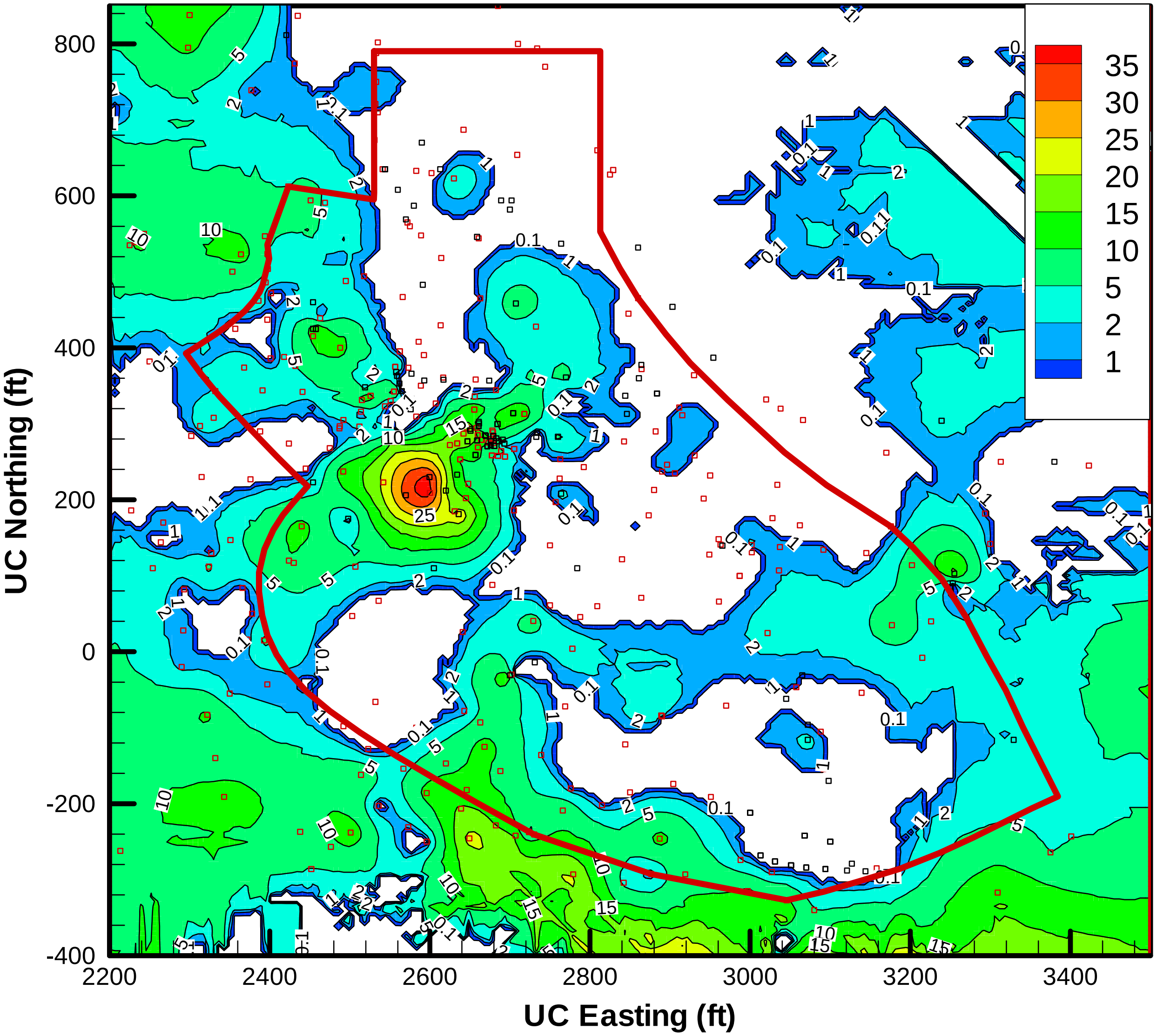

Figure 7. Thickness contours (ft) of the Artificial Fill unit. Red squares indicate “full” boreholes and black squares indicate “partial” boreholes.

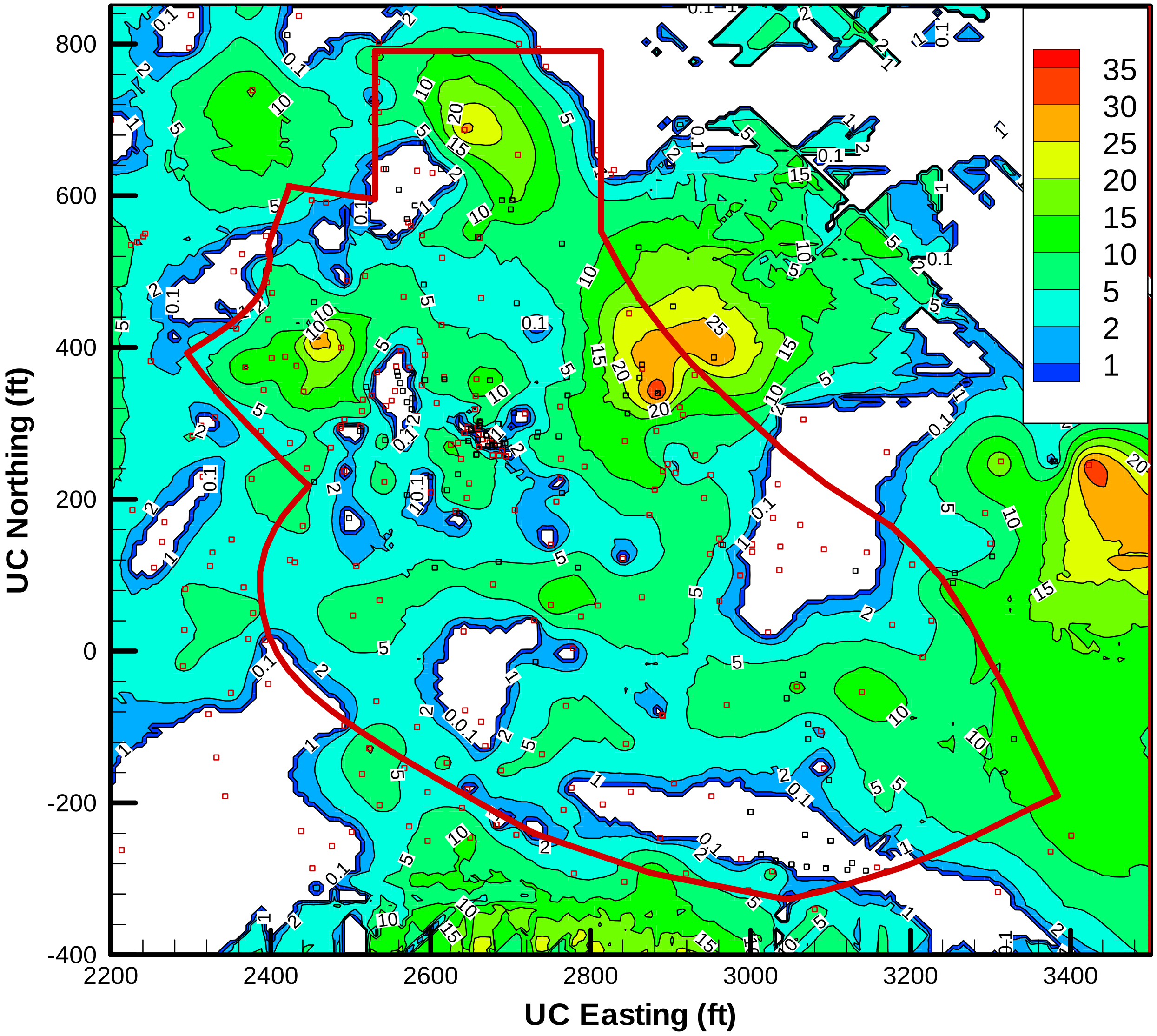

Figure 8. Thickness contours (ft) of the Colluvium unit. Red squares indicate "full" boreholes and black squares indicate "partial" boreholes.

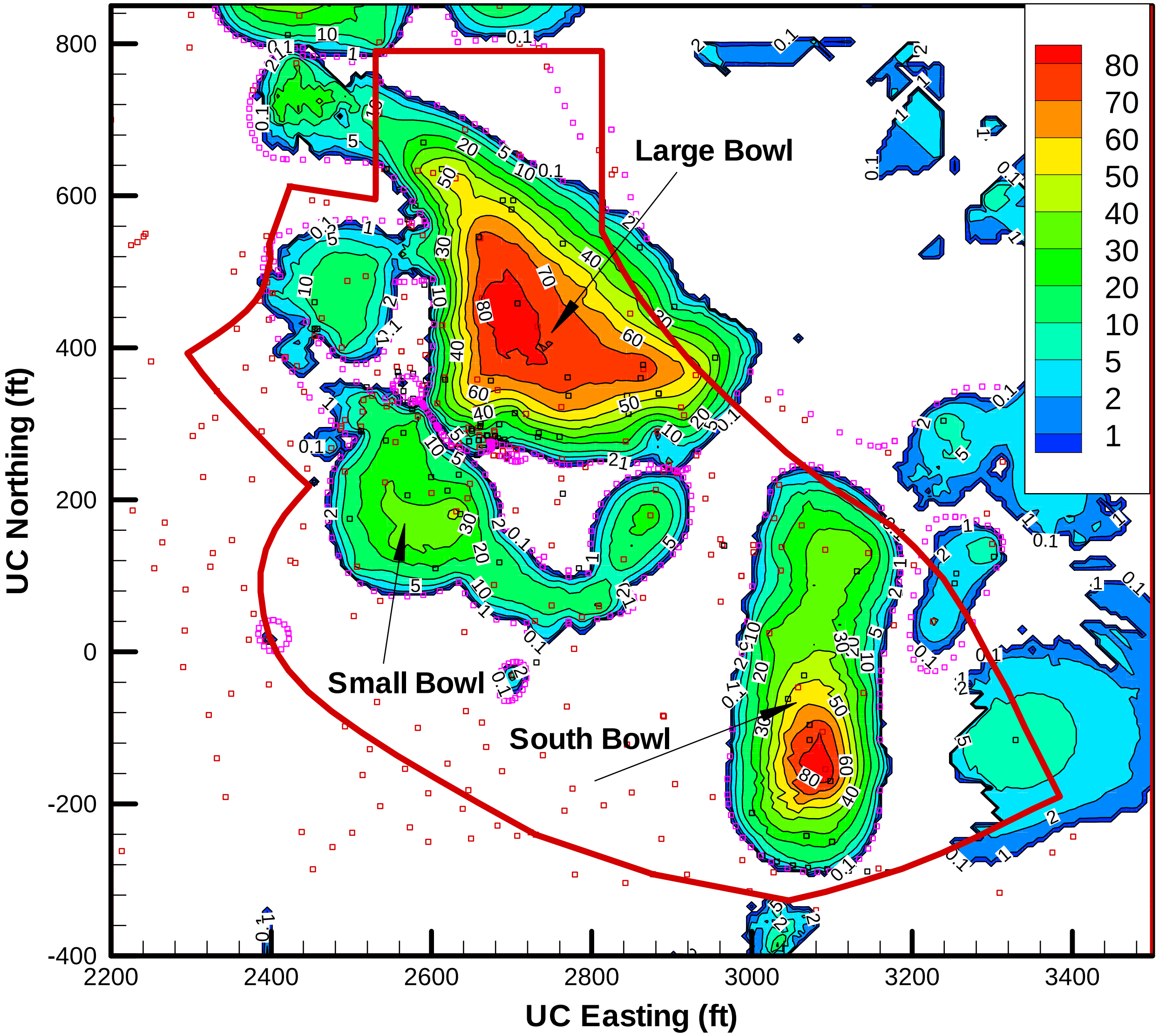

Figure 9. Thickness contours (ft) of the Moraga Formation unit. Red squares indicate “full” boreholes, black squares indicate “partial” boreholes, and purple squares indicate the zero-thickness data points obtained from the outcrop map.

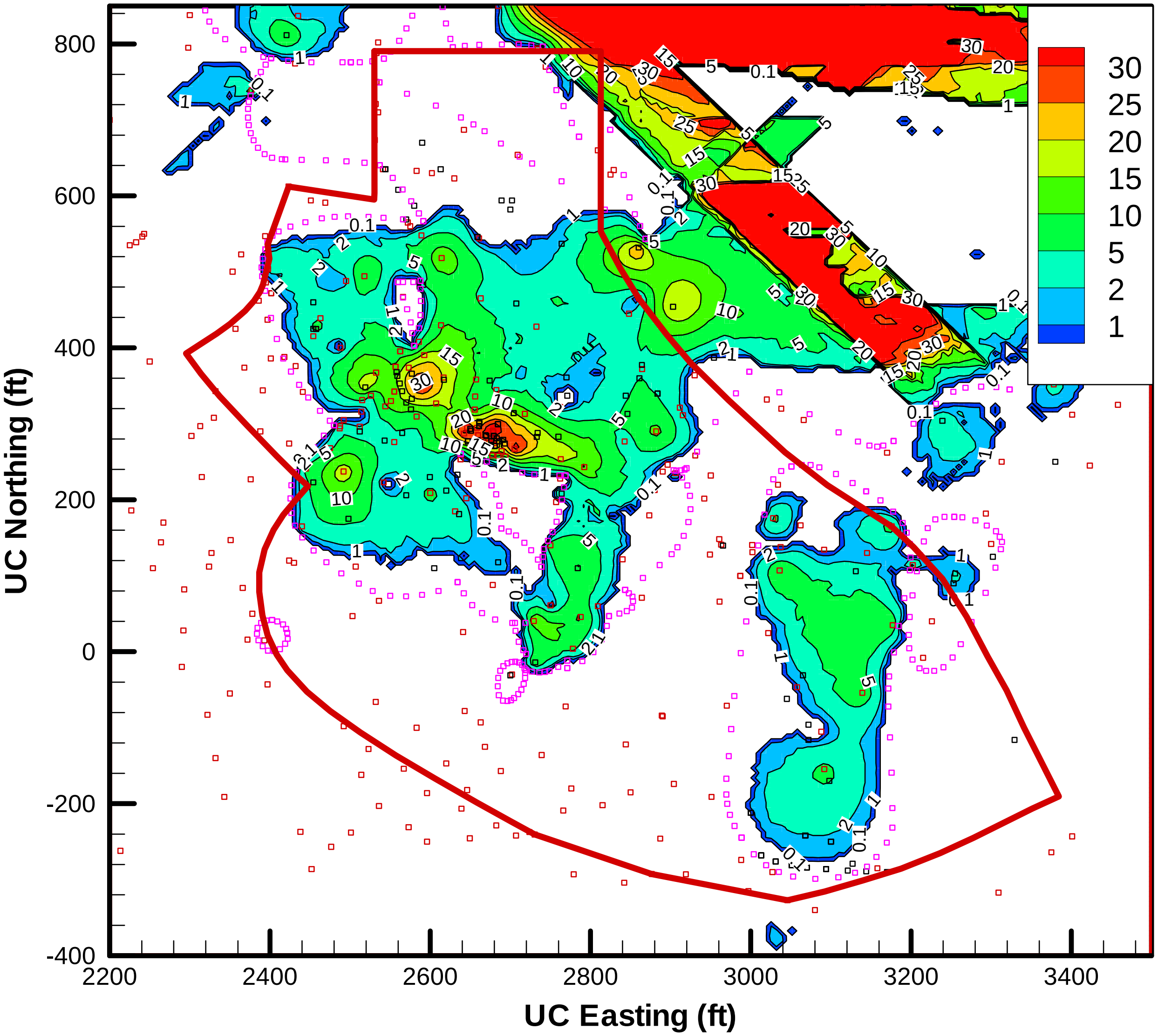

Figure 10. Thickness contours (ft) of the Mixed unit. Red squares indicate “full” boreholes, black squares indicate “partial” boreholes, and purple squares indicate the zero-thickness data points obtained from the outcrop map.

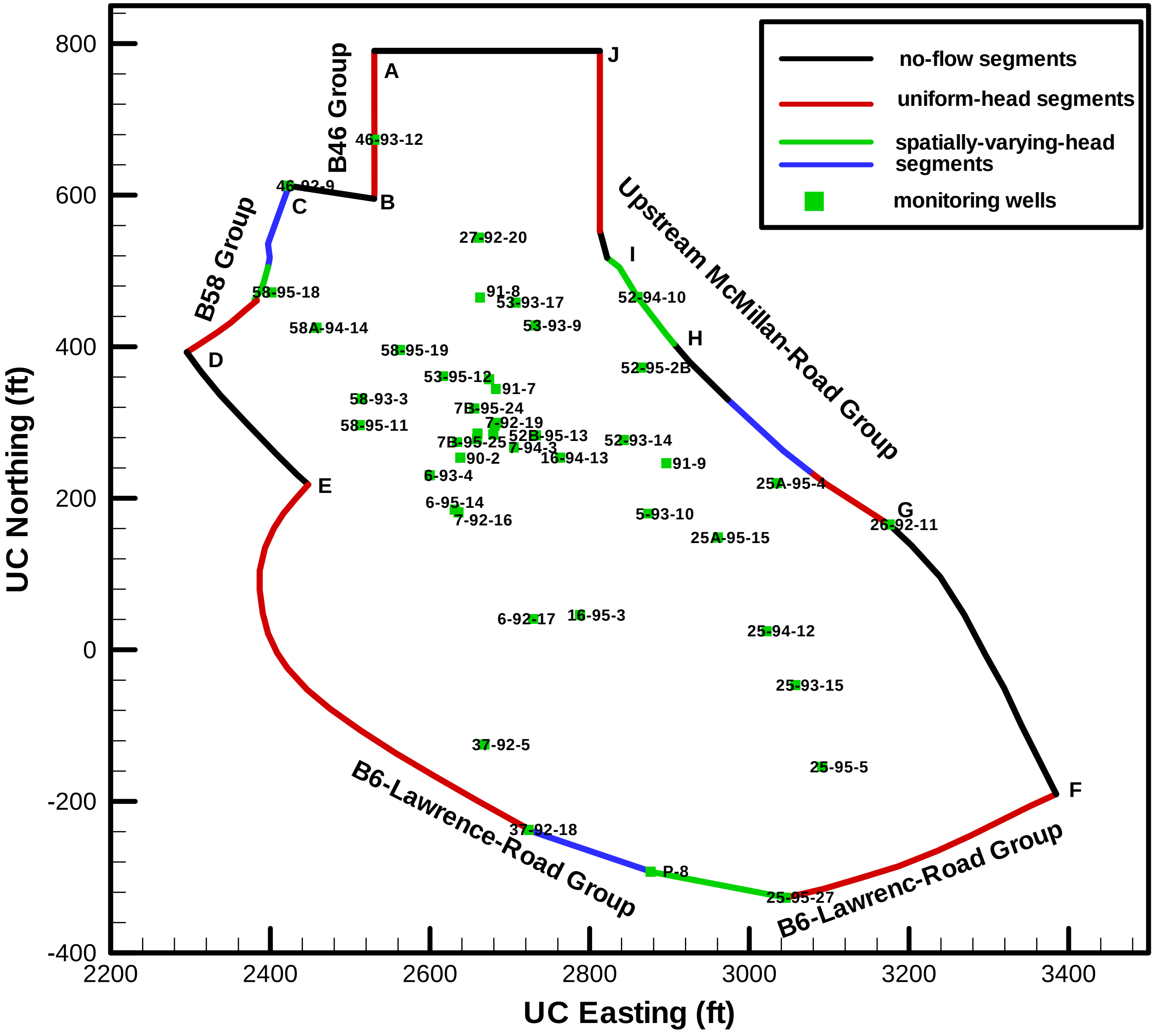

Figure 11. Model boundary, boundary condition types, boundary wells, and other monitoring wells used for determining initial conditions.

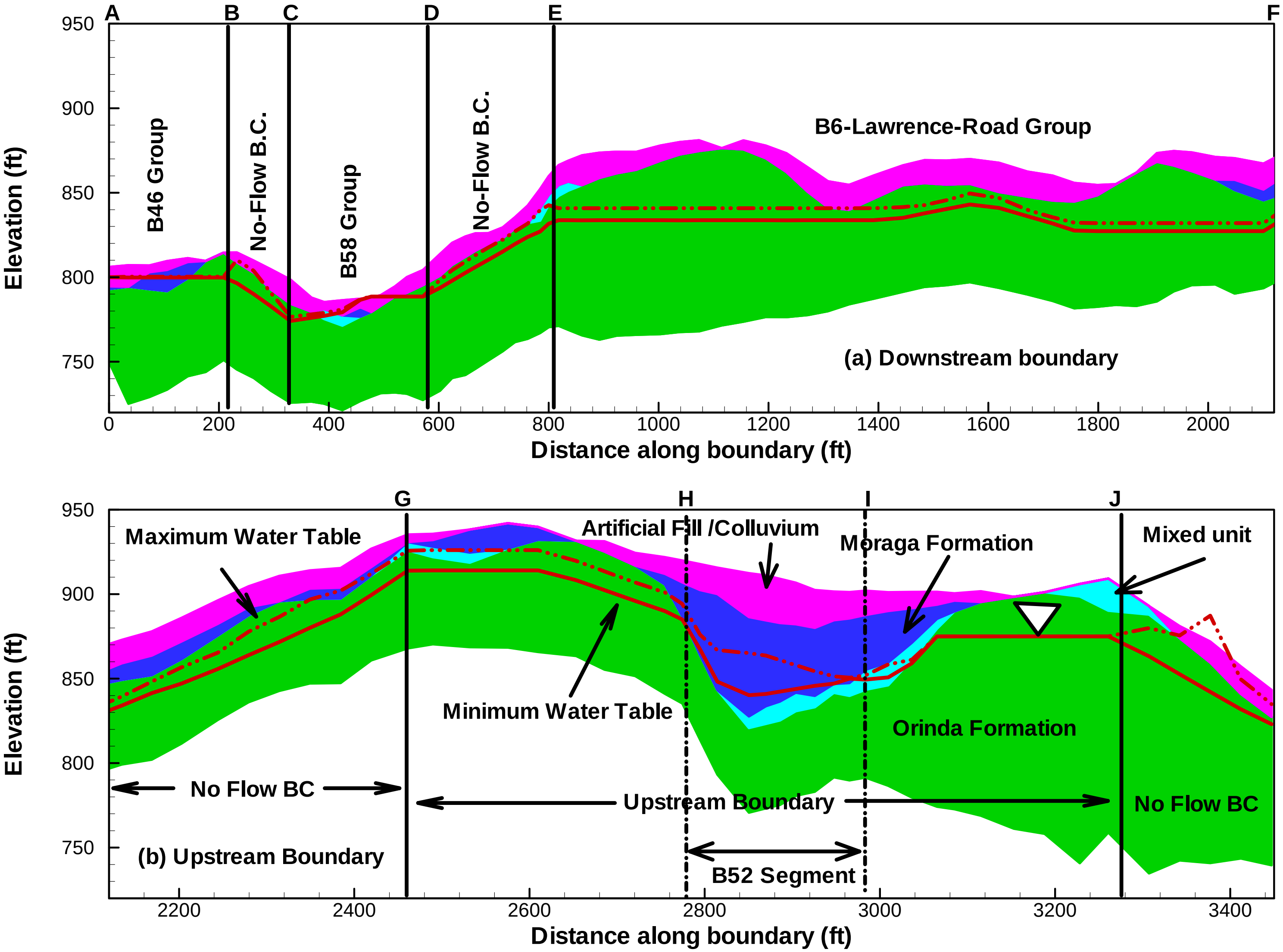

Figure 12. Geologic cross sections along the downstream and upstream boundaries of the model shown in Figure 11, with measured maximum and minimum water table specified on the boundary as boundary conditions.

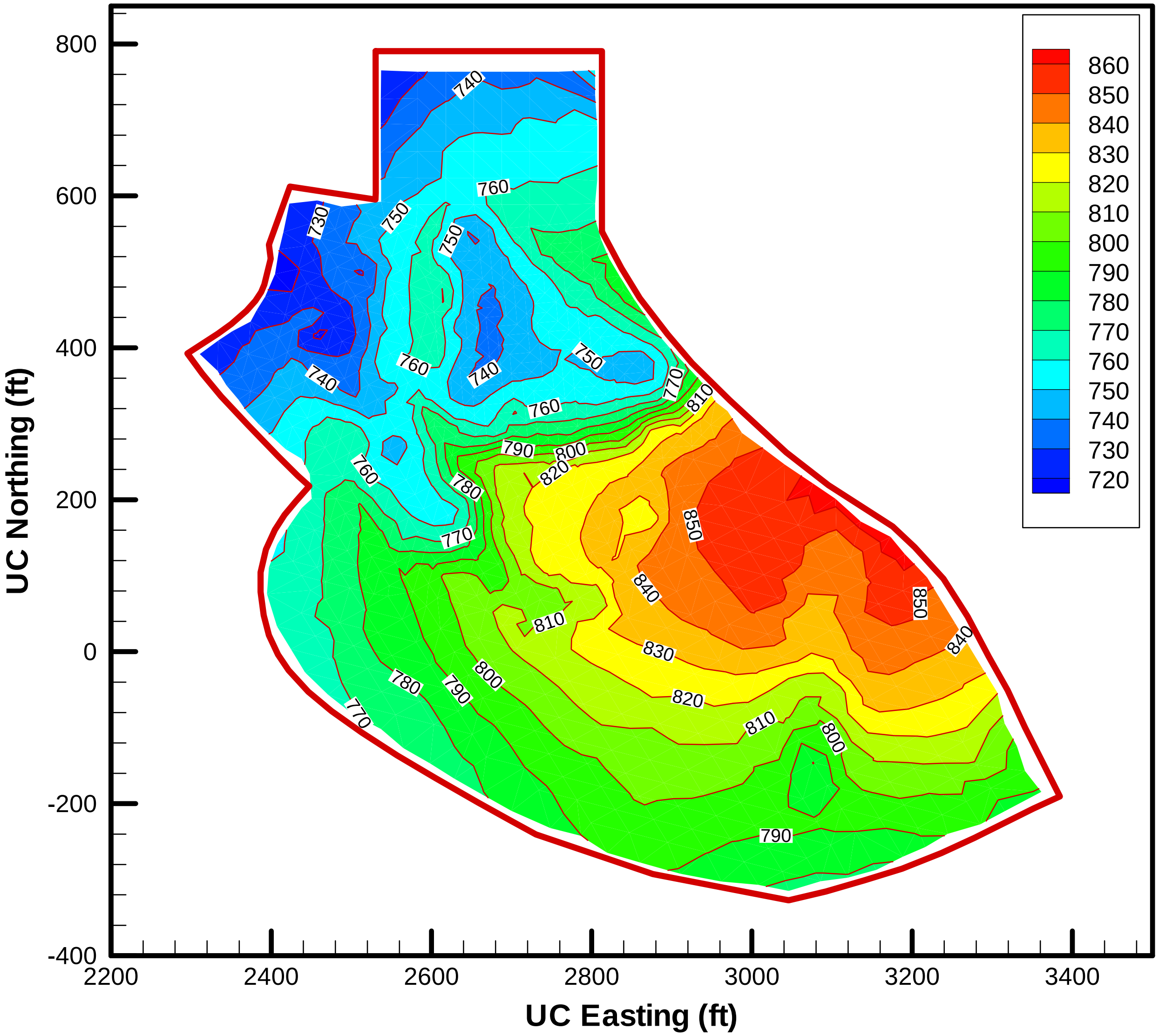

Figure 13. Elevation contours (ft) of model bottom boundary.

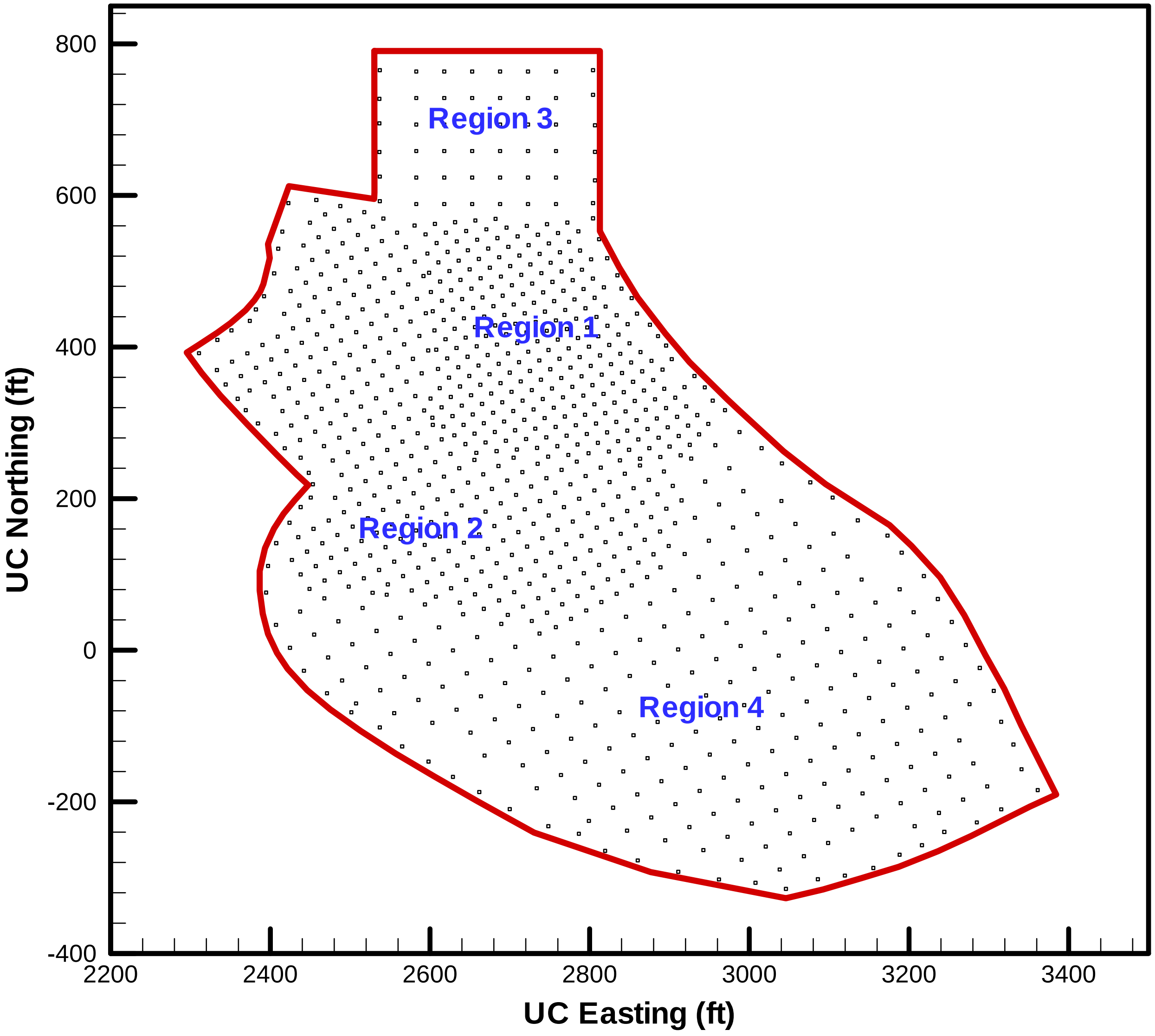

Figure 14. Plan view of the three-dimensional TOUGH2 grid for model calibration. Block dots are the centroids of vertical columns.

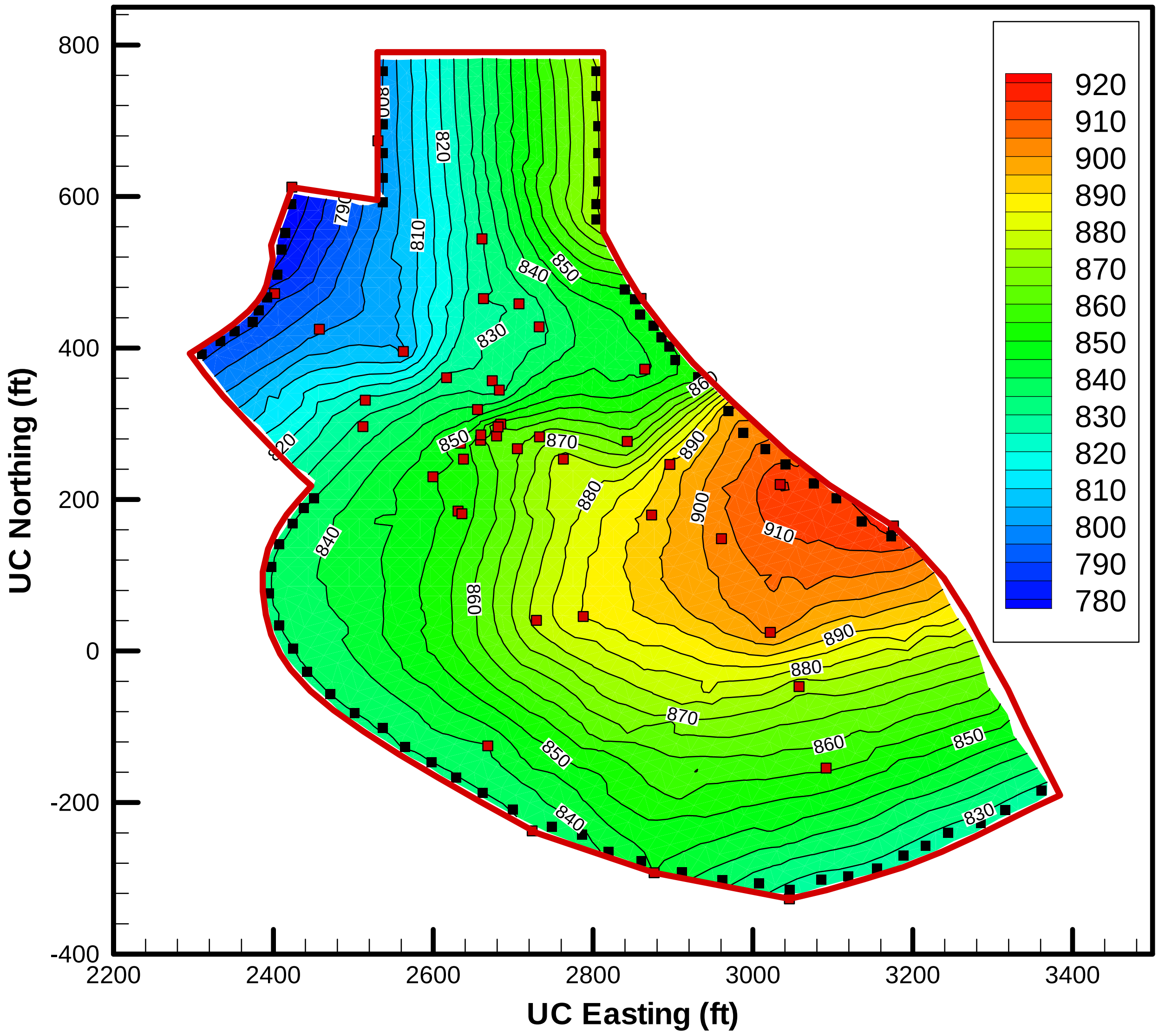

Figure 15. Elevation contours of the initial water table (ft) on June 30, 1994 obtained using the measured water levels at 47 monitoring wells (in red squares) and boundary conditions in boundary cells (in black squares).

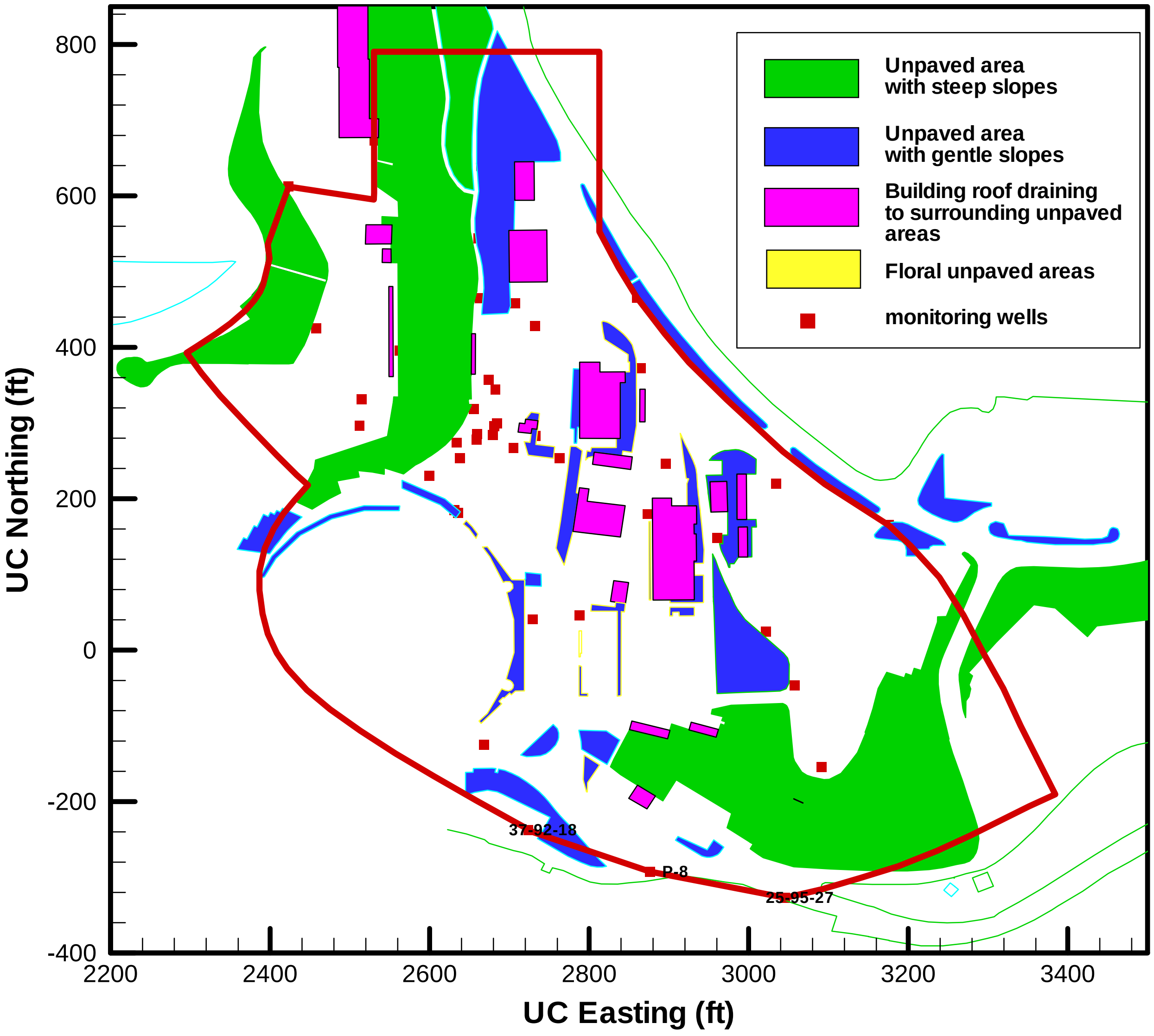

Figure 16. Map of the paved and unpaved areas for net recharge estimation. Green indicates the unpaved areas with steep slopes larger than 30°, whereas blue indicates those with gentle slopes. The purple areas are buildings with rainfall intercepted draining into neighboring unpaved areas.

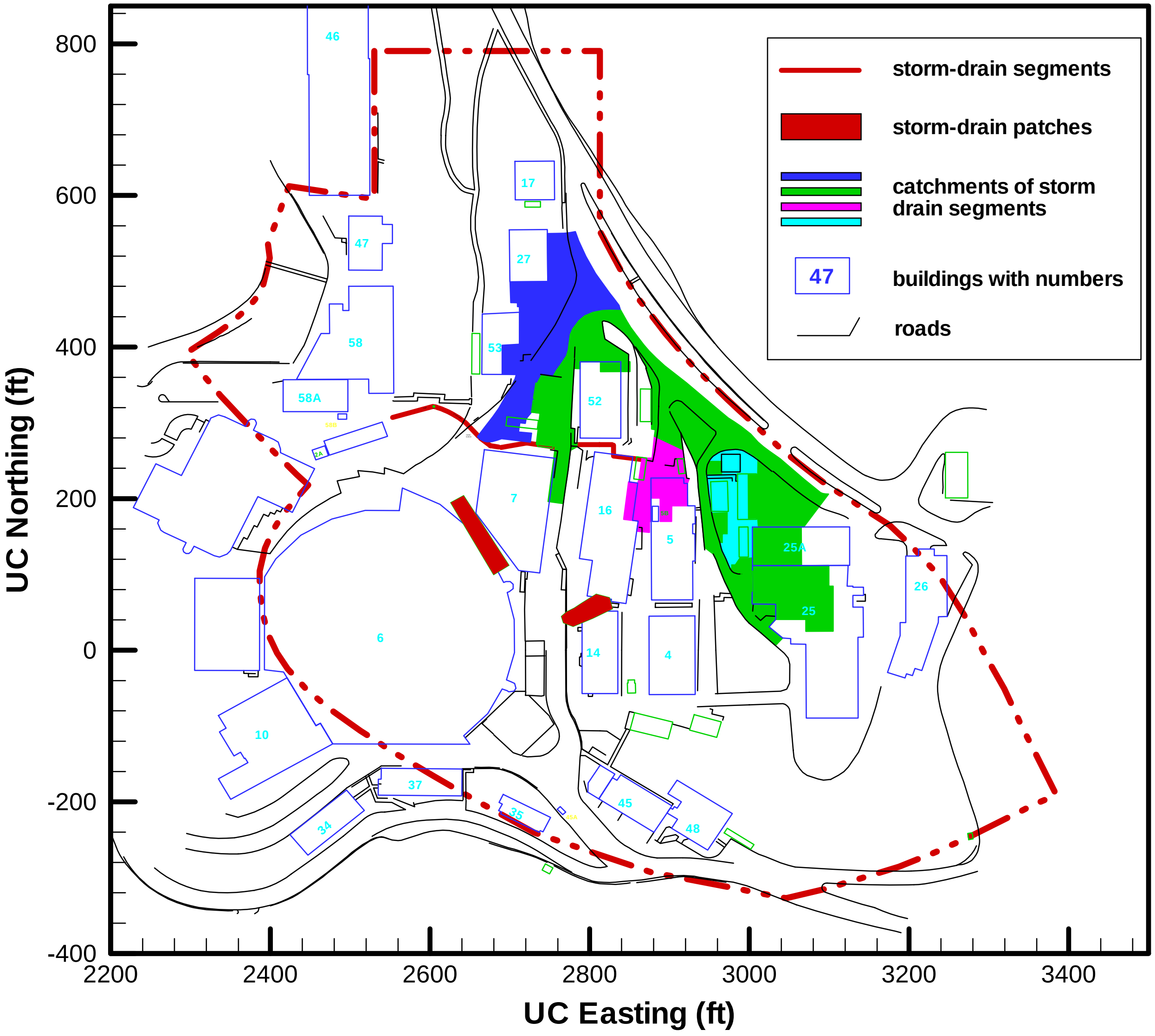

Figure 17. Confirmed leaking storm drains in red lines and patches and their discharge catchments. The main storm drain around Building 7 consists of four pipeline segments, each of which has a catchment for the discharging rainfall into pipeline. The storm drains in the north of Buildings 6 and 14 are in red patches.

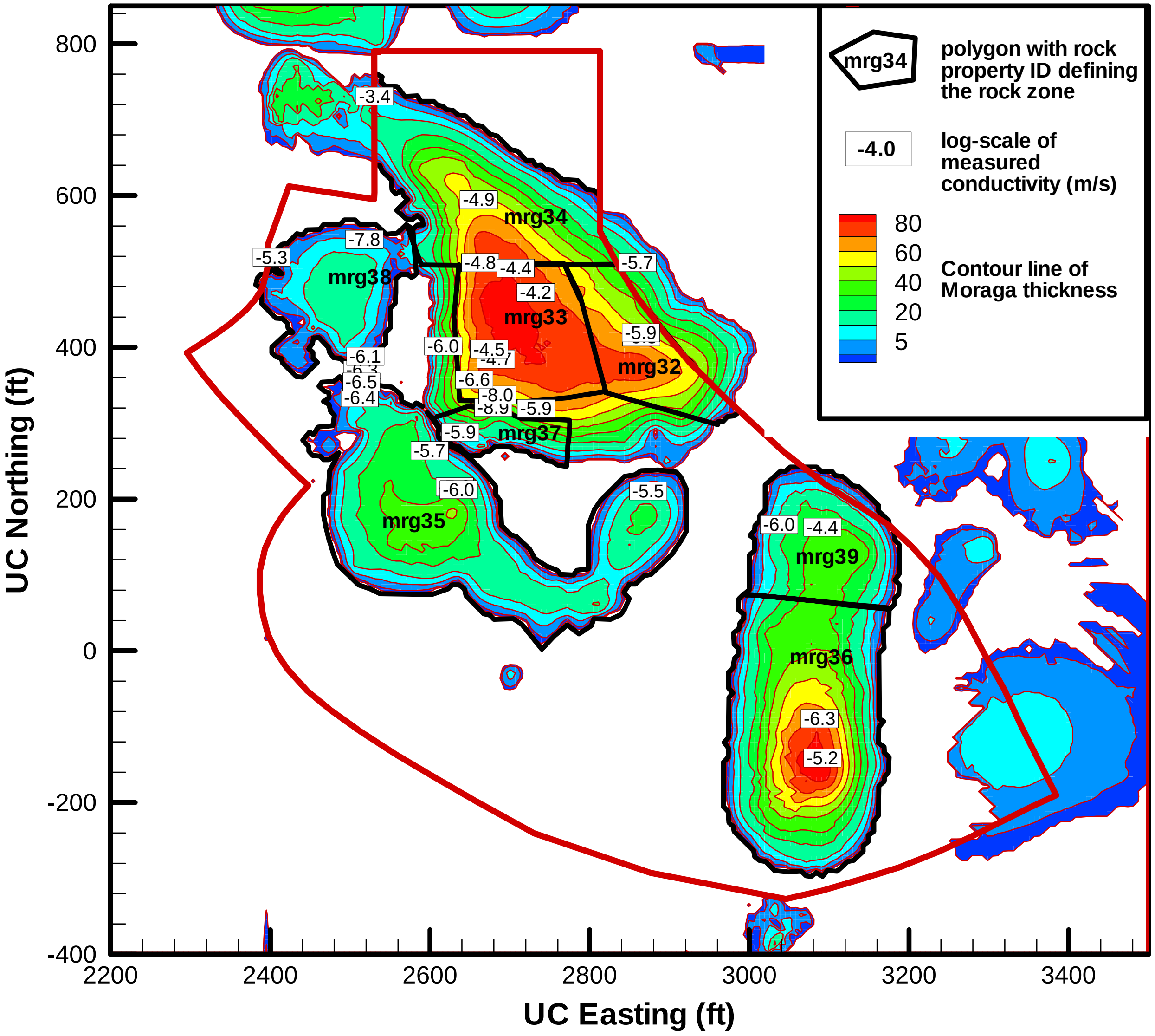

Figure 18. Definition of nine rock zones of different rock properties in the Moraga Formation unit, showing the measured hydraulic conductivities (m/s) in the log scale.

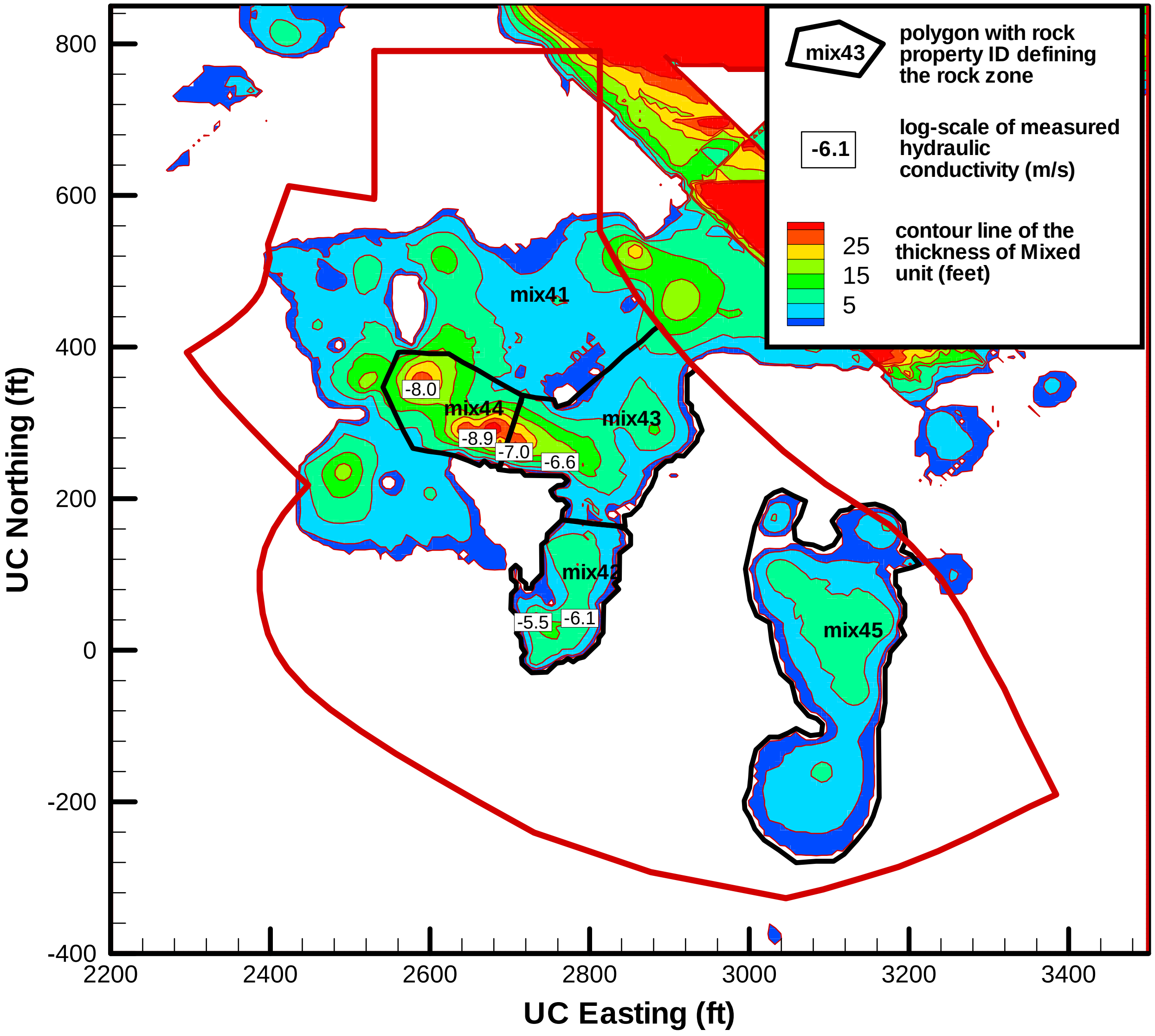

Figure 19. Definition of five rock zones of different rock properties in the Mixed unit, showing the measured hydraulic conductivities in the log scale.

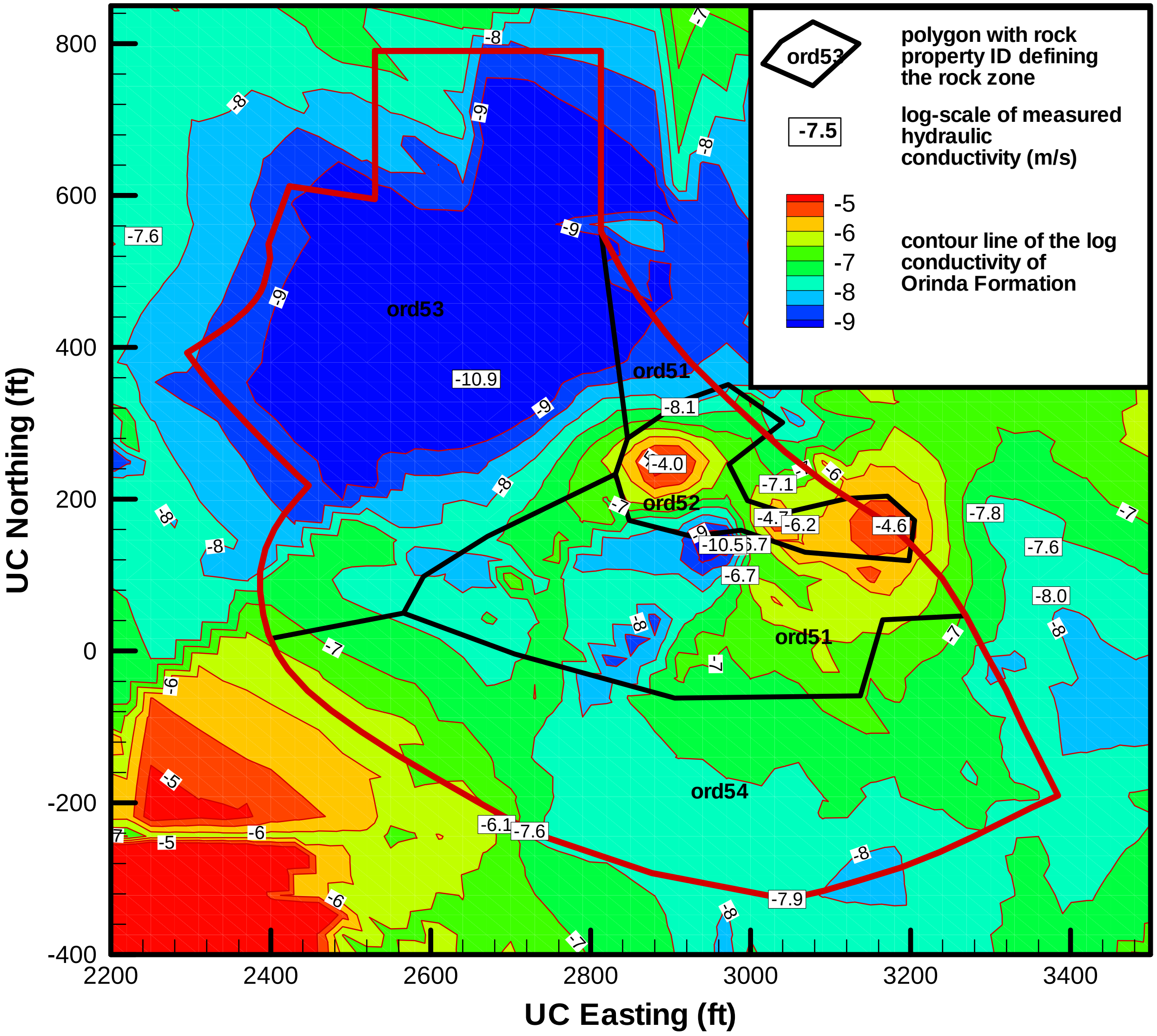

Figure 20. Definition of four rock zones of different rock properties in the Orinda Formation unit, showing the measured hydraulic conductivities in the log scale.

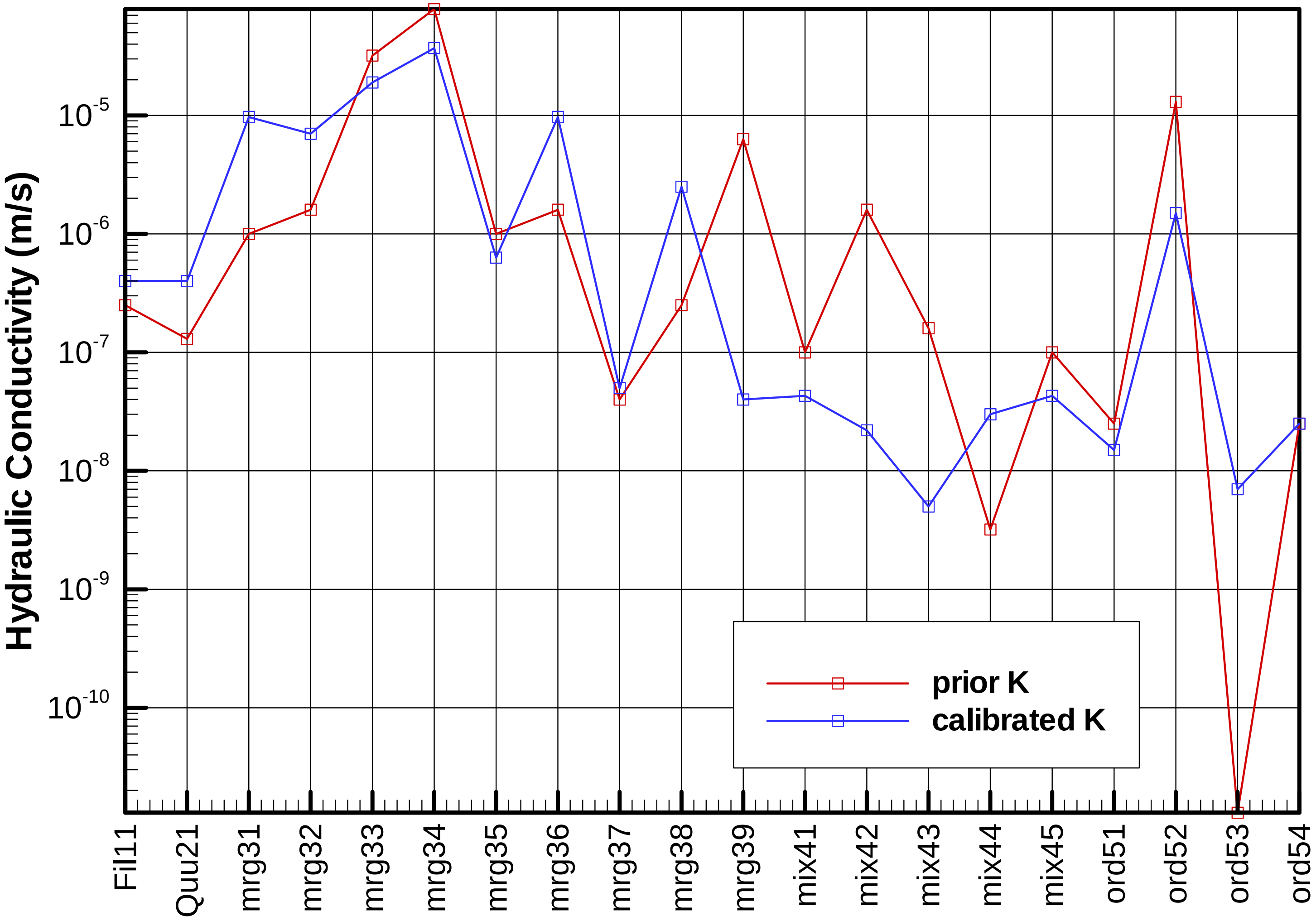

Figure 21. Comparison between the calibrated hydraulic conductivities and the prior ones obtained using hydraulic conductivity measurements for the 20 rock zones. See Figures 18-20 for the locations of the zones.

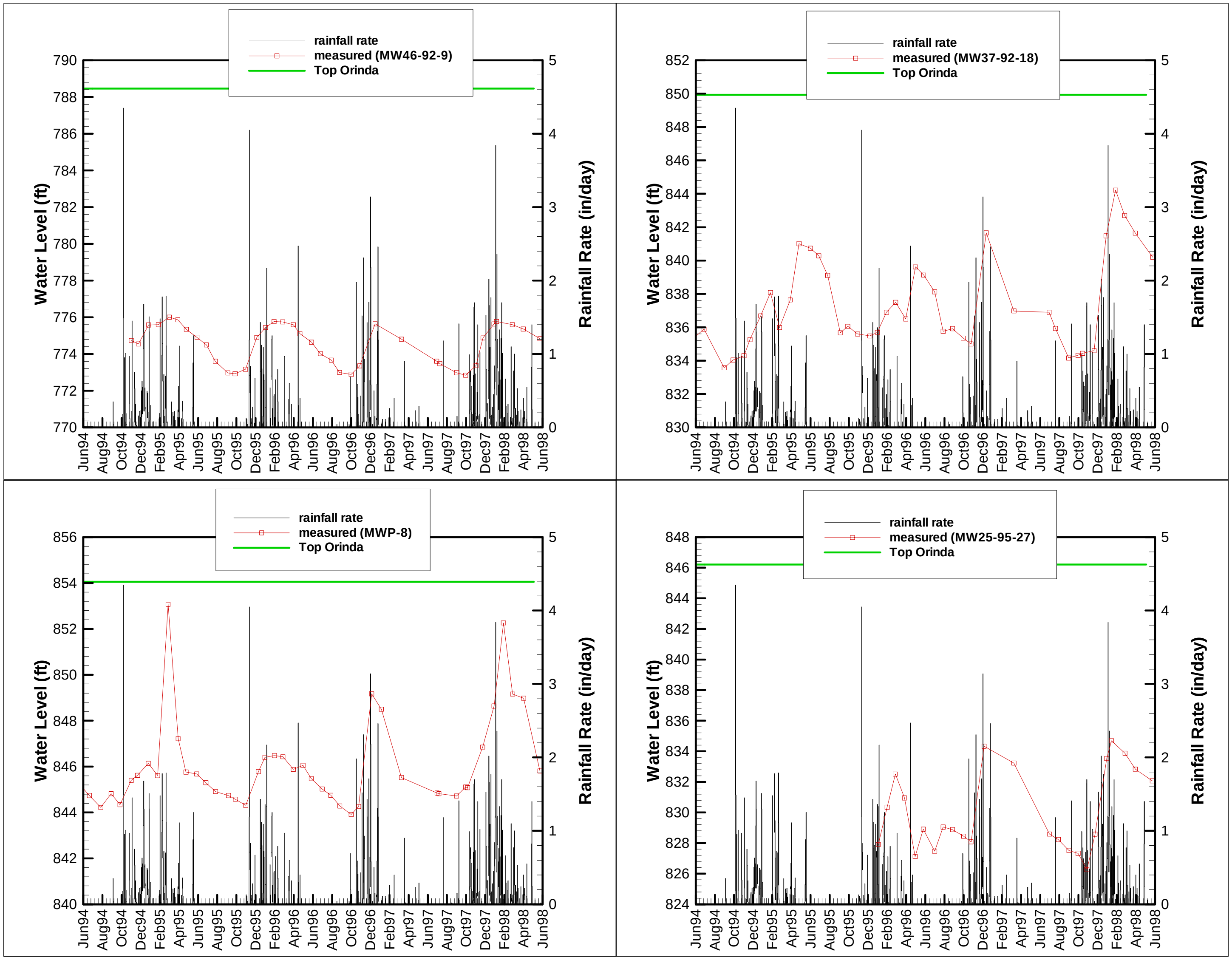

Figure 22. Measured water levels at four monitoring wells on the downstream boundary.

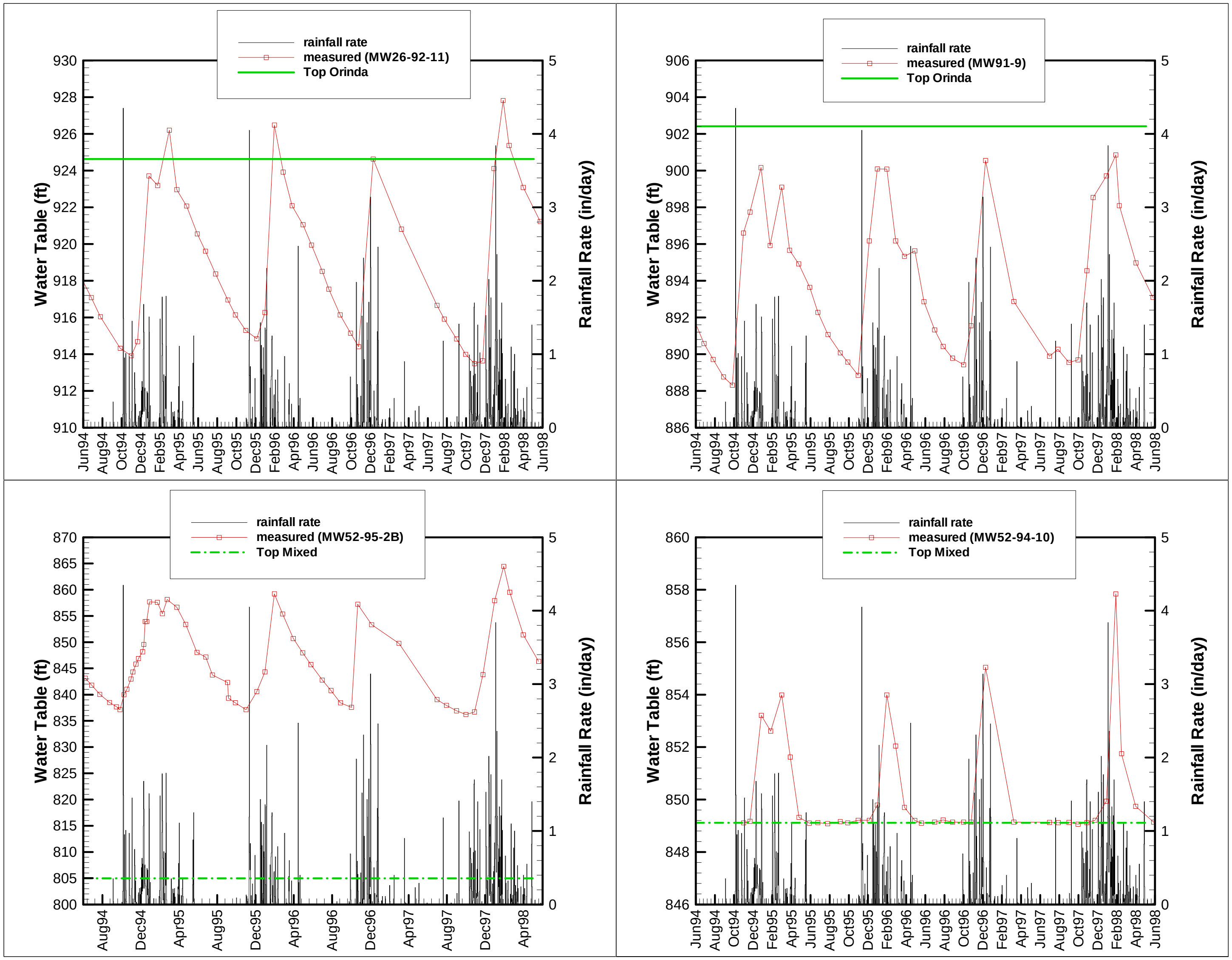

Figure 23. Measured water levels at four wells on the upstream boundary.

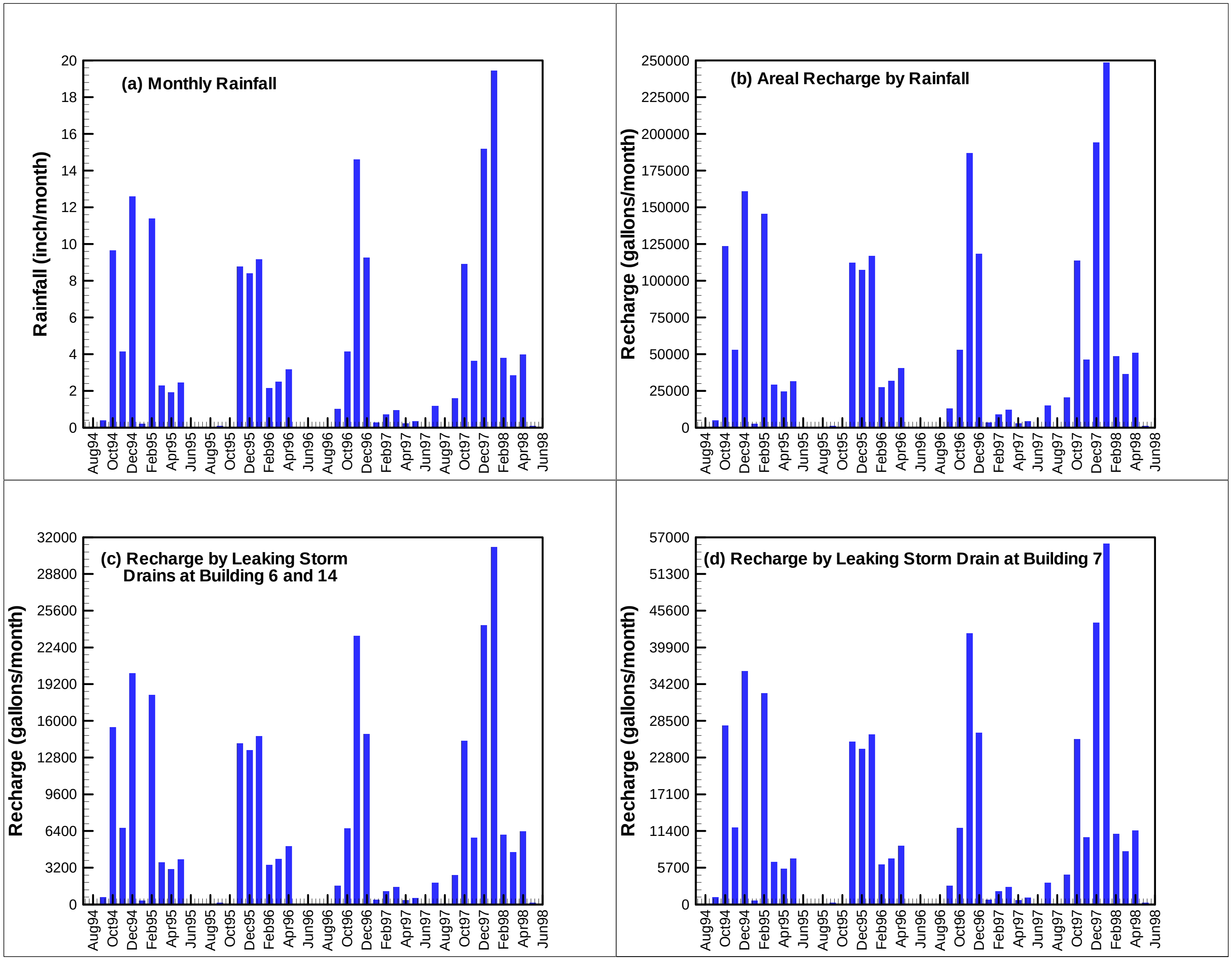

Figure 24. Transient processes of (a) monthly rainfall, (b) net areal recharge via unpaved areas, (c) recharge by storm drain at Building 6 and 14, and (d) recharge by storm drain in the north of Building 7 during the period from July 1994 to June 1998.

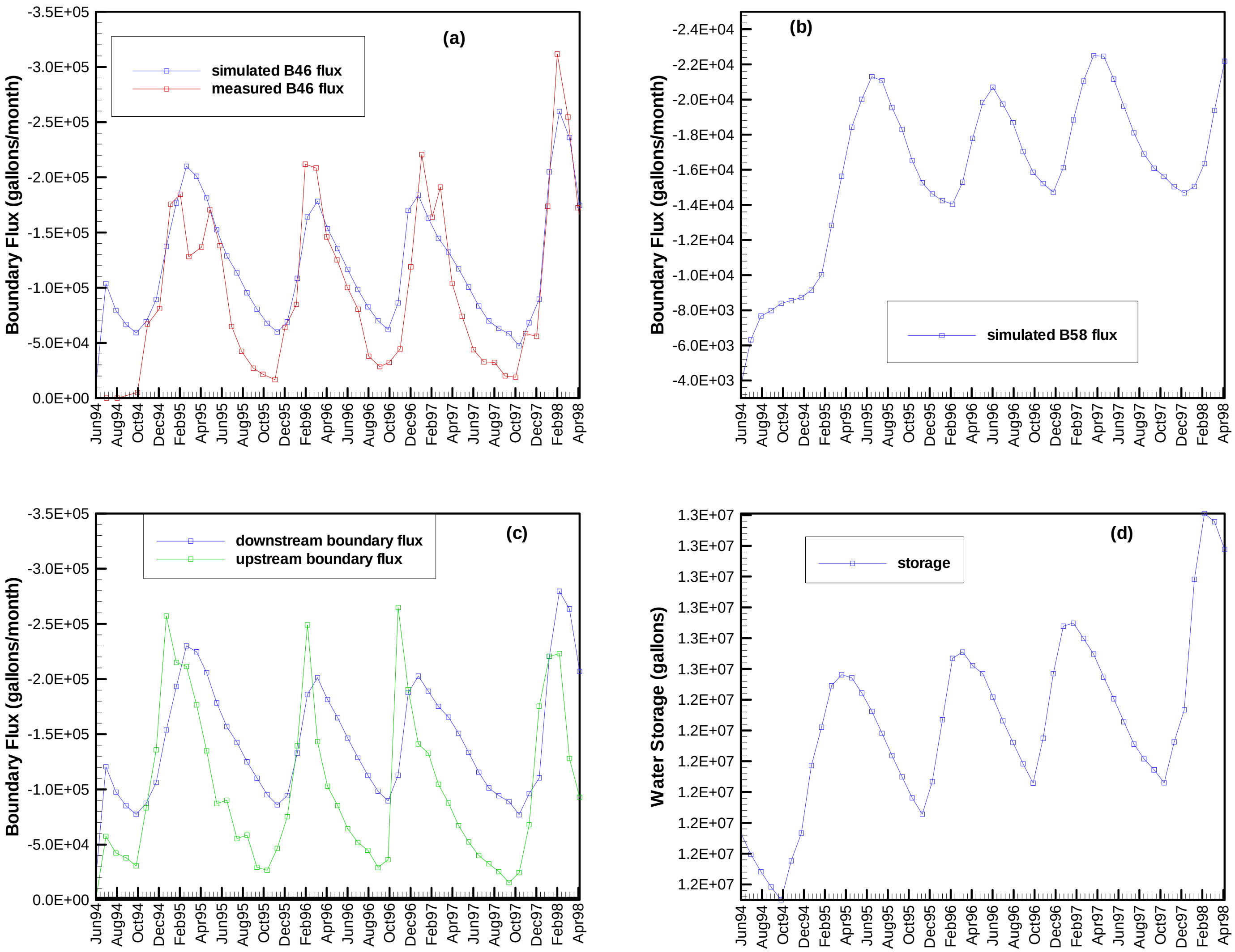

Figure 25. Transient processes of (a) the simulated and measured flow rate (gallons/month) through B46 boundary segment group, (b) the flow rate through B58 boundary segment group, (c) total inflow and outflow rates through the upstream boundary and downstream boundary, and (d) water-storage change (gallons) in the system during the period from July 1994 to June 1998.

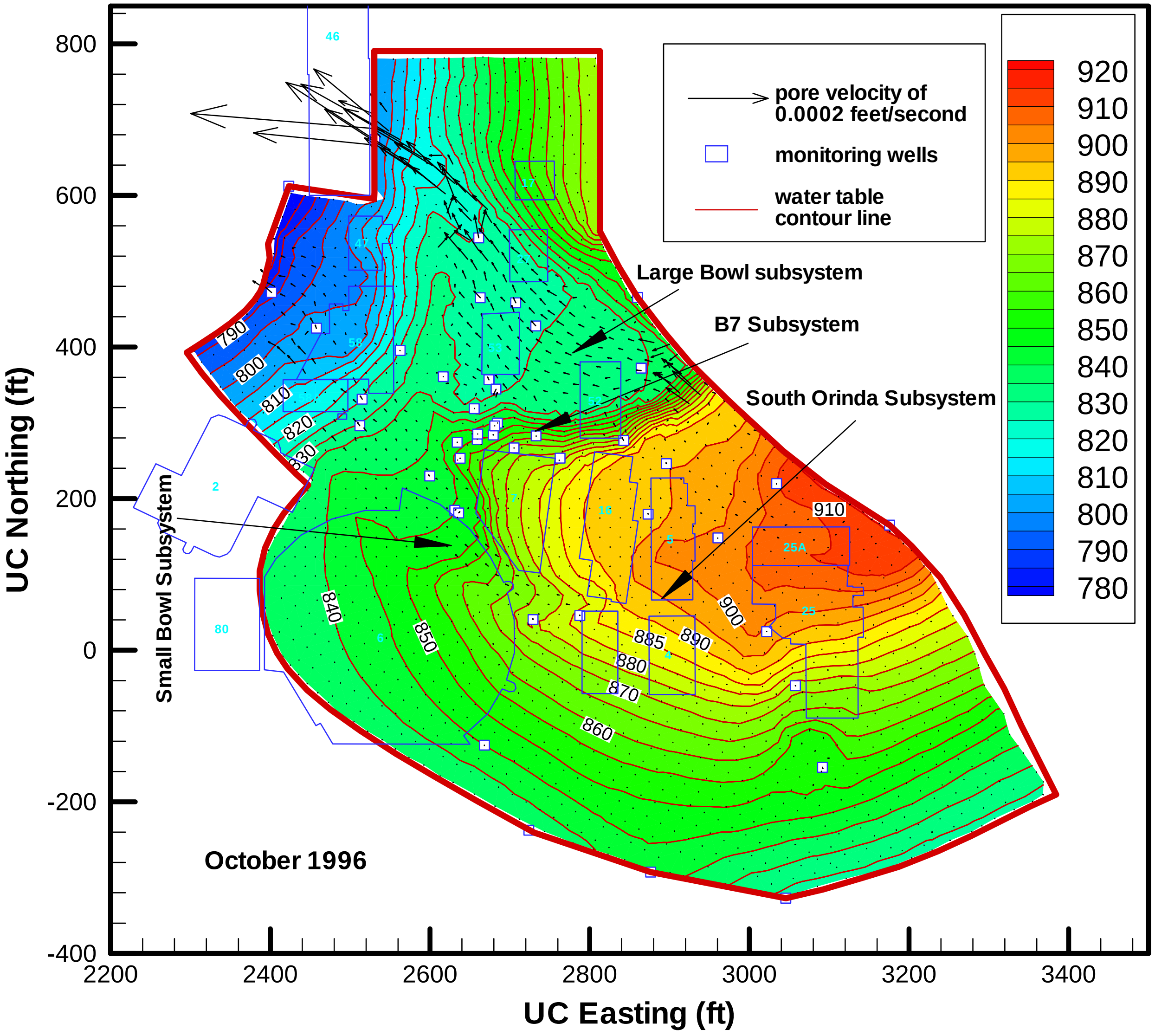

Figure 26. Contour of the simulated water table and vector field of simulated velocity on the water table at October 1996. The blue-white symbols indicate the location of monitoring wells.

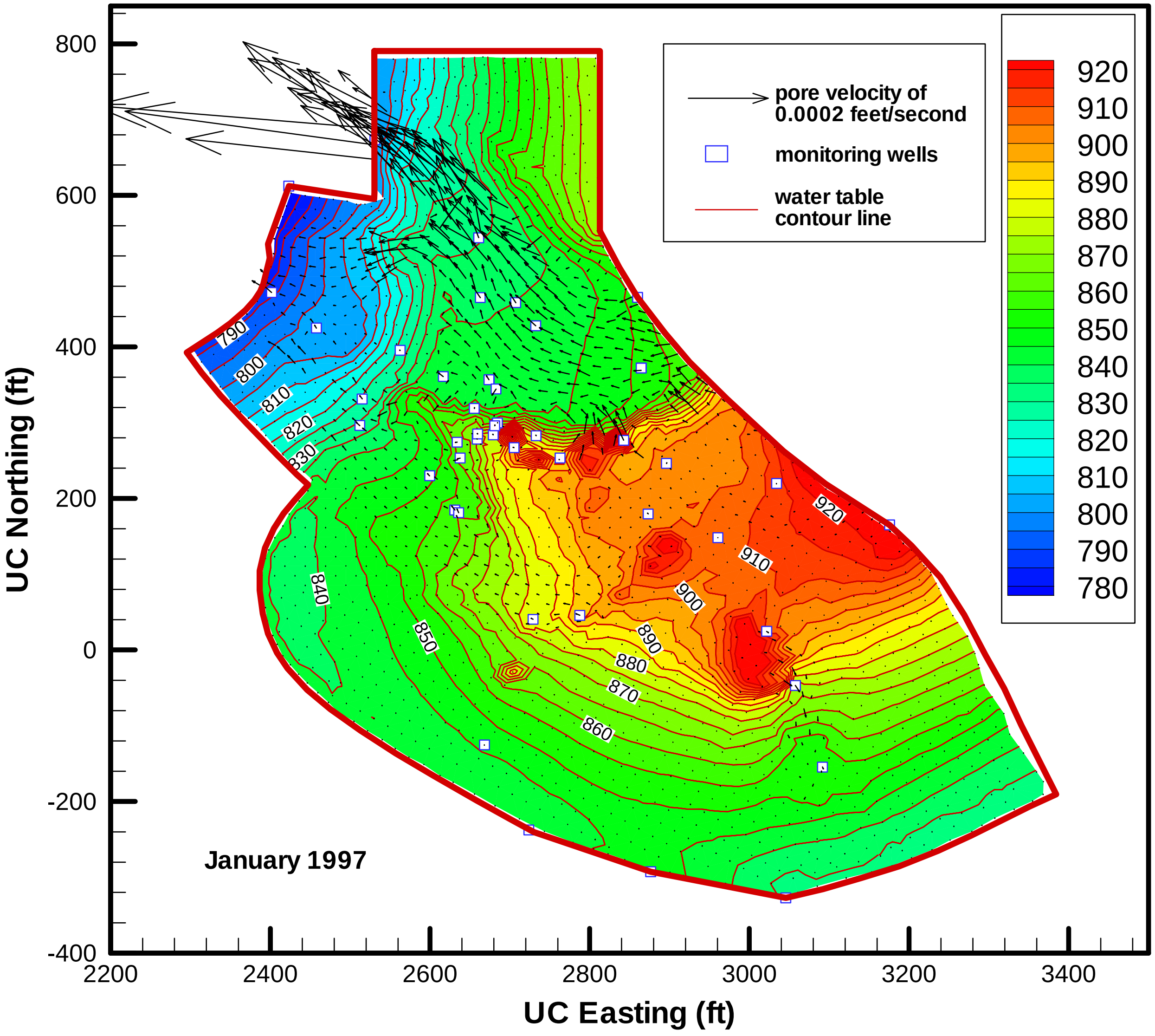

Figure 27. Contour of the simulated water table and vector field of simulated velocity on the water table at January 1997. The blue-white symbols indicate the location of monitoring wells.

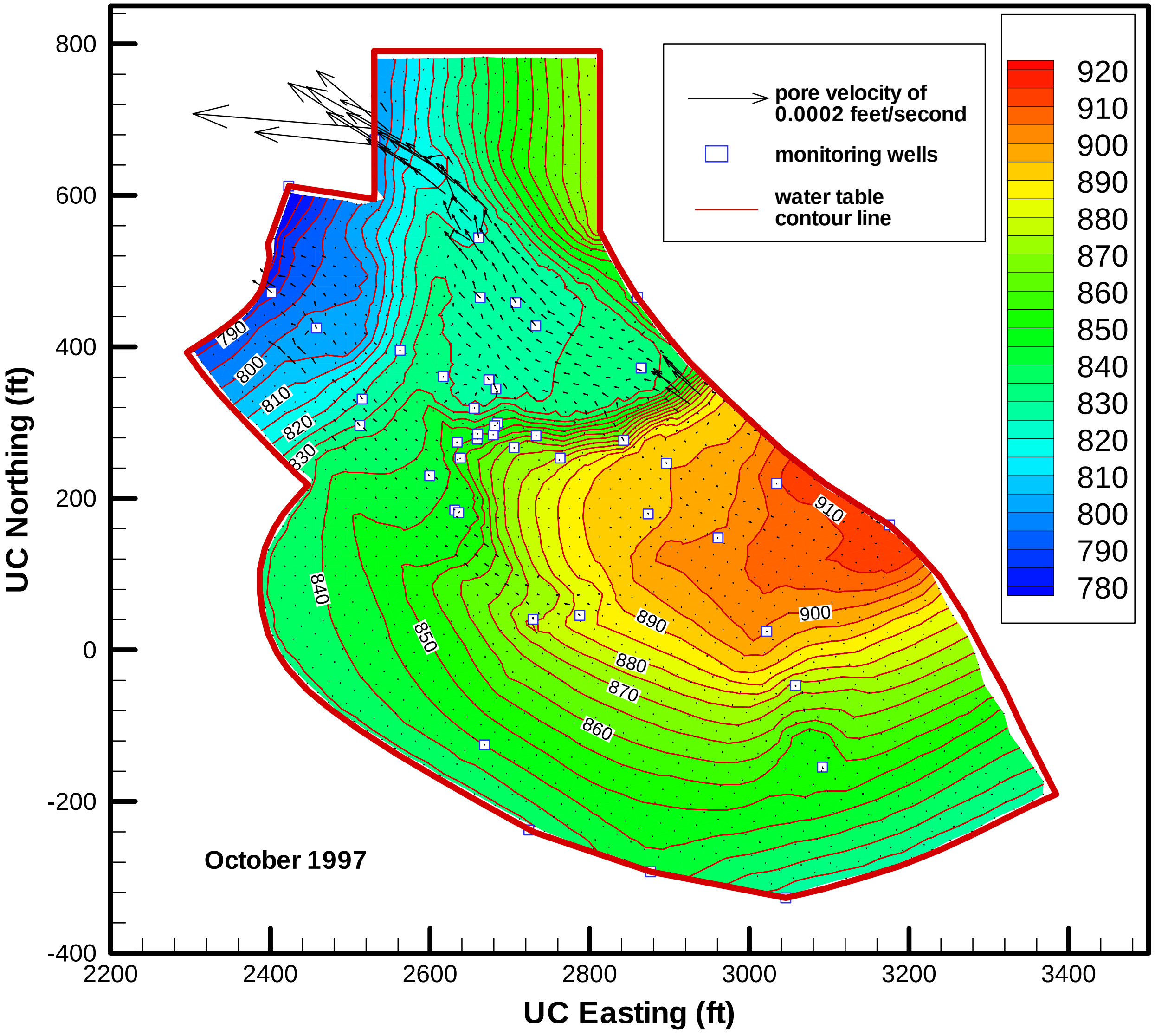

Figure 28. Contour of the simulated water table and vector field of simulated velocity on the water table at October 1997. The blue-white symbols indicate the location of monitoring wells.

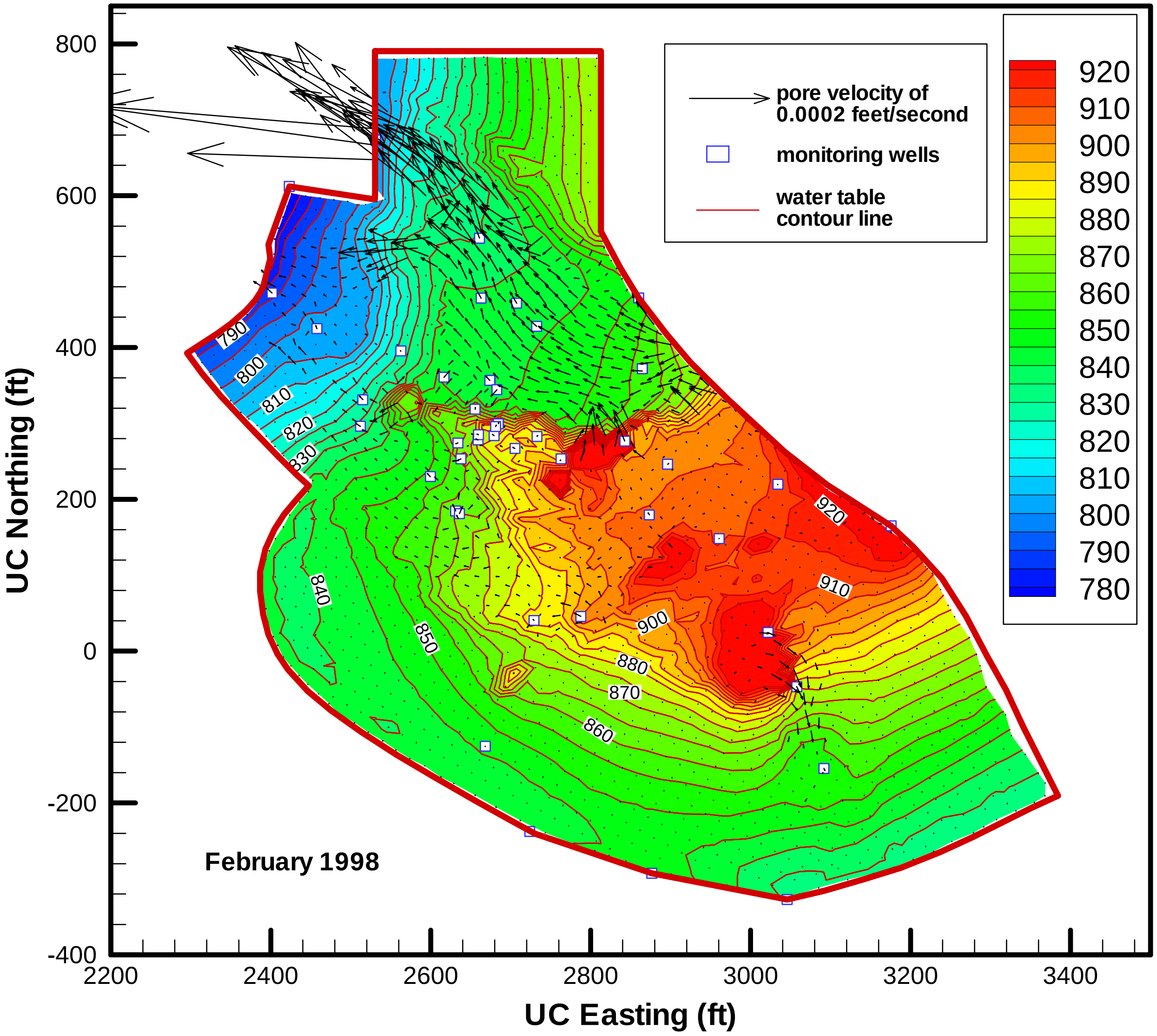

Figure 29. Contour of the simulated water table and vector field of simulated velocity on the water table at February 1998. The blue-white symbols indicate the location of monitoring wells.

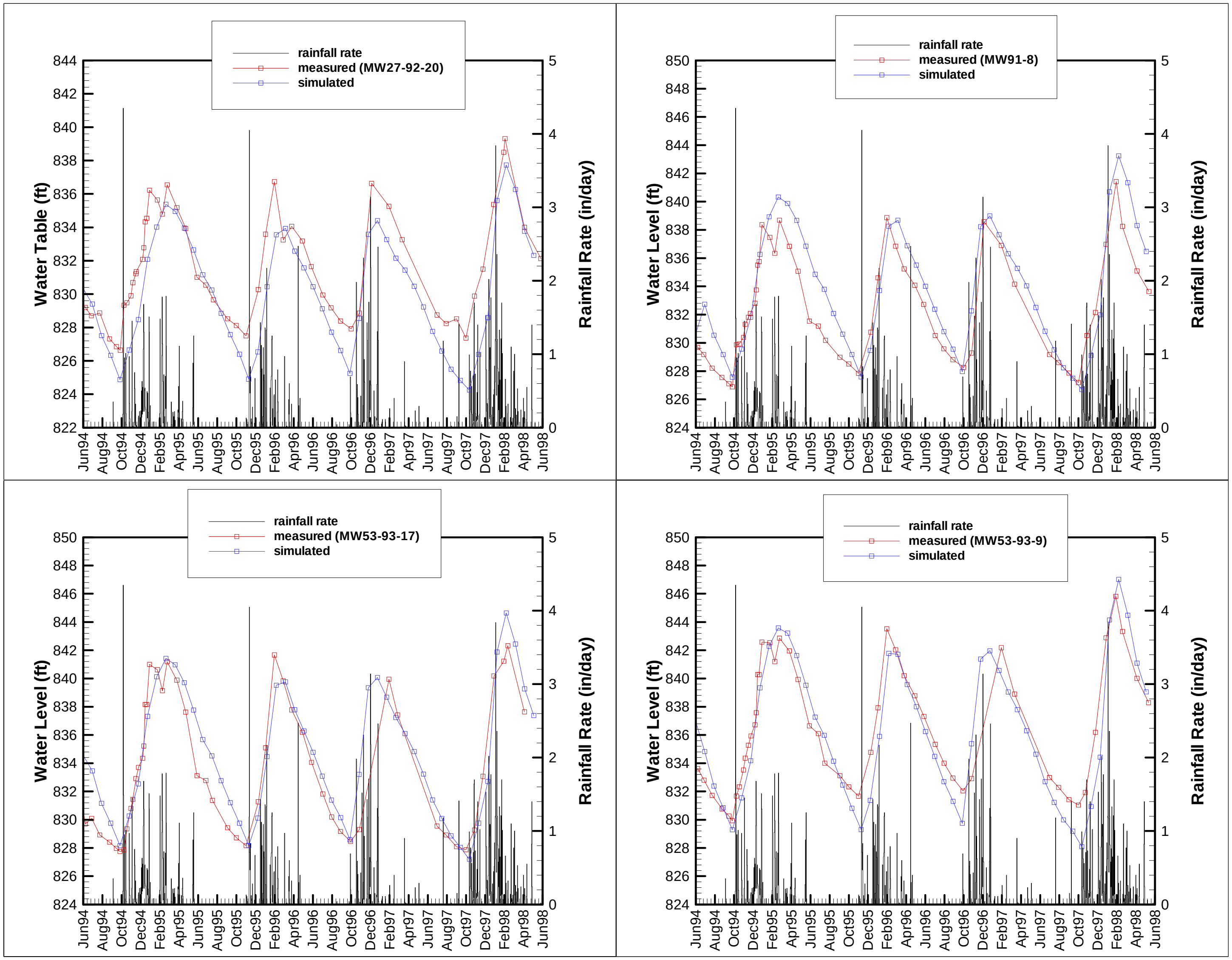

Figure 30. Match between the measured and simulated water levels at four monitoring wells in the Large-Moraga-Bowl subsystem.

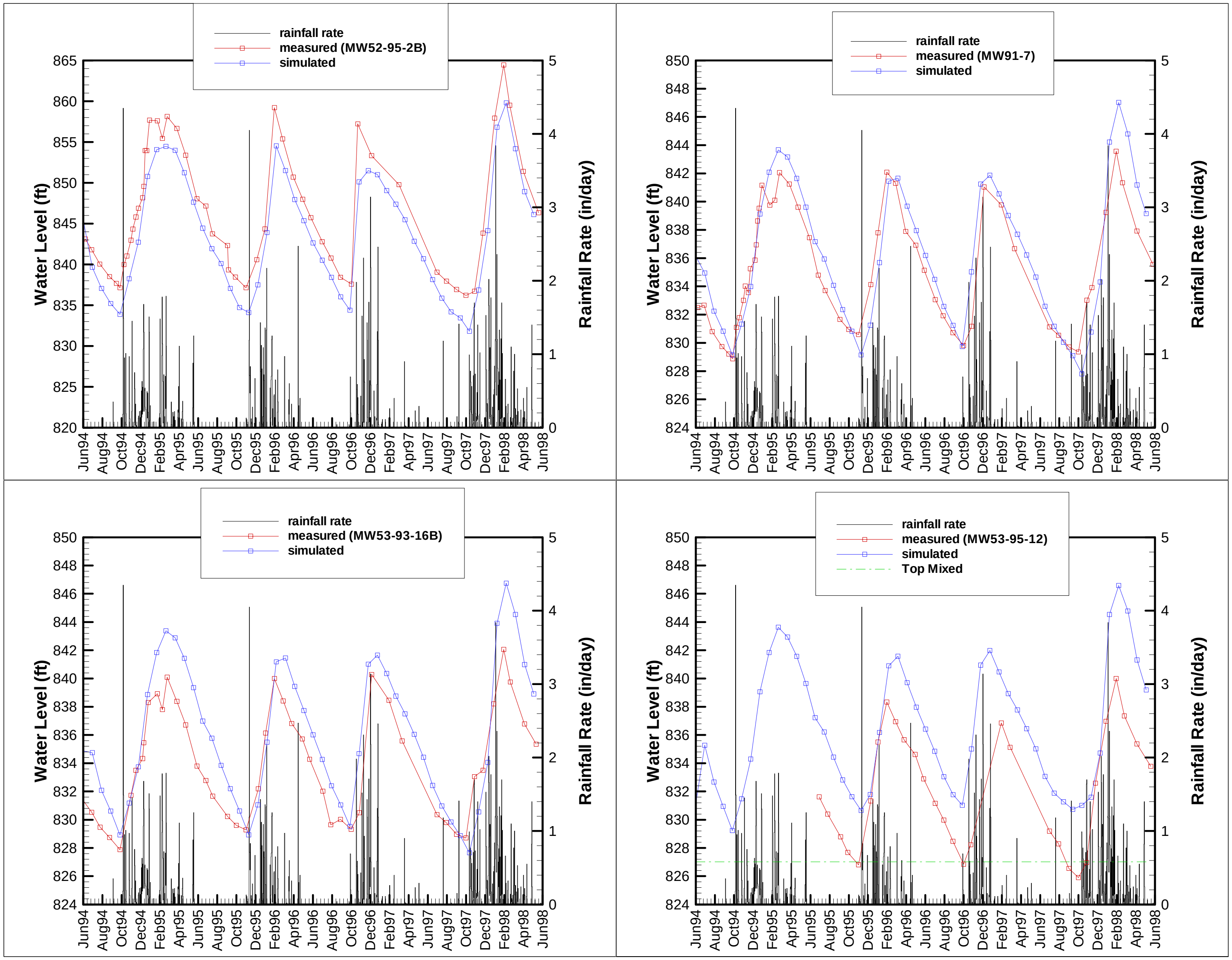

Figure 31. Match between the measured and simulated water levels at four monitoring wells in the Large-Moraga-Bowl subsystem (cont.).

