# U.S. Department of Energy

**Livermore Site Office, Livermore, California 94551**

## Lawrence Livermore National Laboratory

**Lawrence Livermore National Security, LLC, Livermore, California 94551**

**LLNL-AR-533772**


# Fourth Five-Year Review for the Lawrence Livermore National Laboratory Livermore Site


*Authors:*

**P. McKereghan**
**C. Noyes**
**M. Buscheck***
**Z. Demir**
**V. Dibley**

*Contributors:*

**A. Anderson***
**M. Gaud***
**G. Lorega**
**K. Mansoor**
**A. Porubcan***


## September 2012


*Weiss Associates, Emeryville, California



## Environmental Restoration Department

**This work performed under the auspices of the U. S. Department of Energy by Livermore National Laboratory under Contract DE-AC52-07NA27344.**

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# Certification

I certify that the work presented in this report was performed under my supervision. To the best of my knowledge, the data contained herein are true and accurate, and the work was performed in accordance with professional standards.

10/17/12

**Peter F. McKereghan**
California Professional Geologist
No. 5397
License expires: 03/31/14
California Certified Hydrogeologist
No. HG64
License expires: 03/31/14

Date

# Approval for the Fourth Five-Year Review for the Lawrence Livermore National Laboratory Livermore Site

Prepared by:

The United States Department of Energy
Livermore Site Office
Livermore, California

Approved:

Phillip W. Wong 10/22/12

**Phillip W. Wong** **Date**

Federal Project Director
AM for Sustainability and Infrastructure
U.S. Department of Energy
National Nuclear Security Administration
Livermore Site Office

**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY**
**REGION IX**
**75 Hawthorne Street**
**San Francisco, CA 94105**

September 28, 2012

Via USPS and email

Phil Wong
Federal Project Director
U.S. Department of Energy
AM for Sustainability and Infrastructure
NNSA Livermore Site Office
Lawrence Livermore National Laboratory
P.O. Box 808, L-293
Livermore, California 94551

Re: U.S. EPA Concurrence with the Fourth Five-Year Review Report for the Lawrence Livermore National Laboratory, Livermore Site, Livermore, California, September 2012

Dear Mr. Wong:

The U.S. Environmental Protection Agency (EPA) has reviewed the Fourth Five-Year Review (FYR) Report for the Livermore Site, at the Lawrence Livermore National Laboratory (LLNL) dated September 2012. EPA appreciates that DOE addressed many of our concerns with the March 2012 draft submittal, and based on its review of the September 2012 version, EPA agrees with the majority of the overall findings, conclusions and recommendations in the report. EPA does not, however, concur with the protectiveness statement. The remedy for the Livermore Site is protective in the short term because there currently are no known exposure pathways, however, the measures referred to in the FYR as ensuring long-term protectiveness are not part of the remedy selected in the 1992 ROD for the Livermore Site. To the extent long-term protectiveness relies on the measures that are not part of the remedy, the remedy by definition is not protective in the long term. For long term protectiveness to be achieved the remedy decision document must be revised to incorporate long-term protectiveness measures.

The remedy currently is protective of human health and the environment for the Site's industrial land use because the groundwater and soil gas treatment systems are effective in capturing and treating the contaminated media, and there currently are no known completed exposure pathways.

On the basis of the information presented in the Fourth Five Year Review, as well as subsequent meetings and calls with LLNL, EPA has made the following protectiveness determination:

> *The remedy at LLNL Livermore Site currently protects human health and the environment in the short term because there is no current exposure to site contamination and remedial treatment systems are effectively treating groundwater and soil gas. However, in order for the remedy to be protective in the long-term, measures to prevent potential future exposure to groundwater contamination underlying both the LLNL property and off-facility property over the long term must be included in the remedy.*

As the Record of Decision does not address measures to ensure long term protectiveness, EPA expects that LLNL will undertake an evaluation of long-term protectiveness measures akin to a focused feasibility study to identify and evaluate potential remedial options. Whether this evaluative effort leads to ROD revisions in the form of an Explanation of Significant Difference or an Amendment cannot be known at this time. Based on EPA's experience, however, EPA expects that LLNL can complete the evaluation and ROD revisions no later than September 2014 even if a ROD Amendment is required. Changes to the remedy will be documented in EPA's CERCLIS database.