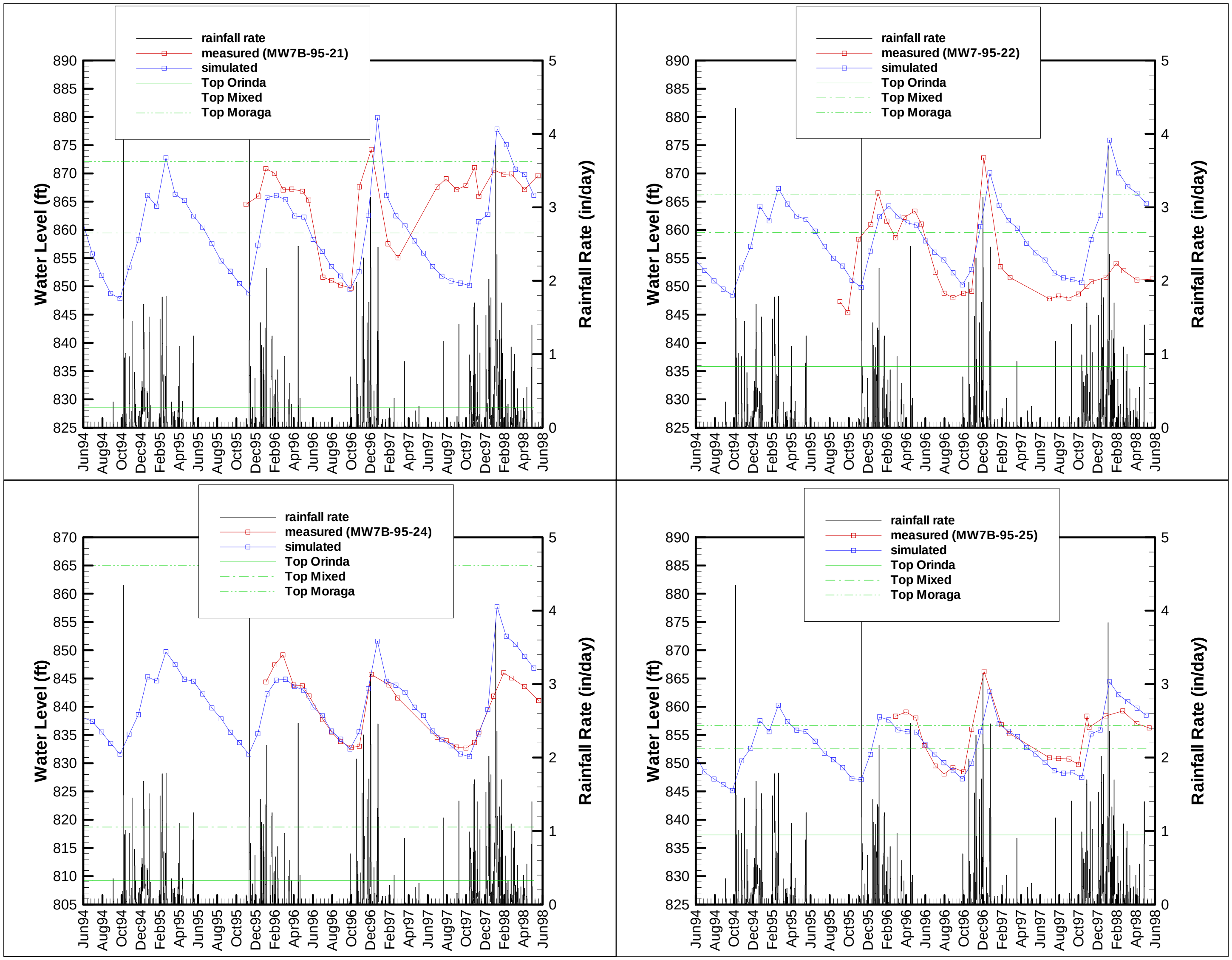

Figure 32. Match between the simulated and measured water levels at four monitoring wells in the Building 7 subsystem.

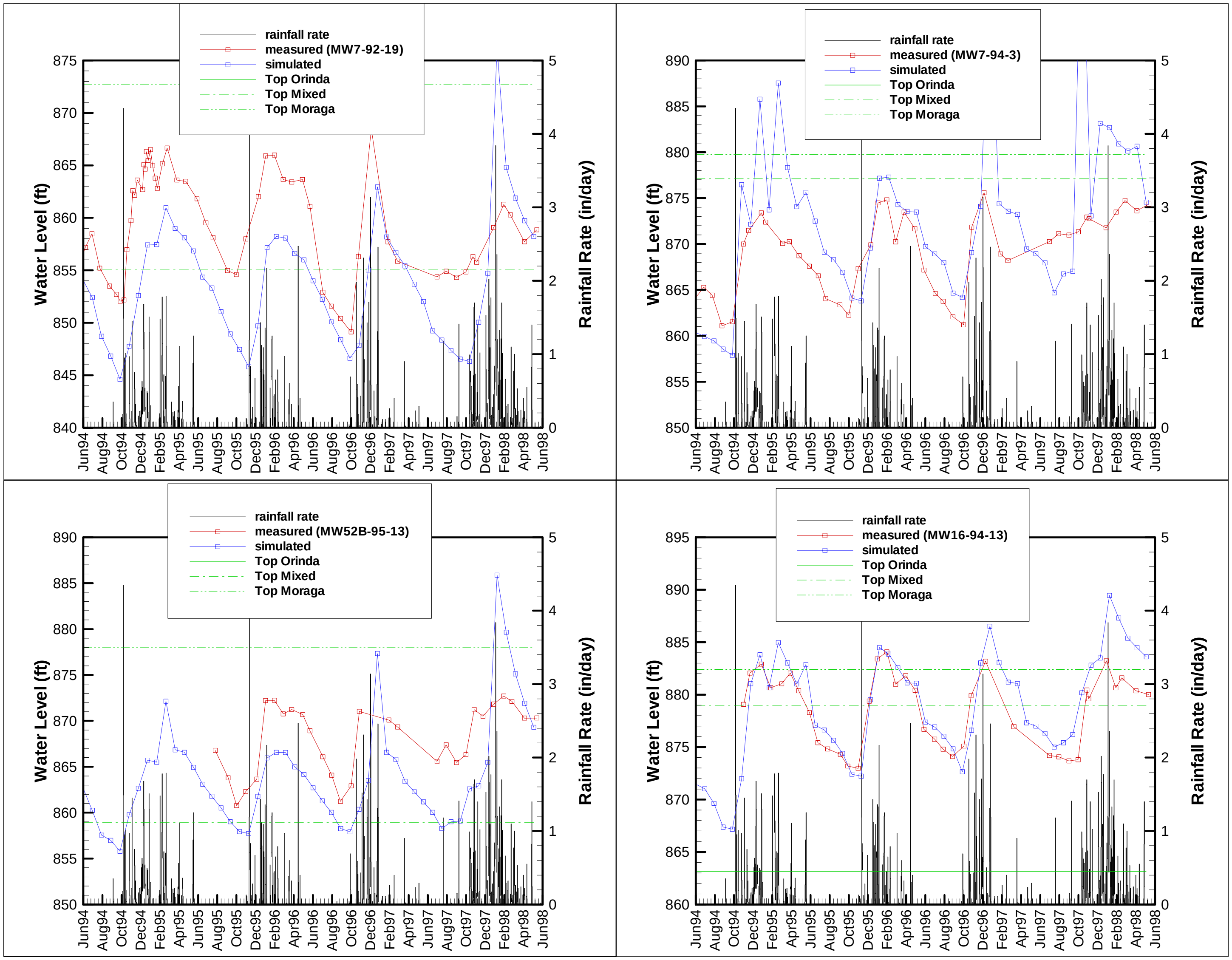

Figure 33. Match between simulated and measured water levels at four monitoring wells in the Building 7 subsystem (cont.).

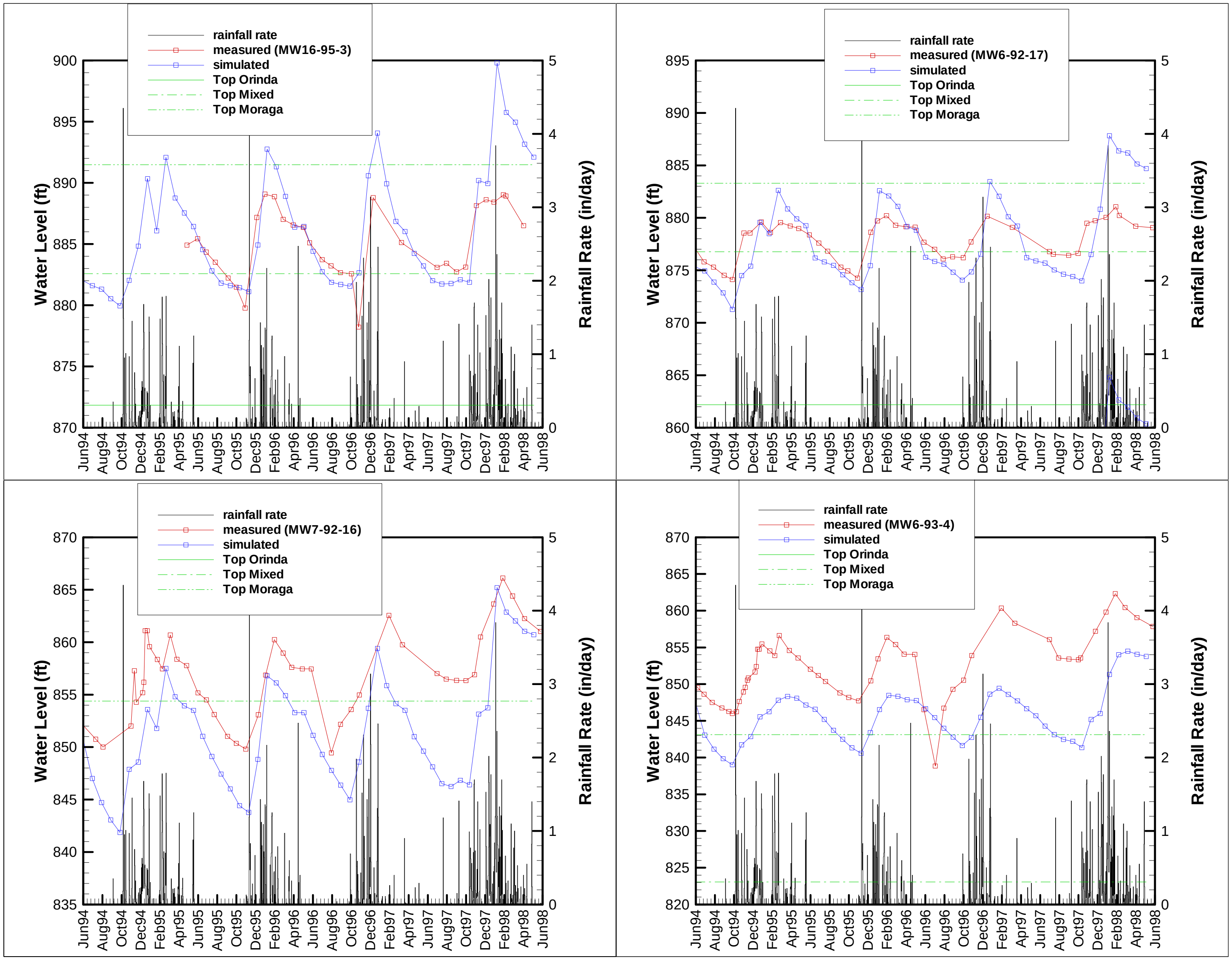

Figure 34. Match between the simulated and measured water levels at four monitoring wells in the Small-Moraga-Bowl subsystem.

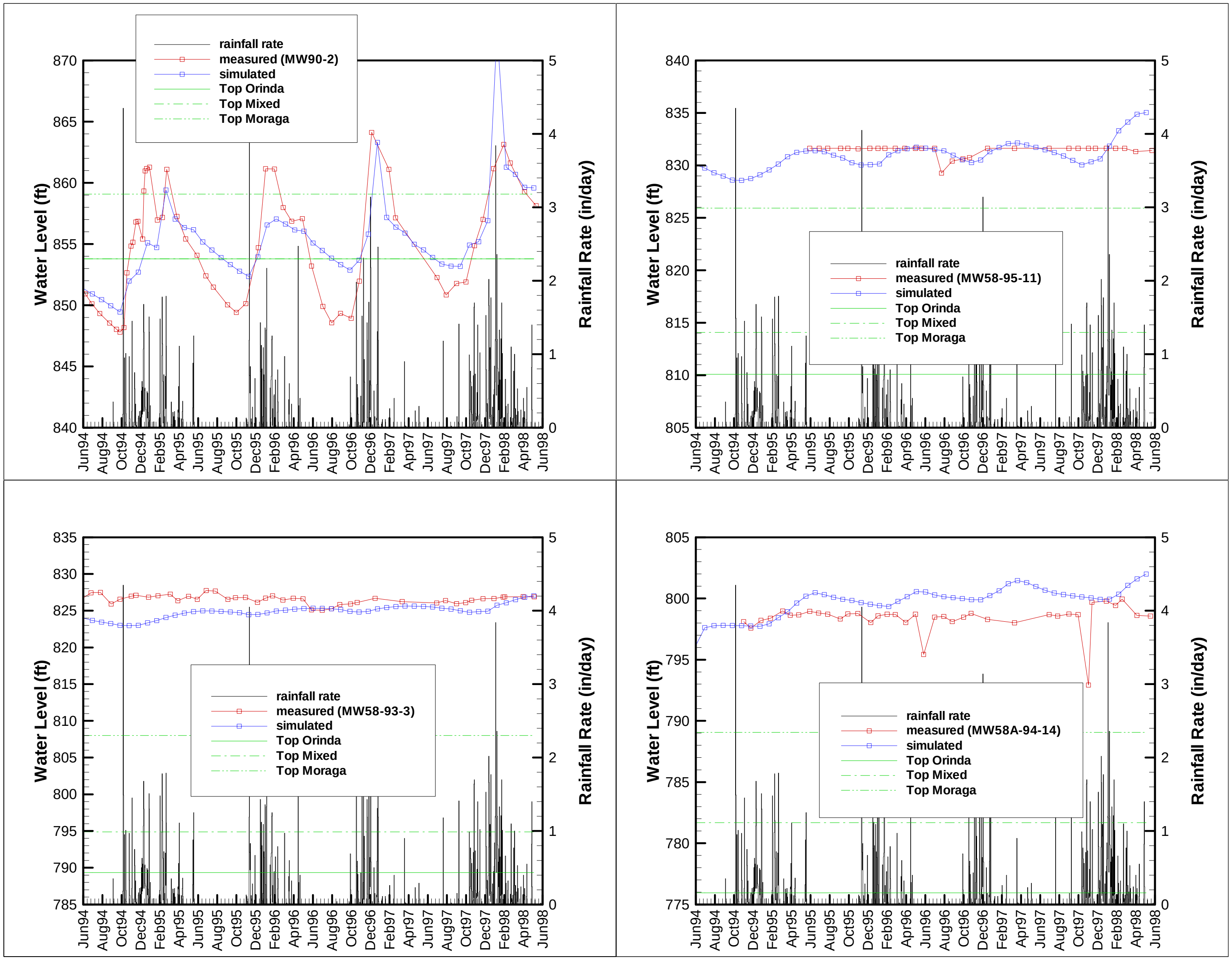

Figure 35. Match between the simulated and measured water levels at four monitoring wells in the Small-Moraga-Bowl subsystem (cont.).

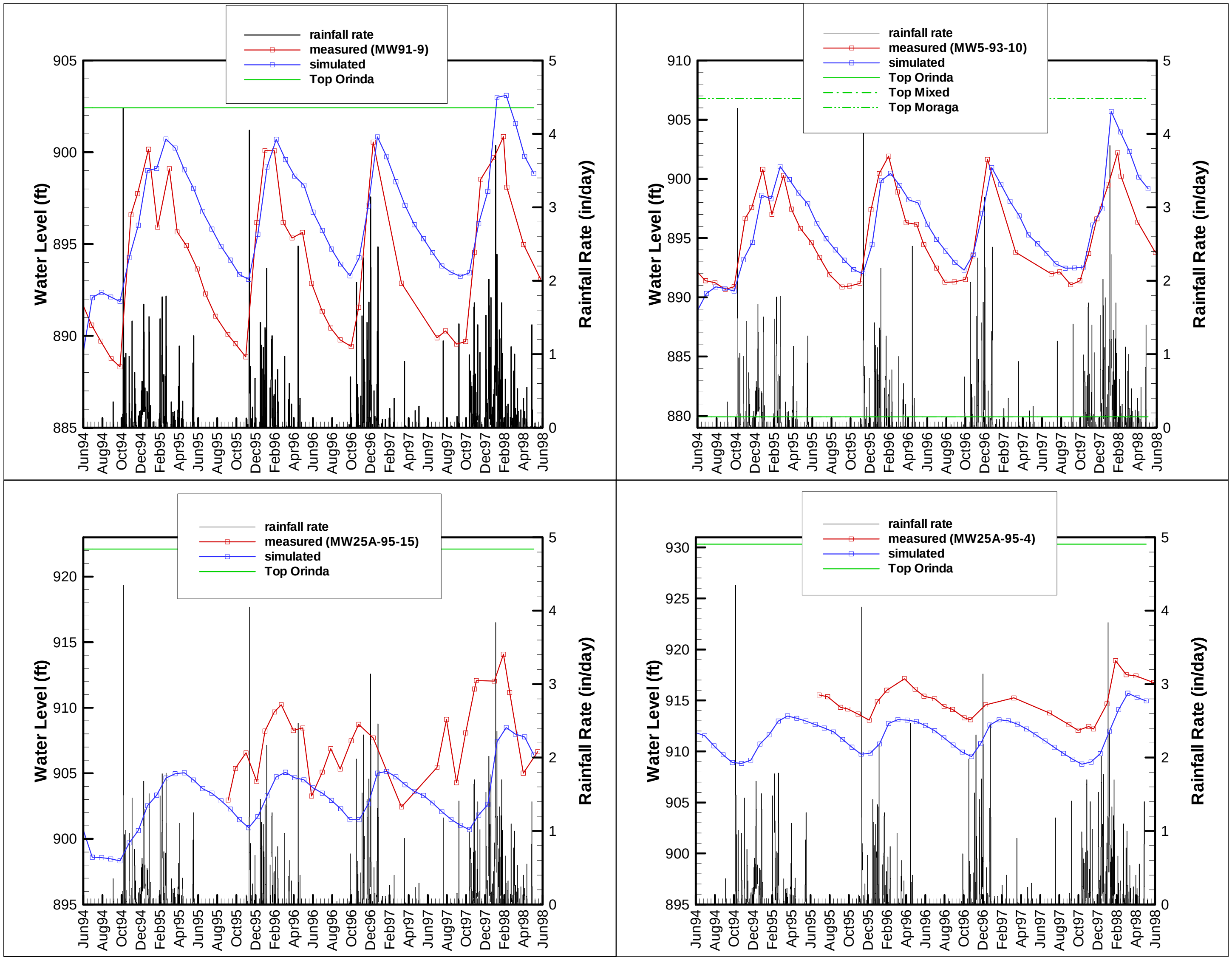

Figure 36. Match between the simulated and measured water levels at four monitoring wells in the South-Orinda subsystem.

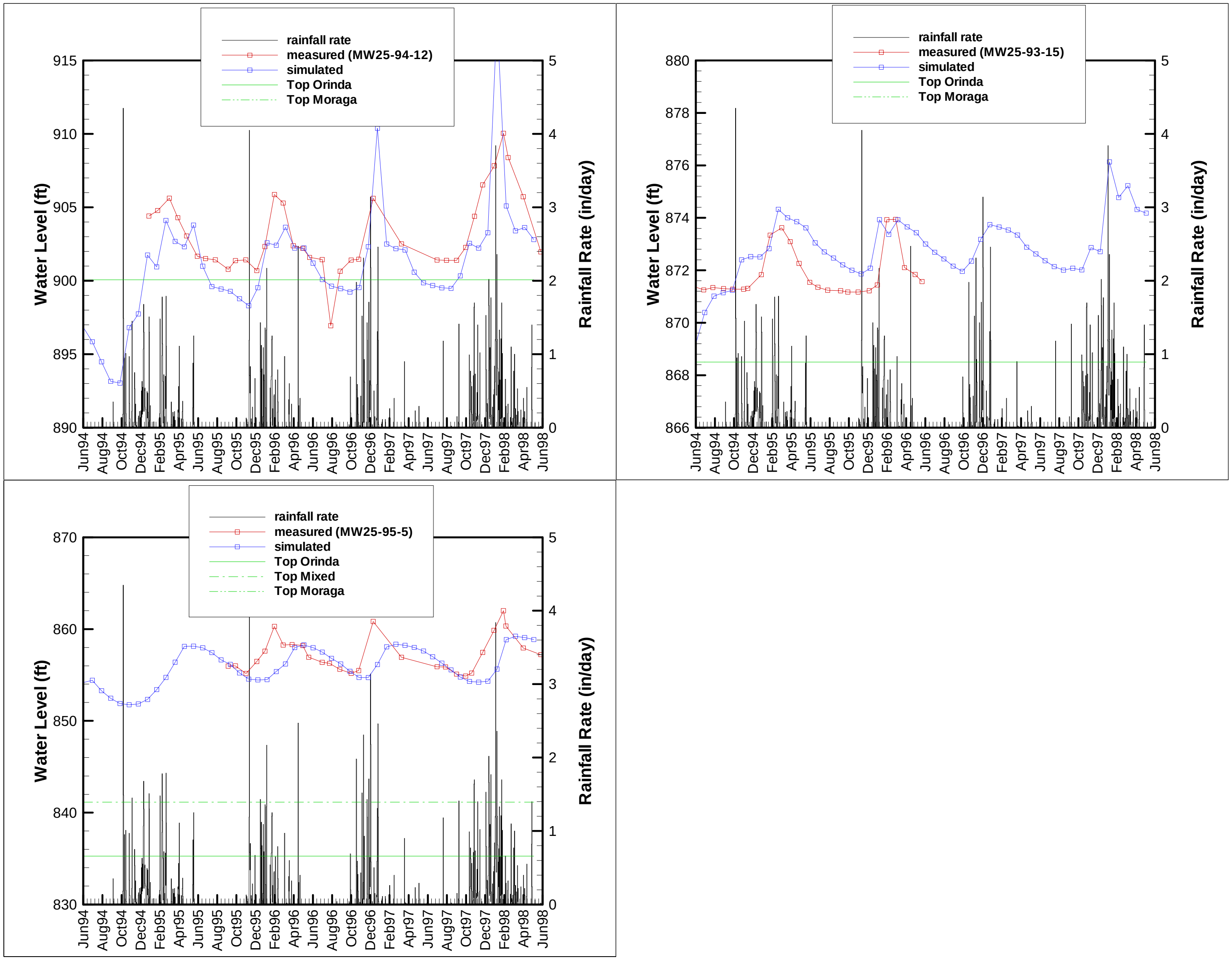

Figure 37. Match between the simulated and measured water levels at four monitoring wells in the South-Orinda subsystem (cont.).

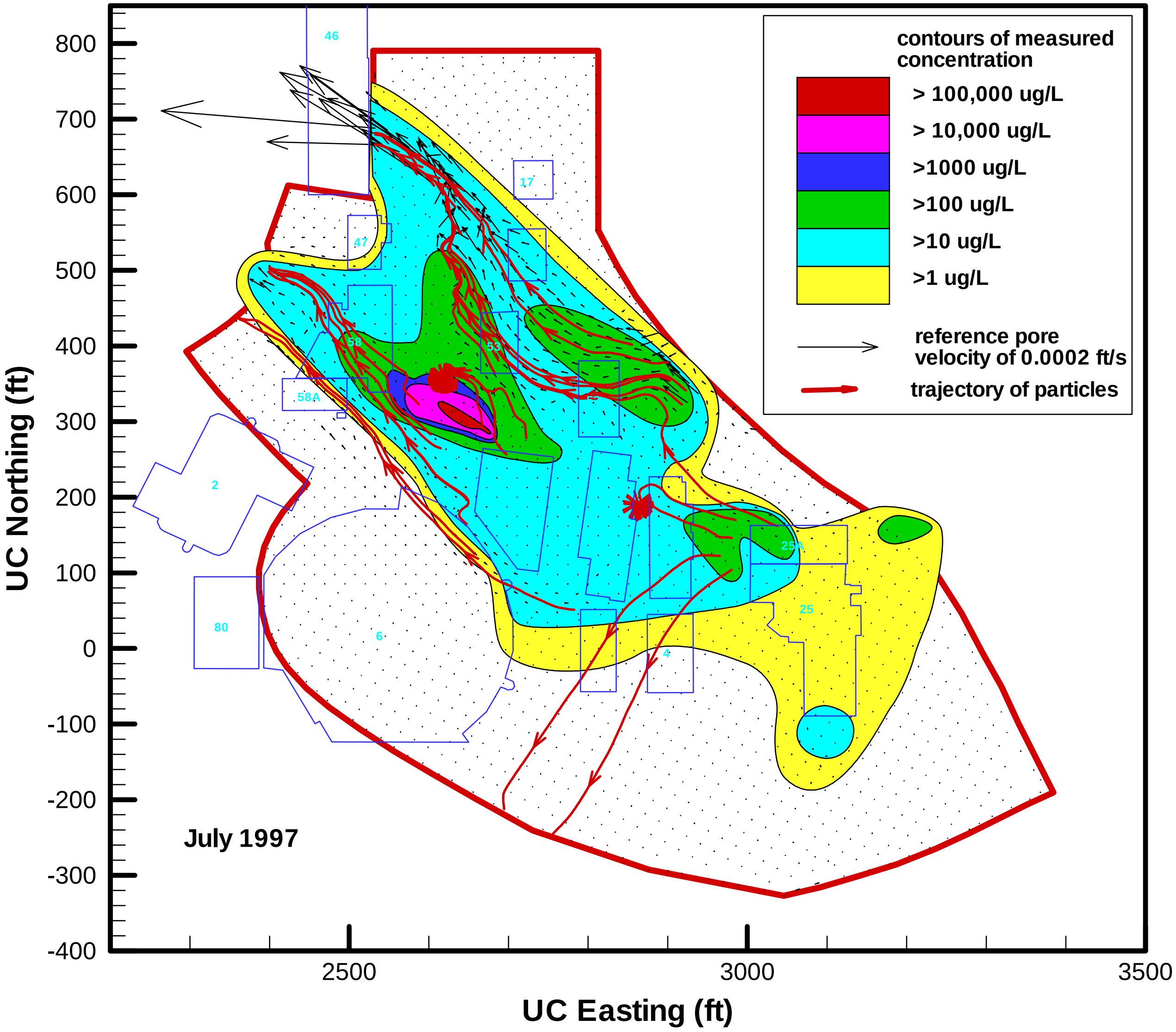

Figure 38. Trajectories of particles originating from the contaminant source areas at B7 lobe, B52 lobe, and B25A lobe. These trajectories are obtained using the steady-state flow in the dry season with pore velocity at July 1997.

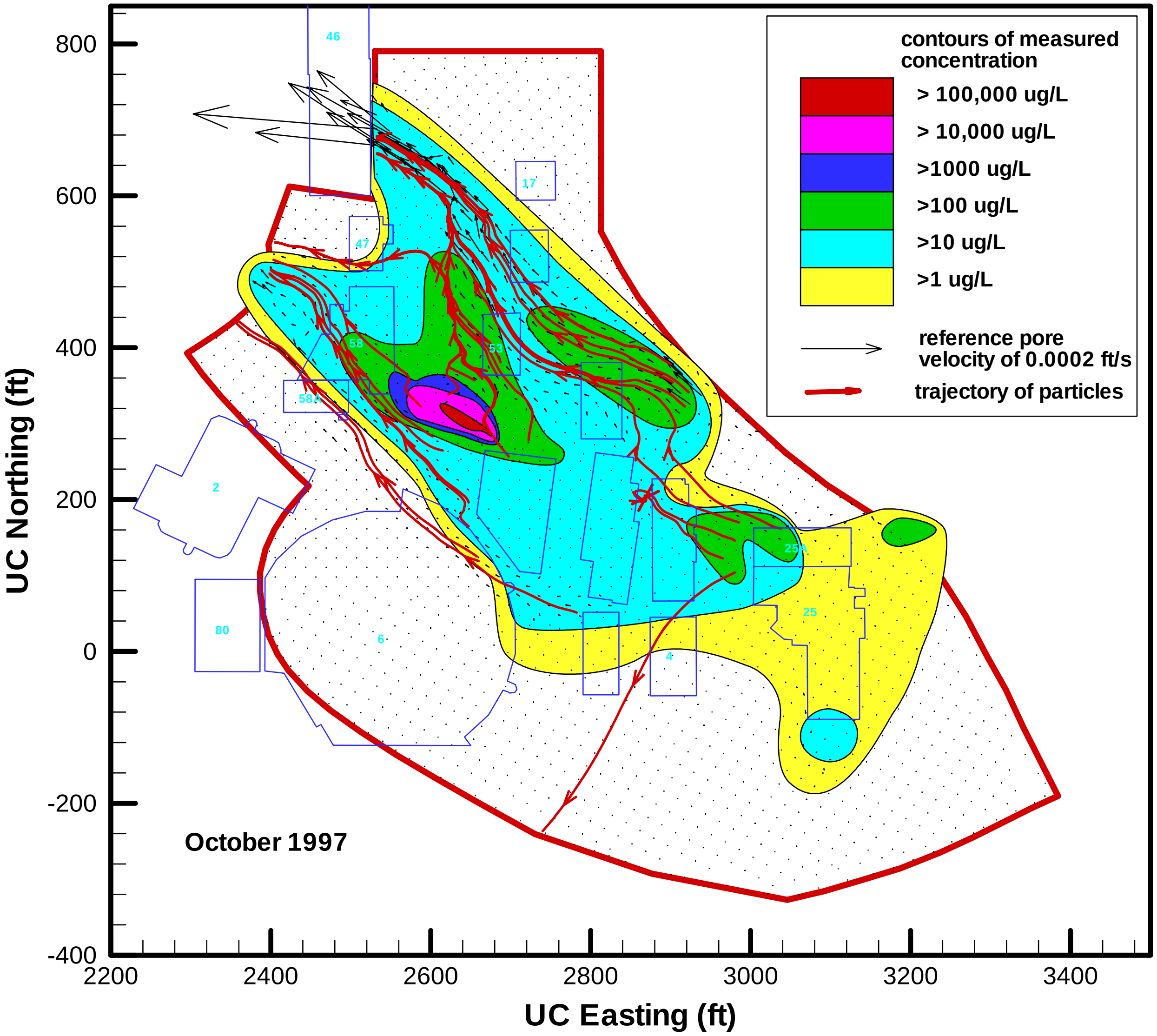

Figure 39. Trajectories of particles originating from the contaminant source areas at B7 lobe, B52 lobe, and B25A lobe. These trajectories are obtained using the steady-state flow in the wet season with pore velocity at October 1997.

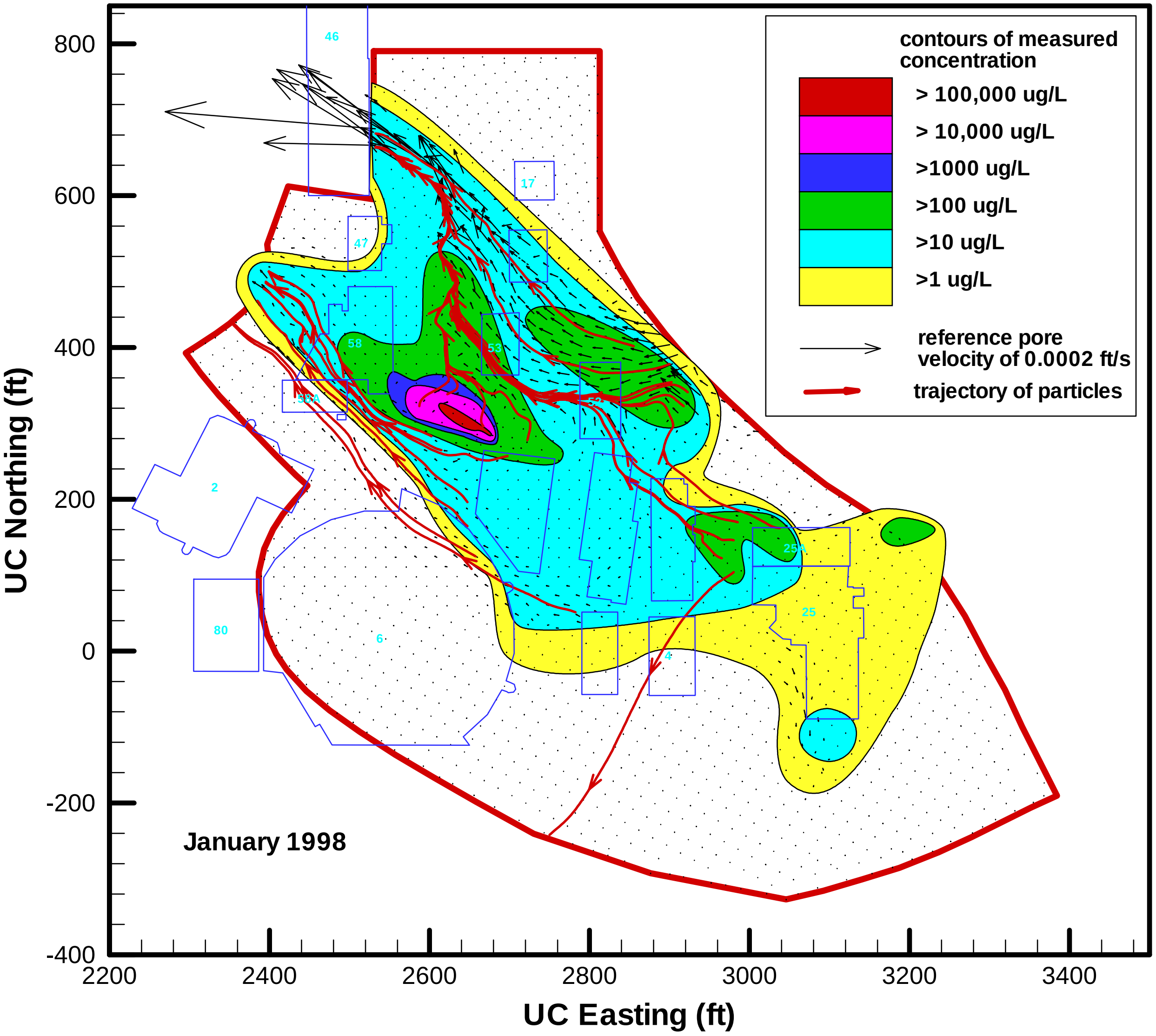

Figure 40. Trajectories of particles originating from the contaminant source areas at B7 lobe, B52 lobe, and B25A lobe. These trajectories are obtained using the steady-state flow in the wet season with pore velocity at January 1998.

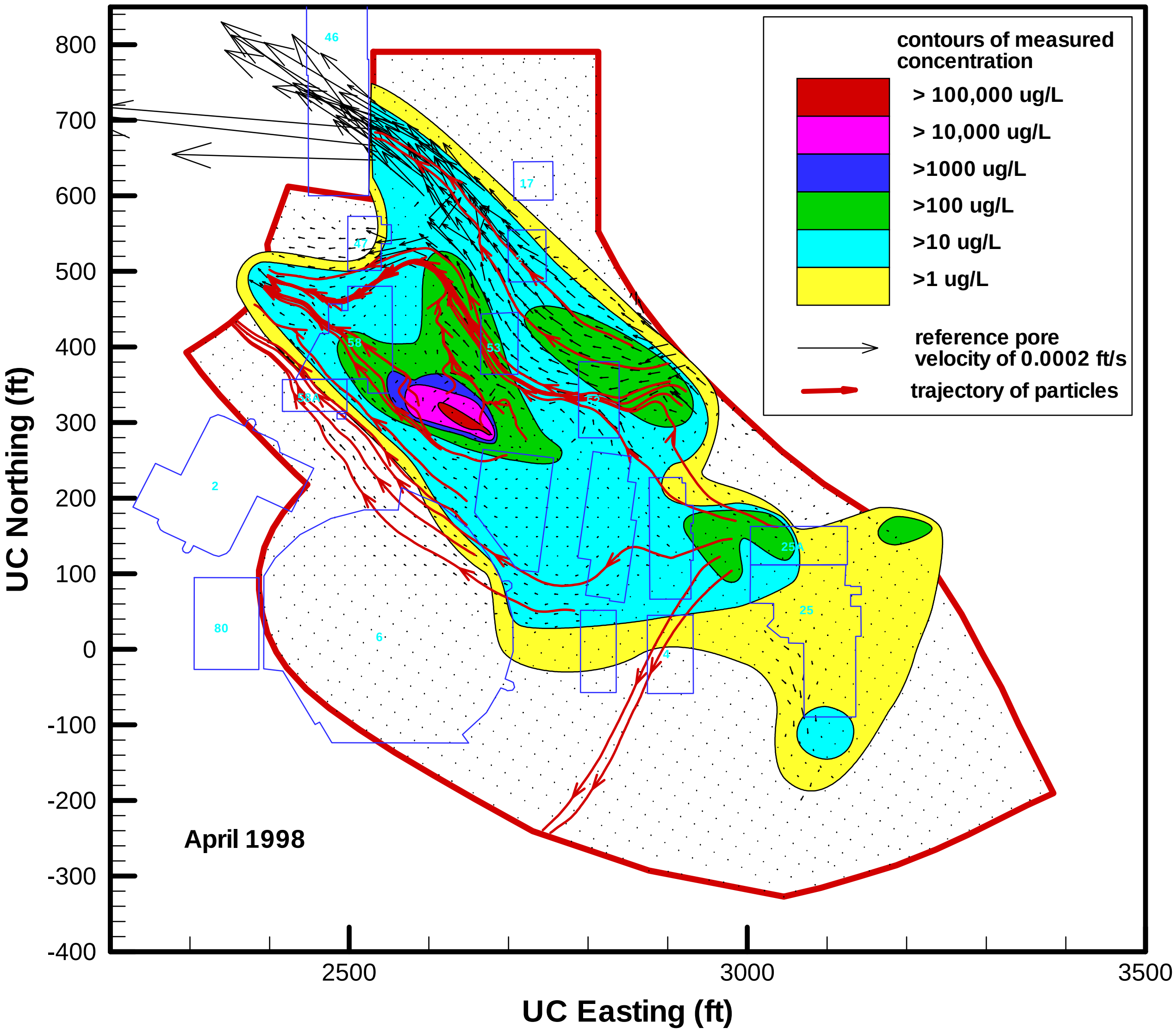

Figure 41. Trajectories of particles originating from the contaminant source areas at B7 lobe, B52 lobe, and B25A lobe. These trajectories are obtained using the steady-state flow in the wet season with pore velocity at April 1998.

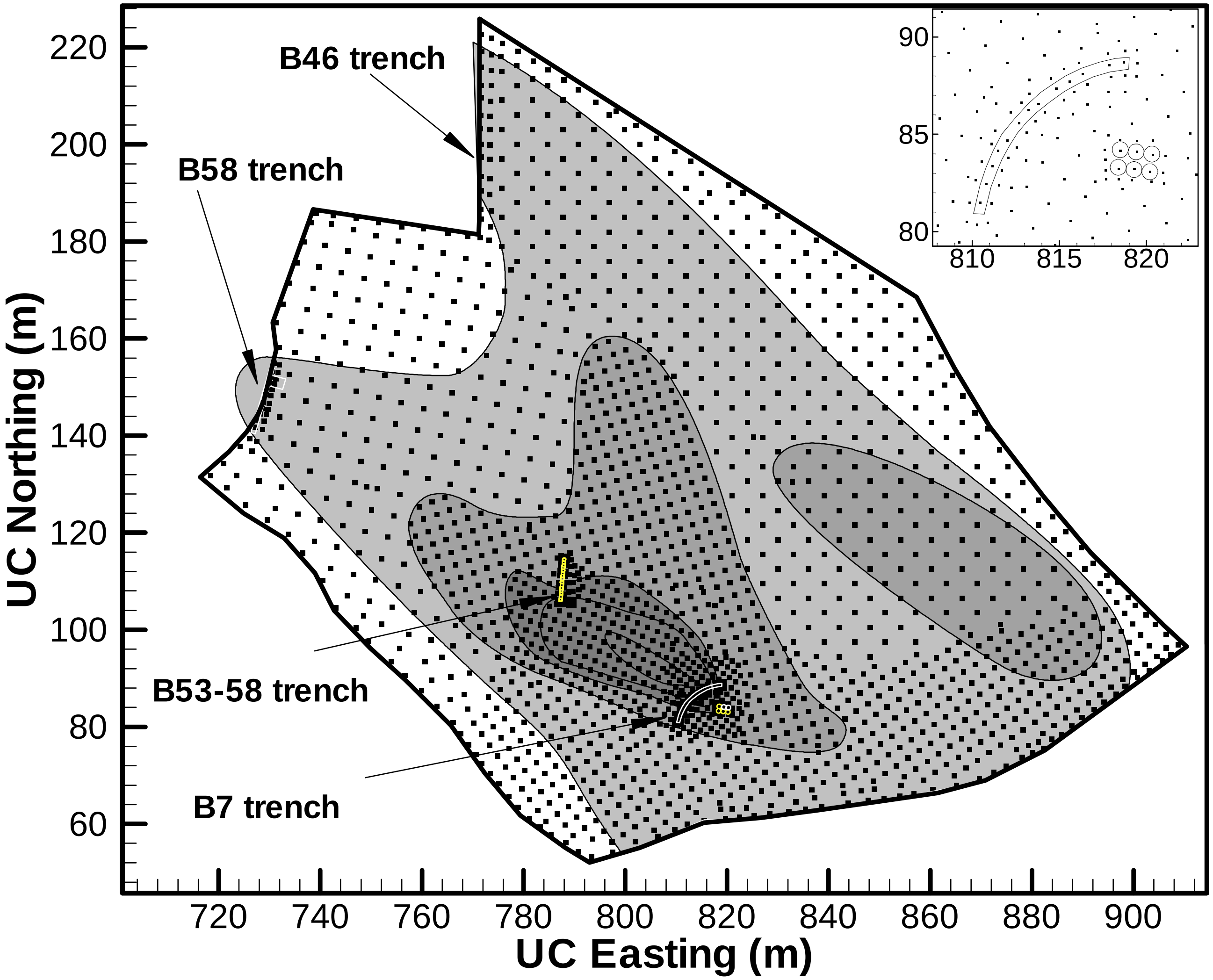

Figure 42. Boundary and plan view of the three-dimensional mesh for the refined model, showing the four trenches implemented for restoration. The background is the measured concentration contour with the contour legend shown in Figure 41. The right upper-corner plot shows a close-up view of the sump and the B7 trench system for controlling the contaminant source.

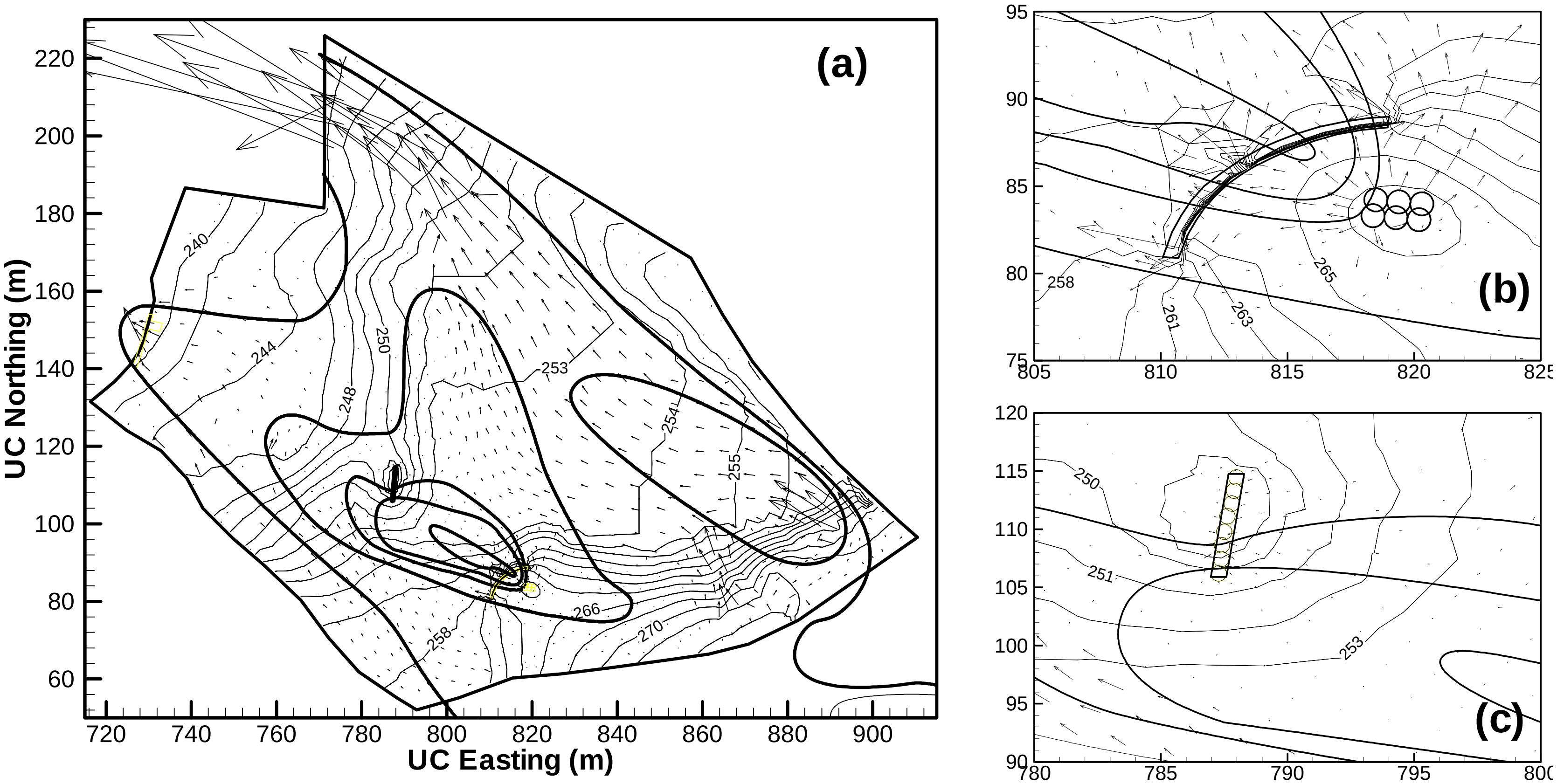

Figure 43. Contour of the predicted groundwater level (light lines) and flow velocity vector fields on the water table in October 1999 for the refined model in (a) the entire model domain, (b) in the vicinity of the B7 trench, and (c) in the vicinity of the B53-B58 trench. Note that the contaminant plume contour lines are indicated by thick lines (for scales, see Figure 41).

Appendix E

Evaluation of Biological Conditions Important to Monitored Natural Attenuation at the Building 51/64 Site

Evaluation of Biological Conditions Important to Monitored Natural Attenuation at the Building 51/64 Site

Final Project Report
May 24, 2004

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Earth Sciences Division
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University of California Berkeley

Executive Summary

The Building 51/64 Site, located at Lawrence Berkeley National Laboratory (LBNL), is contaminated with chlorinated organic compounds including 1,1,1-trichloroethane (TCA), perchloroethene (PCE) and trichloroethene (TCE). TCA, PCE, and TCE were used for cleaning vacuum pumps and other equipment at the southeast corner of Building 64 area prior to 1980. Degradation products of these compounds; including 1,1-dichloroethane (1,1-DCA), 1,1-dichloroethene (1,1-DCE), and cis-1,2-dichloroethene (cis-DCE); have also been detected in the groundwater at the site. In 2000, the highly contaminated sediment identified as the source area was excavated as an interim corrective action.

There is an accumulating base of information indicating that natural attenuation of chlorinated compounds is occurring at the Building 51/64 Site. Data collected since the source was excavated indicates that concentrations are significantly decreasing in response to the removal action. The absence of cis-DCE in the source area and the presence of cis-DCE in the down-gradient extent of the plume is strong evidence natural biodegradation is occurring. Conrad (2000) used stable isotope measurements to prove that biological degradation of contaminants was occurring naturally at the site. Shifts in the stable carbon isotope ratios of TCE, cis-DCE, and vinyl chloride along the length of the plume flow path showed anaerobic biodegradation was occurring at the site. The stable isotope analysis also demonstrated that vinyl chloride was being completely converted to ethane (Conrad, 2000).

In 2002, a review of the Building 51/64 Site was conducted by the US Department of Energy (DOE) Subsurface Contaminant Focus Area (SCFA) technical assistance team, consisting of DOE and non-DOE experts in environmental remediation. The SCFA team evaluated plume hydrology, site geology, monitoring data, and other available information. The SCFA team's conclusion was that Monitored Natural Attenuation (MNA) was the most appropriate technology for remediation of the Building 51/64 Site (SCFA 2002). MNA was recommended because the source area has been successfully removed, dispersion of the plume is limited, transport of the plume is slow, and migration is confined by complex geology and formational constraints. The extremely low hydraulic conductivity has restricted the plume expansion to tens of meters over several decades. Ground water flows primarily within surficial units (artificial fill and colluvium) and in the sedimentary rocks of the low permeability Orinda formation. All of the contaminants are inherently biodegradable and daughter compounds (products of biodegradation) found at the site indicated that natural attenuation had already occurred. The report suggested that studies be conducted to further evaluate the feasibility of applying MNA at this site (SCFA 2002).

The objective of this study was to determine if the environmental conditions at the Building 51/64 Site were appropriate for supporting the natural or intrinsic bacterial degradation of chlorinated compounds. Appropriate environmental conditions are requisite for the application of MNA for site remediation. Historical data was evaluated and sediment and water samples were collected and analyzed. Analysis of the terminal electron acceptors (TEA) necessary for aerobic and anaerobic biological activity indicated five distinct zones along the hydraulic gradient of the plume. Oxygen, nitrate, sulfate, iron, manganese, and methane concentrations in the ground water demonstrated that significant biological activity was occurring and that the redox conditions in up-gradient area from the plume were oxidizing, the old source area was mixed oxidizing/reducing, and that the plume gradually became more and more reducing along

its length. The gradually increasing reducing nature of the plume also suggested adequate electron donor was present to sustain natural biological activity.

The gradient of daughter products found in the ground water in the different zones also suggests that both aerobic and anaerobic biodegradation is occurring in the hydraulic gradient of the plume. 1,1,1-TCA is completely converted to 1,1-DCA by the time it reaches the middle part of the plume. PCE, and TCE decline and their daughter products cis-DCE and vinyl chloride (VC) increase and then decline along the natural gradient of the plume. Sediment pH and moisture were well within the limits of normal activity for chlorinated solvent degrading organisms. Aerobic and anaerobic culturable counts for sediment samples were from 10^3 to 10^6 colony-forming-units (CFU) per gram sediment. These culturable densities are considered normal for an un-stimulated site and suggest normal microbial activity and a healthy soil.

Chlorinated solvent degrading bacteria were detected in sediments and groundwater collected from the site. These included *Dehalococcoides* species, which degrade chlorinated solvents anaerobically, and toluene-degrading bacteria, which degrade chlorinated solvents aerobically. Sediment samples were also used in treatability tests for TCE and VC. These tests demonstrated that VC is quickly mineralized to carbon dioxide, but that TCE degradation takes a significantly longer time. Total organic carbon analysis indicated that 2-5% of total dry weight of the sediment is organic carbon, and a significant fraction of this is soluble and therefore bioavailable. Biological oxygen demand studies of the sediment also demonstrated that the sediment carbon was bioavailable and therefore could support the biodegradation of the chlorinated solvents.

The lines of evidence for this and previous studies that demonstrate that monitored natural attenuation is feasible for the remediation of the Building 51/64 Site are as follows:

1. The contaminant source has been identified and removed.
2. Dispersion of the plume is limited, transport of the plume is slow and migration is confined due to low hydraulic conductivity, complex geology and formational constraints.
3. All contaminants present are inherently biodegradable under both aerobic and anaerobic conditions.
4. Bacteria capable of degrading chlorinated solvents were isolated from the site, including *Dehalococcoides* species, which are unique bacteria in that they are able to completely mineralize chlorinated solvents under anaerobic conditions.
5. Biodegradation daughter products are present and increase as the plume moves away from the source area.
6. The concentration of parent and daughter products along the plume hydraulic gradient also showed biodegradation was occurring.
7. Isotopic analysis of the contaminants and daughter products indicate that they are being biodegraded, and that VC is being completely converted to ethane.
8. The plume can be divided into five distinct zones that have different degrees of biological activity, typical of a contaminant plume with natural biodegradation.
9. Terminal electron acceptors in the gradient of the plume cross-validated the type of biological activity that would be present in terms of aerobic/anaerobic and the reducing nature of the zone.

10. Sediment pH, moisture, and organic carbon content are sufficient to support natural biodegradation.
11. Culturable bacteria densities indicated that microbial activity was normal and high enough to support significant biodegradation activity.
12. Treatability tests with VC demonstrated complete mineralization using sediment from the site. Rates of VC biodegradation were high compared to other contaminated sites.
13. Organic carbon analysis and bioavailable carbon measurements also demonstrated that the site has enough secondary carbon and that it is bioavailable to support natural biodegradation of chlorinated solvents.

The results of this study further support the application of MNA as the best remediation option for the Building 51/64 Site.

Introduction

The Building 51/64 Site

A plume of volatile organic compound (VOC) contaminated groundwater, known as the Building 51/64 VOC plume, extends from the southeast corner of Building 64, under Buildings 64 and 51B (Figure 1). This plume is defined by the presence of chlorinated ethanes such as 1,1,1-trichloethane (TCA) and its degradative daughter, 1,1-dichloroethane (DCA). This plume also contains lower concentrations of other solvents such as the chlorinated ethenes – PCE, TCE and 1,1-DCE. In calendar year 2000, prior to a source removal (excavation) effort, chlorinated solvents were detected at high concentrations (greater than 100,000 µg/L) in the most concentrated portion of the Building 51/64 VOC plume. In this area of the plume, near the original source, contaminant solvents were comprised primarily of 1,1,1-TCA (82%) and 1,1-DCA (7%). The contaminant profile shifted toward the less chlorinated (i.e., more weathered) solvents and overall concentrations decreased as distance from the source increased. This pattern, combined with preliminary stable isotope data discussed below, suggests that some natural degradation of the solvents is occurring in the plume as it migrates. In 2000, highly contaminated sediment was excavated from the source area as an interim corrective measure. According to the LBNL staff, recent data indicate that concentrations are significantly decreasing in response to the removal action. Figure 1 shows the original (circa 2000) extent of VOCs in groundwater in the Building 51/64 area.

The source area has been successfully removed, dispersion of the plume is limited, transport of the plume is slow, and migration is confined by complex geology and formational constraints. The extremely low hydraulic conductivity has restricted the plume expansion to tens of meters over several decades. Groundwater flows primarily within the surficial units (artificial fill and colluvium) and in the sedimentary rocks of the low permeability Orinda formation. All of the contaminants are inherently biodegradable and many of the compounds in the groundwater are daughter products of biodegradation that has already occurred.

Natural Attenuation

The chlorinated compounds found at 51/64 are biodegradable and can be transformed by a number of different bacteria under a variety of environmental conditions; however, both aerobic and anaerobic biodegradation processes require the presence of secondary organic carbon sources, such as natural organic carbon or methane, to drive forward chlorinated compound degradation (Bagley and Gosset 1990; Bradley and Chapelle 1996 and 1997; Bradley et al. 1998; Cabirol et al. 1998; Chang and Alvarez-Cohen 1995; DeBruin et al. 1992; DiStefano et al. 1991; Holliger et al. 1992). Anaerobic reductive dechlorination of chlorinated ethenes also occurs at low redox conditions and therefore can be inhibited by competing terminal electron acceptors (TEA), thus TEA can indicate the probability of reductive dechlorination at a site (Figure 2). If extensive biological degradation of chlorinated compounds is occurring at a contaminated site, natural attenuation of the contaminants will occur. If, in addition, the hydrologic and geologic conditions are appropriate, it is possible to apply “monitored natural attenuation” (MNA) as a remediation strategy for contaminated areas (Wiedemeier et al. 1996).

A previous study developed convincing evidence that natural attenuation, primarily biological degradation, was occurring at the Building 51/64 Site (Conrad, 2000). Evidence that natural attenuation was occurring at the site included the absence of cis-DCE in the source area and the presence of cis-DCE in the down gradient extent of the plume. Shifts in the stable carbon isotope ratios of TCE, cis-DCE, and vinyl chloride along the length of the plume flow path indicated that anaerobic reductive dechlorination was occurring spontaneously at the site (Conrad 2000). Reductive dechlorination of TCE, PCE, and other chlorinated compounds is a well-characterized biodegradation process and is the primary degradative process relied upon during the application of MNA for site remediation (Wiedemeier et al. 1996, Hendrickson et al. 2002). Carbon isotope measurements were used to demonstrate that vinyl chloride, the terminal chlorinated product of the reductive dechlorination degradation pathway, was being converted completely to ethane in the Building 51/64 plume, even under anaerobic conditions (Conrad 2000). This is an especially important finding, as the accumulation of vinyl chloride under anaerobic conditions is a negative indicator for the application of MNA for site remediation (Wiedemeier et al. 1996, Hendrickson et al. 2002).

In 2002, a review of the Building 51/64 Site was conducted by the DOE SCFA technical assistance team, consisting of DOE and non-DOE experts in environmental remediation. The SCFA team evaluated plume hydrology, site geology, monitoring data, and other available information and came to the conclusion that MNA was the most appropriate remediation technology for application at the Building 51/64 Site (SCFA 2000). The report suggested that studies be conducted to further evaluate the feasibility of applying MNA at this site (SCFA 2002).

The objective of this study was to determine if the environmental conditions at the Building 51/64 Site were appropriate for supporting the bacterial degradation of chlorinated compounds. Historical data was evaluated and sediment and water samples were collected and analyzed. Lines of evidence were developed demonstrating that conditions at the site are very favorable for microbial activity and chlorinated solvent biodegradation.

Methods

Sample collection and preparation

Sediment core samples were collected from the Building 51/64 Site on January 13, 2003 using a push core sampler. Water samples from adjacent wells were collected with a Teflon bailer on January 14 and 15. Sediment samples were collected separately from depths that were saturated year round (saturated zone) and from depths that were saturated intermittently as a function of seasonal and annual changes in groundwater depth (seasonal zone). Sample depth intervals, sediment core identification numbers, and identification of associated wells are listed in Tables 3-5.

Sediment samples were collected in four-foot long polycarbonate tubes using sterile techniques. Sediment cores were cut into 2' lengths and were brought to the Biokinetics Laboratory at LBNL from the drilling site in a chilled cooler under a CO_2 atmosphere and placed immediately in a 4°C refrigerator. Intact sediment cores were provided to researchers at the University of California Berkeley (UC Berkeley) for microcosm studies. For experiments and analysis conducted at LBNL, cores were processed under an argon atmosphere in a glove bag using sterile technique. Approximately 5 cm of sediment from each end of the cores were removed and discarded. Each individual core sample was removed from the collection sleeve and thoroughly mixed before being transferred to Whirlpak bags and stored at 4°C until analyzed.

Carbon, moisture and pH analysis

Moisture and organic carbon content of the sediment samples were determined following Standard Methods 2540G for the determination of total, fixed, and volatile solids in solid and semisolid samples (APHA 1998). Sediment organic matter content was measured in duplicate samples from each sample interval using gravimetric measurement before and after combustion. Combusted samples were wetted and dried before measurement to compensate for volatile loss of carbonates.

Sediment pH was determined by mixing a one to one slurry of sediment and distilled deionized water (weight to weight). The slurry was equilibrated and the pH was measured in the aqueous phase after centrifugation.

Bioavailable sediment organic carbon was measured using a biokinetic assay adapted from Standard Method 5210 for the determination Biochemical Oxygen Demand in water (APHA 1998). Sediment core samples were mixed under an aerobic atmosphere to pre-oxidize reduced metals and other chemically reactive species before sub-samples were taken to use in the assay. Cores from saturated and seasonal zones were analyzed separately. Approximately eight grams of sediment (dry weight) was added to 300 mL of BOD buffer in a standard BOD bottle. Oxygen concentration was measured in triplicate samples at the initiation of the assay and at appropriate intervals (approximately every five days) over the course of the assay. BOD Buffer solution was prepared by adding 1 mL each of four stock solutions per liter of Millipore de-ionized water. Solution one contains (0.025 g $FeCl_3 \bullet 6H_2O$/liter) solution two contains (8.5 g KH_2PO_4, 21.75 g K_2HPO_4, 33.4 g $Na_2HPO_4 \bullet 7H_2O$, and 1.7 g NH_4Cl/liter), solution three contains (22.5 g $MgSO_4 \bullet 7H_2O$/liter), and solution four contains (27.5 g $CaCl_2$/liter). Initial oxygen concentrations were determined on an YSI Model 5000 oxygen meter with self-stirring probe that had been calibrated using the Winkler titration method. BOD bottles were sealed and placed in a dark incubator at 20°C. Dissolved oxygen readings were reported as micrograms of dissolved oxygen consumed per gram dry weight of sediment per day.

Soluble total organic carbon (TOC) was measured in ground water samples collected from the wells adjacent to sediment core collection points. TOC was determined on acid preserved samples using a Tekmar Apollo 9000HS combustion/infrared analyzer according to Standard Method 5310A (APHA 1998).

Biological analysis

Aerobic heterotrophic bacteria were enumerated using plate counts on R2A agar. Starting from approximately 1 gram of sediment sample, serial dilutions were made in a buffer solution containing 8.4 g NaCl, 0.3 g KH_2PO_4, 0.6 g Na_2HPO_4, 0.1 g $MgSO_4$, 0.1 g peptone, in 1000 mL de-ionized water. One hundred microliters of each dilution sample were plated in triplicate and the colonies that formed counted 7 and 14 days later.

Toluene degrading bacteria were enumerated using mineral media plates incubated in a toluene atmosphere. Toluene served as the sole carbon and energy source in an aerobic atmosphere.

Anaerobic heterotrophic plate counts were conducted by CytoCulture International, Inc. (Richmond, CA). Sterile agar plates (100 x 15 mm) were prepared with minimal salts medium and 2.35% heterotrophic plate count agar at pH 6.8 without any other carbon sources or nutrients added. Plates were setup and poured in a Coy anaerobic glove box under strict anaerobic conditions (atmosphere of nitrogen, carbon dioxide and hydrogen). Plates were inoculated with 1.0 mL of a 0.2% sodium pyrophosphate extract of the sample, or log dilutions of the extract, in triplicate at sample dilutions of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4}. The heterotrophic plates were counted after 21-28 days incubation in the glove box at ambient temperature.

The presence of *Dehalococcoides ethenogenes* was investigated using molecular techniques. Anaerobic bacteria from sediment and ground water were enriched in the presence of chlorinated solvents and tested for the presence of *D. ethenogenes* by polymerase chain reaction (PCR) assay. DNA was extracted from the anaerobic enrichment by a bead beating procedure using the MoBio Ultra Clean Soil DNA Kit and protocol. PCR primers were designed to target a 45 basepair fragment of the 16s ribosomal DNA exclusive to *D. ethenogenes*. The target DNA fragment was amplified by PCR, and the 45 basepair PCR product was detected.

The 16s rDNA amplification was performed using an Eppendorf Mastercycler Gradient Thermocycler. The 30 µl reactions contained 3 µl of 10x PCR buffer, 2.5 mM $MgCl_2$, 200 µM of each dioxynucleoside triphosphate, 300 nM of each forward and reverse primers, 0.15 µl AmpliTaq Gold, and 1 µl of DNA. The following thermocycling program was used: 12 minutes at 94°C for denaturation, followed by 30 cycles of 1 minute at 94°C, 45 seconds at 50°C, and 2 minutes at 72°C. A final extension step of 12 minutes at 72°C followed by cooling at 4°C was performed. The PCR product was visualized using an Agilent 2100 Bioanalyzer and the accompanying DNA 500 reagents and chip. This PCR method was run concurrently with positive and negative controls.

Microcosms for the detection of TCE degrading bacteria were prepared at LBNL using sediment samples from both saturated and unsaturated depths. All microcosms were prepared as triplicates in a glove bag under an Argon atmosphere. Each microcosm consisted of a 40 mL VOA vial sealed with Mininert cap, contained 20 mL of liquid and approximately 20 g sediment sample from refrigerated Whirlpak bags. All experimental and control microcosms contained 10 mL of Sole Source Carbon (SSC) medium or SSC-Lactate medium and 500 µL trichloroethylene

(TCE) solution. Killed controls also contained 3 mL of a 1 g/L solution of mercuric chloride. The balance of liquid in each vial was brought to 20 mL with sterile distilled-deionized water. SSC media was prepared with 1.00 g KH_2PO_4, 0.86 g Na_2HPO_4, 1.00 g NH_4Cl, 0.12 g $MgSO_4·7H_2O$, 0.06 g $CaCl_2·2H_2O$ to make 1 liter. SSC-Lactate media was prepared as SSC with the addition of 2 mL 60% sodium lactate syrup. Both media had 1 mL of the redox indicator, resazurin (1g/L solution) added before being boiled and then autoclaved and tightly capped to exclude as much oxygen as possible. Following setup, the microcosms were placed in a 25°C incubator on a shaker at 110 rpm. Initially, TCE measurements were made at day one followed by once per week for the next 4 weeks, then about once every 2 weeks thereafter.

TCE concentrations were determined using a Hewlett Packard 6890 gas chromatograph with a micro electron capture detector. Fifty µL headspace injections were made onto a (J&W scientific) 30 m x 250 um DB5ms capillary column using a split ratio of 40 to 1. Injector temperature was constant at 240°C while the column was held at 40°C for 3 minutes then increased to 160°C at 15°C /minute for a total run of 11 minutes. Calibration curves were obtained from headspace analysis of aqueous dilutions prepared by mixing the pure solvent until dissolved in water for several hours in a sealed container with minimal headspace.

Microcosms for the detection of vinyl chloride degrading bacteria were prepared and tested at UC Berkeley. For microcosm preparation, sediment cores were bulked together in an anaerobic chamber, and the sediment was manually homogenized using a sterile spatula to break sediment clumps and remove rocks. Homogenization also released the indigenous volatile contaminants from the sediment. Groundwater used in construction of the aerobic microcosms was mixed on a stir plate open to the air, while nitrogen was bubbled through the groundwater for anaerobic microcosms to allow contaminants to volatilize. Groundwater samples were collected from monitoring wells adjacent to each soil boring (Table 4). Monitoring wells were purged and allowed to recharge overnight before groundwater samples were collected from a depth of approximately 30 feet below ground surface (bgs). All serum bottles and stoppers used for the study were autoclaved. Each experimental microcosm consisted of a 68 mL Wheaton glass serum bottle containing 15 grams of sediment, 15 mL of groundwater, about 38 mL of headspace, 250 µL of vinyl chloride, and possibly nutrients and/or co-substrates. Nitrogen and phosphorous was added to selected bottles as 5 mM diammonium phosphate to test the effect of the presence of nutrients on vinyl chloride degradation. Benzene and toluene were added at 35 mg/L each to selected aerobic bottles to examine possible inhibition or enhancement of vinyl chloride degradation by BTEX compounds. Anaerobic microcosms were amended with toluene alone or lactate as 0.02 M lactic acid to provide electron donors for anaerobic degradation. Killed and abiotic controls were constructed as previously described. The bottles were sealed using butyl rubber stoppers and secured with aluminum crimps purchased from Bellco Glass Co. Sediment was incubated at room temperature in the dark for one week before the construction of the anaerobic microcosms and for one month before construction of aerobic microcosms. After the experiments began, anaerobic microcosms were stored statically in an anaerobic chamber, and aerobic microcosms were stored on a shaker table, both at room temperature in the dark. Anaerobic microcosms were monitored for 126 days, and aerobic microcosms were monitored for 89 days.

In the UC Berkeley microcosm studies, gas phase components were monitored over time by headspace analysis using gas chromatography. Vinyl chloride disappearance, ethene production, and methane production in microcosms were monitored by withdrawing 30 µL of gas from the headspace with a gas-tight syringe and injecting it into a Hewlett Packard 5890

Series II gas chromatograph (GC) equipped with a flame ionization detector. The production of carbon dioxide and consumption of oxygen were monitored using 0.2 mL of gas from the headspace into a Hewlett Packard 5890 Series II GC with a thermal conductivity detector. Samples were collected at time intervals appropriated by degradation progress, with a week maximum interval. Between every injection, the syringes were flushed three times with acetone and suction-dried to avoid cross-contamination. Standard calibration curves (including 4 data points and with R^2 values greater than 0.98) were generated daily to convert GC data to accurate concentration measurements.

Microbial biomass was measured using a Coomassie Protein Assay Reagent Kit from Pierce Biotechnology. One gram of saturated sediment from microcosms sacrificed at the start of the experiments and stored at 4°C throughout the experiments and from microcosms at the end of the experiments was processed with calibration standards according to a modified test tube protocol. Protocol adjustments include the addition of 200 mM final concentration sodium hydroxide to the samples, three cycles of freezing and thawing the samples, and 20 minutes of boiling to aid in cell lysis, followed by a 15 minute centrifugation at approximately 12,000 times gravity to separate protein from cell debris. An IEC Micromax RF centrifuge was used. One hundred µL of the supernatant was then mixed with 500 µL of the Coomassie reagent and incubated at room temperature for 10 minutes. The absorbance of the sample was measured on a Perkin Elmer Lambda 14 UV/Vis spectrometer at 595 nm. Absorbance was converted to protein concentration using the standard calibration curve. Protein calibration standards were prepared identically to microcosm samples. The change in protein concentration in the samples from the beginning to the end of the experiments was compared with the expected yield considering the amount of vinyl chloride consumed throughout the experiments.

Results and Discussion

Analysis of Historical Data

Historical data from the Building 51/64 Site were compiled and analyzed to determine if the historical record indicated a pattern of biological activity consistent with the application of MNA for treatment of the 51/64 plume. Data included in this analysis were measurements for terminal electron acceptors (TEA) conducted in December of 1997 and methane concentration measurements from October 2002. Additionally, chlorinated solvent and chlorinated solvent degradation products data from fiscal year 1999 were also evaluated.

Analysis of TEA and methane data

Historical data was interpreted in the context of the site hydrology and it was determined that the 51/64 plume could be divided into five biological zones (Figure 3). Zone 1 represents the up-gradient, background ground water that is not influenced by the contamination that occurred at the Southeast corner of Building 64. Two wells in Zone 1 (MW 90-4 and MW 90-5, indicated in Figure 3 by ⊗) were found to be influenced by an up-gradient source of contamination (Building 71B plume) and data from these wells was not included in this analysis. Water from SB 64-99-7 is apparently free of contamination and may represent clean groundwater moving into the site from the North-northwest. Data from this well was not included in this study, but this well could serve as an additional background collection point in future studies, particularly if MW 90-6 is compromised. Zone 1 historical data (Table 1) indicate that the up-gradient groundwater entering the site contains oxygen, nitrate and sulfate, electron acceptors used in both the aerobic and anaerobic degradation of chlorinated solvents (Bagley and Gosset 1990; Bradley and Chapelle 1996 and 1997; DiStefano et al. 1991; Wiedemeier et al. 1996, see Figure 2). The TEA profile does not indicate the presence of significant ground water associated biological activity in this zone.

Zone 2 corresponds to the source area. Source removal was accomplished by excavation and an approximately 20 square foot area surrounding MW 51-96-18 was removed and backfilled with gravel (SCFA 2002). TEA data from this area (Table 1) show that dissolved oxygen (DO) is lower than in Zone 1, but that nitrate and sulfate are not significantly lower than background. The TEA profile in this zone indicates the dominance of oxidized conditions in this area. The predominant biological activity in this zone would be aerobic metabolism, but the rate of activity is sufficiently low that the rate of oxygen utilization does not exceed the rate of reoxygenation from diffusion and the in-flow of oxygenated groundwater from Zone 1. Zone 3 and Zone 4 are distinct biological zones as indicated by historical TEA and methane data (Table 1). Wells in Zone 3 still had measurable oxygen concentrations, but increased concentrations of ferrous iron and divalent manganese indicate the occurrence of areas of reduced or anoxic conditions in this zone (Table 1). The presence of soluble iron and manganese is a more reliable indicator of low redox conditions in the subsurface than the measurement of oxygen concentrations in the well water. The presence of anoxic or anaerobic areas in Zone 3 is also indicated by reduced nitrate and sulfate concentrations (compared to Zone 1 and 2) and the presence of low concentrations of methane. Zone 3 TEA conditions indicate that both aerobic and anaerobic chlorinated solvent degrading bacteria could be active in this area. The co-occurrence of both oxygen and methane in proximity suggest that aerobic, cometabolic biodegradation of chlorinated organic compounds by methane-oxidizing bacteria could be an important natural attenuation process in this zone.

Zone 4 appears to be fully anaerobic. Only trace concentrations of oxygen are found in any well, soluble iron and manganese concentrations are high, nitrate and sulfate are reduced, and methane concentrations are high (Table 1). The anaerobic conditions found in Zone 4 also suggest that this is a biologically active zone. Conditions in Zone 4 are appropriate for the growth of strict anaerobes, as evidenced by the high concentrations of methane. The dominant natural attenuation process in this area would be reductive dechlorination, which requires strict anaerobic conditions.

Zone 5 is down-gradient from Zone 4 and has a similar TEA profile as Zone 4, but does not have any detectable solvent contamination. The anaerobic conditions in Zone 5 suggests that groundwater from Zone 4 may be entering Zone 5, since the up-gradient, reference wells indicate that uncontaminated ground water in the area is typically aerobic (Zone 1, Table 1). Since the extent of chlorinated solvent contamination is limited to Zones 2, 3 and 4 (Table 2) and the chemical similarity between Zones 4 and 5 suggest that contaminated groundwater has migrated from Zone 4 to Zone 5, it is possible that groundwater in Zone 5 was once contaminated and has now been completely cleansed of chlorinated solvents by natural attenuation. The alternative interpretation of the TEA data is that the source of groundwater in Zone 5 is not from the Building 51/64 plume and Zone 5 is anaerobic for other reasons (e. g., up-gradient wells in Zone 1 are in natural bedrock, whereas Zone 5 wells are in fill material). To resolve this question, more information is needed on the hydrologic connection between Zones 4 and 5, the ground water travel time between the two zones, and the TEA profile of uncontaminated areas in substrata comparable with Zone 5. The detection of ethane or ethene, chlorinated solvent degradation products, in Zone 5 would also be further proof of natural attenuation is removing solvents between Zones 4 and 5. A better understanding of the link between Zone 4 and Zone 5 is needed before it can be demonstrated that natural attenuation has already resulted in the complete remediation of contaminated groundwater down-gradient of the Building 51/64 Site.

Analysis of chlorinated solvent and degradation product data

Chlorinated organic compound data from 1999 were examined to determine if there was historical evidence for the occurrence of natural attenuation at the Building 51/64 Site. Three chlorinated solvents, 1,1,1-trichloroethane (TCA), perchloroethene (PCE), and trichloroethene (TCE), were used for degreasing vacuum pumps at the Southeast corner of Building 64. TCE and TCA can be degraded under aerobic conditions by bacteria able to grow on methane, toluene, and other compounds via a process typically referred to as co-metabolism (Chang and Alvarez-Cohen, 1995). Aerobic TCE, and TCA degradation can result in complete mineralization, yielding CO_2 and chloride as final products (Aziz et al., 1999; Chang and Alvarez-Cohen, 1995). PCE can also be biodegraded in nominally aerobic environments, but studies have shown this is not actually aerobic, co-metabolic biodegradation, but rather anaerobic reductive dechlorination of PCE that takes place in localized, diffusion limited areas of the sediment (Enzien et al., 1994).

Anaerobic metabolism of chlorinated solvents occurs via a process termed reductive dechlorination, which can yield a number of intermediate chlorinated products before complete mineralization. Chlorinated intermediates products for PCE and TCE are cis-1,2-dichloroethene (cis-1,2-DCE), 1,1-DCE, trans-1,2-DCE, and vinyl chloride (Wiedemeier et al., 1996). Anaerobic biodegradation of TCA can produce the intermediate products 1,1-dichloroethane

(1,1-DCA) and monochloroethane (Wiedemeier et al., 1996). The presence of the chlorinated intermediates in well water samples indicates that natural biodegradation is occurring at the Building 51/64 Site.

Zone 1 wells were free of contamination. Zone 2 has measurable concentrations of the three parent compounds TCE, PCE, and 1,1,1-TCA as well as the degradation products 1,1-DCA, 1,1-DCE, and cis-1,2-DCE. The presence of biological degradation intermediates indicates that biological degradation, most likely anaerobic reductive dehalogenation, is occurring naturally in this zone. Vinyl chloride is not present, as might be expected, considering Zone 2 has a mixed aerobic and anaerobic TEA profile and vinyl chloride is subject to rapid biodegradation under aerobic conditions (West et al. 2003; Wiedemeier et al. 1996).

Zones 3 and 4 do not have measurable amounts of 1,1,1-TCA, but there are trace concentrations of the product 1,1-DCA. 1,1-DCA concentration declines slightly between Zones 3 and 4. Since the hydraulic connectivity between Zones 2, 3, and 4 is established, and the 1,1-DCA would not occur in groundwater that did not have TCA contamination at some time, this data can be interpreted with confidence as indicating that the parent compound 1,1,1-TCA has been removed completely by natural attenuation by the time groundwater has passed from Zone 2 to Zone 4.

The presence of 1,1-DCE, cis-1,2-DCE, and vinyl chloride are definitive evidence that natural biodegradation is occurring in Zones 3 and 4. The significance of the decline in TCE, PCE, and cis-1,2-DCE between Zones 3 and 4 cannot be interpreted using this data set. However the trend toward lower concentrations between Zones 3, 4, and 5 are consistent with the occurrence of natural attenuation at this site and a declining trend is consistent with criteria for determining the applicability of monitored natural attenuation for site remediation.

In summary, the analysis of historical TEA, methane, and chlorinated compound data are supportive of the use of MNA at the Building 51/64 Site. These data indicated that Zones 3 and 4 as the most biologically active areas of the site, and based on this analysis, sediments cores were collected in Zones 3 and 4 for further biological characterization.

Analysis of Sediment Cores and Groundwater Samples

Collection and preparation of sediment cores

Based on the analysis described in the previous section, it was determined that Zones 3 and 4 were the most biologically active. Sediment cores were collected from borings adjacent to MW 51-96-16 in Zone 3 and wells MW 51-97-12, MW 51-97-13, and MW 56-98-2 in Zone 4 for biological characterization (Figure 3).

Sediment cores were sectioned and categorized as either “seasonal” or “saturated.” Seasonal sediments were from the zone of the aquifer that is subject to variable saturation conditions as the water table rises and falls during the year. The saturated sediments were from zones of the aquifer that was below the lowest water table level recorded for the well adjacent to the soil coring. Seasonal and saturated zones were determined from long-term well monitoring data summarized in Table 3.

Analysis of biological conditions

Biological conditions at the Building 51/64 Site were evaluated to determine if they are appropriate for MNA. Sediment pH ranged from 7.5 to 8.4, well within the range compatible with microbial activity. The sediment moisture content (between 14% and 22% by weight) is sufficient to allow bacteria growth in both the seasonal and saturated zones. Both the seasonal and saturated zone had the same moisture content during this sampling event because it took place in the rainy season.

Total heterotrophic bacterial populations at the site were measured using standard aerobic and anaerobic enumeration techniques. Culturable aerobic populations in both the saturated and unsaturated zones were in the hundred of thousands to millions of culturable bacteria per gram of sediment (Table 4). This density of culturable population is well within the range found for uncontaminated clay subsurface sediments and indicates that the bacterial community is not inhibited by unrecognized factors such as heavy metals or tannins in the sediment matrix.

Bacteria able to grow on a heterotrophic media under anaerobic conditions numbered in the tens of thousands in the sediment samples collected from the saturated depths (Table 4). As with the aerobic counts, the presence of easily culturable anaerobic populations indicates that the sediments are active and healthy. The ratio between the bacteria enumerations using aerobic and anaerobic plate counts (approximately 10 to 1) are also typical of healthy natural sediments. Direct bacterial counts, using activity indicators, could not be conducted on these sediments because of their high clay content and natural background fluorescence.

Analysis of chlorinated compound degradation potential

The isolation or detection of bacteria able to transform chlorinated compounds demonstrates biological degradation potential and is a further line of evidence often developed in support of MNA (Wiedemeier et al. 1996, Hendrickson et al. 2002). Direct enumeration techniques and microcosm studies were used to determine if bacteria able to transform chlorinated compounds were present at the Building 51/64 Site. Additionally, DNA was extracted from groundwater and sediment enrichment cultures and gene probes were used to demonstrate the presence of *Dehalococcoides ethenogenes*, a key bacteria in the anaerobic degradation of chlorinated solvents (Hendrickson et al. 2002).

Toluene degrading bacteria were detected by enumeration on bacterial media containing toluene as the sole carbon and energy source. Toluene degrading bacteria were present in all samples tested (Table 4). Bacteria able to grow on toluene contain toluene-oxygenase, which is an effective enzyme for the degradation of many chlorinated compounds including TCE (Chang and Alvarez-Cohen 1995). The activity of the toluene-oxygenase against TCE and other compounds will depend on the level of expression and the presence of oxygen. Many compounds, including natural organic matter, can induce expression of toluene degrading enzymes. The sediments contain significant concentrations of natural organic matter (Table 5). Zone 2 and 3 have oxygenated conditions and therefore this potential transformation mechanism is most significant for those zones.

Molecular analysis of sediment and groundwater from the site demonstrated that the site contained a subsurface population of the bacterium *Dehalococcoides ethenogenes*. *D. ethenogenes* is the only known organism capable of completely dechlorinating PCE and its daughter products to ethene (Maymó-Gatell et al. 1997, Hendrickson et al. 2002). In a wide-ranging study, it was demonstrated that the presence of *Dehalococcoides* in the contaminated subsurface environment was indicative that complete mineralization of chlorinated solvents was occurring and that undesirable intermediates would not accumulate at a site (Hendrickson et al. 2002). Detecting the DNA of *Dehalococcoides* in sediment and groundwater samples is definitive evidence that the indigenous microbial community at a contaminated site is able to reductively dechlorinate chlorinated-ethenes (Hendrickson et al. 2002). Identifying this organism at the Building 51/64 Site is an important step in the application of MNA for site remediation (Wiedemeier et al. 1996, Hendrickson et al. 2002).

The presence of chlorinated solvent degrading bacterial populations were also measured using microcosm studies. In these studies, sediments were incubated under a variety of conditions in the presence of the target contaminant, either vinyl chloride or TCE. Microcosm tests for the presence of TCE degrading bacteria were conducted at LBNL; those for vinyl chloride were tested at UC Berkeley. Activity against the contaminant was indicated by measuring the removal of the target compound over time.

In the UC Berkeley studies, degradation activity against vinyl chloride was observed under both aerobic and anaerobic conditions (Figure 4). Ethene was produced stochiometrically from vinyl chloride in anaerobic conditions, indicating the vinyl chloride was completely transformed to a non-toxic product (Figure 5). This result is particularly significant, because the accumulation of vinyl chloride under (anaerobic) conditions favorable for the reductive degradation of TCE and other chlorinated solvents is undesirable at a site relying on MNA for remediation (Wiedemeier et al. 1996). This result also confirms the result of Conrad (2000), who used stable isotope techniques to show that the biological reduction of vinyl chloride to ethene was occurring in-situ at the Building 51/64 Site. The presence of bacteria able to anaerobically degrade vinyl chloride is supportive of MNA for the Building 51/64 Site.

The studies on vinyl chloride degradation conducted at UC Berkeley were part of a larger study comparing vinyl chloride degradation under different conditions and between different sites (West et al. 2003). The vinyl chloride degrading activity observed using sediments from the Building 51/64 Site was greater than that of sediments from other sites tested in the same study. The addition of nutrients, such as nitrogen or phosphorous, or electron donors, such as lactate or toluene, was not necessary for vinyl chloride degradation to occur (West et al. 2003). This further indicates that active bioremediation strategies, where supplemental materials such as nitrogen, phosphorous or organic carbon are introduced into the groundwater, are not necessary and that natural attenuation is appropriate for the Building 51/64 Site.

At LBNL, microcosms were constructed to measure the presence of bacteria able to reductively dechlorinate TCE. Microcosms were constructed with and without the addition of a supplemental electron donor (lactate). In contrast to the results for vinyl chloride, microcosms incubated for up to 184 days did not demonstrate significant TCE removal (data not shown). The field data clearly demonstrate the presence of chlorinated degradation intermediates that are only produced during biological reductive dechlorination (Table 2) and genetic analysis demonstrated the presence of *Dehalococcoides*, so dechlorinating bacteria are definitely present and active at the site. However, bacteria able to reductively dechlorinate TCE are slow growing. It is apparent that the degradation rate of TCE is significantly slower than that of vinyl chloride (Figure 5) and that an incubation period longer than 184 days is required to demonstrate degradation in these microcosms.

Analysis of sediment carbon as a source of secondary carbon for biodegradation

All of the field data indicate that there is active biological degradation occurring at the Building 51/64 Site (Tables 1 and 2). A source of organic carbon is necessary to maintain biodegradation activity against chlorinated solvents, so tests were conducted to determine if there was sufficient organic matter available at the site to support bacteria activity, particularly reductive dechlorination, for an extended period. Total sediment organic carbon was measured as well as two indicators of available organic carbon, soluble organic carbon in the groundwater and readily biodegradable sediment carbon. The total organic carbon content of the sediment was between 2% to 5% of its dry weight (Table 5), indicating the presence of a potential carbon source to drive the reductive dehalogenation of chlorinated solvents.

Not all sediment carbon is readily available to bacteria, for example, soluble organic carbon is typically more bioavailable than insoluble, particulate organic carbon. Significant concentrations of soluble organic carbon (TOC) were present in site wells (Table 5), indicating that the naturally occurring sediment organic carbon is being dissolved into the groundwater. This suggests that the sediment organic matter will be bioavailable for chlorinated solvent degradation.

To firmly establish whether the sediment organic carbon is bioavailable, we measured the aerobic first-order biodegradation rate for the sediment organic carbon and measured the 30-day oxygen demand of the sediment (Table 5). All of the sediment samples from both the saturated and unsaturated zones had high concentrations of biologically available carbon, as indicated by 30-day oxygen demand measurements (Table 5). The first-order degradation rates were high enough (Table 5) to suggest that carbon availability is unlikely to be the rate-limiting step in chlorinated compound degradation at this site. The amount of sediment carbon present (over 2% of the sediment dry weight, Table 5) suggests that there is enough bioavailable sediment carbon to support chlorinated compound degradation for an extended period.

Summary and Conclusion

In summary, the results of this study are supportive of applying MNA for remediation of the Building 51/64 Site. TEA and methane data indicate an active microbial population at the site, chlorinated compound measurements demonstrate the presence of compounds that are well known microbial degradation products of the chlorinated solvents contaminating the site, biological analysis indicates that environmental conditions favorable for MNA exist at the site, bacterial studies show that chlorinated solvent degrading bacteria are present at the site, including *Dehalococcoides*, which can completely mineralize chlorinated solvents under anaerobic conditions, and sediment and groundwater organic carbon analysis shows that there is a substantial pool of bioavailable organic carbon present to drive forward reductive dechlorination and other degradative processes. In total, the results of this study confirm and further support the results of previous investigations (Conrad 2000, SCFA 2000) that recommended the application of MNA at this site.

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Table 1. Summary of terminal electron acceptor (TEA) and methane concentration data by biological zone.

Biological Zone	Water Level[1] (feet above mean sea level)	Dissolved Oxygen[2] (mg/L)	Ferrous Iron[2] (Fe^{+2} mg/L)	Divalent Manganese[2] (Mn^{+2} mg/L)	Nitrate[2] (NO_3-N mg/L)	Sulfate[2] (SO_4 mg/L)	Methane[3] (CH_4 μg/L)
Zone 1							
Mean	730	6.6	0.00	0.00	2.40	51.0	NA
SD	14						
n	4	1	1	1	1	1	
Zone 2							
Mean	700	1.5	0.05	0.00	2.10	47.5	0.0
SD	2.8	1.4	0.06	0.00	1.83	33.5	0.0
n	2	4	4	4	4	4	2
Zone 3							
Mean	691	2.0	0.13	1.23	0.77	26.3	2.5
SD	3.6	1.6	0.15	1.96	0.83	11.4	3.5
n	3	3	3	3	3	3	2
Zone 4							
Mean	681	0.7	3.75	11.20	1.70	17.0	2171
SD	6.9	0.1	2.62	9.62	2.26	9.9	2173
n	4	2	2	2	2	2	5
Zone 5							
Mean	627	0.3	3.75	8.05	1.70	49.0	NA
SD	37	0.2	5.16	5.59	0.70	8.5	
n	3	2	2	2	2	2	

[1] Fourth quarter 1999; [2] December 1997; [3] October 2002

Table 2. Summary of chlorinated organic compound concentration historical data[1] by biological zone.

Biological Zone	TCE (μg/L)	PCE (μg/L)	1,1,1-TCA (μg/L)	1,1-DCA (μg/L)	1,1-DCE (μg/L)	cis-1,2-DCE (μg/L)	Vinyl chloride (μg/L)	Total VOC (μg/L)
Zone 1								
Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
n	4	4	4	4	4	4	4	4
Zone 2								
Mean	22.4	1.2	0.8	2.1	1.0	4.3	0.0	32.2
SD	28.5	1.3	1.4	3.7	1.7	6.7	0.0	41.0
n	3	3	3	3	3	3	3	3
Zone 3								
Mean	43.0	5.8	0.0	8.0	4.2	115.7	14.0	201.0
SD	68.5	8.0	0.0	13.0	4.7	199.4	24.2	335.2
n	3.0	3	3	3	3	3	3	3
Zone 4								
Mean	1.9	0.6	0.0	4.1	3.8	6.6	9.9	26.5
SD	1.0	0.7	0.0	3.7	3.8	9.8	12.8	17.4
n	3.0	4	4	4	4	4	4	4
Zone 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SD	3	3	3	3	3	3	3	3
n								

[1] Using mean data (n = 4) for fiscal year 1999 for wells in each zone.

Table 3. Screen intervals and depth to groundwater for wells adjacent to soil borings taken January 13, 2003

Well No.	Zone	Screen Interval (feet bgs[1])	Minimum depth to groundwater (feet bgs)	Maximum depth to groundwater (feet bgs)
51-96-16	3	10-30	17.2	19.5
51-97-13	4	48-68	30.5	36
56-98-2	4	35-55	13.7	23.7
51-97-12	4	29.5-49.5	30.8	36.4
51-97-15	5	88-108	70.6	72.1

[1] bsg, below ground surface

Table 4. Sediments collected from Building 51/64 contained substantial populations of aerobic and anaerobic heterotrophic bacteria, including populations of toluene degrading bacteria that contain chlorinated solvent degrading enzymes.

Sediment Samples	**SB51-03-2 Seasonal**	**SB51-03-2 Saturated**	**SB51-03-1 Seasonal**	**SB51-03-1 Saturated**	**SB51-97-3 Seasonal**	**SB51-97-3 Saturated**	**SB56-98-03 Seasonal**	**SB56-98-03 Saturated**
Associated Well	51-96-16	51-96-16	51-97-12	51-97-12	51-97-13	51-97-13	56-98-2	56-98-2
Zone	3	3	4	4	4	4	4	4
Processed Core Interval (feet)	18’-20’	23’-25’ 26’-28’	32’-34’ 34’-36’	42’-44’ 44’-46’	32’-34’ 34’-36’	40’-42’ 42’-44’	19’-21’ 21’-23’	27’-29’ 31’-33’
Aerobic Heterotrophic Plate Count (CFU/g dry sediment)	1.2×10^6	2.0×10^5	8.3×10^5	2.2×10^5	1.6×10^5	2.9×10^5	1.8×10^4	8.3×10^4
Anaerobic Heterotrophic Plate Count (CFU/g dry sediment)	na[1]	5.0×10^4	na	7.0×10^3	na	na	na	2.0×10^4
Toluene Degrading Bacteria Plate Count (CFU/g dry sediment)	7.6×10^3	4.3×10^4	1.2×10^5	4.6×10^4	4.8×10^3	4.9×10^6	1.1×10^3	1.3×10^6

[1] na, not analyzed.

Table 5. Sources of natural electron donor potential needed to maintain reductive dechlorination during monitored natural attenuation at Site 51/54.

	SB51-03-2 Seasonal	SB51-03-2 Saturated	SB51-03-1 Seasonal	SB51-03-1 Saturated	SB51-97-3 Seasonal	SB51-97-3 Saturated	SB56-98-03 Seasonal	SB56-98-03 Saturated
Associated Well	51-96-16	51-96-16	51-97-12	51-97-12	51-97-13	51-97-13	56-98-2	56-98-2
Zone	3	3	4	4	4	4	4	4
Soluble organic carbon in groundwater (mg/L)	4.68		5.96		2.29		2.28	
Total organic carbon in sediment (% of dry weight)	4.3	2.4	3.5	2.7	3.1	3.9	3.6	2.8
Bioavailable carbon (µg of O_2/g sediment organic carbon/day)	0.136	0.067	0.120	0.265	0.099	0.066	0.142	0.079
Sediment oxygen demand (µg of O_2/g sediment/30 day)	1086	788	1029	1070	951	971	989	877

Figure 1. Extent of groundwater contamination as shown by total halogenated hydrocarbons (µg/L) isopleths at Building 51/64 Site using data from September 2000 (from SCFA 2002).

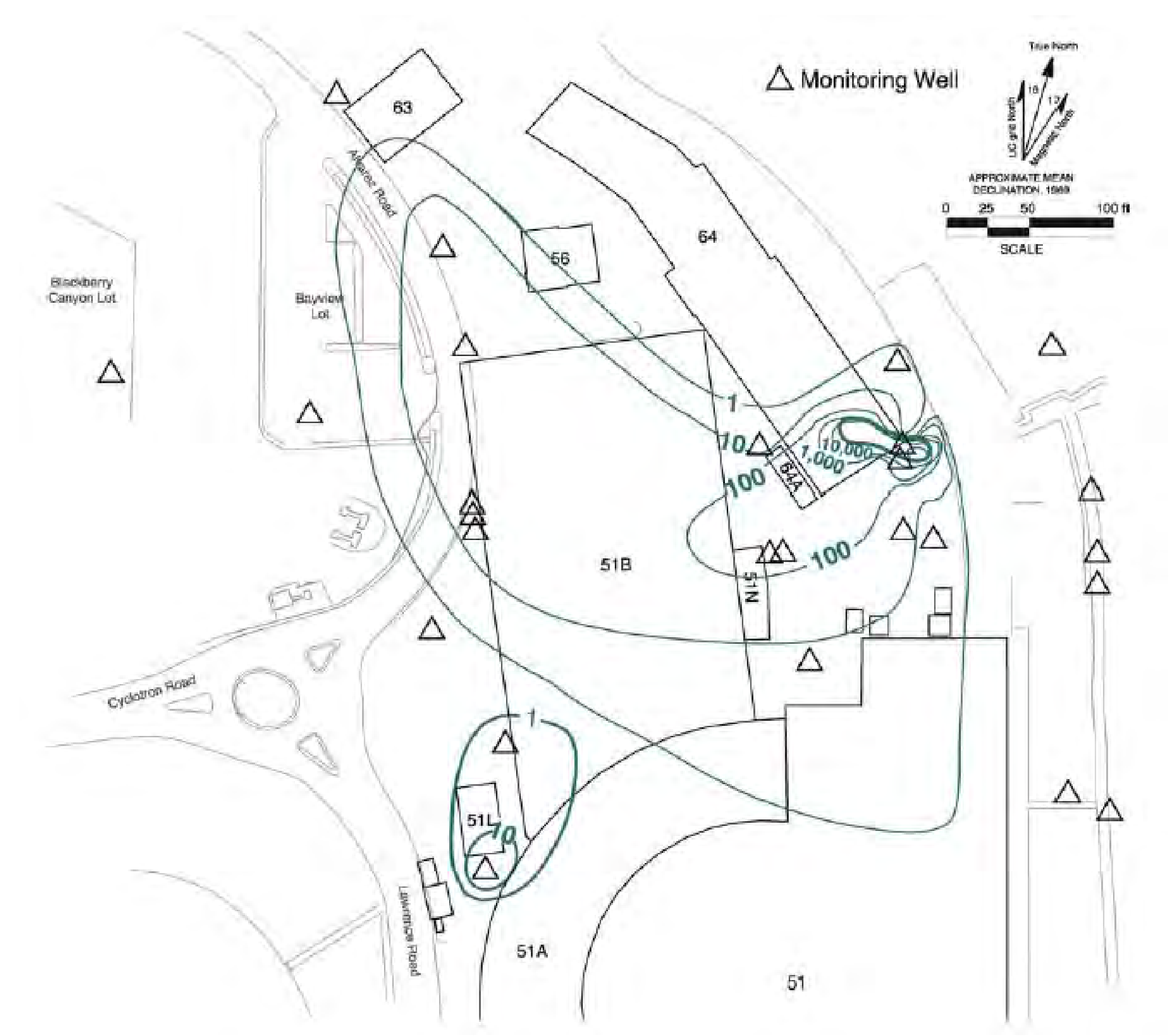


Figure 2. Competing Terminal Electron Acceptors and Chlorinated Solvent Degradation.

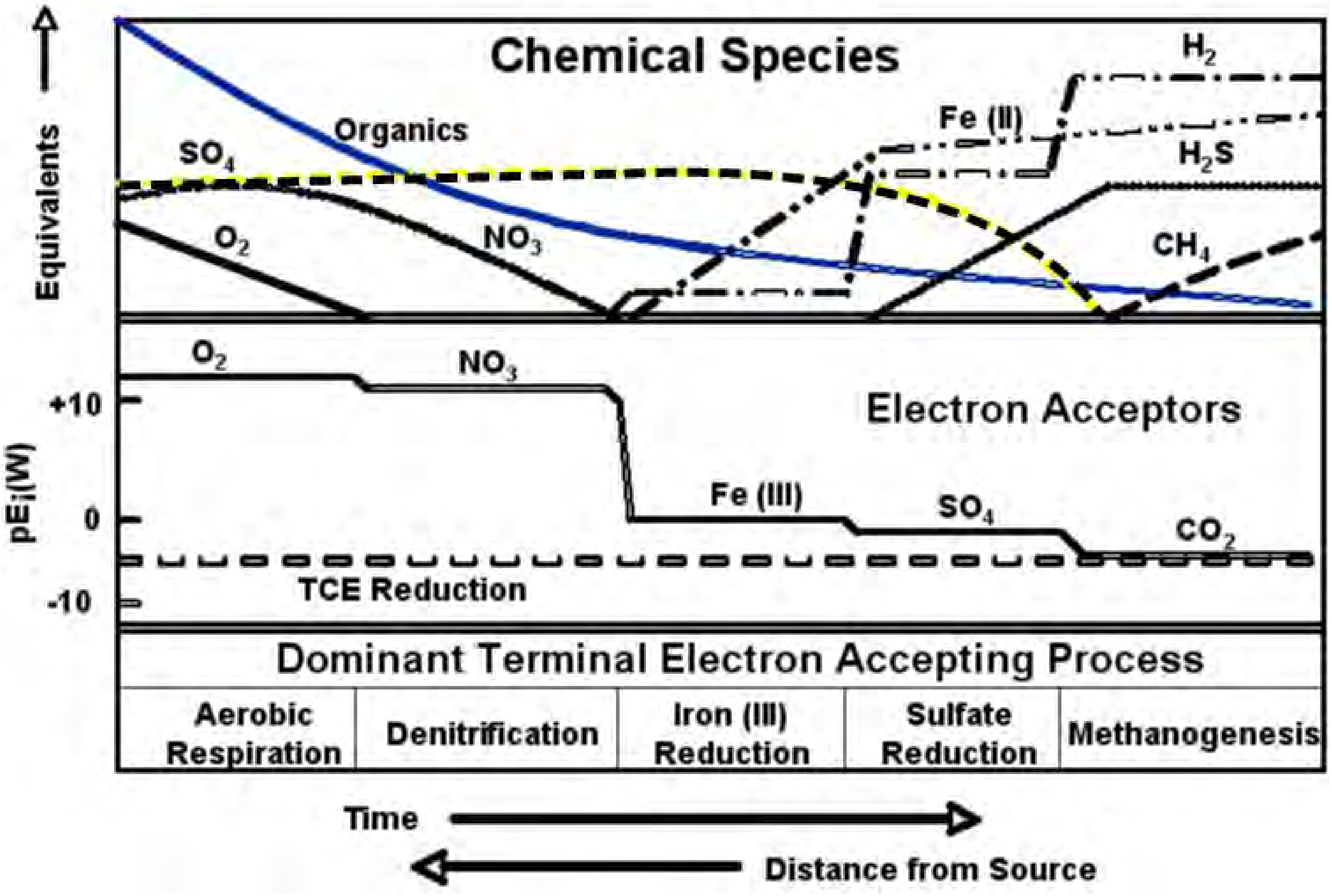


Figure 3. Map of biological zones and associated wells for the Building 51/64 Site.

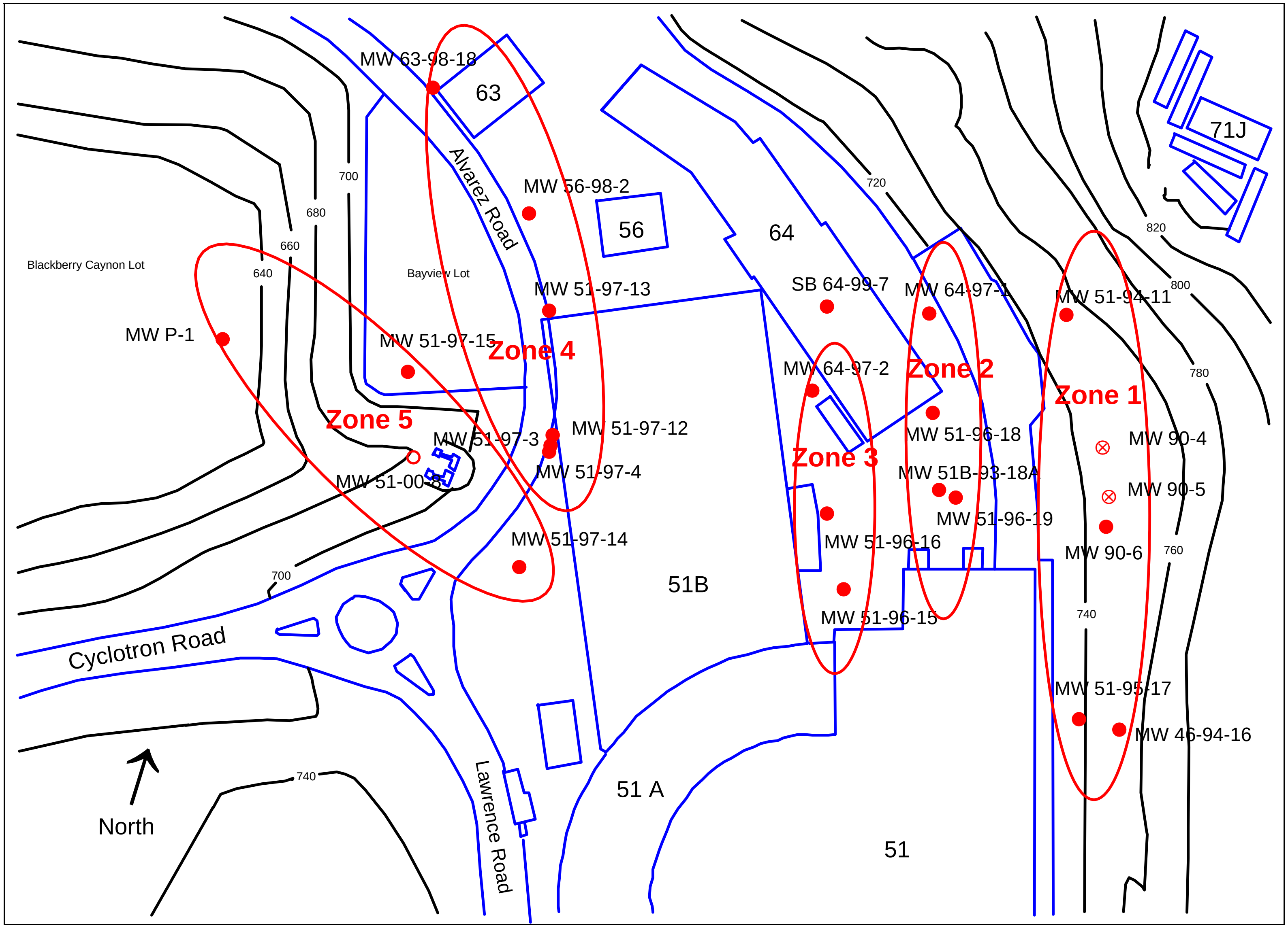
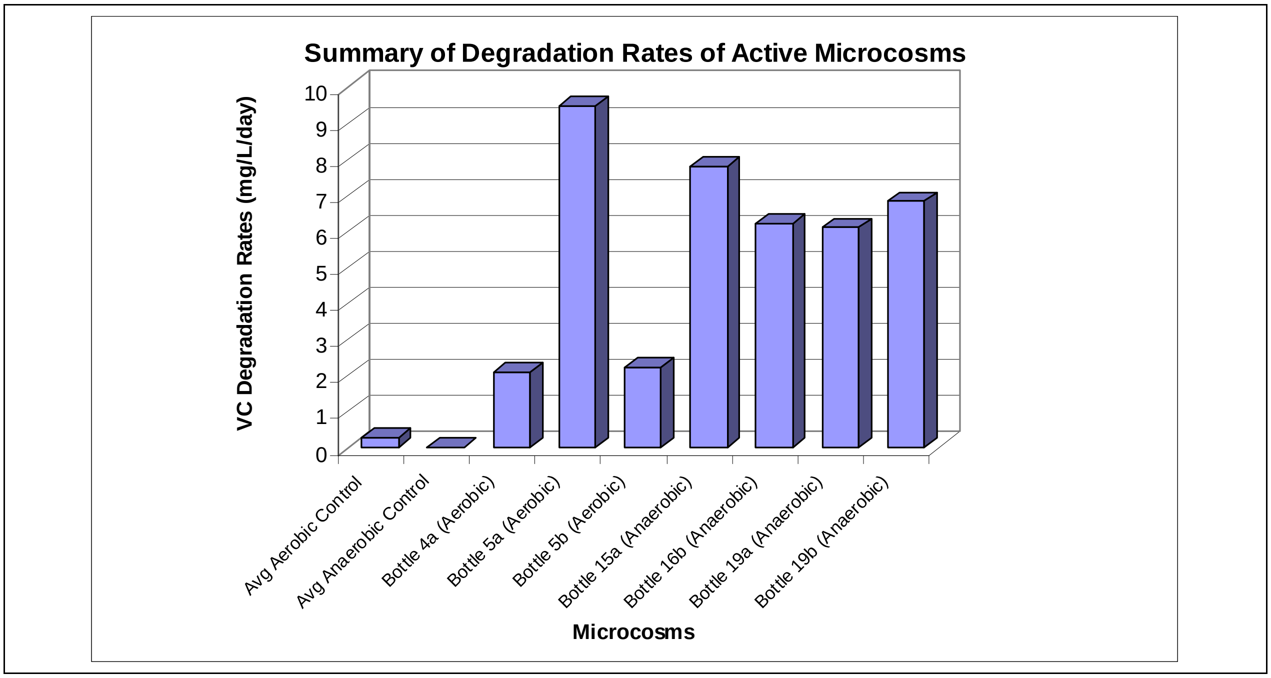
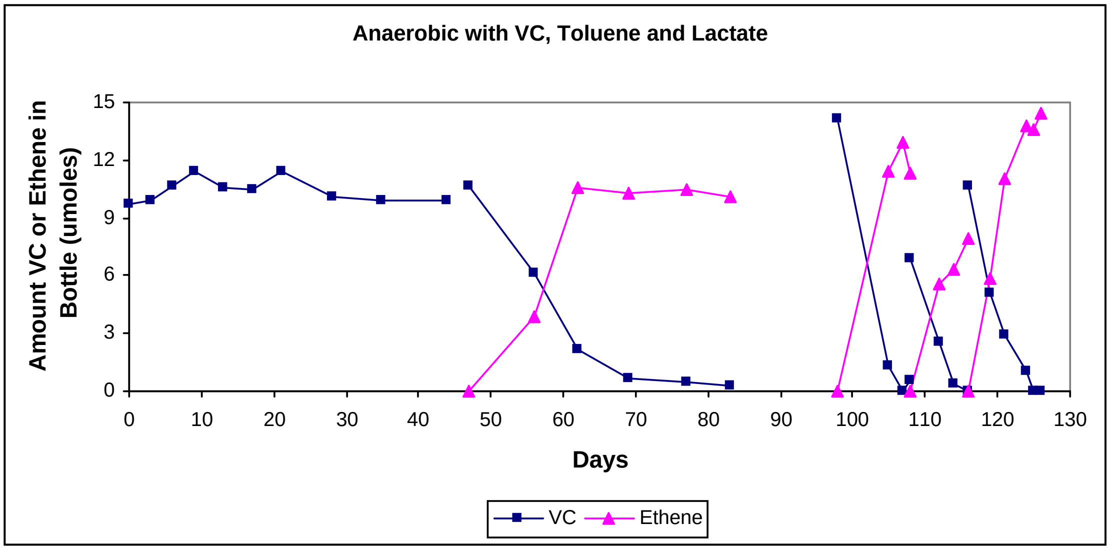


Figure 4. Comparison of maximum net degradation rates of active microcosms made from sediments collected at the Building 51/64 Site (from West et al. 2003).



VC, vinyl chloride

Figure 5. Typical graph of vinyl chloride biodegradation and ethene production observed in microcosms made from sediments collected at the Building 51/64 Site (from West et al. 2003).



Appendix F

Listing of PRG Screening Levels Used in RCRA Facility Investigation

Table F-1
RFI Soil Screening Levels for Detected Organic Contaminants and Cyanide
USEPA Region 9 Preliminary Remediation Goals for Residential Soil (mg/kg)

Contaminant	Abbreviation	2000		1999	1998	1996	1995(a)
Acetone		1.6E+03	nc	1.6E+03	1.4E+03	2.1E+03	
Aldrin		2.9E-02	ca*	2.9E-02	2.6E-02	2.6E-02	
Benzene		6.5E-01	ca*	6.7E-01	6.2E-01	6.3E-01	
Benzyl alcohol		1.8E+04	nc	1.8E+04	1.6E+04	2.0E+04	
Bis(2-ethylhexyl)phthalate	DEHP	3.5E+01	ca*	3.5E+01	3.2E+01	3.2E+01	
sec-Butylbenzene		1.1E+02	nc	1.1E+02	1.0E+02	NS	
tert-Butylbenzene		1.3E+02	nc	1.3E+02	1.2E+02	NS	
Butyl benzyl phthalate		1.2E+04	nc	1.2E+04	9.3E+02	9.5E+02	
Carbon disulfide		3.6E+02	nc	3.6E+02	3.5E+02	7.5E+00	4.7E-01
Carbon tetrachloride		2.4E-01	ca**	2.4E-01	2.3E-01	2.3E-01	
Chlorobenzene		1.5E+02	nc	1.5E+02	5.4E+01	6.5E+01	
Chloroform		2.4E-01	ca**	2.4E-01	2.4E-01	2.5E-01	
Chloromethane		1.2E+00	ca	1.2E+00	1.2E+00	1.2E+00	
Cyanide and compounds		1.1E+01	nc	1.1E+01 to 1.2E+04	1.1E+01 to 1.1E+04	1.1E+01 to 1.1E+04	
DDE		1.7E+00	ca	1.7E+00	1.7E+00	1.3E+00	
DDT		1.7E+00	ca*	1.7E+00	1.7E+00	1.3E+00	
1-2-dibromo-3-chloropropane		4.5E-01	ca**	4.5E-01			3.2E-01
Dibutyl phthalate (Di-n-butylphthalate)		6.1E+03	nc	6.1E+03	5.5E+03	6.5E+03	
1,3-Dichlorobenzene		1.3E+01	nc	1.3E+01	4.1E+01	5.0E+02	2.8E+03
1,4-Dichlorobenzene		3.4E+00	ca	3.4E+00	3.0E+00	3.6E+00	7.4E+00
Dichlorodifluoromethane	Freon-12	9.4E+01	nc	9.4E+01	9.4E+01	9.4E+01	1.1E+02
1,1-Dichloroethane	1,1-DCA	5.9E+02	nc	5.9E+02	5.7E+02	5.0E+02	8.4E+02
"CAL-Modified PRG"		3.3E+00	ca	NS	NS	NS	
1,2-Dichloroethane	1,2-DCA	3.5E-01	ca*	3.5E-01	3.4E-01	2.5E-01	4.4E-01
1,1-Dichloroethylene	1,1-DCE	5.4E-02	ca	5.4E-02	5.2E-02	3.7E-02	

Table F-1 (Continued)
RFI Soil Screening Levels for Detected Organic Contaminants and Cyanide
USEPA Region 9 PRGs for Residential Soil (mg/kg)

Contaminant	Abbreviation	2000		1999	1998	1996	1995 a)
1,2-Dichloroethylene (cis)	cis-1,2-DCE	4.3E+01	nc	4.3E+01	4.2E+01	3.1E+01	5.9E+01
1,2-Dichloroethylene (trans)	trans-1,2-DCE	6.3E+01	nc	6.3E+01	6.2E+01	7.8E+01	1.7E+02
Dieldrin		3.0E-02	ca	3.0E-02	2.8E-02	2.8E-02	
Diethyl phthalate		4.9E+04	nc	4.9E+04	4.4E+04	5.2E+04	
Dimethyl phthalate		1.0E+05	max	1.0E+05	1.0E+05	1.0E+05	
Ethylbenzene		2.3E+02	sat	2.3E+02	2.3E+02	2.3E+02	6.9E+02
Hexachlorobutadiene		6.2E+00	ca**	6.2E+00	5.7E+00	4.5E+02	
Methylene chloride		8.9E+00	ca	8.9E+00	8.5E+00	7.8E+00	1.1E+01
Methyl ethyl ketone	MEK	7.3E+03	nc	7.3E+03	6.9E+03	7.1E+03	
Methyl(methylethyl)benzene		NS		NS	NS	NS	
Methyl tert-butyl ether	MTBE	NS		NS	NS	NS	
"CAL-Modified PRG"		1.7E+01	ca	NS	NS	NS	
n-butylbenzene		1.4E+02	nc	1.4E+02	1.3E+02	NS	
p-isopropyltoluene		NS		NS	NS	NS	
Polychlorinated biphenyls	PCBs	2.2E-01	ca	2.2E-01	2.0E-01	6.6E-02	
Aroclor 1232		2.2E-01	ca	2.2E-01	NS	NS	
Aroclor 1242		2.2E-01	ca	2.2E-01	NS	NS	
Aroclor 1248		2.2E-01	ca	2.2E-01	NS	NS	
Aroclor 1254		2.2E-01	ca**	2.2E-01	NS	NS	
Aroclor 1260		2.2E-01	ca	2.2E-01	NS	NS	
Polynuclear aromatic hydrocarbons	PAHs						
Anthracene		2.2E+04	nc	2.2E+04	1.4E+04	1.1E+02	
Benz[a]anthracene		6.2E-01	ca	6.2E-01	5.6E-01	6.1E-01	
Benzo[a]pyrene		6.2E-02	ca	6.2E-02	5.6E-02	6.1E-02	

Table F-1 (Continued)
RFI Soil Screening Levels for Detected Organic Contaminants and Cyanide
USEPA Region 9 PRGs for Residential Soil (mg/kg)

Contaminant	Abbreviation	2000		1999	1998	1996	1995(a)
Benzo[b]fluoranthene		6.2E-01	ca	6.2E-01	5.6E-01	6.1E-01	
Benzo[k]fluoranthene		6.2E+00	ca	6.2E+00	5.6E+00	6.1E+00	
"CAL-Mod PRG" (PEA, 1994)		6.1E-01		6.1E-01	6.1E-01	6.1E-01	
Chrysene		6.2E+01	ca	6.2E+01	5.6E+01	7.2E+00	
"CAL-Mod PRG" (PEA, 1994)		6.1E+00		6.1E+00	6.1E+00	6.1E+00	
Dibenz[ah]anthracene		6.2E-02	ca	6.2E-02	5.6E-02	6.1E-02	
Fluoranthene		2.3E+03	nc	2.3E+03	2.0E+03	2.6E+03	
Fluorene		2.6E+03	nc	2.6E+03	1.8E+03	9.0E+01	
Indeno[1,2,3-cd]pyrene		6.2E-01	ca	6.2E-01	5.6E-01	6.1E-01	
Naphthalene		5.6E+01	nc	5.6E+01	5.5E+01	2.4E+02	8.0E+02
Phenanthrene		NS		NS	NS	NS	
Pyrene		2.3E+03	nc	2.3E+03	1.5E+03	1.0E+02	
Isopropylbenzene	cumene	1.6E+02	nc	1.6E+02	1.2E+02	1.9E+01	
n-Propylbenzene		1.4E+02	nc	1.4E+02	1.3E+02	NS	
Styrene		1.7E+03	sat	1.7E+03	1.7E+03	6.8E+02	
1,1,1,2-Tetrachloroethane	1,1,1,2-PCA	3.0E+00	ca	3.0E+00	2.8E+00	2.4E+00	
1,1,2,2-Tetrachloroethane	1,1,2,2-PCA	3.8E-01	ca	3.8E-01	3.6E-01	4.5E-01	9.0E-01
Tetrachloroethylene	PCE	5.7E+00	ca*	5.7E+00	4.7E+00	5.4E+00	7.0E+00
Toluene		5.2E+02	sat	5.2E+02	5.2E+02	7.9E+02	
1,2,3-Trichlorobenzene		NS		NS	NS	NS	
1,2,4-Trichlorobenzene		6.5E+02	nc	6.5E+02	4.8E+02	5.7E+02	6.2E+02
1,1,1-Trichloroethane	1,1,1-TCA	6.3E+02	nc	7.7E+02	6.8E+02	1.2E+03	3.0E+03
Trichloroethylene	TCE	2.8E+00	ca**	2.8E+00	2.7E+00	3.2E+00	7.1E+00

Table F-1 (Continued)
RFI Soil Screening Levels for Detected Organic Contaminants and Cyanide
USEPA Region 9 PRGs for Residential Soil (mg/kg)

Contaminant	Abbreviation	2000		1999	1998	1996	1995(a)
Trichlorofluoromethane	Freon-11	3.9E+02	nc	3.9E+02	3.8E+02	3.8E+02	7.0E+02
1,2,3-trichloropropane		1.4E-03	ca				6.6E-03
1,2,3-Trichloropropene		1.2E+01	nc	1.2E+01	1.1E+01	1.1E+01	
1,1,2-Trichloro-1,2,2-trifluoroethane	Freon-113	5.6E+03	sat	5.6E+03	5.6E+03	5.6E+03	4.1E+03
1,2,4-Trimethylbenzene		5.2E+01	sat	5.7E+01	5.1E+01	5.7E+02	6.2E+02
1,3,5-Trimethylbenzene		2.1E+01	nc	2.1E+01	2.1E+01	NS	
Vinyl chloride		1.5E-01	ca	2.2E-01	2.1E-01	1.6E-02	
Xylenes		2.1E+02	sat	2.1E+02	2.1E+02		9.9E+02

Key :
ca=CANCER PRG
nc=NONCANCER PRG
sat=SOIL SATURATION
MAX=ceiling limit
NS=no PRG specified

*(where: nc < 100X ca) **(where: nc < 10X ca)

(a) 1995 PRGs only shown for chemicals detected at units included in January 1996 request for NFA/NFI status.

Table F-2
RFI Soil Screening Levels for Inorganic Chemicals
USEPA Region 9 PRGs for Residential Soil and Berkeley Lab Background (mg/kg)

Metals	Chemical Symbol	2000		1999	1998	1996	1995	Maximum Background
Antimony and compounds	Sb	3.1E+01	nc	3.1E+01	3.0E+01	3.1E+01	3.1E+01	5.5E+00
Arsenic (noncancer endpoint)	As	2.2E+01	nc	2.2E+01	2.1E+01	2.2E+01		1.9E+01
Arsenic (cancer endpoint)	As	3.9E-01	ca*	3.9E-01	3.8E-01	3.8E-01	3.8E-01	1.9E+01
Barium and compounds	Ba	5.4E+03	nc	5.4E+03	5.2E+03	5.3E+03	5.3E+03	3.2E+02
Beryllium and compounds	Be	1.5E+02	nc	1.5E+02	1.5E+02	1.4E-01	1.4E-01	1.0E+00
Cadmium and compounds	Cd	3.7E+01	nc	3.7E+01	3.7E+01	3.8E+01	3.8E+01	2.7E+00
"CAL-Modified PRG" (PEA, 1994)		9.0E+00		9.0E+00	9.0E+00	9.0E+00	9.0E+00	2.7E+00
Total Chromium (1:6 ratio Cr VI:Cr III)	Cr	2.1E+02	ca	2.1E+02	2.1E+02	2.1E+02	2.1E+02	1.0E+02
Chromium III		1.0E+05	max	1.0E+05	NS	NS		
Chromium VI		3.0E+01	ca**	3.0E+01	3.0E+01	3.0E+01		
"CAL-Modified PRG" (PEA, 1994)		2.0E-01		2.0E-01	2.0E-01	2.0E-01	2.0E-01	
Cobalt	Co	4.7E+03	nc	4.7E+03	3.3E+03	4.6E+03	4.6E+03	2.2E+01
Copper and compounds	Cu	2.9E+03	nc	2.9E+03	2.8E+03	2.8E+03	2.8E+03	6.9E+01
Lead	Pb	4.0E+02	nc	4.0E+02	4.0E+02	4.0E+02	4.0E+02	1.6E+01
"CAL-Modified PRG" (PEA, 1994)		NS		NS	1.3E+02	1.3E+02	1.3E+02	
Mercury and compounds	Hg	2.3E+01	nc	2.3E+01	5.5E+00	6.5E+00	6.5E+00	4.0E-01
Molybdenum	Mo	3.9E+02	nc	3.9E+02	3.7E+02	3.8E+02	3.8E+02	7.4E+00
Nickel (soluble salts)	Ni	1.6E+03	nc	1.6E+03	1.5E+03	1.5E+03	1.5E+03	1.2E+02
"CAL-Modified PRG" (PEA, 1994)		1.5E+02		1.5E+02	1.5E+02	1.5E+02	1.5E+02	
Selenium	Se	3.9E+02	nc	3.9E+02	3.7E+02	3.8E+02	3.8E+02	5.6E+00
Silver and compounds	Ag	3.9E+02	nc	3.9E+02	3.7E+02	3.8E+02	3.8E+02	1.8E+00
Thallium compounds (minimum PRG)	Tl	5.2E+00	nc	6.3E+00 to 7.0E+00	6.0E+00 to 6.7E+00	6.1E+00 to 6.9E+00	6.1E+00 to 6.9E+00	7.6E+00
Vanadium	V	5.5E+02	nc	5.5E+02	5.2E+02	5.4E+02	5.4E+02	7.4E+01
Zinc	Zn	2.3E+04	nc	2.3E+04	2.2E+04	2.3E+04	2.3E+04	1.1E+02

Key : ca=CANCER PRG nc=NONCANCER PRG sat=SOIL SATURATION MAX=ceiling limit NS=no PRG specified *(where: nc < 100X ca) **(where: nc < 10X ca)

Appendix G

Results of Short-Term Well Yield Testing

State Water Resources Control Board (SWRCB) Resolution 88-63 (Sources of Drinking Water Policy) assigns municipal and domestic supply designations to all waters of the state with certain exceptions. One of the exemption criteria to the Sources Policy is that "the water source does not provide sufficient water to supply a single well capable of producing an average, sustained yield of 200 gallons per day". In order to determine where areas of groundwater contamination at Berkeley Lab do not meet the 200 gallon per day (gpd) well yield criteria for consideration as a potential drinking water source, short-term pumping tests were conducted. Results of the testing are summarized in Table G-1. As can be seen in the table, wells screened in the Orinda Formation and/or Mixed Unit generally cannot produce 200 gpd. Wells screened entirely in the Moraga Formation were generally not tested since, the Moraga Formation is relatively permeable, and therefore is expected to produce more than 200 gpd in many areas.

The short term well yield testing procedure was generally as follows:

- Each well was purged until dry or up to a maximum of 20 gallons.
- Ten minutes after completion of purging, 1.4 gallons of water was pumped from the well over a 10 minute period (equivalent to a rate of 200 gpd).
- If 1.4 gallons could not be pumped during the ten minute period, the test was ended, and the well was designated as having a yield less than 200 gpd.
- If the well did not go dry, an additional 1.4 gallons was pumped over a second 10 minute period. If 1.4 gallons could not be pumped without the well going dry, or the water level continued to decline to near the bottom of the well, the well was designated as having a yield less than 200 gpd.

The results are considered highly conservative since 1) testing was conducted over a very short time period (approximately 30 minutes or less), 2) the average pumping rate during the test was much less than 200 gpd, and 3) most wells were tested during the winter (March 2004 and October to December 2004) when the water table level and well yields are at their annual maximums. During the summer and fall when groundwater elevations decline, it is likely that additional wells would not produce 200 gpd, particularly in those areas where the water table drops into the less permeable horizons below the base of the Moraga formation.

Table G-1. Estimated Well Yields

Geologic Unit in Screened/Sandpack Interval Below Water Table	Location	Date Tested	Estimated Short-Term Well Yield	Static Water Column Height (feet)	Water Column After Initial Well Purge (feet)	Water Column at End of Test (feet)	Average Pumping Rate (gpd)
Orinda Formation	MW76-1	3/22/04	<200 gpd	11.7	1.2	0.7	(a)
	MW91-2	4/1/04	<200 gpd	8.2	2.4	0	(a)
	MW91-4	4/2/04	< 200 gpd	35.8	7	0	(a)
	MW91-9	3/23/04	>200 gpd	18.5	17	17.2	175
		5/7/04	>200 gpd	16	14.6	13.5	200
	26-92-11	3/23/04	>200 gpd	18.7	16.9	17	175
		5/7/04	>200 gpd	16.9	12.6	15.3	134
		10/21/04	>200 gpd	12.4	4.9	11.5	200
	51B-93-18A	3/19/04	<200 gpd	36	6.1	4.8	155
	25A-95-15	3/25/04	<200 gpd	11.6	5.6	5.4	96
	58-95-19	3/26/04	<200 gpd	17	2.5	1.4	(a)
	51-96-18	3/24/04	<200 gpd	7.2	3.8	2.5	100
	75-96-20	3/22/04	<200 gpd	39.8	4.5	3.1	168
	64-97-1	3/19/04	<200 gpd	7	2.8	1.9	134
	64-97-2	3/18/04	<200 gpd	17.4	6.2	3.2	122
	75-97-6	12/16/04	<200 gpd	16.6	0	0	(a)
	75-97-7	12/17/04	<200 gpd	22.9	0	0	(a)
	69-97-8	3/17/04	<200 gpd	27.4	7.7	4	103
	25A-98-1	3/24/04	<200 gpd	14.9	7	4.5	155
	25A-98-7	3/24/04	<200 gpd	17.9	4.7	4.3	155
	75-98-14	3/25/04	<200 gpd	24.1	6.5	4.5	183
	76-98-21	3/22/04	<200 gpd	17.4	6	4.8	155
	25A-99-2	3/24/04	<200 gpd	0.5	1.9	1.3	(a)
	71B-99-3R	4/2/04	>200 gpd	25	12.8	22.6	100
	25A-99-5	11/2/04	<200 gpd	17.9	0	0	(a)
	75A-00-7	4/2/04	<200 gpd	14.1	4.6	0	(a)
	51-00-9	3/19/04	<200 gpd	7.5	2	0	(a)
	51-00-10	3/19/04	<200 gpd	7.8	1.2	0	(a)
	SB25A-96-3	3/26/04	>200 gpd	19.2	3	8.9	79
		5/10/04	<200 gpd	17.7	0	0	(a)
	W76-97-3	3/26/04	<200 gpd	12.2	2.9	1.5	96
	SB16-97-11	3/31/04	<200 gpd	3.3	0.9	0	(a)
	SB5A-98-1	3/30/04	<200 gpd	35.5	4.6	0	(a)
	SB16-98-1	3/31/04	<200 gpd	5	0	0	(a)

Table G-1. Estimated Well Yields (continued)

Geologic Unit in Screened/Sandpack Interval Below Water Table	Location	Date Tested	Estimated Short-Term Well Yield	Static Water Column Height (feet)	Water Column After Initial Well Purge (feet)	Water Column at End of Test (feet)	Average Pumping Rate (gpd)
Orinda Formation (continued)	SB44-98-1	3/31/04	>200 gpd	23.2	7.2	14.1	150
		5/10/04	<200 gpd	19.3	0	0	(a)
	SB64-98-8	4/6/04	<200 gpd	9.9	2.8	1.8	100
	SB64-98-17	4/6/04	<200 gpd	17.2	7.55	6.6	100
	SB71B-99-2	11/1/04	<200 gpd	5.5	0	0	(a)
	SB64-99-4	4/6/04	<200 gpd	12.9	1.6	1.4	100
	SB64-00-1	4/6/04	<200 gpd	19.5	9.46	8.1	100
	SB64-00-2	4/6/04	<200 gpd	17.3	6.22	3.4	78
	SB25A-02-1	11/1/04	<200 gpd	8.5	0	0	(a)
	SB75-02-1	3/26/04	<200 gpd	8.5	7.3	5.2	100
	SB77-02-1	12/16/04	<200 gpd	1.4	0	0	(a)
	SB64-03-5	11/1/04	<200 gpd	6.6	1.4	0	(a)
	SB64-03-6	11/3/04	<200 gpd	7.4	0	0	(a)
	SB64-03-7	11/3/04	<200 gpd	3.7	0	0	(a)
	SB64-03-8	11/3/04	<200 gpd	7.7	0	0	(a)
	SB64-03-12	11/1/04	<200 gpd	11.6	0	0	(a)
	SB64-03-13	11/1/04	<200 gpd	21.3	0	0	(a)
	SB76-04-1	11/2/04	>200 gpd	7.1	6.6	6.6	148
		12/2/04	>200 gpd	6.9	6	6.1	150
Mixed Unit and Orinda Formation	16-94-13	3/25/04	>200 gpd	31.1	2	9.4	76
		5/7/04	<200 gpd	28.5	0	1.5	134
	16-95-3	3/22/04	>200 gpd	20	11.9	16.9	168
		12/3/04	>200 gpd	22	0	10.1	200
	7-95-23	4/7/04	<200 gpd	37.1	11	9.7	134
	58-96-11	4/5/04	<200 gpd	10.4	4	0	(a)
	58-00-12	4/6/04	<200 gpd	29.8	2.8	0	(a)
	SB58-96-1	3/31/04	<200 gpd	24.7	7	6.4	100
	SB58-96-2	3/31/04	<200 gpd	12.7	1.6	0	(a)
	SB58-97-1	4/1/04	<200 gpd	14	7.4	0	(a)
	SB58-98-7	4/5/04	<200 gpd	11.5	1.9	0	(a)
	SB58-01-2	3/31/04	<200 gpd	15.6	8	0	(a)
	SB58-02-1	3/31/04	<200 gpd	22	7.4	5.3	100
	SB58-02-2	3/31/04	< 200 gpd	16.9	7.2	4.4	100

Table G-1. Estimated Well Yields (continued)

Geologic Unit in Screened/Sandpack Interval Below Water Table	Location	Date Tested	Estimated Short-Term Well Yield	Static Water Column Height (feet)	Water Column After Initial Well Purge (feet)	Water Column at End of Test (feet)	Average Pumping Rate (gpd)
Mixed Unit	52-93-14	3/25/04	<200 gpd	3.1	0	0	(a)
	7B-95-21	4/7/04	<200 gpd	4.1	1.05	0.94	(a)
	7-95-22	4/7/04	<200 gpd	18.1	7.1	5.7	134
	SB58-95-2	3/30/04	>200 gpd	19.4	13.4	17.2	100
	SB58-97-2	4/1/04	>200 gpd	13.5	12.8	13	100
		12/1/04	>200 gpd	7.7	0	7	148
Moraga and Orinda Formations	5-93-10	3/23/04	>200 gpd	19	15.5	17.4	168
		10/22/04	>200 gpd	13.4	0	12.3	200
		11/29/04	>200 gpd	15.4	0	14.8	150
	58A-94-14	3/25/04	<200 gpd	8.3	6.4	5.5	100
	58-95-18	3/23/04	>200 gpd	9.1	5.3	7.9	168
	SB16-98-1	10/22/04	>200 gpd	11.6	9.8	10.6	100
	SB52A-98-1	3/31/04	<200 gpd	9.1	4.4	0	(a)
Orinda Formation and Great Valley Group	51-96-17	3/23/04	<200 gpd	43.1	5.2	4.2	134
Moraga Formation, Mixed Unit, and Orinda Formation	MW90-2	4/6/04	>200 gpd	15.2	4.5	7.9	100
		12/2/04	<200 gpd	13.9	0	2	168
	25-95-26	3/22/04	>200 gpd	19.3	10.7	11.4	160
		10-21-04	<200 gpd	17.5	0	0	172
	58-95-20	3/23/04	>200 gpd	19.4	9.4	13.2	183
		12/3/04	<200 gpd	17.5	0	0	(a)
	7B-95-24	4/7/04	>200 gpd	26	6.6	8.1	100
Moraga Formation and Mixed Unit	7-92-19	4/2/04	<200 gpd	21.9	3.8	3.9	(a)
	25-95-5	3/22/04	>200 gpd	20.1	20	20	168
	52B-95-13	3/25/04	not determined	10.4	8.7	9	98
		12/1/04	not determined	10.4	7.8	5.9	138
	25-98-10	3/22/04	>200 gpd	15.9	16	13	168
	SB53-96-3	4/5/04	>200 gpd	16.9	11.3	14	100
		10/22/04	>200 gpd	10.6	8.3	6.6	189
Great Valley Group	51-97-16	3/24/04	>200 gpd	7.2	5.6	6.7	118
		5/10/04	<200 gpd	dry			

Table G-1. Estimated Well Yields (continued)

Geologic Unit in Screened/Sandpack Interval Below Water Table	Location	Date Tested	Estimated Short-Term Well Yield	Static Water Column Height (feet)	Water Column After Initial Well Purge (feet)	Water Column at End of Test (feet)	Average Pumping Rate (gpd)
Colluvium, Orinda Formation, and Great Valley Group	51-96-15	3/18/04	>200 gpd	19	12.6	16.9	134
		12/2/04	<200 gpd	19	0	0	(a)
Colluvium and Moraga Formation	58-93-3	3/24/04	>200 gpd	19.6	7.6	9.9	149
Colluvium and Great Valley Group	51-97-13	3/19/04	>200 gpd	34.8	32	33.6	175
	51L-02-1	3/24/04	not determined	11.8	10.3	9.6	168
Fill and/or colluvium and Orinda Formation	46A-92-25	11/3/04	>200 gpd	22.3	0	17.8	200
	56-98-2	3/19/04	>200 gpd	39.2	20.9	24.3	149
	71B-98-13	11/3/04	<200 gpd	13.9	0	0	(a)
	51-00-8	3/18/04	<200 gpd	18.5	4.7	1.6	(a)
	SB69A-99-1	3/26/04	<200 gpd	12.9	3.3	2.8	134
Fill and/or Colluvium	MW90-3	11/2/04	<200 gpd	16.7	0	0	(a)
	51-96-16	3/23/04	<200 gpd	12.3	3.7	2.4	134
	51-96-19	3/18/04	>200 gpd	7.8	7.1	7.5	155
	51-97-3	3/19/04	>200 gpd	36.9	33.5	34.4	175
	SB51L-02-3	3/30/04	<200 gpd	10.3	1.3	0	(a)
	SB51L-03-1	3/30/04	<200 gpd	10.3	2.3	0.9	(a)
	SB51L-03-2	3/30/04	<200 gpd	11.5	1.3	0	(a)
Fill and/or Colluvium	51-97-12	3/19/04	>200 gpd	16.1	9.3	10.5	155
	63-98-18	3/18/04	>200 gpd	17.4	12	14	155

(a) Well went dry when trying to pump 1.4 gallons of water over a 10 minute period. Well yield is less than 200 gpd.

Appendix H

95% Upper Confidence Limit Calculations for Building 52 Lobe Soil Samples

The following table shows summary statistics used for the Upper Confidence Limit (UCL) calculation for residual cis-1,2-DCE and PCE in soil samples collected from the Building 52 lobe soil excavation ICM area.

Summary Statistics for Residual Soil Samples Building 52A Soil Excavation ICM Area (mg/kg)

Chemical	Detection Frequency		Percent Detects	Range of Values, mg/kg		Detection Limits	Mean mg/kg	Standard Deviation	Percentile Bootstrap 95%-UCL mg/kg
				Detected Concentrations					
				Minimum	Maximum				
cis-1,2-DCE	16	79	20	0.0058	0.25	0.05	0.0087	0.0291	0.014
PCE	36	79	46	0.0052	0.73	0.005	0.0458	0.1203	0.070

Due to the low detection rates for these analytes, it is likely that the true mean is lower than the estimated UCL. Using the "Percentile Bootstrap" method (used in the HHRA and specified in the CMS workplan), the estimated 95%-UCLs, shown in the following table, are substantially lower than the target risk-based or regulatory-based soil MCSs.

95% Upper Confidence Limit on the Arithmetic Mean for Soil Sample Data
Building 52A Soil Excavation ICM Area

Chemical	Bootstrap 95%-UCL (mg/kg)	MCS* (mg/kg)
cis-1,2-DCE	0.014	0.19
PCE	0.070	0.45

*Lesser of target risk-based MCS and regulatory-based MCS.

Appendix I

Hydrogeologic Maps and Cross Sections

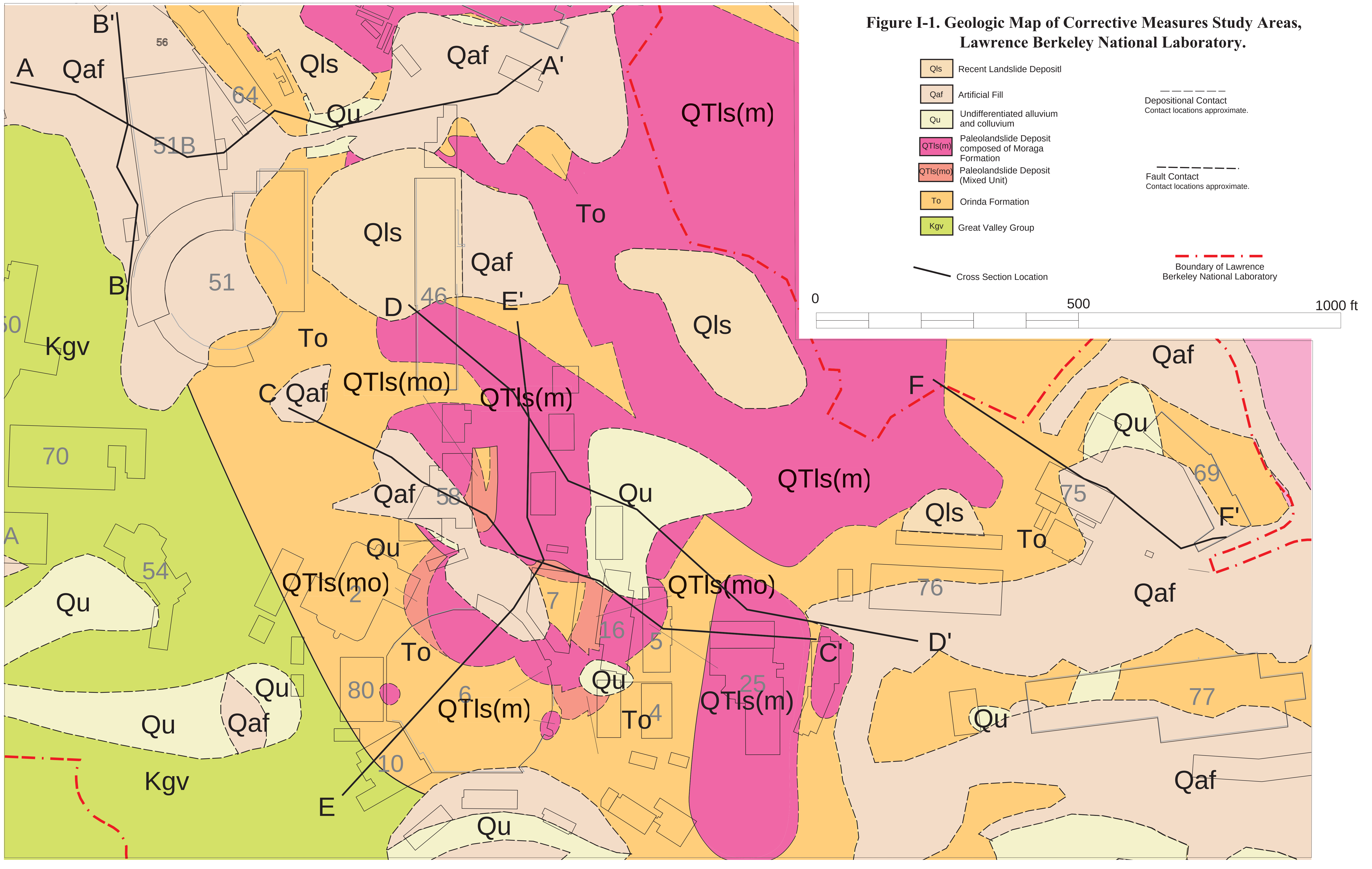


Figure I-1. Geologic Map of Corrective Measures Study Areas, Lawrence Berkeley National Laboratory.

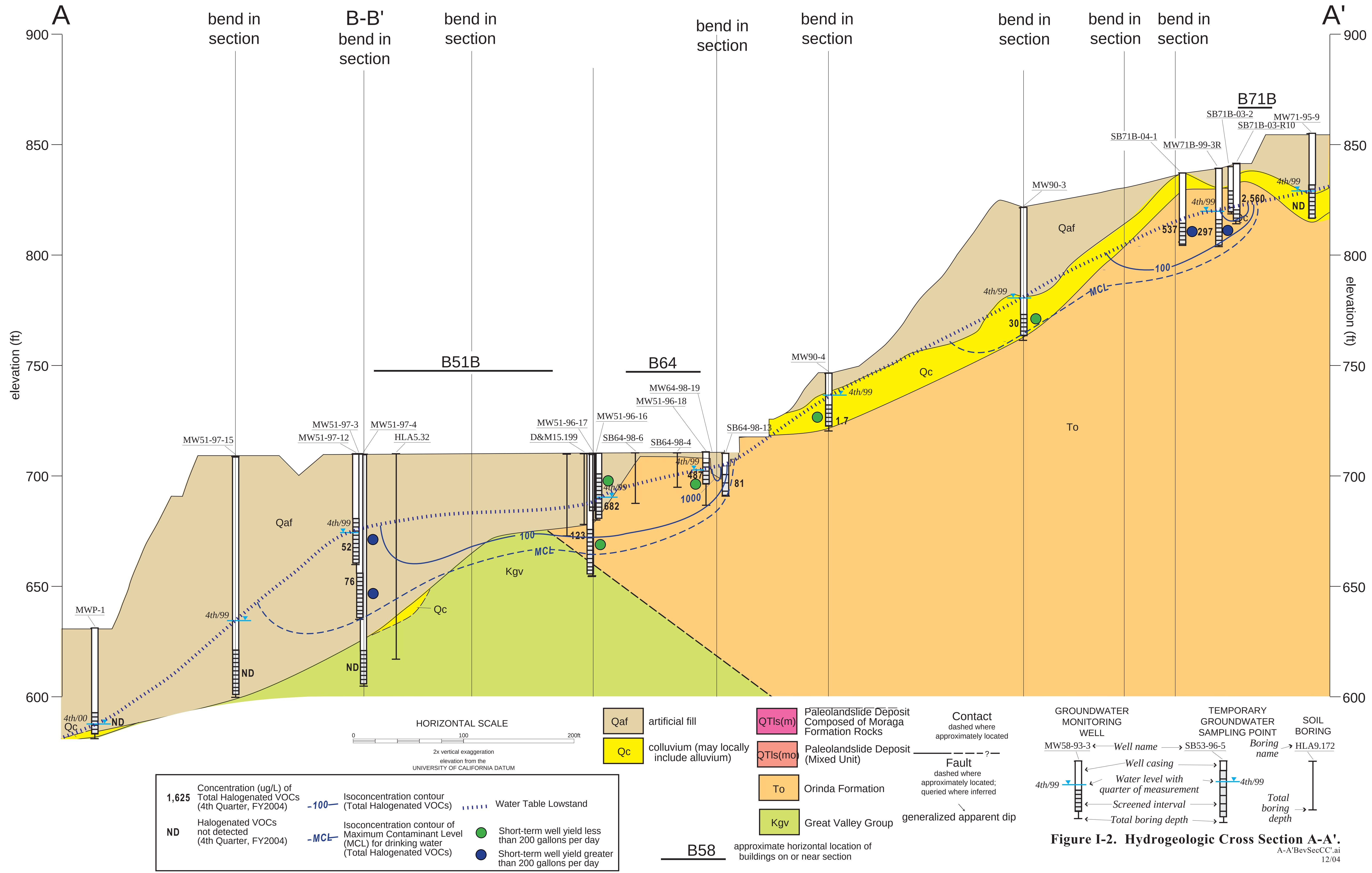


Figure I-2. Hydrogeologic Cross Section A-A'.

A-A'BevSecCC'.ai
12/04

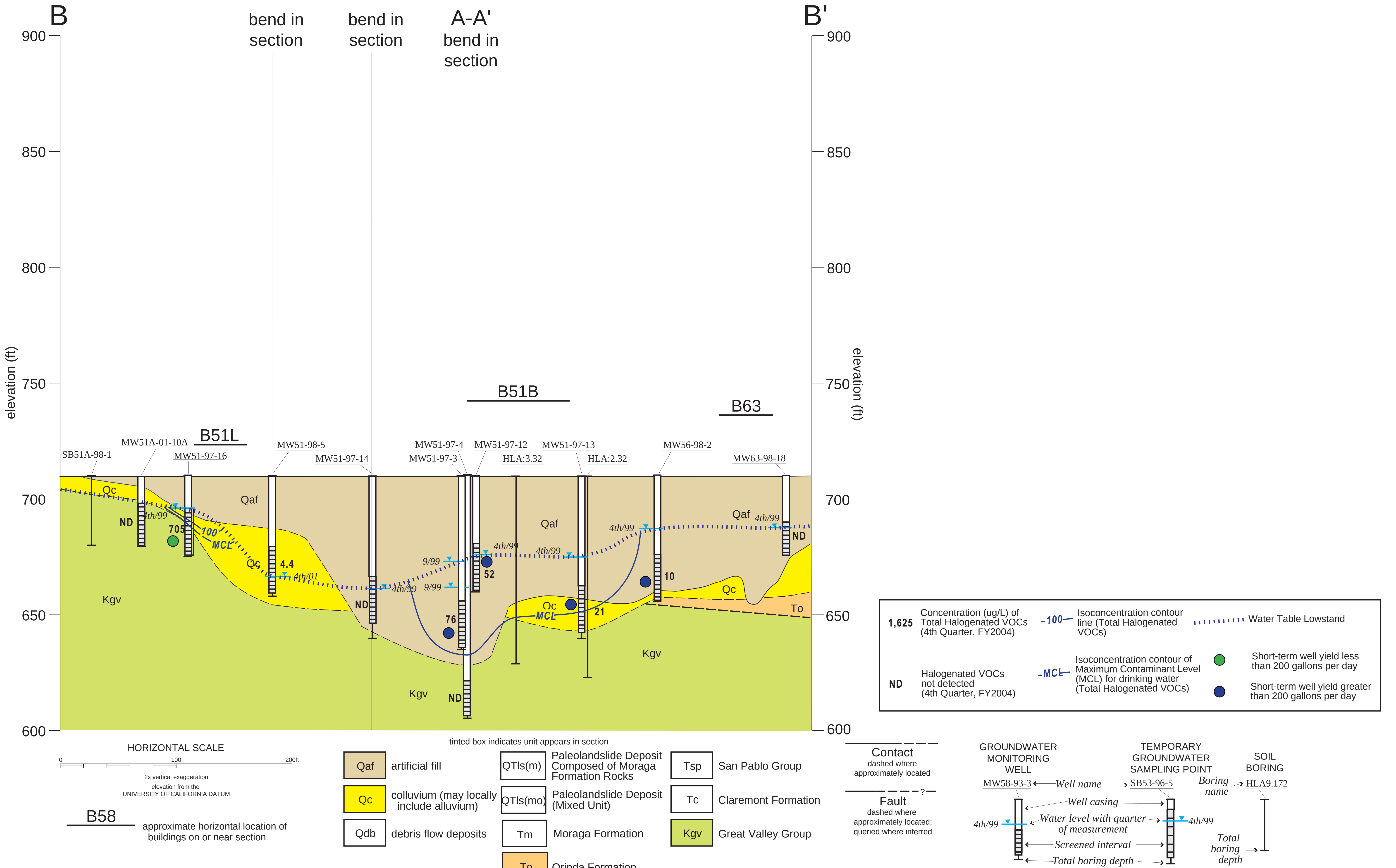
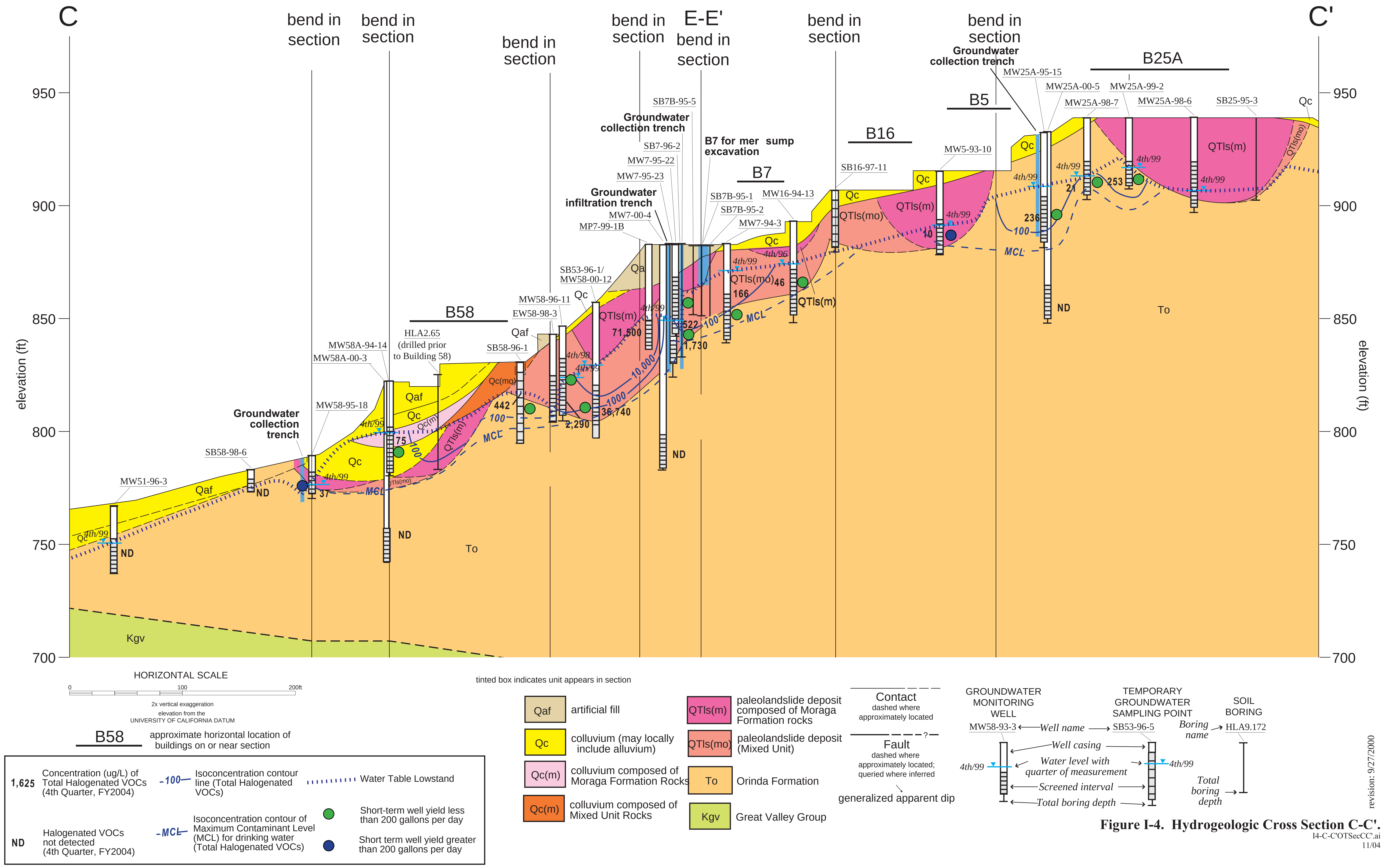


Figure I-3. Hydrogeologic Cross Section B-B'.

B-B' bv sec d.ai
12/04



revision: 9/27/2000

Figure I-4. Hydrogeologic Cross Section C-C'.

I4-C-C'OTSecCC'.ai
11/04

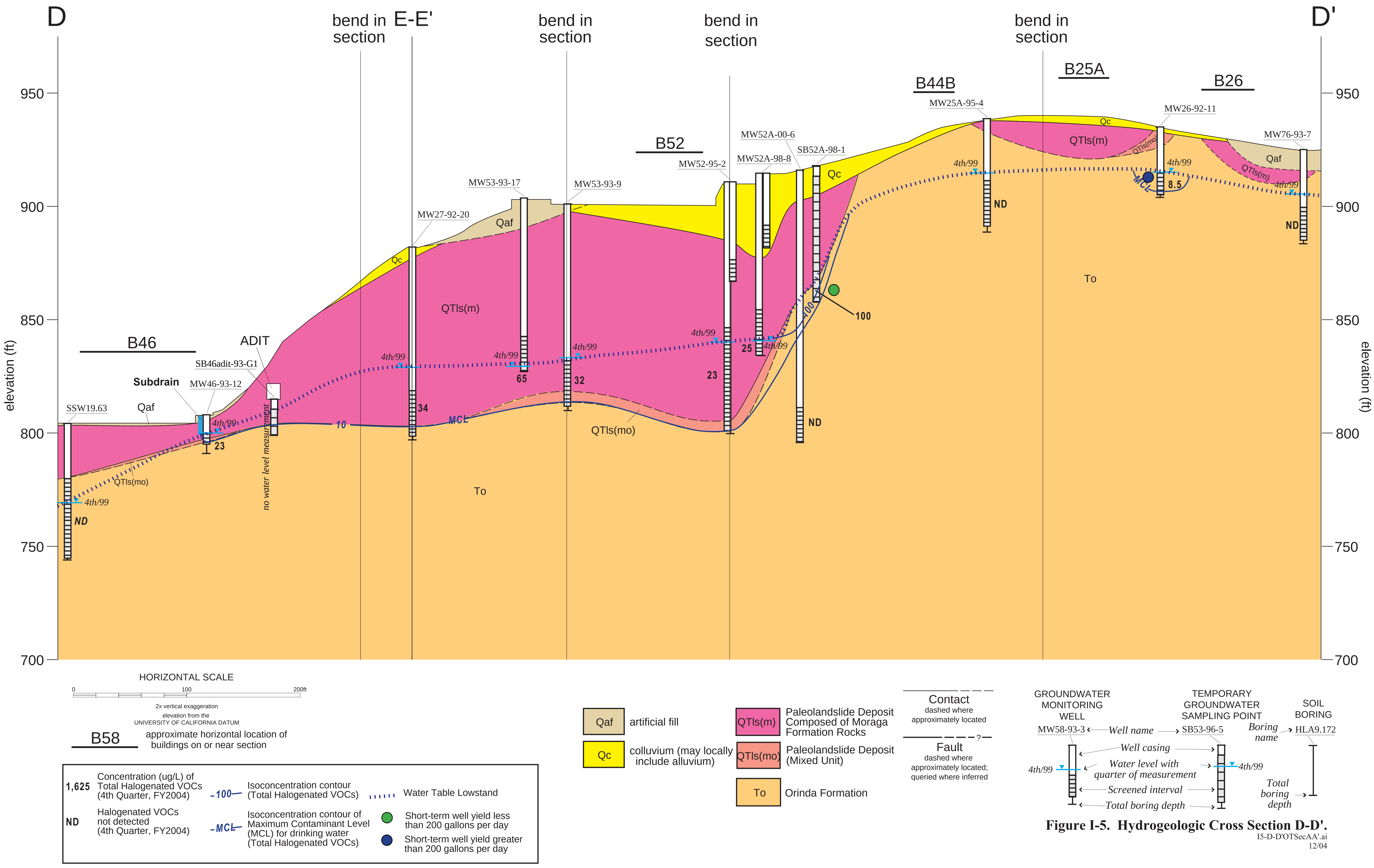


Figure I-5. Hydrogeologic Cross Section D-D'.

I5-D-D'OTSecAA'.ai
12/04

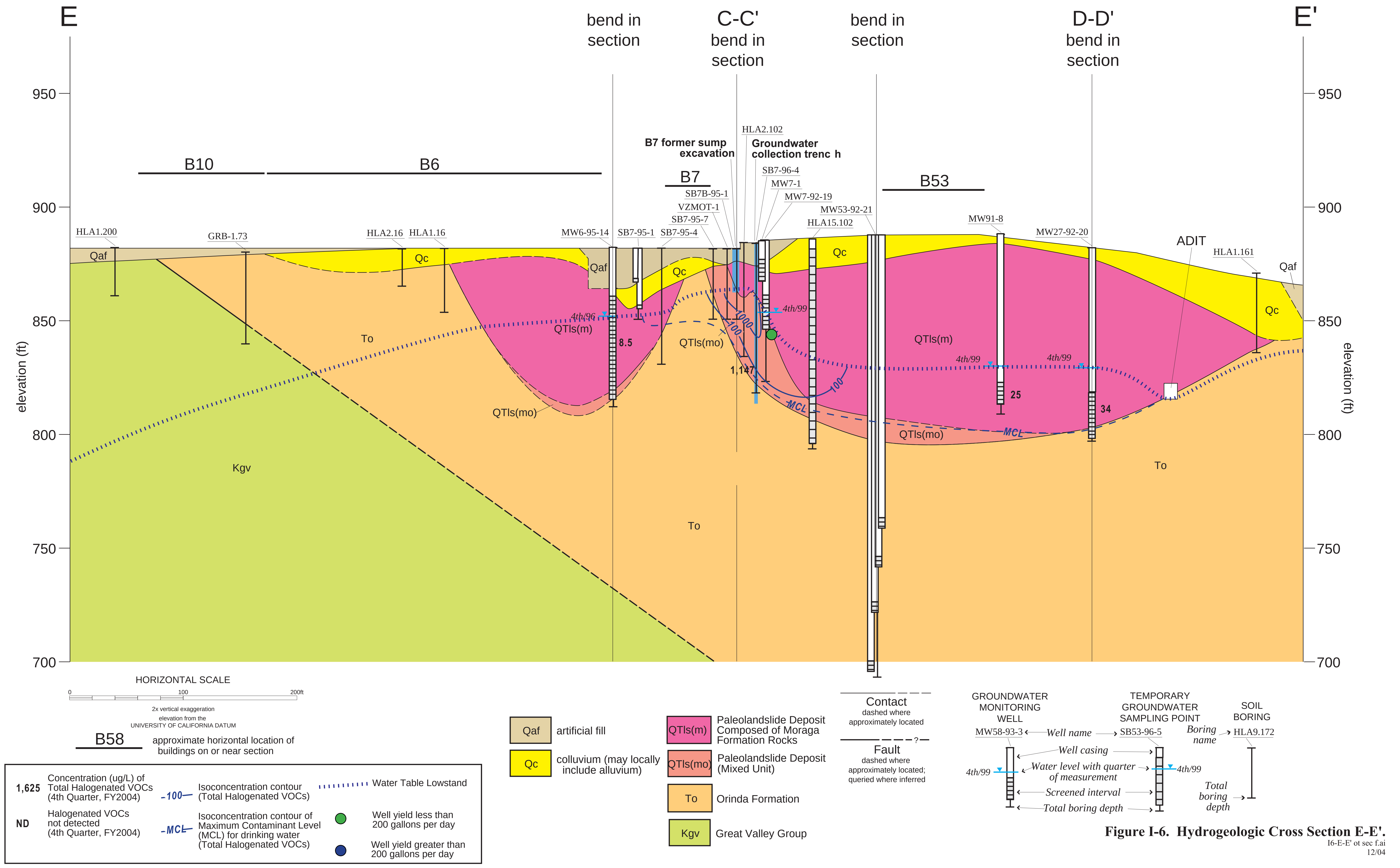


Figure I-6. Hydrogeologic Cross Section E-E'.

I6-E-E' ot sec f.ai
12/04

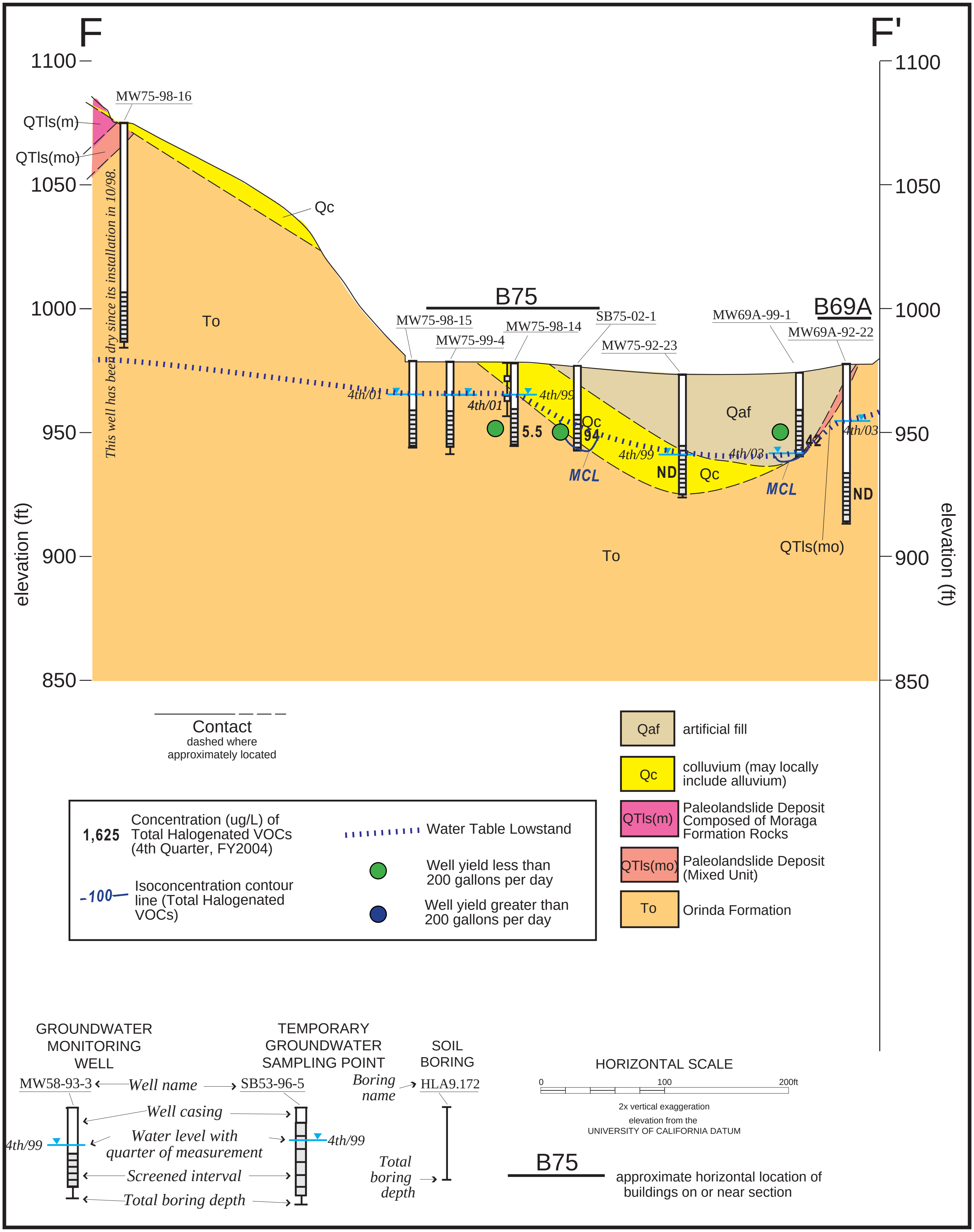


Figure I-7 . Hydrogeologic Cross Section F'F'

I7-FF' corp yard Sec AA'.ai
12/04

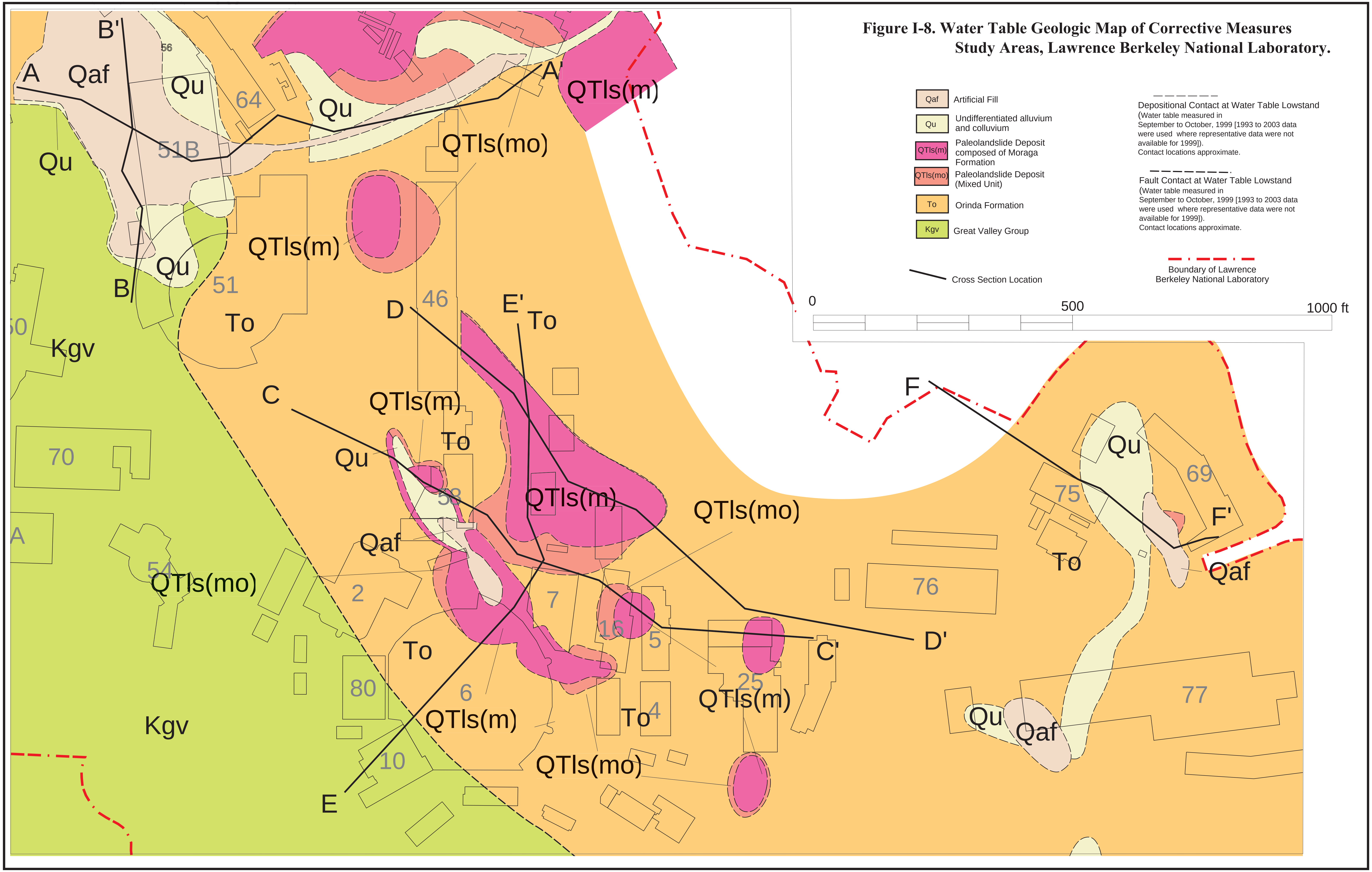
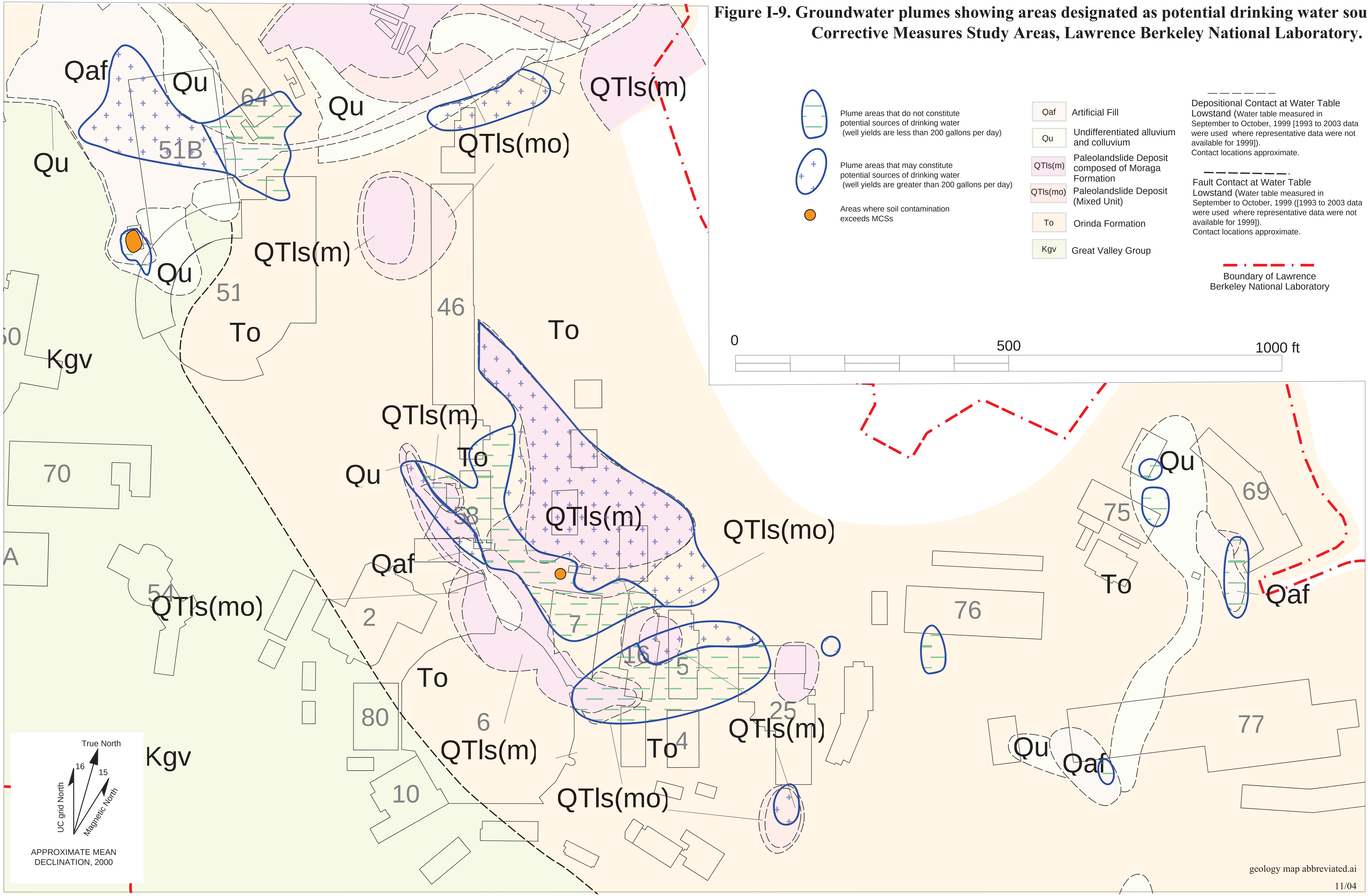


Figure I-8. Water Table Geologic Map of Corrective Measures Study Areas, Lawrence Berkeley National Laboratory.

Figure I-9. Groundwater plumes showing areas designated as potential drinking water sources Corrective Measures Study Areas, Lawrence Berkeley National Laboratory.



Appendix J

Regulatory Agency Comments and Berkeley Lab Responses on the *Draft* Corrective Measures Study Report dated July 2004

Department of Toxic Substances Control

Alan C. Lloyd, Ph.D.
Agency Secretary
Cal/EPA

B.B. Blevins, Director
700 Heinz Avenue, Suite 200
Berkeley, California 94710-2721

Arnold Schwarzenegger
Governor

January 27, 2005

Mr. Iraj Javandel
Environmental Restoration Program
Mail Stop 90-1116
Lawrence Berkeley National Laboratory
One Cyclotron Road
Berkeley, California 94720

REQUEST FOR SUBMITTAL OF REVISED DRAFT CORRECTIVE MEASURES STUDY REPORT, LAWRENCE BERKELEY NATIONAL LABORATORY (LBNL), BERKELEY, CALIFORNIA, EPA ID No. CA 4890008986

Dear Mr. Javandel:

DTSC has completed its review of the draft CMS Report, July 2004. We have also received letter from the Regional Water Quality Control Board informing DTSC that the Board has no additional comments (see Attachment). Please submit the revised CMS Report in triplicate and an electronic copy (pdf) by February 18, 2005.

Should you have any questions, please call me at 510- 540-3932.

Sincerely,

Waqar Ahmad

Waqar Ahmad
Hazardous Substances Engineer
Standardized Permits and Corrective Action Branch

cc: Mr. Hemant Patel
U.S. Department of Energy
Oakland Environmental Programs Division
Oakland Operations Office
1301 Clay Street
Oakland, California 94612-5208

Mr. Michael B. Rochette
California Regional Water Quality Control Board
San Francisco Bay Region (2)
1515 Clay Street, Suite 1400
Oakland, CA 94612

Calvin Willhite, Ph.D.
Staff Toxicologist
DTSC, Human and Ecological Risk Division
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Berkeley, CA 94710

Mr. Buck King, RG
Hazardous Substances Engineering Geologist
Hazardous Waste Management Program
700 Heinz Ave, Suite 200
Berkeley, CA 94710

Mr. Nabil Al-Hadithy
Manager, Toxic Management Division,
City of Berkeley, Planning and Development Department
2118 Milvia Street, 2nd Floor
Berkeley, CA 94704

California Regional Water Quality Control Board
San Francisco Bay Region

Dr. Alan Lloyd
Secretary for Environmental Protection

1515 Clay Street, Suite 1400, Oakland, California 94612
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http://www.swrcb.ca.gov/rwqcb2

Arnold Schwarzenegger
Governor

Date: January 26, 2005
File No.: 2199.9026 (MBR)

Department of Toxic Substances Control
Attn: Salvatore Ciriello
700 Heinz Avenue, Suite 200
Berkeley, California 94612

SUBJECT: Acceptance of the revised Draft RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory, Alameda County

Dear Mr. Ciriello:

The San Francisco Bay Regional Water Quality Control Board (Water Board) staff has received the Department of Toxic Substances Control's letter dated January 14, 2005, regarding Lawrence Berkeley National Laboratory's (Berkeley Lab) responses to our second round of comments on the draft Corrective Measure Study Report (CMS).

The two remaining issues identified in our comments were the establishment of a long-term goal of protecting groundwater as a potential drinking water supply beneficial use in areas of limited well yield and the identification of any collocated volatile organic compounds (VOC) and radionuclides groundwater contamination.

In their responses, Berkeley Lab has agreed to revise the draft CMS to establish the long-term goal of protecting groundwater for the potential drinking water supply beneficial use in areas of limited yield. The short-term goals for groundwater in these limited yield areas are for the protection of existing institutional land use activities and to maintain plume stability. For areas of higher yields, protecting groundwater as a potential drinking water supply had already been agreed to in the initial draft CMS.

Additionally, Berkeley Lab has agreed to add a Responsiveness Summary appendix to the revised CMS that incorporates all comments including those regarding the identification of collocated VOC and radionuclide groundwater contamination.

Based on these responses, Water Board staff has no additional comments and supports distribution of the revised draft CMS. Please contact me at (510) 622-2411 or via email at <mrochette@waterboards.ca.gov> if you have any questions or comments.

Sincerely,

Michael B. Rochette

Michael Bessette Rochette P.G.
Groundwater Protection Division

DTSC Comments

September 17, 2004

Department of Toxic Substances Control

Terry Tamminen
Agency Secretary
Cal/EPA

Edwin F. Lowry, Director
700 Heinz Avenue, Suite 200
Berkeley, California 94710-2721

Arnold Schwarzenegger
Governor

FILE COPY

September 17, 2004

Mr. Iraj Javandel
Environmental Restoration Program
Mail Stop 90-1116
Lawrence Berkeley National Laboratory
One Cyclotron Road
Berkeley, California 94720

COMMENTS ON CORRECTIVE MEASURES STUDY REPORT, JULY 2004 FOR THE LAWRENCE BERKELEY NATIONAL LABORATORY (LBNL), BERKELEY, CALIFORNIA, EPA ID No. CA 4890008986

Dear Mr. Javandel:

The Department of Toxic Substances Control (DTSC) has reviewed the Draft Corrective Measures Study Report for the Lawrence Berkeley National Laboratory, dated July 2004.

Mr. Michael B. Rochette of California Regional Water Quality Control Board, Dr. Calvin C. Willhite of our Human and Ecological Risk Division, and Mr. Buck King of our Geologic Services Unit have provided their comments (see Attachments). Please note that Mr. Nabil Al-Hadithy of the City of Berkeley has not sent his comments in a letter to DTSC which we have requested.

Please provide your response by October 18, 2004.

Should you have any questions, please call me at 510- 540-3932.

Sincerely,

Waqar Ahmad

Waqar Ahmad
Hazardous Substances Engineer
Standardized Permits and Corrective Action Branch

cc: Mr. Hemant Patel
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Oakland Operations Office
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Department of Toxic Substances Control

Terry Tamminen
Agency Secretary
Cal/EPA

700 Heinz Avenue, Suite 200
Berkeley, California 94710-2721

Arnold Schwarzenegger
Governor

MEMORANDUM

TO: Waqar Ahmad
Hazardous Substance Engineer
Standardized Permitting and Corrective Action Branch
Berkeley Regional Office

FROM: Buck King, RG, CHG BK
Engineering Geologist
Geology, Permitting and Corrective Action Branch, Northern California
Geological Services Unit, Berkeley Regional Office

CONCUR: Brian Lewis, CEG, CHG BK for BL
Engineering Geologist Supervisor I
Geology, Permitting and Corrective Action Branch, Northern California
Geological Services Unit, Sacramento Regional Office

DATE: September 16, 2004

SUBJECT: Review of Draft RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory, Berkeley, Alameda County, California
Project No. 22120/200178-48/39-HWMP

DOCUMENT REVIEWED

Draft RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory. Prepared by Lawrence Berkeley National Laboratory. (CMS Report)

INTRODUCTION

The Northern California Geological Services Unit (GSU) of the Department of Toxic Substances Control (DTSC) has completed our review of the CMS Report dated July, 2004. The GSU has no comments on the CMS Report. If you have any questions, please contact Buck King at (510) 540-3955 or Brian Lewis at (916) 255-6532.

Department of Toxic Substances Control

Terry Tamminen
Agency Secretary
Cal/EPA

Arnold Schwarzenegger
Governor

MEMORANDUM

TO: Waqar Ahmed
Standardized Permitting and Corrective Action Branch
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FROM: Calvin C. Willhite, Ph.D.
Human and Ecological Risk Division
700 Heinz Street, Suite 200
Berkeley, California 94710

DATE: September 10, 2004

SUBJECT: Lawrence Berkeley National Laboratory
University of California
Berkeley, California

PCA: 22120 Site-WP: 200178-48 MPC: 39-PER

In response to a request from the Hazardous Waste Management Program to the Human and Ecological Risk Division (HERD) on July 27, 2004 for review of the "RCRA Corrective Measures Study Report for the Lawrence Berkeley National Laboratory, the following is provided. No comment is made concerning site characterization protocols, sampling locations or criteria, data quality objectives, constituent or media sampling depths, numbers of samples, specific analytical methods, quality assurance or verification. No comment concerning any aspect of site ecological risk (if any) associated with regulated materials site is offered.

INTRODUCTION

The Lawrence Berkeley National Laboratory (LBNL) has advanced to the Corrective Measures Study (CMS) phase of site discovery, evaluation and remediation. The plan for conduct of the CMS was approved by the DTSC on June 8, 2002 and the materials reviewed here followed the approved plan.

The soil and groundwater areas presented in the CMS of previously unresolved concern are those identified on the attached figure: SWMUs and AOCs Recommended for Inclusion in Corrective Measures Study, Lawrence Berkeley National Laboratory (LBNL). The present review focused primarily upon media clean-up standards (Sections 3.1-3.4, 4 and 5) and directs the reader to new, published risk assessment information for a primary risk-driver at the site.

GENERAL COMMENT

The report is well-organized and clearly presents nearly all options with estimated financial costs for each level of theoretical health risk. Each of the various options is presented with each risk level identified in the U.S. EPA acceptable risk range. While it is beyond the expertise of risk assessment to evaluate the accuracy of the range of cost estimates, it appears that the authors have identified correctly the applicable or relevant and appropriate requirements (ARARs) specified under the Solid Waste Disposal Act, the Toxic Substances Control Act, and the Clean Water Act. Identification of ARARs is important in establishing performance goals for remedial alternatives; ARARs are reiterated throughout the CMS and the ARARs proposed at LBNL have specific bearing on the Ground Water Project Tasks described in the CMS. It appears the LBNL authors have considered carefully all three ARAR types [ambient or chemical-specific ARARS that establish health- or risk-based specific chemical concentration limits in various LBNL environmental media; performance, design or action-specific ARARs that establish requirements on specific remedial activities related to management of hazardous materials released at LBNL; location-specific ARARs that establish administrative restrictions on and control of remedial activities based on the specific character of the LBNL). ARARs are so important to the CMS that, in fact, at LBNL the baseline public health risk assessment could have been satisfied by simply documenting the chemical-specific ARARs since all materials considered in the CMS have promulgated ARARs.

At page xiii, it is not clear why a well-head treatment option of site groundwater prior to its use as either industrial process water and/or landscape irrigation was not included in the present analysis? Given the clear need to conserve EBMUD drinking water and the opportunity to reduce the long-term financial costs associated with site mitigation, an explanation for rejection of those options should be included at some point in the document.

In general, risk analyses rely upon the upper 95% confidence limit on the arithmetic mean of the chemical concentration data for each material considering all site groundwater. The authors present the risk analyses and the proposed risk reductions based on well-by-well concentrations. While this approach takes into account possible "hot-spots" (see Risk Assessment Guidance for Superfund. Volume 1. Human Health Evaluation Manual (Part A; EPA/540/1-89/002 Section 4.3.2), this is not the customary approach to a site as a whole (U.S. EPA Publ. 9285-7-081, May 1992). Because the heterogeneous, fractured and complicated geology at LBNL provides physical limitations to handling site groundwater as a homogeneous "aquifer" data set, a brief explanation of the geologic and groundwater characteristics included either in Section 1.2 (Introduction) or as a brief clarification in the Executive Summary would facilitate the readers' understanding of the CMS approach used here.

At page 24 (line 11 from bottom), the document should do a much better job of explaining the site-specific features that lead one to the conclusions about "technical impracticability". This is a key concept presented in the CMS and must be clearly delineated – specifically, which area are amenable to remediation to MCLs and which areas are unlikely to meet the CMS goals – and – what features of those areas which are unlikely candidates for complete remediation to ARARs account for that failure? While Section 2 describes water yield and site geology, the authors should more directly explain the critical physical features which lead to the proposed ultimate "technical impractability". It is very important that the document be very clear on the specific factors that preclude certain area site groundwater remediation to MCLs.

SPECIFIC COMMENT

1. Page xv-xvii. Please identify the common names of the chemicals of concern (e.g., PCBs and/or specific VOCs) for each soil and groundwater unit listed in the table. At the soil units AOC 6-3 and SWMU 3-6, please either delete or modify the entry "No action" with a footnote the explanation of the CMS document section describing the completed interim measures or revise the entry to state "No further action". As written, the text is confusing and suggests that nothing was proposed, planned or has been completed.
2. Page xvi. At the column "Recommended Corrective Measure Alternative for Cleanup", the status of the various alternatives for AOC 1-9 and AOC 2-4 is confusing. The status of the various alternatives is not readily apparent and it is not clear which of the various alternatives are actually recommended?
3. Page xvii. At the column "Recommended Corrective Measure Alternative for Cleanup", the entry can be clarified by deletion of the phrase "is not a potential drinking water source" and replacement with "and groundwater characteristics do not meet SWRCB Resolution 88-63 provisions".
4. Page 8, Section 1.3.3. Please list the areas of concern and/or solid waste management units that have been the subjects of interim soil removals. As written, it appears that the all of the materials of concern may remain on-site where this in fact is not necessarily the case.
5. Page 10. It is worthwhile to point out that any hypothetical off-site exposure would be far less than that accounted for by the hypothetical on-site future residential exposure scenario. Therefore, the on-site risk assessments included in the HHRA account for off-site residential exposure scenarios.
6. Page 10. Please clarify what is meant by the term "relatively stable"?
7. Page 14; Tables 1.3.4-2 and 1.3.4-3. Please identify the primary chemical(s) encountered at each entry and please footnote the current status of that AOC or SWMU. Where the area or unit was retained in the CMS based on excess health risk, indicate the primary chemical that accounts for that risk.

8. Page 16. Please explain the ultimate fate of the treated water that has been collected for the past 12 years as "hydrauger effluent". Since this water is treated, to what total water volume over this dozen years does this correspond and have those treated waters been used for any beneficial purpose (e.g., LBNL industrial process or landscape irrigation)?
9. Page 23, line 11 from bottom. As written, the conclusion is speculation. Either replace the word "would" with "could" or replace the phrase with "there could be a possible adverse impact on private property values in neighborhoods adjacent to the Berkeley lab." There is no direct evidence for the statement as written.
10. Page 191, Section 5.0. Interim remedial measures for soil PCBs have already been completed at Area of Concern (AOC) 6 Building 88 and Solid Waste Management Unit (SWMU 3-6) Building 75 (Attachment 1). It is important that the reader recognize that the interim remedial measures for the laboratory were achieved and verification sampling found compliance with the soil polychlorinated biphenyl ARARs for all congeners consistent with unrestricted future site land use (e.g., Toxic Substances Control Act 40 CFR 761; Federal Register 59: 62788 and OSWER Directive No. 93555.4-01 FS, August 1990). It may be worthwhile to expand the presentation of this fact in the Executive Summary.

CONCLUSION

The CMS represents a clear presentation of options available to regulatory risk managers. The authors and the facility should be given public credit for their achievements in removal of soil PCBs to less than ARARs intended for unrestricted future land use – especially at Building 88. This is remarkable in light of the fact that the facility was able to accomplish removal actions in spite of the high voltage electrical and critical utility lines with concrete supports at the this AOC (Figure 1). These utility lines are located in soils where PCBs were found and are located near the Berkeley cyclotron; clearly the immediate danger to workers engaged in soil excavations could have been brought forward as obstacles that could impede these remedial measures. The facility has made remarkable progress in site PCB risk reduction and this fact should be recognized by regulatory agencies.

The CMS appendices should include an update on the carcinogenic potency of trichloroethylene (TCE), a material which accounts in large measure for the risk estimates presented for the various areas of concern and solid waste management units. Given the marked discrepancy between recent advancements in the science (Attachments 2-4) and the 20 year old risk assessments which formed the historical basis of the promulgated ARARs for TCE, to neglect considerations of these published advancements in TCE risk assessment would be to present an incomplete picture of the hazards (if any) associated with the TCE found in soil and groundwater at LBNL.

REFERENCES

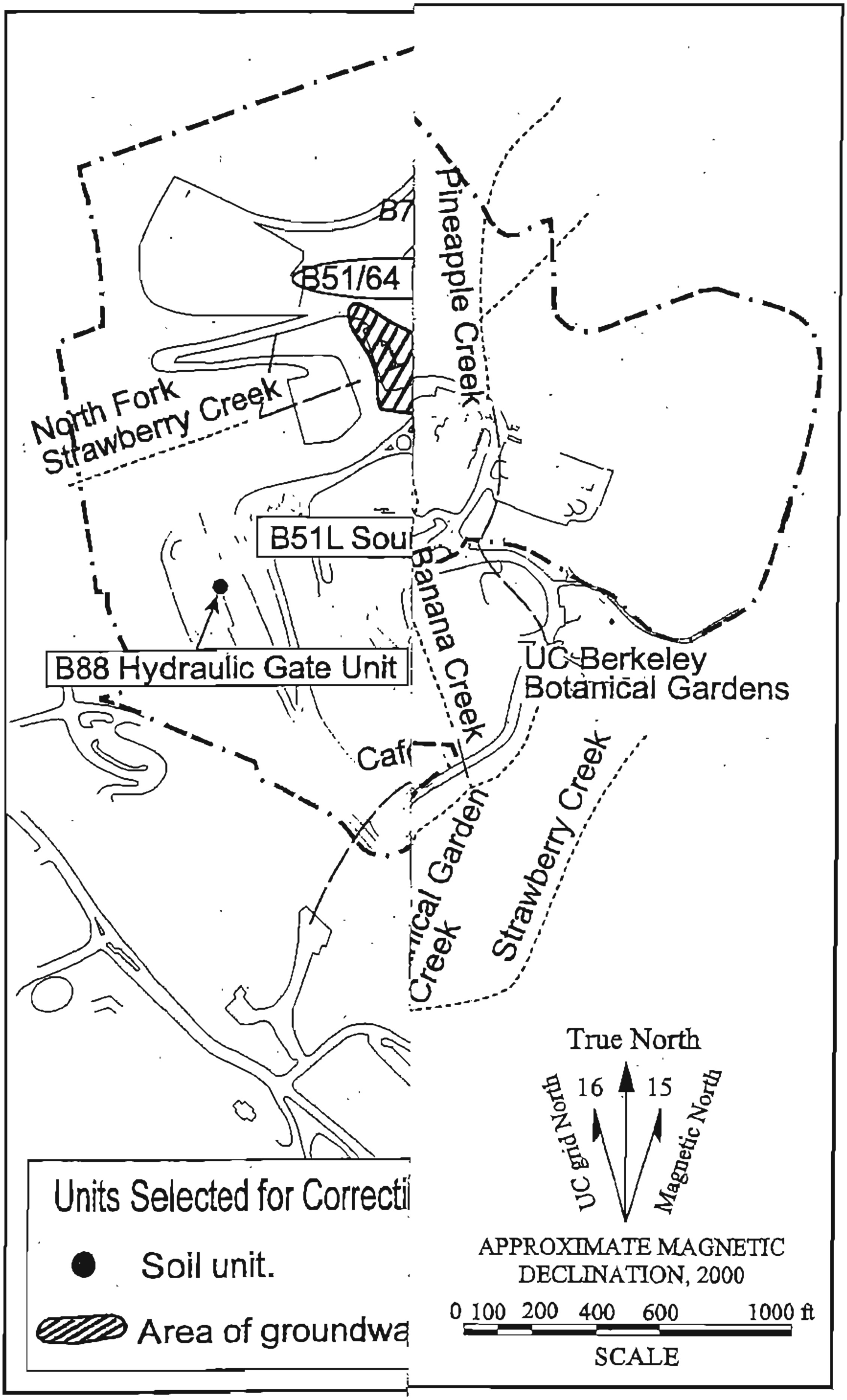
Clewell, H.J. and M.E. Andersen. 2004. Applying mode-of-action and pharmacokinetic considerations in contemporary cancer risk assessments: An example with trichloroethylene. Crit. Rev. Toxicol. 34(5): 385-445.

Kester, J.E. and H.J. Clewell. 2004. The perils and promise of modern risk assessment: the example of trichloroethylene. Clin. Occup. Environ. Med. 4: 497-512.

Ruden, C. 2001. Interpretations of primary carcinogenicity data in 29 trichloroethylene risk assessments. Toxicology 169: 209-225.

Attachments (4)

Reviewed by: David L. Berry, Ph.D.
Senior Toxicologist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DOI: 10.1080/10408440490500795

Taylor & Francis healthsciences

Applying Mode-of-Action and Pharmacokinetic Considerations in Contemporary Cancer Risk Assessments: An Example with Trichloroethylene

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ABSTRACT: The guidelines for carcinogen risk assessment recently proposed by the U.S. Environmental Protection Agency (U.S. EPA) provide an increased opportunity for the consideration of pharmacokinetic and mechanistic data in the risk assessment process. However, the greater flexibility of the new guidelines can also make their actual implementation for a particular chemical highly problematic. To illuminate the process of performing a cancer risk assessment under the new guidelines, the rationale for a state-of-the-science risk assessment for trichloroethylene (TCE) is presented. For TCE, there is evidence of increased cell proliferation due to receptor interaction or cytotoxicity in every instance in which tumors are observed, and most tumors represent an increase in the incidence of a commonly observed, species-specific lesion. A physiologically based pharmacokinetic (PBPK) model was applied to estimate target tissue doses for the three principal animal tumors associated with TCE exposure: liver, lung, and kidney. The lowest points of departure (lower bound estimates of the exposure associated with 10% tumor incidence) for lifetime human exposure to TCE were obtained for mouse liver tumors, assuming a mode of action primarily involving the mitogenicity of the metabolite trichloroacetic acid (TCA). The associated linear unit risk estimates for mouse liver tumors are 1.5×10^{-6} for lifetime exposure to 1 μg TCE per cubic meter in air and 0.4×10^{-6} for lifetime exposure to 1 μg TCE per liter in drinking water. However, these risk estimates ignore the evidence that the human is likely to be much less responsive than the mouse to the carcinogenic effects of TCA in the liver and that the carcinogenic effects of TCE are unlikely to occur at low environmental exposures. Based on consideration of the most plausible carcinogenic modes of action of TCE, a margin-of-exposure (MOE) approach would appear to be more appropriate. Applying an MOE of 1000, environmental exposures below 66 μg TCE per cubic meter in air and 265 μg TCE per liter in drinking water are considered unlikely to present a carcinogenic hazard to human health.

KEYWORDS: Cancer risk assessment, Mode-of-action, Pharmacokinetics, Trichloroethylene

I. INTRODUCTION

Assessing the potential risk associated with human exposure to carcinogenic environmental contaminants represents an uncomfortable admixture of scientific evaluation and political policy, with the potential for enormous impact on both the public health and the economic well-being of the nation. A difficult challenge facing cancer risk assessors today is to realistically consider the implications of the chemical's mechanism(s) of carcinogenicity in developing a risk assessment approach for

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4 (2004) 497–512

CLINICS IN
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ENVIRONMENTAL
MEDICINE

The perils and promise of modern risk assessment: the example of trichloroethylene

Janet E. Kester, PhD*, Harvey J. Clewell III, MS

Health Sciences Institute, ENVIRON International Corporation, 5401 Veterans Memorial Parkway, Suite 201, Saint Peters, MO 63376, USA

Trichloroethylene (TCE; C_2HCl_3) is on the Agency for Toxic Substances and Disease Registry/US Environmental Protection Agency (EPA) Top 20 CERCLA priority list of hazardous substances (http://www.atsdr.cdc.gov/clist.html#list). It is present at 852 of 1430 Superfund sites and was selected in 1988 as the primary contaminant for the first subregistry of the Agency for Toxic Substances and Disease Registry's national exposure registry [1]. Because of the environmental prevalence of TCE, the fact that the toxicologic criteria for its systemic and carcinogenic effects have been "under review" by the EPA since the late 1980s has complicated assessments of potential human health risk for more than 15 years. Given the rapid evolution in understanding of molecular mechanisms of toxic action in recent years, the EPA's long-anticipated draft "Trichloroethylene Health Risk Assessment: Synthesis and Characterization" (TCE HRA) [2] was viewed by many as a critical test of the EPA's resolve to incorporate the best available science into its toxicity assessments, a goal articulated through several iterations of the EPA's guidelines for carcinogen risk assessment [3–5].

The EPA's re-evaluation of TCE health risks was conducted according to a new procedure in which recognized outside experts were commissioned by the EPA and other parties to document the literature and analyze key scientific questions, forming a consensus on major issues on which the EPA would rely in completing the HRA. Consensus was built through a joint EPA/government/industry effort that included two "Williamsburg meetings" [6], at which the opinions of experts on TCE and risk assessment were solicited. Subsequently, papers by several EPA scientists and outside experts, several of whom had been involved in the consensus process, were published together as "state-of-the-science" (SOS) papers in an *Environmental Health Perspectives* supplement in May 2000 [7,8]. Despite these efforts, the Agency's draft TCE HRA [2] immediately provoked fundamental criticism of its underlying assumptions and

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Toxicology 169 (2001) 209–225

TOXICOLOGY

www.elsevier.com/locate/toxicol

Interpretations of primary carcinogenicity data in 29 trichloroethylene risk assessments

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[b] Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden

Received 13 June 2001; received in revised form 25 September 2001; accepted 25 September 2001

Abstract

This paper explores to what extent interpretations of individual primary carcinogenicity data differ between different risk assessors, and discusses possible reasons for such differences as well as their impact on the overall risk assessment conclusions. For this purpose 29 different TCE carcinogenicity risk assessments are used as examples. It is concluded that the TCE risk assessors surprisingly often interpret and evaluate primary data differently. Two particular reasons for differences in data interpretation are discussed: different assessments of statistics, and different assessments of whether the results obtained in bioassays have toxicological relevance. Differences in the interpretation and evaluation of epidemiological data are also explored and discussed. © 2001 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Primary carcinogenicity data; Trichloroethylene; Risk assessments; Regulatory toxicology

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1. Introduction

Health risk assessments of chemicals are being made on national, regional and international basis. Often different risk assessors come to different conclusions about the magnitude, and even the nature, of risks. Little attempt has been made in the past to describe and understand the reasons for these differences. In-depth studies of the crucial issues of scientific uncertainty and interpretative practices require toxicological training and should be made within the community of toxicologists. A deeper understanding of the risk assessment process may help increasing the transparency and reliability of risk assessments so that they better serve the needs of risk managers and the public.[1]

This is the second report from a case study in which the chlorinated solvent trichloroethylene (TCE) is taken as a model substance for a detailed study of how risk assessments of chemicals are performed by different risk assessors. TCE has been chosen as a model substance for this study

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[1] These issues are also currently being addressed by the International Programme on Chemical Safety (IPCS) in their project aiming at global co-ordination and harmonization of the risk assessment process (see www.who.int/pcs/).