The cleanup standards for groundwater are drinking water Maximum Contaminant Levels (MCLs). For contaminants in subsurface soil, the cleanup standards are based on reduction of concentrations to mitigate risk to onsite workers and prevent further impacts to groundwater to the extent technically and economically feasible. Because some contaminants may remain in subsurface soil following the achievement of these cleanup standards, the revised remedy decision shall include a land use control prohibiting the transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition will remain in place until and unless a risk assessment is performed in accordance with current EPA risk assessment guidance and is agreed to by the Department of Energy, EPA, and the State agencies as adequately showing no unacceptable risk for unrestricted use and unlimited exposure scenarios.

This Five-Year Review identifies seven recommendations which will be implemented as part of the routine administrative or programmatic processes that are already in place to optimize the operation of the remedy. Since these recommendations address concerns that do not directly impact remedy protectiveness, we do not include them as Five-Year Review protectiveness recommendations. For the next 5-Year Review, please clarify the institutional roles and/or responsibilities of the various DOE/LLNL Livermore Site entities that play a role in the identified on-site IC mechanisms.

We appreciate the opportunity to work with you on this project and look forward to continued success at the LLNL Livermore Site. If you have any questions regarding this letter, please feel free to contact Andrew Bain at (415) 972-3167:

Sincerely,

Michael M. Montgomery
Assistant Director, Superfund Division
Federal Facilities and Site Cleanup Branch

cc by EMail: Ariel Robertson, DOE
Pete McKereghan, LLNL
Jacinto Soto, DTSC
Agnes Farres, SFBRWQCB

# Five-Year Review Summary Form

<table>
<tr><th colspan="3">SITE IDENTIFICATION</th></tr>
<tr><td colspan="3">Site name: Lawrence Livermore National Laboratory (LLNL) Livermore Site</td></tr>
<tr><td colspan="3">EPA ID: CA 2890012584</td></tr>
<tr><td>Region: IX</td><td>State: California</td><td>City/County: Livermore/Alameda</td></tr>
<tr><th colspan="3">SITE STATUS</th></tr>
<tr><td colspan="3">NPL status: Final</td></tr>
<tr><td>Multiple OUs: No</td><td colspan="2">Has the site achieved construction completion? Yes. September 2006; approved by EPA September 2007</td></tr>
<tr><th colspan="3">REVIEW STATUS</th></tr>
<tr><td colspan="3">Lead agency: U.S. Department of Energy</td></tr>
<tr><td colspan="3">Author name: Peter McKereghan</td></tr>
<tr><td>Author title: Program Leader</td><td colspan="2">Author affiliation: Lawrence Livermore National Security, LLC</td></tr>
<tr><td colspan="3">Review period: September 2006 to September 2011</td></tr>
<tr><td colspan="3">Date(s) of site inspection: April 30, 2007</td></tr>
<tr><td colspan="3">Type of review: Statutory</td></tr>
<tr><td colspan="3">Review number: 4</td></tr>
<tr><td colspan="3">Triggering action date: July 1992, August 2007. Record of Decision, Third Five-Year Review</td></tr>
<tr><td colspan="3">Due date: August 29, 2012</td></tr>
</table>