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LBNL Responses to DTSC Comments

October 18, 2004

BERKELEY LAB
Environment, Health and Safety Division
Environmental Restoration Program

Dr. Waqar Ahmad
Facility Permitting Branch
Cal EPA-DTSC
700 Heinz Avenue, Suite 200
Berkeley, CA 94710-2737

October 18, 2004
ERP-3028

Subject: Responses to Comments on the *Draft* RCRA Corrective Measures Study Report for the Lawrence Berkeley National Laboratory Environmental Restoration Program, CA-EPA ID No: CA4890008986, dated July 2004

Dear Dr. Ahmad:

Berkeley Lab appreciates the thorough review and constructive comments by DTSC and RWQCB on the *Draft* RCRA Corrective Measures Study Report dated July 2004. Enclosed are LBNL's responses to comments, as requested in the DTSC letter dated September 17, 2004.

Please contact me at (510) 486-6106 if you have any questions.

Sincerely,

Iraj Javandel

Iraj Javandel
Environmental Restoration Program

Encls.

Ernest Orlando Lawrence Berkeley National Laboratory
One Cyclotron Road | Berkeley, California 94720-8126 | Mail Stop 90R1116 | Tel: 510.486.6106 | Fax: 510.486.8694

LBNL Responses to Comments from *Calvin Willhite* of DTSC Human and Ecological Risk Division (HERD) dated September 10, 2004 to Waqar Ahmad of DTSC Standardized Permits and Corrective Action Branch.
Subject: Lawrence Berkeley National Laboratory, University of California, Berkeley, California; PCA: 22120 Site-WP: 200178-00 MPC: 39-PER (Review of the "Corrective Measures Study Report, July 2004, for the Lawrence Berkeley National Laboratory Environmental Restoration Program, Berkeley, California, EPA ID No. CA 4890008986)

Item	Page/Para	DTSC Comment	LBNL Response
General Comments		The report is well-organized and clearly presents nearly all options with estimated financial costs for each level of theoretical health risk. Each of the various options is presented with each risk level identified in the U.S. EPA acceptable risk range. While it is beyond the expertise of risk assessment to evaluate the accuracy of the range of cost estimates, it appears that the authors have identified correctly the applicable or relevant and appropriate requirements (ARARs) specified under the Solid Waste Disposal Act, the Toxic Substances Control Act, and the Clean Water Act. Identification of ARARs is important in establishing performance goals for remedial alternatives; ARARs are reiterated throughout the CMS and the ARARs proposed at LBNL have specific bearing on the Ground Water Project Tasks described in the CMS. It appears the LBNL authors have considered carefully all three ARAR types [ambient or chemical-specific ARARS that establish health- or risk-based specific chemical concentration limits in various LBNL environmental media; performance, design or action-specific ARARs that establish requirements on specific remedial activities related to management of hazardous materials released at LBNL; location-specific ARARs that establish administrative restrictions on and control of remedial activities based on the specific character of the LBNL). ARARs are so important to the CMS that, in fact, at LBNL the baseline public health risk assessment could have been satisfied by simply documenting the chemical-specific ARARs since all materials considered in the CMS have promulgated ARARs.	

Item	Page/Para	DTSC Comment	LBNL Response
General Comments (cont'd.)		At page xiii, it is not clear why a well-head treatment option of site groundwater prior to its use as either industrial process water and/or landscape irrigation was not included in the present analysis? Given the clear need to conserve EBMUD drinking water and the opportunity to reduce the long-term financial costs associated with site mitigation, an explanation for rejection of those options should be included at some point in the document.	The following paragraph will be added to Section 3.5.4, Subsection: Comply with Applicable Standards for Management of Waste.: On-site reuse options were evaluated for treated groundwater when treatment systems were initially installed. Effluent from two treatment systems was used as makeup for cooling tower water at Building 88 and Building 37. The Building 88 reuse was halted when it was determined that the water was potentially damaging to cooling tower operations (total dissolved solids concentrations were too high). Reuse at the Building 37 cooling tower has continued. Currently, and according to the proposed remedies, most of the treated groundwater will be recirculated as part of implemented corrective measures to flush contaminants from the subsurface. Reuse options for extracted groundwater will be reevaluated in the future, if the water is no longer needed for recirculation.

Item	Page/Para	DTSC Comment	LBNL Response
General Comments (cont'd.)		In general, risk analyses rely upon the upper 95% confidence limit on the arithmetic mean of the chemical concentration data for each material considering all site groundwater. The authors present the risk analyses and the proposed risk reductions based on well-by-well concentrations. While this approach takes into account possible "hot-spots" (see Risk Assessment Guidance for Superfund. Volume 1. Human Health Evaluation Manual (Part A; EPA/540/1-89/002 Section 4.3.2), this is not the customary approach to a site as a whole (U.S. EPA Pub. 92857-081, May 1992). Because the heterogeneous, fractured and complicated geology at LBNL provides physical limitations to handling site groundwater as a homogeneous "aquifer" data set, a brief explanation of the geologic and groundwater characteristics included either in Section 1.2 (Introduction) or as a brief clarification in the Executive Summary would facilitate the readers' understanding of the CMS approach used here.	The following paragraph will be added to Section 2.2.2, Hydrogeologic Characteristics and Groundwater Yield. The hydrogeological characteristics of the bedrock units and surficial materials, along with the physiography of the site, are the primary factors controlling groundwater flow and contaminant transport. There are several bedrock geologic units in the areas of LBNL where groundwater contamination is present including Orinda Formation sedimentary rocks that dip moderately toward the northeast. Overlying this unit in most areas of the site are colluvium, artificial fill, and/or isolated masses of Moraga formation volcanic rock that are interpreted to be paleolandslide (ancient landslide) deposits. Each of these geologic units consists of a distinct assemblage of soil and rock types with its own characteristic hydrogeologic properties. Due to the complex structural geometry of these units, the hydrogeology at LBNL is characterized by a number of discrete, relatively permeable zones, where groundwater flow is relatively rapid, separated and underlain by broad areas where underlying relatively impermeable rocks inhibit flow. As a result of this geometry, most of the contaminated groundwater plumes at LBNL are also discrete, and do not interact hydrologically.

Item	Page/Para	DTSC Comment	LBNL Response
General Comments (cont'd.)		At page 24 (line 11 from bottom), the document should do a much better job of explaining the site-specific features that lead one to the conclusions about "technical impracticability". This is a key concept presented in the CMS and must be clearly delineated – specifically, which area are amenable to remediation to MCLs and which areas are unlikely to meet the MCS goals – and – what features of those areas which are unlikely candidates for complete remediation to ARARs account for that failure? While Section 2 describes water yield and site geology, the authors should more directly explain the critical physical features which lead to the proposed ultimate "technical impractability". It is very important that the document be very clear on the specific factors that preclude certain area site groundwater remediation to MCLs.	As requested, additional text encompassing the following discussions will be added to Section 3.4 (Technical Impracticability) to more adequately explain the site-specific characteristics that lead to the cited conclusions regarding the technical impracticability of remediating areas to meet cleanup goals. Low permeability rock and soil containing dense non-aqueous-phase liquids (DNAPL) or very high levels of dissolved VOCs are present at several of the LBNL groundwater units. These features, compounded by geologic characteristics such as multiple layers, heterogeneities, and fractured rock which are present over most of the site, limit the effectiveness of remedial measures in attaining MCSs. The presence of low permeability rock and soil below the water table results in very low rates of advection (flow) of contaminated groundwater, so that contaminant migration mechanisms are in many cases dominated by diffusion. Diffusion of contaminants out of such contaminated materials is generally an extremely slow process, even where the process is enhanced by in situ remediation technologies, thus limiting the ability to achieve MCSs and impacting adjacent areas for many years. The length of time necessary to achieve MCSs in areas with these characteristics is generally difficult to estimate, both because diffusion rates are difficult to estimate in heterogeneous geologic media, and because cleanup rates are also dependent upon unknowns such as the mass of contaminant released and the length of time the contaminant has been present in the subsurface. For in situ remediation methods, the presence of low permeability materials and/or DNAPL can result in contaminant removal rates that tail off (reach asymptotic levels) at concentrations that may be significantly above MCSs.

Item	Page/Para	DTSC Comment	LBNL Response
General Comments (cont'd.)			The areas subject to corrective measures can be divided into the following three categories: 1) Areas where MCSs are unlikely to be attained. These areas are characterized by low permeability rocks and soil where DNAPL and/or very high levels of dissolved VOCs are present and excavation is not feasible, such as areas at or adjacent to the source zone of the Building 7 lobe of the Old Town Groundwater Solvent Plume. 2) Areas where attaining MCSs is likely. These areas fall into two subcategories: a) areas such as the Building 52 lobe of the Old Town Groundwater Solvent Plume characterized by relatively high permeability rock and soil where plume constituents consist of low to moderate concentrations of dissolved phase VOCs which migrate primarily due to advection; and b) areas where permeabilities are relatively low, but where DNAPLs are not present, and where dissolved phase constituent concentrations do not significantly exceed MCSs and are amenable to reductions due to natural attenuation mechanisms (e.g., the Building 69A Area of Groundwater Contamination). 3) Areas where the ability to attain MCSs is uncertain. These areas are generally characterized by low permeability rocks, absence of DNAPL, and moderate to high groundwater contaminant concentrations. These areas have characteristics generally intermediate between categories 1 and 2. A large fraction of the Building 7 lobe of the Old Town Groundwater Solvent Plume falls into this category, since the achievable long term rates of diffusion and advection of contaminants have not yet been ascertained. Assessment of the achievability of MCSs cannot be completed until sufficient time has elapsed to allow measurement of contaminant reduction rates resulting from the implemented corrective measures.

Item	Page/Para	DTSC Comment	LBNL Response
General Comments (cont'd.)			The specific areas that "are amenable to remediation to MCLs and which areas are unlikely to meet the CMS goals will not be delineated, however, since an estimate of those areas is premature at this time and the Category 3 areas (where attaining MCSs may or may not be possible) would likely be the major site subdivision. In addition, text will be added to Section 3.4 providing an estimate of the area of LBNL where concentrations of contaminants in the underlying groundwater exceed MCLs. This area is estimated to be approximately 4% of the entire LBNL site.
Specific Comments			
1	**Page xv-xvii**	Please identify the common names of the chemicals of concern (e.g., PCBs and/or specific VOCs) for each soil and groundwater unit listed in the table. At the soil units AOC 6-3 and SWMU 3-6, please either delete or modify the entry "No action" with a footnote the explanation of the CMS document section describing the completed interim measures or revise the entry to state "No further action". As written, the text is confusing and suggests that nothing was proposed, planned or has been completed.	*Agree.* A column will be added to the table listing the chemicals of concern at each soil and groundwater unit. The entry "No Action" will be modified to "No further action" for AOC 6-3 and SWMU 3-6. The following note will be added for AOC 6-3 and SWMU 3-6 in the table column Recommended Corrective Measure Alternative for Cleanup "See text paragraph preceding this table for a description of the ICM."

2	**Page xvi**	At the column "Recommended Corrective Measure Alternative for Cleanup", the status of the various alternatives for AOC 1-9 and AOC 2-4 is confusing. The status of the various alternatives is not readily apparent and it is not clear which of the various alternatives are actually recommended?	*Agree*. At the column "Recommended Corrective Measure Alternative for Cleanup", the status of the various alternatives for AOC 1-9 and AOC 2-4 will be revised as follows: *AOC 1-9* The following combination of corrective measures alternatives is recommended for the plume source area: 1) excavation and offsite disposal of accessible shallow unsaturated zone soil, 2) limited in situ chemical oxidation of unsaturated zone soils adjacent to the building foundation, and 3) in situ soil flushing. For contaminated groundwater adjacent to the plume source area, enhanced bioremediation using Hydrogen Release Compounds (HRC) is the recommended measure. In addition, surface water (hydrauger effluent) capture and treatment will continue until groundwater discharge to surface water is shown to be below detectable levels. *AOC 2-4* The following combination of corrective measures alternatives is recommended for the different areas of the plume. 1) soil excavation (as described under AOC 2-5) for the plume source area, 2) continued in situ soil flushing combined with groundwater capture for the plume core area, 3) Monitored Natural Attenuation (MNA) in the downgradient area, and 4) continued groundwater capture and treatment within and at the downgradient edge of plume until downgradient migration of COCs within the plume does not result in exceedences of applicable MCSs and migration of detectable levels of COCs beyond the plume boundary would not occur in the absence of controls.

<table>
<tr>
<td>3</td>
<td>Page xvii</td>
<td>At the column "Recommended Corrective Measure Alternative for Cleanup", the entry can be clarified by deletion of the phrase "is not a potential drinking water source" and replacement with "and groundwater characteristics do not meet SWRCB Resolution 88-63 provisions".</td>
<td><i>Agree.</i> "is not a potential drinking water source" will be deleted and replaced with the following text "and groundwater characteristics do not meet criteria of SWRCB Resolution 88-63 – Sources of Drinking Water Policy."</td>
</tr>
<tr>
<td>4</td>
<td>Page 8,
Section 1.3.3</td>
<td>Please list the areas of concern and/or solid waste management units that have been the subjects of interim soil removals. As written, it appears that the all of the materials of concern may remain on-site where this in fact is not necessarily the case.</td>
<td><i>Agree.</i> Text will be revised as follows "The ICMs primarily included excavation and offsite disposal of contaminated soil…" The following table will also be added to Section 1.3.3:

Table 1.3.3-1. Locations of Soil Excavation ICMs Implemented at LBNL
<table>
<tr><th>Unit Number</th><th>Unit Name</th></tr>
<tr><td colspan="2"><i>Units Included in CMS Report</i></td></tr>
<tr><td>SWMU 3-6</td><td>Building 75 Former Hazardous Waste Handling and Storage Facility</td></tr>
<tr><td>AOC 1-9</td><td>Building 71 Groundwater Solvent Plume: B71B Lobe</td></tr>
<tr><td>AOC 2-5</td><td>Building 7 Sump</td></tr>
<tr><td>AOC 6-3</td><td>Building 88 Hydraulic Gate Unit</td></tr>
<tr><td>AOC 10-5</td><td>Building 52A Groundwater Plume Source Area</td></tr>
<tr><td colspan="2"><i>Units Not Included in CMS Report</i></td></tr>
<tr><td>AOC 1-10</td><td>Building 71 Room 003 Mercury Release</td></tr>
<tr><td>AOC 5-5</td><td>Building 77 Diesel Generator Pad</td></tr>
<tr><td>AOC 9-2</td><td>Building 51 Former Diesel UST</td></tr>
<tr><td>AOC 9-9</td><td>Building 51 Sanitary Sewer and Drainage System</td></tr>
<tr><td>AOC 9-10</td><td>Building 51/64 Catch Basin</td></tr>
<tr><td>AOC 9-13</td><td>Building 51/64 Groundwater Solvent Plume</td></tr>
<tr><td>AOC 11-1</td><td>Building 74 Former Diesel UST</td></tr>
<tr><td>AOC 14-1</td><td>Building 2 Diesel UST</td></tr>
<tr><td>AOC 14-7</td><td>Building 37 Electrical Substation</td></tr>
<tr><td>SWMU 2-1</td><td>Former Building 7 Plating Shop</td></tr>
<tr><td>SWMU 2-2</td><td>Former Building 52B Abandoned Above-Ground Liquid Waste Storage Tank</td></tr>
<tr><td>SWMU 2-3</td><td>Former Building 17 Scrap Yard and Drum Storage Area</td></tr>
<tr><td>SWMU 9-4</td><td>Building 51 Vacuum Pump Room Sump and Collection Basins</td></tr>
<tr><td>SWMU 9-6</td><td>Building 51 Motor Generator Room Sump</td></tr>
<tr><td>SWMU 10-10</td><td>Building 25 Plating Shop Floordrains</td></tr>
<tr><td>not a unit</td><td>Building 51 Basement Oil Pumps</td></tr>
</table>
</td>
</tr>
</table>

5	**Page 10**	It is worthwhile to point out that any hypothetical off-site exposure would be far less than that accounted for by the hypothetical on-site future residential exposure scenario. Therefore, the on-site risk assessments included in the HHRA account for off-site residential exposure scenarios.	*Agree with comment.* No revision to the text is proposed.
6	**Page 10**	Please clarify what is meant by the term "relatively stable"?	*Agree.* The phrase "relatively stable will be revised to "stable' and the following clarification will be added "The stability of the plumes is indicated by measured groundwater concentrations that are generally static or decreasing at monitoring points located throughout the plume areas and by the absence of detectable concentrations of contaminants in wells monitoring the areas downgradient from the plumes."
7	**Page 14; Tables 1.3.4-2 and 1.3.4-3**	Please identify the primary chemical(s) encountered at each entry and please footnote the current status of that AOC or SWMU. Where the area or unit was retained in the CMS based on excess health risk, indicate the primary chemical that accounts for that risk.	*Agree.* A column will be added to the tables listing the risk-based Chemicals of Concern. The primary chemicals that account for the risk will be shown in boldface type. Note that different chemicals may be the primary contributors to risk in different areas of the plumes (e.g. PCE in the source area and vinyl chloride in downgradient areas) or different chemicals may have similar risks. Therefore, more than one chemical may be shown as the primary contributor to risk at a unit. Text will be added to the footnote for AOC 6-3 and SWMU 3-6 to indicate that no further action is proposed for these two units and that a removal action has been completed.
8	**Page 16**	Please explain the ultimate fate of the treated water that has been collected for the past 12 years as "hydrauger effluent". Since this water is treated, to what total water volume over this dozen years does this correspond and have those treated waters been used for any beneficial purpose (e.g., LBNL industrial process or landscape irrigation)?	See response to general comments. The treated hydrauger effluent has been discharged to the sanitary sewer under conditions of Berkeley Lab's Wastewater Discharge Permit issued by the East Bay Municipal Utility District (EBMUD). Approximately 4.8 million gallons have been treated by this system.
9	**Page 23, line 11 from bottom**	As written, the conclusion is speculation. Either replace the word "would" with "could" or replace the phrase with "there could be a possible adverse impact on private property values in neighborhoods adjacent to the Berkeley lab." There is no direct evidence for the statement as written.	*Agree.*

10	**Page 191, Section-5.0**	Interim remedial measures for soil PCBs have already been completed at Area of Concern (AOC) 6 Building 88 and Solid Waste Management Unit (SWMU 3-6) Building 75 (Attachment 1). It is important that the reader recognize that the interim remedial measures for the laboratory were achieved and verification sampling found compliance with, the soil polychlorinated biphenyl ARARs for all congeners consistent with unrestricted future site land use (e.g., Toxic Substances Control Act 40 CFR 761; Federal Register 50: 62788 and OSWER Directive No. 93555.4-01 FS, August 1990). It may be worthwhile to expand the presentation of this fact in the Executive Summary.	*Agree.* The following paragraph from the Executive Summary has been modified as indicated to address the comment. "The HHRA identified PCBs as the COC at two units, the Building 88 Hydraulic Gate Unit and the Building 75 Former Hazardous Waste Handling and Storage Facility. Subsequent to completion of the HHRA, Berkeley Lab conducted Interim Corrective Measures (ICMs) (soil excavation and offsite disposal) that resulted in reduction of residual PCB concentrations to less than the proposed MCS for PCBs of 1 mg/kg at both units. The MCS was set at the Toxic Substances Control Act (TSCA) (40 Code of Federal Regulations [CFR] Parts 750 and 761) self-implementing cleanup level of 1 mg/kg, for soil in high occupancy areas, which is both a risk-based and regulatory-based level. Verification sampling found compliance with this level, which is consistent with unrestricted future land use. No additional corrective action is therefore recommended for either of these units."

Item	Page/Para	DTSC Comment	LBNL Response
Conclusion		The CMS represents a clear presentation of options available to regulatory risk managers. The authors and the facility should be given public credit for their achievements in removal of soil PCBs to less than ARARs intended for unrestricted future land use especially at Building 88. This is remarkable in light of the fact that the facility was able to accomplish removal actions in spite of the high voltage electrical and critical utility lines with concrete supports at this AOC (Figure 1). These utility lines are located in soils where PCBs were found and are located near the Berkeley cyclotron; clearly the immediate danger to workers engaged in soil excavations could have been brought forward as obstacles that could impede these remedial measures. The facility has made remarkable progress in site PCB risk reduction and this fact should be recognized by regulatory agencies. The CMS appendices should include an update on the carcinogenic potency of trichloroethylene (TCE), a material which accounts in large measure for the risk estimates Presented for the various areas of concern and solid waste management units. Given the marked discrepancy between recent advancements in the science (Attachments 2-4) and the 20 year old risk assessments which formed the historical basis of the promulgated ARARs for TCE, to neglect considerations of these published advancements in TCE risk assessment would be to present an incomplete picture of the hazards (if any) associated with the TCE found in soil and groundwater at LBNL.	*Agree.* As shown in the revised Table 1.3.4-2, TCE does not "account in large measure for the risk estimates", as indicated in the DTSC comment. However, the text will be modified as described below to discuss recent advancements in the science concerning the toxicity of TCE. The following text will be added at the end of Section 3.2.1: Although no revisions have been made to cancer risk factors for TCE, recent research on TCE carcinogenicity strongly suggests that the cancer risk factors used to estimate the risk-based MCSs for TCE are overly conservative by approximately a factor of 10. A discussion of this research is given in Appendix A. The following text will be added to Appendix A: The TCE carcinogenic toxicity factor recommended by CalEPA (www.oehha.ca.gov/risk/ChemicalDB/index.asp) was used in the Human Health Risk Assessment (LBNL, 2003a) and was also used to develop proposed Media Cleanup Standards (MCSs) in the CMS Report. However, recent peer-reviewed articles by experts in the toxicity of TCE (Clewell and Andersen, 2004; Kester and Clewell, 2004) suggest that the carcinogenic potency of TCE may not be as great as suggested by either CalEPA, or USEPA [2002] which proposed a cancer potency value approximately 60-times more conservative than the CalEPA value in their TCE Health Risk Assessment. As discussed in Clewell and Andersen (2004), "a physiologically based pharmacokinetic (PBPK) model was applied to estimate target tissue doses for the three principal animal tumors associated with TCE exposure: liver, lung, and kidney" by USEPA (2002) in deriving cancer potency values. Clewell and Anderson (2004) state, "However, these risk estimates ignore the evidence that the human is likely to be

Item	Page/Para	DTSC Comment	LBNL Response
Conclusion (cont'd.)			much less responsive than the mouse to the carcinogenic effects of TCA [trichloroacetic acid] in the liver and that the carcinogenic effects of TCE are unlikely to occur at low environmental exposures ... environmental exposures below 66 µg TCE per cubic meter in air and 265 µg TCE per liter in drinking water are considered unlikely to present a carcinogenic hazard to human health." For comparison, the 10-6 theoretical ILCR used to develop the MCSs corresponds to a concentration of 6.1 µg TCE per cubic meter in air, and the Maximum Contaminant Level (MCL) for drinking water for TCE is 5 µg/L. Kester and Clewell (2004) provide a detailed discussion of the scientific deficiencies of the USEPA (2002) draft TCE health risk assessment and state that, "As a result, its major conclusions regarding the potential health risks associated with TCE exposure are scientifically indefensible." Therefore, based on this recent scientific evidence the risks associated with potential exposure to TCE detected in soil or groundwater and the potential risks from migration of TCE into indoor air would be significantly less than estimated in the Human Health Risk Assessment (LBNL, 2003a) and the MCS proposed for TCE in the CMS Report would be overly conservative by a factor of 10 or more. Clewell, H.J. and M.E. Andersen. 2004. Applying mode-of-action and pharmacokinetic considerations in contemporary cancer risk assessments: An example with trichloroethylene. Crit. Rev. Toxicol. 34(5): 385-445. Kester, J.E. and H.J. Clewell. 2004. The perils and promise of modern risk assessment: the example of trichloroethylene. Clin. Occup. Environ. Med. 4: 497-512. USEPA, 2002. USEPA Science Advisory Board, Trichloroethylene Health Risk Assessment Synthesis and Characterization, An EPA Science Advisory Board Report, EPA-SAB-EHC-03-002, Washington, DC.

RWQCB Comments

September 13, 2004

California Regional Water Quality Control Board
San Francisco Bay Region

ry Tamminen
ec for
vironmental
Protection

1515 Clay Street, Suite 1400, Oakland, California 94612
(510) 622-2300 • Fax (510) 622-2460
http://www.swrcb.ca.gov/rwqcb2

Arnold Schwarzenegger
Governor

Date: September 13, 2004
File No. 2199.9026 (MBR)

Department of Toxic Substances Control
Attn: Salvatore Ciriello
700 Heinz Avenue, Suite 200
Berkeley, California 94612

SUBJECT: Draft RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory, dated July 2004. Berkeley, Alameda County

Dear Mr. Ciriello;

The San Francisco Bay, Regional Water Quality Control Board (Water Board) staff has reviewed the above referenced document and has prepared the attached comments.

Please contact me at (510) 622-2411 if you have any questions or comments.

Sincerely,

Michael B. Rochette

Michael Bessette Rochette
Groundwater Protection Division

Attachment: Water Board Comments

Preserving, enhancing, and restoring the San Francisco Bay Area's waters for over 50 years

General Comments:

1) The Department of Energy (DOE) has proposed regulatory-based media cleanup standards based on corrective action objectives including the protection of the potential drinking water supply beneficial use for groundwater. However, based on Resolution 88-63, this corrective action objective protecting groundwater as a potential drinking water supply is only proposed for specific areas of Berkeley Lab where well yields exceed 200 gallons per day. From a review of Figures 2.2-1 and 2.2-2 depicting estimated well yields from the upper and lower geologic units and the statement on page 20, " Therefore, areas where groundwater is present solely in the Great Valley Group, the Orinda Formation or the Mixed Unit are considered to not represent potential sources of drinking water", it appears that proposed areas where the corrective action objectives include the drinking water supply are very limited.

   Water Board staff request DOE provide a site-wide geological map, with cross sections, specifically delineating the areas where the corrective action objective of protecting groundwater as a potential drinking water supply is and is not proposed. Also include all contaminated soil areas and all contaminated groundwater plumes.

   Furthermore, DOE has identified hydrogeologic units that have well yields less than 200 gallons per day and has proposed that the potential drinking water beneficial use in these units is not applicable. This non-drinking water evaluation is also proposed for areas where a higher yielding upper hydrogeologic unit is underlain by a lower yielding hydrogeologic unit of less than 200 gallons per day. Using this upper/lower assessment is problematic since the most significant amounts of contamination are in the upper unit with higher yield and basing cleanup standards on characteristics of the relatively less contaminated lower unit is inappropriate.

2) In general, Water Board staff is in agreement with the recommended corrective measure alternatives for the groundwater units where the drinking water beneficial use is a corrective action objective; however, Water Board staff recommends the CMS be revised to incorporate the development of a subsequent Groundwater Monitoring and Management Plan. This document should include, at a minimum, identification of the vertical and lateral extent of current VOC contamination plume, a proposal for perimeter groundwater monitoring wells to assure that migration beyond current plume margins does not occur, a proposal for specific surface water monitoring, and a proposal of Berkeley Lab future management controls to prevent any potential risks exposures associated with contaminated groundwater.

3) DOE has based the development of risk-based media cleanup standards for Lawrence Berkeley National Laboratory (Berkeley Lab), in part, on institutional land use controls. However, the institutional land use is not defined, nor are the permitted or un-permitted activities defined. The text should be revised to address this deficiency.

ecific Comments:

1) **Page xi:** What type of land use is the land cost of $100/square foot based on?

2) **Page 20, Second paragraph:** The statement " Therefore, areas where groundwater is present solely in the Great Valley Group, Orinda Formation or Mixed Unit are considered to not represent potential sources of drinking water" is too broad and is not consistent with State policy defining drinking water sources.

3) **Page 30, Section 3.3, first paragraph:** Groundwater monitoring wells proposed as superfluous for monitoring compliance and approved by the Water Board shall be "properly destroyed." This issue should be addressed in the recommended Groundwater Monitoring and Management Plan.

4) **Page 31, Section 3.4, third paragraph:** Revise text, here and in all other references, stating that a determination of technical impracticability of groundwater cleanup requires Water Board approval.

5) **Figures:** In addition to the figure requested in General Comment 2, Water Board staff requests an additional Site-wide Map showing all soil and groundwater areas of concern evaluated in the CMS including the various Module boundaries.

LBNL Responses to RWQCB Comments

October 18, 2004

LBNL Responses to Comments from *Michael Bessette Rochette* of RWQCB San Francisco Bay Region Groundwater Protection Division)
dated September 13, 2004 to Salvatore Ciriello of Department of Toxic Substances Control
Subject: Draft RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory, dated July 2004. Berkeley, Alameda County.
File No. 2199.9026 (MBR)

Item	Page/Para	RWQCB Comment	LBNL Response
General Comments		1) The Department of Energy (DOE) has proposed regulatory-based media cleanup standards based on corrective action objectives including the protection of the potential drinking water supply beneficial use for groundwater. However, based on Resolution 88-63, this corrective action objective protecting groundwater as a potential drinking water supply is only proposed for specific areas of Berkeley Lab where well yields exceed 200 gallons per day. From a review of Figures 2.2-1 and 2.2-2 depicting estimated well yields from the upper and lower geologic units and the statement on page 20, "Therefore, areas where groundwater is present solely in the Great Valley Group, the Orinda Formation or the Mixed Unit are considered to not represent potential sources of drinking water", it appears that proposed areas where the corrective action objectives include the drinking water supply are very limited.	
		Water Board staff request DOE provide a site-wide geological map, with cross sections, specifically delineating the areas where the corrective action objective of protecting groundwater as a potential drinking water supply is and is not proposed. Also include all contaminated soil areas and all contaminated groundwater plumes.	*Agree.* Berkeley Lab will provide a site-wide geologic map and cross sections showing areas where groundwater is/is not proposed for protection as a potential drinking water supply, and showing areas where soil and groundwater COCs exceed MCSs.
		Furthermore, DOE has identified hydrogeologic units that have well yields less than 200 gallons per day and has proposed that the potential drinking water beneficial use in these units is not applicable. This non-drinking water evaluation is also proposed for areas where a higher yielding upper hydrogeologic unit is underlain by a lower yielding hydrogeologic unit of less than 200 gallons per day. Using this upper/lower assessment is problematic since the most significant amounts of contamination are in the upper unit with higher yield and basing cleanup standards on characteristics of the relatively less contaminated lower unit is inappropriate.	*Disagree.* The *Draft* CMS Report does not propose a non-drinking water evaluation for areas where a contaminated higher yielding upper hydrogeologic unit is underlain by a contaminated lower yielding hydrogeologic unit of less than 200 gallons per day. In addition, the CMS Report does not base cleanup standards on characteristics of the relatively less-contaminated lower unit in locations where contaminants are primarily present in upper units.

Item	Page/Para	RWQCB Comment	LBNL Response
General Comments (cont'd.)		2) In general, Water Board staff is in agreement with the recommended corrective measure alternatives for the groundwater units where the drinking water beneficial use is a corrective action objective; however, Water Board staff recommends the CMS be revised to incorporate the development of a subsequent Groundwater Monitoring and Management Plan. This document should include, at a minimum, identification of the vertical and lateral extent of current VOC contamination plume, a proposal for perimeter groundwater monitoring wells to assure that migration beyond current plume margins does not occur, a proposal for specific surface water monitoring, and a proposal of Berkeley Lab future management controls to prevent any potential risks exposures associated with contaminated groundwater.	Text will be added to the CMS Report stating that a Groundwater Monitoring and Management Plan will be prepared as part of the Corrective Measures Implementation phase of the Corrective Action Process (CAP). The text will state that specific plan elements will include: a description of the vertical and lateral extent of current VOC contamination plumes, a listing of specific perimeter groundwater monitoring wells that will be used to monitor potential migration beyond current plume margins, a description of specific surface water monitoring requirements, and a description of Berkeley Lab management controls that will be used to reduce potential risks from exposures associated with contaminated groundwater.

Item	Page/Para	RWQCB Comment	LBNL Response
General Comments (cont'd.)		3) DOE has based the development of risk-based media cleanup standards for Lawrence Berkeley National Laboratory (Berkeley Lab), in part, on institutional land use controls. However, the institutional land use is not defined, nor are the permitted or un-permitted activities defined. The text should be revised to address this deficiency.	A section will be added to the text defining institutional land use following the definition presented in Section 3 of the Berkeley Lab Human Health Risk Assessment (HHRA), which encompasses continued use of Berkeley Lab as a research laboratory. The exposure assumptions used to develop the risks estimated in the HHRA are based on this definition. A separate discussion will indicate the applicability of land use restrictions to specific areas of Berkeley Lab. This discussion will indicate the following: a. In all areas where groundwater COC concentrations are less than regulatory-based groundwater MCSs (MCLs), no land use restrictions associated with the CAP will be applicable. b. In all areas where groundwater COC concentrations exceed regulatory-based groundwater MCSs (MCLs), land use restrictions would be implemented as follows: • Extraction of groundwater for domestic, industrial, or agricultural use would be prohibited unless it is treated to the required standards. • Development of residential facilities would be prohibited unless subsequent site-specific studies documenting that risks to residential receptors were below levels of concern were submitted to, and approved by, the DTSC. • Institutional land use would be permitted without restriction, except for areas where groundwater or soil COC concentrations exceed the upper-limit risk-based MCSs (i.e., theoretical ILCR>10^{-4}, HI>1). For areas exceeding the upper-limit risk-based MCSs (i.e., theoretical ILCR>10^{-4}, HI>1), development of institutional facilities would be prohibited unless a mitigation and monitoring plan was developed to ensure that COC exposures contributing to risks were below levels of concern. Mitigation and monitoring plans would be submitted to DTSC for review and approval.

LBNL Responses to Comments from *Michael Bessette Rochette* of RWQCB San Francisco Bay Region Groundwater Protection Division) dated September 13, 2004 to Salvatore Ciriello of Department of Toxic Substances Control
Subject: Draft RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory, dated July 2004. Berkeley, Alameda County.
File No. 2199.9026 (MBR) *(continued)*

Specific Comments

Item	Page/Para	RWQCB Comment	LBNL Response
1	**Page xi**	What type of land-use is the land cost of $100/square foot based on?	The statement pertaining to a land cost of $100/square foot will be deleted.
2	**Page 20, Second paragraph**	The statement "Therefore, areas where groundwater is present solely in the Great Valley Group, Orinda Formation or Mixed Unit are considered to not represent potential sources of drinking water" is too broad and is not consistent with State policy defining drinking water sources.	The sentence will be deleted.
3	**Page 30, Section 3.3, First paragraph**	Groundwater monitoring wells proposed as superfluous for monitoring compliance and approved by the Water Board shall be “properly destroyed." This issue should be addressed in the recommended Groundwater Monitoring and Management Plan.	The following sentence will be added to the text: “Groundwater monitoring wells that are considered superfluous will be identified as such in the Groundwater Monitoring and Management Plan or in other documentation submitted to the Water Board, and will be properly destroyed after receiving Water Board approval”.
4	**Page 31, Section 3.4, Third paragraph**	Revise text here and in all other references, stating that a determination of technical impracticability of groundwater cleanup requires Water Board approval.	It is understood that the Water Board provides review and comment to DTSC regarding approval of specific actions pertaining to groundwater. However, it is Berkeley Lab’s understanding that DTSC retains approval authority for such actions, including Determinations of Technical Impracticability. Based on this understanding, the following sentence will be added to the text: “A Determination of Technical Impracticability requires approval of the DTSC”.
5	**Figures**	In addition to the figure requested in General Comment 2, Water Board staff requests an additional Site-wide Map showing all soil and groundwater areas of concern evaluated in the CMS including the various Module boundaries.	A figure showing the features requested in the comment will be added to the report.

COB Comments

October 5, 2004

David O.

Department of Toxic Substances Control

700 Heinz Avenue, Suite 200
Berkeley, California 94710-2721

Terry Tamminen
Agency Secretary
Cal/EPA

Arnold
Schwarzenegger
Governor

October 19, 2004

Iraj Javandel
Environmental Restoration Program
Lawrence Berkeley National Laboratory
Mail Stop: 90-1116
1 Cyclotron Road, Building 90
Berkeley, California 94720

COMMENTS ON CORRECTIVE MEASURES STUDY, LAWRENCE BERKELEY NATIONAL LABORATORY, BERKELEY, CALIFORNIA EPA ID No. CA 4890008986

Dear Mr. Javandel:

The Department of Toxic Substances Control (DTSC) received comments from the City of Berkeley on the draft Corrective Measures Study dated July 2004. Attached is a copy of the City of Berkeley letter to DTSC dated October 5, 2004. The general comments listed in this letter were discussed at the October 14, 2004 meeting with regulatory agencies.

Please address these comments in your revised Corrective Measures Study Report. Please clarify in the revised CMS Report the program that will be utilized by LBNL regarding excavation and other possible future work activities in areas that will be included in a land use covenant for institutional land use.

If you have any questions, please call Waqar Ahmad of my staff at (510) 540-3932.

Sincerely,

Salvatore Ciriello

Salvatore Ciriello, P.E.
Supervising Hazardous Substances Engineer I
Standardized Permitting and Corrective Action Branch

cc: Nabil Al-Hadithy
Toxics Management Division
Planning and Development Department
City of Berkeley
2118 Milvia Street
Berkeley, CA 94704

Michael Rochette
San Francisco Bay Regional Water Quality Control Board
1515 Clay Street
Oakland, CA 94612

Buck King
Geologic Support Services and Corrective Action Branch
700 Heinz Avenue
Berkeley, CA 94710

Planning and Development Department
Toxics Management Division

October 5, 2004

Department of Toxic Substances Control
Attn: Sal Ciriello
700 Heinz Avenue, Suite 200
Berkeley, California 94710

Regarding: Comments on Lawrence Berkeley Laboratory, Corrective Measures Study

Dear Mr. Ciriello:

The Toxics Management Division (TMD) has reviewed the Draft Corrective Measures Study (CMS) dated July 2004. The TMD is generally satisfied with the site restoration progress in identifying the chemical contamination concerns in soil and groundwater and is also satisfied with the variously proposed corrective measures. The general thrust to clean up to drinking water standards is acknowledged and we comment on ways to strengthen this goal.

The primary concern for the TMD has been to identify appropriate cleanup goals that would allow for the highest uses of the site and not limit it to "institutional" uses. The TMD understands that some areas of the site will not be cleaned up to the highest, most protective standard, primarily because of the limitations of technically feasible, and cost effective ways to bring these areas to the most protective cleanup standard. We would refer you to the Regional Water Quality Control Board (RWQCB), which has provided good guidance on how to meet the maximum contaminant levels (MCLs) as a "long term" objective. In the absence of MCLs, written controls and procedures should be submitted for review and approval to local agencies and the RWQCB prior to adoption.

The TMD is concerned with creating a patchwork of areas on the LBL campus that meet the state criteria for beneficial uses. These would be hard to map and regulate. The TMD would also like to see human health risk analyses determined more pathways of exposure. We would like to see bathing, washing, irrigation considered as exposure pathways. As with the RWQCB, we are prepared to consider that drinking is an unlikely pathway for exposure and that the MCL goals can be met in the not too distant future.

2118 Milvia Street, Suite 200, Berkeley, California 94704 • TEL (510) 981-7460 • FAX: (510) 981-7470 • TDD: (510) 981-7474

In contrast, the CMS report presents the non-degradation policy and MCL as "goals" or "objectives" rather than a long term "requirement".

In presenting this report with limited risks due to limiting the pathways for exposure, we present the federal government with the excuses to stop payment for additional clean up to the highest standards possible.

The TMD has no specific comments on specific areas of concern in CMS report. Below I have reiterated the general comments for your convenience. These comments have been made on previous occasions by staff, the Community Environmental Advisory Commission and the City Council.

1. Historically, regulatory agencies have had difficulty maintaining controls for sites closed with contamination left in-place. Institutional controls are proposed for LBNL when the ILCR is greater than 10^{-6} calculated for pathways that include bathing, irrigation etc, or when the HI is greater than 1. The TMD would like to review the proposed policies and procedures and details of the specific controls that will be implemented.

2. There are some controls that the TMD would consider problematic. Examples are declaring groundwater of no potential beneficial use as a drinking water source due solely to contamination and land-use restrictions for the property.

Should you have any additional queries, please do not hesitate to contact Geoffrey Fiedler or myself.

Sincerely,

HADITHY

Nabil A Al-Hadithy, PhD
Toxics Management Division

Cc: Geoffrey Fiedler, TMD
Wendy Cosin, Deputy Director of Planning and Development
Michael Rochette, RWQCB,1515 Clay Street, Suite 1400,Oakland, CA 94612

LBNL Responses to COB Comments

November 15, 2004

BERKELEY LAB
Environment, Health and Safety Division
Environmental Restoration Program

Mr. Sal Ciriello
Facility Permitting Branch
Cal EPA-DTSC
700 Heinz Avenue, Suite 200
Berkeley, CA 94710-2737

November 15, 2004
ERP-3035

Subject: Responses to October 19, 2004 DTSC Letter Containing City of Berkeley Comments on the Corrective Measures Study, Lawrence Berkeley National Laboratory, Berkeley, California EPA ID No: CA4890008986

Dear Mr. Ciriello:

Enclosed are the Ernest Orlando Lawrence Berkeley National Laboratory (Berkeley Lab) responses to comments from the City of Berkeley on the *Draft* Corrective Measures Study (CMS) Report dated October 5, 2004. At this time, Berkeley Lab does not anticipate revising the report based on the City of Berkeley comments, except where the comments are similar to those previously provided by Regional Water Quality Control Board (RWQCB). In those cases, Berkeley Lab will revise the text as indicated in our October 18, 2004 responses to comments on the *Draft* CMS Report.

Berkeley Lab is providing the following response to the request included in your October 19, 2004 letter: *"Please clarify in the revised CMS Report the program that will be utilized by LBNL regarding excavation and other possible future work activities in areas that will be included in a land use covenant for institutional land use."* As indicated in Berkeley Lab's responses to RWQCB comments on the *Draft* CMS Report, Berkeley Lab will be preparing a Groundwater Monitoring and Management Plan. The Plan will include a description of Berkeley Lab management controls that will be used to reduce potential risks from exposures associated with contaminated groundwater. To address the DTSC concern, the following sentences will be added to the revised *Draft* CMS report:
Berkeley Lab will also prepare a Soil Management Plan. The Plan will include a description of Berkeley Lab management controls that will be used to reduce potential risks from exposures associated with contaminated soil.

Please contact me at (510) 486-6106 if you have any questions.

Sincerely,

Iraj Javandel

Iraj Javandel
Environmental Restoration Program

Encls.

Ernest Orlando Lawrence Berkeley National Laboratory
One Cyclotron Road | Berkeley, California 94720-8126 | Mail Stop 90R1116 | Tel: 510.486.6106 | Fax: 510.486.8694

LBNL Responses to Comments from *Nabil Al-Hadithy* of City of Berkeley (COB) Toxics Management Division dated October 5, 2004 to Sal Ciriello of DTSC Standardized Permits and Corrective Action Branch.
Subject: Comments on Lawrence Berkeley Laboratory Corrective Measures Study

Item	Page/Para	COB Comment	LBNL Response
First Comment		The primary concern for the TMD has been to identify appropriate cleanup goals that would allow for the highest uses of the site and not limit it to "institutional" uses.	The past, current, and foreseeable future land use at Lawrence Berkeley National Laboratory (Berkeley Lab) has been, and will continue to be, institutional (commercial/industrial type land use). The institutional land use scenario was therefore provided as the likely and realistic present and future land use scenario in the Berkeley Lab Human Health Risk Assessment. It was also the basis for proposing Media Cleanup Standards (MCSs) in the *Draft* Corrective Measures Study (CMS) Report. Cleanup of the areas described in the *Draft* CMS report based on an institutional land use scenario does not restrict the entire Berkeley Lab site to institutional use. Only approximately 5% of the site or less would be subject to any restricted use requirements while cleanup activities were proceeding. In addition, institutional-land-use-based cleanup standards do not preclude other types of land use in the future under certain regulatory agency approved conditions. These might include, for example, project area-specific studies documenting that risks were below levels of concern for the specific use intended, additional cleanup, and/or appropriate mitigation measures.
Second Comment		The TMD understands that some areas of the site will not be cleaned up to the highest, most protective standard, primarily because of the limitations of technically feasible, and cost effective ways to bring these areas to the most protective cleanup standard. We would refer you to the Regional Water Quality Control Board (RWQCB), which has provided good guidance on how to meet the maximum contaminant levels (MCLs) as a "long term" objective. In the absence of MCLs, written controls and procedures should be submitted for review and approval to local agencies and the RWQCB prior to adoption.	As indicated in Berkeley Lab's responses to RWQCB's comments on the *Draft* CMS Report dated October 18, 2004, Berkeley Lab will prepare a Groundwater Monitoring and Management Plan as part of the Corrective Measures Implementation (CMI) phase of the Corrective Action Process (CAP). Specific plan elements will include a description of the Berkeley Lab management controls that will be used to reduce potential risks from exposures associated with contaminated groundwater. The plan will be submitted to the regulatory agencies for review and approval.

Item	Page/Para	COB Comment	LBNL Response
Third Comment		The TMD is concerned with creating a patchwork of areas on the LBL campus that meet the state criteria for beneficial uses. These would be hard to map and regulate.	As a response to a comment from RWQCB on the *Draft* CMS Report, Berkeley Lab will revise the report to include site-wide maps and cross sections showing areas where groundwater is or is not proposed for protection as a potential drinking water supply. As discussed in the October 14, 2004 Remedial Project Managers (RPM) meeting, affected portions of land parcels subject to restricted use would be regulated through a Land Use Covenant (LUC) between the University of California (UC) and the California Environmental Protection Agency Department of Toxic Substances Control (DTSC), in accordance with California Code of Regulations (CCR), Title 22, Division 4.5, Section 67391.1. The LUC would not be a site-wide control, but would be placed only on those sections of individual parcels, which are subject to land use restrictions. The location/extent of the restricted areas would be documented by survey and included in the LUC, which would be reviewed by DTSC annually. In addition, conditions of the LUC would be included in Berkeley Lab's Hazardous Waste Handling Facility Permit, which is reviewed by DTSC every five years. The location/extent of the areas where groundwater does not meet the state criteria for domestic use would also be described and discussed in Berkeley Lab's Groundwater Monitoring and Management Plan.

Item	Page/Para	COB Comment	LBNL Response
Fourth Comment		The TMD would also like to see human health risk analyses determined more pathways of exposure. We would like to see bathing, washing, irrigation considered as exposure pathways. As with the RWQCB, we are prepared to consider that drinking is an unlikely pathway for exposure and that the MCL goals can be met in the not too distant future.	The potential exposure pathways and receptors used to develop the proposed MCSs in the *Draft* CMS Report were derived from the DTSC-approved Human Health and Ecological Risk Assessment Work Plan and Assumptions Document for Berkeley Lab (Berkeley Lab, 2002). These potential pathways and receptors were further defined in the Berkeley Lab Human Health Risk Assessment (HHRA) (Berkeley Lab, 2003). The HHRA utilized potential exposure pathways and receptors based on the reasonable and likely future use of the Berkeley Lab site to calculate risks to human health. These pathways did not include the domestic use of groundwater for drinking, bathing, or washing; or the use of groundwater for irrigation. Nevertheless, the cleanup standards proposed in the *Draft* CMS Report are protective of these pathways where groundwater meets the criteria for domestic or municipal supply under State Water Resources (SWRCB) Resolution 88-63. In these areas, the proposed cleanup standard is the Maximum Contaminant Level (MCL) for drinking water. Note that if drinking groundwater is an unlikely exposure pathway, as noted in the comment, bathing or washing are also unlikely pathways.

Item	Page/Para	COB Comment	LBNL Response
Fifth Comment		In contrast, the CMS report presents the non-degradation policy and MCL as "goals" or "objectives" rather than a long-term "requirement".	Compliance with SWRCB non-degradation policy (Resolution 68-16) under the Porter-Cologne Water Quality Control Act is a requirement and is listed as such in Section 3.1 of the Draft CMS Report. In areas where groundwater meets minimum SWRCB yields for potential domestic supplies, attainment of MCLs is the goal or objective corresponding to that requirement. Where the CMS report lists "goals" and "objectives", those terms are used in compliance with regulatory agency guidance and nomenclature. The United States Environmental Protection agency (EPA) Handbook of Groundwater Protection and Cleanup policies for RCRA Corrective Action (EPA, 2004) states the following "Implementing goals in terms of 'what, where, and when' is not a new approach to corrective action but rather a clarification of 'cleanup objectives' as described in the May 1, 1996 Advance Notice of Proposed Rulemaking (ANPR - EPA, 1996a; page 19449). For example, to measure achievement of final groundwater cleanup goals, the ANPR described final cleanup objectives in terms of (1) groundwater cleanup levels, (2) the point of compliance, and (3) cleanup timeframes…" The California RWQCB San Francisco Bay Region's Water Quality Control Plan (Basin Plan) (RWQCB,1995) establishes beneficial uses and water quality objectives (WQOs) for groundwater and surface water in the San Francisco Bay region. The Basin Plan notes that the "The overall goals of water quality regulation are to protect and maintain thriving aquatic ecosystems and the resources those systems provide… California's regulatory framework uses water quality objectives both to define appropriate levels of environmental quality and control activities that can adversely affect aquatic systems."

Item	Page/Para	COB Comment	LBNL Response
Sixth Comment		In presenting this report with limited risks due to limiting the pathways for exposure, we present the federal government with the excuses to stop payment for additional clean up to the highest standards possible.	(See also response to the fourth comment.) Potential exposure pathways were based on the likely and realistic present and future land use scenario for Berkeley Lab for continued institutional use. The potential exposure pathways and receptors for institutional use were not limited, but included all anticipated receptors, including current indoor workers; potential future indoor workers who might work in future buildings located in areas where buildings are not presently constructed; outdoor landscape workers; and construction workers who might excavate soil or be exposed directly to groundwater. In addition, although the RCRA site cleanup is based on the institutional land use scenario, it does not preclude additional site cleanup by the federal government in the future. The ongoing responsibilities of the Department of Energy (DOE) for remediation are specified in the UC/DOE contract to manage and operate Berkeley Lab. Clause 6.20 of the contract states the following: <u>Responsibility for environmental restoration and remedial work</u>. Upon termination or expiration of this contract or any lease or occupancy agreements identified in Appendix I, DOE shall be responsible for complying with all applicable laws, regulations, and DOE directives requiring investigation, monitoring, cleanup, containment, restoration, removal, or other remedial activity with respect to any hazardous substances present in soil, ground water, or buildings as a result of activities conducted during the term of the contract or any prior contract modifications or during the term of any said lease or occupancy agreements.

Item	Page/Para	COB Comment	LBNL Response
Summary Comment 1 (part 1)		Historically, regulatory agencies have had difficulty maintaining controls for sites closed with contamination left in-place.	(See also response to third comment.) This is a regulatory issue, which was discussed at the Remedial Project Managers (RPM) meeting held at the DTSC offices on October 14, 2004. Representatives of the City of Berkeley, DTSC, the RWQCB, DOE, and Berkeley Lab were in attendance. The DTSC would be the regulatory agency responsible for maintaining site control under a Land Use Covenant (LUC) with the University of California. Also, Berkeley Lab's previously conducted ICMs and remedies proposed in the CMS have wherever feasible provided for the removal of contaminated materials rather than leaving contamination in-place.
Summary Comment 1 (part 2)		Institutional controls are proposed for LBNL when the ILCR is greater than 10^{-6} calculated for pathways that include bathing, irrigation etc., or when the HI is greater than 1. The TMD would like to review the proposed policies and procedures and details of the specific controls that will be implemented.	This is a regulatory issue, which was discussed at the RPM meeting on October 14, 2004. At that meeting, the DTSC agreed to allow the City of Berkeley to participate in negotiations between the DTSC and University of California regarding any implementation of a LUC.
Summary Comment 2		There are some controls that the TMD would consider problematic. Examples are declaring groundwater of no potential beneficial use as a drinking water source due solely to contamination and land-use restrictions for the property.	The CMS Report does not propose declaring groundwater of no potential beneficial use as a drinking water source due solely to contamination and land-use restrictions for the property. Provisions included in the *Draft* CMS Plan relative to groundwater are in compliance with State of California laws and regulations. Any controls on Berkeley Lab groundwater imposed under the RCRA process would be approved by the DTSC in consultation with the RWQCB.

REFERENCES

Berkeley Lab 2002. RCRA Corrective Measures Study Plan for the Lawrence Berkeley National Laboratory, Environmental Restoration Program, May 2002.

Berkeley Lab, 2003. Human Health Risk Assessment for the Lawrence Berkeley National Laboratory Environmental Restoration Program, May 2003.

EPA, 2004, Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action for Facilities Subject to Corrective Action Under Subtitle C of the Resource Conservation and Recovery Act: Solid Waste and Emergency Response (5303W), EPA530/R-01/030, April, 2004.

RWQCB, 1995, Water Quality Control Plan, California Regional Water Quality Control Board San Francisco Bay Region.

RWQCB Comments

December 23, 2004

California Regional Water Quality Control Board
San Francisco Bay Region

Dr. Alan Lloyd
Secretary for Environmental Protection

1515 Clay Street, Suite 1400, Oakland, California 94612
(510) 622-2300 • Fax (510) 622-2460
http://www.swrcb.ca.gov/rwqcb2

Arnold Schwarzenegger
Governor

Date: December 23, 2004
File No. 2199.9026 (MBR)

Department of Toxic Substances Control
Attn: Salvatore Ciriello
700 Heinz Avenue, Suite 200
Berkeley, California 94612

SUBJECT: Water Board's Comments on Draft RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory dated July 2004, Alameda County

Dear Mr. Ciriello;

On September 13, 2004, the San Francisco Bay, Regional Water Quality Control Board (Water Board) staff provided the Department of Toxic Substances Control (DTSC) with our comments on the U.S. Department of Energy's (DOE) Draft RCRA Corrective Measure Study Report (CMS) for Lawrence Berkeley National Laboratory (Berkeley Lab). Our comments, along with DTSC's were forwarded to DOE for their response.

On October 27, we received DOE's written response to our comments but without the figures we had requested. Most recently on December 8, 2004, DOE submitted the requested figures after a technical meeting between Water Board and Berkeley Lab staff. With these figures, we have completed our review of the Draft Corrective Measure Study.

Overall, Water Board staff finds that DOE's responses to our comments acceptable; however, two issues remain. The first issue is to maintain the designated potential beneficial use of a drinking water supply for all groundwater underlying Berkeley Lab but establish short-term and long-term Media Cleanup Standards (MCSs) for areas of low well yield. The second issue is to revise the CMS to identify any collocated radionuclide and volatile organic compounds (VOCs) groundwater plumes.

Regarding the first issue, the draft CMS presents data to support a proposed exclusion of the drinking water beneficial use based on State Board Resolution 88-63. This resolution states that all groundwater of the State is considered to be suitable, or potentially suitable, for municipal or domestic drinking water supply and so designated with the exception of groundwater where:

a. The concentration of total dissolved solids (TDS) exceeds 3,000 mg/L (5,000 uS/cm, electrical conductivity) and it is not reasonably expected by Regional Boards to supply a public water system, or

b. There is contamination, either by natural processes or by human activity (unrelated to the specific pollution incident), that cannot reasonably be treated for domestic use using either Best Management Practices or best economically achievable treatment practices, or

c. The water source does not provide sufficient water to supply a single well capable of producing an average, sustained yield of 200 gallons per day (gpd), or

d. The aquifer is regulated as a geothermal energy producing source or has been exempted administratively pursuant to 40 Code of Federal Regulations (CFR), Section 146.4 for the purpose of underground injection of fluids associated with the production of hydrocarbon or geothermal energy, provided these fluids do not constitute a hazardous waste under 40 CFR, Section 261.3.

The CMS presents hydrogeologic data identifying small specific areas where groundwater yield is less than 200 gpd and proposes that drinking water supply should not be a designated beneficial use for these areas. However, "de-designation" of groundwater beneficial uses requires Water Board adoption of a Basin Plan amendment and typically takes place on a regional aquifer or sub-aquifer basis. The facility-wide data shows considerable variation of yield, above and below 200 gpd, and does not support drinking water supply de-designation of the regional aquifer or sub-aquifer scale.

Based on presented data, Water Board staff concurs that groundwater conditions directly underlying specific area may limit potential use as a municipal or domestic drinking water supply but that hydrogeologic site-wide conditions do not support de-designation of the drinking water supply potential beneficial use for groundwater at Berkeley Lab.

To address these low yield areas, Water Board staff recommend establishment of short term and long-term Media Cleanup Standards (MCS) for areas where groundwater yield is less than 200 gpd. The short-term MCS would remain as currently proposed in the CMS but the long-term MCS would be protective of groundwater as drinking water supply, e.g., MCLs. The establishment of a long-term MCS for the areas with well yields less than 200 gpd does not appear to require any changes in the proposed corrective measures since the plumes in areas with a groundwater yield less than 200 gpd are already required to be monitored to demonstrate long-term plume stability. The long-term MCS time frame should be proposed by Berkeley Lab based on attenuation rates for the contaminants of concern in each groundwater contaminate plume.

The second issue is more of a restatement of an earlier comment by Water Board staff requesting identification groundwater plumes with collocated radionuclide and non-radionuclide contamination. In our September 27, 1999, letter on the Request for No Further Investigation Status for Areas of Groundwater Contamination Designated as Areas of Concern, staff commented that, " DTSC has notified LBNL and RWQCB that they have no authority to regulate radionuclides and radioactive waste under RCRA. Additionally, DTSC has proposed LBNL remove all radionuclide investigations from the RFI and include them as part of the Site Restoration Program. RWQCB concurs with DTSC's proposal but requests notification of any collocated radionuclide contamination within each identified groundwater AOCs." The identification of any collocated radionuclide and non-radionuclide groundwater contamination should be continued as part of the CMS to insure that the selected corrective measures for the VOC groundwater contamination are not influenced by or influencing any radionuclide groundwater contamination.

Please contact me at (510) 622-2411 or via email at <mrochette@waterboards.ca.gov> if you have any questions or comments.

Sincerely,

Michael B. Rochette

Michael Bessette Rochette
Groundwater Protection Division

LBNL Responses to RWQCB Comments

January 13, 2005

BERKELEY LAB
Environment, Health and Safety Division
Environmental Restoration Program

Dr. Waqar Ahmad
Facility Permitting Branch
Cal EPA-DTSC
700 Heinz Avenue, Suite 200
Berkeley, CA 94710-2737

January 13, 2005
ERP-3049

Subject: Responses to the January 3, 2005 DTSC letter containing RWQCB Comments dated December 23, 2004 on the *Draft* Corrective Measures Study, Lawrence Berkeley National Laboratory, Berkeley, California EPA ID No: CA4890008986

Dear Dr. Ahmad:

Enclosed are the Ernest Orlando Lawrence Berkeley National Laboratory (Berkeley Lab) Responses to the January 3, 2005 DTSC letter containing Regional Water Quality Control Board (RWQCB) Comments dated December 23, 2004 on the *Draft* Corrective Measures Study (CMS) Report (July 2004).

Please contact me at (510) 486-6106 if you have any questions.

Sincerely,

Iraj Javandel
Environmental Restoration Program

Encls.

Ernest Orlando Lawrence Berkeley National Laboratory
One Cyclotron Road | Berkeley, California 94720-8126 | Mail Stop 90R1116 | Tel: 510.486.6106 | Fax: 510.486.8694

LBNL Responses to Comments from *Michael Bessette Rochette* of RWQCB San Francisco Bay Region Groundwater Protection Division) dated December 23, 2004 to Salvatore Ciriello of Department of Toxic Substances Control
Subject: Draft RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory, dated July 2004. Berkeley, Alameda County.
File No. 2199.9026 (MBR)

Item	Page/Para	RWQCB Comment	LBNL Response
Comment 1		Overall, Water Board staff finds DOE's responses to our comments acceptable; however, two issues remain. The first issue is to maintain the designated potential beneficial use of a drinking water supply for all groundwater underlying Berkeley Lab but establish short-term and long-term Media Cleanup Standards (MCSs) for areas of low well yield.	Berkeley Lab will include the following text at the appropriate location(s) in the Corrective Measures Study Report. As noted by RWQCB, "groundwater conditions directly underlying specific areas may limit potential use as a municipal or domestic drinking water supply" (Appendix J). Therefore for those areas of groundwater contamination where well yields are less than 200 gpd, risk-based levels are considered applicable and are proposed as MCSs, at least for the short term. However, it is acknowledged that the RWQCB designates all groundwater potentially suitable for municipal or domestic supply unless it has been formally de-designated. Therefore, the long-term goal for these areas would be to restore groundwater quality to the maximum beneficial use (MCLs), if practicable. Once the short-term goal is achieved, the long-term approach would be natural degradation within the framework of a long-term monitoring program to document the status of natural degradation and that migration of contaminated groundwater is under control.

Item	Page/Para	RWQCB Comment	LBNL Response
Comment 2		The second issue is to revise the CMS to identify any collocated radionuclide and volatile organic compounds (VOCs) plumes.	RCRA only regulates hazardous materials/waste and not radiological contamination. In previous comments, DTSC has indicated that radionuclide information should not be included in RCRA corrective action process documents, and therefore it will not be included in the RCRA Corrective Measures Study Report. Areas of collocated radionuclide and chemical contamination were previously discussed in the report titled Summary of Radionuclide Investigations for Lawrence Berkeley National Laboratory (September 2003). The information regarding collocated radionuclide and volatile organic compounds (VOCs) plumes is provided below, and has been updated based on the most recent data available (July to September 2004).

COLLOCATED CHEMICAL AND RADIOLOGICAL CONTAMINATION

There are five relatively small locations, all in the Support Services Area, where collocated chemical (VOCs) and radiological (tritium) contamination is present in the groundwater (attached Figure 1). These locations correspond to the areas (or portions of areas) of VOC-contaminated groundwater included in the RCRA Facility Investigation (RFI) and listed in the following table. The last four of the listed areas are also included in the Corrective Measures Study (CMS) Report, since concentrations of VOCs are above MCLs.

Areas of Collocated Tritium and Chemical Contamination

Area of Groundwater Contamination	VOCs Above MCLs	Tritium Above MCL
Building 75B Area of Groundwater Contamination	No	Yes
Building 69A Area of Groundwater Contamination	Yes	No
Building 75/75A Area of Groundwater Contamination	Yes	No
Solvents in Groundwater South of Building 77	Yes	No
Benzene in Wells East of Building 75A	Yes	No

Item	Page/Para	RWQCB Comment	LBNL Response
Comment 2 (cont'd.)			As shown in the table, there are no locations where both tritium and VOCs are present in the groundwater at concentrations above MCLs. Concentrations of tritium detected in most wells have been decreasing since closure of the National Tritium Labelling Facility (NTLF). Tritium has been detected above the MCL in only a single well, MW75-97-5, which also monitors the Building 75B Area of Groundwater Contamination. Concentrations of tritium detected in the well have been decreasing with the current concentration (21,211 pCi/L) only slightly above the 20,000 pCi/L MCL. Only relatively low concentrations of VOCs have been detected in the well (1.2 µg/L 1,1-dichloroethane [DCA] and 2.1 µg/L of 1,1-dichloroethene [DCE] in August 2004). Benzene has been detected at concentrations above the MCL in several deep Orinda Formation wells, including two wells east of Building 75A in which tritium has also been detected. The benzene detected in these deep Orinda Formation wells may be naturally occurring. How the tritium plume will be managed in the future is outlined in the Summary of Radionuclide Investigations for Lawrence Berkeley National Laboratory (September 2003) submitted to the United States Department of Energy.

Item	Page/Para	RWQCB Comment	LBNL Response
Comment 3		The CMS presents hydrogeologic data identifying small specific areas where groundwater yield is less than 200 gpd and proposes that drinking water supply should not be a designated beneficial use for these areas. However "de-designation" of groundwater beneficial uses requires Water Board adoption of a Basin Plan amendment and typically takes place on a regional aquifer or sub-aquifer basis. The facility-wide data shows considerable variation of yield, above and below 200 gpd, and does not support drinking water supply de-designation of the regional aquifer or sub-aquifer scale. Based on presented data, Water Board staff concurs that groundwater conditions directly underlying specific area may limit potential use as a municipal or domestic drinking water supply but that hydrogeologic site-wide conditions do not support de-designation of the drinking water supply potential beneficial use for groundwater at Berkeley Lab.	Berkeley Lab agrees with the comment. The intent of the data presentation was to address community concerns by limiting the areal extent where groundwater would not be protected as a potential drinking water source. Short term well yield testing was therefore conducted only in those areas where the groundwater is contaminated. However, it should be noted that longer term sitewide testing would likely indicate that the major portion, if not all, of the site could not sustainably produce 200 gpd from individual wells, and therefore may represent a broad area where de-designation of municipal and domestic supply beneficial uses may be appropriate. The few areas at Berkeley Lab where short-term well yields exceed 200 gpd generally consist of isolated Moraga Formation landslide blocks. Due to their relatively small storage capacity, these blocks may become depleted during the dry season or during long-term yield tests, as indicated by the large magnitude of groundwater fluctuation observed in many Moraga Formation wells (greater than 12 feet) between the dry and rainy season.
Comment 4		To address these low yield areas, Water board staff recommend establishment of short-term and long-term Media Cleanup Standards (MCS) for areas where groundwater yield is less than 200 gpd. The short-term MCS would remain as currently proposed in the CMS but the long-term MCS would be protective of groundwater as drinking water supply, e.g., MCLs. The establishment of a long-term MCS for the areas with well yields less than 200 gpd does not appear to require any changes in the proposed corrective measures since the plumes in areas with groundwater yield less than 200 gpd are already required to be monitored to demonstrate long-term plume stability. The long-term MCS time frame should be proposed by Berkeley Lab based on attenuation rates for the contaminants of concern in each groundwater contaminate plume.	See Response to Comment #1. Also, Berkeley Lab will include the following text at the appropriate location(s) in the Corrective Measures Study Report. It is not possible to specify with a high level of confidence the timeframe when MCLs would be achieved in areas where the well yield is less than 200 gpd. Based on the very low rates of attenuation observed, it will likely take at least several decades to achieve MCLs in most of these areas. In the interim, groundwater will be monitored to document the status of natural degradation and assure that migration of contaminated groundwater is under control.

Item	Page/Para	RWQCB Comment	LBNL Response
Comment 5		The second issue is more a restatement of an earlier comment by Water Board staff requesting identification groundwater plumes with collocated radionuclide and non-radionuclide contamination. In our September 27, 1999, letter on the Request for No Further Investigation Status for Areas of Groundwater Contamination Designated as Areas of Concern, staff commented that, "DTSC has notified LBNL and RWQCB that they have no authority to regulate radionuclides and radioactive waste under RCRA. Additionally DTSC has proposed LBNL remove all radionuclide investigations from the RFI and include them as part of the Site Restoration program. RWQCB concurs with DTSC's proposal but requests notification of any collocated radionuclide contamination within each identified groundwater AOCs." The identification of any collocated radionuclide and non-radionuclide groundwater contamination should be continued as part of the CMS to insure that selected corrective measures for the VOC groundwater contamination are not influenced by or influencing any radionuclide groundwater contamination.	See Response to Comment #2. Selected corrective measures for VOC-contaminated groundwater will not be influenced by, or influence, any radionuclide groundwater contamination. The only corrective measure that is proposed in areas of collocated radionuclide (tritium) and chemical contamination is Monitored Natural Attenuation (MNA), which is planned only for the Building 69A Area of Groundwater Contamination. The presence of tritium in the groundwater in this area will have no effect on the proposed remedy and conversely, the proposed remedy will have no effect on the magnitude or extent of tritium contamination in the groundwater.

Appendix K

Department of Toxic Substances Control (DTSC)

RESPONSE TO COMMENTS

Lawrence Berkeley National Laboratory on Proposed Cleanup Remedies in the Corrective Measures Study Report and CEQA Negative Declaration

August 31, 2005

Department of Toxic Substances Control

700 Heinz Avenue, Suite 200
Berkeley, California 94710-2721

Alan C. Lloyd, Ph.D.
Agency Secretary
Cal/EPA

Arnold Schwarzenegger
Governor

RESPONSE TO COMMENTS LAWRENCE BERKELEY NATIONAL LABORATORY ON PROPOSED CLEANUP REMEDIES IN THE CORRECTIVE MEASURES STUDY REPORT AND CEQA NEGATIVE DECLARATION

BACKGROUND

The Department of Toxic Substances Control (DTSC) has prepared this document to respond to comments submitted by public during the pubic comment period and public hearing regarding the cleanup remedies as proposed by the Lawrence Berkeley National Laboratory (LBNL) in its Corrective Measures Study (CMS) Report. DTSC solicited public input in a 45-day public comment period that ran from April 25, 2005 to June 8, 2005. DTSC held a public workshop on May 26, 2005 from 6:30 to 9:00 pm at the North Berkeley Senior Citizens Center located at 1901 Hearst Street, Berkeley. During this workshop, DTSC staff made presentations to provide overview of the corrective action activities at LBNL. The contents of the CMS Report were reviewed and proposed remedies were discussed. Questions from the attendees were answered during this workshop. A public hearing was also held on May 26, 2005 from 8:00 to 9:00 pm to receive public testimony on the CMS Report and proposed remedies. The proceedings of the public hearing were recorded by a court reporter. This Response to Comment Document responds to all comments provided verbally or in writing during the public hearing and all other comments received during the public comment period. A review of all comments received indicated that there were several general issues raised by numerous commenters. DTSC has chosen to respond to these general issues at the beginning of this Response to Comments document and then in the specific comments and responses section of this document make a cross-reference back to these general issues where appropriate.

GENERAL COMMENT NO. 1 – PUBLIC OUTREACH

Several commenters stated that DTSC has not conducted adequate public outreach during the entire Corrective Action cleanup process at LBNL.

RESPONSE TO GENERAL COMMENT NO. 1

DTSC disagrees with this assertion. It is DTSC’s opinion that it has conducted extensive public outreach activities since the beginning of Corrective Action investigations at this site. The following is a listing of specific public outreach activities conducted during each phase in chronological order from the Facility Investigation Phase to the most recent Corrective Measures Study Phase.

RCRA Facility Investigation (RFI) Phase

On November 15, 2000, DTSC issued a public notice of a 45-day public comment period on the availability of the RFI Report. A public workshop was held on December 6, 2000. The public was informed via a mailing of a fact sheet to 469 addresses. Approximately ten persons attended this workshop. At this workshop the attendees raised concerns about inadequate public outreach. These concerns consisted of: a) an advertisement was not placed in local newspapers; b) the names of certain commissioners from the City of Berkeley were not included on the mailing list; c) the proceedings of the public workshop were not being recorded so that they could become part of the public record. At the December 6, 2000 public workshop, members of the public requested that additional outreach be conducted, the comment period be extended, and a public meeting be held with a court reporter in attendance. DTSC responded by extending the public comment period until February 15, 2001 and by holding a second public meeting on January 24, 2001. DTSC mailed fact sheets containing the announcement of the second public meeting to approximately 600 persons on a revised mailing list that included the addition of representatives of the City of Berkeley commissions. Display advertisements announcing the extended comment period and the second public meeting were placed in two local newspapers (the Oakland Tribune and the Berkeley Daily Planet). An announcement was also broadcast on a local radio station (KALX). Approximately eight members of the public attended the second public hearing, which was held on January 24, 2001. A court reporter recorded the proceedings. It should be noted that both federal and State public participation guidelines for this phase of the corrective action process call for preparation and mailing of a fact sheet to the facility mailing list. DTSC took additional steps of holding public meeting/workshops to provide additional information to public in person and to provide opportunities to discuss their concerns with DTSC staff and to submit comments. It should also be noted that in spite of the fact that DTSC implemented all of the expanded public outreach activities as requested by the limited number of attendees of the December 6, 2000 meeting, the attendees at the January 24, 2001 did not change. The primary parties submitting comments remained Mrs. Pamela Sihvola, Chair, Committee to Minimize Toxic Waste (CMTW) and Mr. L.A. Wood. In addition, based on their request form the December 6, 2000 meeting attendees, DTSC had invited representatives of Department of Energy (DOE) to explain their activities regarding cleanup of radionuclides at this site, California Regional Water Quality Control Board (CRWQCB), etc. We were not allowed to make presentations. It is noted DTSC cancelled the presentations it planned to make at this hearing at the request of the attendees and proceeded directly to accepting oral testimony.

In response to a request from one of the City of Berkeley Council members, DTSC representatives attended Berkeley's Community Environmental Advisory Commission (CEAC) meeting, February 1, 2001, to present the findings of the RFI and to describe future steps of the RCRA Correction Action Process. However, that presentation did not take place, due to commissioners' departures, resulting from concerns about the legality of a commission quorum.

Human Health and Ecological Risk Assessment Phase

In October 2003, DTSC updated the community on the status of cleanup activities at LBNL. Accordingly, DTSC held a public workshop on October 28, 2003. In this workshop DTSC presented the findings of the Human Health and Ecological Risk Assessments, which had been reviewed by DTSC's toxicologists. In addition, DTSC made a presentation to CEAC on these human and ecological risk assessments on. DTSC informed the community about this workshop via a fact sheet titled, "*Update on Environmental Analysis*" which was mailed to the mailing list. Also, display advertisements were placed in the Berkeley Daily Planet and Oakland Tribune newspapers.

Corrective Measures Study Report Phase

LBNL submitted the CMS Report to DTSC on July 1, 2004. DTSC informed the public of the receipt of the CMS Report in July 2004 by mailing copies of a Fact Sheet to the facility mailing list. The facility mailing list consists of approximately 2000 persons. DTSC also placed a display advertisement in the Berkeley Daily Planet and Oakland Tribune newspapers.

In July 2004, DTSC conducted a survey of the community in the vicinity of LBNL. Approximately 2000 survey letters were mailed. DTSC reviewed the responses from the community survey and prepared a

“DTSC Provides Responses to Community Questions” Fact Sheet. This Fact Sheet was posted on DTSC’s internet website.

DTSC informed the public of a 45-day public comment period on the proposed cleanup remedies in the CMS Report on April 21, 2005. The public comment period ended on June 8, 2005. Display advertisements were placed in the Berkeley Daily Planet and Oakland Tribune newspapers. Copies of a Fact Sheet titled “DTSC Proposes Soil and Groundwater Cleanup at LBNL, April 2005“were mailed to the facility mailing list. A paid public notice announcing the public comment period, workshop, and public hearing was aired on an English language radio station. DTSC placed another display advertisement in local newspapers announcing notice of change of public hearing date, which was originally scheduled for May 24, 2005 to May 26, 2005.

DTSC held a public workshop and public hearing at 6:30 PM on May 26, 2005 at the North Berkeley Senior Citizens Center at 1901 Hearst Street, Berkeley. DTSC received oral testimony during the public hearing, which was recorded by a court reporter.

Additional Community Outreach Activities by LBNL:

In the fall of 1992, LBNL issued its first Community Relations Fact Sheet to help keep the community informed on the environmental restoration activities at LBNL. In July 1993, LBNL issued its Community Relations Plan (CRP). Interviews conducted with elected officials, environmental organizations, businesses, site neighbors, and LBNL employees formed the basis for the information contained in the CRP. LBNL prepared and distributed subsequent fact sheets in 1993, 1994, and 1995, updating the community on the progress of environmental restoration activities at LBNL. Since 1999 LBNL has made presentations to the City of Berkeley CEAC on a quarterly basis. These presentations were normally made prior to the normal start time of the CEAC meetings. The presentations were summaries of the same presentations made by LBNL to government regulators at its Site Restoration meetings which were held at LBNL’s offices. DTSC representatives also attended the public meetings and were available during question and answer periods.

Reference Fact Sheets Cited in the above Response to General Comment No. 1:

The reader is referred to the following Fact Sheets for specific details of public outreach conducted for each phase of investigation at LBNL.

- Fact Sheet, RCRA Facility Investigation Final Report, November 2000
- Fact Sheet, RCRA Facility Investigation, January 2001
- Fact Sheet, *Update on Environmental Analysis* covered human and ecological risk assessment, October 2003
- Fact Sheet, *DTSC Provides Responses to Community Questions,* July 2004
- Fact Sheet, *Draft Permit Available for Comments*, September 2004
- Fact Sheet, *DTSC Proposes Soil and Groundwater Cleanup at LBNL*, April 2005

GENERAL COMMENT NO. 2 – RADIONUCLIDES CONTAMINATION

Several commenters raised concerns that DTSC did not address radionuclide contamination at LBNL.

RESPONSE TO GENERAL COMMENT NO. 2

DTSC would like to clarify that assessment and cleanup of radionuclides releases at LBNL are not subject to RCRA Corrective Action investigation. Those areas where radionuclides were potentially released were identified by LBNL in their Facility Assessment of the site as part of the U.S. Department of Energy (DOE), Site Restoration Program in 1992 (LBNL, 1992). The authority in law relating to the regulation of radioactive materials was established under the U.S. Atomic Energy Act of 1954. This authority is delegated to the DOE, U.S. Department of Defense, and the Nuclear Regulatory Commission. The California Department of Toxic Substances Control has not been delegated this authority.

The following summary is provided by the DOE of their investigations regarding radionuclides at LBNL.

“The DOE completed the investigation of the eight units identified in their facility assessment and determined that no further action is required at any of these units. The results of the investigation were presented in the Summary of Radionuclides Investigations (September 2003). For seven of the eight units, it was determined that either 1) no release had occurred or 2) the levels of radionuclides found in the soil and groundwater were within LBNL background levels or for soil, less than the Preliminary Remediation Goals established by the United States Environmental Protection Agency, Region IX. A human health risk assessment was completed in 1997 for the eighth unit, the former National Tritium Labeling Facility (SWMU 3-7). In addition, an ecological risk assessment was completed for radionuclides. The ecological risk assessment concluded that exposure to radionuclides in environmental media at LBNL does not present a significant risk to ecological receptors. Both risk assessments overestimated the potential risk from tritium, since the estimates were based on the assumption that the NTLF would continue to operate and emit tritium to the air over a lifetime of exposure. However, the NTLF stopped operations more than three years ago, so tritium emissions have decreased significantly and will ultimately be eliminated. Furthermore tritium levels present in the environmental media are expected to decline over time due to its natural decay. This is confirmed by the declining levels of tritium detected in groundwater, with concentrations in all monitoring wells currently below the drinking water standard. Based on the results of the risk assessments and the declining levels of tritium in the environment, DOE determined that no additional investigation or remedial actions are warranted for the former NTLF unit, or are required under applicable regulations or policies. Nevertheless, DOE will continue to monitor groundwater and surface water to ensure that current conditions are maintained or improved.

The Summary of Radionuclides Investigations report has been available for public review at the LBNL environmental restoration program repositories located at the City of Berkeley’s Main Public Library and the LBNL library since August 2003. Alternately the report is also available on-line at http://www.lbl.gov/ehs/erp/html/documents.shtml. A status update on the findings of the investigation was presented by DOE at the RFI public meeting conducted on January 24, 2001. The final results were presented at the City of Berkeley’s Community Environmental Advisory Commission meeting on August 7, 2003.”

Also a commenter has implied that the groundwater in-place in the vicinity of the National Tritium Labeling Facility (NTLF) is considered a “mixed waste”. The groundwater near the former NTLF is not a “mixed waste” for the following reasons. First, groundwater cannot be considered a “waste” until it is brought above ground. Second, even if the groundwater is brought above ground, it could not be classified as a “mixed waste” since concentrations of VOCs are below levels that would characterize the water as hazardous. Again, for clarification, under the RCRA Corrective Action Program, DTSC does not have regulatory authority for the investigation/remediation of contaminated media with radionuclides. That responsibility is delegated to the DOE.

References

LBNL, 1992. RCRA Facility Assessment at the Lawrence Berkeley Laboratory, Environmental Restoration Program, September 30, 1992.

GENERAL COMMENT NO. 3 – REQUEST FOR A COMMUNITY ADVISORY GROUP

Several commenters requested that DTSC should sponsor a Community Advisory Group regarding the implementation and monitoring phases of remediation measures at LBNL.

RESPONSE TO GENERAL COMMENT NO. 3

The oversight of cleanup at LBNL is being conducted under the authority of California Health and Safety Code, Chapter 6.5, the federal Resource Conservation and Recovery Act (RCRA) and accompanying state and federal regulations. A Community Advisory Group (CAG) is a specific entity that is not legally provided for in these laws for oversight of corrective measures implementation. In another chapter of the Health and Safety Code (Chapter 6.8), there is a provision for establishing a Community Advisory Group (CAG) for response actions for state superfund cleanups. The LBNL corrective measures are not subject to that chapter or process. Chapter 6.5 already has a well defined public outreach process for decisions made under the provisions of this Chapter. As discussed under Response to General Comment No. 1, DTSC has followed a very open and inclusive public outreach process for the site assessment and proposed remedy selection activities at the LBNL site. DTSC is committed to implementing corrective measures in a fully transparent manner and allowing the City of Berkeley and the community meaningful input to the process. We will make all reports and monitoring results available for public review. In response to a resolution on this subject adopted by the City Council of the City of Berkeley, the City Manager has recommended that DTSC use the Community Environmental Advisory Commission (CEAC) as the venue through which to distribute this monitoring information and to receive public input. DTSC plans to work with CEAC to exchange this information.

It should also be noted that DTSC has also provided reports and other information to the Committee to Minimize Toxic Waste giving it recognition as a community group. DTSC will continue its coordination with CEAC and CMTW during the corrective measures implementation phase at the LBNL.

RESPONSES TO SPECIFIC COMMENTS RECEIVED DURING THE PUBLIC COMMENT PERIOD

COMMENTER #1: Ms. Leuren Moret

MS. MORET: My name is Leuren Moret. I worked five years at the Lawrence Berkeley Laboratory, two years at the Lawrence Livermore Laboratory. I'm a nuclear weapons lab whistleblower. I blew the whistle on the Yucca Mountain Project and the Superfund Project at Livermore. I'm a geoscientist and I worked on the groundwater cleanup at Livermore, and I'm now an international expert on radiation as a result of blowing the whistle, having a Karen Silkwood experience, and I survived it.

COMMENT 1-1

I would just like to make a comment about the date that was set for this public hearing, the first one that we've had, and to ask why this was scheduled on a busy holiday weekend. This is not the first time this has happened in public process it seems to be a pattern. And I think this is unfair to the community and people who wanted to be here and could not.

RESPONSE 1-1

DTSC had initially planned to hold the public hearing on Tuesday, May 24, 2005, but the date was changed to Thursday, May 26, 2005 at the request of community members. Please note that we have been selecting our community workshop or public hearing dates after consultation with Committee to Minimize Toxic Waste (Pamela Sihvola et al) and the City of Berkeley.

COMMENT 1-2

I'm going to address the regulatory standard and the risk model now for chemical and radiation exposure. In 1989, I interviewed Calvin Willhite, I'm sure he does not remember me. I asked him what the EPA chemical exposure limits were based on, and he said, well, we couldn't do experiments on humans to determine the risk and we couldn't afford to do experiments on animals, animal studies, to determine the risk, so we made them up. So the chemical risk standards for the EPA and the US government are made up. They are not based on science.

RESPONSE 1-2

Quantitative health risk assessment uses animal (primarily rodent) and human (primarily occupational) exposure-response data to estimate both non-cancer and cancer toxicity factors. Due to the relative paucity of reliable and robust human data, the majority of non-cancer and cancer risk assessments may rely upon the results of long-term mouse and rat bioassays. Using standardized statistical methods, inter- and intra-species uncertainty factors (historically called ‘safety’ factors) are used to extrapolate rodent data to the human and calculate a reference dose. Using an assumed (primarily linear) model, rodent and/or human carcinogenicity data are fit to an assumed dose-response relationship to calculate an upper bound potency value (usually referenced as q1*). Potency values are published by both the U.S. EPA and the California Office of Environmental Health Hazard Assessment (OEHHA). Potency values are often highly controversial; in fact, the potency estimate for trichloroethylene (TCE) found in LBNL groundwater is currently under review by the U.S. National Academy of Sciences (www.nas.edu). Since potency values are based on the mode of action and dose-response assumptions and the interspecies scaling is often based only on body surface relationships, potency values are theoretical estimates. Thus, combining hypothetical populations, estimated frequency and duration of exposure taken together with theoretical potency values lead to abstract results. Nonetheless, the various assumptions in each of the regulatory health risk assessments combine to over-estimate health risk. The conservative assumptions and theoretical nature of regulatory health risk estimates derived using current U.S. EPA procedures that are followed by DTSC are specifically addressed in the LBNL Baseline Human Health Risk Assessment.

LBNL has completed both an Ecological Risk Assessment (ERA) and a Human Health Risk Assessment (HHRA) in accordance with our approved workplans. The HHRA determined that 15 units should be further evaluated in the CMS Report.

The ERA evaluated the potential for chemical contaminants detected in soil, sediment, surface water, and groundwater to adversely affect the reproduction, growth, or survival of plant and wildlife individuals and populations. The ERA concluded that no adverse impacts exist for ecological receptors from exposure to chemicals in soil, groundwater, or surface waters at LBNL.

The HHRA estimated risk to human health from potential exposures to chemicals in soil, groundwater, surface water, and air. The HHRA identified the current and reasonably likely land use at LBNL as industrial-type institutional land use. The potential receptors associated with this land use scenario are LBNL employees (laboratory workers, office workers, and outdoor workers such as landscape maintenance workers) and construction workers. Off-site receptors were not evaluated in the HHRA because there was no complete exposure pathways to these individuals and none are anticipated in the future. The HHRA also addressed protection of the beneficial uses of groundwater by comparing concentrations of chemicals of concern to drinking water standards.

In conclusion, DTSC disagrees with the comment that chemical risk standards are made up or that they not based on science. On the contrary, DTSC believes that the chemical risk standards considered at LBNL are based on sound science and there are several layers of safety factors built into these standards to be protective of human health and the environment.

The text of the HHRA is organized into eight sections. Section 2 provides a brief description of the history and operations of LBNL, as well as an overview of the physical setting and resource use plans that are important to characterizing current and reasonable future human exposure scenarios. Section 3 is an overview of the HHRA process, including a summary of the basis for the specific exposure assumptions. Sections 4 and 5 present the results of the risk assessment for the institutional and residential scenarios, respectively. The combined risks associated with exposure to Chemicals of Potential Concern (COPCs) in soil and groundwater are discussed in this section. Section 6 discusses the uncertainties associated with the HHRA. A summary of risk assessment findings and conclusions is presented in Section 7. Section 8 presents recommendations, and rationale for recommendations, pertaining to whether or not further remedial action requirements should be considered, and whether the units should be retained in the CMS. This information is provided within the HHRA as an aid in identifying, evaluating and ultimately selecting appropriate corrective action approaches for specific sites during the CMS process.

Appendices that contain supporting information for the HHRA follow the main body of text. Appendix A presents the risk calculations by exposure pathway for each receptor for the soil units. Appendix B presents the risk calculations for the groundwater pathways and maps showing the locations of LBNL groundwater monitoring wells. Appendix C provides revised risk estimates based on new EPA guidance that excludes cancer risk from 1,1-DCE. Appendix D presents the results of the soil to groundwater leaching evaluation. Appendix E presents the risk calculations for the surface water pathways. Appendix F contains the Analysis *of the Background Distribution of Inorganic Elements in Groundwater at LBNL*. Appendix G contains the *Indoor and Outdoor Air sampling Report for the LBNL*, the *Supplemental Indoor and Outdoor Air Sampling Report for the LBNL*, and results of the risk calculations based on the 1999 indoor air samples.

References

- Ecological Risk Assessment for Chemicals for Lawrence Berkeley National Laboratory, Environmental Restoration Program, December 2002
- Human Health Risk Assessment for the Lawrence Berkeley National Laboratory, Environmental Restoration Program, May 2003

COMMENT 1-3

The radiation standards which were conducted or they were based on the A-bomb study of Hiroshima and Nagasaki survivors were based on external gamma ray exposure and neutrons, there was no determination of internal exposure or even recognition of it. We were dealing with internal exposure. And the studies were fraudulently done because they threw out the first five years of data when most of the people died.

In fact, I have worked around the world with radiation experts from Russia working on Chernobyl and Japan and European countries. This is a European Parliament independent study, the regulator's edition, published in 2003, January 2003, on low-level radiation risk, and it determines that the A-bomb study which provided the data for the ICRP standard, International Committee on Radiation Protection, are mutually exclusive from a model, radiation risk model, which we then see in this study for the European Parliament based on internal exposure. And what they determined in this study is that internal exposure to low-level radiation risk is a hundred to a thousand times greater than the ICRP standard. So your radiation standard, they are based on the ICRP model. What you have not recognized is the synergistic effect of chemicals and radiation working together and that enhances the risk by at least ten times, maybe more, it depends on the chemicals and the radiation, and that low-level radiation also reduces the quality of life by ten percent. The superlinear effect of radiation and chemical exposure, this is exposure to very low levels of chemicals and radiation, has proven that low-level radiation and low-level chemical exposure for certain chemicals is actually many, many times more harmful per unit of radiation than higher levels. Now, I haven't heard any of these things mentioned by any of your experts. So having a Ph.D doesn't mean anything. Thank you.

RESPONSE 1-3

The LBNL Baseline Human Health Risk Assessment that was presented at the DTSC October 28, 2003 public workshop addressed the distinction between procedures utilized in quantitative radiation risk and quantitative chemical exposure risk. The differences between radiation risk analysis and non-radioactive chemical risk analysis are described in U.S. EPA (December 1989) Risk Assessment Guidance for Superfund Volume 1.Human Health Evaluation Manual (Part A).Interim Final. EPA/540/1-89/002.pp.10-1 to 10-37. U.S. EPA provides a guidance in Section 10.7.3 concerning combining radionuclide and chemical cancer risks posed by exposure to chlorinated solvents. It states that "… the two sets of risk estimates should be tabulated separately". DTSC review of procedures followed by LBNL authors found that those procedures were consistent with U.S. EPA guidance. Regarding the synergistic effect of chemicals and radionuclides, there is no scientific methodology to calculate these effects.

In addition, please see the Response to General Comment No. 2.

COMMENT 1-4

The drinking water standards, for example, for tritium is 1,000 picocuries per liter, means over a year that every cell in your body has the possible exposure of being exposed to tritium. That doesn't sound too safe to me. This is all part of the cold war mortgage. The Lawrence Berkeley Lab, the Livermore Lab, 10,500 sites in the United States, are contaminated with radiation and chemicals. And that's out of a

DOE publication. There are at least five national superfund sites that can never be cleaned up. LBNL is not one of them: The Nevada test site, Hanford, the Savannah and Clinch Rivers.

The 1995 cost to clean up the environmental legacy of the nuclear weapons program is $250 billion. It means that 2.3 million acres under DOE ownership and 120 million square feet of buildings are potentially contaminated. No wonder they don't want to do it, or they want to cut corners. But I'm here tonight to tell you you're not going to get away with not cleaning up LBNL now and then ask us to re-license LBNL to contaminate us more.

RESPONSE 1-4

Regarding the radionuclide tritium, please see Response to General Comment No. 2 which clarifies that the DOE is the lead agency for radionuclide cleanup.

COMMENT 1-5

We're in an active tectonic region there are active faults from the sea coast inland from the plate tectonics. You don't know when it's fractured, faulted you don't know where the micro faults are. You don't know anything about this environment because you sure haven't told us about them. And the risk of a major earthquake is one of the highest risks in the United States.

RESPONSE 1-5

The location of, and seismic risk associated with, active faults in the vicinity of LBNL and potential geologic hazards, including seismic hazards, are discussed in the RCRA Facility Investigation (RFI) Report dated September 2000, hereinafter referred to in this RTC document as RFI Report. The impact of faults and earthquake induced landsliding on the potential migration of contaminants at LBNL is discussed in response to several comments included in the RFI Report. It is understood that large magnitude earthquakes are predicted for the northern Hayward Fault, which lies at the western boundary of LBNL, and that significant ground-shaking could be expected to occur throughout the facility. The term "microfault" refers to microscopic geologic discontinuities in rocks. Since the magnitude of an earthquake is generally proportional to the size of the ruptured area of the fault, the presence of such microfaults would have no bearing on the seismic risk at LBNL. It is suspected that groundwater travels through rock units primarily via fractures, which would include microfractures. The presence of micro faults, which would have maximum displacements on the order of centimeters, would have no relation to major earthquakes. However, it is not necessary to know the precise locations of such small fractures, since the hydrogeologic properties of the fractured rock bodies as a whole may be determined by testing entire sections of these bodies using standard hydrogeologic well testing techniques. A discussion of the hydrogeologic testing conducted is provided in the RFI Report.

Reference

- RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory, Environmental Restoration Program, February 2005

COMMENT 1-6

And you've come here to tell us you only want to clean up 20 percent. You want to leave 80 percent of the mess. It's not acceptable. We have to live here. You don't have to live here. Our children have to live here. There are people in this community who are sterile, they can never have children. You don't have the right, the government doesn't have the right to take our reproductive ability away from us. You don't have the right to kill and poison our children and our babies and the unborn. 1.3 billion people as a result of a nuclear weapon and a nuclear power project have been killed, maimed, and diseased around the world. Because in seven days what you're releasing here into the air goes around the world. I'm an expert on atmospheric dust. You know, you're coming here to tell us you're going to clean it up, but it's a broken promise and it's been a broken process, and you need to listen to us.

RESPONSE 1-6

DTSC respectfully disagrees with statement that DTSC wants to leave behind 80 percent of the contamination. The cleanups specified in the CMS Report, and the Interim Corrective Measures (ICMs) completed to date, will remove most of the contaminant mass that has been present in both the soil and groundwater. Although it is not clear what the basis is for this assertion that DTSC wants to clean up only 20% is, however, we assume that it is based on the information presented on the figure included after Attachment 13 in the June 7, 2005 comments from the Committee to Minimize Toxic Waste (CMTW) on the Draft CMS Report. The figure, prepared by CMTW, shows areas highlighted in black that are interpreted to “indicate contamination plumes for which no cleanup is proposed” and areas in yellow interpreted to indicate areas where cleanup is proposed. This figure does not accurately portray the cleanup requirements for the site. Although DOE has no active cleanup plans for the Tritium Plume, which represents more than one third of the area highlighted in black, DOE has informed us that the plume is being cleaned up by natural attenuation processes. Concentrations of tritium in all wells monitoring the tritium plume are currently below the drinking water standard. Concentrations of tritium in most wells monitoring the plume are decreasing, and the lateral extent of the plume is shrinking. No cleanup is required in several other areas highlighted in black on the figure (Building 71 Freon Plume, Building 37 VOC Plume, Building 7 Diesel plume) because concentrations of all chemicals of concern are well below drinking water standards. Concentrations of VOCs in the Building 37 VOC Plume were reduced to levels below detection limits as a result of an ICM. Also, contrary to what is indicated on the figure, cleanup is proposed for most of the remaining areas highlighted in black. Although the required cleanup level is not the drinking water standard for all these areas, LBNL has indicated that there long-term goal is to restore all groundwater to drinking water standards, if practicable.

Regarding radioactivity, please also see Response to General Comment No. 2 for approval information.

COMMENT 1-7

And we need to have a Community Action Committee. Because if we don't, you're not going to do it, our corrupt city council is not going to do it, our infiltrated CEAC Commission is not going to do it. We are going to insist on a community action committee, and we hope that you will work with us.

RESPONSE 1-7

Please see Response to General Comment No. 3.

COMMENT 1-8

Now, it turns out your report and the DOE report, I'm going to point out, especially to the community, that Department of Energy report, and we have no authors, they have no peer review process, and the first thing to read when you open a DOE report is the disclaimer. They take no responsibility for anything in the report. And the one thing I learned at Livermore that I tell everyone and I will never forget is the day I was looking out the window of my laboratory and I said, my God, scientists are prostitutes for the military war preparations. I had the great fortune because of my whistleblowing experience to become a citizen scientist, and I hope that some of you when you retire will do that and come and help us, because our problems are your problems too. What's happening to us is happening to you.

RESPONSE 1-8

No disclaimer has been included in the CMS report submitted by LBNL to DTSC. All documents submitted to DTSC include the signature of the LBNL Environmental Restoration Program (ERP) Manager as the approver and/or his signature on the transmittal letter. In addition, reports that have been submitted since 2000 have been signed by and stamped with the seal of a California Professional Geologist, a California Certified Hydrogeologist, and/or a California certified Engineering Geologist. In addition, these reports have been reviewed by our DTSC staff, most of whom are registered engineers and geologists.

COMMENT 1-9

And even no health studies have been allowed. The State of California Department of Health wanted to do a health study in Livermore because children had leukemia and there's very high rate of cancer there. The funds were cut.

RESPONSE 1-9

Human Health (HHRA) and Ecological (ERA) Risk Assessments were prepared as part of this project. The ERA determined that that there are no negative effects to ecological receptors. Please see Response to Comment 1-2 for more details on the HHRA.

Regarding the cutting of funds for a health study at Lawrence Livermore National Laboratory in Livermore, this comment is not relevant to this project and therefore is just noted.

COMMENT 1-10

I don't know if the Water Quality Control Board is measuring radiation in our drinking water, but I can tell you that at the Livermore Lab is measuring radiation washing out of the Sierras, the bomb testing fallout, the Chernobyl fallout, the Rancho Seco fallout, it's all in the Sierras and it's washing right through our bay. And actually Livermore measured it all the way down to the tip of Baja. The Marin County breast cancer cluster is a result of that contamination washing up in the meth lab of the Marin coastline.

RESPONSE 1-10

Water Board staff reviews LBNL’s groundwater monitoring program which includes radionuclides but is not directly involved with testing domestically supplied drinking water in Berkeley. The testing of domestically supplied drinking water is the responsibility of the supplier, which, for most all Berkeley, is the East Bay Municipal Utility District (EBMUD). As the supplier, EBMUD tests drinking water for radionuclides as well as numerous other analyses. In addition, the State of California, Department of Health Services (DHS) has a drinking water program. There are drinking water field operations branches with DHS that are responsible for the enforcement of the federal and California safe drinking water acts.

For purpose of public health epidemiologic investigations, Marin County results are tabulated separately from those of Alameda County. Thus, the Marin County data have no direct bearing on Alameda County data. Nevertheless, risk factors known to be associated with increased risk of breast cancer include family history, ethnic background, age, lifestyle (e.g., exercise) and body mass, dietary fat and ethanol consumption, child bearing history and use of prescription drugs (hormone replacement therapy). Please see Response to Comment 1-2.

COMMENT 1-11

So we need an oversight committee, the citizens need to be able to talk, they need to be able to know that you are listening. We need to have your answers to our comments. We have put a lot of time into research on this issue, many years, a great deal of effort, and in all due respect, you need to address our concerns. We need an oversight committee because this chemical and radiation exposure is in addition to the burden that is already in the San Francisco Bay Area. Because of the rain, the fog, the pollution, we have higher levels of exposure more is washed into our environment.

RESPONSE 1-11

Regarding an oversight committee, please see Response to General Comment Nos.1 and 3.

Regarding radiation exposure, please see Response to General Comment No. 2.

COMMENT 1-12

The risk is unknown and the standard, the regulatory standards are based on false premises. This is obvious from, for instance, problems that people getting organ donations, they suddenly have discovered that chemicals and radiation are being passed on to patients, organ donor patients. And it's a risk that they were unaware of before.

RESPONSE 1-12

The primary chemicals of concern at LBNL are the common dry cleaning solvent perchloroethylene (PCE), the related trichloroethylene (TCE) and products of their environmental decomposition by soil microbes (e.g., 1,1,-DCE, cis/trans-1,2-DCE). At the present time, there is no complete exposure pathway to any of these substances found in LBNL groundwater. Both PCE and TCE are lipophilic and tend to accumulate in body fat. The rate of human elimination from adipose tissue (biological half-life = 55 and 3.5-5 hours, respectively) has been measured in controlled clinical studies. Using these observations taken together with the hypothetical exposures assumed in the LBNL health risk assessment, it is not pharmacologically possible that chronic levels of these substances under current conditions at LBNL could accumulate in adipose or other tissues of people who live nearby or who work at LBNL.

Regarding radiation exposure, please see Response to General Comment No. 2.

For more information about human health and risk assessment, please see Response 1-2.

COMMENT 1-13

Climate variability will impact our water supply. We need to have a water supply here independent of the normal one. And potential x-rays on pregnant women of very low levels of radiation have a very serious impact on the fetus. In fact, they do permanent brain damage.

RESPONSE 1-13

Regarding a water supply independent of the normal one, that issue is beyond the scope of this CMS project.

Regarding radiation exposure, please see Response to General Comment No. 3.

COMMENT 1-14

So all these new studies and new information about the impact of low levels of radiation and chemicals have not been taken into consideration, and we want to be sure these concerns are addressed. And at this time, we're living in a time that is going to have an increasing negative impact on the environment because our economy requires it.

So I thank you very much for listening, and I'm very thankful to the citizens who came tonight, and I would like to thank our Council Member, Chris Worthington, for coming this evening.

RESPONSE 1-14

Regarding radiation and chemical exposure please see response to comments 1-3 and 1-4. Also, please refer to Response to General Comment No. 2.

COMMENTER #2: Mr. Tom Kelly

Good evening. My name is Tom Kelly. And the first thing I'd like to do is I'd really like to express my appreciation to all of the citizens of Berkeley who have really stuck with this issue over the last 10 or 12 years and doggedly so, and have done so with no compensation and at great personal expense and obviously taking great personal risks in a way to continue to go up against the Lab and what seems to me to be a very conflictual situation which of course all of us realize is not the way we like to lead our lives. So to these people I really want to say thank you very much, you've been very inspirational to me in terms of keeping me interested and following it up.

COMMENT 2-1

Up until just a couple of months ago, I worked at the California Department of Health Services in the Environmental Health Investigations Branch. And in some ways we're kind of a, I won't say a counterpart to DTSC, but they often work together. And one of the things that we have learned is that you need to get the community involved in these types of issues very, very early in the process, and you have to do that because that's the only way you're ever going to get a good outcome. Now, you can avoid doing that and all of us have seen and I'm sure the folks at DTSC recognize it too that when you develop a resolution with someone like the Lab, if the community gets involved in that late in the inning, you run the risk of whatever process you developed being undermined, and often taking you right back to where you started from. So with that in mind, I would also like to leave with you a copy of the letter that we at the Community Health Commission sent to the City Council, which essentially asks that the area that's being considered to be cleaned up to be the highest possible levels. And, you know, it makes sense. Think about it. I mean all of us when we were growing up, you know, we were told if you make a mess, clean it up. And essentially that is what the lab has done over the last 40 years. And I don't know if you can say that it's been due to its own negligence or even intentional.

I mean I don't understand how solvents and VOCs and PCBs and everything else actually get into our groundwater, the way they did here, unless someone wasn't paying attention or the best management practices at the time weren't being used. So with that in mind too, I hope you understand that that's some of the reasons why there's a great deal of distrust of the Lab and its motives and its willingness to follow through on the promises that they even make to DTSC.

RESPONSE 2-1

DTSC agrees with Mr. Kelly that the community should be involved at very early stages of these projects. Both LBNL and DTSC have involved the community from the very beginning of the process. The community involvement in this project started in February 1993. Please refer to Response to General Comment No. 1 for more details on the public outreach. The contamination documented in the CMS Report originated from spills and leaks that mostly occurred decades ago. Since that time, waste handling and management practices have considerably improved. In addition, there has been a significant increase in Federal, State, and local government oversight of waste handling and management practices as a result of legislation passed to address environmental concerns. It should be noted that the requirement that RCRA regulated facilities implement corrective action came into existence in 1984. This requirement included investigation and remediation of historical releases that could have occurred over the 60-year operational life of LBNL.

COMMENT 2-2

So the second thing that I want to ask is that you consider, well, actually recognize that you put together a citizens' advisory group, and I'm sure you could figure out a way to make that work. I mean other than this advisory group, it would be made up of people who would necessarily be there to undermine this effort, but I think it could be structured in such a way that everybody would get off to the right foot and actually came out with enough good will that they all agreed that they would work to try to get the best outcome possible.

So this is a tough situation. People in Berkeley haven't given up, unlike most of the rest of the people in this country, and they still continue to demand involvement in the process, we're active in this process, and that's what democracy is all about. And so you can encourage that and maybe even help to foster a rebirth in the rest of this country if you could look beyond all this past acrimony and distrust and let's get started on a new footing and see if we can't work together as a team that will ultimately provide a better result for everybody. So thank you very much, I appreciate it.

RESPONSE 2-2

DTSC is committed to a meaningful community involvement in its decisions. For this project, DTSC has been implementing a very robust and interactive community outreach. Please see the Response to General Comment No. 1 for more details. DTSC coordinates outreach activities with the Community Environmental Advisory Commission (CEAC), which is an appointed commission by the Berkeley City Council as well as the Committee to Minimize Toxic Waste.

DTSC reviewed the Draft Corrective Measures Study, under the regulatory authority of the California Health and Safety Code, Chapter 6.5, and the federal Resource Conservation and Recovery Act. As we have informed the City of Berkeley, a Community Advisory Group is a specific entity that is not legally provided for in corrective action law. There is a provision in another Chapter of Health and Safety Code (Chapter 6.8) for establishing a Community Advisory Group for response actions as part of the state superfund cleanup process.

However, in line with our policy and practice, DTSC remains fully committed to overseeing this corrective action in a fully transparent manner and allowing the City of Berkeley and its citizens meaningful input in the process. With this in mind and in response to the City of Berkeley's request, DTSC plans to regularly brief the City's Community Environmental Advisory Commission.

Please also see the Response to General Comment No. 3.

COMMENTER #3: Ms. Joan Levinson

COMMENT 3-1

My comment is that all of you who have come here tonight to tell us are clearly very smart, well-informed specialists in your field and you know what you're doing in the Lab and you know what you're talking about. And I suspect that all of you had an early impulse to get into this field because of 30 years ago and longer there was the idea that the environment is important and we should keep as much toxicity out of it as we can. And now 30 years later there is more than ever. So my comment is what do you do in your very quiet alone moments when you remember original motivations and what you are doing now sounds not a little like Orwell's 1984, and it's very, very troublesome, extremely troublesome to we who have come in great honestly and sincerity asking simple questions that affect our lives and your lives and everybody else and we hit the fog. In the context of that, I would like to give Nathan a copy of similar questions that were asked ten, nine years ago when you were applying for a permit to develop hazardous waste again, and yet nine years later it's all the same questions and the same nonanswers.

RESPONSE 3-1

Regarding the Class 2 permit modification for the Hazardous Waste Handling Facility which DTSC approved in 1997, it is DTSC's opinion and position that the Response to Comments document adequately addressed all the issues raised by the community. DTSC stands behind its decision to approve the Class 2 permit modification and the associated Response to Comments document. DTSC respectfully disagrees that our responses are "nonanswers". For example, DTSC has repeatedly stated that we do not have regulatory jurisdiction on radionuclides but some community members keep on raising the same issues again and again. So DTSC believes that it is being responsive to the community.

Regarding permit modification, DTSC held a public workshop and a hearing on the Permit Modification in 1997. DTSC received numerous comments. DTSC prepared Response to Comments document that addressed the issues raised during public comment period and public hearing.

Regarding permit renewal, DTSC public noticed receipt of Permit Renewal Application in November 2002. After its review DTSC announced a 45-day public comment period in the Berkeley Daily Planet and Oakland Tribune. A fact sheet was issued to inform the public about the Draft Permit at LBNL. A public hearing was held on October 20, 2004 and comments were received on the Draft Permit and the related California Environmental Quality Act Negative Declaration from September 21, 2004 to November 19, 2004. DTSC will prepare a Response to Comments (RTC) document.

COMMENT 3-2

My question is, and you can write to me and tell me, to your knowledge, is there anything being done at the moment to prevent this horrible contamination situation with ongoing and new projects that are being developed at the Lab? Thank you very much.

RESPONSE 3-2

The permitted operations have been reviewed and DTSC believes that the permitted facility is designed properly to prevent future contamination. Regarding contamination associated with ongoing and new projects, it is not clear to what the commenter is referring to. Lacking details on specific ongoing or new projects, a focused response on those projects is not possible. However, as stated previously, the contamination documented in the CMS Report originated from spills and leaks that mostly occurred decades ago. Since that time, waste handling and management practices have considerably improved. LBNL has established extensive training program for all current as well as new staff depending on their activities. The following training courses are required for generators of hazardous wastes at LBNL:

- Environmental Health and Safety (EHS) # 604, *Hazardous Waste Generator Training*, is required for all generators of hazardous waste at Berkeley Lab.
- EHS # 610, *Waste Accumulation Area (WAA) Supervisor's Training*, is required for WAA managers at Berkeley Lab.
- EHS # 614, *Satellite Accumulation Area (SAA) Management*, is required of researchers and others who generate hazardous and mixed wastes and who are responsible for management of SAAs.

Containment for accidental releases of hazardous materials at the LBNL Hazardous Waste Handling Facility is provided in all handling and storage areas. The building is designed to prevent spilled or leaked liquids from passing through the floors. Floors are constructed of reinforced concrete covered with a chemical-resistant, epoxy resin-based coating, trowel-applied and able to withstand high-impact loads such as forklift traffic. Each storage unit and other areas where hazardous materials are handled have grate-covered trenches (draining to containment sumps) at all door openings and perimeter concrete curbs at the base of all interior and exterior walls. Curbs are coated with the epoxy material described above.

COMMENTER #4: Mr. Daniel Robert Zangato

COMMENT 4-1

Where did you sleep last night? I slept outside. And I have to sneak in where I have to sleep. I'm homeless. And you're talking about saving the environment. Screw the environment, you know. Hey, talk to me, you know. Like I said, I can say it in 20 seconds.

RESPONSE 4-1

Comment noted.

COMMENTER #5: Mr. Jim Cunningham

COMMENT 5-1

First of all, I do want to put it into the record and give you a copy of a letter that we sent to DTSC a couple of years ago. This has two elements that are very important about the subject we're talking about.

RESPONSE 5-1

DTSC acknowledges receipt of the letter dated June 20, 2003 (Please see Attachment1 in the List of Attachments at the end of this document). DTSC responded to that letter on October 16, 2003.

COMMENT 5-2

And the other thing, I'm very happy to hear the people who commented about the positive nature of a citizen advisory group. I would hope that DTSC would realize that any rule that exists can be changed or whatever and I would like that DTSC realize that a citizen group can be a help to this whole process. So I would like to have a positive response from you on that issue. Thank you.

RESPONSE 5-2

Please refer to Response to General Comment No, 3.

COMMENTER #6: Mr. LA Wood

COMMENT 6-1

My name is LA Wood and I sit on Berkeley's Environmental Commission. I have sat on that commission for four years. I have been involved with LBNL for almost the extent of the 15 years I want to speak to a number of things about this process. I will write written comments to some of the technical aspects of the project, because I do believe that it is under-investigated in certainly the areas of geology. I mean it's a no-brainer. And certainly the areas that we are most concerned about, you know the report tracks around.

RESPONSE 6-1

Characterization of the geology as under-investigated is not accurate. As noted in the Response to Comment 1-6, the RFI report presents detailed maps of bedrock geologic units, faults, surficial geologic units, stream courses, storm water drainage systems, and landslides, as well as geologic cross sections. These maps and cross sections were based on the highly detailed synthesis of LBNL geologic data presented in the Converse Consultants 1984 Hill Area Dewatering and Stabilization report (Converse, 1984), and supplemented by additional geologic mapping and a substantial amount of subsurface drilling data obtained by Environmental Restoration Program (ERP) scientists during the RFI. The Converse Consultants synthesis included a thorough review and analysis of all known previously existing geologic studies at and adjacent to LBNL, and presents a detailed geologic map of LBNL and the surrounding regions as Plate 2 of that report. In addition, the CMS Report presents site-specific conceptual models describing hydrogeologic characteristics and the distribution and fate of contaminants for each site.

Please see Response to Comment 9-2 of this section for more details.

COMMENT 6-2

But I think sooner or later I think with environmental restoration, I think the Lab looks at a good number of you folks here, that we need to figure out a way in the future for us to walk into this concerned community instead of running side by side with it, avoiding it.

RESPONSE 6-2

DTSC appreciates the commenter’s concern for interaction between the community and DTSC. Again, DTSC sincerely believes it has made a good faith effort in public outreach on this project. Please refer to the Response to General Comment No. 1. The history of public outreach activities by DTSC regarding this project is summarized in that section.

COMMENT 6-3

I do also want to support the community in their request for a CAG. And I want to bring to the public record some of the history.

RESPONSE 6-3

Please see Response to General Comment No. 3 and Response to Comment 2-2 regarding a Community Advisory Group.

COMMENT 6-4

Unlike everyone in this room, I'm a Commissioner and I've sat at the environmental meetings so I can speak directly to them. I can tell you that over the course of the last four or five years that I'm probably the only commissioner who has sat at that table consistently for the four quarterly meetings and that we haven't had commission participation. Oh, yes, we've had it at the top of our agenda announcing a meeting, but it has been very contentious the issue of bringing LBNL -- as a matter of fact, six months ago LBNL made a presentation or thereabouts. The question was asked, listen, you guys seem to be brain dead about responding to this issue, we want them to come. There was silence. In other words, even though our political arm of the city wants to extend this monitoring and have this commission be an oversight, it has expressed too that if the bodies come to the agreement that we don't want to, not that I'm not interested, and not that I'm not responding to you as a private citizen, but I'm not here as a commissioner tonight.

RESPONSE 6-4

The RCRA public involvement process is specified under regulation, which does not provide for the establishment of another coordinating body like a CAG. However, if any citizen wishes to participate in our decision making process, we are open to discussing ways to accommodate the request. Please refer to the Response to General Comment No.1.

Regarding the level of community participation in the public workshops and public hearings that have been held on this project, the number of members of the public that have attended ranged from approximately 8 to 15 persons.

COMMENT 6-5

Also, you should also know that the citizen participation has been half-hearted and I wish there was more. I am grateful for people like Tom Kelly stated, it would be great if you could draw a line and not bring back the 2001 remembrance of being here. There are many, many reasons why the community has reacted to you the way that they have. And I know it hasn't' pleased you, but the truth is that we have been disenfranchised by this process and that we only get brought into it a month or two or three before we have to come in for a meeting like this and sign off. And that's what this meeting is, it's a sign-off. And so we haven't had the kind of process that's necessary.

RESPONSE 6-5

LBNL has been placing all project related documents in the Berkeley Public Library for public review at the same time that they have been submitted to DTSC. The CMS Report was available in the library in July 2004, approximately 10 months prior to the public hearing. At that time we announced we would accept public input on the report throughout out technical review. DTSC previously informed the public that it was free to review and comment on documents at any stage. Therefore, DTSC respectfully disagrees with the comment that “not enough time has been provided” to review documentation on this project. Please see the Response to General Comment No. 1 for more details on the availability of documents for review by the public.

COMMENT 6-6

I was appalled at the fact that DTSC would dare send a letter to our city government regarding a community CAG. As I understand it, a CAG is driven by community members, not by the City of Berkeley, but by community members. Yet, we didn't even request to DTSC to have a CAG, but you were already responding politically to the City of Berkeley. That to me is indicative of how political this process is and how much we have sat in the back seat of this process and we are very, very concerned about that.

RESPONSE 6-6

It was brought to DTSC’s attention by a City of Berkeley representative that a request for a Community Advisory Group was going to be brought before the City Council by the Community Environmental Advisory Commission. DTSC took the proposal under consideration and determined that the Berkeley City Council should have additional information when they considered this matter at their May 24, 2005 session. That was the reason the letter was sent to the City Council members and the City Manager. Also, please refer to the Response to General Comment No. 3.

COMMENT 6-7

I know that I have been working now at the Richmond Field Station, and I recognize what happened out there. It found itself in this quagmire, regulatory quagmire, where you couldn't get responsibility out of anyone, no one was being responsible, no one was taking protective action. So what did they do, they went to Cal EPA and maybe that's what we need to do as a community group, go to Cal EPA and say, hey, we're an affected community, we've been standing here for 15 years trying to get the facts and can't get them. And I say that, and I look at this letter that you sent to the City Council saying, oh, we would prefer to deal with community groups.

RESPONSE 6-7

DTSC has been and will continue to be transparent in its oversight of the LBNL’s implementation of these corrective measures. If, at any time, community members have questions or concerns, they should contact Nathan Schumacher at his toll free number, 1-866-495-5651 or send E-mail at NSchumac@dtsc.ca.gov. Mr. Schumacher and other DSTC staff will respond to all such inquiries as quickly as possible.

Regarding the DTSC letter to the City of Berkeley, City Council, please refer to Response 6-6.

COMMENT 6-8

Well, what we really need is for the community members to come together so you don't have to give the information to each of us one at a time. When I call your offices what response do I get? I get the sense that I'm wasting your time and I'm taking away your workday, and maybe I am, but if each one of us does that, do you see how problematic the education of the public is. And that is what this public participation component is all about, and we missed it. And as a matter of fact, six months ago I asked for some information regarding this process that I thought was critical that was public information. I waited over a week so that DTSC's attorney could make the determination that, yes, these documents should be given to me. And I would say that's a back seat that we don't like with DTSC.

RESPONSE 6-8

DTSC strives to be responsive to public information request. However, DTSC also has legal obligations to facilities to not release trade secret information which is submitted to DTSC. Therefore, sometime, a decision on whether a document can be made available to the public may take us a week or longer. As noted in Response 6-7, DTSC staff will respond to all inquiries as quickly as possible.

COMMENT 6-9

We recognize how difficult it is to come and regulate a business when that business is the federal government, when that business is DOE. That is a very difficult thing. We know it because we live in a community where we have to go approach that business at the federal building, at DOE processes, and not just in a normal zoning process that we would normally deal with any business. So we meet them there. And so what I'm asking from you tonight, and I think a number of us are asking for, is for you to look at this. Look at this failed process. It has some elements that work. And for the people that are coming around, because, you know, we're known entities here and we are trying to educate ourselves piecemeal, and your workshops are only a product of a year ago when you came to the process and said, well, hey, it's not working here, and you said, well, if you sit down with us across the table so we could ask you questions, it would be great, and at least we had some of that happening today. But you know what the problem is, it's too little, too late. Fifteen years and here we are.

RESPONSE 6-9

DTSC would like to again reiterate that it believes that all documentation related to Corrective Action at LBNL has been made available to the public at the same time it has been submitted to DTSC. DTSC appreciates the technical complexity of this information and that is why it has held public workshops prior to public hearings to inform the community. This activity was in addition to Fact Sheets and surveys regarding investigations at the site. DTSC points with pride at its public outreach activities as described under the Response to General Comment No.1. DTSC is committed to continuing this public outreach during future phases of corrective action activities at LBNL.

COMMENT 6-10

Accelerate the cleanup. Someone talked about the money. Damn right the money pushes this process. Don't be dizzy thinking it doesn't. This is a political process. Environmental protection is a political process. In 2000, I think I was over in San Francisco with some of the staff here at the DOE when you were talking about waste management saying, well, here comes Bush, we know what's going to happen to environmental protection. And that's what has happened to it, it's gone away, it hasn't been there to stand up. That's why we see some of the cleanup actions are non-cleanup actions. And it's fearful for us that we would have the cleanup process take place in a political time where we had someone who is not responsible for cleanup, because we know that we're still here with the contamination. So, hey, don't clean it up now if you don't want, but what we want from you is a guarantee that you will clean it up and that you will monitor and track it and track the person that polluted it, because I think that's important. I think of all the things, solar energy and all of the magnificent science, things that come from the Lab, environmental protection is not one of them. It doesn't come. Environmental Restoration. If you look up there at the last 30 years, you could write a book on failure, that's why I'm here tonight.

RESPONSE 6-10

Regarding the implementation (including monitoring and tracking) of these corrective measures, DTSC and LBNL are both committed to cleaning the remaining contamination at this facility. Regarding the quality of the cleanup actions at LBNL, there were pilot studies conducted on several groundwater remediation technologies. LBNL reviewed and selected the best available technologies for groundwater remediation at this site. DTSC has required this cleanup under the HWHF permit issued to LBNL. This is the enforceable mechanism that DTSC has used and will continue to use to ensure remediation activities are implemented by LBNL and its funding agency, the DOE. LBNL and DOE have shown that they are committed to completing the cleanup at this site and DTSC anticipates the same commitment to continue into the future.

COMMENT 6-11

And also, I do want to mention one more thing about the radiation issue, because I'm not going to try to address that in my comment, because it's a serious issue. You've got the radiation just like this and you posture up one slope at one median and say it's not our jurisdiction and another. And tonight we've talked about it in two different terms and we need to have a different kind of process, we need to have the cooperation.

In 1999 when our City Council unanimously supported us being involved in the environmental restoration program at LBNL, that would have been a perfect opportunity for you to allow a few of us, a commissioner, a few people from community groups to come forward to sit there instead of putting us to this point so I have to stand up here tonight and so we have to push against you and so I have to file public records requests or I have to call your phone and harass you because you won't even tell me that I call you too much. And that's what's wrong with public participation.

So if you want us to buy in, there's a lot you can do beyond just the program you put up on the table. I don't think the program you put on the table is an appropriate one for this community. I believe that you need to clean that site up to the way that you found it, and I think that that’s the least that this community be owed and I believe that I -- and I respectfully request that DTSC look at this issue, a community action group, call it what you want, and set up a process so that we can essentially monitor it at least for the rest of the cleanup, and that, you know, we be a part of some of the fine tuned parts of the process after you just rubberstamp and go up there, and that we be a part of that process so we can monitor it. And that you take our comments seriously, because I feel as though I've made lots of comments through this process and I don't see one of my comments embraced by anything that LBNL has done over the last 15 years, and that's very disappointing to me that things that I've offered have not been obstructionist, they have been protectionist, and I don't see any of them. Thank you.

RESPONSE 6-11

DTSC would like to acknowledge that the commenter feels frustrated regarding the public outreach between himself and DTSC on this project. DTSC believes it has made a good faith effort in reaching out to concerned citizens such as the commenter and organizations such as the Committee to Minimize Toxic Waste. As stated in responses 6-4 and 6-5 as well as Response to General Comment No.1, DTSC has made extensive outreach to the community on this project. It is unfortunate that the commenter does not have the same opinion.

COMMENTER #7 Ms. Jane Kelly

MS. KELLY: Hi, my name is Jane Kelly. I'm a resident of Berkeley. I am very new to this discussion. I certainly have zero scientific credentials, and to be perfectly frank, I don't know much about the issue, the contamination, that we are talking about this evening.

COMMENT 7-1

However, I have spent the last seven years of my life working for a firm that specializes in community outreach and public participation. And as a neutral observer, I believe it's fair to say that this is not working. There is obviously a large measure of distrust from the community. This is not a functioning dialogue and I just wanted to say that we in my firm would strongly advocate the establishment of a citizens' advisory group. It's a good thing. It is truly a good thing. I have seen it work extraordinarily well over the past seven years, I would ask you to embrace it. I'm sure nobody likes to have this conflict, I know you don't and I know these folks don't, and I really do believe that if you accept this and embrace it and form a citizens advisory group and set the past aside and start over, that this can truly be a good result.

RESPONSE 7-1

DTSC concurs with the commenter regarding the importance of community outreach and public participation. As stated in the Response to General Comment No. 1, DTSC believes that it has been conducting a very robust community outreach effort on this project.

COMMENTER #8 Ms. Tuala Gordon

MS. GORDON: I'm Tuala Gordon at 1546 Milvia.

COMMENT 8-1

And on behalf of Save the Strawberry Creek Watershed, I would like to hand you a petition to save the Strawberry Creek watershed signed by over 400 individuals reflecting wide community concern over the contamination at LBNL, and wide community interest and support for the preservation, cleanup, and responsible management of the headwater areas of Strawberry Creek. [Petition requested the following]

Stop the further destruction of the Strawberry Creek Watershed.

RESPONSE 8-1

DTSC acknowledges the receipt of petition to save Strawberry Creek Watershed signed by 400 plus individuals reflecting wide community concern over the contamination at LBNL and community interest/support for the preservation/cleanup of the head water areas of Strawberry Creek.

Regarding the Strawberry Creek Watershed and the contamination at LBNL, please see Responses to several other comments including Comment 9-2, Comment 9-6, and Comment 15-1.

COMMENT 8-2

Prepare an Environmental Impact Report. LBNL avoided conducting an EIR for the Molecular Foundry as required in the law.

RESPONSE 8-2

Please be advised that the UC Regents is the lead agency under CEQA for the molecular foundry project, not DTSC. Accordingly, we suggest that the commenter direct her concerns related to CEQA and the molecular foundry directly to the UC Regents office.

COMMENT 8-3

Acknowledge that Nanotech may have serious health and environmental impacts. The US EPA states that the health effects and environmental impacts of nanotechnology are unknown. LBNL claims that there is no danger, yet they have no scientific evidence to support that claim. Ultrafine particles, similar in size to nanoparticles, cause respiratory and cardiovascular disease.

RESPONSE 8-3

Please note that DTSC is not in a position to make any statements regarding nanotechnology. DTSC does not have any regulatory authority in this area.

COMMENT 8-4

Decontaminate existing buildings that have been decommissioned. LBNL has contaminated and abandoned its own buildings on the site. LBNL should remediate this contamination instead of constructing new facilities in the watershed.

RESPONSE 8-4

LBNL is in process of cleaning up past contamination at the site. There are buildings where decommissioning will occur such as the Bevatron Building. That building would be under the oversight of DOE, not DTSC.

COMMENTER #9 Ms. Pamela Sihvola

COMMENT 9-1

My name is Pamela Sihvola, and I co-chair on the Committee on Toxic Waste here in Berkeley We have followed the situation at LBNL, myself personally for over a decade, and the environmental condition since the early 1990s.I will repeat what I said before. I believe the verification of risks. We heard from DTSC, it's indeed misleading, if all radioactive contamination and exposure has been involved. Also, as I said before, it appears that the methods used as a foundation for these investigations is flawed. It is based only on known contamination or known activities, and indeed if you are truly following the scientific process, a lot of the grounds and higher than the Strawberry Creek watershed should have a grid, and in each grid within a certain known distance from each other, monitoring wells to see if the contamination has spread beyond what these subjects that we are currently dealing with indicate.

RESPONSE 9-1

The commenter raises a question on radioactive contamination and exposure. We respectfully refer the commenter to the Response to General Comment No. 2 for more details regarding radioactive contamination.

Regarding the commenters' assertion that the investigation methods conducted to date were not based on sound scientific principles, DTSC must respectfully disagree. The facility investigation followed the standard environmental investigation approach which sequentially identified areas of potential contamination, confirmed the status of potential contamination, and then defined the lateral and vertical extent of contamination when it was identified. This approach is based on the scientific principle of biased sampling and it is designed to optimize the ability to identify and define areas of potential surface and subsurface contamination. The investigation approach focuses on areas of contamination and allows for the incorporation of additional information such as site history, groundwater flow gradients, and contaminant migration characteristics that would otherwise not be considered if the investigation were based on uniform monitoring grid approach that you recommend.

DTSC has conducted an assessment that evaluated past operating practices and historical uses of the site. It identified where spills, leaks, or other chemical releases either occurred or could have occurred.

Eight of the 163 units were identified as radiological units that are addressed under the authority of the US Department of Energy.
References

- RCRA Facility Assessment for Lawrence Berkeley National Laboratory, Department of Toxic Substances Control, Region 2, November 1991
- RCRA Facility Assessment at the Lawrence Berkeley National Laboratory, Environmental Restoration Program, September 30, 1992

COMMENT 9-2

The Strawberry Creek watershed has a very complex hydrogeology. And actually what I would like to do is to bring up the map. For many years we have asked the Lawrence Berkeley National Laboratory to provide a comprehensive site map that would include the entire watershed. What we did with the help of UC Berkeley, we put together several overlays which are based on the 1875 surveyor map of the vicinity. Everything in blue indicates the original historic creeks. Everything in red indicates the USGS fault lines in the canyon. Everything in that area is in the middle here. The black spots indicate the groundwater contamination plumes.
These red lines here, these are related to the east canyon Wildcat Fault which is a fault zone on the eastern side of the canyon, an LBNL site. This is the Hayward Fault Zone, and there are cross faults, the New Fault, and similar cross faults across the LBNL site.

RESPONSE 9-2

Mapping conducted for the Converse Consultants 1984 geologic synthesis and for the LBNL RFI provides data that extends a significant distance beyond the LBNL boundary and is sufficient to address the needs of the corrective action investigations. This mapping includes a substantial portion of the Strawberry Creek watershed east of the UC campus. A synthesis of geologic and geotechnical information for the entire Strawberry Creek watershed would involve mapping of a large area outside the boundary of LBNL. This is beyond the scope of the corrective action investigations, and is not necessary to address the characterization and migration potential of contaminated soil and groundwater. Please note that the RFI report clearly indicates that nature and extent of contamination is well established and mapped.

Based on the site assessment, DTSC has conducted site investigation over eight years (1992-2000). DTSC implemented a screening process that determined which units with soil contamination should be evaluated further due to potential risks to human health and the environment, and which units should be excluded from any further action. Soil screening process consisted of a comparison of the concentrations of chemicals detected in soil to all three standards: LBNL background levels, US Environmental Protection Agency Region 9 Preliminary Remediation Goals (PRGs) for residential soil, and California modified PRGs for residential soil. Chemicals detected at 30 units were considered potential threat to human health or the environment.

References

- Draft Final RFI Phase I Progress Report, Environmental Restoration Program, Lawrence Berkeley Laboratory, October 30
- Draft Final RFI Phase II Progress Report, Environmental Restoration Program, Lawrence Berkeley Laboratory, November 1994
- Draft Final RFI Phase III Progress Report, Environmental Restoration Program, Lawrence Berkeley Laboratory, September 1995

- Draft Final RCRA Facility Investigation Report for the Lawrence Berkeley National Laboratory, Environmental Restoration Program, September 2000

COMMENT 9-3

You can see that the plumes have odd shapes. This is a plume here, it is flowing in an old creek bed of Chicken Creek, and I can't really -- I understand that anyone by looking at the shape of this one or this one or this one or this one, can you say that these plumes are contained? They clearly have moved. The source of contamination that sweeps forth right here and all of these that you see here is moving downstream, downstream along the old creek bed, and the canyon wall is here.

The water contamination is up here, so the BLC plume is also moving south to the canyon bottom. And then the other water here, which is in the Blackberry Canyon watershed, is moving along the north slope of Strawberry Creek, as are these other plumes.

RESPONSE 9-3

Groundwater contaminants at LBNL initially moved down-gradient from the locations where the original chemical spills or leaks occurred, thereby forming groundwater contaminant plumes. These plumes eventually reached equilibrium and further down-gradient movement of the plumes stopped. The shape of a plume cannot be used to determine whether or not it is currently moving, but is the result of the combined effects of several factors including: a) the locations of the original spills; b) the chemical properties of the contaminants, c) the groundwater gradient (direction of flow) and velocity; d) the time since the initial contaminant release; and, e) the action of natural and artificial mechanisms (diffusion, dilution, degradation, pumping etc.) that attenuate (reduce concentrations of) contaminants. The plumes stabilized after attenuation processes reached equilibrium with the factors that caused them to move. The groundwater contaminant plumes at LBNL are not currently moving, and there is no evidence of recent movement, based on data collected over the past 13 years.

The degree of containment of a plume cannot be determined from its shape, but, must be assessed by viewing variations in contaminant concentrations with time in key monitoring wells. Such data are presented in detail in both the RFI and CMS Reports, and show that the groundwater contaminant plumes are contained; that is, the concentrations of contaminants remain relatively static or are have been decreasing in key wells monitoring the down-gradient edges of the plumes.

LBNL monitors the quality of water in creeks flowing offsite, including tributaries of Strawberry Creek. No chemicals of concern have been detected in surface water samples collected over the past seven years. The long-term surface water monitoring program at LBNL will consist of annual sampling for Volatile Organic Compounds (VOCs) and metals during the rainy season and also during the dry season from creeks that are flowing. Surface water sampling requirements will be specified in the Groundwater Monitoring and Management Plan.

Please note that LBNL submitted a CMS Workplan in May 2002. The primary purpose of the workplan was to appropriate remedial alternatives that were to be considered and evaluated to eliminate, reduce, or control risks to human health and the environment from the contaminants identified during the investigation. The CMS Workplan determined that in addition to 30 units, six other units required further evaluation. This determination was based partly on new findings for some of the areas and partly on comparison of chemical concentrations in the soil to the most updated PRG values. The CMS Workplan also specified that all locations where chemicals were detected in groundwater and surface water were to be included in the CMS.

All issues in the draft Final RFI report have been addressed during the course of examining 155 units (both SWMUs and AOCs). These 155 units have been reported at quarterly intervals.

Reference

- RCRA Corrective Measures Study Plan for the Lawrence Berkeley National Laboratory, Environmental Restoration Program, May 2002

COMMENT 9-4

In 2003, we met with Mohinder Sandhu and his staff. We sent them a letter requesting that DTSC request LBNL to provide for the benefit of the community a comprehensive map that would show all these elements, including slide zones, sewer lines, every possible element that will impact the site and the movement, and that would add to the contamination. They refused to do that. The DTSC said we are not going to ask LBNL to do that. Of course, we have asked LBNL to do it on our own. We don't see a comprehensive map here, everything is piecemeal. When you look at the site on the RSI report, they are all 8 1/2 by 11 sheets, 8 1/2 by 17 sheets. You don't get the comprehensive view. I'm asking that this be remedied before any final decision is made on these corrective measures. There should be a map that would show the whole entire site, all of the elements. And I will also add in more detail in my written comments.

RESPONSE 9-4

The RFI Report presents a unified site-wide approach to characterization of the site and assessment of surface and groundwater pathways for contaminants. Data on stream courses, geology, faults, landslides, areas of contamination, hydraugers, storm drains, and springs were all considered in this analysis and maps of these features are presented in the RFI Report. The scales and areas selected for maps of these data were selected to best illustrate the features of interest. All the mentioned features are not compiled on a single map, since showing numerous features on one map creates a figure that is crowded, confusing, and difficult to interpret. The locations of sanitary sewer lines are not relevant on a regional basis, but have been considered in the detailed site-specific investigations presented in the RFI Report for cases where they potentially impact contaminant migration.

Please see Response to Comment 9-2 for more details.

COMMENT 9-5

And I would like to read for the record what I read before from a 1949 geologist's report for this site, where the Orinda Formation is used as the foundation for not cleaning up these plumes. The Orinda Formation, and I'm not going to read the whole thing here, the area as available is a four-acre site needs to be X-rayed, this is 1949 before the building was constructed, and leveled off. The bedrock beneath this beveled surface will be comprised of poorly consolidated marine sediments. The Orinda Formation absorbs water freely and a lot of those features that are associated with it are also quite pervious so the whole mass is really saturated in the area adjoining the Lisbon Tract to the east, which is comprised of the same formation as those under consideration, all the Lisbon Tract. They had 68 streams from which they once collected water for the domestic supply of Berkeley in the early days. There appears to have been considerable landsliding in this active area, and the appearance of heavy rainfall, the deep overburden and underlying marine sediment becomes quite soft from the absorbed water, seeps come out of the ground in many places, and even while several inches of rain are falling, this was a stream in 1949. There are about four seeps issuing from the ground in the vicinity of the Bevatron.
There are two known permanent streams in the area where puddles have been at the old site, and pipes leading out from the paved entrances have been flowing water for many years. There is a sump pump in

the basement of the Bevatron pumping water constantly. The former water reports water from each well, and it is these three wells here, all of which flow to Strawberry Creek.

RESPONSE 9-5

The 1949 report by Marlave cited in the comment provides subjective observations of surface infiltration only in a very small part of LBNL, so it cannot be used to estimate permeability for the Orinda Formation either below the water table, or throughout the facility. The CMS Report notes that rocks of the Orinda Formation have low permeability values with the exception of a few areas where permeability is relatively high apparently due to the local presence of coarse-grained strata. The hydraulic conductivity (permeability) of the saturated portion of the Orinda Formation at LBNL has been extensively tested in numerous locations by hydraulic testing and yield testing of monitoring wells. The results of these tests are documented in the RFI and CMS report.

Please see Response to Comment 9-2 and 9-3.

COMMENT 9-6

The creeks don't seem to exist. The water goes somewhere and we need to see a comprehensive diagram that shows where all of these waters are going right at the moment, and indeed, the formation of a citizen advisory group, and we would like to call it citizen watershed advisory group, should be formed to include many citizens who are very interested in the three issues in the city of Berkeley. The city of Berkeley has a policy of day-lighting creeks downstream. There is a proposal currently considered for the west campus site to open Strawberry Creek there. They are day-lighting sections all the way down to the bay. And there is community-wide interest in the creeks and the leveling of the creeks, and I think it is absolutely imperative that DTSC will sponsor a citizen watershed advisory group to address all of these issues to guarantee that we will have clean, good water in Strawberry Creek from here on and for years to come. It is very, very important, and I would comment, as I said, more in detail in my written comments. But I ask you to consider for the group and those 400 signatures that you already have received, they are a foundation to show that there is wide community interest in this issue, and I hope that you will start helping us starting tonight. Thank you.

RESPONSE 9-6

As noted in Response to Comment 9-3, LBNL monitors the quality of water in creeks flowing offsite, including tributaries of Strawberry Creek. No chemicals of concerns have been detected in surface water samples collected over the past seven years. The groundwater plumes at LBNL are not a source of contamination to Strawberry or any other creeks that originate in the Berkeley hills.

COMMENTER #10: City of Berkeley, Phil Kamlarz, May 26, 2005

COMMENT 10-1

The Berkeley City Council recently took a position on the process of cleaning up legacy pollution at the Lawrence Berkeley National Laboratory. Please accept these comments in addition to comments made by the City's Toxics Management Division.

The City encourages the Department of Toxic Substances Control (DTSC) to clean up the site to the most restrictive cleanup standards feasible. To this end, the City seeks additional funds from the Department of Energy to fulfill this goal.

The City also encourages the DTSC to use the Community Environmental Advisory Commission meetings as a venue to disseminate information, receive public input, and respond to public concerns for the long term monitoring of any pollutants left in place.
In addition, the City requests that DTSC and the Water Board review the geological structure of the campus in more detail to determine if pollution plumes are fully delineated and stable or whether the complex geology will permit migration downhill or into surface or near surface water.

RESPONSE 10-1

Regarding the cleanup of the site to the most restrictive cleanup standards feasible, the DTSC is aware of the City of Berkeley's concerns with cleanup standards for LBNL. DTSC considers applicable requirements of all local, state, and federal laws and regulations in establishing site specific cleanup goals that are protective of human health and the environment. Some of the applicable statutes include, but are not limited to, the Safe Drinking Water Act, the Solid Waste Disposal Act, the Toxic Substances Control Act, the Clean Air Act, and the Clean Water Act. DTSC applies these requirements consistently at regulated sites all across the State of California in accordance with nationally accepted risk assessment guidance protocols. In addition, DTSC also evaluates the long term and short term effectiveness of proposed remediation alternatives, Please note that the long-term goal for groundwater cleanup goal is MCLs. In some case, due to technology limitations, this goal may not be feasible. DTSC believes that goal of achieving MCLs may be highest possible standard in this case.

DTSC agrees with the City of Berkeley's recommendation to use the Community Environmental Advisory Commission meetings as a venue to disseminate information, receive public input and respond to public concerns regarding the long term monitoring of groundwater contamination at LBNL. DTSC has and will continue to work with CEAC to share information and seek input on this project.

Regarding the geological structure of LBNL and the migration of contamination, please refer to Response to Comment 9-6.

COMMENTER #11 East Bay Municipal Utility District, William R Kirkpatrick

COMMENT 11-1

East Bay Municipal Utility District (EBMUD) appreciates the opportunity to comment on the Negative Declaration for the Department of Toxic Substances Control Proposed Soil and Groundwater Cleanup at Lawrence Berkeley National Laboratory located in the City of Berkeley. EBMUD has no comments regarding environmental issues for this project.

RESPONSE 11-1

Comment noted.

COMMENTER # 12 Andrea Pflaumer

COMMENT 12-1

As a resident in the Northeast Berkeley Hills I am deeply concerned about the groundwater clean-up (and the eventual site clean-up) at the Lab. I want to strongly encourage you to develop a citizen review/action panel similar to the one that was formed after DTSC took over the Campus Bay project from Richmond.

RESPONSE 12-1

Please refer to Response to Comment 1-8 regarding a Community Advisory Commission.

COMMENTER #13: Sean Nozzari, District Office Chief, Office of Permits Department of Transportation, District 4 (letter dated June 7, 2005)

COMMENT 13-1

Thank you for including the California Department of Transportation (Department) in the environmental review process for the corrective Measures Study project. The comment presented below is based on the Negative Declaration (ND), and applies only if the project involves work in the State Right of Way (ROW). As lead agency, the Department of Toxic Substances Control is responsible for all project mitigation, including any needed improvements to state highways. Please notify the applicant that the Department will not issue an encroachment permit, discussed below, until our concerns are adequately addressed. Further comments will be provided during the encroachment permit process; see below for more information regarding encroachment permits.

Work that encroaches onto the State ROW requires an encroachment permit that is issued by the Department. To apply, a completed encroachment permit application, environmental documentation, and five (5) sets of plans clearly indicating State ROW must be submitted to the address below. Traffic-related mitigation measures should be incorporated into the construction plans during the encroachment process. See the website link for more information.
http://www.dot.ca.gov.hq/traffops/developserv/permits/

RESPONSE 13-1

This project does not involve any work in the State Right of Way.

COMMENTER #14: D Thompson and KJ Sharp (letter dated June 8, 2005)

COMMENT 14-1

Since 1988, we have been two of the Lawrence Berkeley National Laboratory's nearest downstream neighbors. A daylighted portion of Strawberry Creek's North Fork flows across the street in front of our home. Hence we are eager to hear of any progress being made to clean up soil and groundwater contamination stemming from Lab operations over the past 65 years.

On the technical side, neither of us feel qualified to judge whether the recommendations set forth in the DTSC's Draft Corrective Measures Study are adequate to remediate this legacy contamination to the highest standards feasible in the most cost-effective and timely manner.
However, from the standpoint of *public involvement*, we think that the cleanup effort – if handled correctly – represents a great opportunity for your agency (and LBNL) to build visibility and some much-needed good will among the Lab's residential neighbors.

For this reason we strongly suggest that the DTSC do everything within its power to encourage that a Citizen Watershed Advisory Group (CWAG**)** be established to track implementation of whatever corrective action measures are adopted.

We are aware that the Berkeley City Council recently frowned upon this idea when proposed by Berkeley's Community Environmental Advisory Commission. Likewise, we know that LBNL typically prefers to limit citizen participation in oversight activities to the bare minimum required under the law. Yet it is our understanding that CWAG will be associated with DTSC's new cleanup effort near UC's

Richmond Field Station. If appropriate for Richmond, why shouldn't a CWAG also be a part of the DTSC's cleanup strategy for LBNL?

Our feeling is that to be real, "public involvement" should be more that a DTSC fact-sheet title, an annual public hearing, or a headline in one of the Lab's many PR publications.

RESPONSE 14-1

DTSC appreciates the commenter's concerns. DTSC believes that the LBNL site is properly characterized to identify past releases and the proposed remedies in the CMS Report are proper cleanup measures to address soil and groundwater contamination at this site.

Please refer to the Background, Past Public Participation section of this Response to Comments document regarding DTSC public outreach activities.

Please refer to Response to Comment 1-8 regarding a Community Advisory Group.

COMMENTER #15: Mr. Bill Walzer (letter dated 5/28/2005)

COMMENT 15-1

I own a house on Allston Way that has Strawberry Creek running through the backyard. It is lovely but would be so much richer if more fish could survive in it. Please do everything to clean up the contamination up at the Lab.

RESPONSE 15-1

Soil and groundwater contamination at LBNL are not affecting plants or wildlife either at the Lab or at offsite areas. LBNL monitors the quality of water in creeks flowing offsite, including tributaries of Strawberry Creek. No chemical contaminants have been detected in surface water samples collected over the past seven years, and ecological risk assessments conducted using historical data showed no adverse effects to plants or wildlife. Monitoring of surface waters at LBNL will continue during the remedy implementation phase which will be overseen by DTSC.

COMMENTER # 16 Sihvola – Wood (letter dated June 7, 2005)

The following comments represent years of community effort, frustration and disappointment with regulators in our commitment to analyze, inform, and insist on seriously cleaning up Lawrence Berkeley National Laboratory site's radioactive and hazardous chemical contamination from the air, soil, soil water, groundwater, creeks, trees, vegetation, and aquatic species on the University of California lands in the headwater areas of the Strawberry Creek watershed in Berkeley and Oakland.

COMMENT 16-1:

DANGEROUS TOXIC CONTAMINANTS WILL REMAIN IN SOIL AND GROUNDWATER!
The proposed CMS Report is a good start but certainly it does not qualify to be called site cleanup, but rather it is a token cleanup plan that will leave in place at least 80% of the existing, kwon contamination for future generations to deal with. The CMS process is being used to facilitate LBNL's application to review its Hazardous Waste Handling Facility's operating permit. LBNL is a contaminated site that needs immediate, comprehensive cleanup and a Groundwater/Surface water Monitoring and Management Plan.

RESPONSE 16-1

Please note that the CMS and the permit renewal are two discrete issues that are being addressed independently. The Corrective Measures Study investigations are not being used to facilitate LBNL's permit renewal application for the Hazardous Waste Handling Facility. LBNL was directed to implement Corrective Action investigations in accordance with the May 1993 permit issued by DTSC and will continue to do so even after a permit renewal decision is made.

Regarding the comment that the cleanup is a token cleanup that will leave 80% of known contamination, this comment was also raised by commenter 1. Please refer to Response 1-7 which responds to this issue.

Regarding a Groundwater Monitoring and Management Plan, LBNL will prepare one as part of the Corrective Measures Implementation (CMI) phase. The Plan will include: a description of the vertical and lateral extent of groundwater contamination; a listing of specific perimeter groundwater monitoring wells that will be used to monitor potential migration; a description of specific surface water monitoring requirements; and, a description of LBNL management controls. The plan will include surface water sampling requirements.

Throughout the investigation phase, LBNL has implemented interim corrective measures to protect human health and the environment. These measures included excavating soil contaminated with solvents, metals, PCBs or petroleum hydrocarbons; removing source of groundwater contamination; eliminating pathways that could contaminate groundwater or surface water, and preventing further migration of contaminated groundwater. Groundwater has been pumped and treated to non-detectable levels of contaminants using activated carbon. The treated water has been discharged to sanitary sewer under East Bay Municipal District permit or reused during pilot tests to flush contaminant from the subsurface.

Examples of interim corrective measures include:

- Excavation of contaminated soil and offsite disposal - 20 locations
- Removing contaminants from subsurface soil using Soil Vapor Extraction - 2 locations
- Removing contaminated equipment/material and offsite disposal - 3 locations
- Pumping contaminated groundwater and surface treatment - 10 locations
- Collecting and treating contaminated subdrain water to protect surface water - 3 locations

References

- RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory, Environmental Restoration Program, February 2005 (See section 1.3.3 for a detailed listing of Interim Corrective Measures)

COMMENT 16-2:

We ask that DTSC require LBNL to include an analysis of the Environmental Impacts from the proposed and continued operation of the Lab's Hazardous Waste Handling Facility (HWHF) in LBNL's Long Range Development Plan Environmental Impact Review (LRDP EIR), currently under preparation. In addition, we request that DTSC postpone its decision regarding the LBNL HWHF permit renewal until after the LRDP process has been completed. (Attachment A.)

RESPONSE 16-2

These issues are outside the scope of this CMS project. These same comments were raised during the Hazardous Waste Handling Facility draft permit comment period and they will be addressed in a separate Response to Comments document associated with a final permit renewal decision.
Note – Attachment A referred in the comment is included as Attachment 27 in the list of Attachments at this end of this document.

COMMENT 16-3

15 YEARS OF INVESTIGATIONS WITHOUT MEANINGFUL COMMUNITY INPUT! The lack of any meaningful citizen participation caused the Berkeley City Council on November 2, 1999, to formally request that members of the Berkeley community be included at the RCRA Quarterly Review Meetings (Attachment 1). DTSC, Department of Energy and LBNL all refused to allow any community participation at those meetings.

Instead, the Lab's response was to provide only an hour-long presentation, just four times per year, by a LBNL representative at 6PM before the officially scheduled Community Environmental Advisory Commission's (CEAC) meeting at 7PM. This untimely arrangement was poorly noticed and attended, providing no chance for the public to gain comprehensive understanding of the RCRA activities at LBNL, nor was there any time for meaningful discussion or input.

DTSC has failed to engage the public and for this reason we request that DTSC sponsor a representative Community Advisory Group that would be involved in the development of the Groundwater/Surface Water Monitoring and Management Plan (Attachment 2).

RESPONSE 16-3

DTSC understands the concerns regarding public participation. DTSC strongly believes that for the past several years, it has implemented numerous suggestions made by CMTW etc. to enhance the public participation activities. We are disappointed however, that the commenters fail to recognize the depth and breadth of DTSC's public participation activities in their comments.

Please refer to the Response to General Comment No. 1 for more details regarding public outreach activities by DTSC.

Please refer to Response to General Comment No. 3 regarding a Community Advisory Group.

Note – Attachments 1 and 2 referred in the comment are included as Attachments 10 and 11 in the list of Attachments at the end of this document.

COMMENT 16-4

HISTORY/BACKGROUND OF CONTAMINATION AT LBNL. The Lab originated on the UC Berkeley Campus in 1932 as the UC Radiation Laboratory (the Rad Lab). In 1940 it was relocated to its present site in the Strawberry Creek Watershed in the steep Berkeley Hills, east of the Central Campus next to the Hayward Earthquake Fault. The first major facility, the 184" Synchrocyclotron was built with funds from both private and university sources. After 1948, the US Atomic Energy Commission and its successor agencies funded the Lab. In 1972, the name was changed to from the Lawrence Radiation Laboratory to Lawrence Berkeley Laboratory.

From the past 65 years radioactive and chemical releases, and accidents have contaminated the once beautiful, pristine watershed of the Strawberry Canyon and nearby wild lands, affecting neighboring residents, and school children attending the Lawrence Hall of Science, as well as people recreating on the canyon trails, swimming etc. (Attachment 3.)

The first Environment, Health and Safety related assessment of LBNL made by DOE was published in 1988. This first assessment was followed by Tiger Team Report of 1991 which found 678 violations of DOE regulations concerning management practices at LBNL, finding Berkeley-Oakland air, soil, and water contaminated with tritium, other radioactive substances and toxic chemicals. It is indisputable that the Lab was not in compliance with federal standards for radioactivity in air. Because of these findings, DOE funded the California Agreement in Principle (AIP) Program to be conducted by the California Department of Health Services (DHS), which has jurisdiction over radioactivity in California.

In September of 1995, the DHS Environmental Management Branch released the AIP Annual Report (Attachment 4). One of the AIP Report's criticisms was over the "efficiency and validity of the methods employed at LBNL to measure and monitor air-born tritium" (p.14). We believe this criticism caused DOE to cut the funding for the entire program a few months later. DOE then took over the handling of the 8 radioactively contaminated sites at LBNL for which the DHS Report had expressed serious concern. To Date, no report has been released for public review and comment regarding corrective action for clean up of these radioactive sites!

RESPONSE 16-4

According to the Department of Energy, which is the lead agency for investigation of radionuclides at LBNL, the Summary of Radionuclide Investigations (2003) has been available for public review in the information repository at the Berkeley Public Library since August 2003.

Note – Attachments 3 and 4 referred in the comment are included as Attachments 12 and 13 in the List of Attachments at the end of this document.

COMMENT 16-5

In July 1998 the US Environmental Protection Agency determined, based upon a preliminary hazard Ranking System (HRS) score, that LBNL was eligible for the National Superfund Priorities List, (NPL) under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA or "Superfund") (Attachment 5).

RESPONSE 16-5

On July 18, 2002 the United States Environmental Protection Agency (USEPA) announced that they had changed the site's Superfund status from "potentially eligible" for listing to "no further federal response". The USEPA noted that analysis of air, water, and soil samples confirmed that the site does not present a health threat to those working and living in and around the facility.

Note – Attachment 5 referred in the comment is included as Attachment 14 in the List of Attachments at the end of this document.

COMMENT 16-6

At that same time, the State of California had listed six locations at LBNL in the Hazardous Waste and Substances Sites List, aka the Cortese List (Attachment 6). And more recently in 2001, LBNL was included in the government list of cold war nuclear sites as a "California Hot Spot", because the facility handled Beryllium or radioactive materials (Attachment 7). These facts reflect both the complexity and extent of the environmental impacts that LBNL operations have had on the Strawberry Creek Watershed lands in the Berkeley hills.

RESPONSE 16-6

The California Hazardous Waste and Substances List, more commonly known as the Cortese List, include six locations within LBNL. These sites are included as underground fuel storage tank sites where leaks had occurred. The City of Berkeley has made a determination of No Further Action for all six of these underground tank sites.

According to LBNL, they were not included in a government list of cold war nuclear sites as a “California Hot Spot”. The newspaper article provided as Attachment 7 of the comments only refers to a list of facilities that could be eligible for federal compensation under the Energy Employees Occupational Illness Compensation Act (EEOICA), a program to provide compensation to individuals who developed illnesses as a result of their employment in certain federally-owned facilities in which radioactive materials or beryllium were used. The EEOICA is only applicable to LBNL because it was a DOE facility that handled beryllium and radioactive materials, and not because of environmental impacts. LBNL stated that they have collected numerous soil samples in the area of the beryllium shop inside Building 77. None of the 105 soil samples collected shown beryllium at levels of concern.

Note – Attachments 6 and 7 referred in the comment are included as Attachments 15 and 16 in the list of Attachments at the end of this document.

COMMENT 16-7

CMS Report lacks a comprehensive, cohesive, verifiable geologic mapping of the Strawberry Creek Watershed Area at LBNL, as well as the Synthesis of Surface and Subsurface Geologic Information

LBNL is located in an area that is seismically very active, i.e., next to the Hayward Fault (Attachment 8). It is for this reason that the Final CMS report should include comprehensive, verifiable geologic mapping of Strawberry Canyon, which depicts bedrock outcrops and geomorphic features including stream courses and landslides. It should also include the synthesis of surface and subsurface geologic information previously developed independently for the University of California (UCB) and LBNL.

RESPONSE 16-7

The CMS Report is a complementary report to, and relies on the data presented in the LBNL RFI report, which is the principal site characterization document. For this reason, the CMS only presents a brief summary of the geologic characterization data presented in the RFI Report and cites the RFI report for detailed information. The RFI Report was released for public review on November 15, 2000 and public hearings were held on December 6, 2000 and January 24, 2001.

The RFI report presents site-wide maps of bedrock geologic units, faults, surficial geologic units, stream courses, storm water drainage systems, and landslides. In addition, the site was divided into module areas for which more detailed geologic maps, geologic cross sections, and hydrauger locations were presented. These maps and cross sections were based on the highly detailed synthesis of geologic data presented in the Converse Consultants 1984 Hill Area Dewatering and Stabilization report (Converse, 1984), and supplemented by additional geologic mapping and subsurface drilling data obtained by Environmental Restoration Program (ERP) scientists during the RFI. The Converse Consultants synthesis included a thorough review and analysis of all known previously existing geologic studies at and adjacent to LBNL, and presents a detailed geologic map of LBNL and the surrounding regions as Plate 2 of that report.

It should be noted that Plate 3 in the 1984 Converse Consultants report (included as Attachment 8 in the comments) is an historical compilation and is not an illustration of the geologic faults currently known to be present at LBNL. Plate 3 depicts the locations of all previously located geologic faults, including those whose presence was identified based solely on conjecture. As indicated on the note on Plate 3, "Of the faults shown, those interpreted by Converse to exist based on field investigation and a thorough review of existing geologic data are shown on Plate 2 (Geologic Map). A number of faults shown on this map *(Plate 3)* could not be confirmed including the University fault, New fault, Space Sciences fault, and members of the Lawrence Hall of Science fault complex." The lack of evidence for the existence of these geologic faults is discussed in detail in the Converse Consultants report and is summarized in that report as follows:

"Over the past 20 years various investigators have proposed the existence of numerous faults in the study area. Plate 3 shows a compilation of these faults by source. The existence of some of these faults is conjectural, while others exist beyond a doubt. Plate 2 shows those faults which could be verified and for which there is a reasonable basis for assuming the existence of a fault."

LBNL used the verified geologic map, Plate 2 of the Converse Report, as a basis for the geologic maps presented in the RFI and CMS Reports.

Note – Attachment 8 referred in this comment is included as Attachment 17 in the List of Attachments at the end of this document.

COMMENT 16-8

The LBNL Environmental Restoration Program has produced small scale, mostly building specific maps of areas where known activities had resulted in contamination of soil and groundwater. This piecemeal approach to understanding site geology has seriously narrowed the site investigations and discussions about overall impact of the contamination on the Strawberry Creek Watershed. We therefore ask that DTSC:

- Resolve confusion about the location of geologic units and associated faults by locating verifiable bedrock outcrops as the basis for geologic interpretation;
- Provide a common base of geologic information, identify sites of slop instability, especially those associated with groundwater, faults and bedrock contacts;
- Synthesize preexisting surface geologic and geotechnical information for the entire Seismic Creek Watershed.

A unified site-wide approach would provide the necessary information to better assess surface and groundwater pathways of contaminants such that an effective groundwater monitoring and management plan can be developed. This would include stream networks, geology, faults, landslides, all areas of contamination evaluated in the RCRA process, all sewer lines and hydraugers, storm drains and springs, etc.

Response 16-8

The RFI Report divided the site into four area-specific modules to present a more comprehensive integration of the soil and groundwater contamination at the site. Areas were selected for inclusion in each module based on the locations of groundwater plumes, the direction of groundwater flow, and potential contaminant migration pathways. Maps of groundwater contamination, geology, and hydrogeology were presented for each module area. Also included in each module were several site-wide maps showing geological and drainage features, and the relationship of the module area to the site. Building-specific maps were generally used to illustrate small areas of soil contamination that would have an impact only on localized areas and that could not be depicted on large-scale maps.

There is no confusion regarding the location of geological units and associated faults at LBNL. Extensive geologic mapping has been conducted at LBNL utilizing photogeology, field outcrop mapping, mapping of excavations during building construction, logging of soil borings, and hydrologic testing of groundwater wells as data sources.

Detailed information on areas of slope instability is provided in the RFI Report. Figure 4.2-7 in the RFI Report includes the locations of recent landslide deposits mapped by Harding-Lawson Associates (1982). The RFI Report also contains a landslide hazard map (Figure 4.2-8) showing areas that are considered to have a risk of landslide movement. These areas include both known historical landslide deposits (generally classified as high risk) and areas where landslides have not occurred, but that are known or suspected to be susceptible to landsliding.

Mapping conducted for the Converse Consultants 1984 geologic synthesis and for the RFI provides data that extends a significant distance beyond the LBNL boundaries and is sufficient to address the needs of the corrective action investigations. A synthesis of geologic and geotechnical information for the entire Strawberry Creek watershed would involve mapping of a large area outside the boundary of LBNL. This is beyond the scope of the corrective action investigations at LBNL, and is not necessary to address the characterization and migration potential of contaminated soil and groundwater.

The RFI Report presents a unified site-wide approach to characterization of the site and assessment of surface and groundwater pathways for contaminants. The relevant individual components mentioned in the comment (stream networks, geology, faults, landslides, areas of contamination, hydraugers, storm drains and springs) were considered in this analysis and maps of these features are presented in the RFI Report. All the mentioned features are not compiled on single map, since showing numerous features on one map creates a figure that is crowded, confusing, and difficult to interpret. The locations of sanitary sewer lines are not relevant on a regional basis, but have been considered in the detailed site-specific investigations presented in the RFI Report for cases where they potentially impact contaminant migration.

COMMENT 16-9

EARTHQUAKE DISASTER: POTENTIAL HAZARD LANDSLIDE ZONES. On February 14, 2003 the California State Department of Conservation Geological Survey released the final seismic hazard maps that illustrate the seismic hazard zones of the University of California lands, of Berkeley and Oakland (including LBNL), that encompass areas prone to soil liquefaction (failure of water saturated soil) and earthquake induced landslides.

In spite of the contention of the CMS report, areas of contamination cannot be considered “contained” in earthquake potential hazard landslide zones that appear on the Seismic Hazard maps. Landslides break road, buildings and even borders of containment plumes, cause underground soil erosion, subsidence, lateral spreading and collapse. Disturbed lands allow contaminants to migrate in the soil, soil water, groundwater, storm drains and creeks into residential neighborhoods putting at risk human and ecological health. It appears that the RCRA/CMS reports do not address such a disaster potential predicted in the event of a strong earthquake on the Hayward Fault within the next 30 years by the US geological Survey.

RESPONSE 16-9

The seismic hazard maps referred to in the comment are highly generalized maps showing that there is a potential for landslide-induced earthquakes throughout much of the Oakland/Berkeley Hills. No areas of LBNL are identified on the maps as prone to soil liquefaction. Detailed studies have been conducted to evaluate and mitigate slope stability concerns. The principal synthesis of these studies is presented in a report on the geology of LBNL by Harding and Lawson Associates (Harding and Lawson, 1982). A summary map of landslide hazards derived from these studies, and classified according to risk of failure, is presented in the RFI Report. Only a very small fraction of the areas of contaminated groundwater at LBNL is coincident with areas identified as having potential landslide risks. Even in the unlikely event that landslide slip planes cut deeply enough to intersect the groundwater surface within the groundwater plume areas, seepage rates would be limited by the low groundwater velocities, and seeps could be readily captured and treated.

COMMENT 16-10

Nor does the CMS Report acknowledge the geologic impact on the site contamination as seen in the changes in plume sizes, shapes and movement since 1992 (Attachment 9).

RESPONSE 16-10

Attachment 9 of the comment does not depict changes in plume sizes, shapes and movement since 1992, and is not valid for comparing changes in plume geometry. The Attachment compares the areas where groundwater contamination had been observed in January 1992 to the extent of groundwater contamination that was determined to be present in 1999, after extensive characterization work had been completed as part of the RFI. The figure titled “Areas where groundwater contamination has been observed (January 1992)” was based essentially on information collected from 17 groundwater monitoring wells, and therefore provided an incomplete characterization of the extent of contamination at that time. During the RFI, several hundred additional wells were installed to characterize the magnitude and extent of contamination, with the resultant definition of plume geometry shown on the figure titled “Groundwater Contamination Plumes, Second Quarter FY99” included in Attachment 9.

Both the RFI Report and CMS Report provide extensive analysis of the sizes, shapes, movement, and concentration trends within the LBNL groundwater plumes. Comparing changes in concentrations over time on a well-by-well basis provides a more accurate evaluation of the changes in plume sizes, shapes, and movement, than comparing site-wide maps of groundwater contamination based on different data sets. Groundwater concentration trend graphs for key wells are presented in both reports, and clearly show that essentially all of the LBNL groundwater contaminant plumes have either remained relatively stable, or have diminished in size since monitoring began.

Pleas see Response to Comments 9-2 for more details.

Note – Attachment 9 referred in the comment is included as Attachment 18 in the List of Attachments at the end of this document.

COMMENT 16-11

STRAWBERRY CREEK WATERSHED. The test of the Human Health Risk Assessment (May 2003) fails to acknowledge the historical creek restoration work and laboratory studies that have been carried out on the Upper Canyon reaches of Strawberry Creek, as well as the Campus Strawberry Creek Watershed Management Plan and the entire daylighted portions of Strawberry creek flowing into the San Francisco Bay.

RESPONSE 16-11

Acknowledging the historical creek restoration work and the other items noted in the comment are not within the scope of the Human Health Risk Assessment. Daylighted portions of Strawberry Creek are acknowledged in the Ecological Risk Assessment.

COMMENT 16-12

The Urban Creeks Council, Friends of Strawberry Creek, and countless students work in the waters and along banks to clean up trash and debris, weed infestations of non-native plants, restore banks with native plants, test and GIS the streams on a year round basis. The Incremental Lifetime Cancer Risk (ILCR) theoretical modeling only calculates surface water exposure to a "recreational receptor" of the "residential scenario", without acknowledging those workers involved in creek restoration as receptors too.

RESPONSE 16-12

Although the risk assessment does not specifically refer to the workers involved in creek restoration, any potential risks to those workers would be less than those estimated in the Human Health Risk Assessment for the on-site recreational receptor. In addition, there is currently no risk to creek workers since chemical contaminants are not migrating offsite in surface (creek) water.

COMMENT 16-13

RCRA/CMS reports fails to consider the historical Map of Strawberry Valley and Vicinity Showing the Natural Sources of Water Supply of the University of California by Frank Soule, Jr., Professor of Engineering, 1875 (Attachment 10). Today, 130 years later, several dozen creeks and their tributaries, as reflected on the Soule Map, are well known Mediterranean streams and appear on LBNL's Annual Site Environmental Reports. These include Berkeley Creek, Ten-Inch Creek, Chicken Creek, No-Name Creek, South Fork of Strawberry Creek, Botanical garden Creek, Banana Creek, Pineapple Creek, etc., and close to 30 springs.

RESPONSE 16-13

Both the RFI Report and the CMS Report consider the historical Map of Strawberry Valley and Vicinity. Several features from that map are included and referenced on maps in the RFI and CMS Reports. Most of the creeks mentioned are routinely sampled for contaminants

Note – Attachment 10 referred in the comment is included as Attachment 19 in the list of Attachments at the end of this document.

COMMENT 16-14

The significance of the creeks as conduits for migrating contaminants from soil runoff, seepage from underground plumes etc., such as in the case with Chicken Creek and the tritium groundwater plume, has not been addressed (Attachment 11). There has been no evaluation of the potential health hazards following a seismic event or of the soil liquefaction potential/soil failure within the creek basins that lace the Strawberry Creek Watershed.

RESPONSE 16-14

The potential of creeks to act as conduits for migrating contaminants from soil runoff is discussed in the Draft CMS Report under the subsections titled potential migration of contaminants. Groundwater samples are routinely collected from perimeter wells located along potential migration pathways to site creeks to evaluate the potential for seepage from groundwater to the creeks, and the creeks are routinely sampled for contaminants. The conclusion of these evaluations, as discussed in the RFI and Draft CMS Reports, is that the creeks are not acting as conduits for chemical contaminant migration. DTSC's authority in law does not include investigation of the releases of radionuclides including tritium.

The RFI and Draft CMS Report do evaluate potential seismic hazards. The Alquist-Priolo Earthquake Fault Zone near LBNL is shown on Figure 4.2-6 in the RFI Report. The zone represents an area within approximately 1/8 of a mile of the surface trace of an active fault where surface rupture might be expected to occur during an earthquake. All areas of soil and groundwater contamination are outside this area, except for a small area of soil contamination under Building 88 that has been cleaned up to an unrestricted land use-level. As discussed in response to comment 16-9, earthquake induced landsliding would not have a significant effect on groundwater contamination. No areas of LBNL have been identified on state hazard maps as prone to soil liquefaction. Liquefaction/soil failure within the "basins that lace Strawberry Creek" would result in no health hazard from LBNL contamination.

Note – Attachment 11 referred in the comment is included as Attachment 20 in the List of Attachments at the end of this document.

COMMENT 16-15

WATER QUALITY, GEOLOGY AND SOILS, BIOLOGICAL RESOURCES, HAZARDOUS AND HAZARDOUS MATERIALS AND HYDROLOGY ISSUES WITHIN THE WESTERN HALF OF LBNL. The Bevatron, a decommissioned particle accelerator, is located on a four-acre site in the western portion of LBNL within the Blackberry Creek (a.k.a. the North Fork of Strawberry Creek) Watershed. The site is in the Hayward/East Canyon/Wildcat Canyon Earthquake Fault Zone, surrounded by at least two cross faults: the Cyclotron Fault to the south and the New Fault to the north. Currently the Bevatron and Building 51 are under review for potential demolition. This site central to the CMS cleanup evaluation but many questions have not been answered or information provided about the site.

RESPONSE 16-15

The Bevatron site is not located within any Alquist Priolo Earthquake Fault Zone. Regarding the Bevatron, Building 51 and corrective action investigations in this area, please refer to Response to Comment 16-21. Regarding earthquake faults at LBNL please refer to Response to Comments 16-17 and 16-14.

COMMENT 16-16

The Final CMS Report must include a comprehensive earthquake fault map that would include all the faults in the entire Strawberry Creek Watershed, whether active or not, and an interpretation of the significance of the presences of these faults regarding the transport of surface, soil and groundwater within the LBNL site.

RESPONSE 16-16

A fault map of the entire Strawberry Creek watershed would cover large areas outside the LBNL site and is outside the scope of the CMS. LBNL provided earthquake fault maps in the RFI Report that include faults that could potentially play a role in the migration of contaminants. There is no evidence that any of these faults act as conduits for contaminant migration.

COMMENT 16-17

The Final CMS Report must include a watershed map for the LBNL hill site showing the various watershed and sub-watershed divides with a detail of the Blackberry Creek watershed and the four-acre Bevatron site as well as the Strawberry Creek watershed including the Chicken Creek sub-basin and the East Canyon area above the UC Botanical Garden.

RESPONSE 16-17

Maps showing the boundary between the Blackberry Creek watershed and the Strawberry Canyon watershed (and also showing site creeks and drainage systems) are provided in the module-specific volumes of the RFI Report. This information is provided along with details of the stormwater discharge system to show which offsite creeks (Strawberry or North Fork Strawberry) are the receptors of surface water runoff from the site. The locations of the sub-basins are not relevant to the CMS.

Please see Response to Comment 9-2 for more details.

COMMENT 16-18

The Final CMS Report must include a Seismic Hazard Zone Map which would show areas in the Strawberry and Blackberry Creek Watersheds where previous landslides have occurred, as well as all topographic, geological, geotechnical, and subsurface conditions which indicate a potential for permanent ground displacement.

RESPONSE 16-18

As stated in the Response to Comment 16-8, a map depicting both prior landslides and areas susceptible to future landslides is presented in the RFI Report. This map is based on a synthesis of topographic, geologic, geotechnical, and hydrogeologic data.

Please see Response to Comment 9-2. Also refer to Responses to Comments 16-8 and 16-19 for further discussion of seismic hazards.

COMMENT 16-19

It should be noted that in a 1949 geologist (c. Marliave) report on the bedrock conditions at the Bevatron site "…the area at the Bevatron is to be excavated and leveled off to elevation 710. The bedrock beneath this beveled surface will be comprised of poorly consolidated Orinda sediments…The Orinda Formation absorbs water freely and the lava flows and breccia that are associated with it are also quite pervious so that the whole mass becomes readily saturated… There appears to have been considerable land sliding in the amphitheatre in which the Bevatron is to be located – and during periods of heavy rainfall, the underlying Orinda sediments become quite soft from absorbed water … seeps come out of the ground in many place, there are two known permanent springs in the area where tunnels have been driven into the hillside and pipes leading out from the caved entrances have been flowing water for many years" (Attachment 12).

Further, though landsliding deposits may have been modified or have fill placed over them their subsurface characteristics /failure planes may exert control on groundwater flow patterns and thus on the movement contaminant plumes at the hill site. Mapping of the historical landslide distribution in the Final CMS Report is extremely important for understanding/interpreting how the contaminant plumes may be distributed on the hill.

Response 16-19

Slope stability analyses and extensive engineering of cut-and-fill operations have been an integral part of development of LBNL facilities, particularly large facilities such as the Bevatron. This work has included extensive mapping, drilling, and logging of soil borings, and geotechnical testing of soil samples. Much of these data were used for preparation of geologic maps and cross sections presented in the RFI and CMS reports. The 1949 report by Marliave documents conditions that were present prior to preparation and placement of engineered fill at the Bevatron site, not current conditions.

Geologic maps showing the distribution of historically active landslides and paleolandslides are included in the RFI Report and Appendix I in the CMS Report. The subsurface distribution and hydrogeologic properties of bedrock units and surficial geologic units (including landslide deposits) and the relation of these units to contamination plume locations are discussed in the RFI and CMS Reports, and were a primary consideration in the assessment of the fate and transport of groundwater contaminants and siting of groundwater monitoring wells. Groundwater monitoring wells are located in the downslope area of a number of the slide deposits that intersect contaminated groundwater. Based on the logging of the borings for the wells and the groundwater sampling data, there is no evidence that former landslide slip planes are a preferential pathway for contaminant migration.

Note – Attachment 12 referred in the comment is included as Attachment 21 in the List of Attachments at the end of this document.

COMMENT 16-20

The Final CMS Report must include the current configuration and condition of the engineered drainage around the Bevatron site. How is groundwater from the seeps and springs intercepted and captured? Where are water source diverted? Do creek beds of the historic creek function as conduits for these waters? According to the 1875 F. Soule Map titled: Strawberry Valley and Vicinity Showing the Natural Sources of the Water Supply of the University of California, at least two of the branches of the North Fork of Strawberry Creek were located directly under the Bevatron Complex. The Final CMS Report should provide a historic map of the site showing these watercourses and their current state.

RESPONSE 16-20

Detailed discussion of the engineered drainage around site buildings, including the Bevatron, is outside the scope of the CMS. As indicated in Responses to Comments 9-4 and 16-8, the RFI Report provides site-wide maps showing the principal stormwater drainage systems and stream courses. The stormwater drainage systems connect to various smaller building subdrain systems within the buildings of the Bevatron Complex. Building subdrains that intercept clean groundwater discharge to the storm drain system that drains to the creeks. Building subdrains that intercept contaminated groundwater (including a portion of the Building 51 subdrain system) are routed to on-site groundwater treatment systems. Segments of several creek beds (including part of North Fork Strawberry Creek), were culverted during construction of the facility.

A number of groundwater monitoring wells has been installed in former creek bed locations in several of the historic creeks to evaluate whether they function as conduits for contaminant migration. These include North Fork Strawberry Creek and some of its tributaries and Chicken Creek. At some locations the historic creek beds appear to be preferential flow paths, while at others they do not. Groundwater contaminant flow paths are discussed in the Draft CMS Report.

The RFI Report contains detailed maps of both the original topography and current topography of the Bevatron Complex that illustrate the locations of former drainage courses beneath those buildings. Geologic cross sections in the RFI Report and Appendix I of the CMS Report show the geometry of artificial fill that has been placed in these drainages.

COMMENT 16-21

The Final CMS Report must include a geologic cross section of each plume to show the depth and concentration of groundwater contamination in the four-acre Bevatron site and vicinity. According to the Environmental Checklist's Project Description for the proposed demolition of the Bevatron, soil and groundwater contamination are known to be present in some areas beneath Building 51/Bevatron. The primary known chemicals of concern are chlorinated volatile organic compounds (VOCs) in soil and groundwater. In addition, PCBs have been detected in some groundwater samples. Contamination in soil, outside the plume source areas, has included primarily chlorinated VOCs, petroleum, aromatic hydrocarbons, polycyclic aromatic hydrocarbons, PCBs, and Mercury. Three groundwater plumes converge at the Bevatron site: Building 51/64 VOC plume, Building 7 Freon/VOC plume and the old town VOC/Building 7 Diesel plume.

It appears that the location of the groundwater monitoring wells in the general Bevatron site is insufficient to characterize the full extent of these plumes.

Are the contamination plumes interrelated? It appears that there are no groundwater sampling wells located in the basement of the Bevatron core area. A sampling strategy must be developed and implemented prior to the publication of the Final CMS Report to characterize and comprehensive data on the extent of the potential groundwater contamination plume under the Building 51/Bevatron. Soil boring(s) and testing should be part of this investigation.

RESPONSE 16-21

Geologic cross sections showing depth and contaminant concentrations in each of the groundwater contaminant plumes in the Bevatron site are presented in the RFI Report, with the exception of the Building 51L plume, which was still being characterized at the time. Geologic cross sections illustrating key relationships for the major plume are also presented in Appendix I of the CMS Report, which includes a cross section through the Building 51L plume area.

The number and locations of groundwater monitoring wells are sufficient to characterize the magnitude and extent of the groundwater plumes in the Bevatron area and no additional wells are needed to characterize the extent of the plumes. For each of the plumes in the Bevatron area, groundwater monitoring wells have been installed at the contaminant source location, within the plume bodies, cross-gradient from the plumes, and down-gradient from the plumes, thereby defining the extent of the plumes. In addition, a number of wells have been installed in multilevel clusters to assess the depth distribution of contaminants in key areas of the plumes.

As described in the RFI Report, the three contaminant plumes described in the comment are not interrelated. These plumes are each derived from distinct sources, have distinct chemical compositions, and are not contiguous.

No groundwater monitoring wells have been installed beneath the Bevatron core area because of logistical constraints on installing wells in that area. In addition, no Solid Waste Management Units (SWMUs) or Areas of Concern (AOCs) that might constitute potential sources of contamination have been identified in the core area. Wells down-gradient from the core area do not show results indicative of a source of chemical contaminants in groundwater beneath that area. Therefore, there is no basis for installing wells or collecting soil samples. If there are any indications of contamination beneath the core area when the Bevatron is demolished, additional investigation will be conducted.

COMMENT 16-22

The Final CMS Report must include the potential effects of the increased rainfall on the now pervious site, if the Bevatron structure is removed. What protections will be put in place in the future site design to protect further impact of rainwater on existing groundwater plumes? How will the increased groundwater influence slope stability? In addition to the Bevatron core area, more monitoring wells should be located laterally along the Cyclotron Fault and New Fault because they could act as conduits for the contaminated groundwater.

RESPONSE 16-22

The future use of the Bevatron site has not been determined; however, it is likely that a new building will be constructed on the site and/or the area will be paved. Therefore, the infiltration of rainwater would not increase and there would be no effect on slope stability or on any groundwater plumes, if present. Factors such as slope stability, potential soil and groundwater contamination beneath the building, and the effect on corrective measures proposed for adjacent areas of groundwater contamination would be considered in any redevelopment of the site.

Based on results from the numerous groundwater monitoring wells surrounding the Building 51 complex footprint, there is no evidence for significant groundwater contamination beneath the Bevatron core area. Potential groundwater contamination will be evaluated during demolition and redevelopment of the site, and additional monitoring wells will be installed if necessary. There is no geologic evidence for the presence of the New Fault, which was proposed by Lennert and Associates. The reference to the Cyclotron Fault is not known. If this refers to Great Valley Group/Orinda Formation fault contact, then more monitoring wells are not required, since the fault contact is oriented approximately perpendicular to the groundwater flow direction. Several monitoring wells are located close to this contact near Building 51, and groundwater sampling or water level data from those wells do not show any evidence that the contact acts as a preferential conduit for contaminated groundwater flow. It should be noted that the depiction of geologic faults as conduits for groundwater flow is not correct. Although the ability of earth materials to transmit water can in some cases be higher in fault zones, in many cases faults have little or no effect on flow and the fine-grained materials formed by fault movement often serve to impede flow.

COMMENT 16-23

Additional groundwater monitoring wells are needed (a) west of the northern lobe of the Building 51/64 plume as well as (b) west of the western lobe of Building 71 solvent plume to show whether the two plumes converge into a topographic swale and (c) west of the old town plume, specifically in the area between Building 46 and 51. All of these plumes are in the Blackberry Creek Watershed and drain west toward the city of Berkeley and San Francisco Bay (Attachment 13).

RESPONSE 16-23

There is no technical basis for the additional groundwater monitoring wells suggested. Two groundwater monitoring wells are located down-gradient (west) of the Building 51/64 plume along the former drainage to North Fork Strawberry Creek. Groundwater flow from the “northern lobe” of the Building 51/64 plume would converge on these wells. Contaminants have not been detected in either of these wells and therefore additional monitoring wells are not needed.

Two monitoring wells are located along the former drainage to North Fork Strawberry Creek at the down-gradient edge of the “western lobe” of the Building 71 solvent plume (assumed to refer to the Building 71 Solvent/Freon plume in the vicinity of Buildings 71C through 71K). Concentrations of groundwater contaminants in these wells have either been below the detection limit or well below MCLs for the past 10 years. Groundwater contaminants were generally not detected in a third well that was located in this area. Based on the extensive data available, the Building 51/64 and Building 71 plumes do not converge; however, even if they did converge, there would be no change in the proposed corrective measures.

Several monitoring wells are located between Building 46 and Building 51. Groundwater contaminants have generally not been detected in these wells. In addition, there is a slope stability well SSW19.63 located between Buildings 51 and 46 in the area of potential concern indicated on Attachment 13. SSW19.63 has been sampled approximately annually for VOCs since 1994 to ensure that the Building 46 subdrain adequately captured the down-gradient edge of the Building 52 Lobe. Except for trace concentrations of chloroform (approximately 1 µg/L or less), contaminants have not been detected in this well.

Note that Attachment 13 of the comments does not accurately reflect current geologic conditions at LBNL. The attachment shows “earthquake faults”, “historic landslides” and “unsampled areas which could contain contaminated plume(s)” superimposed on a facility map of the known groundwater chemical plumes and the Building 75 tritium plume. The “earthquake faults” shown on the map are primarily those shown on Plate 3 (i.e. compilation of prior work) of the Converse Consultants 1984 geologic synthesis. As described above, the presence of most of these faults was based solely on conjecture; extensive analysis of field data by Converse Consultants indicated that there was no evidence for their existence. The feature labeled “earthquake fault liniation (sic) undetermined interpreted from 1939 photos” is not based on any known field observations. The areas labeled “historic landslides” do not reflect the current distribution of landslide deposits, which is illustrated in Figure 4.2.7 and 4.2.8 of the RFI Report. The “historic landslides” shown on Attachment 13 are apparently derived from studies that predate cut-and-fill operations, slope stability engineering, and most recent geotechnical studies conducted during development of the facility. In addition to the areas addressed in the preceding paragraph, several other “unsampled areas which could contain contaminated plume(s)” are shown on Attachment 13. These areas are either monitored by existing wells that are part of the groundwater sampling program (and are shown on the map), or are located in undeveloped areas of the facility where contaminants would not be present.

Note – Attachment 13 referred in the comment is included as Attachment 22 in the List of Attachments at the end of this document.

COMMENT 16-24

The Final CMS Report must include how the removal of the Bevatron (a concrete plug) and its subterranean structures impact the movement and current hydraulic controls of these groundwater contamination plumes. This factor alone is reason for additional groundwater evaluation and monitoring wells. How is LBNL preparing to prevent any contamination form entering the creeks and ending up in downtown Berkeley where Strawberry Creek flows day lighted through many public and private properties? For this reason, all site clean-up must be done to residential standards.

RESPONSE 16-24

The removal of the Bevatron is not anticipated to have a significant effect on the movement or current hydraulic controls of groundwater contamination plumes. Chemical concentrations and water levels in numerous wells down-gradient from the Bevatron will be monitored and corrective action will be taken if it is determined that contaminated water might enter the creek.

COMMENT 16-25

The Final CMS Report must include a description of the air monitoring systems LBNL has in place to determine any changes in air quality during the corrective measures process.

RESPONSE 16-25

Air quality impacts are discussed in the CEQA Initial Study/Negative Declaration. No air monitoring is required or planned. However, LBNL will comply with requirements of the Bay Area Air Quality Management District (BAAQMD) during the corrective measures implementation process. Under its CEQA guidelines, the BAAQMD's approach for air quality impacts analysis for construction activities is to emphasize effective and comprehensive dust control measures rather than detailed quantification of emissions. Because corrective measures excavations will be relatively small and located in areas that are paved, only the BAAQMD's "Basic Control Measures," would be implemented.

COMMENT 16-26

The Final CMS Report must include the effects on the potential beneficial uses of Berkeley's large aquifer, e.g., availability in times of drought. Of special concern is the Lennert aquifer, currently pumped by the Shively well #1. The Final CMS Report should provide an update on the pumping rates, water quality, where the water is currently being dumped and why (Attachment 14).

RESPONSE 16-26

The Lennert Aquifer is up-gradient from areas of groundwater contamination at LBNL; and therefore, there is no effect on the potential beneficial uses of this "aquifer" from LBNL groundwater contaminants. The Shively Well #1 is located on University of California property near the southern end of the Space Sciences laboratory parking lot and managed by UC. Discussion of this UC well is not relevant to the soil and groundwater remediation activities proposed in the CMS Report.

Note – Attachment 14 referred to in the comment is included as Attachment 23 in the List of Attachments at the end of document.

COMMENT 16-27

The Final CMS Report must include the potential effects upon the endangered Alameda Whipsnake for which the LBNL site is critical habitat. The Final CMS Report should evaluate the cumulative and significant effects, on the human (and endangered Alameda Whipsnake) environment, with the implementation of the corrective measures that proposes to leave some 80% of the existing contamination in place, concurrent with the Bevatron demolition, decommissioning and decontamination of the National Tritium Labeling Facility and the construction and operation of the Molecular Foundry.

RESPONSE 16-27

The Alameda Whipsnake, which is a threatened species, is not known to be present at LBNL. The only area at LBNL that has the potential to provide habitat for the Alameda Whipsnake is a stand of north coastal scrub at the southeast corner of LBNL immediately east of the University's Botanical Gardens. This area would not be affected by any of the proposed corrective measures and is well outside any area of soil or groundwater contamination.

Significant and cumulative effects of the project on the environment (human and ecological) were considered in the CEQA Initial Study/Negative Declaration, including cumulative effects from construction of the Molecular Foundry. All impacts identified in the analysis were determined to be less-than-significant. Cumulative effects resulting from Corrective Measures Implementation and the Bevatron/Building 51 demolition project will be considered by LBNL in the cumulative effects section of the draft EIR that LBNL will prepare for the Bevatron/Building 51 Project.

COMMENT 16-28

The Final CMS Report must include a comprehensive description of the various beam targets (including the magnet gap) and the beam dump areas during the Bevatron's forty-year history, and a sampling strategy to determine where the highest concentrations and types of radioactivity and toxic chemicals/solvents are located.

RESPONSE 16-28

Please refer to Response to Comment 1-2 regarding DTSC's authority and radioactivity. Potential soil and groundwater contamination beneath the building will be evaluated after the Bevatron is removed and the area is accessible to investigation.

COMMENT 16-29

The Final CMS Report must include all the stable isotope studies performed at LBNL, in the early 1990s (Attachment 4, page 9.) and in 1998-2000 when LBNL conducted stable isotope studies to characterize the hydrogeology of the site. Further, we ask that stable isotope studies be used as part of the development of the new Groundwater Monitoring and Management Plan.

RESPONSE 16-29

The results of the stable isotope studies would contribute no significant information to the CMS Report. Stable isotope ratios measured in selected LBNL site-wide monitoring wells from 1992 through 1995 are listed and compared in the 1995 Annual Report California Agreement in principal (AIP). The only conclusion relative to groundwater derived by DHS from four years of stable isotope data was that low oxygen-stable-isotope ratios indicate areas where suspected water or sewer line leaks are present. The data provided little information to help characterize the site. To implement a site-wide stable isotope program to monitor for indications of pipe leaks is not within the scope of the CMS. In addition, more direct indications of pipe leaks and the resulting effects on groundwater contamination would be observed in LBNL's routine chemical concentration monitoring and water level measurements.

Stable isotope studies were also conducted from October to December 1995 as part of a tracer test to investigate potential groundwater migration pathways from the Building 7 sump area. The test did not add any new information to characterize the hydrogeology of the site (the treated EBMUD water that was used as a tracer was only detected in the closest well). Additional stable isotope studies were conducted in the late 1990's to assess whether biological degradation of contaminants was occurring naturally in the Building 51/64 Groundwater Solvent Plume.

The Groundwater Monitoring and Management Plan will include: a description of the vertical and lateral extent of groundwater contamination; a listing of the specific wells that will be used to monitor groundwater and analytical requirements; a description of surface water monitoring requirements; and a description of management controls that will be used to reduce potential risks from exposures associated with contaminated groundwater. Stable isotope studies are not required for the development of this plan.

COMMENT 16-30

The Final CMS Report must include in the Statement of Bases regarding compliance that compliance must be determined only after each monitoring well demonstrates measurements lower than MCLs for at least eight (8) consecutive quarters. This would be a change to the current proposal to certify LBNL to be in compliance when multiple data is averaged over four quarters and the average for these wells is below the MCL.

RESPONSE 16-30

Neither the Draft CMS report nor the Statement of Basis proposes averaging multiple well data. The proposal is to consider the corrective measure to be complete when the concentrations of constituents of concern (COCs) averaged over four consecutive quarters of monitoring in each compliance-well at a groundwater unit are lower than media cleanup standards (MCSs).

Four quarters of monitoring are proposed as a sufficient period of monitoring based on a positive evaluation of the following criteria: (a) the plumes are stable; (b) the sources have been removed and/or removal or containment actions have been implemented which would reduce the chemical flux into the plumes; (c) there is more than adequate spatial monitoring of the plumes; (d) parameters affecting the fate and transport of the chemicals of concern (COCs) within the plume have been fully evaluated; and (e) concentrations of COCs in point-of-compliance monitoring wells along the property perimeter are all less than detection limits. Four quarters would be sufficient time to observe any seasonal effects.

COMMENT 16-31

The Final CMS Report must include carefully considered alternative to demolition and removal that would allow the Bevatron and its contamination to remain on site in relative containment. On site containment will allow the radioactivity to decay in place and not be hauled away to impact other communities. This option would save tax payers millions of dollars and save many communities from the serious pollution which the demolition, transportation, and waste dumping would bring about.

The projected cost of 85 million dollars for the Bevatron demolition and removal is truly appalling taking into consideration the enormous initial cost of the construction of the facility in the early 1950s, which was approximately 10 million dollars. Since the 4 acre Bevatron site is part of the current cleanup effort outlined in the Draft CMS Report, we propose that some of those funds be used for DTSC to sponsor a Citizen Watershed Advisory Group. Further, in a June 2, 2003 Bay Guardian article "DOE considers the pollution serious enough to spend 82.6 million dollars to cleanup LBNL." We should like to have a full public accounting as to how this money has been spent over the last dozen years (Attachment 15).

Response 16-31

Demolition and removal of the Bevatron is neither under the regulatory jurisdiction of DTSC nor within the scope of the CMS.

Note – Attachment 15 referred in the comment is included as Attachment 24 in the List of Attachments at the end of this document.

COMMENT 16-32

The Final CMS Report must include an evaluation of the Chicken Creek tritium and collocated radioactive solvent plumes, as well as the diesel plume in the east canyon above the Botanical garden. Special cleanup strategies must be considered for these areas in addition to a very carefully developed monitoring plan, using stable isotope studies (Attachment 16).

RESPONSE 16-32

The diesel plume is evaluated in the RFI Report. Concentrations of individual chemicals are below MCLs and therefore no additional cleanup under Corrective Measures Implementation (CMI) work phase is required. DTSC's authority in law does not include investigation of the releases of radionuclides, and therefore an evaluation of collocated tritium and chemical contamination in the groundwater is not within the scope of the CMS. However, an evaluation of collocated radiological and chemical contamination was included in the LBNL Summary of Radionuclide Investigation report (September 2003) that is available for review at the Berkeley Public Library. The information contained in that report was updated in LBNL's January 2005 responses to comments from the Water Board regarding the Draft CMS Report. LBNL will be preparing a Groundwater Monitoring and Management Plan for the entire site as part of Corrective Measures Implementation (CMI) work phase. Currently, LBNL is not considering using stable isotopes studies, since stable isotopes are generally used to help with initial site characterization requirements and not for long term monitoring.

Note – Attachment 16 referred in the comment is included as Attachment 25 in the List of Attachments at the end of this document.

COMMENT 16-33

GROUNDWATER PRESERVATION. Our Berkeley city government has communicated to the Regional Water Quality Control Board that the City and citizens of Berkeley strongly oppose the implementation of risk-based clean-up standards, which permit significant amounts of federally generated contamination to remain in place at LBNL that threatens groundwater in the Berkeley/Oakland hills. The City of Berkeley has a history against the use of risk based corrective measures as a first measure of hazardous materials clean-up.

City policy, like that of the state water codes (Porter Cologne Act) contains a significant principle that resources that are deemed to have existing and potential groundwater beneficial uses should be preserved. Similarly, the state water board has a non-degradation policy. This means that the first consideration for any site clean-up is that it should be brought back to the pristine condition in which it was found.

The City of Berkeley's comment letter to LBNL dated November 26, 2003 states the following "Should DOE reduce its budget for clean-up at LBNL, the facility will not meet any restrictive cleanup goals. Mitigation measures should be expressed as measures required to comply with the most restrictive applicable standards to insure implementation of such requirements regardless of changes in Federal funding for remediation."

Deed restrictions should not be used as a last resort for failure to clean up since they are more clearly associated with Brownfields than they are with a successful clean-up. Brownfields are generally used in depressed areas where the contamination will not be cleaned up due to the absence of a responsible party and/or general economic depression. Berkeley is not depressed economically nor is the federal government. Thus, LBNL/DOE does not require either the use of deed restrictions or Brownfields.

Preservation of the groundwaters of the State of California must be of the highest priority. The Berkeley City Council and its environmental commission support full environmental restoration at LBNL so as to preserve the Berkeley/Oakland hills groundwater for future generations. This is mandatory because in an emergency Berkeley groundwater will be used for domestic, municipal, irrigation and industrial purposes. Today, the LBNL site is contaminated by the presence of large quantities of radionuclides and 162 contaminants including Volatile Organic Compounds (VOCs), Polychlorinated Biphenyls (PCBs), Pesticides, Fuels, Metals and Freon.

RESPONSE 16-33

Please refer to Response to Comment 10-1 regarding the City of Berkeley letter and cleanup goals.

COMMENT 16-34

The official Zoning Map of the city of Berkeley designates the UC hill campus lands including LBNL, as a residential district. This zoning permits, for instance, the construction of resident structures such as apartments and hotels that will provide housing opportunities for transient or seasonal residents. LBNL/DOE must evaluate the cleanup scenarios within the context of actual residential zoning and land use provisions. The city of Oakland's land use designation (S-7 Preservation) for the UC/LBNL hill area is Park, Recreation or Natural area or Watershed (Attachment 17).

Response 16-34

LBNL is being cleaned up to an institutional land use level, which is consistent with the current and reasonably foreseeable potential future land use at LBNL, and the land use designated by both the City of Berkeley and City of Oakland general plan maps. The City of Berkeley Planning and Development Department Zoning Districts and Overlays (January 2005) designates LBNL as zoned R5 (high density residential); however, this is a default designation only used for LBNL and the adjacent UC Berkeley campus, since the City has no jurisdiction for zoning over those lands. The Planning and Development Department's existing Land Use Map and General Plan Land Use Diagram (April 4, 2003) designate LBNL as institutional. Also, the City of Oakland's General Plan and Zoning Map (January 2005) designates LBNL as Institutional.

Note – Attachment 17 referred in the comment is included as Attachment 26 in the List of Attachments at the end of this document.

COMMENT 16-35

COMMUNITY WATERSHED ADVISORY GROUP (CAG) TO OVERSEE ENVIRONMENTAL CLEANUP AT THE LAWRENCE BERKELEY NATIONAL LABORATORY. In addition to the four hundred (400) signatures already submitted at the May 26, 2005 Public Hearing showing considerable community interest in environmental issues related to the LBNL site, we now are submitting over eighty (80) additional signatures on petitions regarding that the State of California Department of Toxic Substances Control (DTSC) sponsor a representative citizen's watershed advisory group to participate in the implementation of the environmental cleanup at the Lawrence Berkeley National Laboratory. This DTSC sponsored advisory group, (CAG) would be involved in the development of the Groundwater Monitoring and Management Plan for the laboratory site, located in the Strawberry Creek Watershed.

DTSC has failed to adequately engage the Berkeley public in the RCRA process and for this reason we request that DTSC support our community's desire for more involvement and grant our request now for a DTSC sponsored CAG.

RESPONSE 16-35

Please refer to Response to Comment 1-8 regarding a Community Advisory Group.

Please refer to the Background, Past Public Participation Activities section regarding DTSC's public outreach on this project.

COMMENT 16-36

IN SUMMARY WE CALL FOR A SOURCE WATER PROTECTION PLAN. For the intent of the Resource Conservation and Recovery Act, we call for a Source Water Protection Plan to conserve and recover the Upper Strawberry Creek Watershed that is still impacted by spreading toxic groundwater plumes. In this regard, we request a comprehensive watershed analysis be conducted, including the drinking water bank, Lennert aquifer, and its groundwater movements feeding Strawberry Creek tributaries for a healthy environmental recovery.

RESPONSE 16-36

The RFI and CMS provided data showing that the groundwater contaminant plumes at LBNL are not currently spreading, but are either stable or retreating. Chemical contaminants from these plumes are not migrating offsite and so pose no threat to surface water or groundwater within the Strawberry Creek Watershed, with the exception of the current groundwater plume areas within the LBNL boundary. Proposed corrective measures described in the CMS Report are expected to reduce the area of the groundwater contaminant plumes and improve the quality of groundwater at LBNL. The Lennert Aquifer is up-gradient from areas of groundwater contamination at LBNL. Therefore, there is no effect on the potential beneficial uses of this "aquifer" from LBNL groundwater contaminants.

COMMENT 16-37

We call for an ECOLOGICAL PROTECTION ZONE in the Strawberry Creek canyon and the Berkeley-Oakland Hills to conserve and protect human and ecological life from further harm in the 21st Century.