# Five-Year Review Summary Form (continued)

| | | | | |
|---|---|---|---|---|
| **ISSUES/RECOMMENDATIONS** | | | | |
| | | | | |
| **OU(s) without Issues/Recommendations Identified in the Five-Year Review:** | | | | |
| Not applicable. | | | | |
| **Issues/Recommendations Identified in the Five-Year Review:** | | | | |
| **OU(s):** 1 | **Issue Category:** No Issue | | | |
| | **Issue:** No deficiencies in the overall remedy were identified during the fourth Five-Year Review. The remedy is performing as intended and is demonstrating good progress in remediating the ground water. To further expedite the ground water cleanup, some follow-up actions are recommended. | | | |
| | **Recommendation #1:** Implement a strategy to accelerate cleanup of the perchloroethylene (PCE) plume in the TFA West area, most likely through an Arroyo Seco Pipeline extension. | | | |
| **Affect Current Protectiveness** | **Affect Future Protectiveness** | **Implementing Party** | **Oversight Party** | **Milestone Date** |
| No | No | Federal Facility | EPA/State | August 2017 |
| **OU(s):** 1 | **Issue Category:** No Issue | | | |
| | **Issue:** NA | | | |
| | **Recommendation #2:** Complete Enhanced Source Area Remediation (ESAR) treatability tests currently underway at the Livermore Site, as well as zero valent iron (ZVI) emplacement using pneumatic fracturing, and where applicable, formulate a plan for implementing successful, cost-effective technologies at appropriate source areas to accelerate cleanup there. | | | |
| **Affect Current Protectiveness** | **Affect Future Protectiveness** | **Implementing Party** | **Oversight Party** | **Milestone Date** |
| No | No | Federal Facility | EPA/State | August 2017 |

<table>
<tr><th colspan="5">ISSUES/RECOMMENDATIONS<br>Continued</th></tr>
<tr><td rowspan="3">OU(s): 1</td><td colspan="4">Issue Category: No Issue</td></tr>
<tr><td colspan="4">Issue: NA</td></tr>
<tr><td colspan="4">Recommendation #3: Resolve the mixed waste management issues that have resulted in the temporary shutdown of four treatment facilities. Implement alternate treatment technologies or restart clean up operations at these four locations based on the findings of the Focused Feasibility Study (FFS) and the ESAR treatability tests being conducted at the Livermore Site. Also, begin implementing cleanup in the T5425 source area, where appropriate, and expand cleanup of the Building 511 and 514 source area.</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>No</td><td>Federal Facility</td><td>EPA/State</td><td>August 2017</td></tr>
<tr><td rowspan="3">OU(s): 1</td><td colspan="4">Issue Category: No Issue</td></tr>
<tr><td colspan="4">Issue: NA</td></tr>
<tr><td colspan="4">Recommendation #4: Evaluate the need for additional hydrostratigraphic unit 4 (HSU) source area delineation at TFD Southeast, in light of declining contaminant concentrations in this area.</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>No</td><td>Federal Facility</td><td>EPA/State</td><td>August 2017</td></tr>
</table>

<table>
<tr><th colspan="5">ISSUES/RECOMMENDATIONS<br>Continued</th></tr>
<tr><td rowspan="3">OU(s): 1</td><td colspan="4">Issue Category: No Issue</td></tr>
<tr><td colspan="4">Issue: NA</td></tr>
<tr><td colspan="4">Recommendation #5: Complete a hydrogeologic investigation to determine the source of increasing tritium activities observed in TFE Southwest and TF518 North influent, and conduct tests in HSU-4 to evaluate recirculation of water in the subsurface to control tritium migration in the Southeastern corner of the Livermore Site (the Building 419, 412, 511, and 411 areas).</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>No</td><td>Federal Facility</td><td>EPA/State</td><td>August 2017</td></tr>
<tr><td rowspan="3">OU(s): 1</td><td colspan="4">Issue Category: No Issue</td></tr>
<tr><td colspan="4">Issue: NA</td></tr>
<tr><td colspan="4">Recommendation #6: Once the VTF518 Perched Zone source delineation analysis has been completed, evaluate the need to expand the TF518 wellfield to include more of the western area.</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>No</td><td>Federal Facility</td><td>EPA/State</td><td>August 2017</td></tr>
<tr><td rowspan="3">OU(s): 1</td><td colspan="4">Issue Category: No Issue</td></tr>
<tr><td colspan="4">Issue: NA</td></tr>
<tr><td colspan="4">Recommendation #7: Once the Resource Conservation and Recovery Act closure of Building 419 is complete and a resolution of the mixed waste management issues has been reached, continue delineating the source and begin implementing clean up measures there.</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>No</td><td>Federal Facility</td><td>EPA/State</td><td>August 2017</td></tr>
</table>

| PROTECTIVENESS STATEMENT | | |
|---|---|---|
| **OU:** | **Protectiveness Determination** | **Addendum Due Date:** |
| 1 | Protective | NA |

**Protectiveness Statement:** The remedy is protective of human health and the environment for the industrial land use at the site. The remedy protects human health because exposure pathways that could result in unacceptable risk to onsite workers are being controlled by the implementation of institutional controls, the Health and Safety Plan, and the Contingency Plan.