RESPONSE 16-37

Based on the findings of the Human Health and Ecological Risk Assessments prepared for this project, there are no anticipated adverse impacts to human health or the environment associated with this corrective action project in Strawberry Creek Canyon or the Berkeley/Oakland Hills (outside the area of LBNL). Accordingly, an Ecological Protection Zone is not warranted.

COMMENT 16-38

As for the Corrective Measures Study we call for a state-of-the-art assessment of 1) LBNL contamination using GIS mapping data of all the water sources, 2) the earthquake faults from the Hayward Fault Zone to the east Canyon/Wildcat Fault Zone, including, but not limited to the following cross faults the New fault, the University fault, the Cyclotron fault, the Strawberry canyon Fault. We further request that the cumulative environmental impacts of the 174 radioactive and hazardous units be considered as well as the synergistic effects of radionuclides and chemicals and bio-agents (combined) on human and ecological receptors.

RESPONSE 16-38

An extensive geographic information system (GIS) database has been used to locate and manage all environmental sampling and geologic logging data for this project. Potential “water sources” in the vicinity of LBNL contaminant plumes have been identified through testing of site wells to assess which areas of LBNL have sufficient groundwater yield to potentially produce water in quantities sufficient for domestic use. These areas are depicted on maps presented in Appendix I of the CMS Report. Further mapping of “water sources” that are outside areas that might be impacted by groundwater plumes at LBNL is outside the scope of the CMS. As noted in a Response to Comment 16-7 the presence of the “New Fault” and “University Fault” were previously identified by Converse Consultants as conjectural, has not been corroborated by detailed field studies. The reference to the “Cyclotron Fault” is not known, although the fault contact between the Orinda Formation and Great Valley Group to which it might refer is located close to the former 184” Cyclotron Building (currently the Advanced Light Source building) and is included on geologic maps presented in both the RFI and CMS. The Strawberry Canyon Fault is located outside the LBNL boundary, a significant distance down-gradient from LBNL groundwater contaminant plumes and has no relevance to contaminant migration.

Synergistic effects of chemicals and radionuclides are discussed in Response to Comment 1-3. Except for low levels of pesticides, which were detected at only few locations, biohazards are not present in the environment at LBNL. The cumulative effects of the detected pesticides and chemicals on human and ecological receptors were considered in the HHRA and ERA. Cumulative environmental effects from exposure to chemicals at different units were not considered since it would result in an estimate of average risk, which would underestimate the risk at the site.

COMMENTER # 17 LA Wood (letter dated June 7, 2005)

COMMENT 17-1

At the workshop portion of the May 26, 2005 Public Hearing regarding the proposed soil and groundwater cleanup plans at the Lawrence Berkeley National Laboratory there were many good questions asked by members of the community who were not able to stay for the Public Hearing portion held later that night.

During the discussions Berkeley Councilmember Worthington had several questions but also stated that he would not be around for the Public Hearing. You indicated that his questions would be referred to the process. In fairness to others, I have included a CD of the “Questions & Answers” period. I also request that all questions asked during this workshop portion of the meeting be considered as part of the Public Hearing record. I also ask that DTSC have this audio recording transcribed so community questions can be responded by DTSC.

I will be happy to provide the names of all those from the community who asked questions on the CD.

RESPONSE 17-1

DTSC informed the audience at the public hearing on May 26, 2005 that the question/answer session will not be recorded and will not be considered as formal comments to be responded to in the Response to Comments document. All comments needed to be submitted during the public hearing when the court reporter was present and designated by DTSC to formally record oral testimony. Therefore, the compact disk with the recording of all questions asked during the public workshop portion are not included as part of the public hearing record.

ATTACHMENTS

Attachment 1 - Letter to DTSC June 20, 2003 from Jim Cunningham et al

Attachment 2 - Petition - Friends of Strawberry Creek Watershed 6-07-05

Attachment 3 - Letter from Phil Kamlarz - City of Berkeley May 26, 2005

Attachment 4 - Letter from EBMUD - William Kirkpatrick May 16, 2005

Attachment 5 - Letter from Andrea Pflaumer June 7, 2005

Attachment 6 - Letter from Department of Transportation - Sable June 7, 2005

Attachment 7 - Letter from D Thompson and KJ Sharp June 8, 2005

Attachment 8 - Letter from Bill Walzer May 28, 2005

Attachment 9 - Letter from Pamela Sihvola and LA Wood June 7, 2005

Attachment 10 - Attachment 1 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 11 - Attachment 2 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 12 - Attachment 3 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 13 - Attachment 4 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 14 - Attachment 5 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 15 - Attachment 6 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 16 - Attachment 7 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 17 - Attachment 8 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 18 - Attachment 9 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 19 - Attachment 10 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 20 - Attachment 11 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 21 - Attachment 12 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 22 - Attachment 13 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 23 - Attachment 14 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 24 - Attachment 15 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 25 - Attachment 16 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 26 - Attachment 17 of Pamela Sihvola and LA Wood letter June 7, 2005

Attachment 27 - Attachment A of Pamela Sihvola letter - Nov 19, 2004 letter to DTSC

Attachment 28 - Attachment B of Pamela Sihvola letter - October 5, 2004 COB letter to DTSC

Attachment 29 - Attachment C of Pamela Sihvola letter - May 15, 2005 letter CHC to Mayor

Attachment 30 - Letter from LA Wood June 7, 2005.pdf

Appendix L

U.S. Department of Energy (DOE)

RESPONSE TO COMMENTS
on the Environmental Assessment / RCRA Corrective Measures Study Report for the Lawrence Berkeley National Laboratory

September 29, 2005

U.S. Department of Energy Response to Comments on the Environmental Assessment/RCRA Corrective Measures Study Report for the Lawrence Berkeley National Laboratory

September 29, 2005

Background

On April 25, 2005, the U.S. Department of Energy (DOE) distributed a Public Notice soliciting comments on an Environmental Assessment (DOE/EA-1527) that evaluated a number of potential remedies for soil and groundwater contamination by hazardous substances at the Lawrence Berkeley National Laboratory (LBNL). No comments were submitted to DOE. Concurrently, the California Department of Toxic Substances Control (DTSC) solicited public comments on an identical document, the Corrective Measures Study (CMS) for LBNL, as well as several related documents, that it had prepared pursuant to the Resource Conservation and Recovery Act (RCRA). The public's comments, together with DTSC's responses, may be viewed under "Facility-Related Documents" at http://www.dtsc.ca.gov/HazardousWaste/LBNL/index.html. Because several of these comments concerned radionuclide contamination, over which DTSC has no jurisdiction under RCRA, DOE is providing the following supplemental information in order to give a more complete picture of contamination at LBNL. The numbered comments below are those used by DTSC in their responses to comments.

The DOE has completed investigations of the eight units that had been identified in facility assessments as potential sites of radionuclide releases and concluded that no further action is required at any of these units. For seven of the eight units, DOE found that either 1) no release had occurred or 2) the levels of radionuclides found in soil and groundwater were either within LBNL background levels for those media or they were less than the Preliminary Remediation Goals for soil established by the U.S. Environmental Protection Agency, Region IX. The results of these investigations were presented in the "Summary of Radionuclide Investigations (September, 2003)", which may be found in the Berkeley Public Library as well as on-line at http://www.lbl.gov/ehs/erp/assets/pdfs/RadionuclidePDFfinal.pdf.

Tritium contamination that remains in soil, vegetation, and groundwater near the eighth unit, the former National Tritium Labeling Facility (NTLF), has also been investigated extensively. A human health risk assessment was completed in 1997. In addition, an ecological risk assessment concluded that exposure to radionuclides in environmental media at LBNL does not present a substantial risk to ecological receptors. Both of these risk assessments overestimated the potential risk from tritium, because the estimates presumed that the NTLF would continue to operate and emit tritium to the atmosphere over a lifetime of exposure. However, the NTLF ceased operation near the end of 2001, so tritium emissions have decreased greatly and will ultimately be eliminated. Furthermore, the residual tritium in environmental media will continue to decline through tritium decay. This is confirmed by the declining levels of tritium detected in groundwater, with concentrations in all monitoring wells now below the drinking water standard. Based on the results of the risk assessments and the declining levels of tritium in the environment, DOE determined that no additional investigation or remedial action was required or warranted for the former NTLF unit. Nonetheless, DOE will continue to monitor groundwater and surface water, at least through 2008, to assure that current conditions are maintained or improved.

Specific Comment 16-4

"…DOE then took over the handling of the eight radioactively contaminated sites at LBNL for which the DHS Report had expressed serious concern. To date, no report has been released for public review and comment regarding corrective action for clean up of these radioactive sites!"

Response 16-4

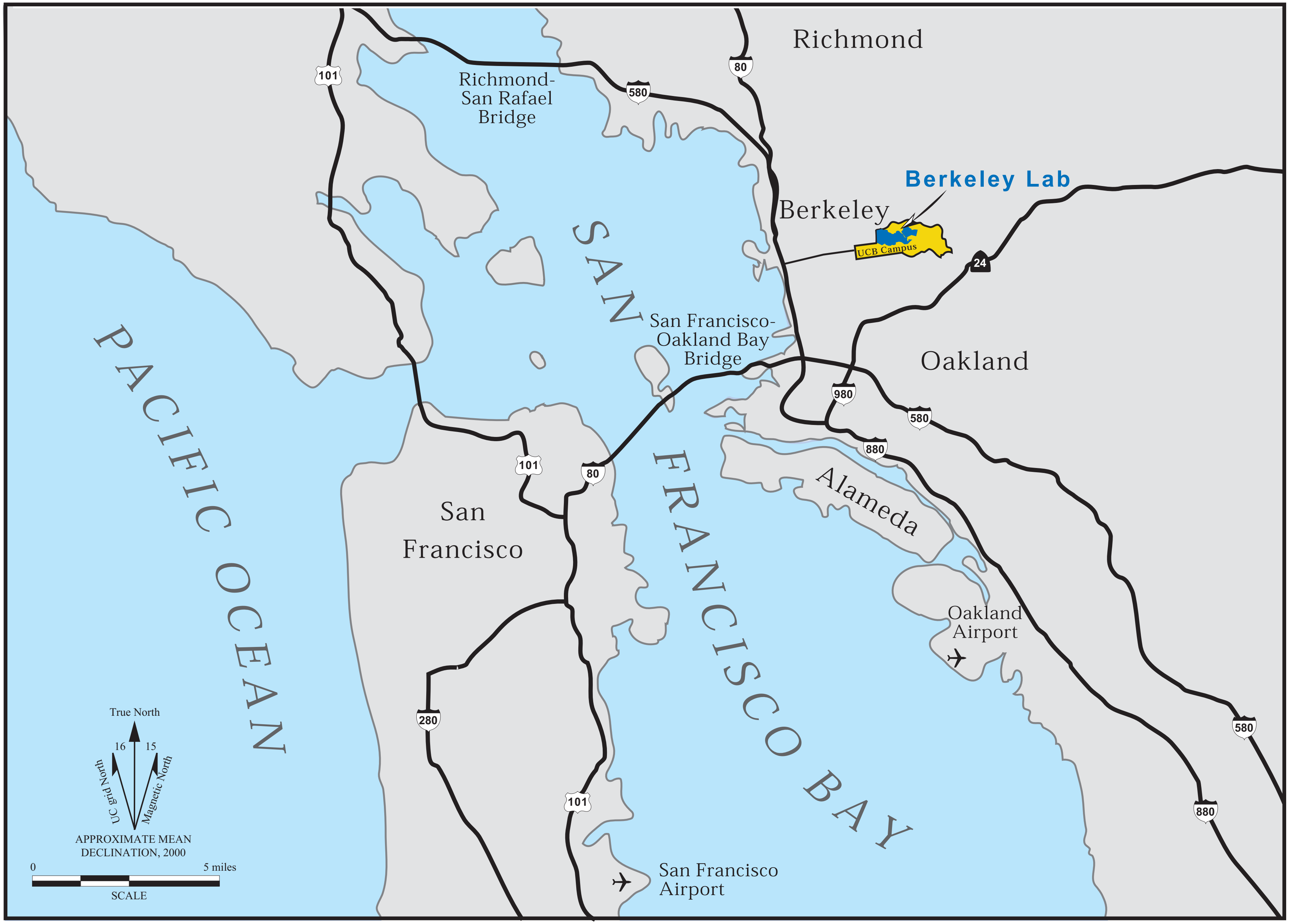
Please see "Background" above. A status update on the findings of investigations completed at LBNL was presented by DOE at the RCRA Facility Investigation public meeting held on January 24, 2001. The final results were presented at the Berkeley Community Environmental Advisory Commission meeting on August 7, 2003. The "Summary of Radionuclide Investigations" has been available for public review in the Main Berkeley Public Library since August, 2003. It is also available online at http://www.lbl.gov/ehs/erp/assets/pdfs/RadionuclidePDFfinal.pdf.

Specific Comment 16-28

"The Final CMS Report must include a comprehensive description of the various beam targets (including the magnet gap) and the beam dump areas during the Bevatron's forty-year history, and a sampling strategy to determine where the highest concentrations and types of radioactivity and toxic chemicals/solvents are located."

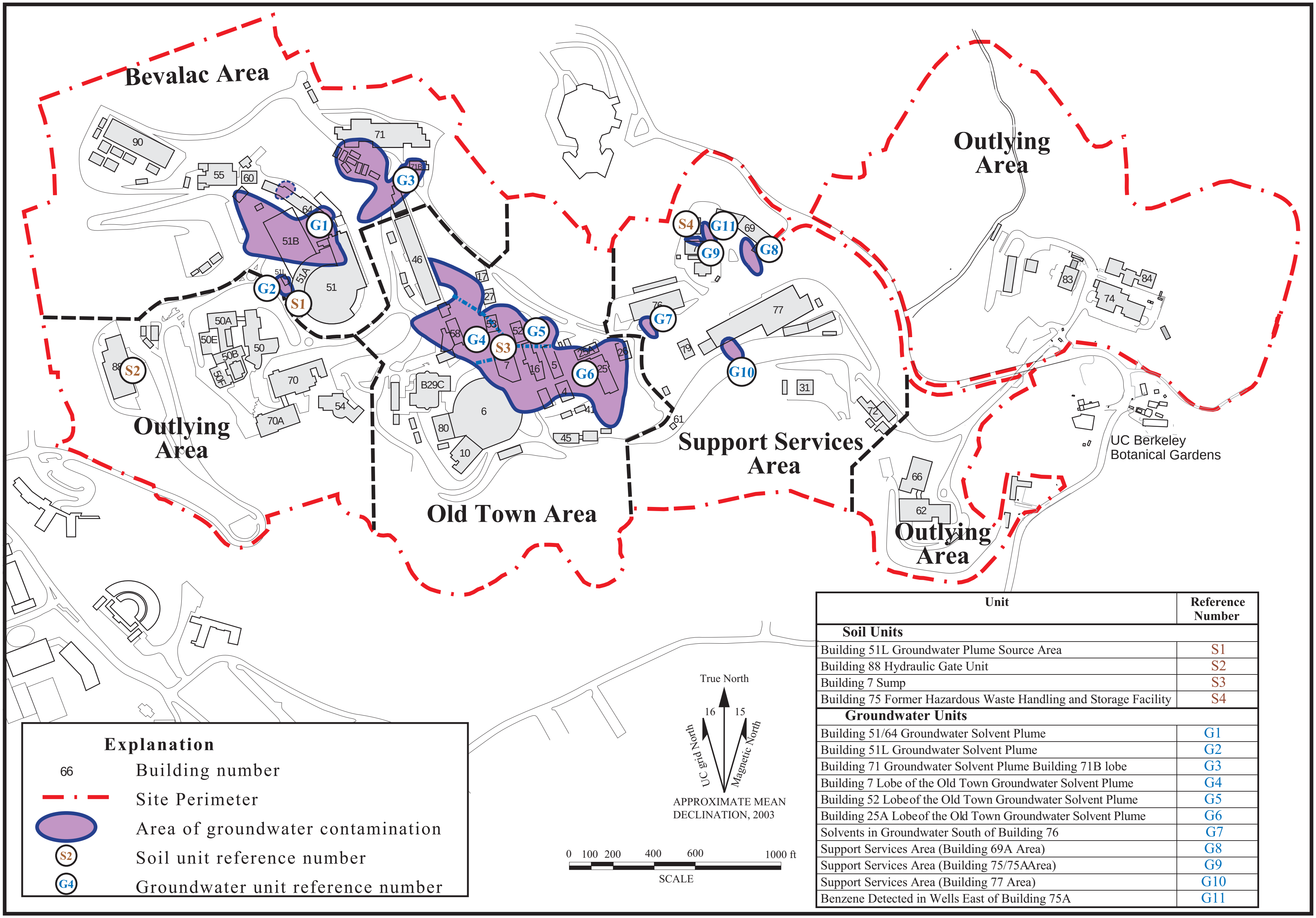
Response 16-28

DOE announced on May 5, 2005 that an Environmental Assessment entitled "Demolition of Building 51 and the Bevatron" is being prepared. The University of California will issue an EIR with the same title. Public input to these documents is welcome and comments will be solicited when the draft EA/EIR becomes available.



f1.2-1regionalsetting.ai
4/04

Figure 1.2-1. Location of Lawrence Berkeley National Laboratory.



Unit	Reference Number
Soil Units	
Building 51L Groundwater Plume Source Area	S1
Building 88 Hydraulic Gate Unit	S2
Building 7 Sump	S3
Building 75 Former Hazardous Waste Handling and Storage Facility	S4
Groundwater Units	
Building 51/64 Groundwater Solvent Plume	G1
Building 51L Groundwater Solvent Plume	G2
Building 71 Groundwater Solvent Plume Building 71B lobe	G3
Building 7 Lobe of the Old Town Groundwater Solvent Plume	G4
Building 52 Lobe of the Old Town Groundwater Solvent Plume	G5
Building 25A Lobe of the Old Town Groundwater Solvent Plume	G6
Solvents in Groundwater South of Building 76	G7
Support Services Area (Building 69A Area)	G8
Support Services Area (Building 75/75A Area)	G9
Support Services Area (Building 77 Area)	G10
Benzene Detected in Wells East of Building 75A	G11

f1.3.4-1-units.ai
9/04

Figure 1.3.4-1. Locations of Soil and Groundwater Units Evaluated in the CMS Report, Lawrence Berkeley National Laboratory.

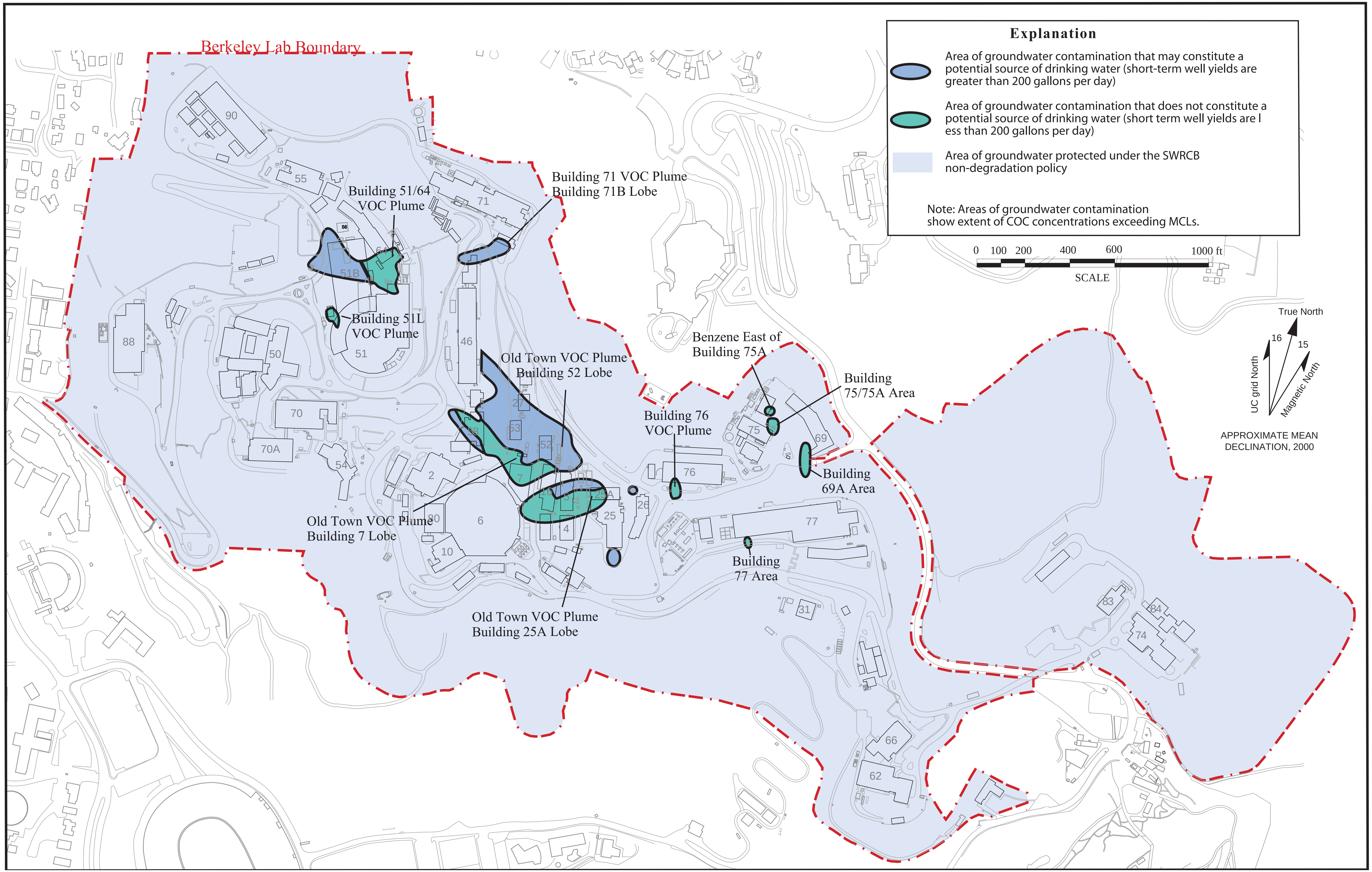


Figure 2.2-1. Areas of Groundwater Contamination Showing Subareas That May Constitute Potential Sources of Drinking Water.

2.2-1-MCLS-12-01-04rotr2.ai
12/04

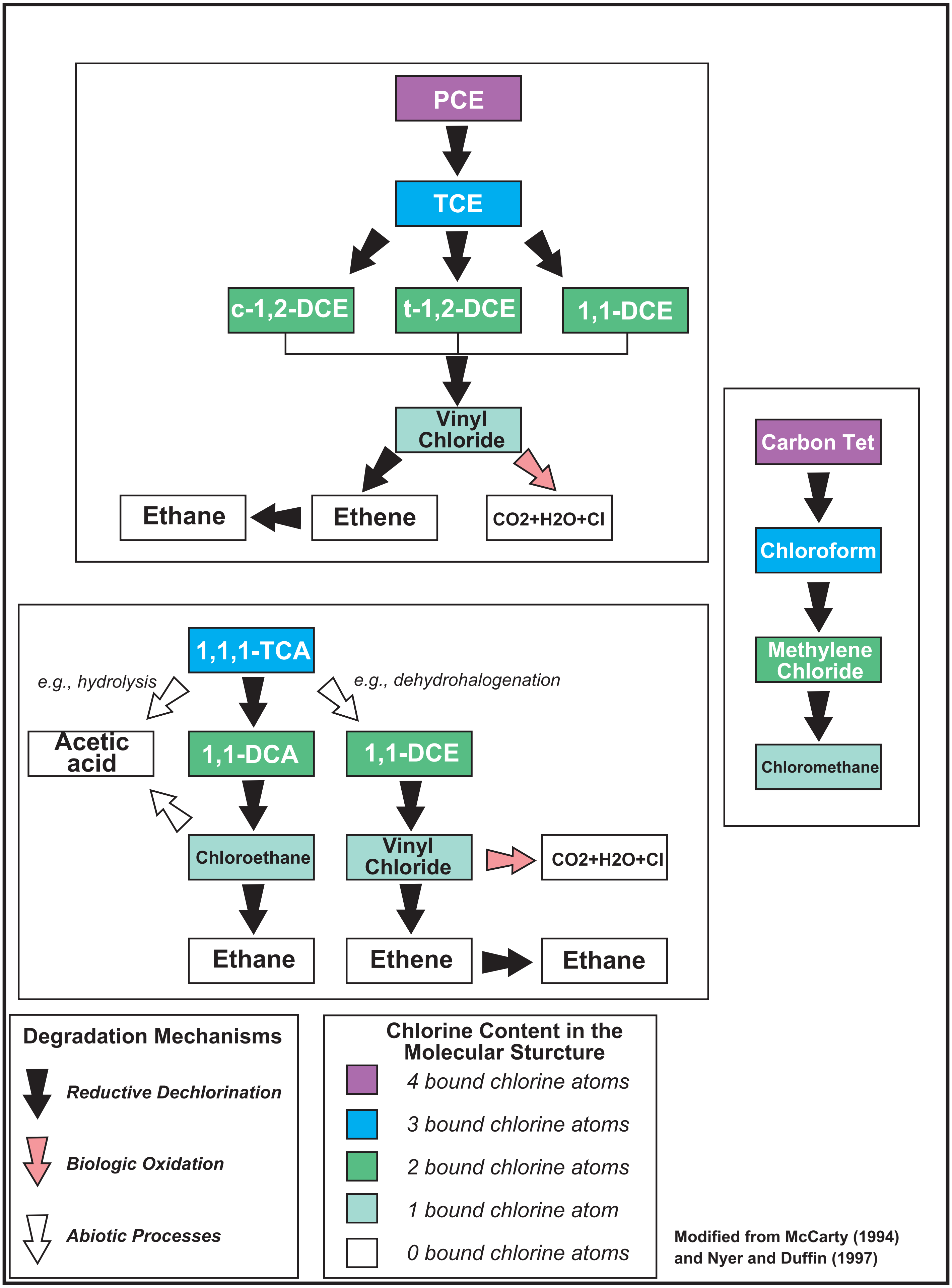


Figure 3.5-1. Generalized Degradation Pathways of Chlorinated Hydrocarbons.

3.5-1BioDegChart.ai
09/00

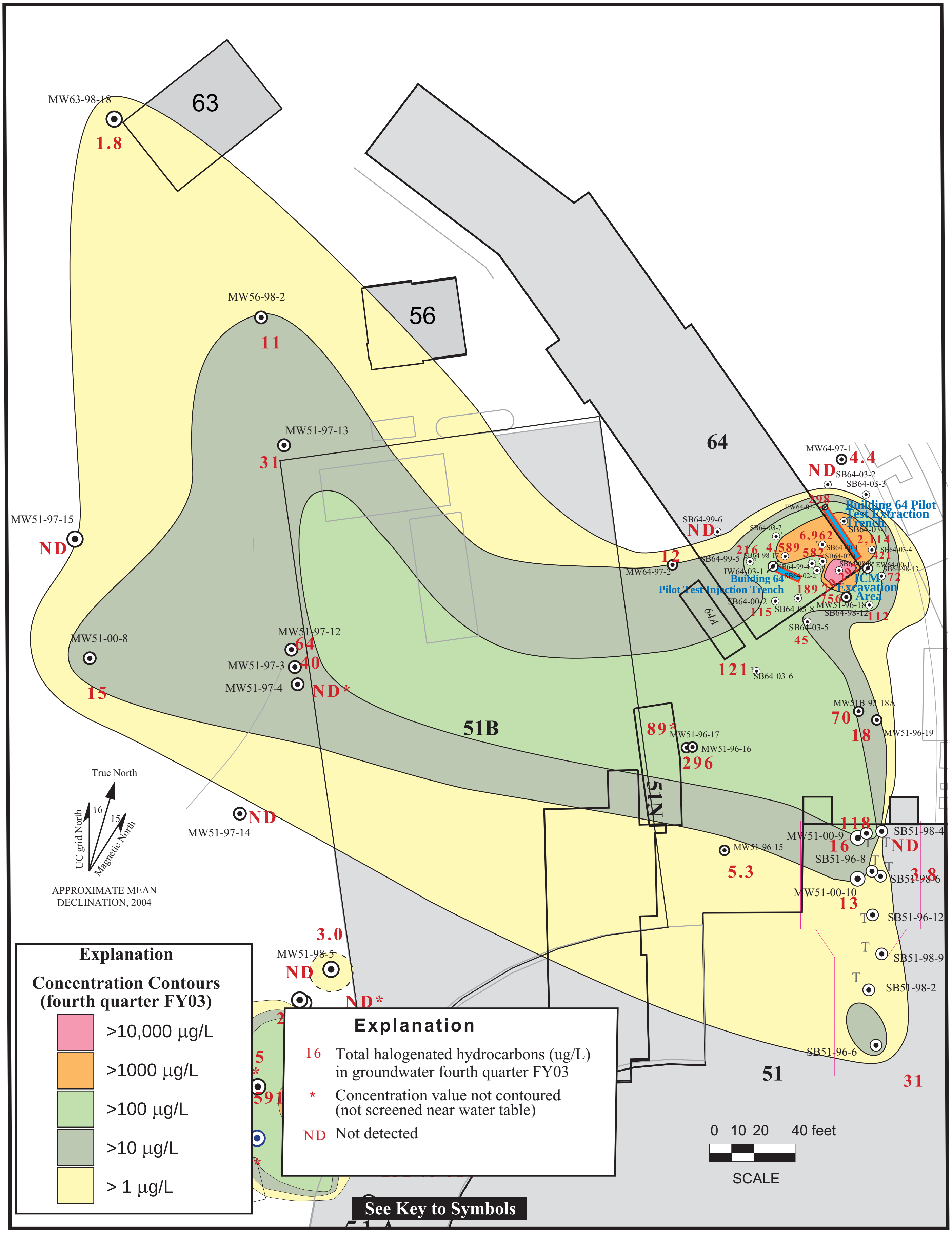


Figure 4.3.1-1. Total Halogenated Hydrocarbons in Groundwater (ug/L), Building 51/64 Groundwater Solvent Plume.

4.3.1-1, -2 B51-64 Plume.ai
4/04

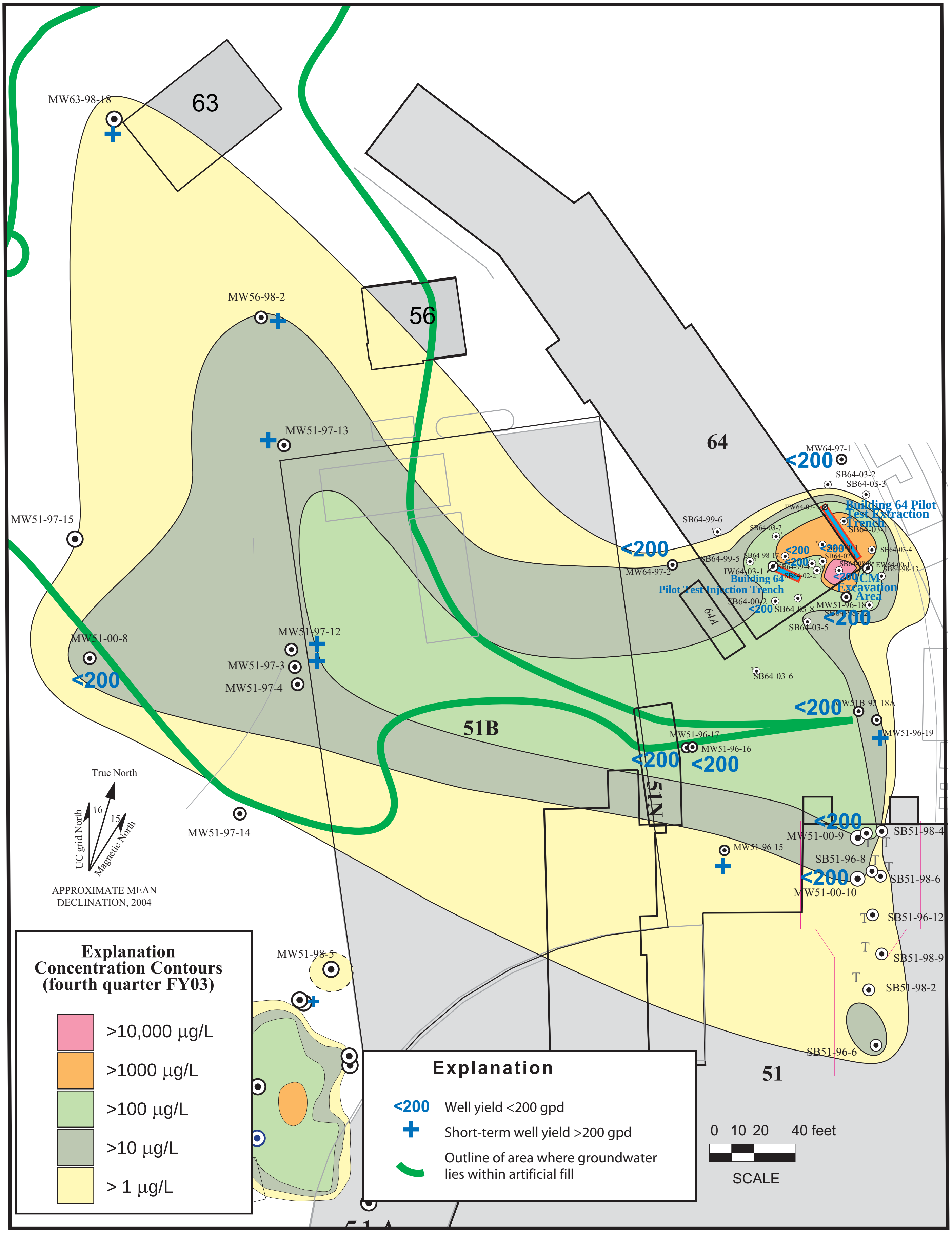


Figure 4.3.1-2. Estimated Well Yields, Building 51/64 Groundwater Solvent Plume.

4.3.1-1, -2 B51-64 Plume.ai
4/04

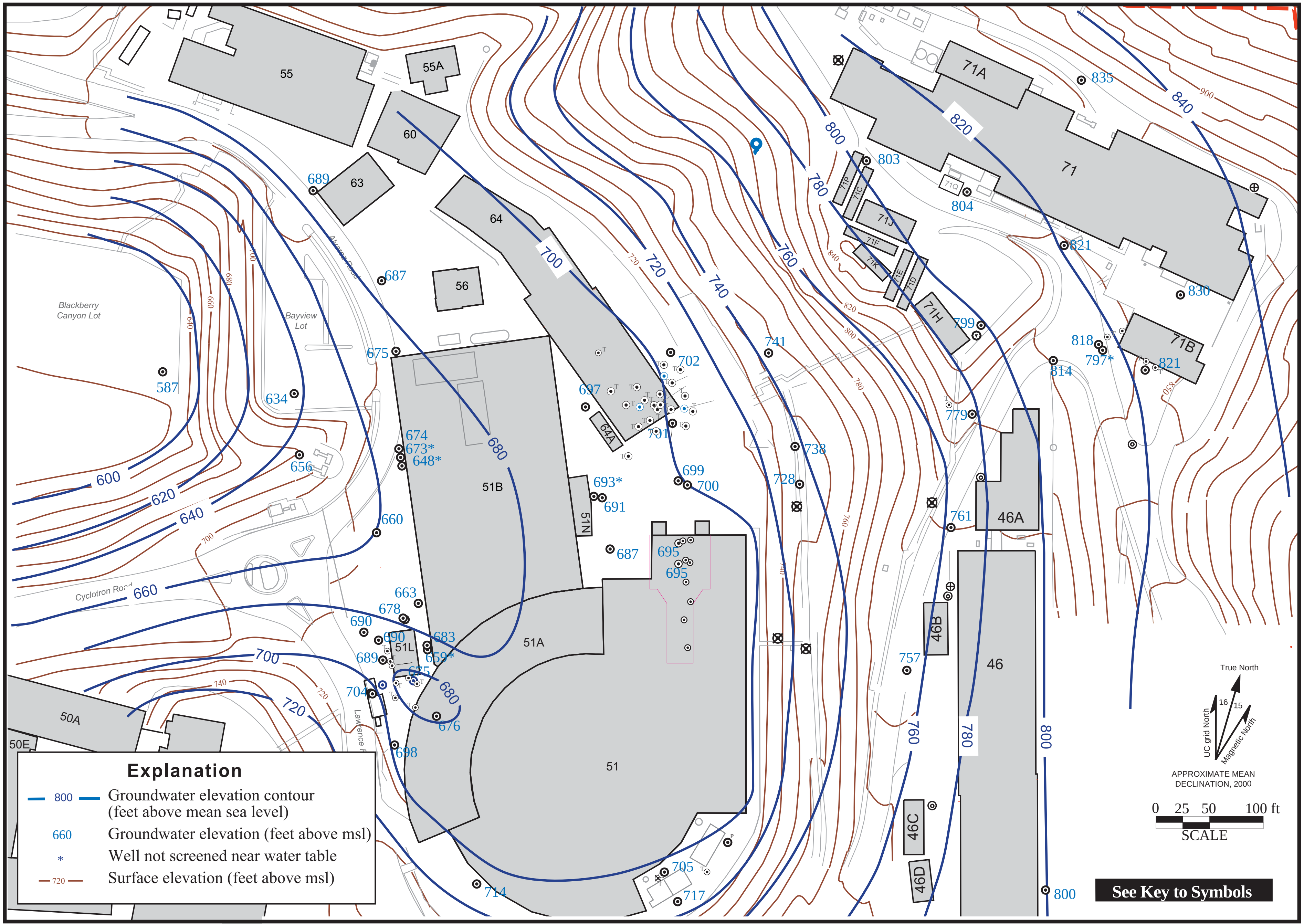


Figure 4.3.1-3. Water Level Elevation Map in the Bevalac Area, Fourth Quarter FY2003.

f4.3.1-3_Bevalac3qfy03.ai
4/04

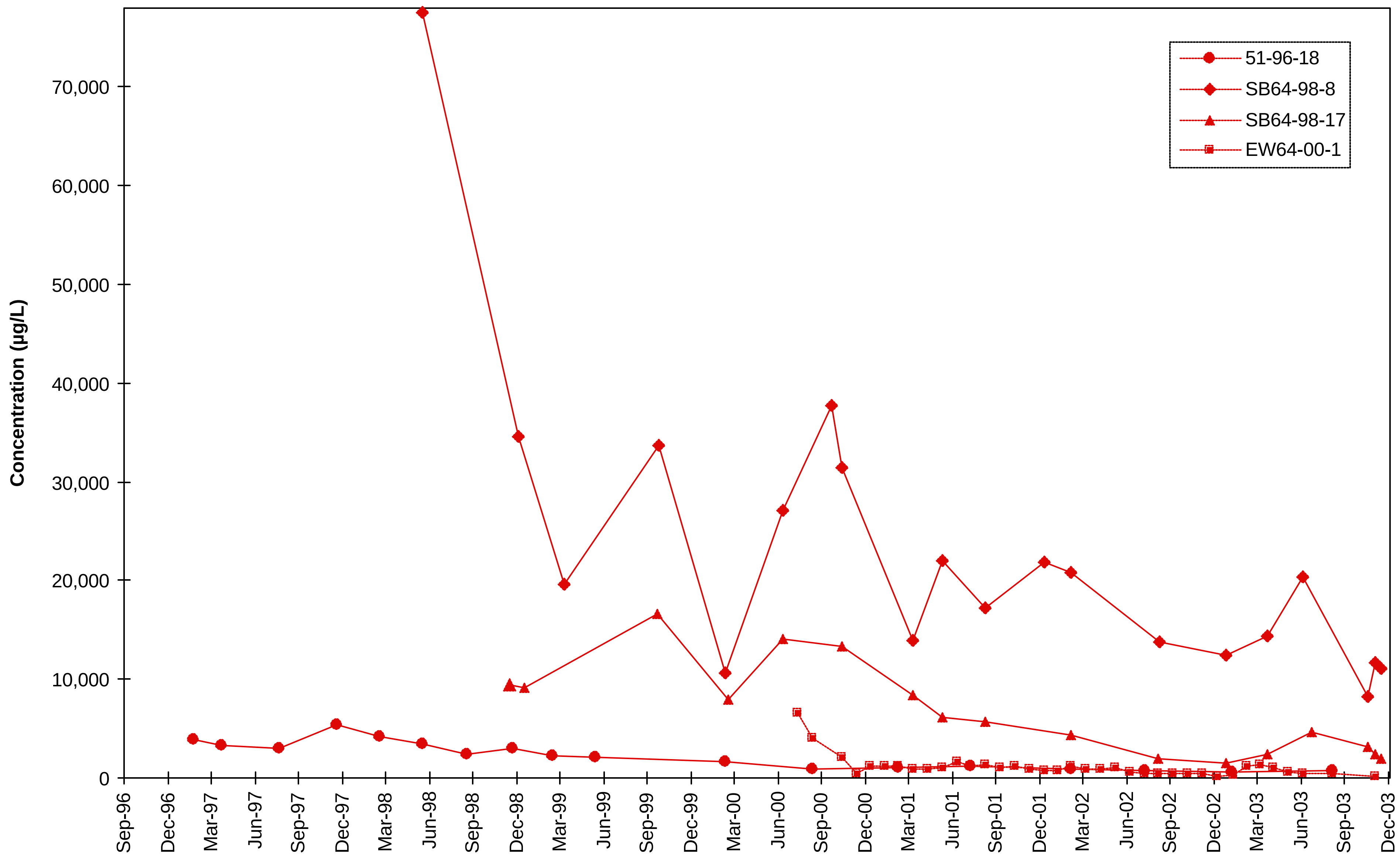


Figure 4.3.1-4a. Concentrations of Halogenated VOCs (excluding Freon compounds) in Selected Wells Monitoring the Source Area of the Building 51/64 Groundwater Solvent Plume

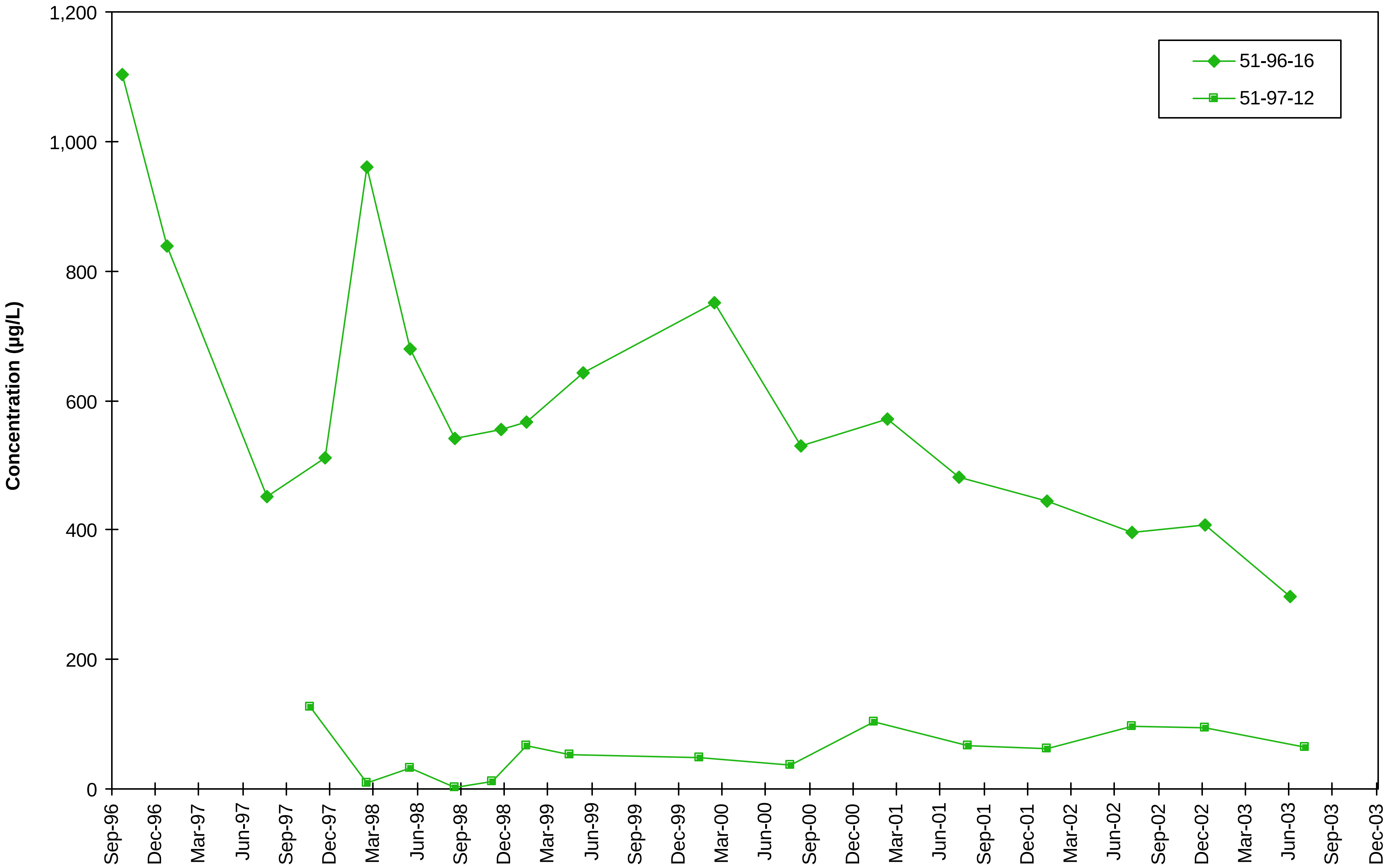


Figure 4.3.1-4b. Concentrations of Halogenated VOCs (excluding Freon compounds) in Selected Wells Monitoring the Core Area of the Building 51/64 Groundwater Solvent Plume

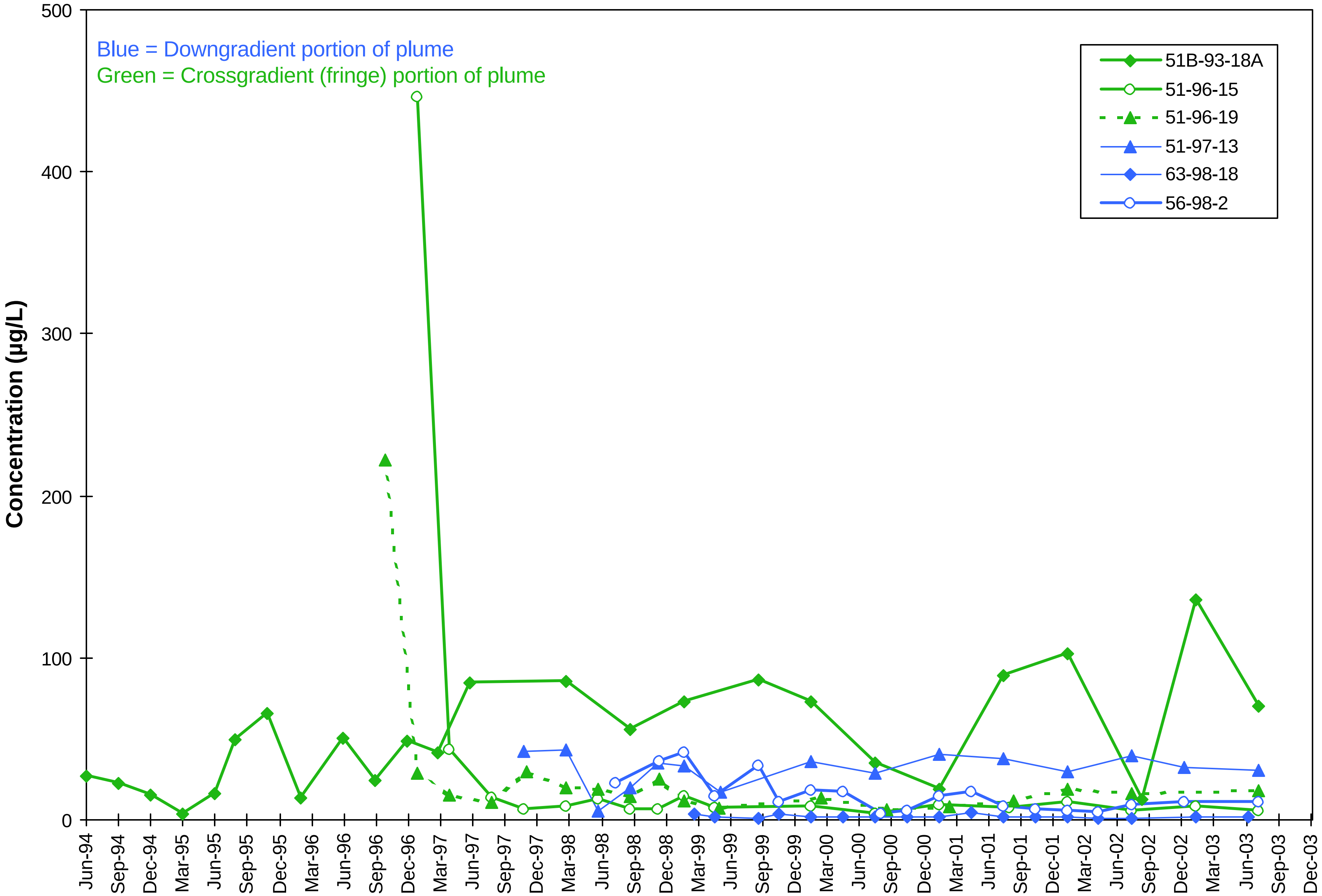


Figure 4.3.1-5. Concentrations of Halogenated VOCs (excluding Freon compounds) in Selected Wells Monitoring the Crossgradient and Downgradient Areas of the Building 51/64 Groundwater Solvent Plume

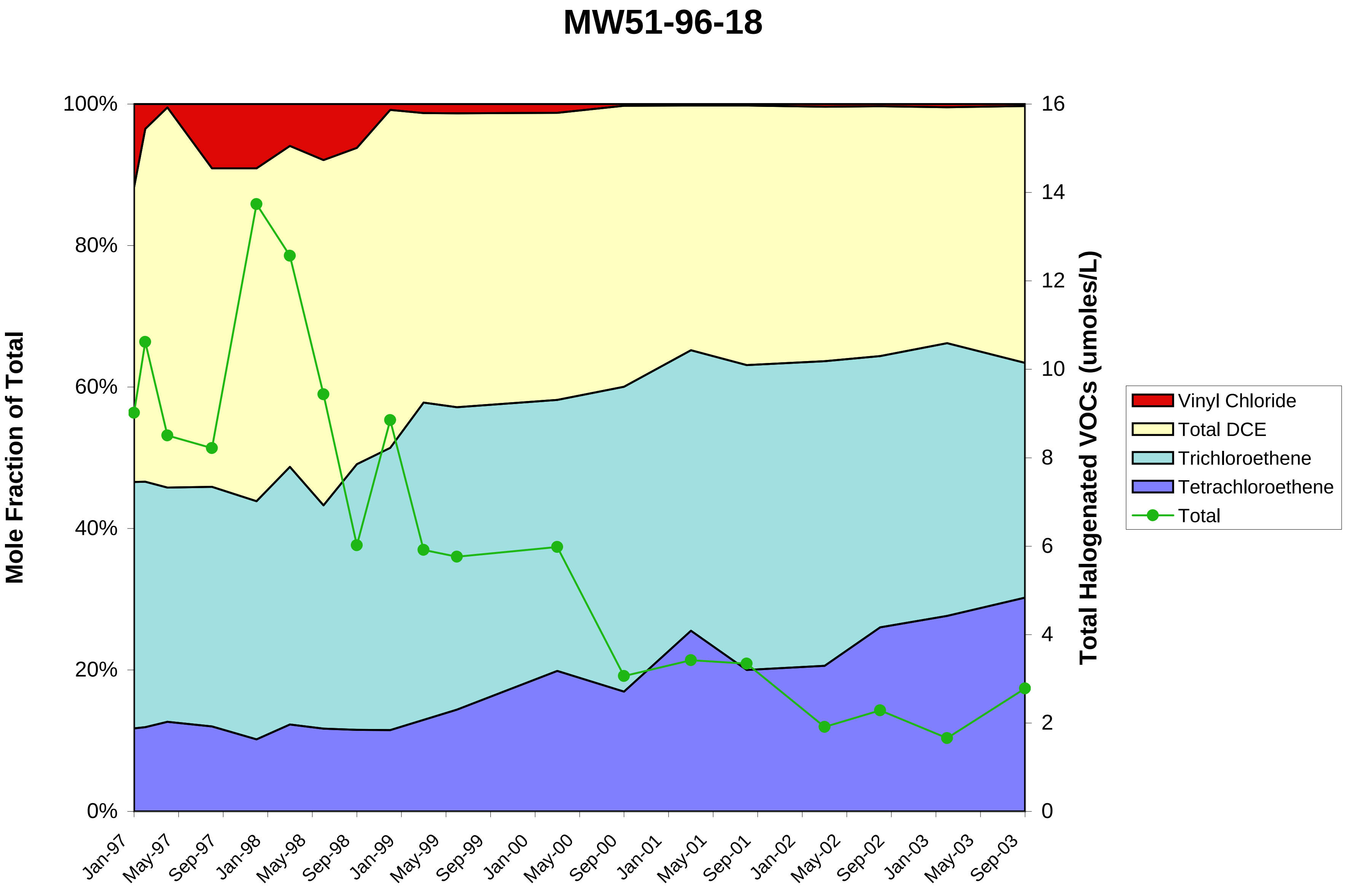


Figure 4.3.1-6. Temporal Variations in Halogenated Non-aromatic VOC Concentrations in Well MW51-96-18, Plume Source Area, Building 51/64 Plume.

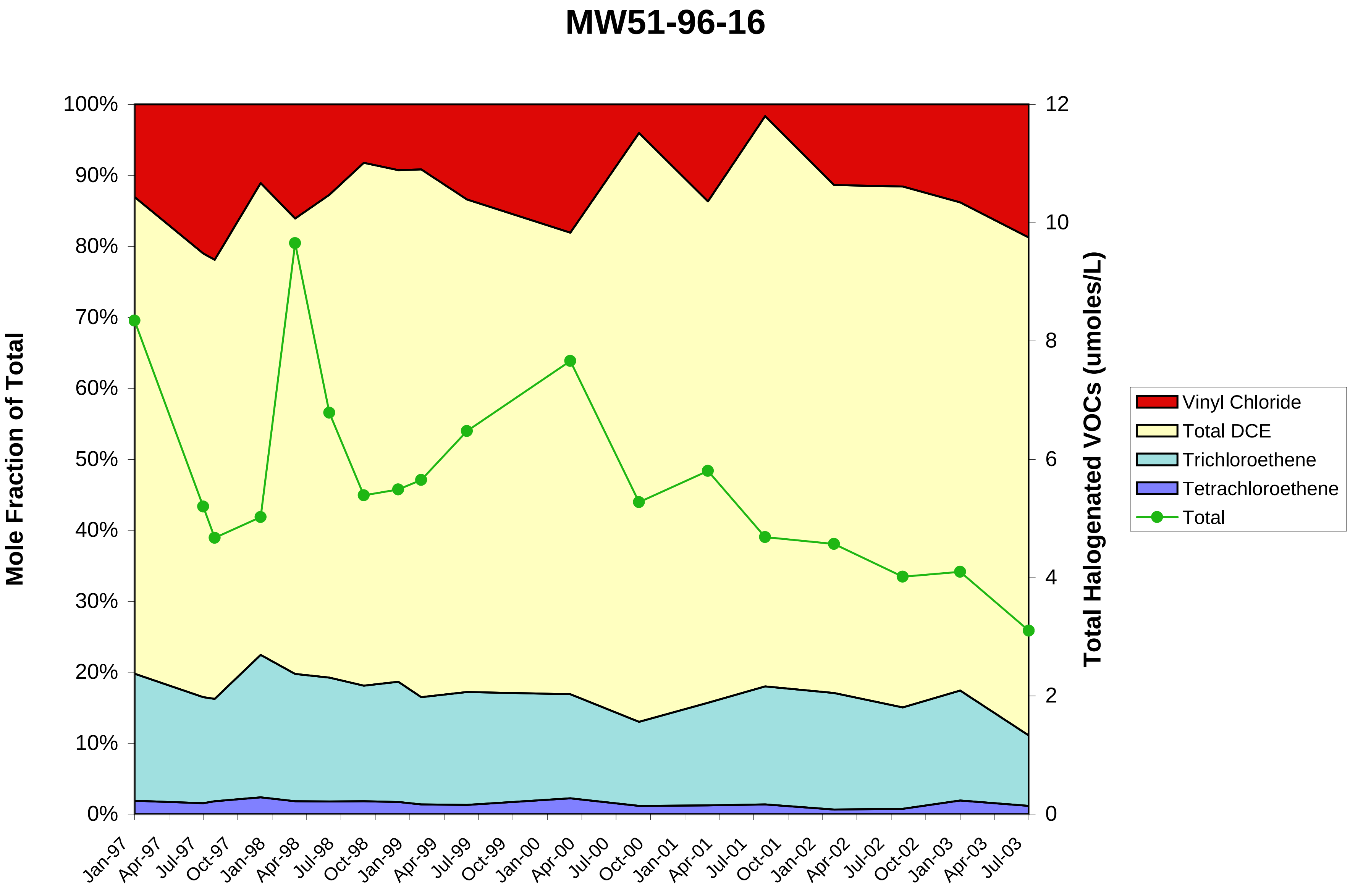


Figure 4.3.1-7. Temporal Variations in Halogenated Non-aromatic VOC Concentrations in Well MW51-96-16, Midplume Area, Building 51/64 Plume.

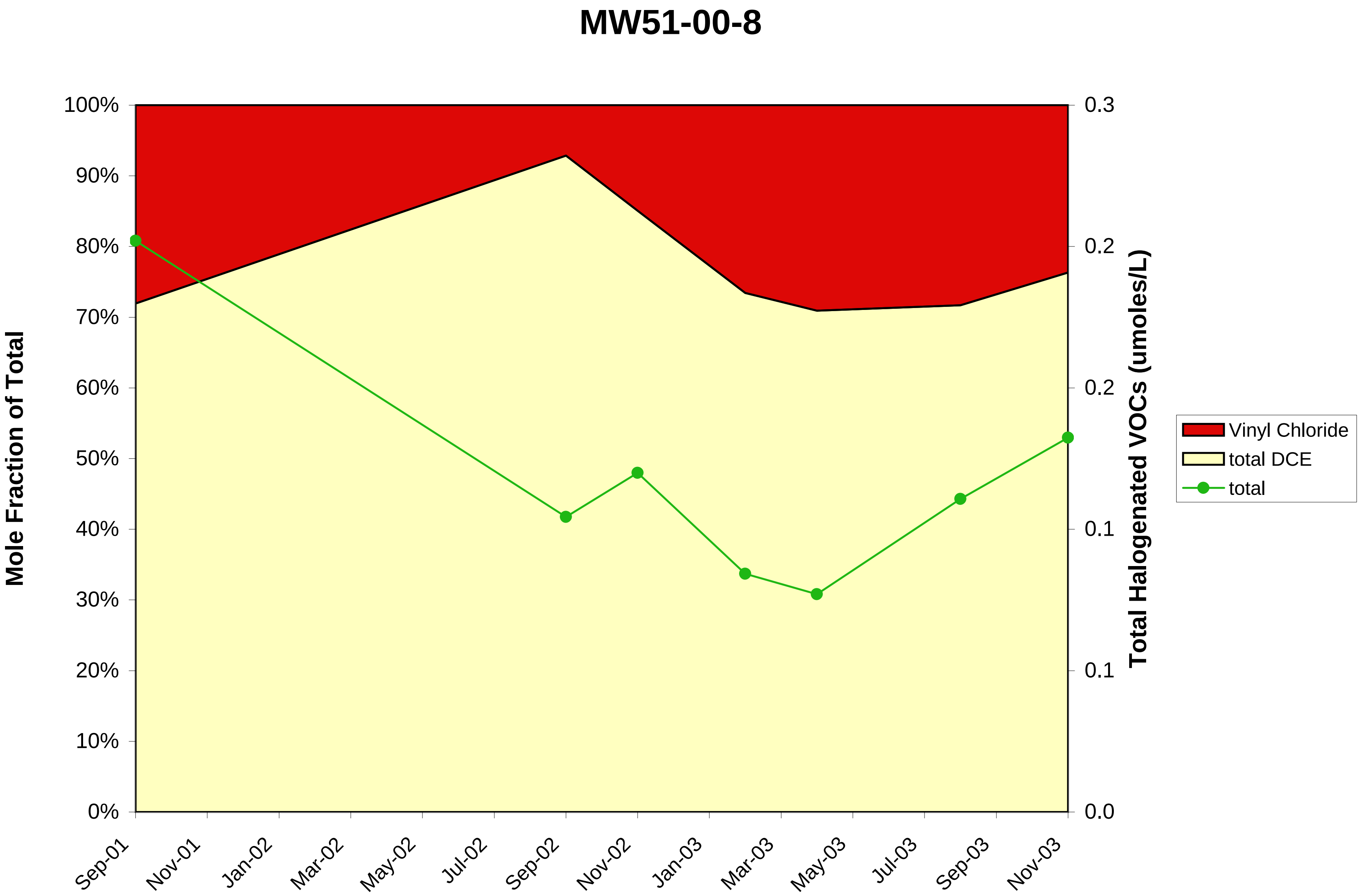


Figure 4.3.1-8. Temporaral Variations in Halogenated Non-aromatic VOCs in Well MW51-00-8, Downgradient Area, Building 51/64 Plume.

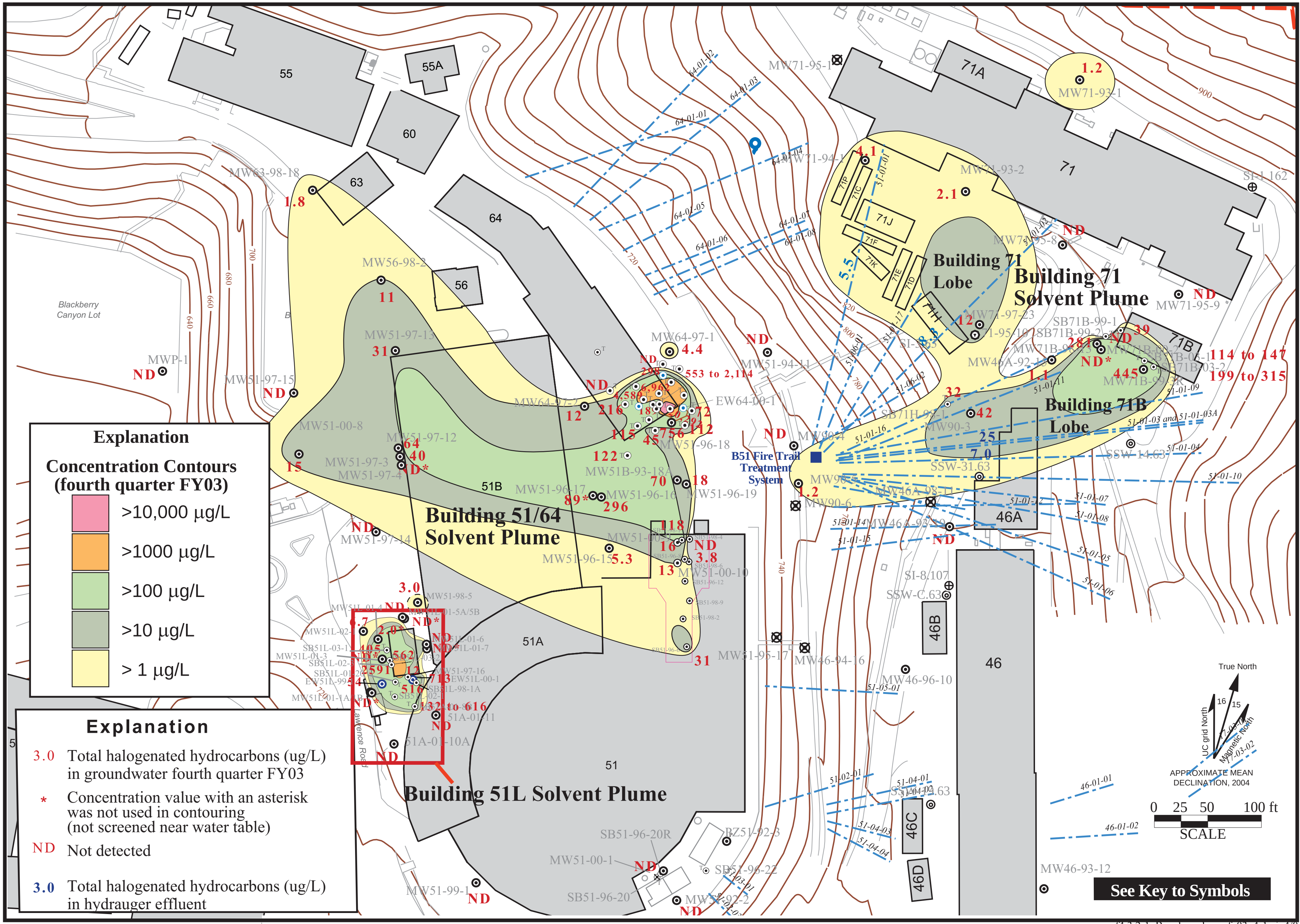


Figure 4.3.2-1. Total Halogenated Hydrocarbons in Groundwater (Excluding Freon) (ug/L), Bevalac Area.

f4.3.2-1_Bevalac_plume-fy03q4r1.ai 4/04

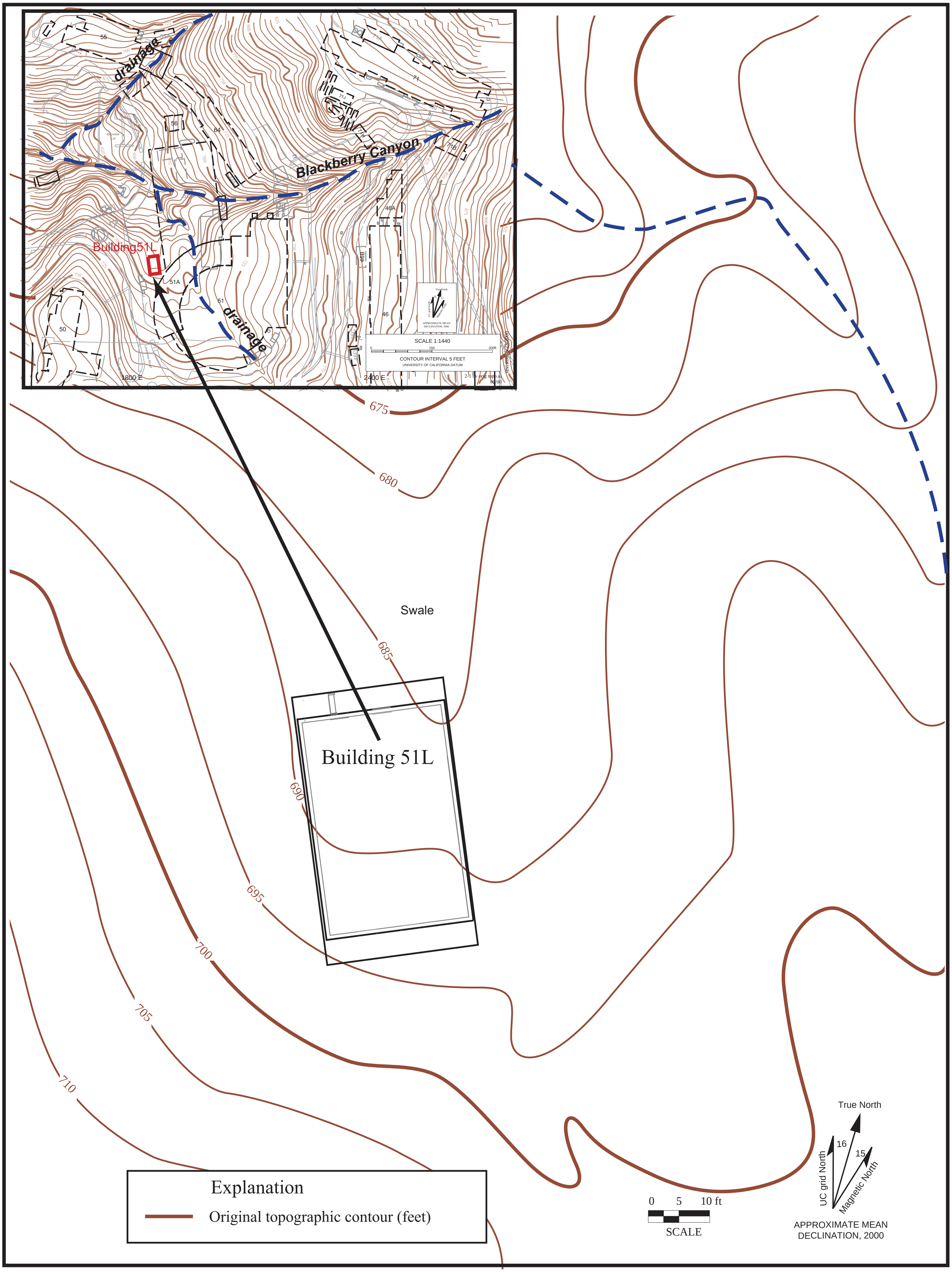


Figure 4.3.2-2. Original Topography Building 51L Area.

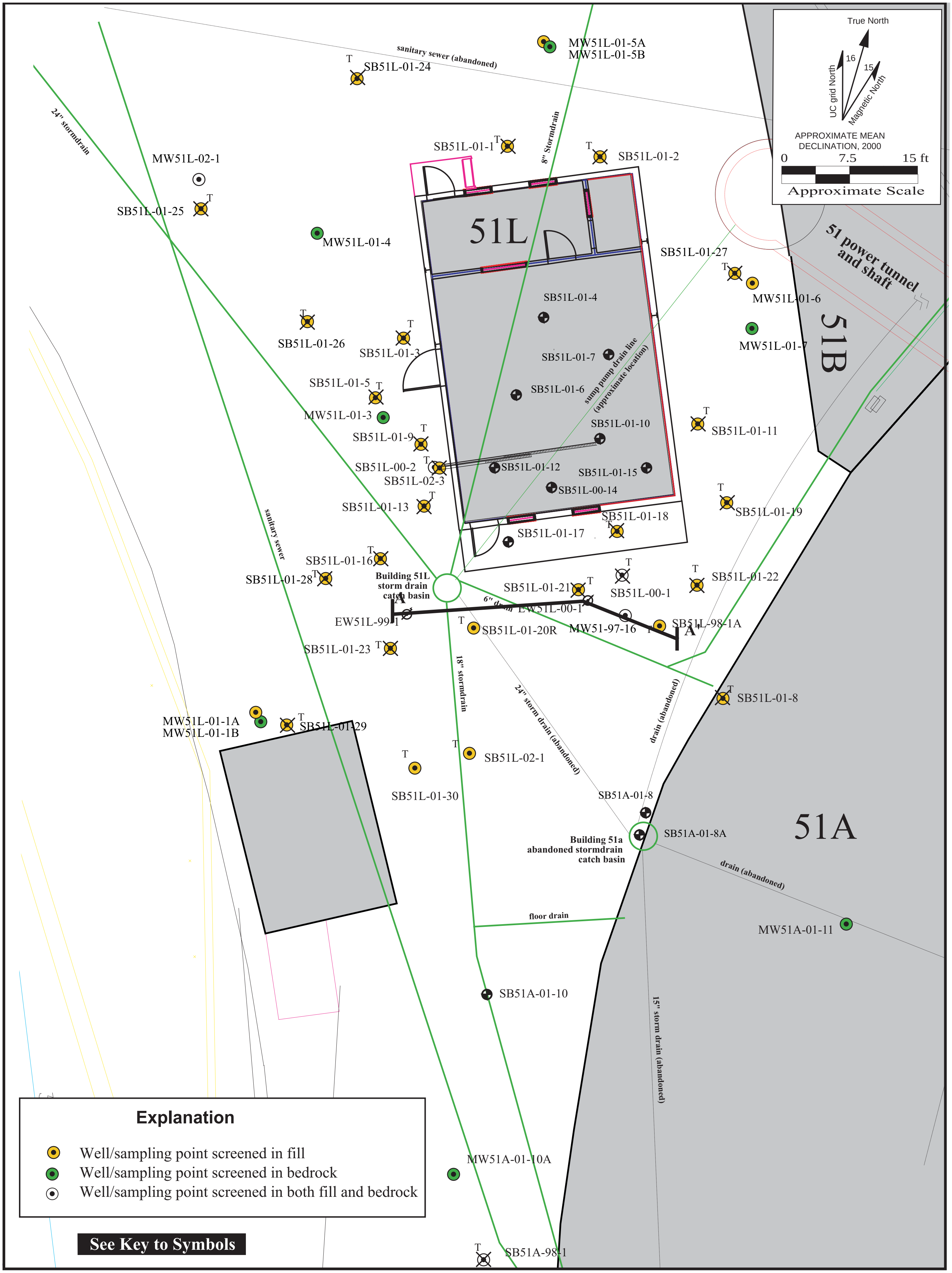
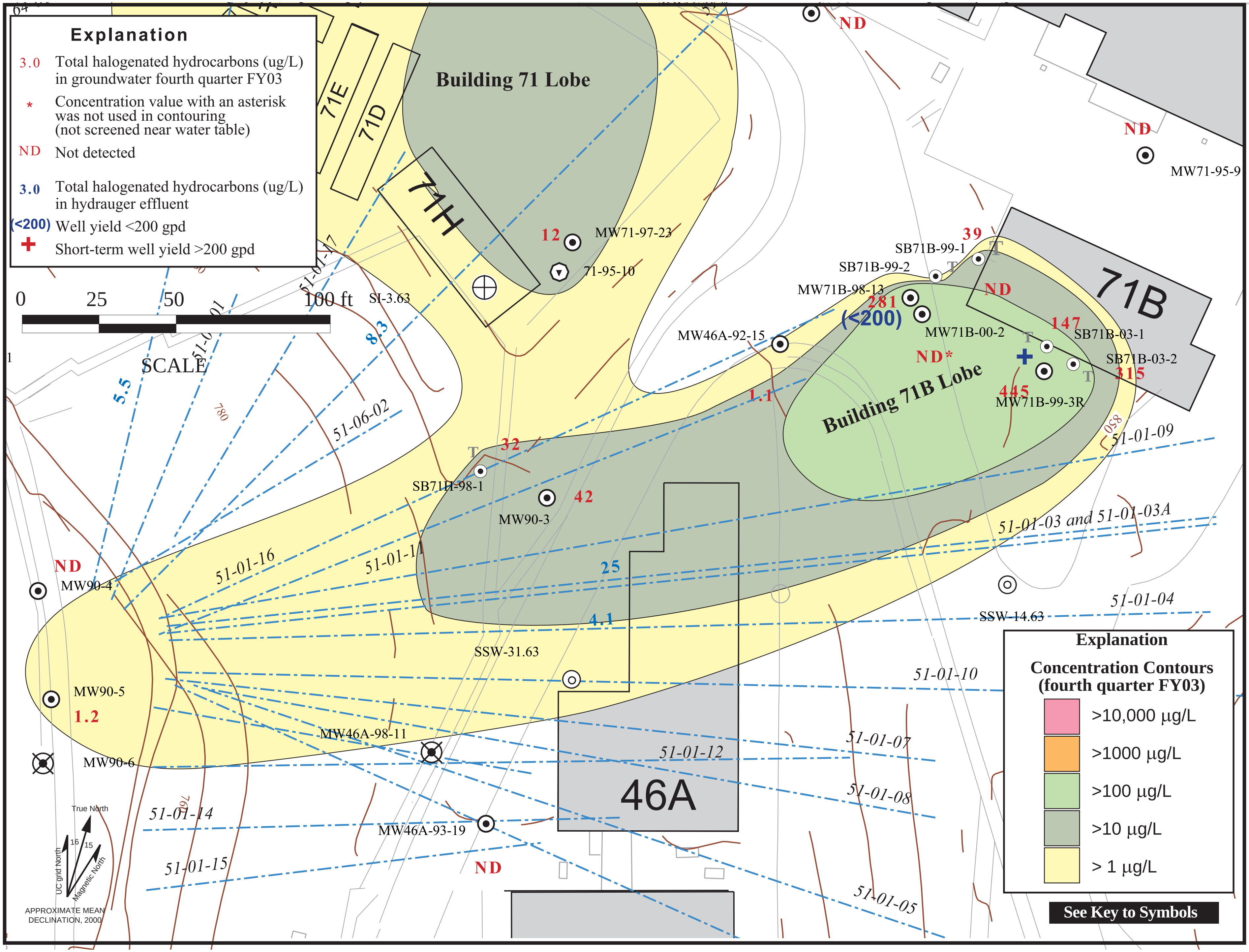


Figure 4.3.2-3. Detailed Site Map Building 51L Area.

f4.3.2-3_basemap51L.ai
4/04



f4.3.3-1,-2 B71B Lobe fy03q4.ai
4/04

Figure 4.3.3-1. Total Halogenated Hydrocarbons in Groundwater (Excluding Freon) (ug/L) and Estimated Groundwater Yields, Building 71B Lobe Building 71 Groundwater Solvent Plume.

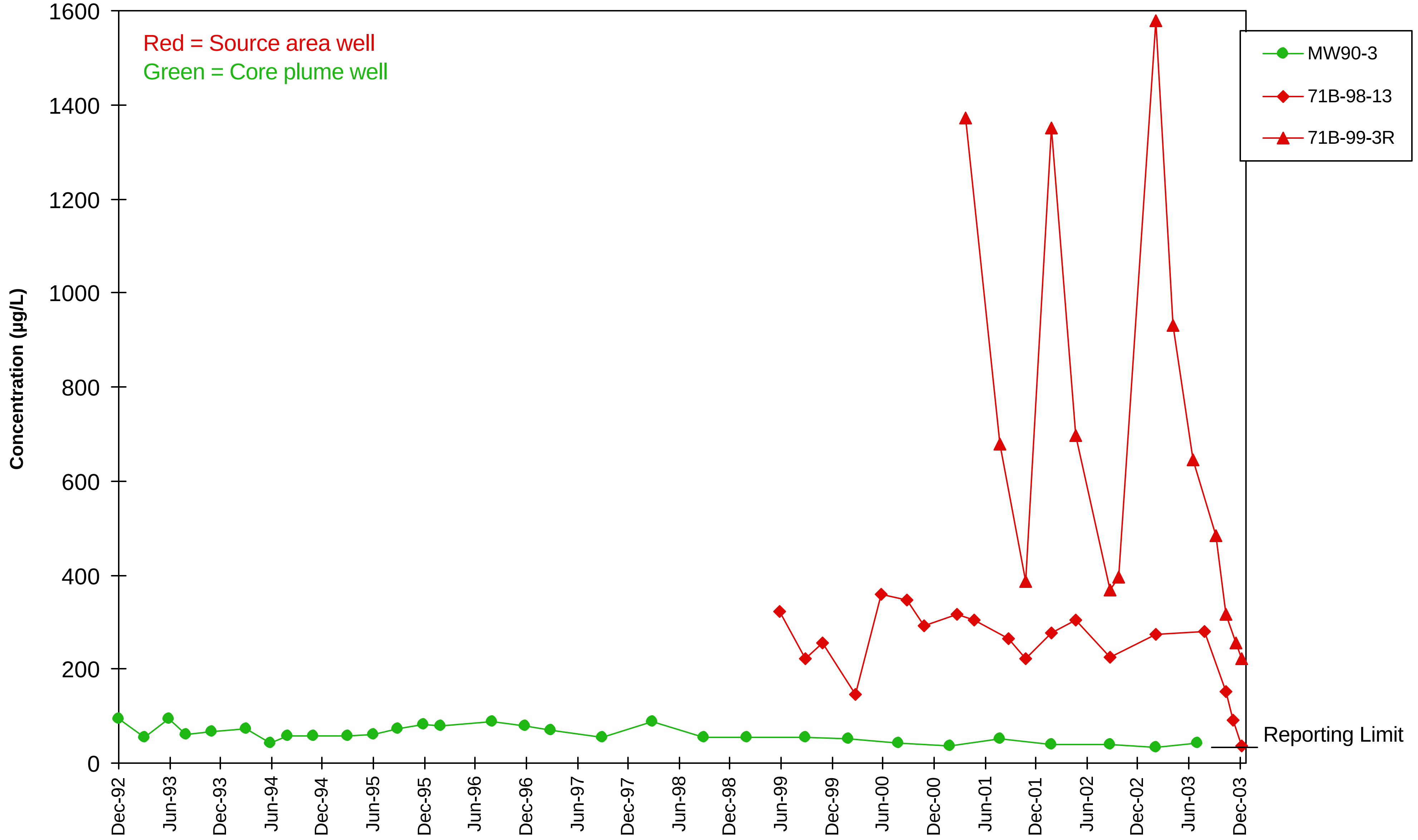


Figure 4.3.3-2a. Concentration Trends for Halogenated Non-Aromatic VOCs (excluding Freon compounds, Chloroform, and Bromodichloromethane) in Source and Core Area Wells Monitoring Building 71 Solvent Plume (Building 71B Lobe)

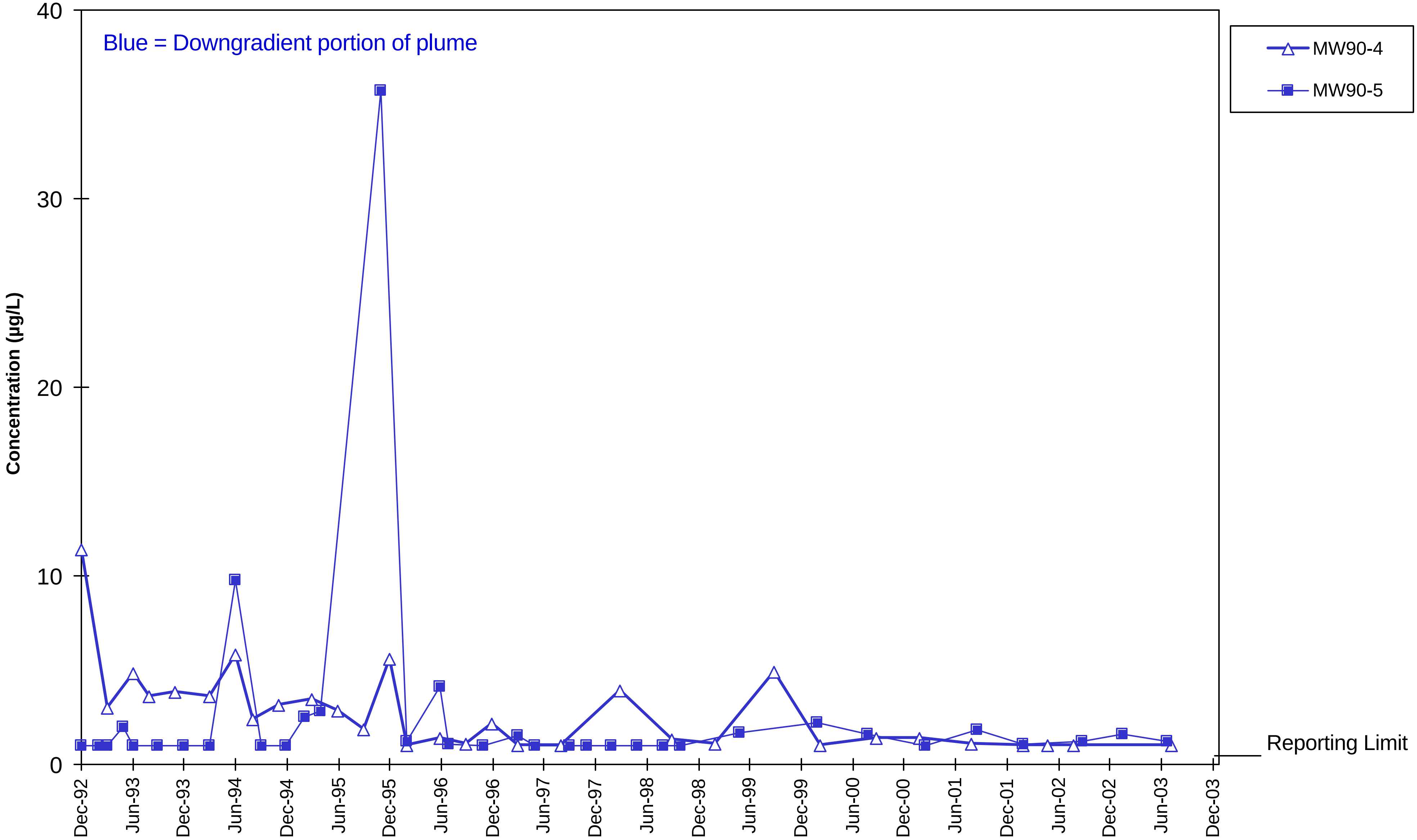


Figure 4.3.3-2b. Concentration Trends for Halogenated Non-Aromatic VOCs (excluding Freon compounds, Chloroform, and Bromodichloromethane) in Downgradient Wells Monitoring Building 71 Solvent Plume (Building 71B Lobe)

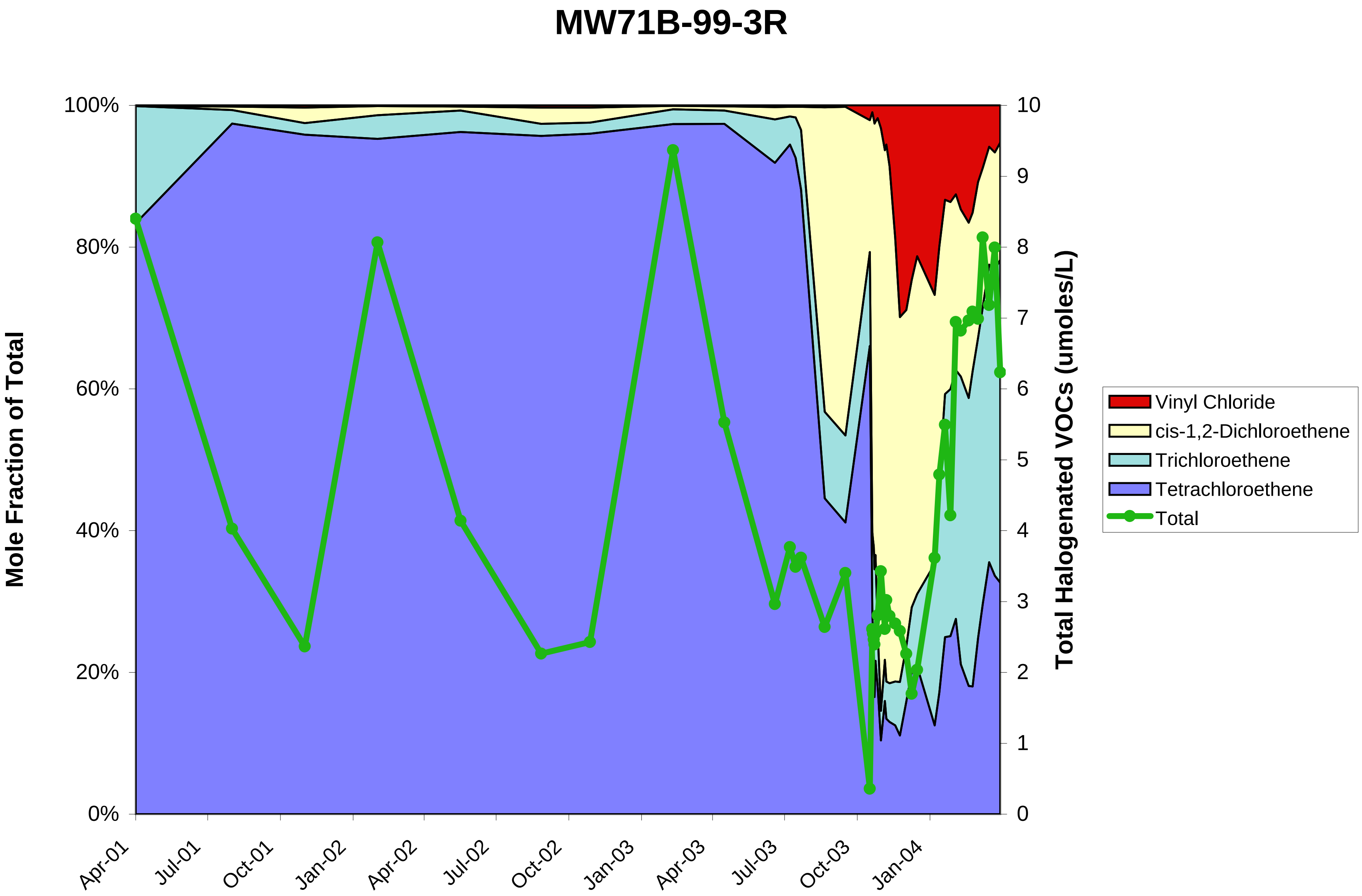


Figure 4.3.3-3. Temporal Variations in Halogenated Non-aromatic VOC Concentrations in Well MW71B-99-3R, Upgradient Area, Building 71B Lobe.

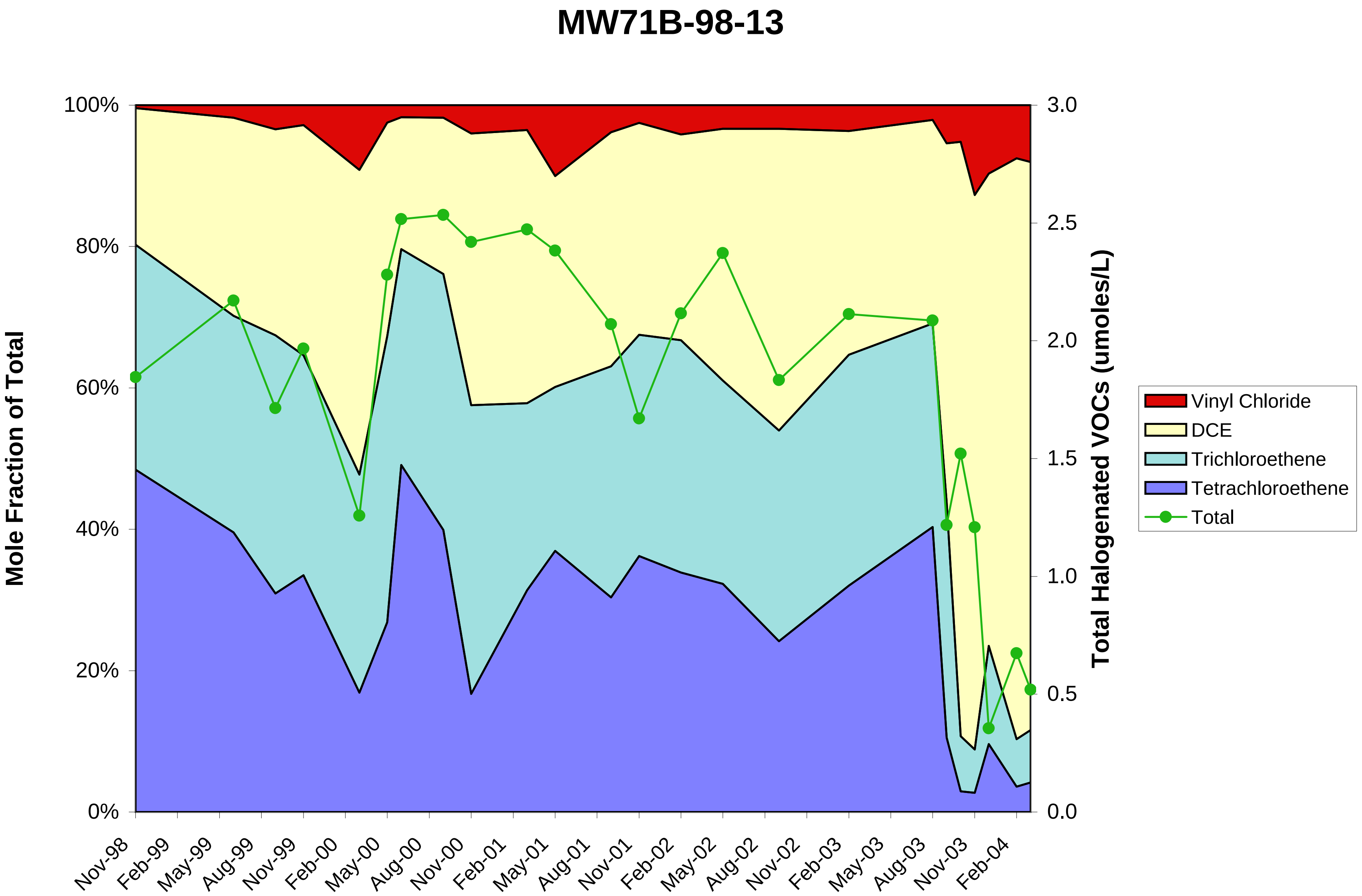


Figure 4.3.3-4. Temporal Variations in Halogenated Non-aromatic VOC Concentrations in Well MW71B-98-13, Building 71B Lobe.

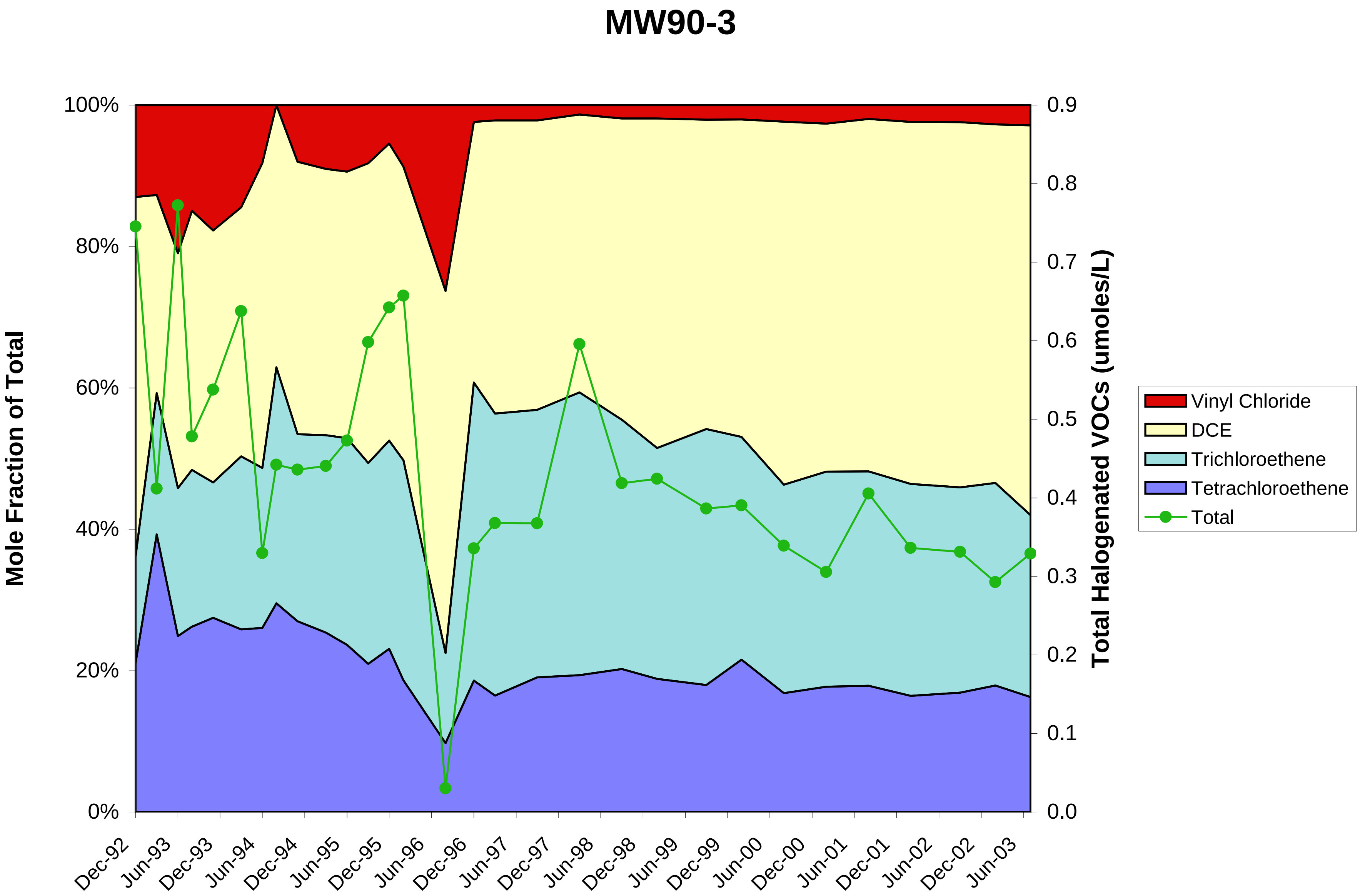


Figure 4.3.3-5. Temporal Variations in Halogenated Non-aromatic VOC Concentrations in Well MW90-3, Downgradient Area, Building 71B Lobe.

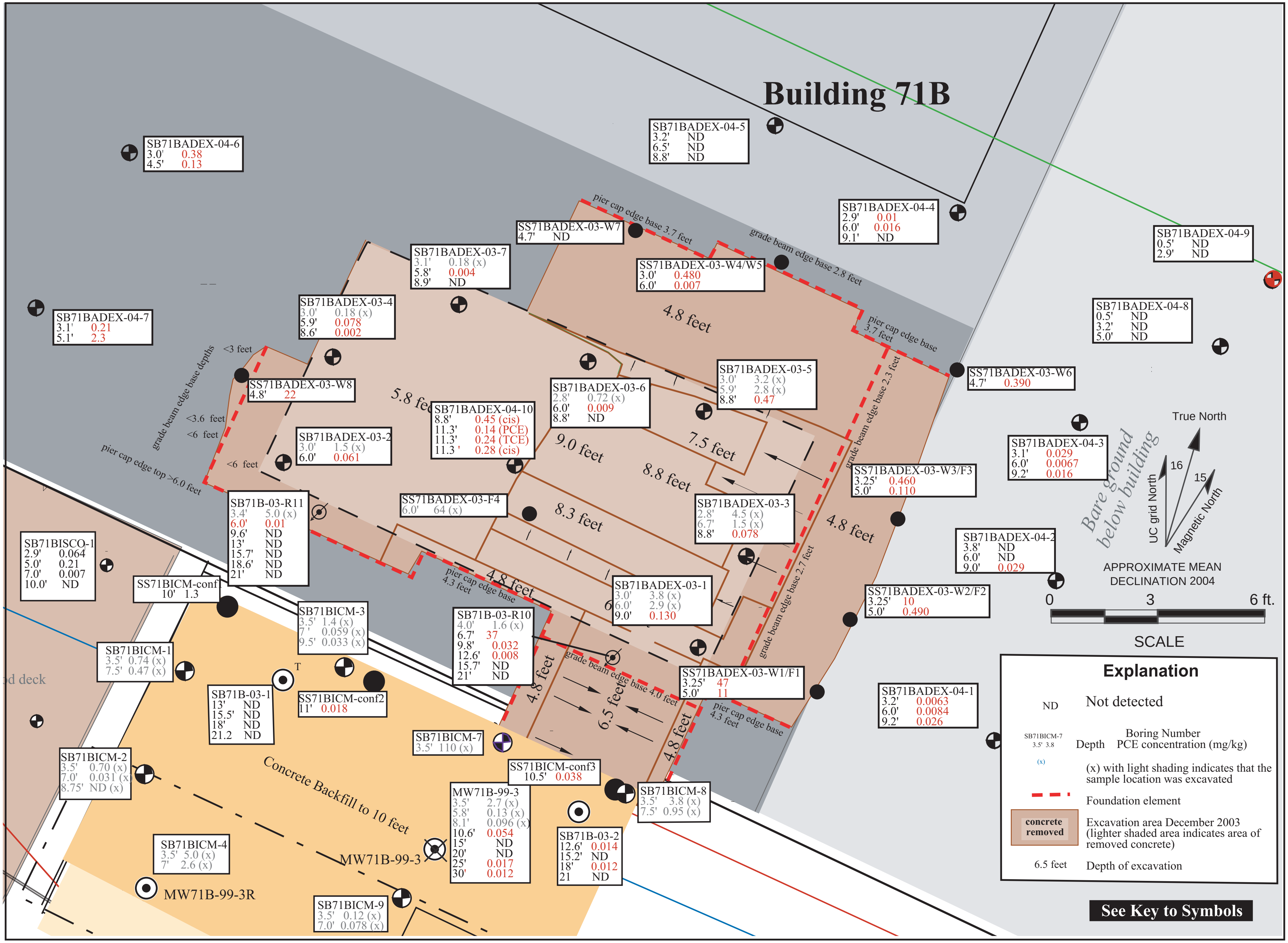
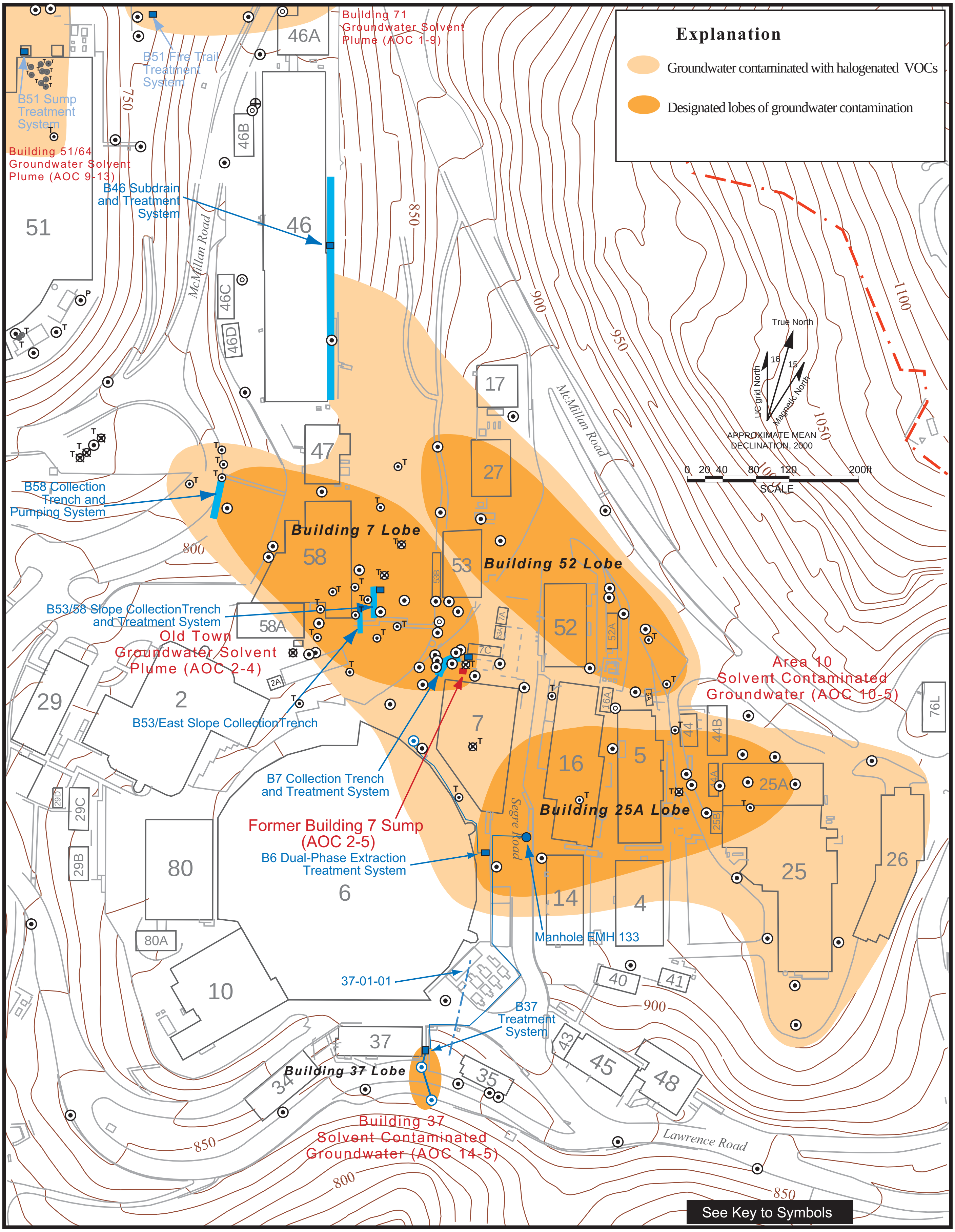


Figure 4.3.3-6. Concentrations of PCE Detected in Soil Samples, Building 71B Lobe Source Area.



4.3.4-1, 4.3.4-3 OldTown.ai
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Figure 4.3.4-1. Location of Building 7 Sump and Building 7 Lobe.

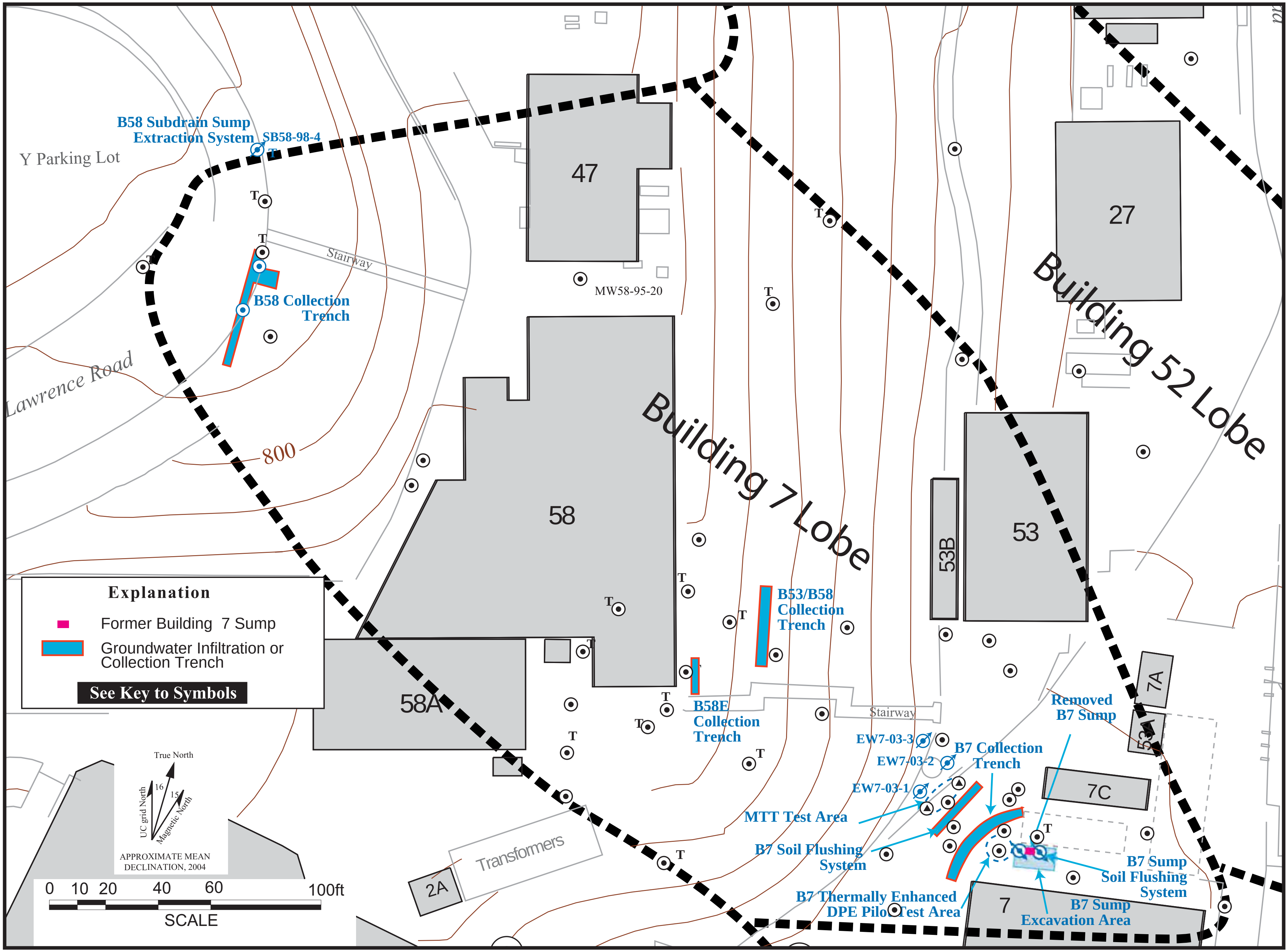

Figure 4.3.4-2. Pilot Tests and ICMs in the Building 7 Lobe Old Town Groundwater Solvent Plume Area.

4.3.4-2, -11a-19-Pilot tests, ICMs, zones.ai
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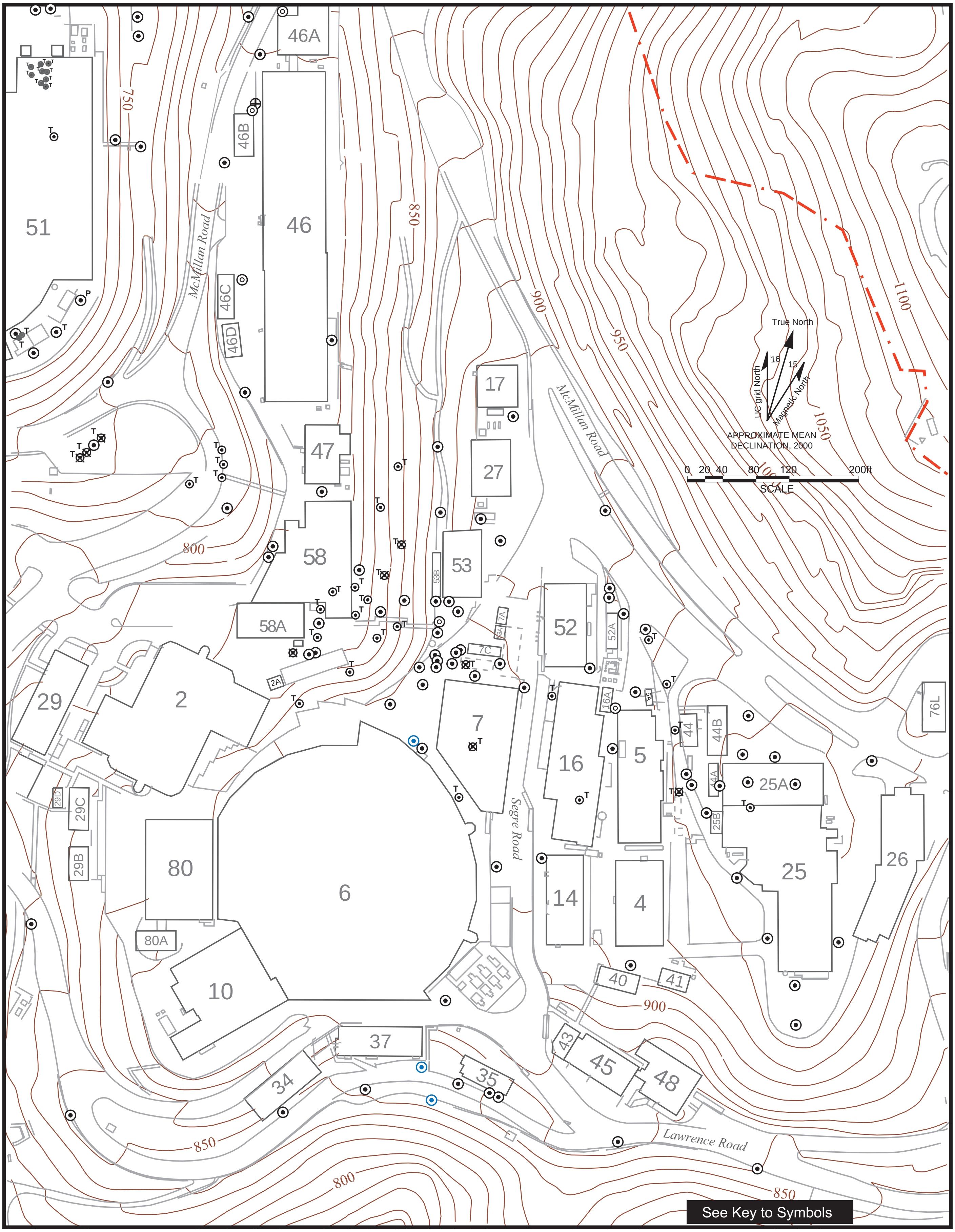

Figure 4.3.4-3. Topography of the Old Town Area.

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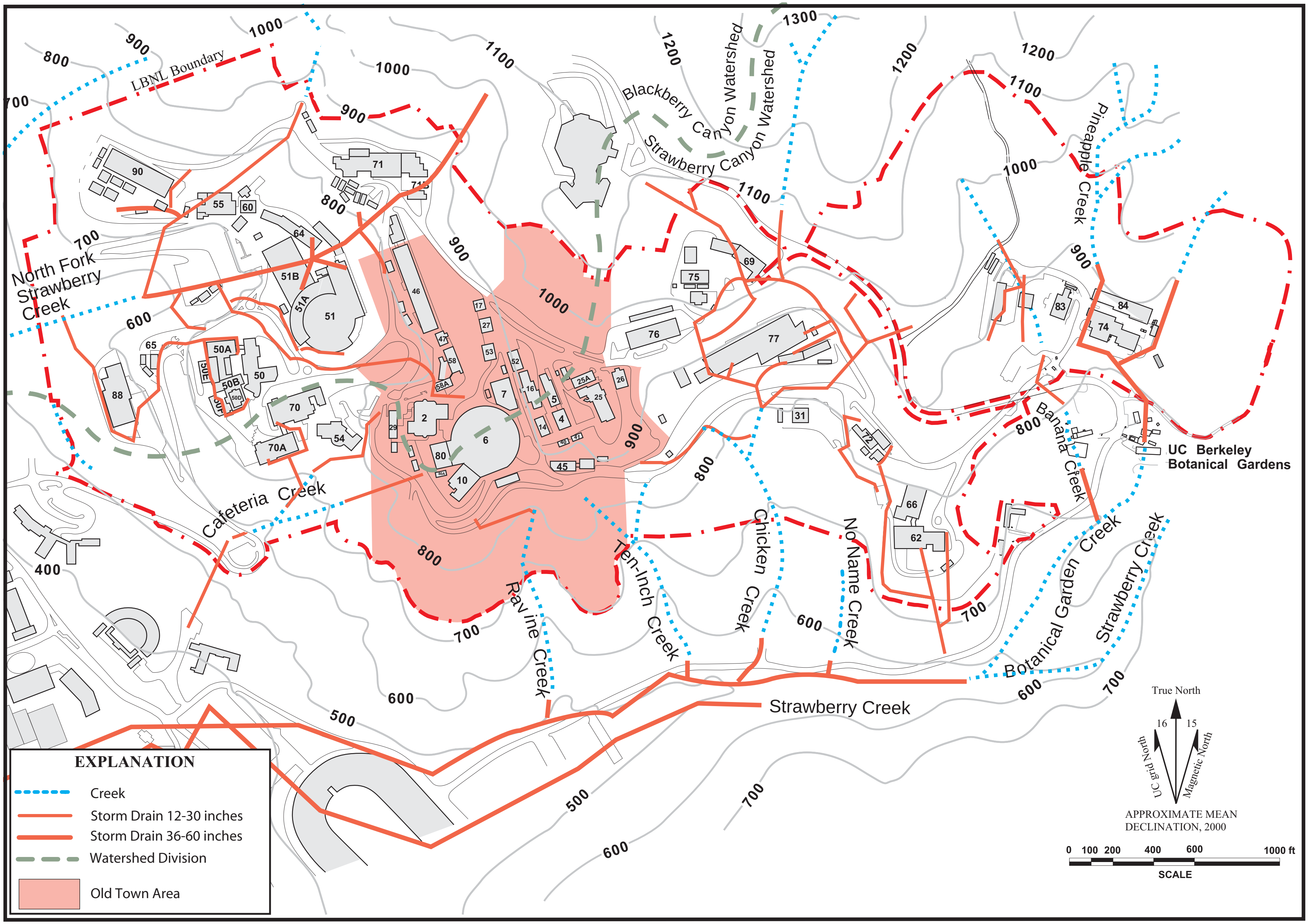

4.3.4-4 drainage.ai
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Figure 4.3.4-4. LBNL Surface Hydrology and Stormwater Drainage System.

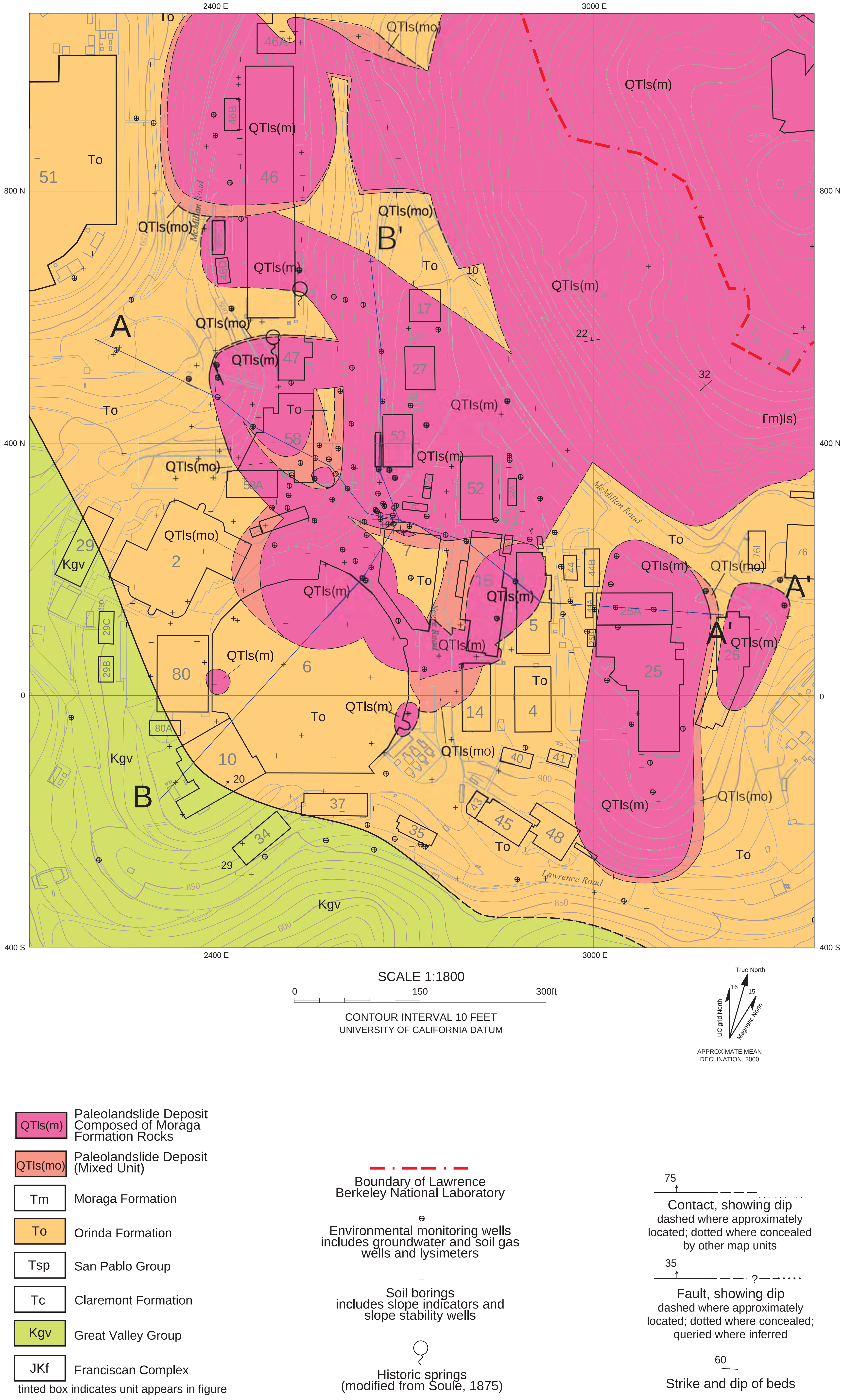

Figure 4.3.4-5. Old Town Area Bedrock Geologic Map.

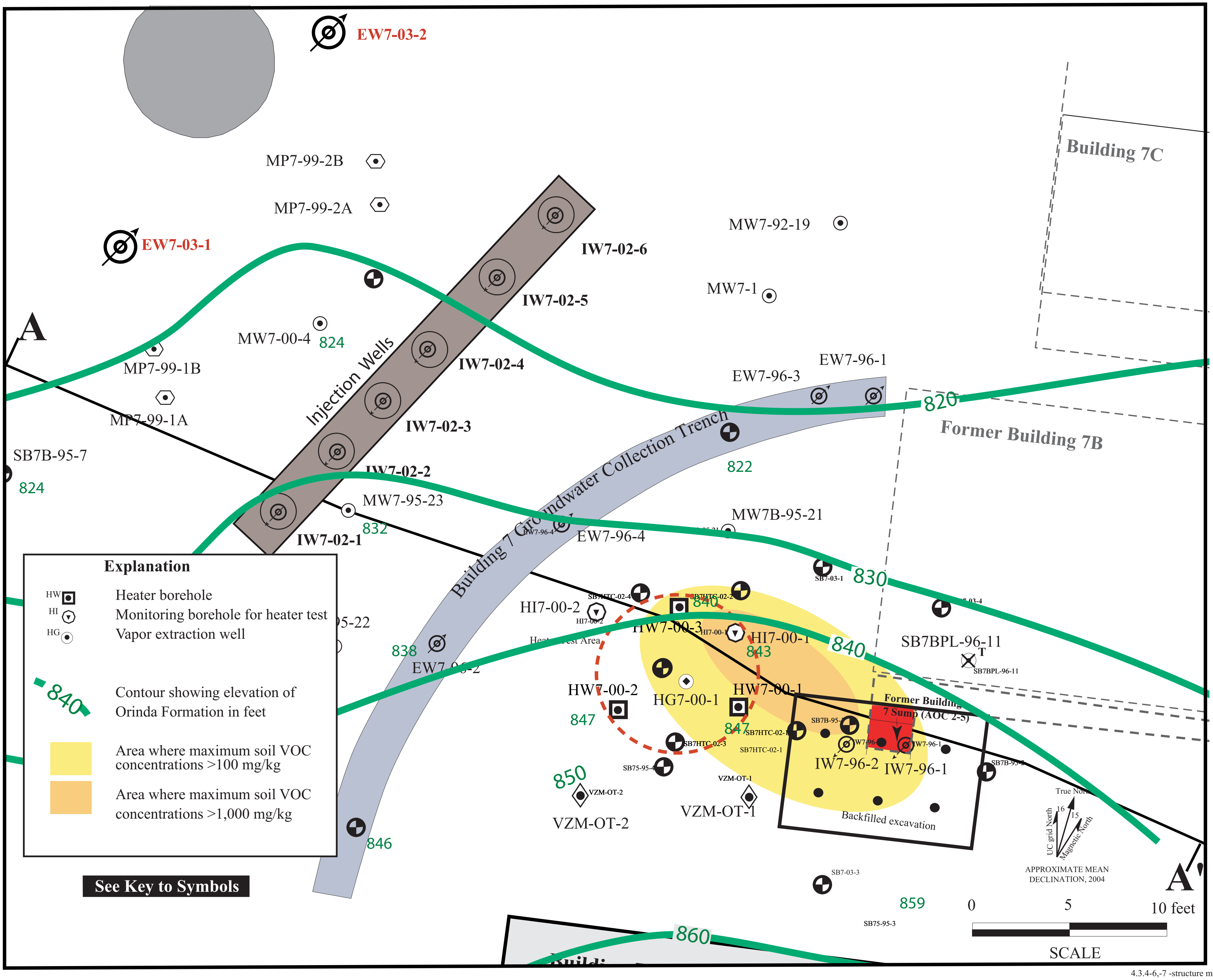

Figure 4.3.4-6. Elevation of Top of Orinda Formation.

4.3.4-6,-7 -structure maps.ai
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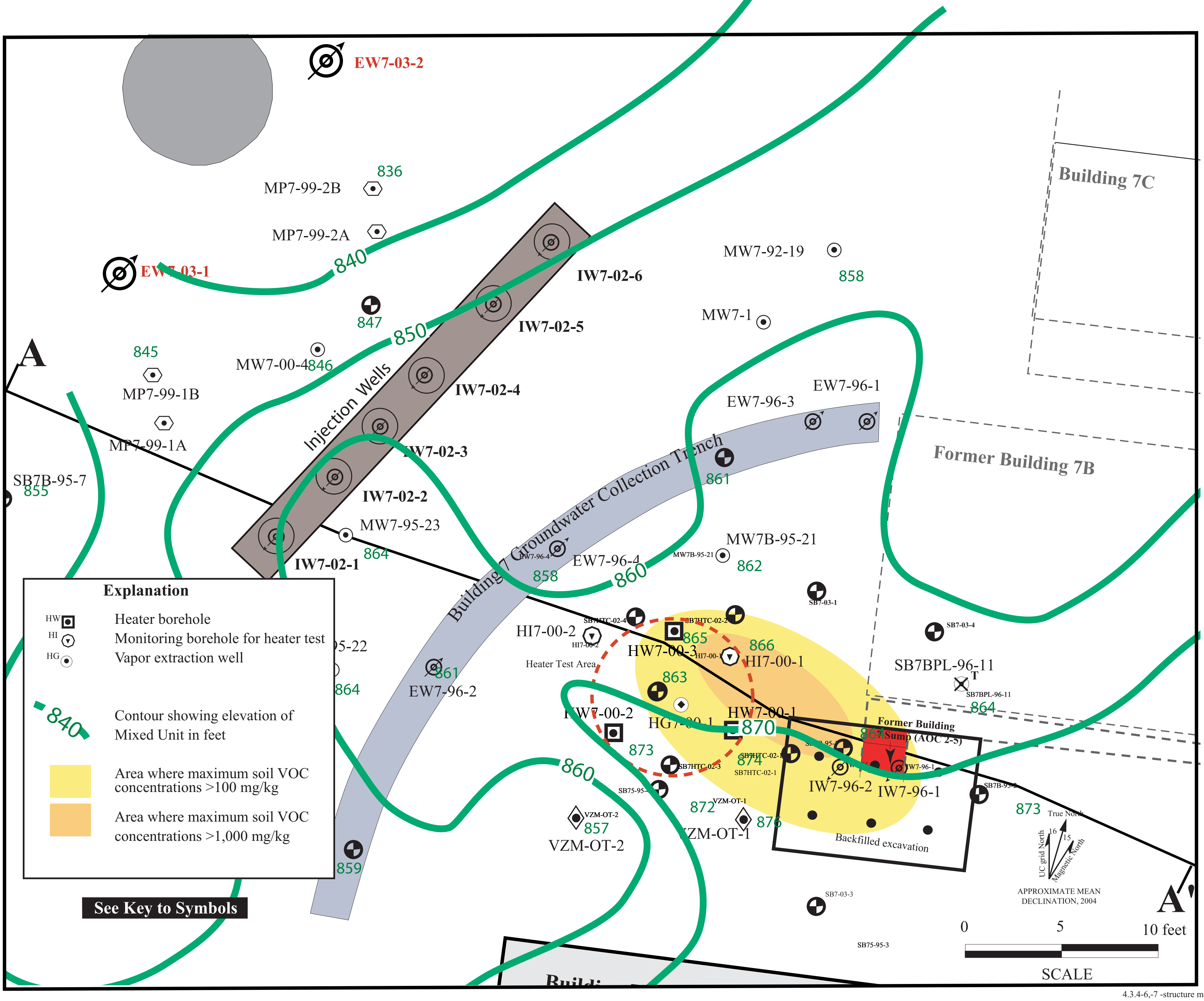

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Figure 4.3.4-7. Elevation of Top of Mixed Unit.

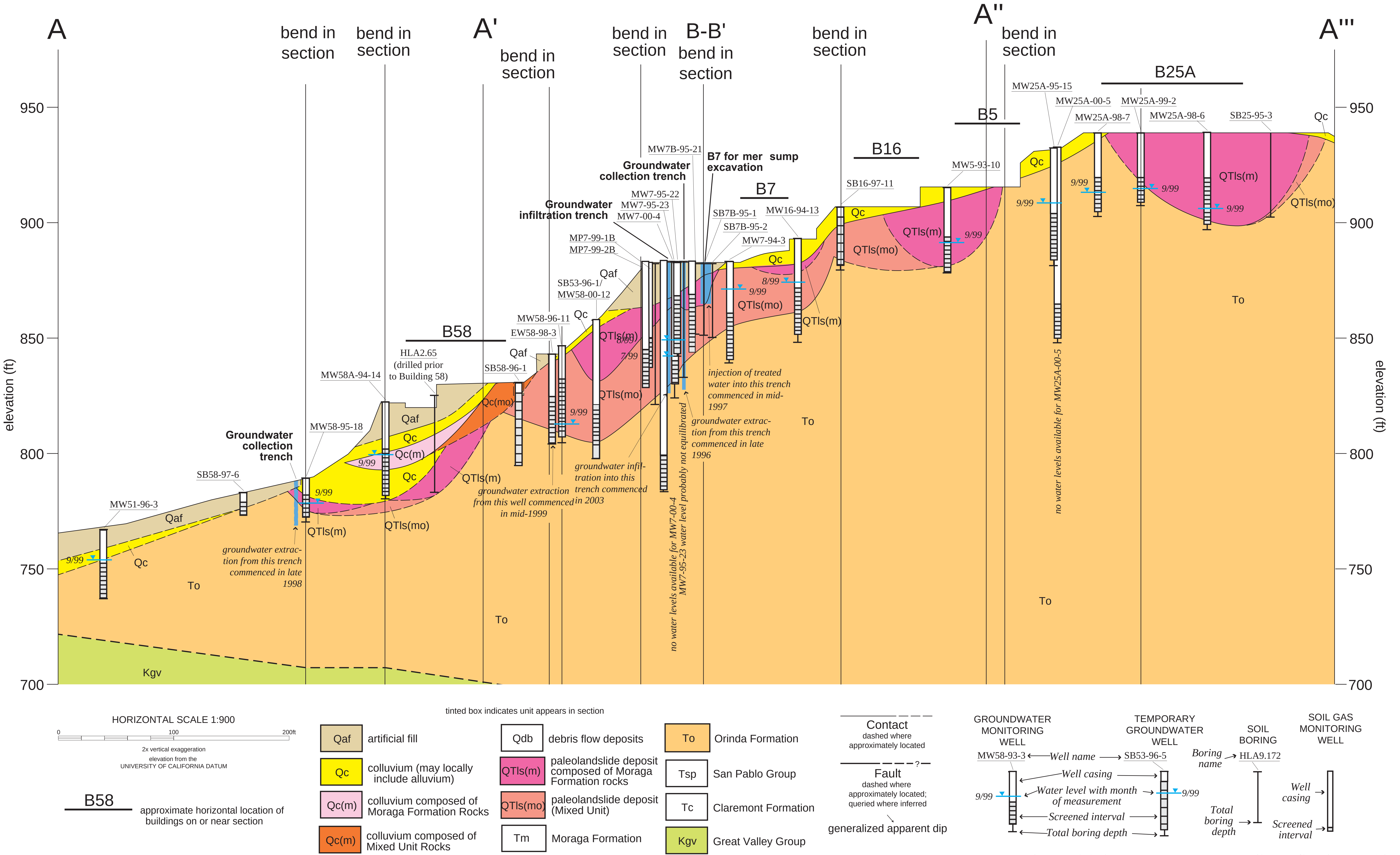

Figure 4.3.4-8. Old Town Area Cross Section A-A'.

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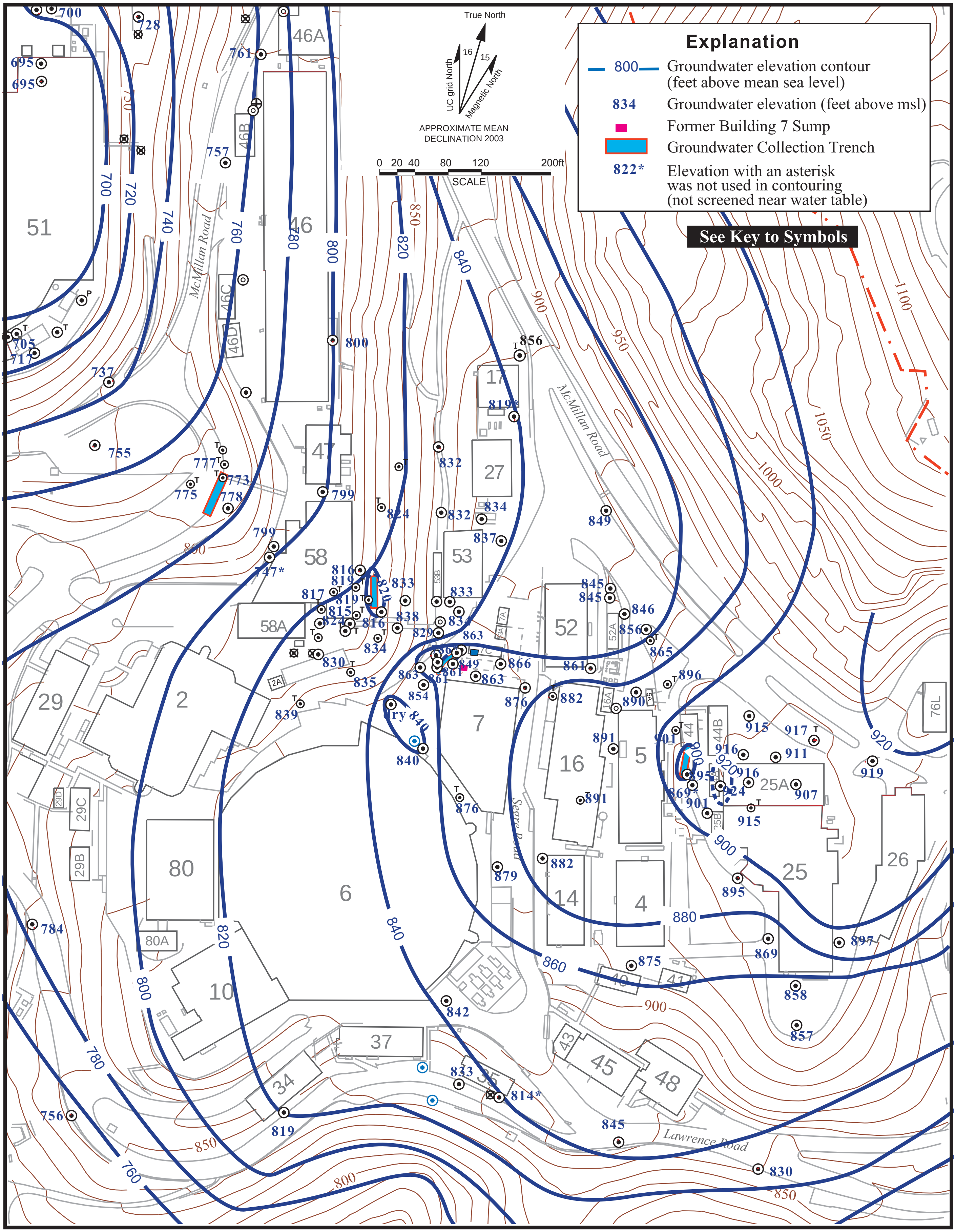

4.3.4-9-OldTown wl fy03q4.ai
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Figure 4.3.4-9. Water Level Elevation Map of the Old Town Area, Fourth Quarter FY2003.

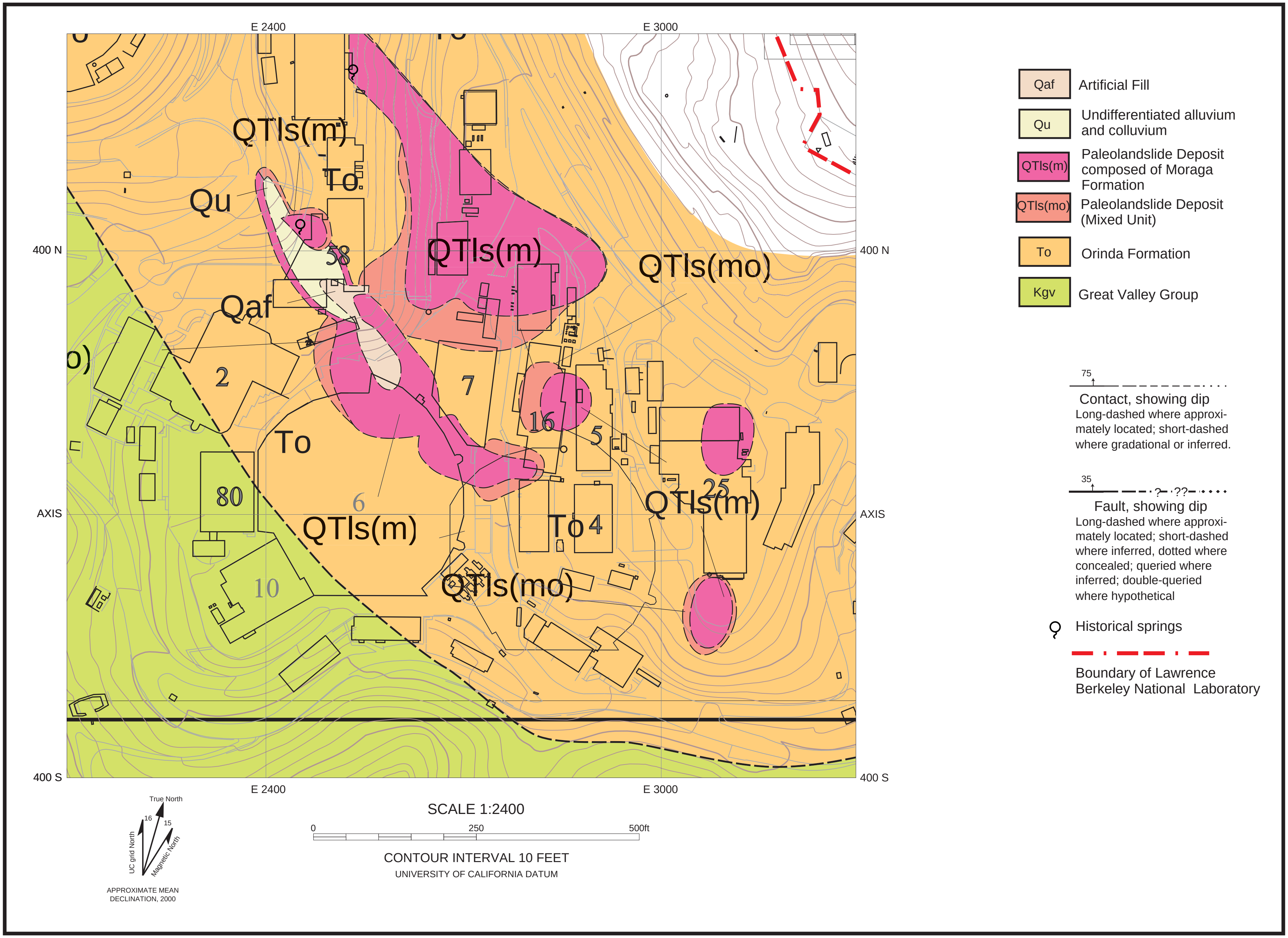

Figure 4.3.4-10. Water Table Geology in the Old Town Area.

4.3.4-10-wtgeology.ai
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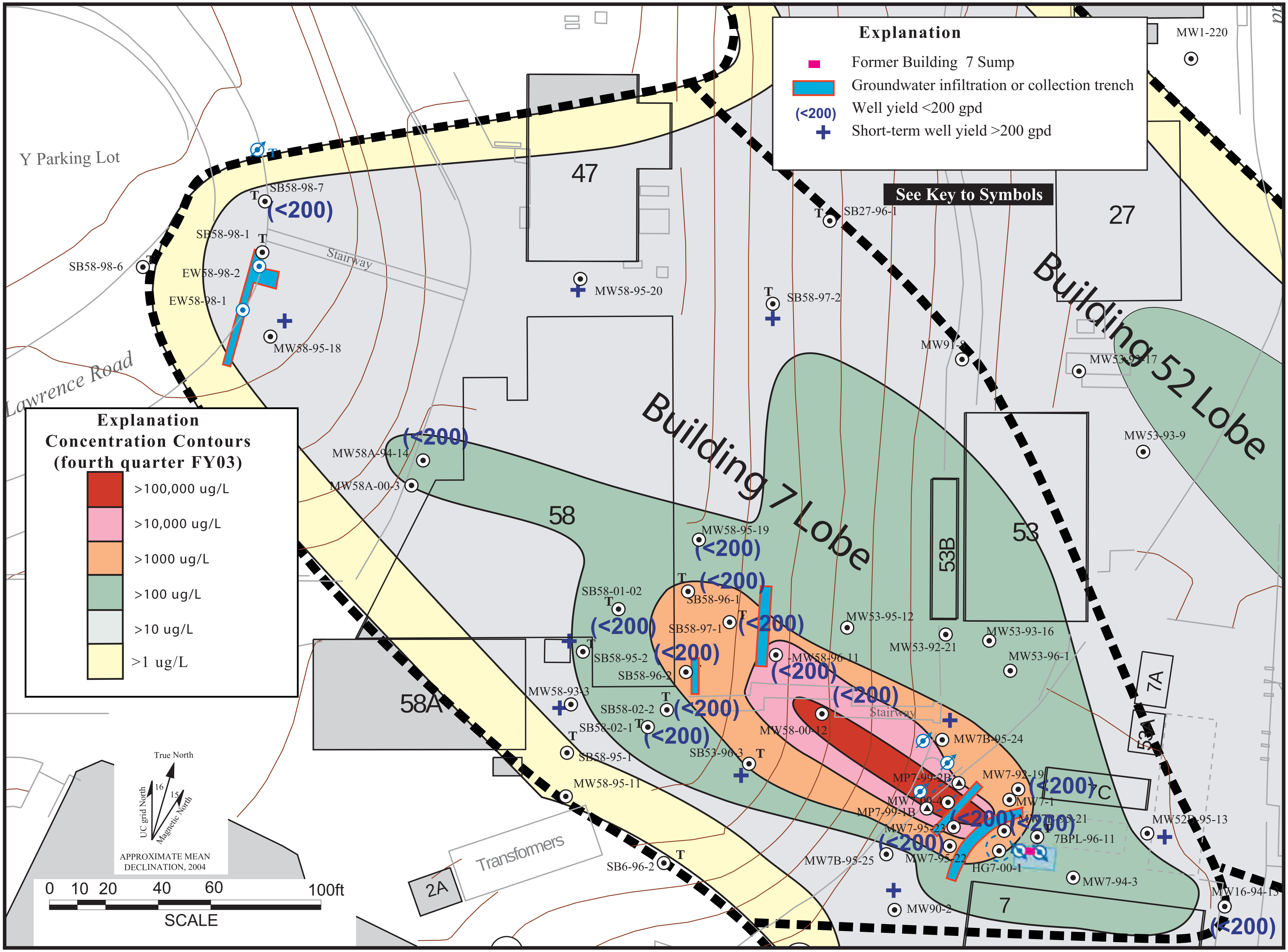

Figure 4.3.4-11a. Total Halogenated Hydrocarbons in Groundwater (ug/L) and Estimated Well Yields, Building 7 Lobe Old Town Groundwater Solvent Plume.

4.3.4-2, -11a-19-Pilot tests, ICMs, zones.ai
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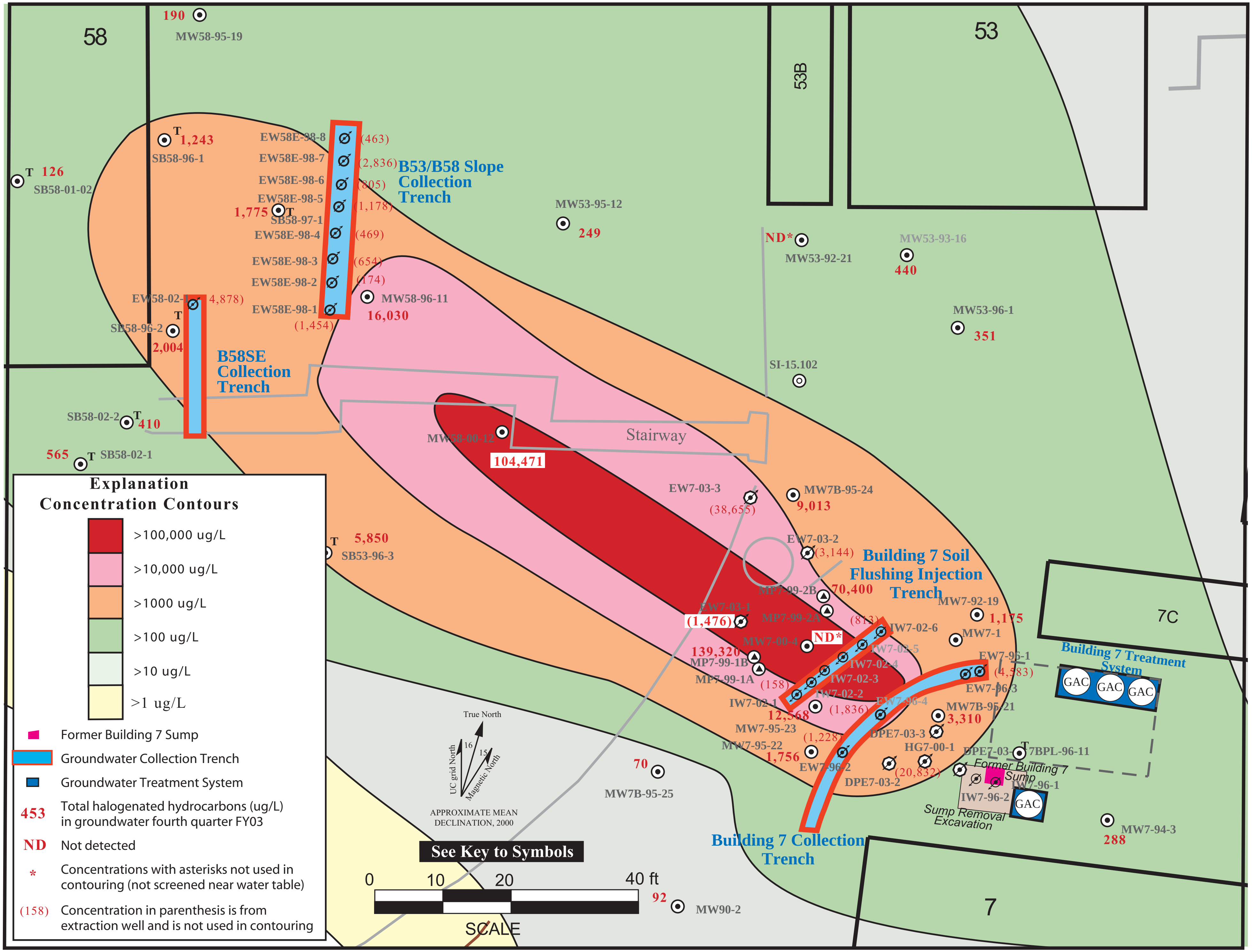

Figure 4.3.4-11b. Total Halogenated Hydrocarbons in Groundwater (ug/L) in the Source Area of the Building 7 Lobe Old Town Groundwater Solvent Plume.

f4.3.4-11b
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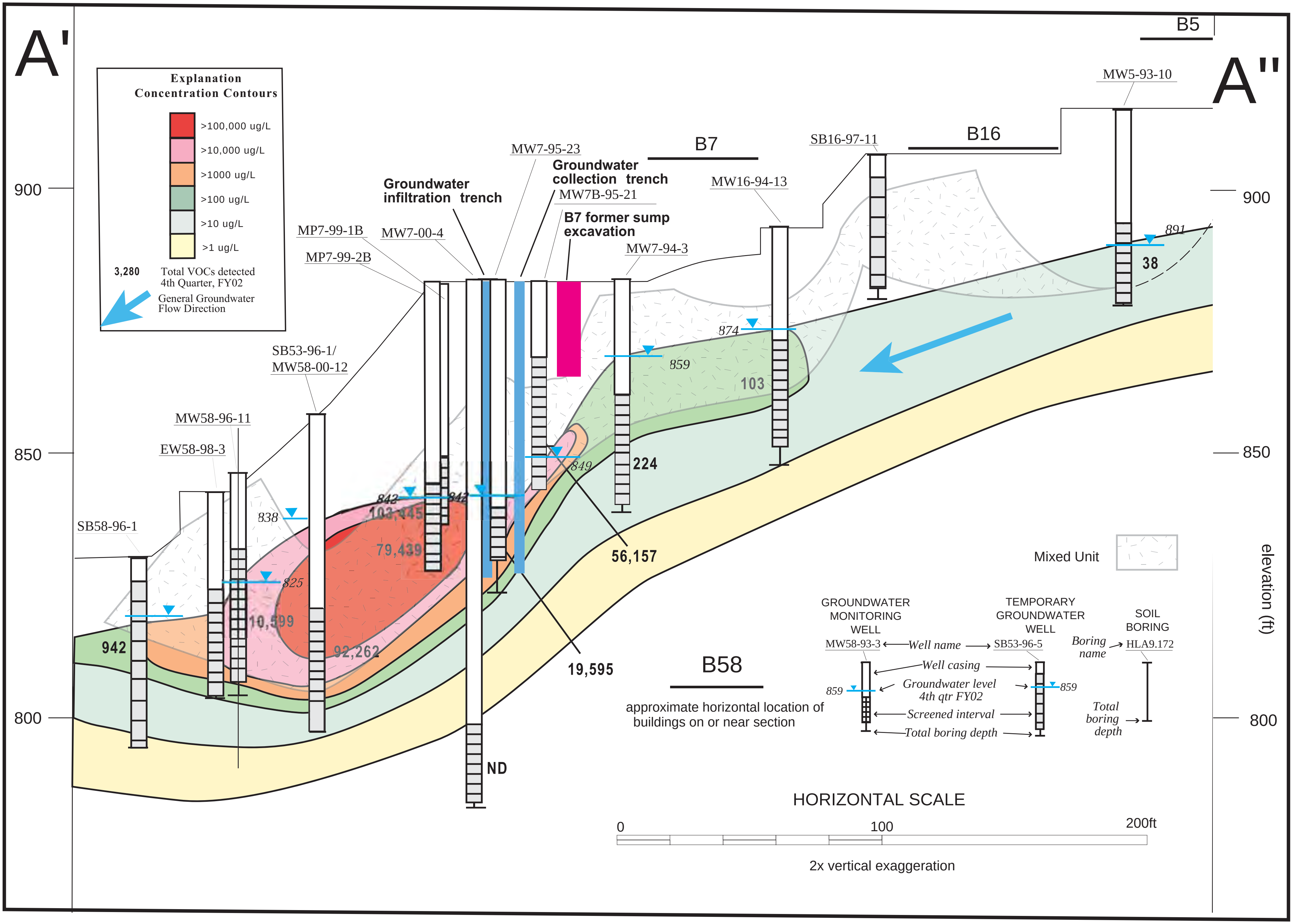


Figure 4.3.4-12. Geologic Cross Section Showing Total Halogenated Non-Aromatic VOC Concentrations, Building 7 Area.

4.3.4-12 voc gw cross section
08/03

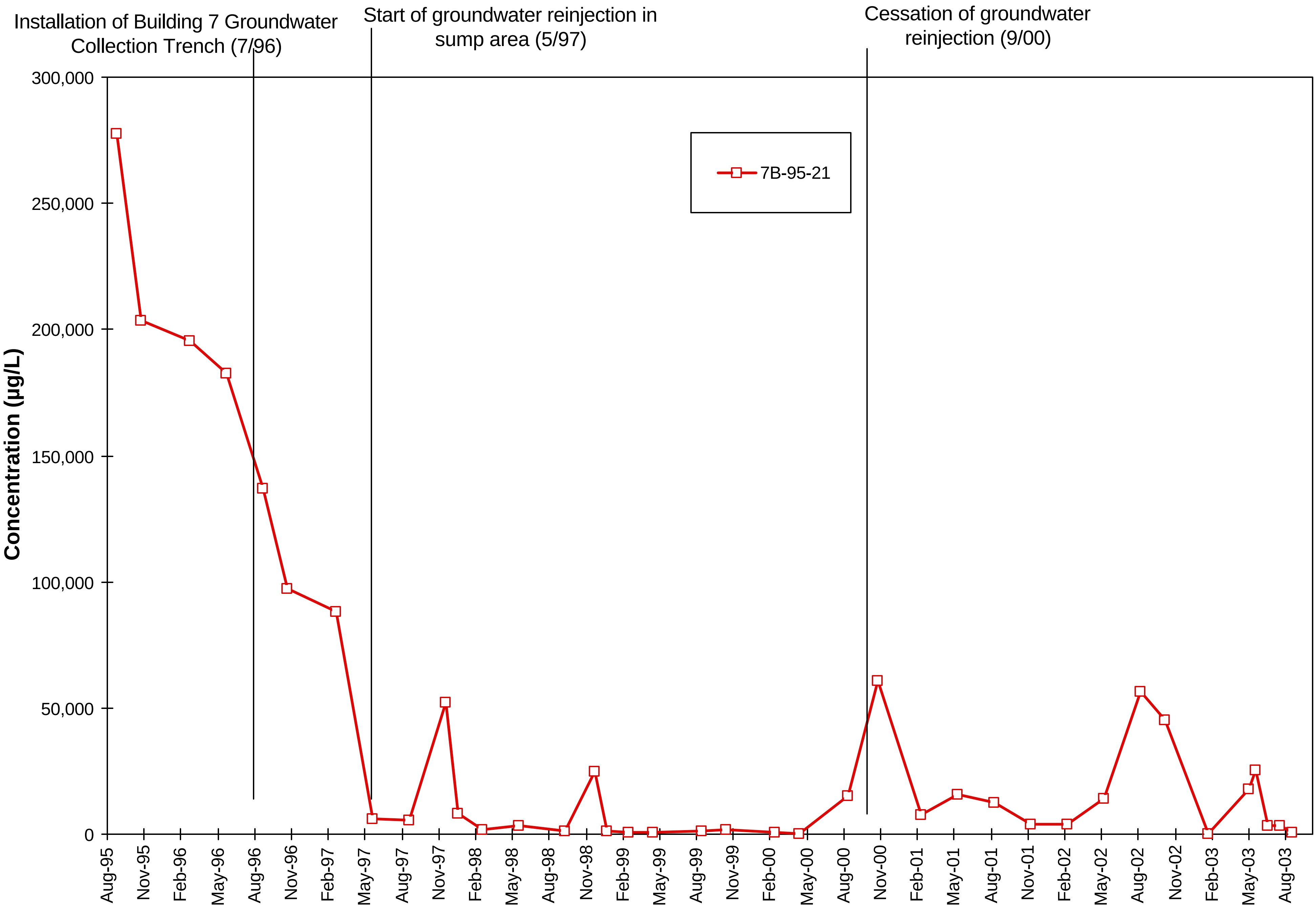


Figure 4.3.4-13a. Concentration Trends for Total Halogenated VOCs in Well 7B-95-21 Located Near Source of the Old Town Plume, (Building 7 Lobe)

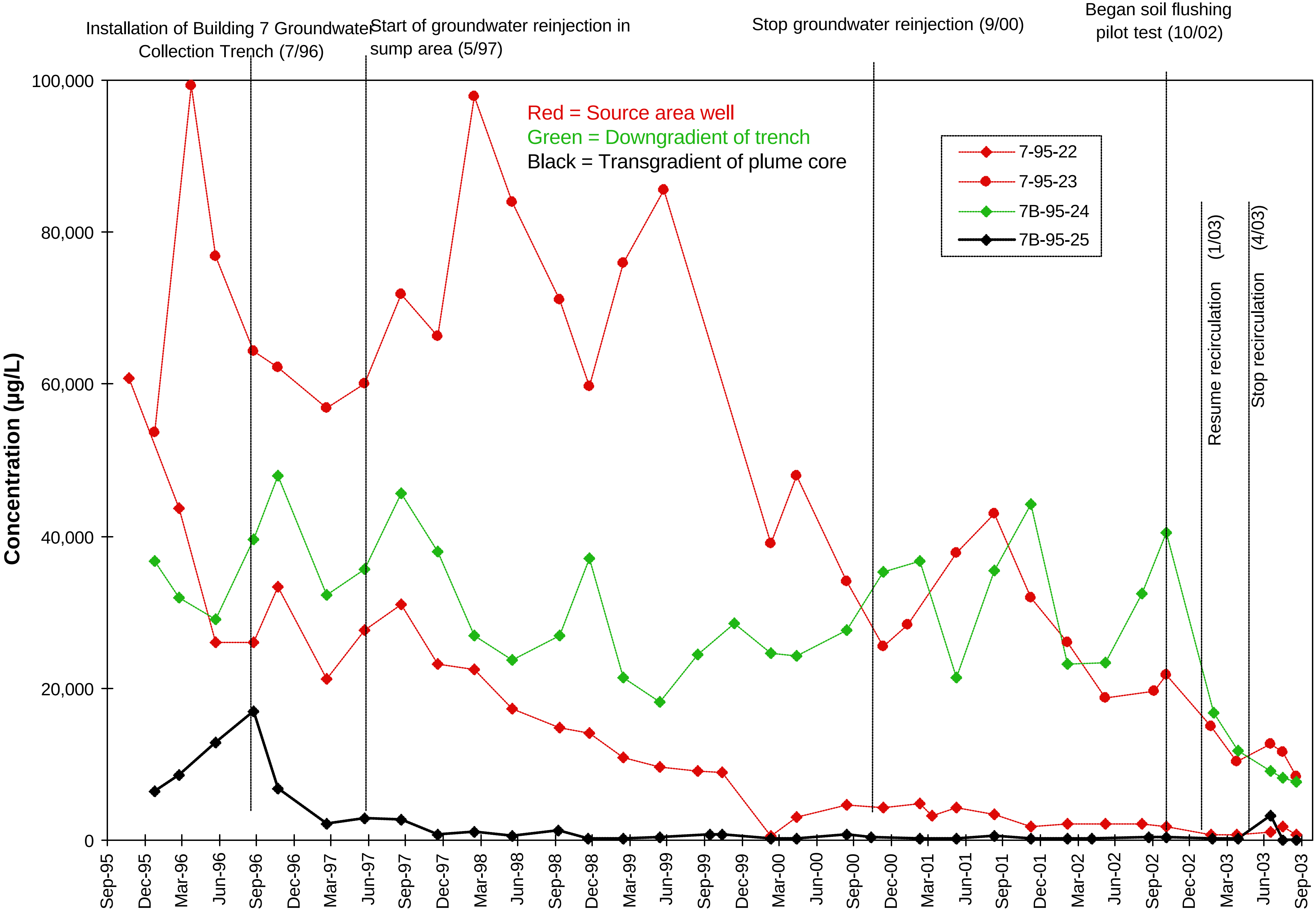


Figure 4.3.4-13b. Concentration Trends for Total Halogenated VOCs in Wells Located Near Source of the Old Town Plume, (Building 7 Lobe)

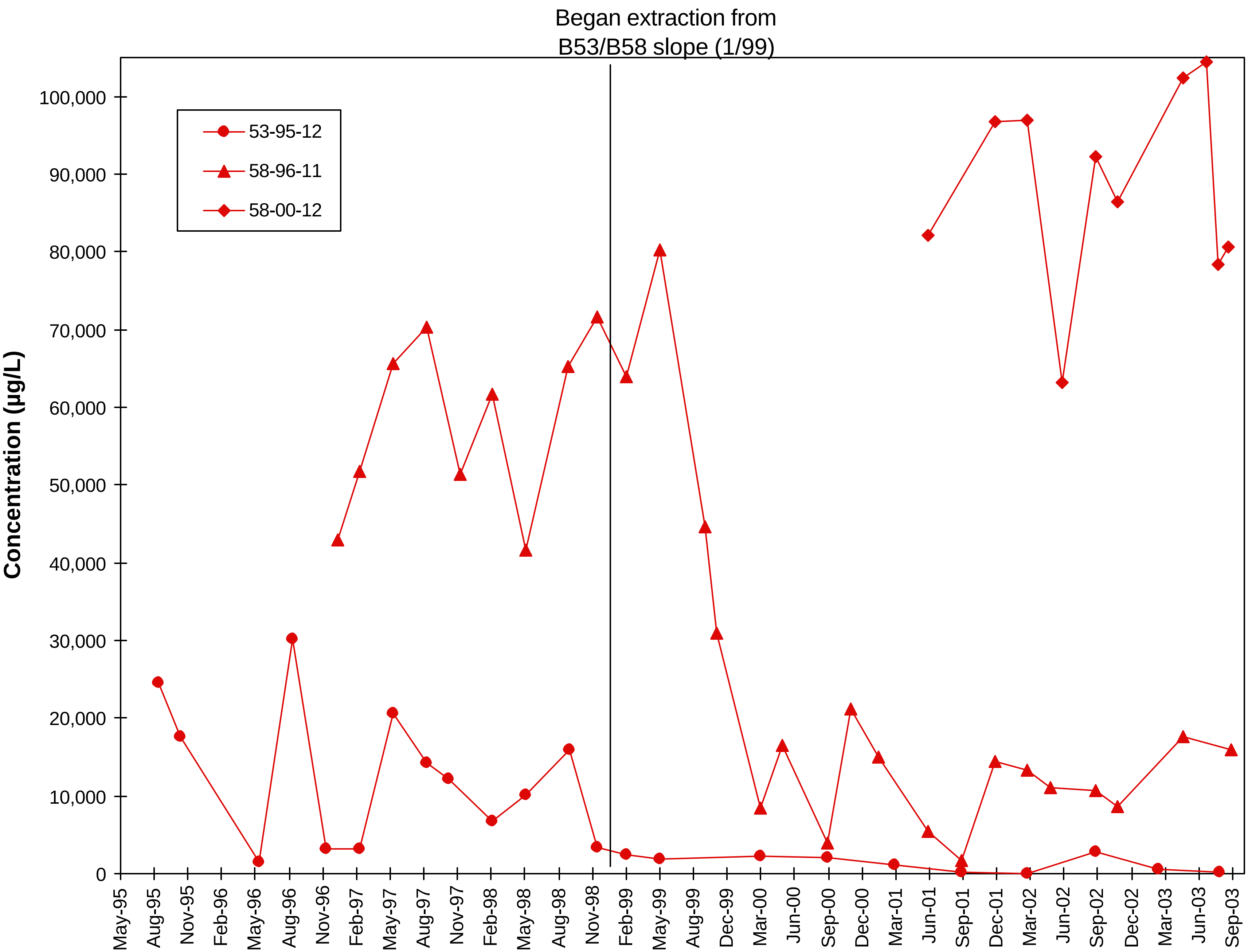


Figure 4.3.4-13c. Concentration Trends for Total Halogenated VOCs in Wells Located Within the Core of the Old Town Plume (Building 7 Lobe)

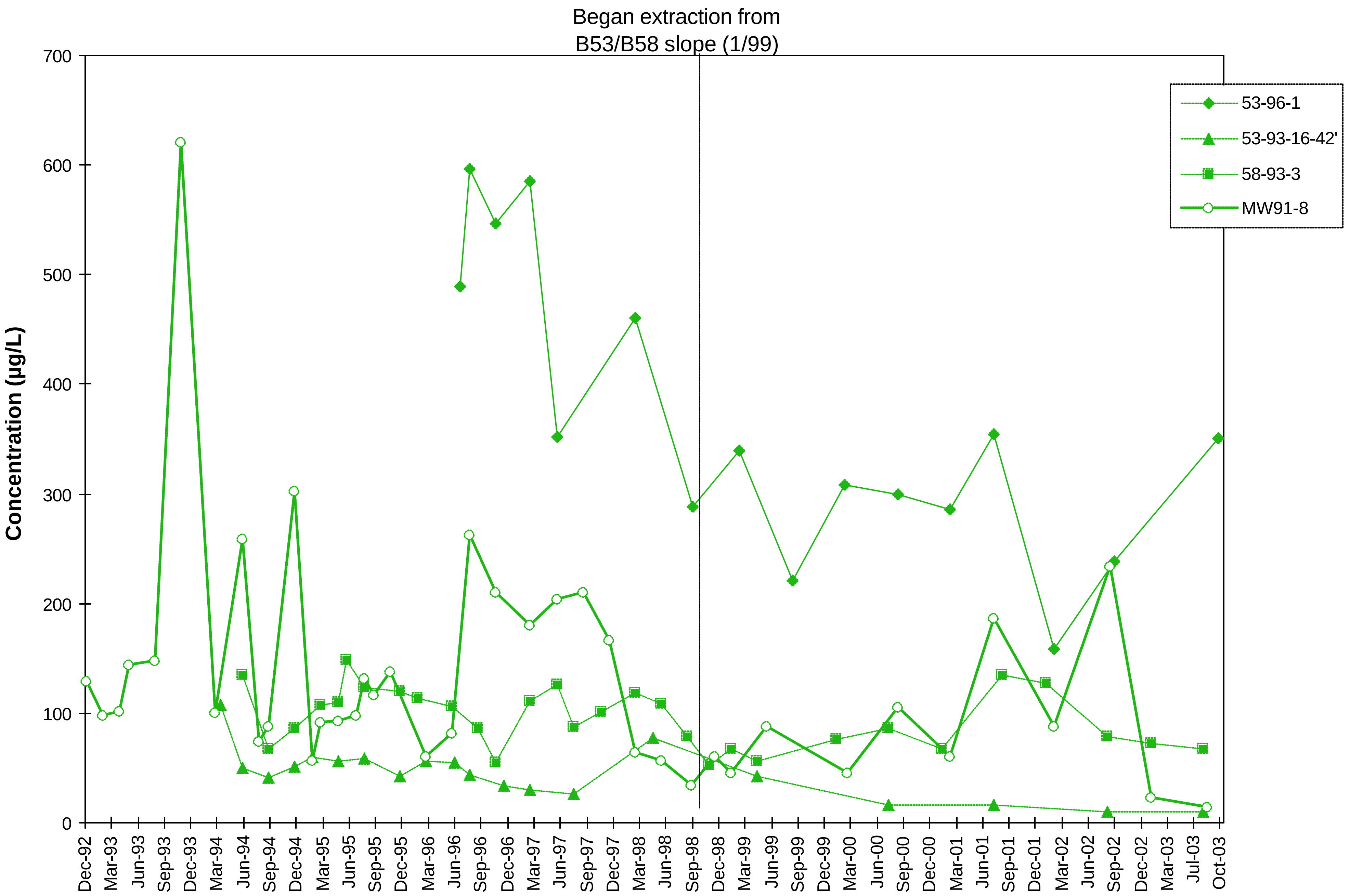


Figure 4.3.4-13d. Concentration Trends for Total Halogenated VOCs in Wells Located Crossgradient from the Core of the Old Town Plume (Building 7 Lobe)

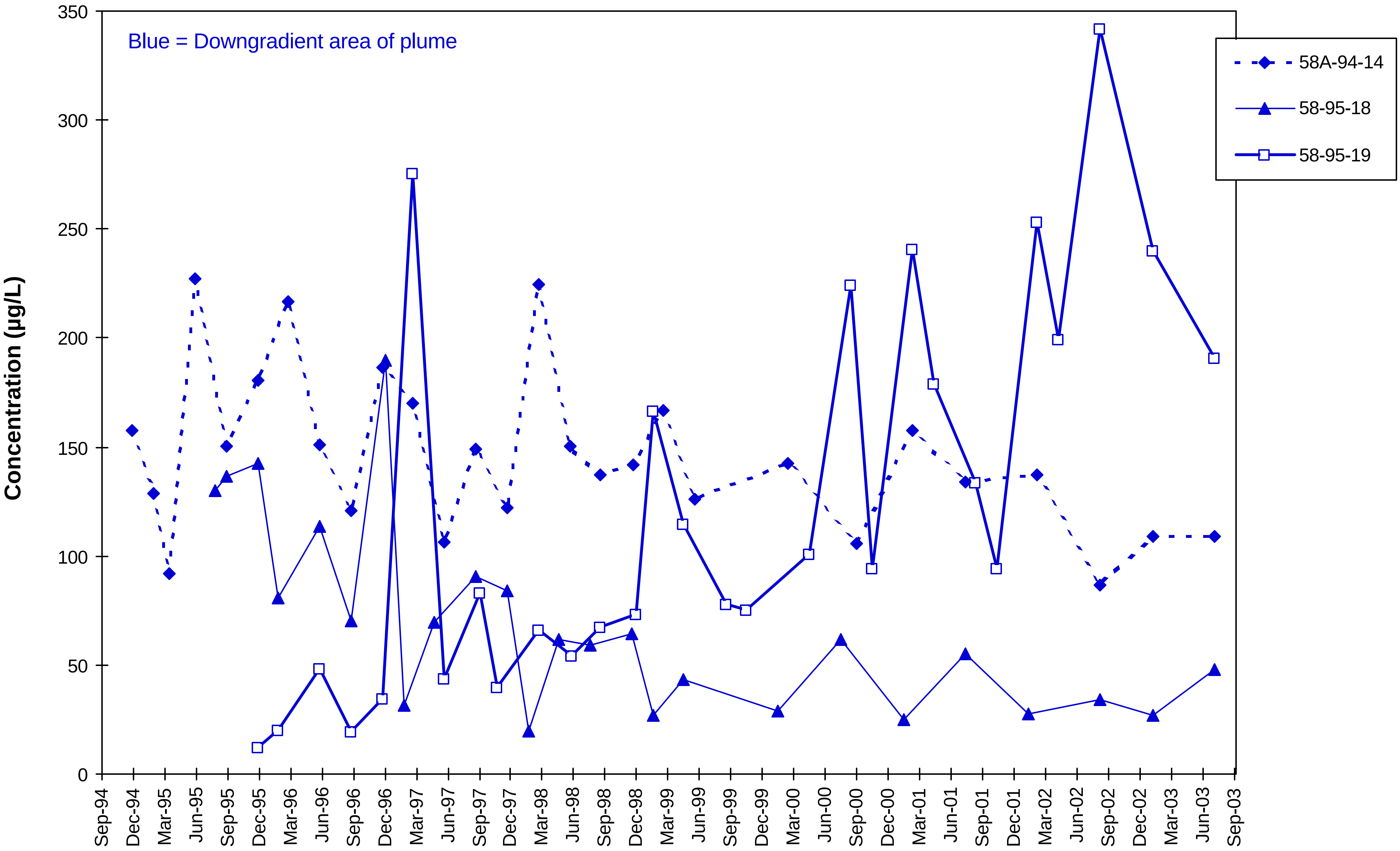


Figure 4.3.4-13e. Concentration Trends for Total Halogenated VOCs in Wells Located in the Downgradient Portion of the Old Town Plume (Building 7 Lobe)

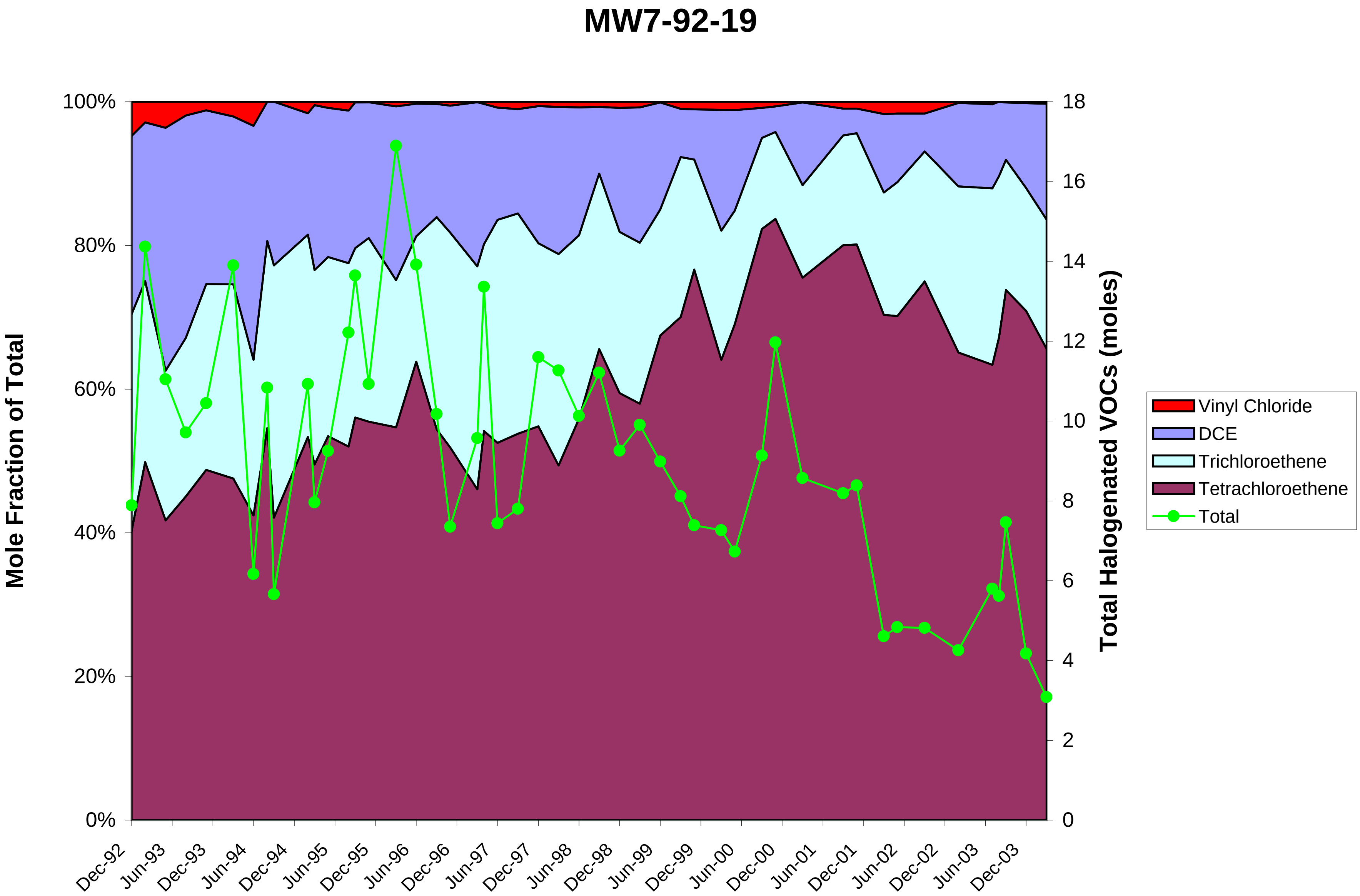


Figure 4.3.4-14a. Temporal Variations in Relative Proportions of Halogenated Non-aromatic VOCs, MW7-92-19

MW58-93-3

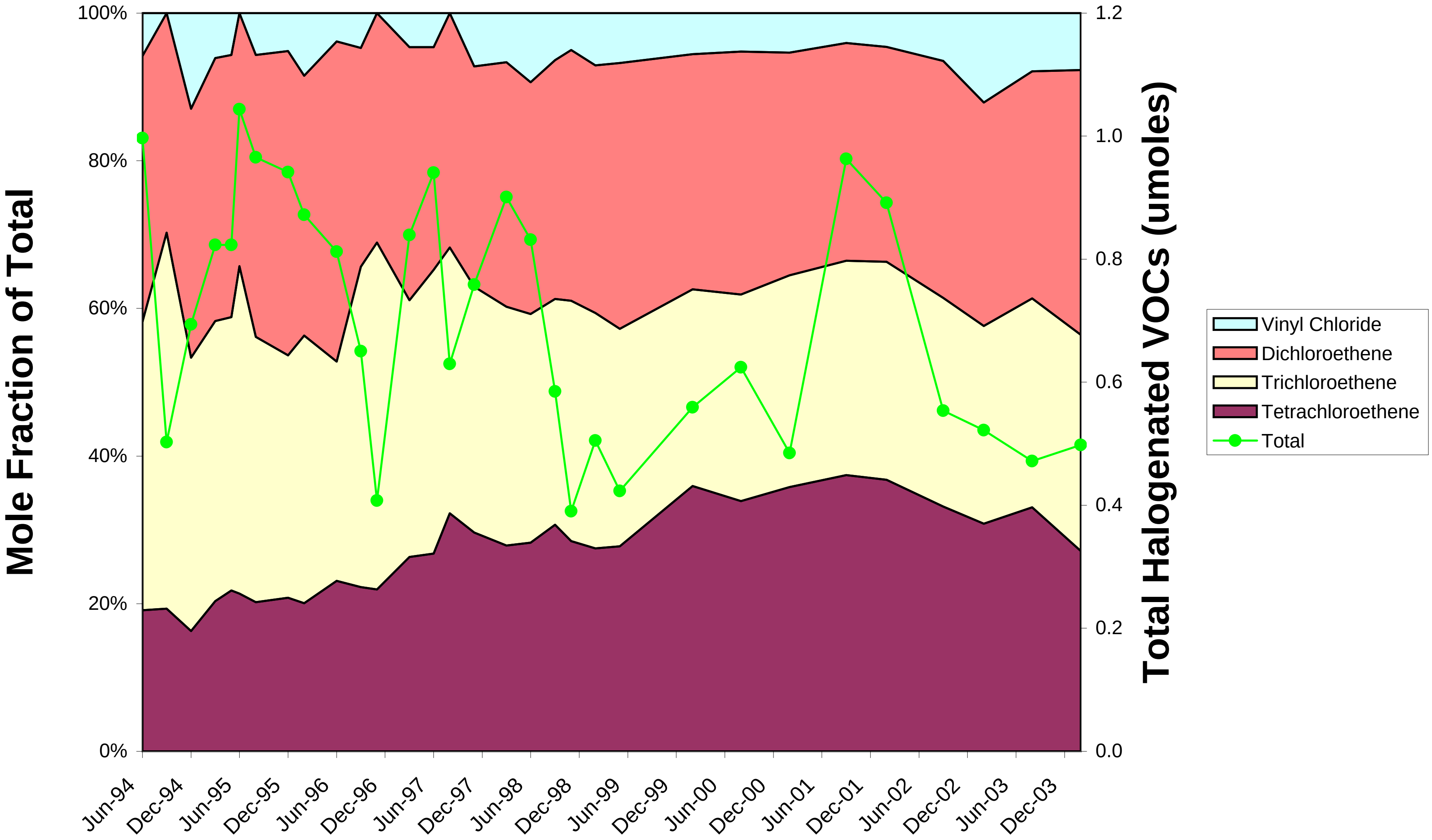


Figure 4.3.4-14b. Temporal Variations in Relative Proportions of Halogenated Non-aromatic VOCs in Well MW58-93-3, Periphery Area of Building 7 Lobe

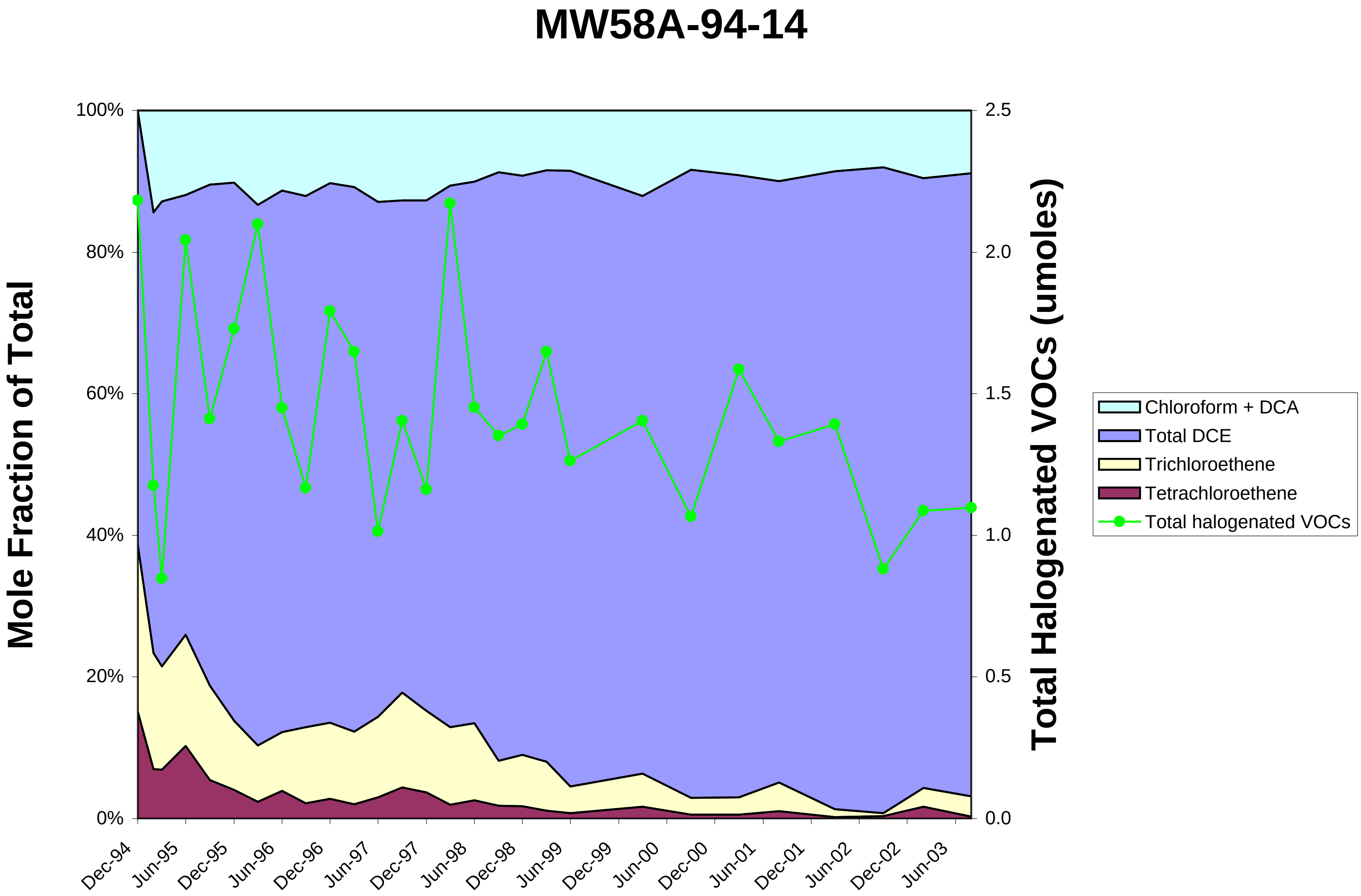
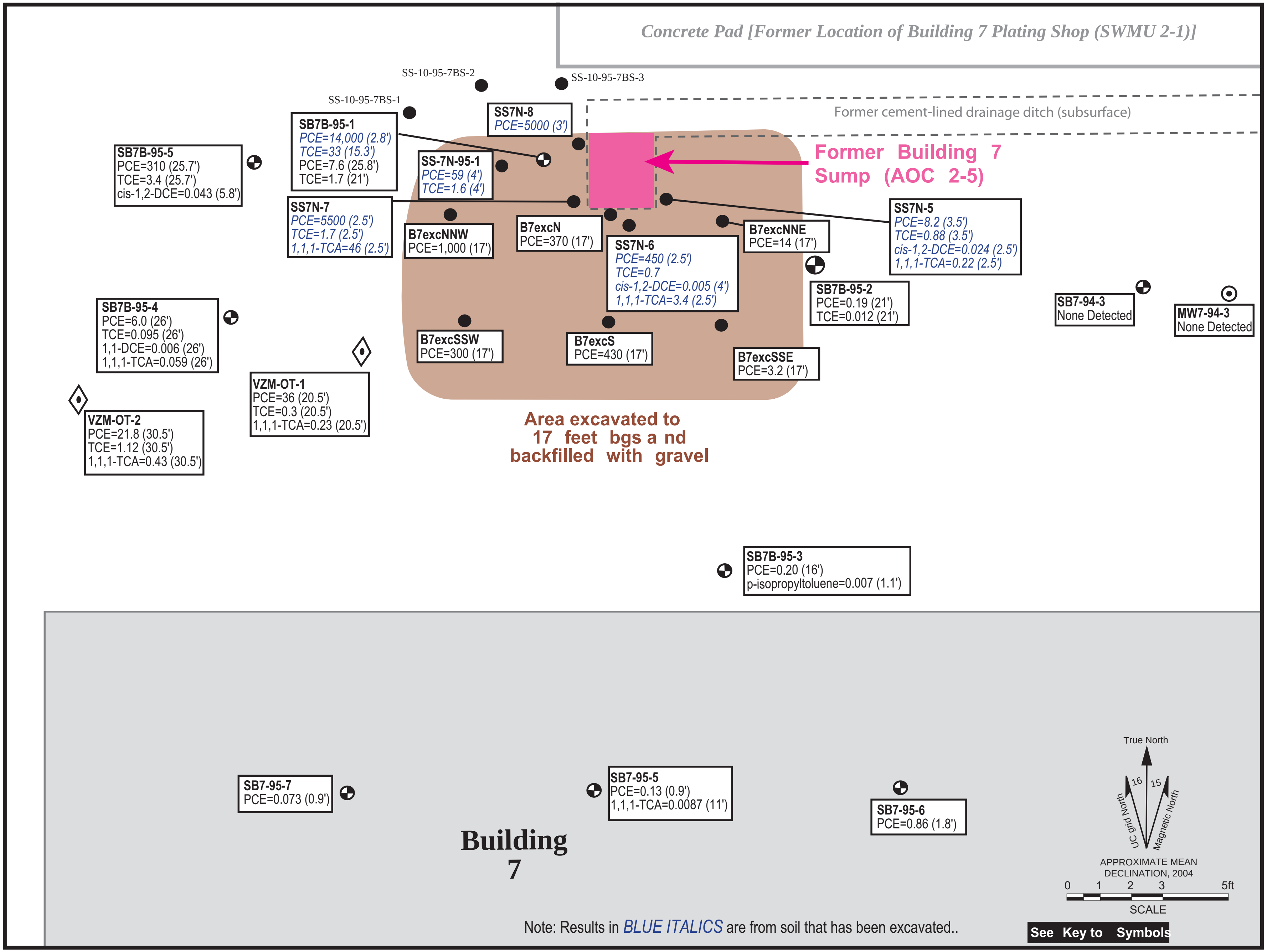


Figure 4.3.4-14c. Temporal Variations in Relative Proportions of Halogenated Non-aromatic VOCs in Well MW58A-94-14



4.3.4-16AOC2-5 preexcav soil.ai
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Figure 4.3.4-15. Maximum Concentrations of VOCs Detected (mg/kg) in Soil Samples Prior to Soil Excavation Near Former Building 7 Sump (AOC 2-5).

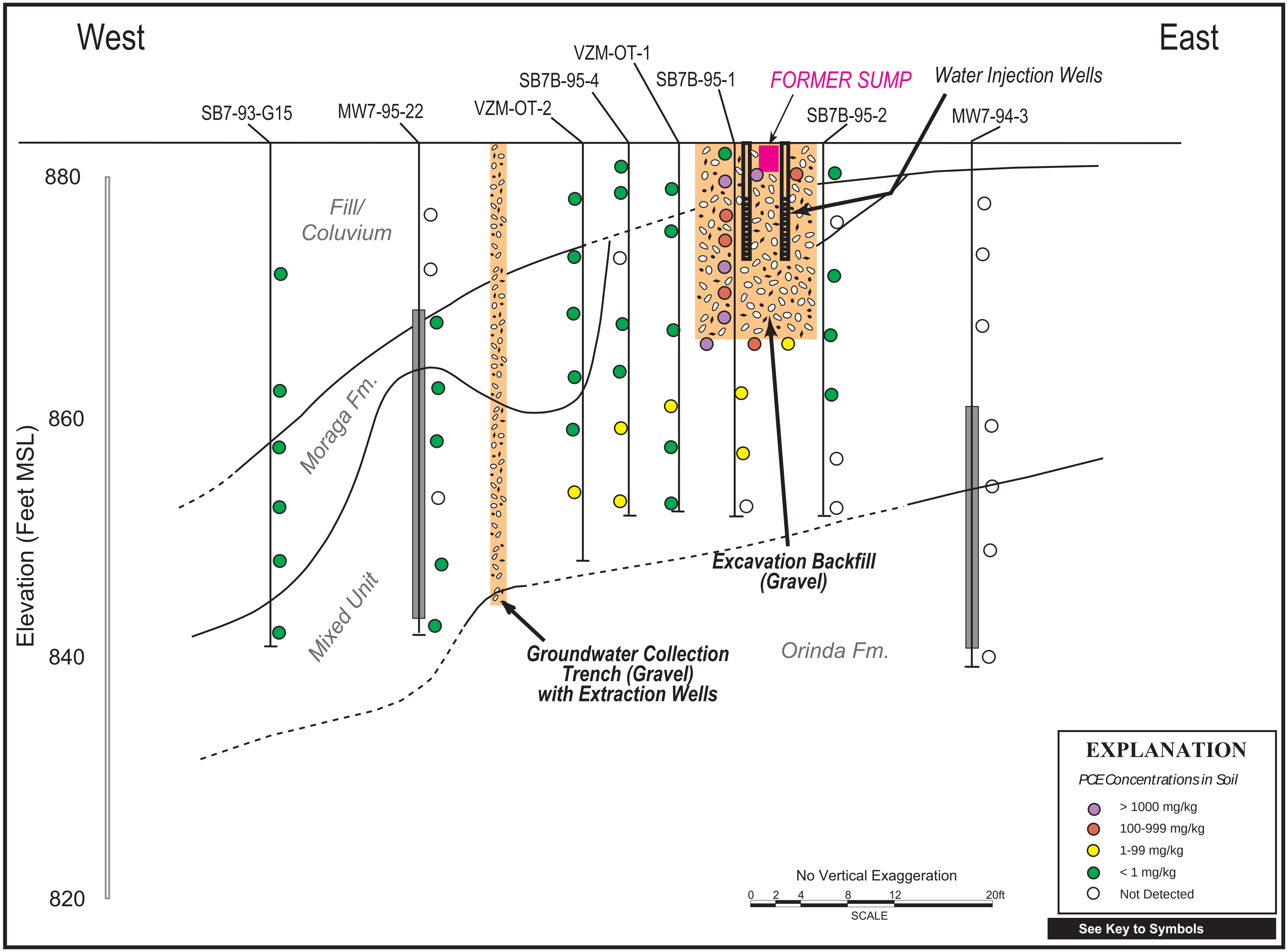

Figure 4.3.4-16. **Geological Cross-Section Showing Concentrations of PCE Detected in Soil Samples Prior to Soil Excavation Near Former Building 7 Sump (AOC 2-5).**

4.3.4-16AOC2-5 preexcav soil xsect.ai
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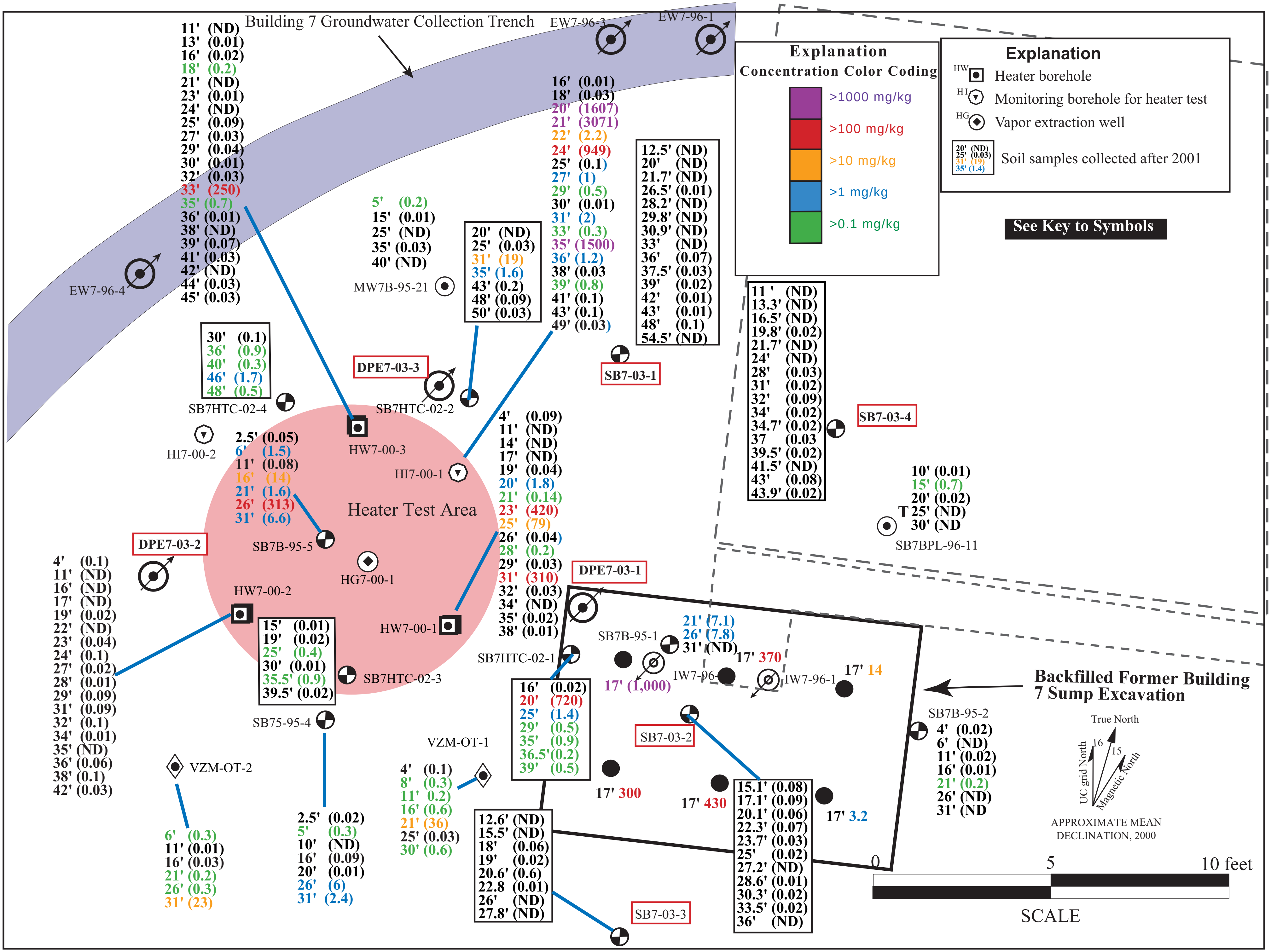

Figure 4.3.4-17. Concentrations of Total VOCs Detected (mg/kg) Former Building 7 Sump Area.