A letter to file in the Administrative Record prohibits the transfer of the property with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition may be lifted if a risk assessment shows no unacceptable risk for residential or unrestricted land use and is agreed to by the DOE, the U.S. Environmental Protection Agency, Department of Toxic Substances Control, and the Regional Water Quality Control Board. In the event that the site is transferred in the future, the DOE will execute a land use covenant at the time of transfer in compliance with Title 22, California Code of Regulations, Section 67391.1.

DOE/LLNL are actively evaluating source areas cleanup technologies to reduce long-term operational costs and shorten the time to cleanup. DOE/LLNL are committed to the Livermore Site remediation objectives of: (1) preventing present day and future human exposure to contaminated ground water and soil; (2) preventing contaminant migration at concentrations above Maximum Contaminant Levels; (3) reducing contaminant concentrations in ground water to levels below the state and federal Maximum Contaminant Levels; and (4) minimizing contaminant migration in the unsaturated zone that would result in concentrations in ground water above a Maximum Contaminant Level.

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# Appendices

# 1. Introduction

The United States (U.S.) Department of Energy (DOE) has conducted a Five-Year Review of the remedial actions implemented at the Lawrence Livermore National Laboratory (LLNL) Livermore Site. Environmental cleanup is conducted under the oversight of the U.S. Environmental Protection Agency (EPA), the California Department of Toxic Substances Control (DTSC), and the California Regional Water Quality Control Board (RWQCB) – San Francisco Bay Region. DOE is the lead agency for environmental restoration at LLNL. The review documented in this report was conducted from September 2006 through September 2011. Parties providing analyses in support of the review include:

- U.S. DOE, Livermore Site Office.
- LLNL, Environmental Restoration Department (ERD).
- Weiss Associates.

The purpose of a Five-Year Review is to evaluate the implementation and performance of a remedy to determine whether the remedy will continue to be protective of human health and the environment. The Five-Year Review report presents the methods, findings, and conclusions of the review. In addition, the Five-Year Review identifies issues or deficiencies in the selected remedy, if any, and presents recommendations to address them. The format and content of this document is consistent with guidance issued by the EPA (EPA, 2002).

This Five-Year Review was conducted pursuant to Section 300.430(f)(4)(ii) of the National Oil and Hazardous Substance Pollution Contingency Plan (NCP), Title 40 Code of Federal Regulations (CFR) Part 300, which implements Section 121(c) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). Under these statutes and regulation, the Livermore Site is subject to a Five-Year Review because hazardous substances, pollutants, or contaminants remain at the site above levels that allow for unlimited use and unrestrictive exposure. Consistent with Executive Order 12580, other Federal agencies are responsible for ensuring that Five-Year Reviews are conducted as required or appropriate.

The Livermore Site (Figure 1) consists of one Operable Unit (OU). The OU is divided into the following treatment areas based on contaminant location (Figure 2):

- Treatment Facility A
- Treatment Facility B
- Treatment Facility C
- Treatment Facility D
- Treatment Facility E
- Treatment Facility G
- Treatment Facility H

This is the fourth Five-Year Review for the Livermore Site. The first, second, and third Five-Year Reviews were completed in December 1997 (Berg et al., 1997), September 2002 (Berg et al., 2002), and August 2007 (Berg et al., 2007), respectively. This review is considered a statutory review because: (1) contamination will remain onsite upon completion of the remedial action; (2) the Record of Decision was signed after October 17, 1986 (the effective date of the SARA); and (3) the remedial action was selected under the CERCLA. The triggering action for the first review was the completion of the Livermore Site Record of Decision (ROD) in 1992.

During fiscal year (FY) 2008, the Livermore Site Project experienced a severe budget reduction that necessitated a dramatic reduction in both staff and cleanup activities at the site (Valett et al., 2008, and Buscheck et al., 2009). Available resources for treatment facility operations were allocated so as to meet the priorities for site remediation established in the March 2009 Consensus Statement and the Contingency Plan (McKereghan et al., 1996), namely 1) western plume capture, 2) southern plume capture, and 3) internal source control/mass removal. While 19 treatment facilities were shut down or became non-operational in FY 2008, ten facilities remained operational. Detailed post-shutdown monitoring indicates no uncontrolled plume migration resulted from the shutdown, indicating no reduction in the protectiveness of the site remedies. Consequently, enhanced source area remediation (ESAR) treatability tests begun in 2007 were put on hold and existing ground water and soil vapor treatment operations were significantly curtailed for the year.

When funding was restored in July 2008, ERD developed a process to restart facilities in a phased and deliberate fashion based on risk to human health and the environment, and importance to the cleanup effort. The ERD process, known as the Remediation Evaluation (REVAL) process, was also used to perform a comprehensive review of each reactivated treatment facility and remedial well field to ensure that each system operates in a safe and optimal manner to remove and treat contaminated ground water and soil vapor, and ultimately accomplish cleanup of the subsurface.

Following the restart of most idled treatment facilities, ERD began once again implementing the ESAR treatability tests, starting in 2009, while continuing to implement the REVAL process. ERD also continued seeking resolution of mixed waste management issues that resulted in the temporary shutdown of four treatment facilities during the review period: TF5475-1, TF5475-3, VTF5475, and TF518 North (Figure 2).

Ground water cleanup along the western margin continued unabated, although persistent concentrations at the leading edge of the TFA offsite plume prompted a year-long treatability test, conducted by ERD. The purpose of this treatability test was to (1) determine whether full hydraulic capture of the contaminant plume could be attained through pumping at this location, and (2) evaluate the resulting reduction in ground water contaminant concentrations. During the test, extracted ground water was filtered and discharged to the sanitary sewer for treatment at the Livermore Water Reclamation Plant (LWRP). Based on extensive hydrogeologic and cost-benefit analysis, as well as stakeholder and regulatory input, an extension of the Arroyo Seco Pipeline to clean up this area is planned. To the north at TFB, a remedial wellfield expansion was initiated to ensure comprehensive capture of contaminant plumes along the western margin of LLNL.

# 2. Site Chronology

Table 1 lists the chronology of major events for the Livermore Site relative to environmental restoration. Table 2 presents project restoration highlights since the third Five-Year Review.

# 3. Background

Livermore Site background is briefly summarized below. Complete site description, history, and characterization information was presented in the ROD, the Livermore Site Remedial Investigation Report (Thorpe et al., 1990), and the Feasibility Study (Isherwood et al., 1990).

## 3.1. Physical Characteristics

### 3.1.1. Site Description

In 1942, the U.S. Navy converted the land area currently comprising the Livermore Site from agricultural use. The Navy used the site until 1946 as a flight-training base and for aircraft assembly, repair, and overhaul. Solvents, paints, and degreasers were routinely used during this period. Between 1946 and 1950, the Navy housed the Reserve Training Command at the site. In 1950, the Navy allowed occupation of the site by the Atomic Energy Commission (AEC), which formally received transfer of the property in 1951. Under the AEC, the site became a weapons design and basic physics research laboratory. In 1952, the site was established as a separate part of the University of California Radiation Laboratory. Responsibility for the site was transferred to the Energy, Research, and Development Administration in 1975. In 1977, responsibility for LLNL was transferred to DOE for the foreseeable future.

The Lawrence Livermore National Security, Limited Liability Corporation (LLNS) currently operates LLNL. The Livermore Site is located approximately three miles east of downtown Livermore, California (Figure 1). The Livermore Site comprises approximately 800 acres. Historic LLNL operations involved the release of hazardous materials to the environment. History of contamination is discussed in Section 3.3 below.