4.3.4-18 B7 residual soil results.ai
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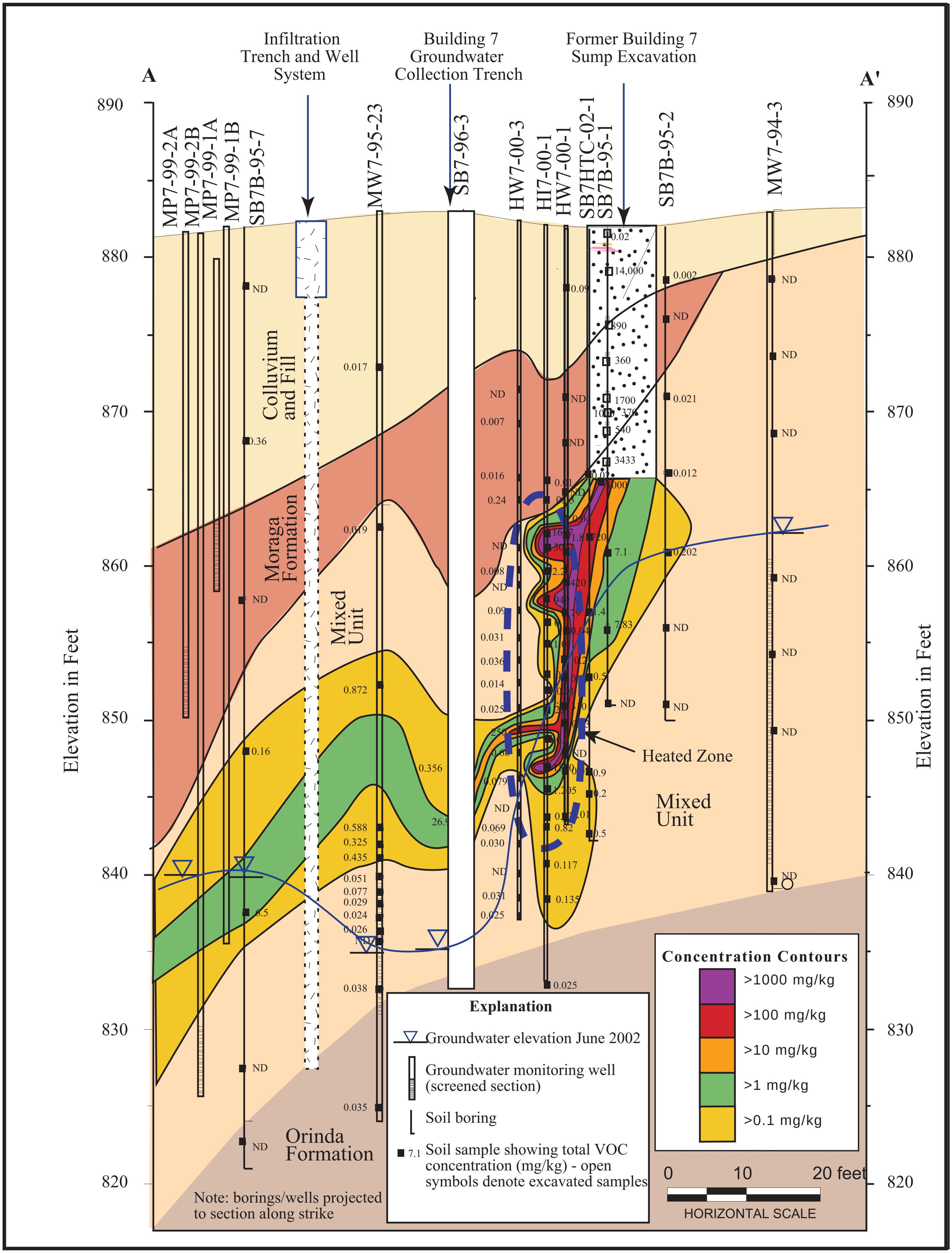

Figure 4.3.4-18. Geologic Cross Section A-A' Showing Soil Sample Results, Building 7 Area. 4.3.4-18 crosssec A-A'.ai 8/03

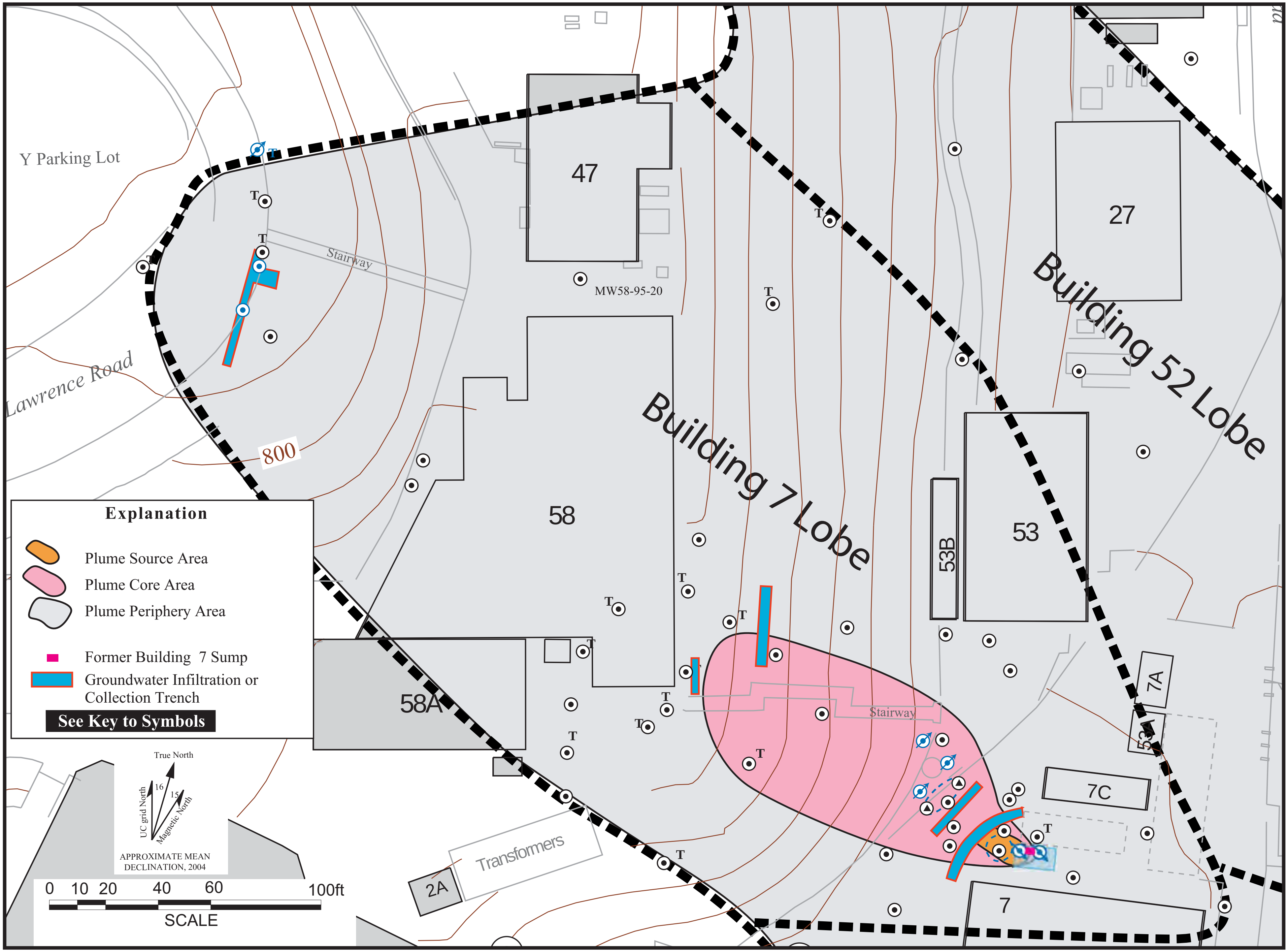

Figure 4.3.4-19. Location of Plume Source, Plume Core, and Plume Periphery Areas, Building 7 Lobe Old Town Groundwater Solvent Plume.

4.3.4-2, -11a-19-Pilot tests, ICMs, zones.ai
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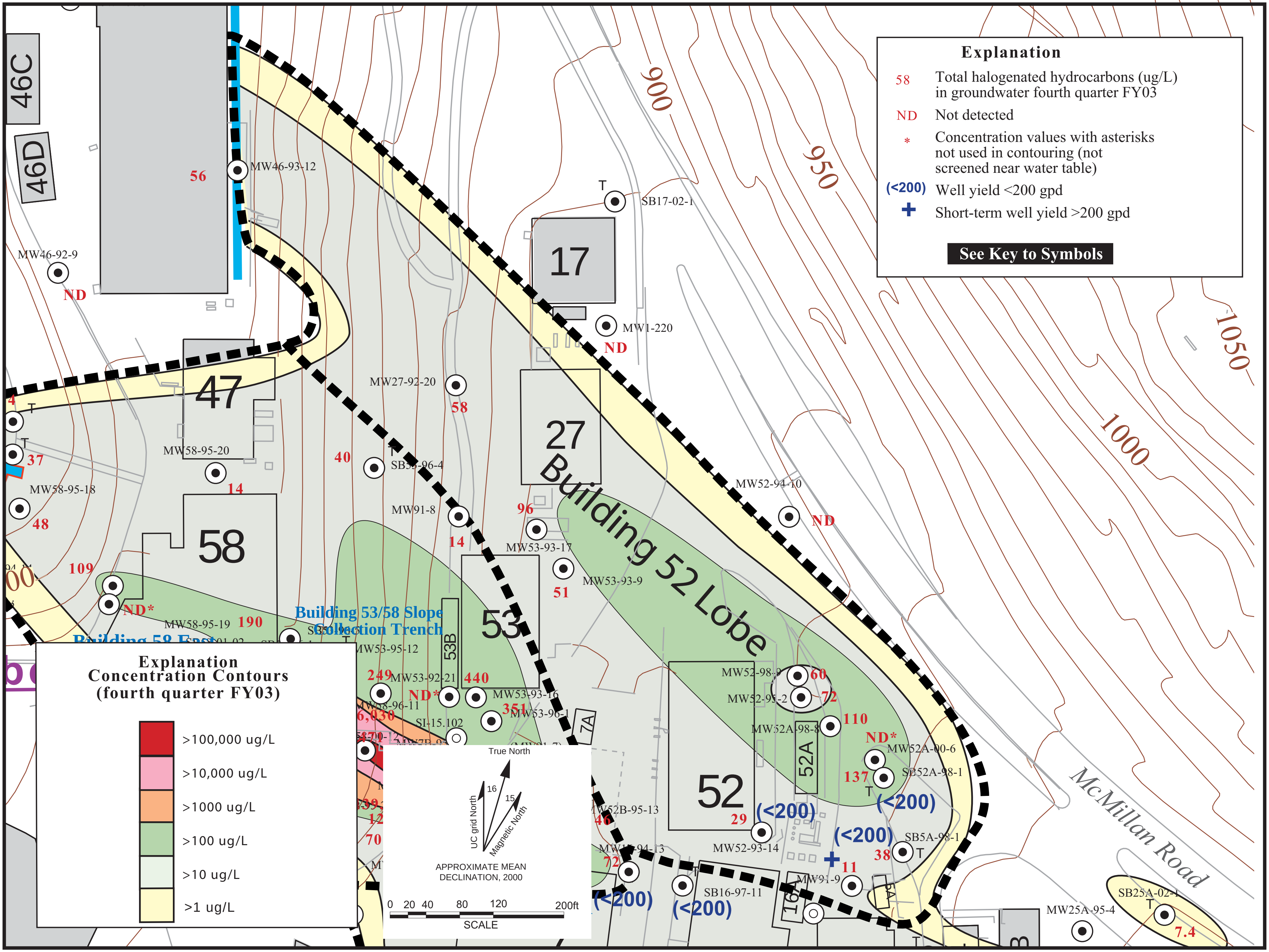

Figure 4.3.5-1. Total Halogenated Hydrocarbons in Groundwater (ug/L) and Estimated Well Yields, Building 52 Lobe Old Town Groundwater Solvent Plume.

4.3.5-1-3qfy03total_halogB52 Lobe.ai
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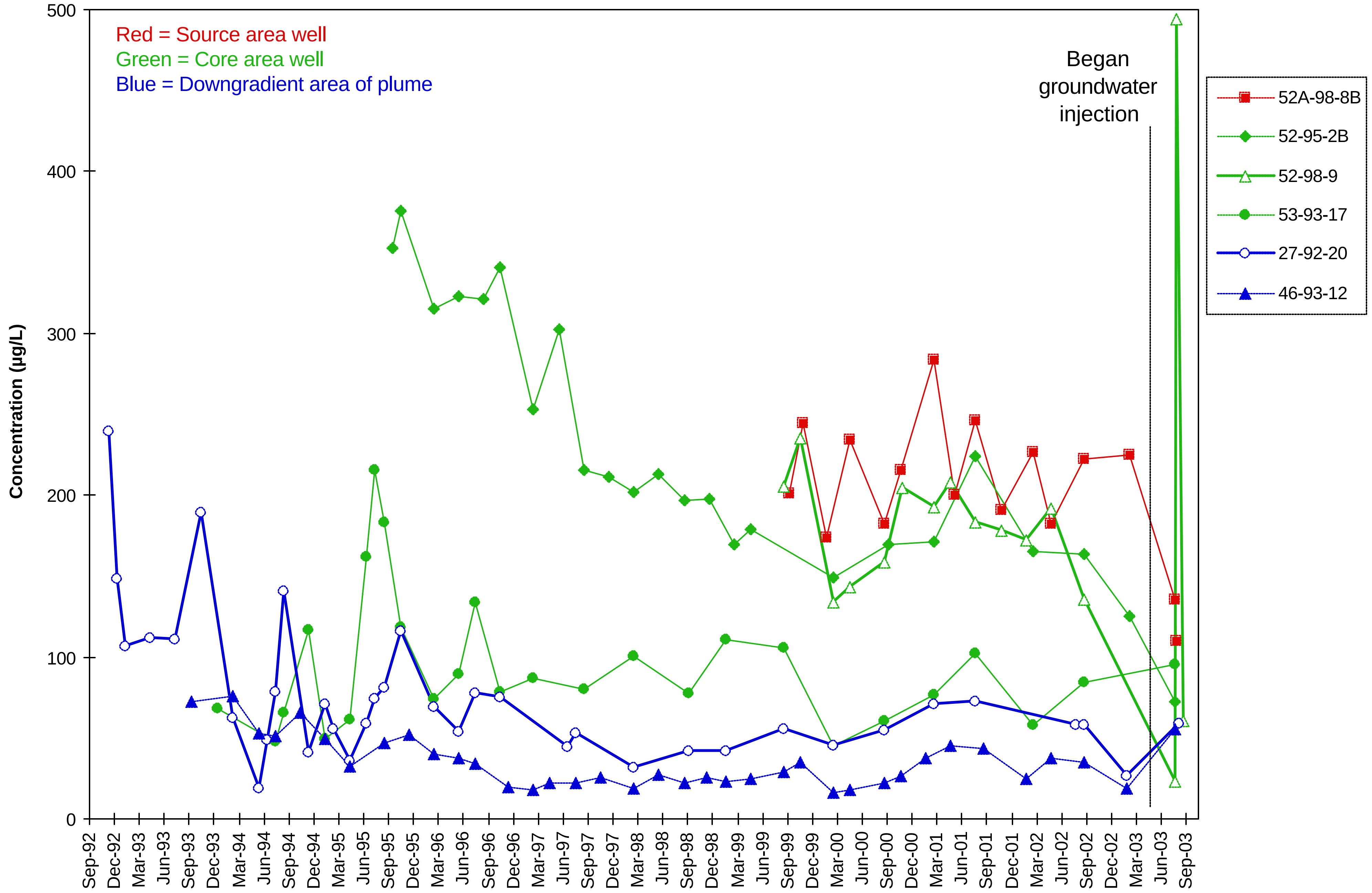

Figure 4.3.5-2. Total Halogenated Non-Aromatic VOC Concentrations in Wells Monitoring the Old Town Plume, B52 Lobe

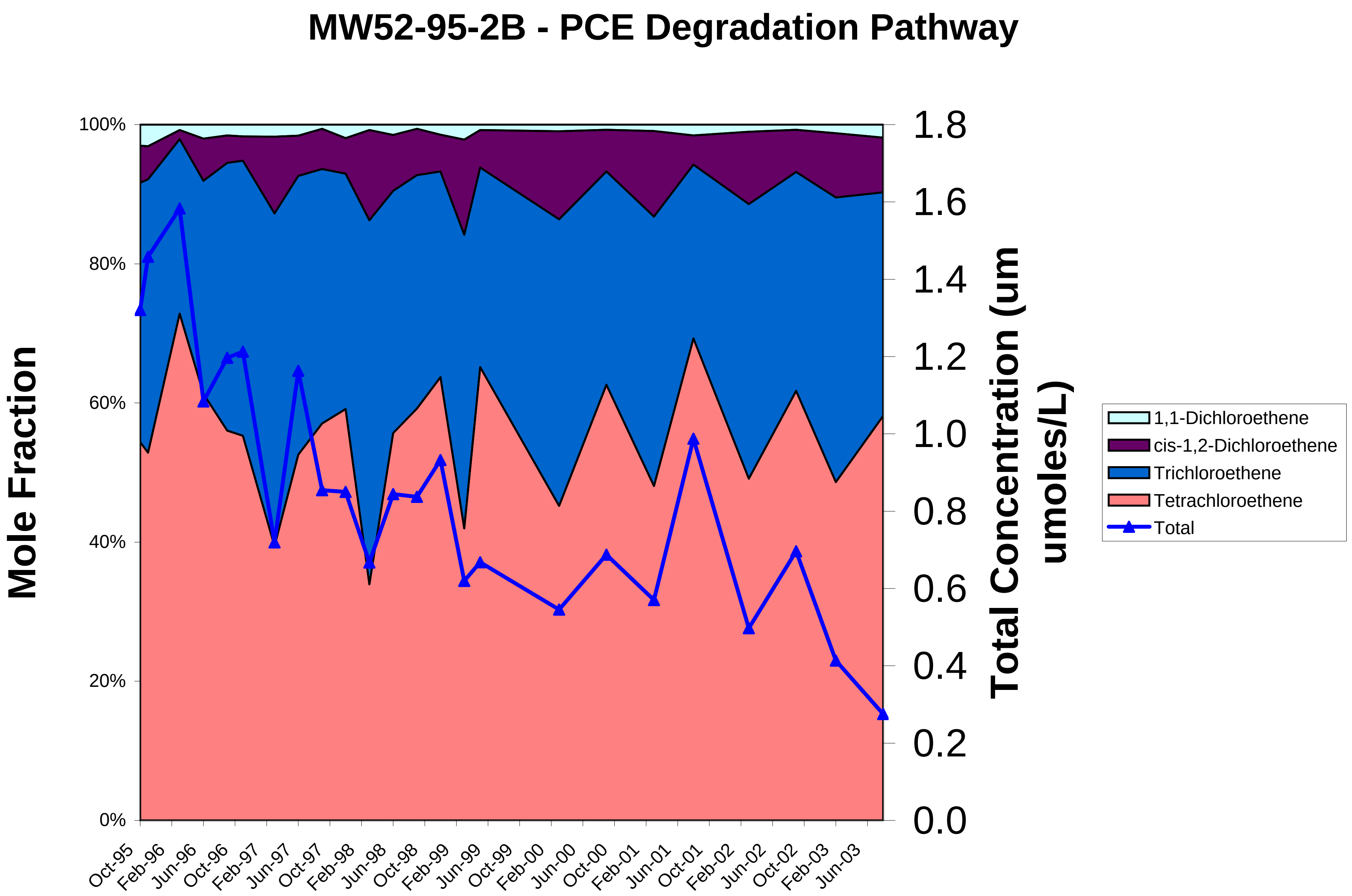

Figure 4.3.5-3. Temporal Variations of Halogenated Non-aromatic VOCs (PCE Degradation Pathway) for Well 52-95-2B, Core Area, Building 52 Lobe

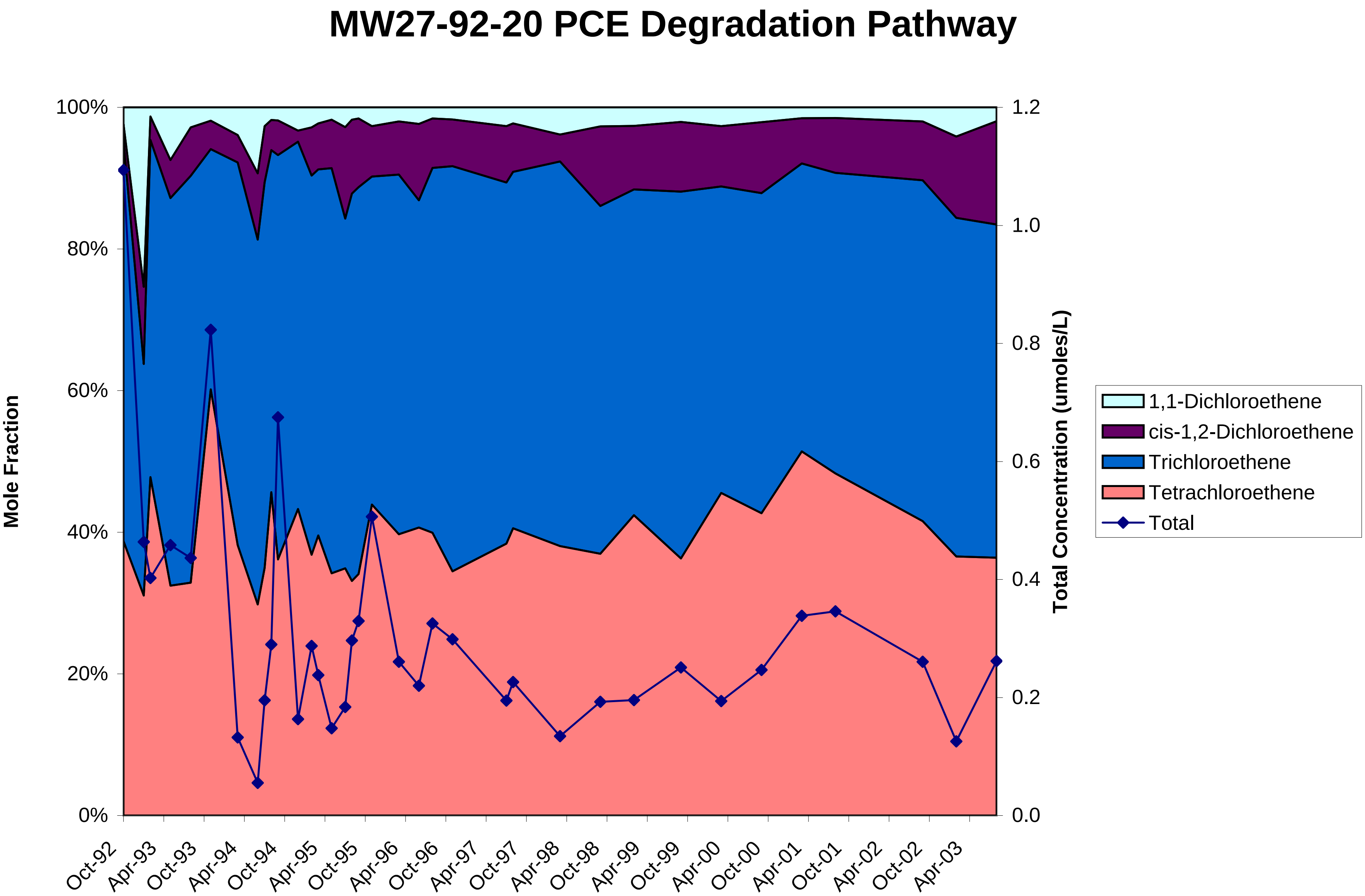

Figure 4.3.5-4. Temporal Variations of Halogenated Non-aromatic VOCs (PCE Degradation Pathway) in Well MW27-92-20, Periphery Area, Building 52 Lobe.

46-93-12 - PCE Degradation Pathway

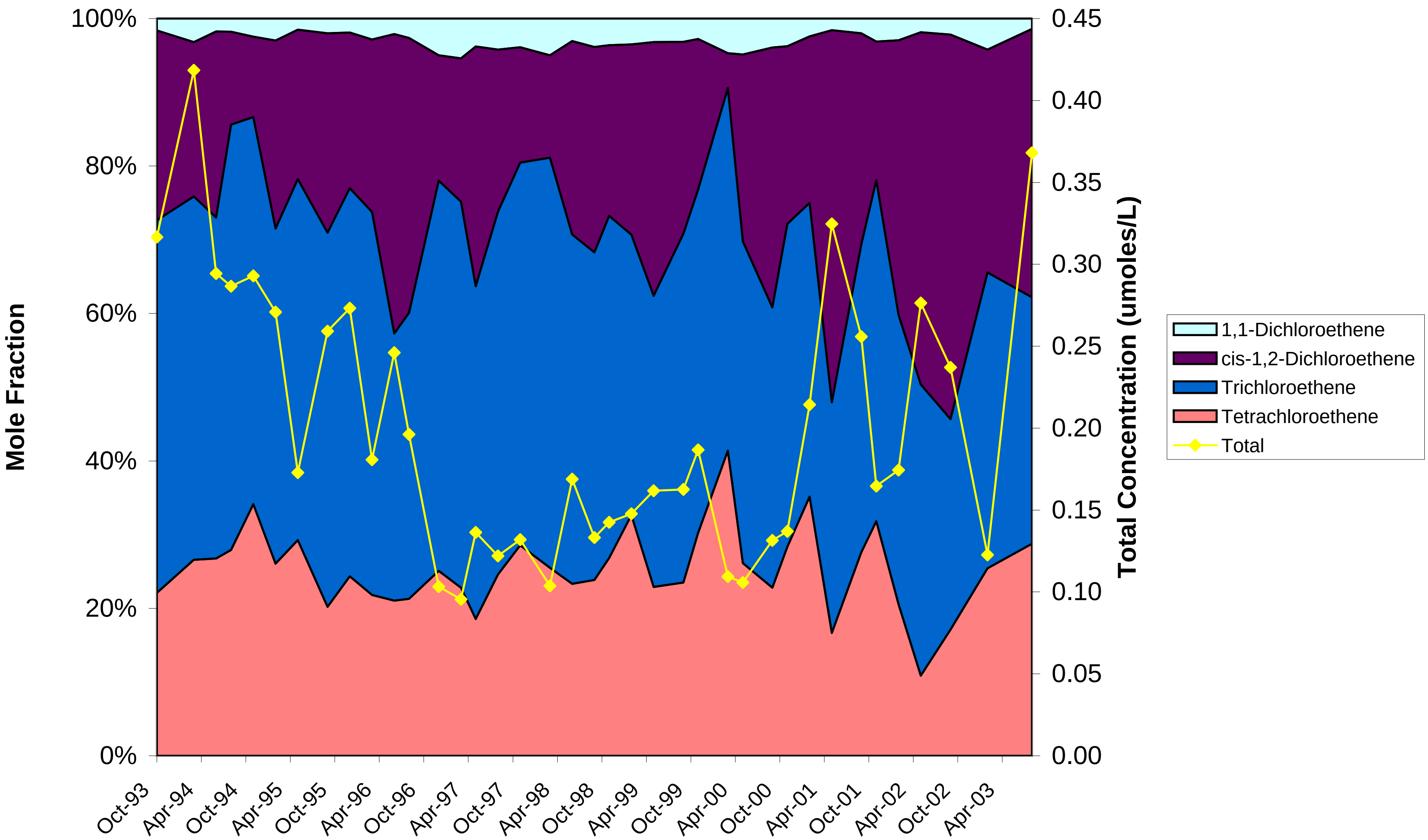

Figure 4.3.5-5. Temporal Variations of Halogenated Non-aromatic VOCs (PCE Degradation Pathway) in Well MW46-93-12, Downgradient Edge, Building 52 Lobe.

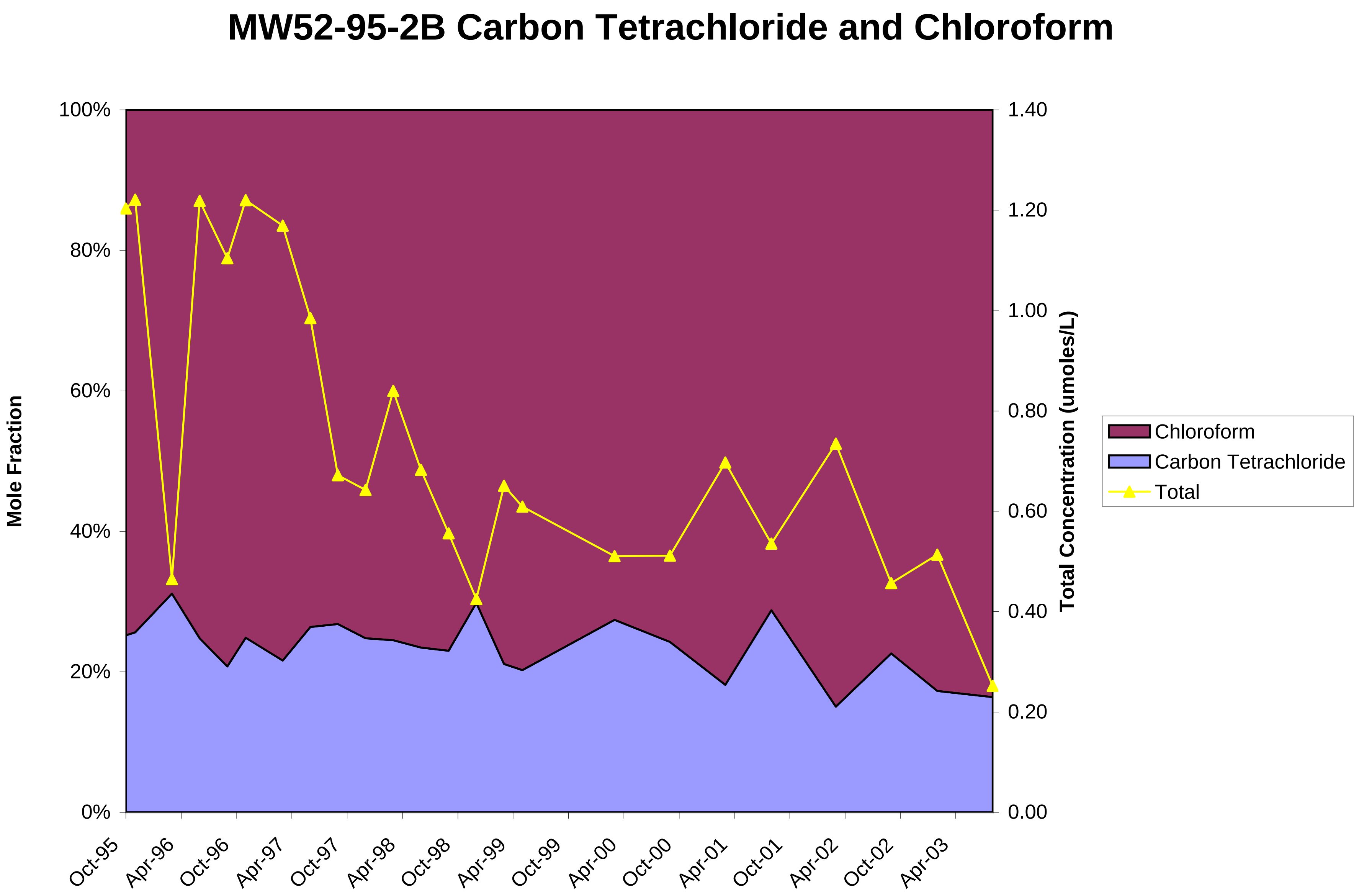

Figure 4.3.5-6. Temporal Variations in Halogenated Non-aromatic VOC Concentrations in Well MW52-95-2B, Plume Core Area, Building 52 Lobe.

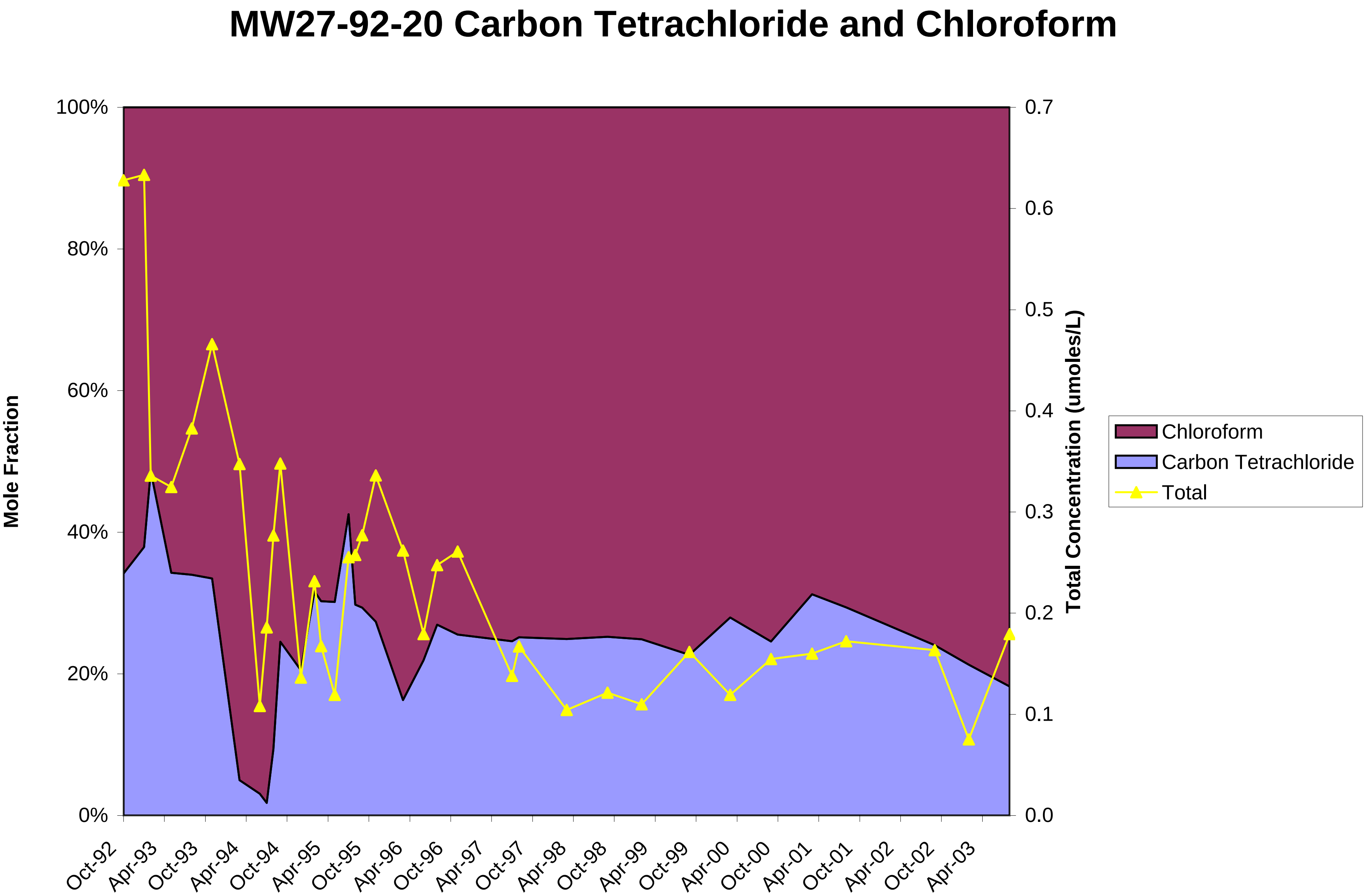

Figure 4.3.5-7. Temporal Variations of Halogenated Non-aromatic VOCs (Carbon Tetrachloride Degradation Pathway) for Well MW27-92-20, Building 52 Lobe.

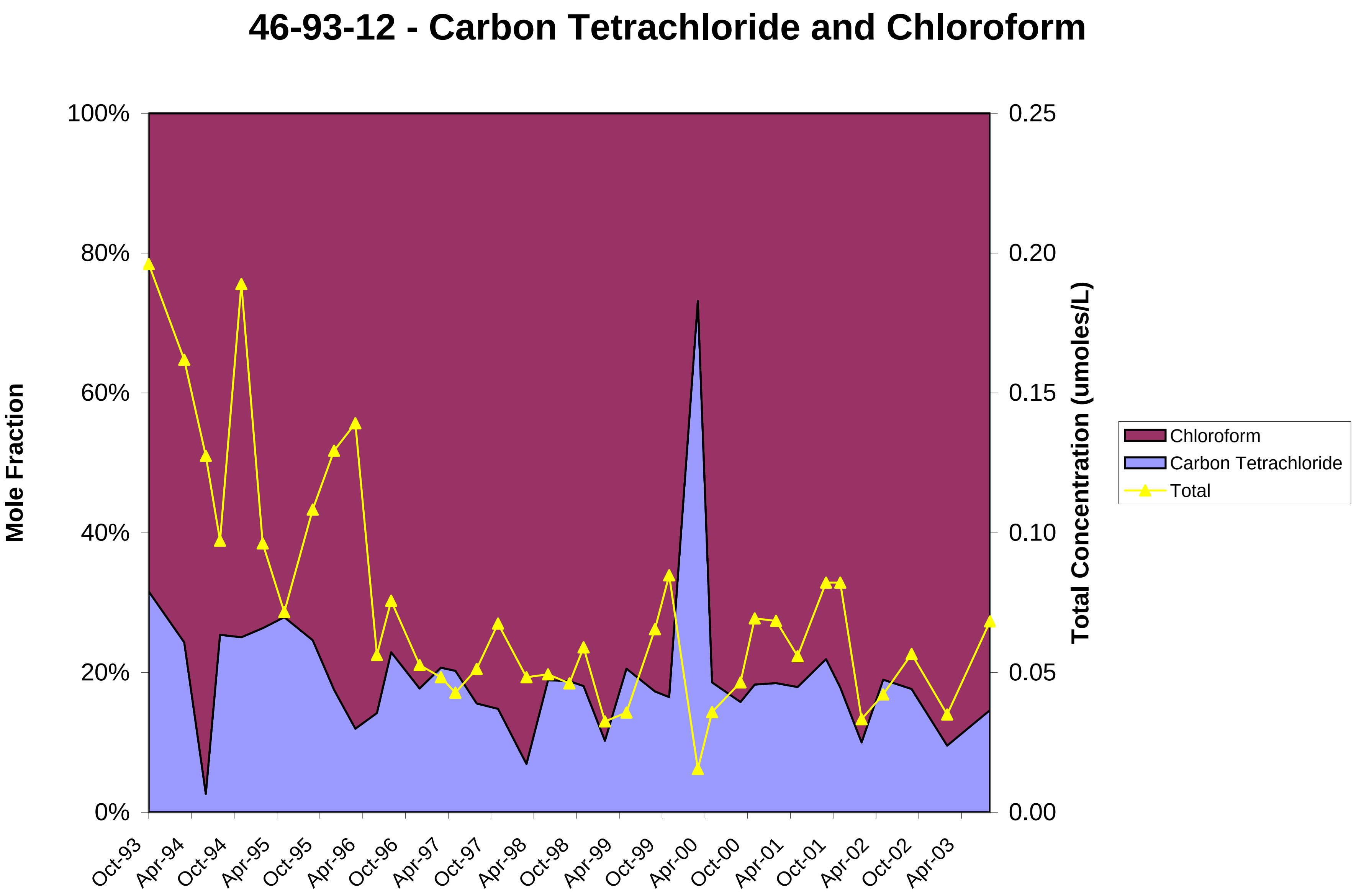

Figure 4.3.5-8. Temporal Variations of Halogenated Non-aromatic VOCs (Carbon Tetrachloride Degradation Pathway), Downgradient Edge, Building 52 Lobe.

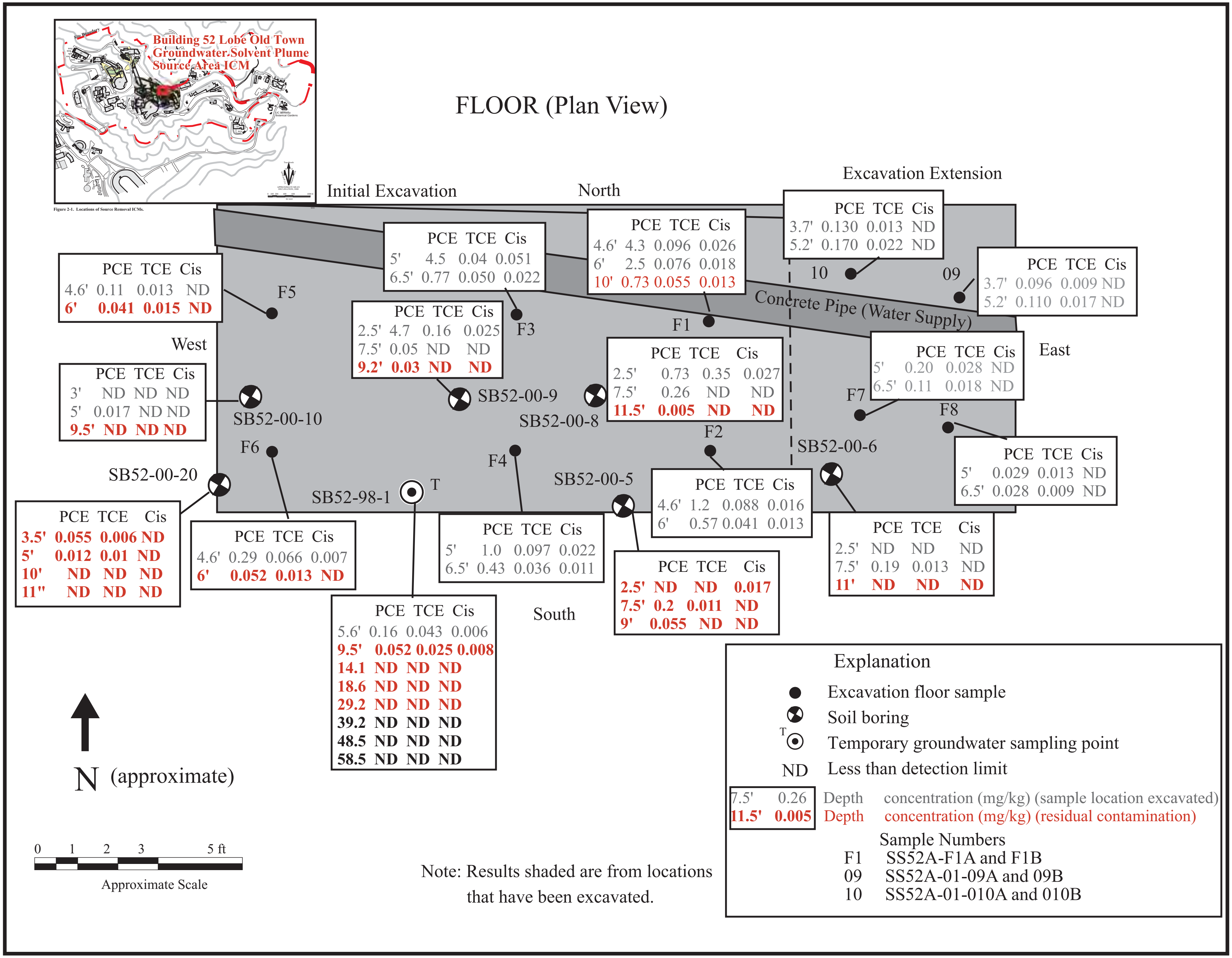

Figure 4.3.5-9a. Concentrations of PCE, TCE, and Cis-1,2-DCE Detected (mg/kg) in Floor Samples, Building 52A Source Area ICM.

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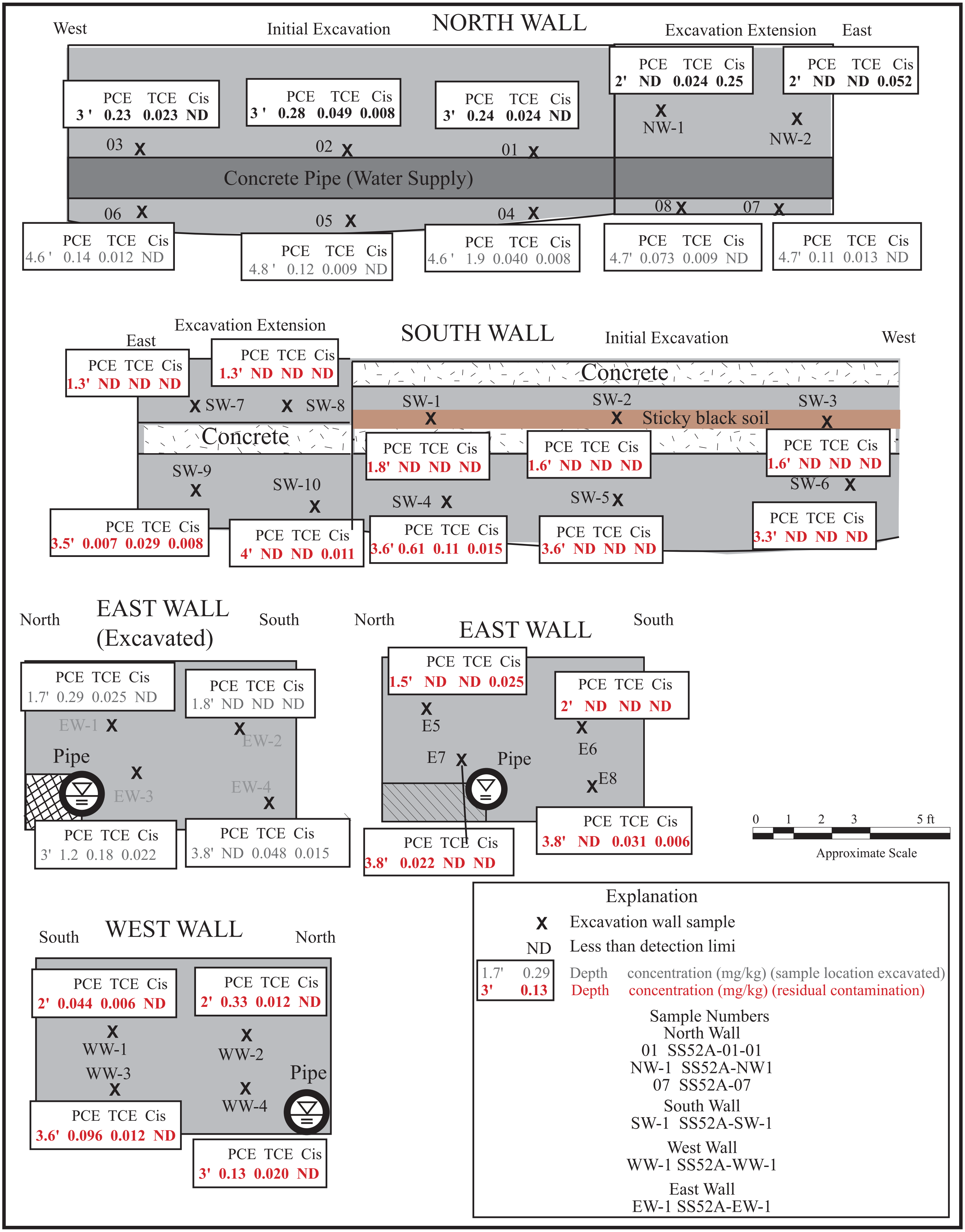

Figure 4.3.5-9b. Concentrations of PCE, TCE, and Cis-1,2-DCE Detected (mg/kg) in Wall Samples, Building 52A Source Area ICM

f4.3.5-9bb52ACMwalls.ai
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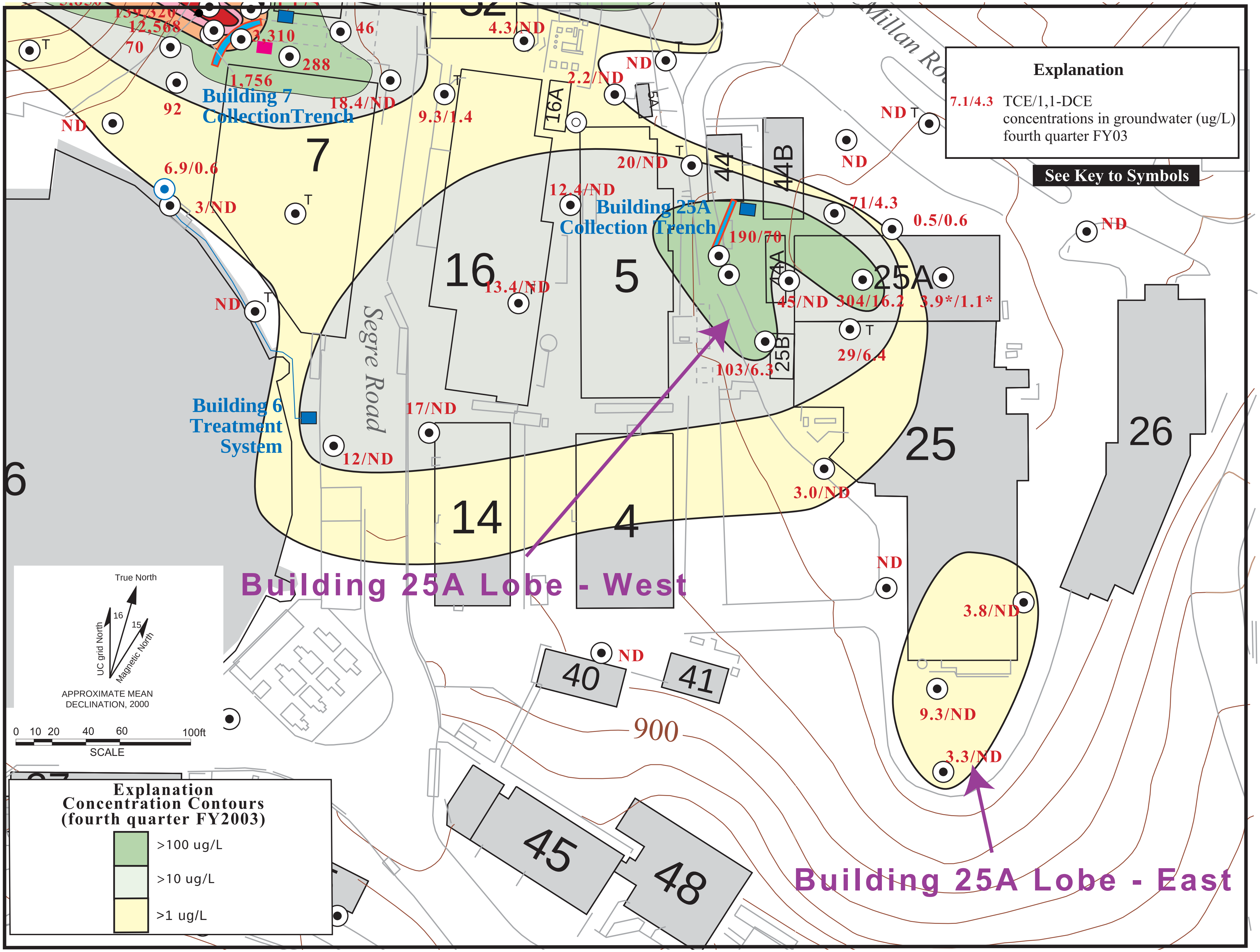

Figure 4.3.6-1. Concentrations of Trichloroethene and 1,1-Dichoroethene in Groundwater (ug/L), Building 25A Lobe Old Town Groundwater Solvent Plume.

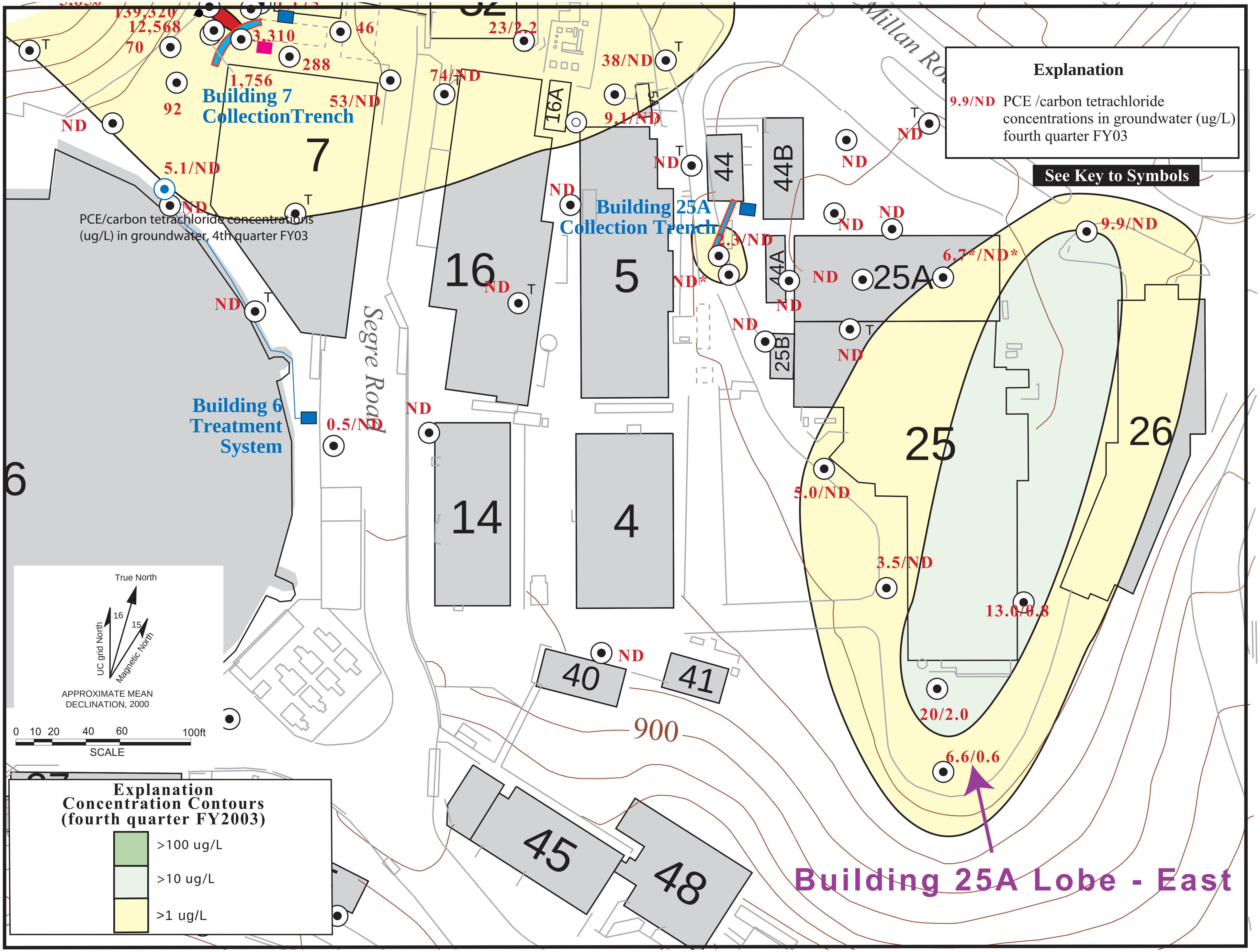

Figure 4.3.6-2. Concentrations of Tetrachloroethene and Carbon Tetrachloride in Groundwater (ug/L), Building 25A Lobe Old Town Groundwater Solvent Plume.

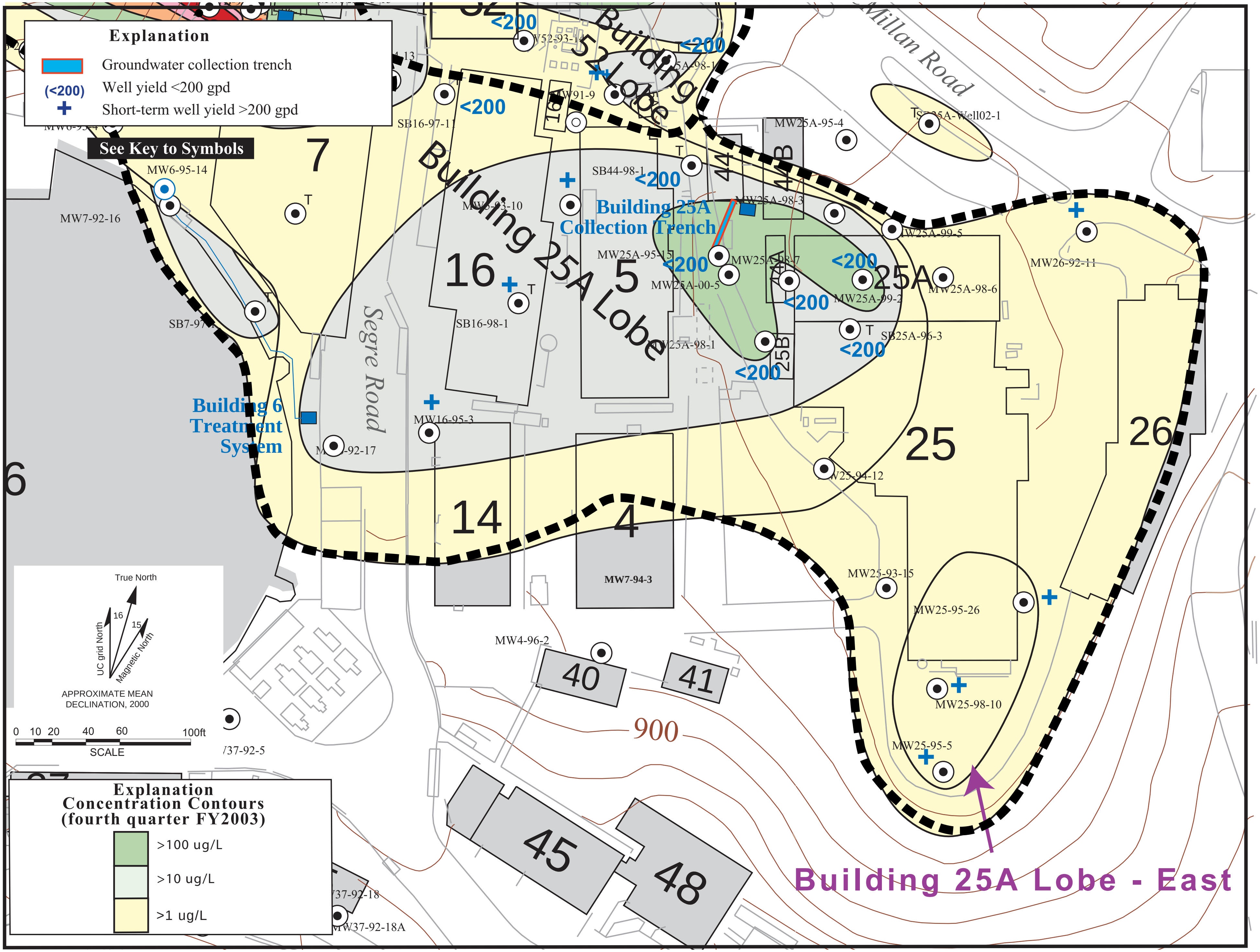

Figure 4.3.6-3. Total Halogenated Hydrocarbons in Groundwater (ug/L) and Estimated Well Yields, Building 25A Lobe Old Town Groundwater Solvent Plume.

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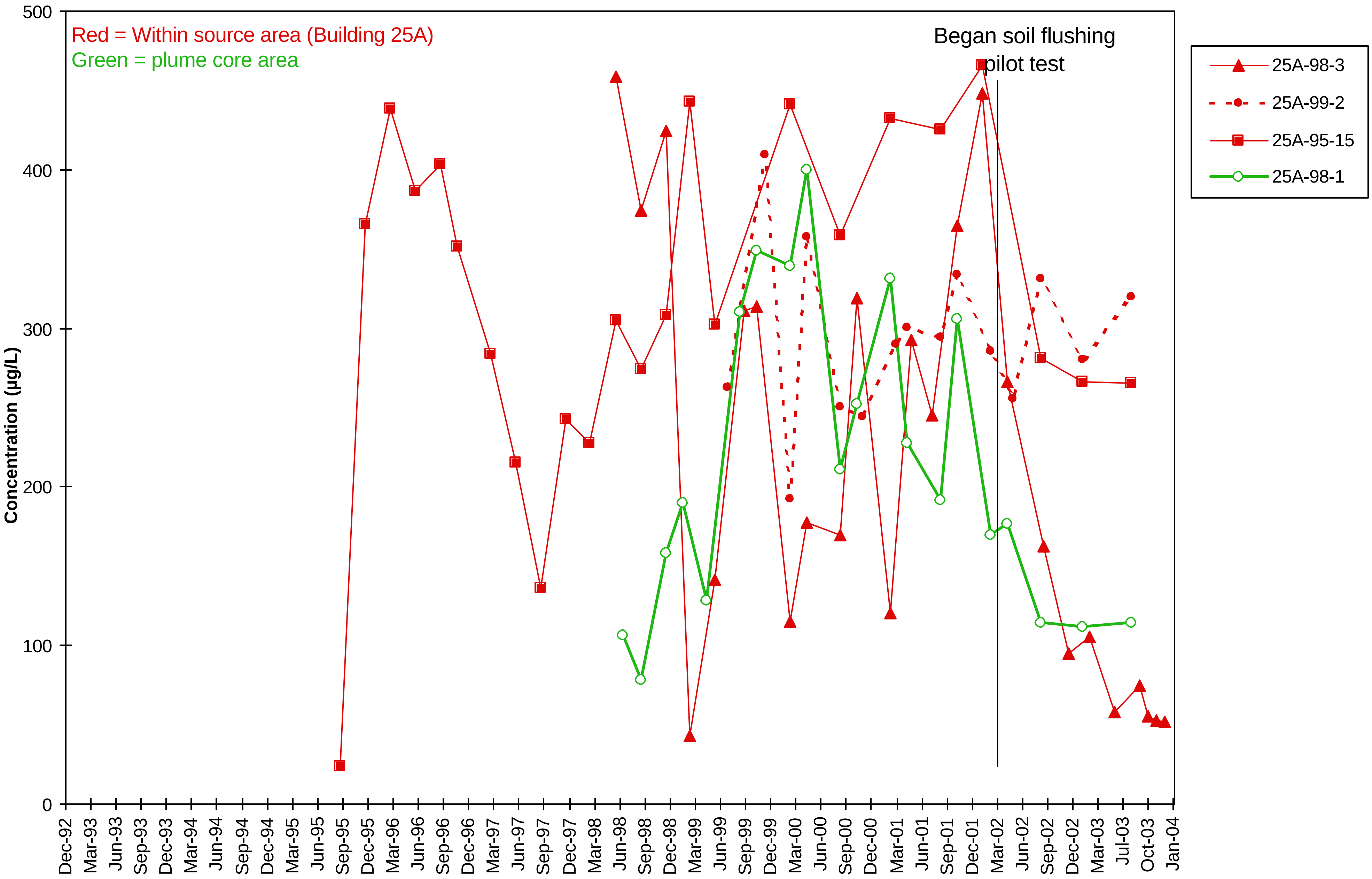

Figure 4.3.6-4a. Concentration Trends for Total Halogenated VOCs in Source and Core Area Wells Within the Old Town Solvent Plume (Building 25A Lobe)

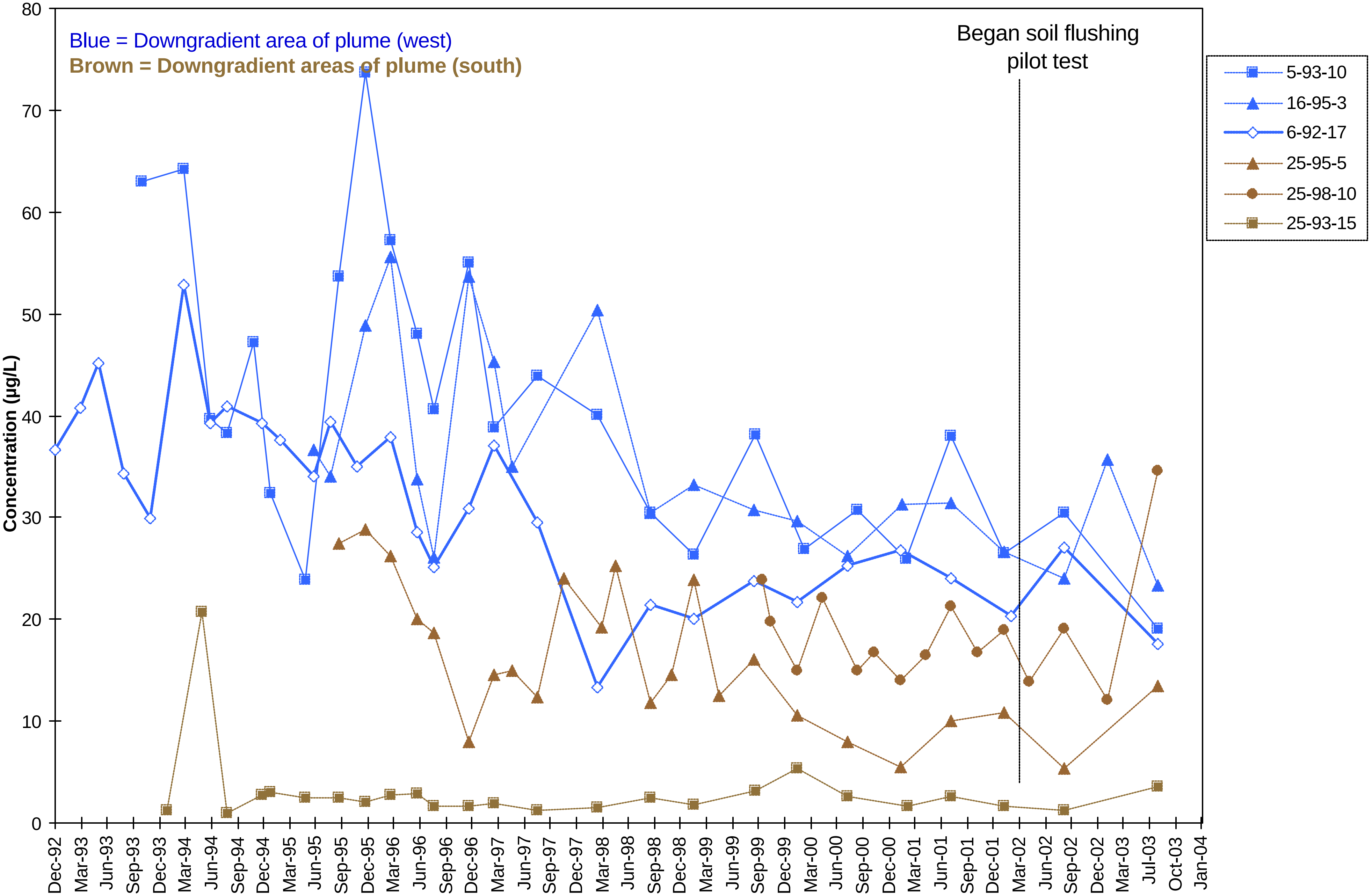

Figure 4.3.6-4b. Concentration Trends for Total Halogenated VOCs in Wells Within the Downgradient Portion of the Old Town Solvent Plume (Building 25A Lobe)

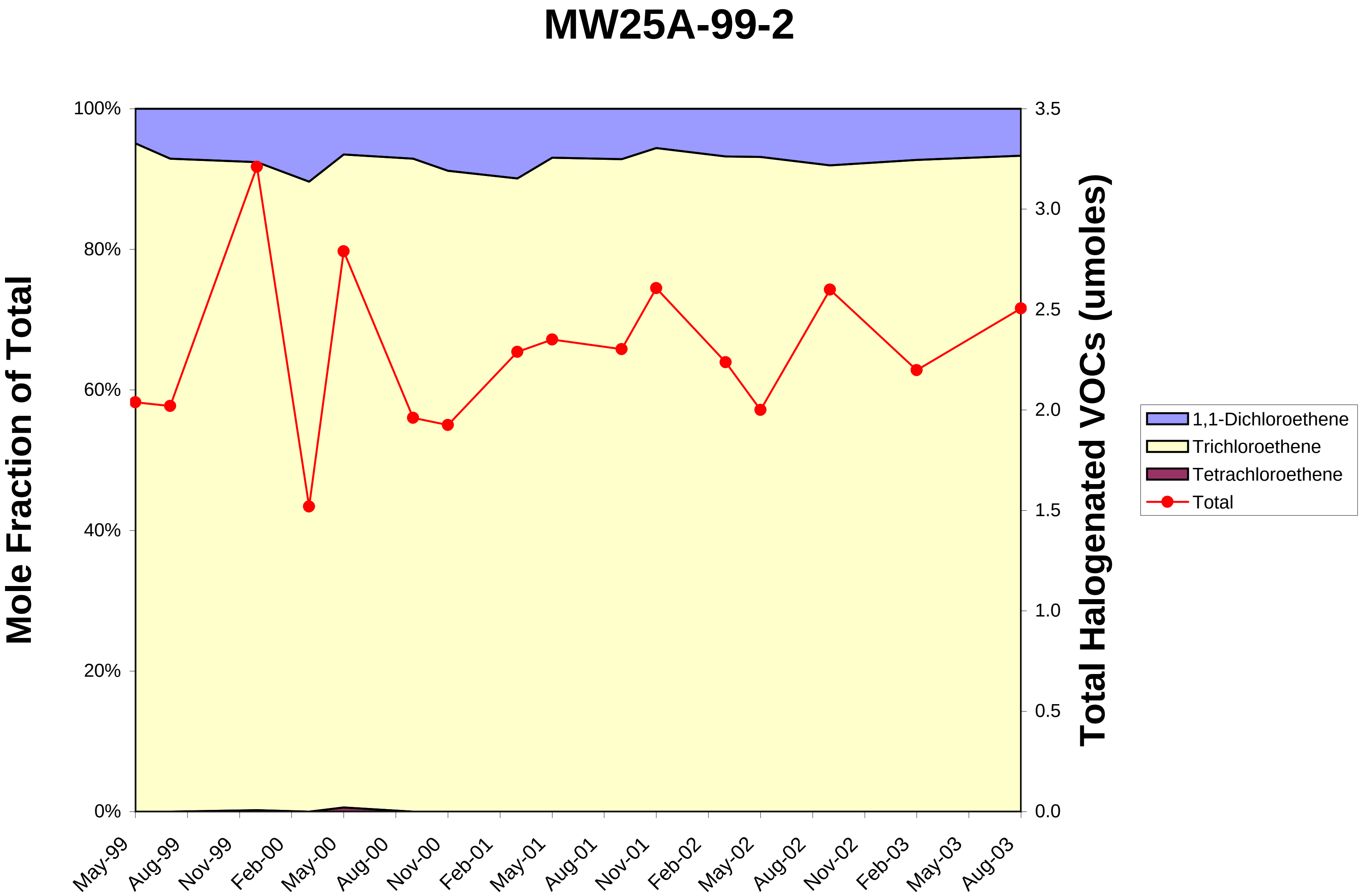

Figure 4.3.6-5. Temporal Variations in Halogenated Non-aromatic VOC Concentrations in Well MW25A-99-2, Building 25A Lobe

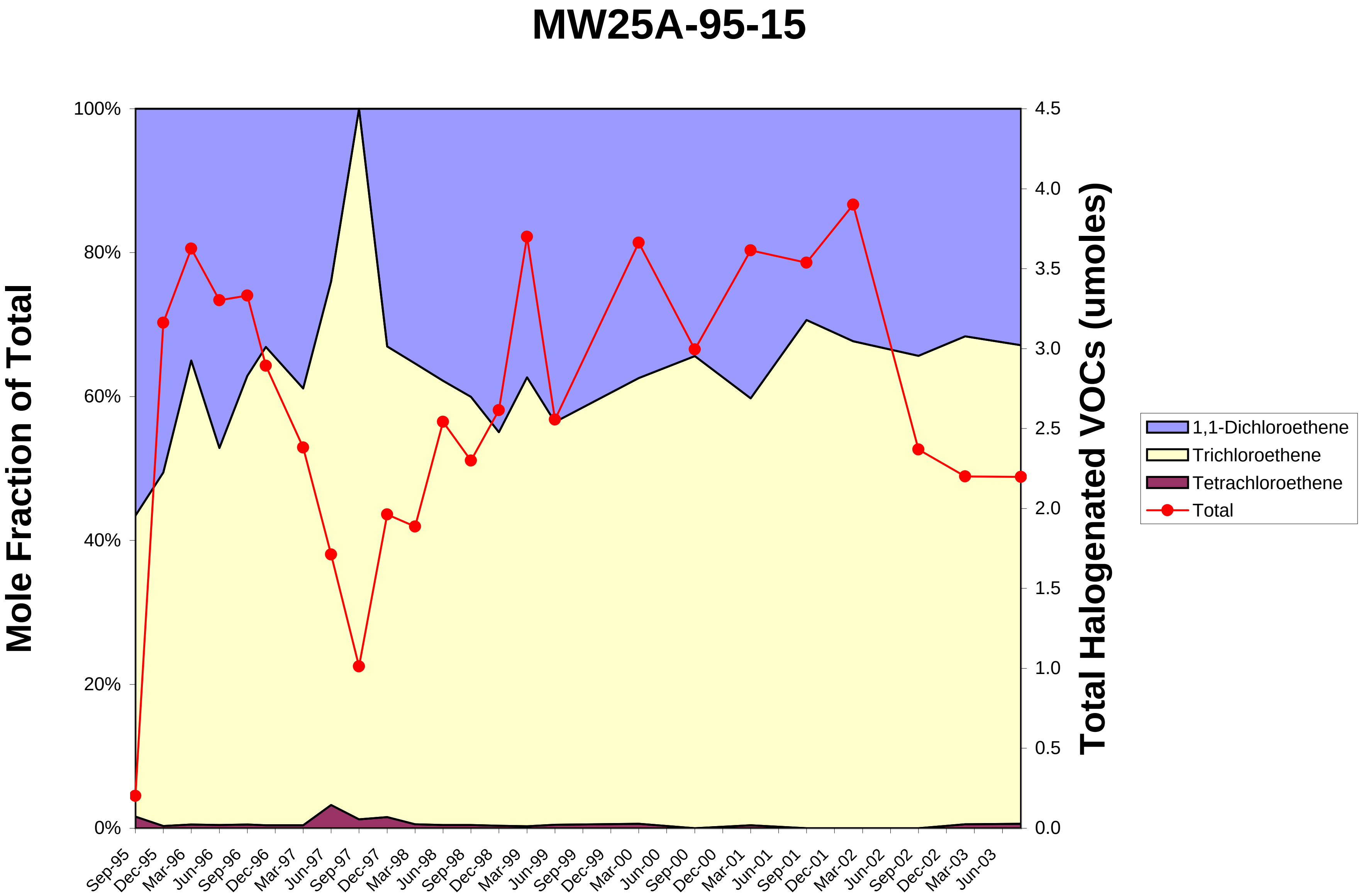

Figure 4.3.6-6. Temporal Variations in Halogenated Non-aromatic VOC concentrations in Well MW25A-95-15, Building 25A Lobe

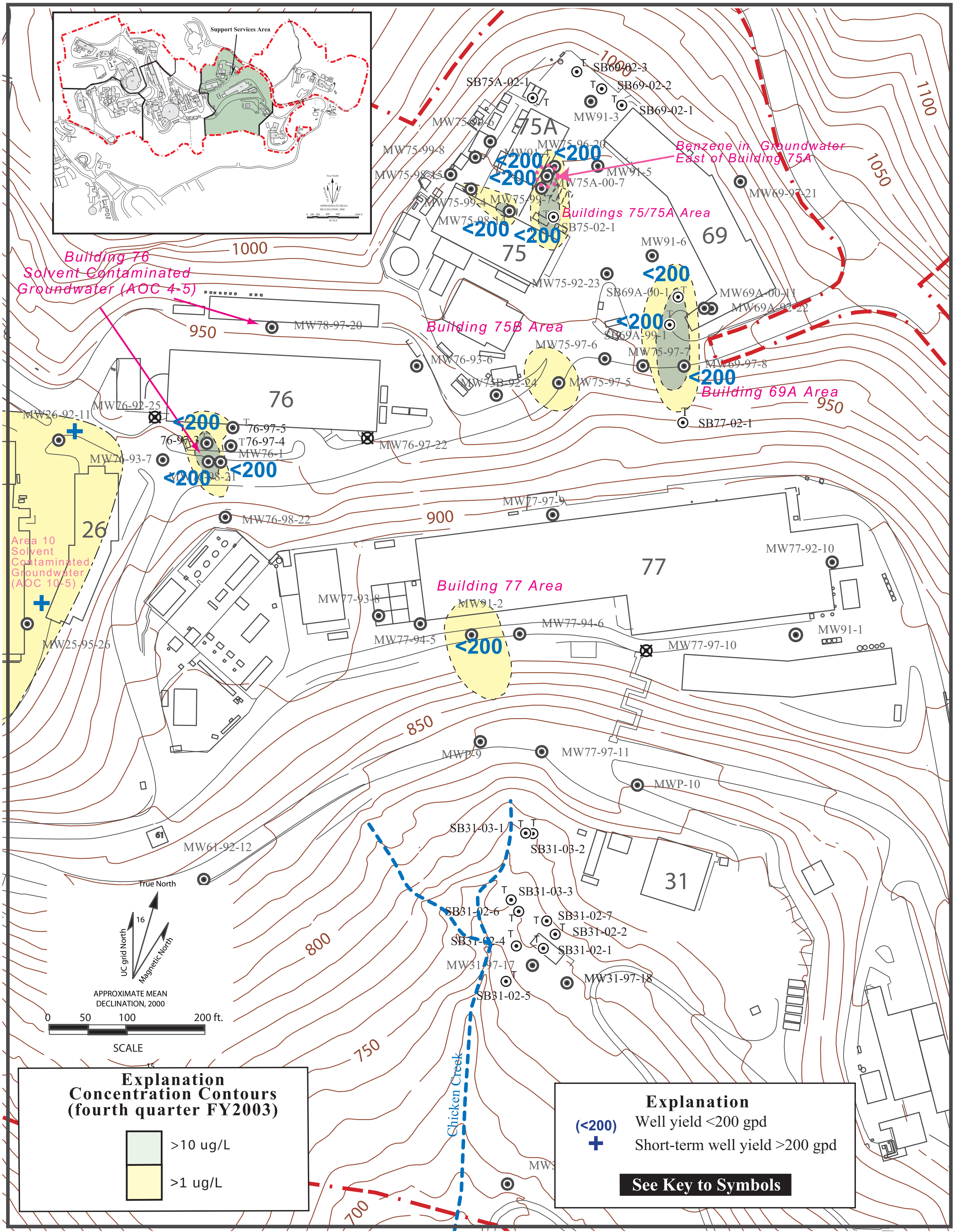

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Figure 4.3.7-1. Total Halogenated Hydrocarbons in Groundwater and Estimated Well Yield in the Support Services Area.

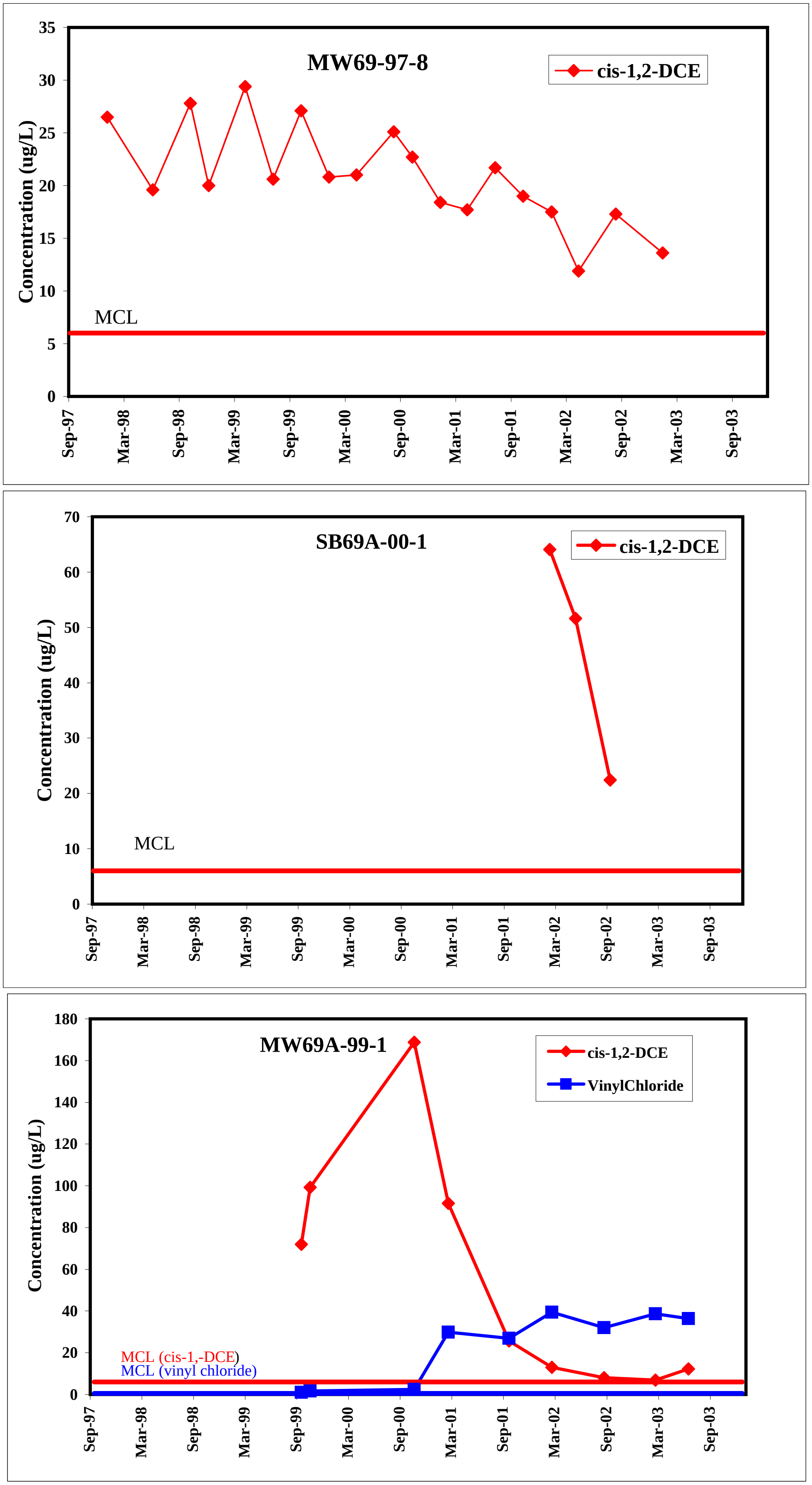


Figure 4.3.7-2. Variations in Concentrations of Halogenated Hydrocarbons Detected in MW69-97-8, MW69A-00-1, and MW69-99-1.

f4.3.7-2-b69vocs.xls

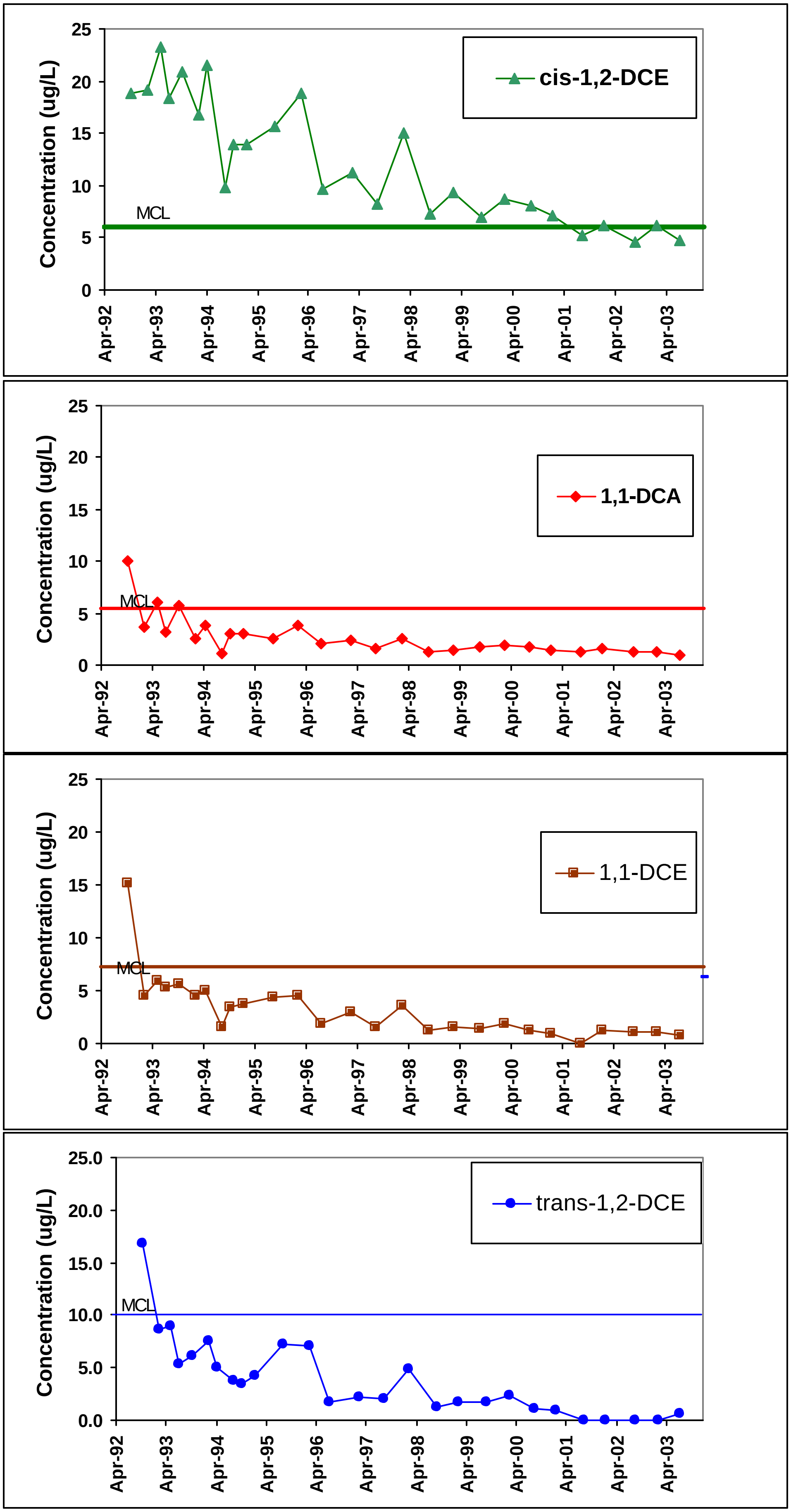
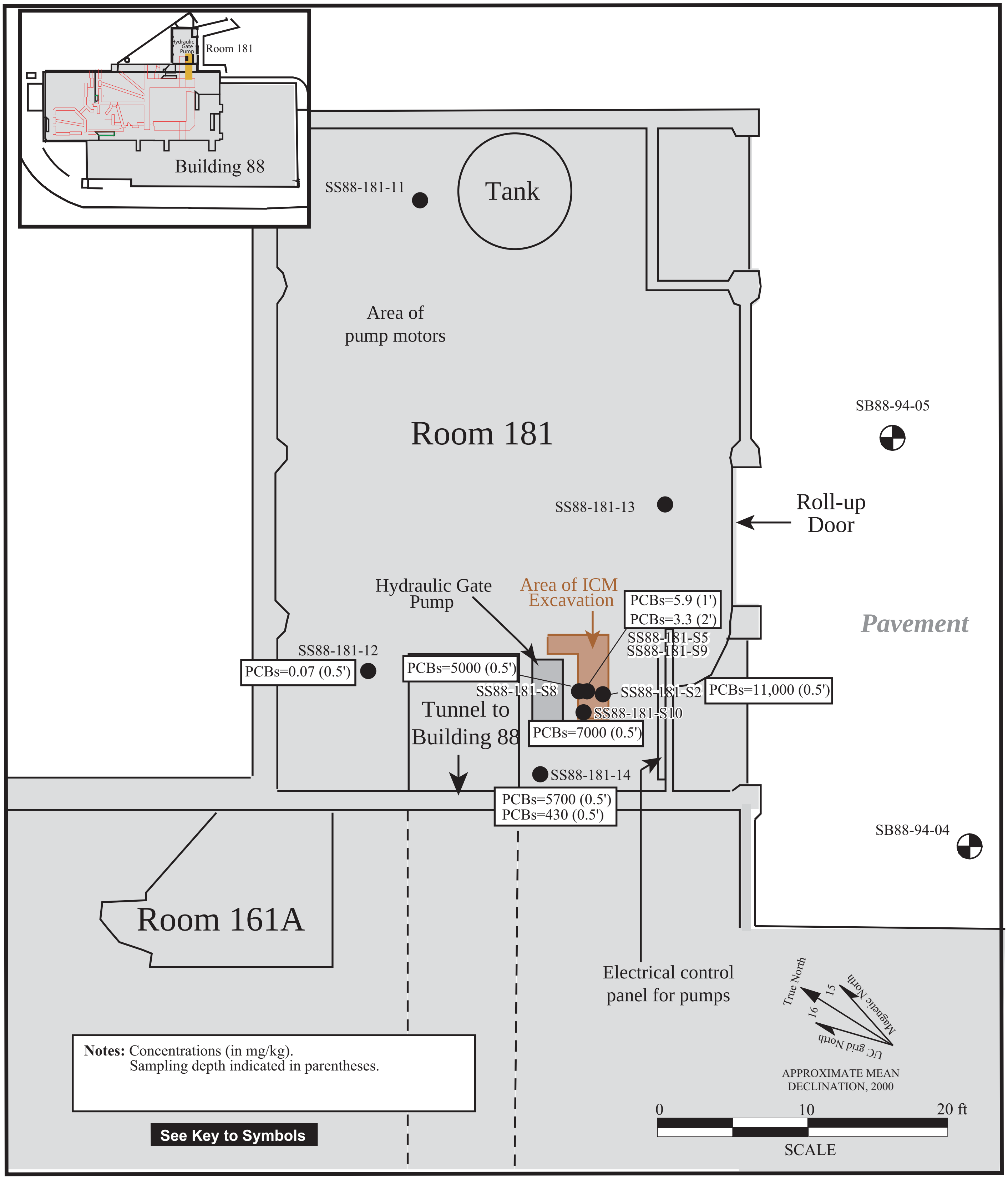


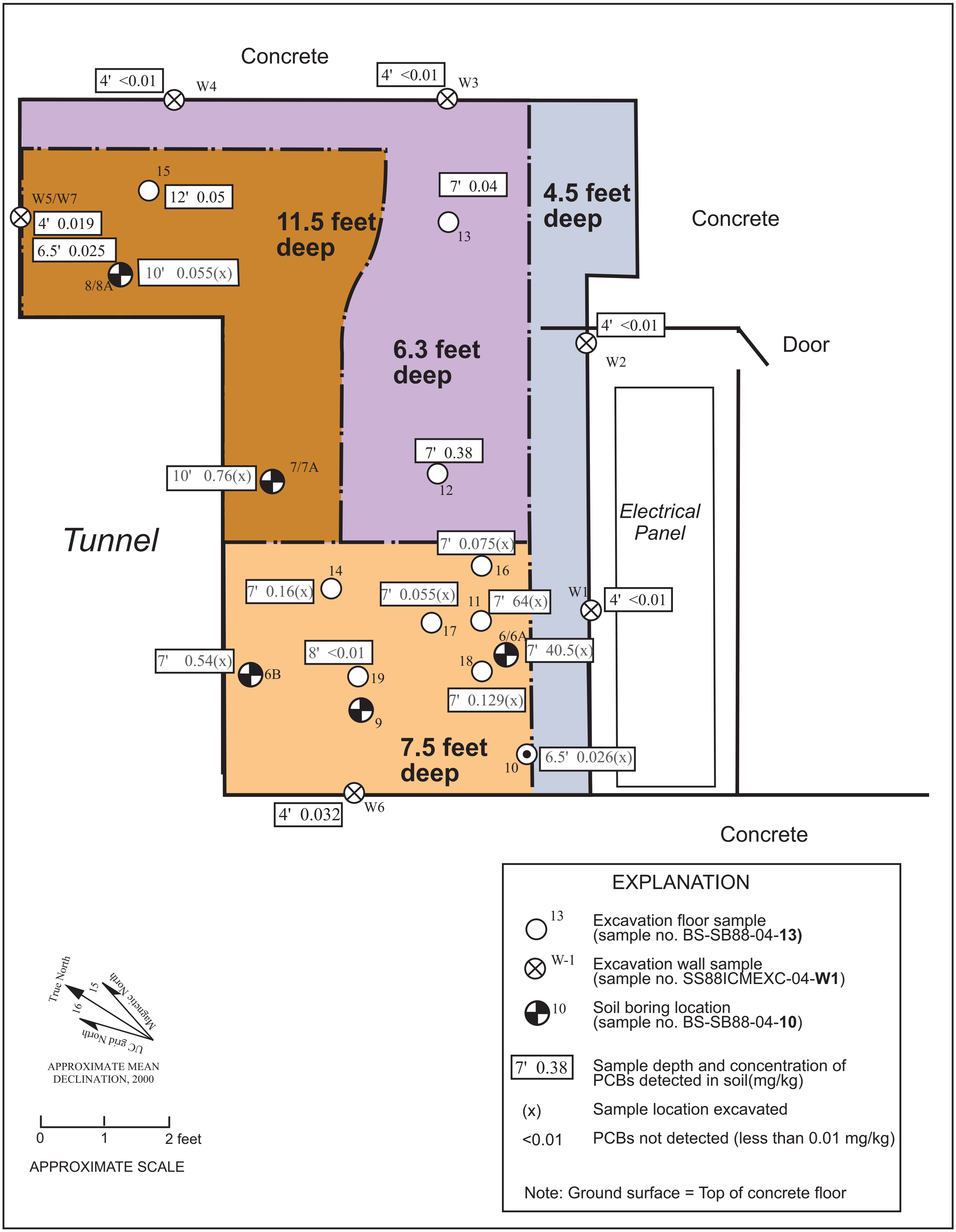
Figure 4.3.9-1. Variations in Concentrations of Halogenated Hydrocarbons Detected in MW91-2.

f4.3.9-1MW91-2.xls



f5.3-1aoc6-3.ai
4/04

Figure 5.3-1. Building 88 Hydraulic Gate Unit (AOC 6-3) Showing Residual Concentrations of PCBs in Soil after 1995 ICM.



F5.3-2_b88icm2.AI
7/04

Figure 5.3-2. Building 88 ICM Excavation, Confirmation Soil Sample Results.

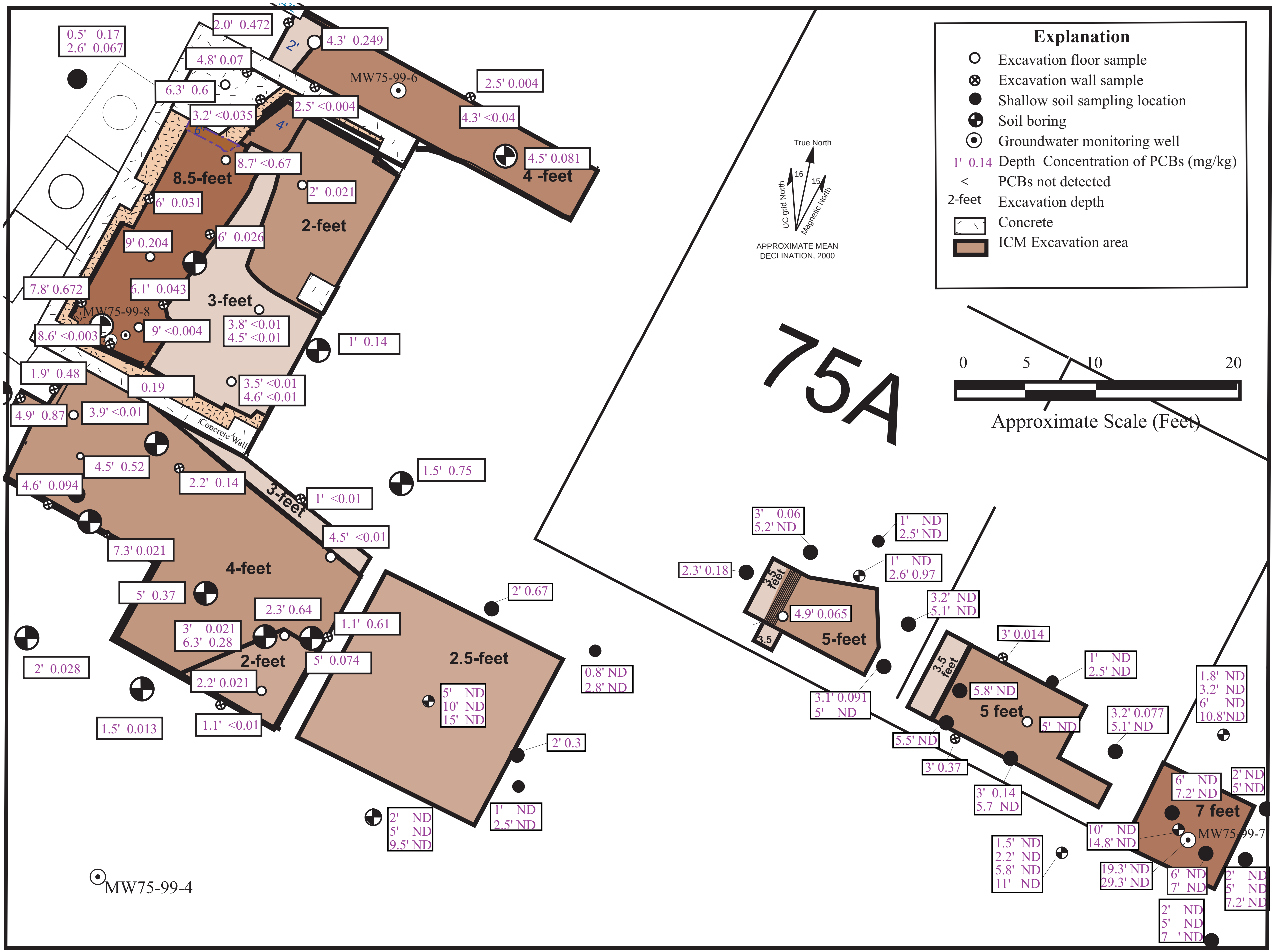
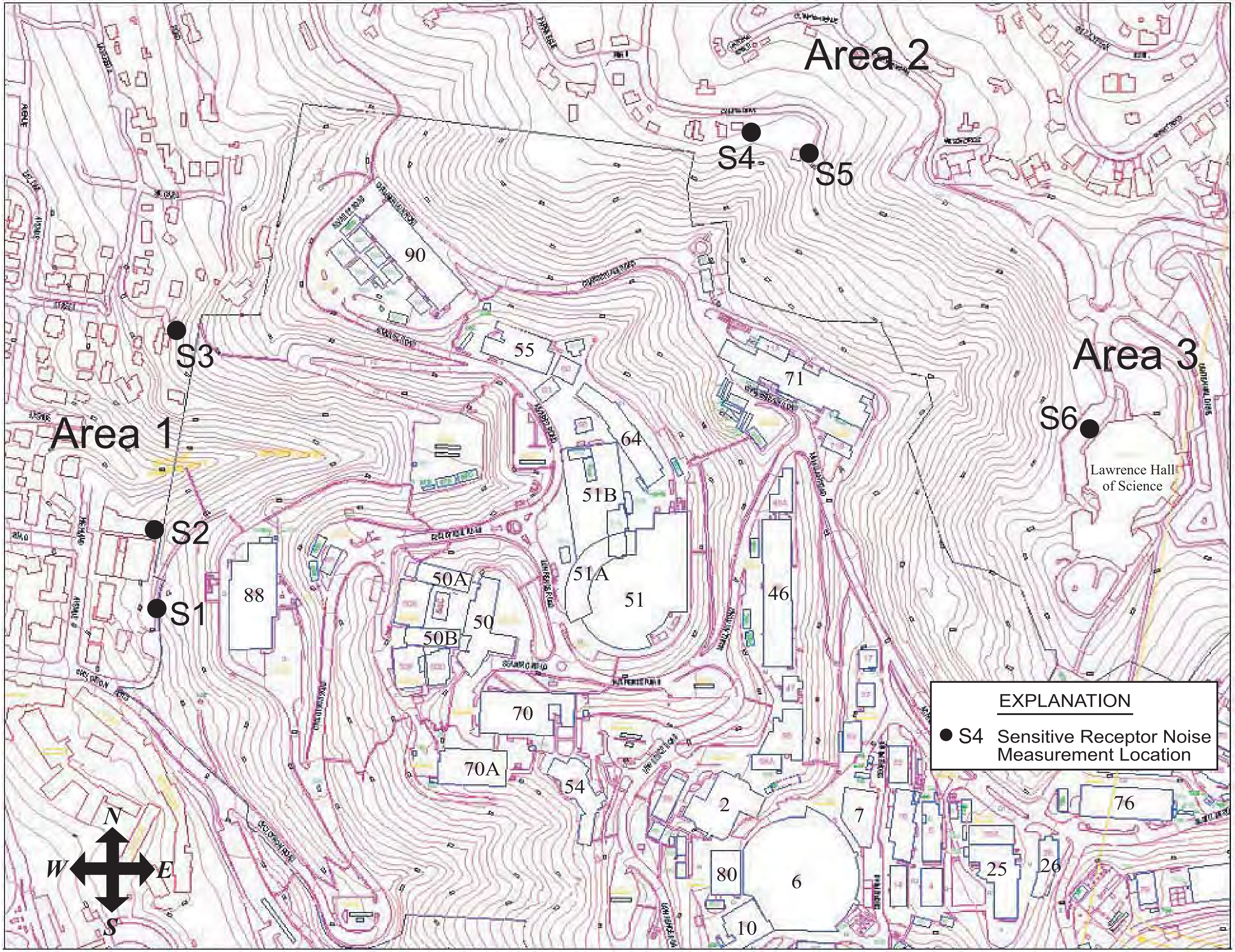


Figure 5.4-1. Building 75/75A ICM Area, PCB Concentrations in Confirmation Samples.

f5.4-1 b75a pcb.ai
7/04



2/05

Figure 7.4-1. Sensitive Receptor Locations