The Diablo Range hills flank Livermore Site to the south and east, and the ground surface slopes down approximately 1% to the northwest. The site is underlain by up to 1000 ft of unconsolidated sediments that are subdivided into the Plio-Pleistocene age Livermore Formation and undifferentiated late Pleistocene to Holocene alluvium (Thorpe et al., 1990, and Isherwood et al., 1990). The sediments were deposited in a topographic and structural (pull-apart) basin bounded by the Calaveras Fault zone to the west and the Greenville Fault to the east. The majority of the sediments beneath LLNL were derived from the Diablo Range to the south and the Altamont Hills to the east. The Livermore Formation is made up of an Upper Member composed of complexly-interbedded and interfingered alluvial fan deposits consisting of sands, gravels, silts, and clays and a Lower Member consisting of more laterally-continuous fluvial and lacustrine deposits, predominantly silts and clays with lesser sands and gravels. The lower member sediments form a regional confining layer below which contaminants derived from the site do not occur.

### 3.1.2. Hydrogeologic Setting

Ground water beneath Livermore Site is partly within the Spring and Mocho I hydrologic subbasins (California Department of Water Resources, 1974). Depth to ground water at the site varies from about 130 feet (ft) in the southeast corner to about 25 ft in the northwest corner. Municipal wells about two miles west of the site supply water to downtown Livermore. Ground water south and west of the site is used for agricultural irrigation. Two intermittent streams, Arroyo Seco and Arroyo Las Positas, are located on the site and recharge the ground water during wet periods. In order to implement the clean up strategy detailed in the ROD (DOE, 1992), nine hydrostratigraphic units (HSUs) were defined in the mid-1990s (Berg et al., 1994, and Blake et al., 1995). By identifying the primary hydraulic controls within the LLNL sedimentary sequence, HSUs consistent with ground water flow and contaminant transport were established, allowing site remediation systems to be designed to treat and capture individual contaminant plumes, and to be optimized with respect their location, geometry, and mobility. HSU-1A, defined for the western portion of LLNL, is unsaturated onsite and thus does not contain impacted ground water. HSUs-1B through 5 are known to contain contaminants and have therefore been targeted for cleanup. HSU-1B consists of complexly-interbedded sands, silts, and gravels. HSU-1B is unsaturated in the eastern third of the site. Contamination in HSU-1B is largely restricted to the site's western margin (TFA, TFB, and TFC). HSU-2 is composed of higher-permeability alluvial sands and gravels set within a matrix of lower-permeability silts and silty sands. The sand and gravel zones become more laterally-continuous and more transmissive along the western margin of the site. HSU-2 also becomes unsaturated to the east, and is known to be contaminated across most of the site. HSU-3A is composed of finer-grained, lower-permeability sands, silts, and clays, but does contain occasional higher-permeability sands and gravels. Wells completed in this HSU typically have lower sustainable yields. HSU-3A is known to pinch out in the southeastern corner of the site (TFH area). Contamination in HSUs-3A, 3B, 4, and 5, is largely restricted to the eastern portion of the site (TFD, TFE, and TFH). HSU-3B consists largely of moderate-permeability sands and gravels. HSU-3B also pinches out eastward and is absent in the southeast corner of the site. HSU-4 is a laterally-continuous, high-permeability channelized sand and gravel unit that occurs on top of the Lower Member of the Livermore Formation. Pumping tests indicate a high degree of lateral hydraulic continuity within HSU-4, particularly in the TFD, TFE, TFG, and TFH areas. HSU-4 also pinches out to the east and is largely absent along the eastern margin of the site. HSU-5 consists predominantly of fine-grained sediments, commonly silts and clays with interbeds of higher-permeability silty to clayey gravel and sand. The more laterally-continuous sands and gravels show a pronounced lateral hydraulic continuity in the north-south direction. Contamination derived from LLNL is not known to occur below the base of HSU-5. HSU-6 is a green-colored silty-clay to clayey-silt interval that forms a regional confining layer beneath LLNL. HSU-7 is composed of the rest of the Lower Member of the Livermore Formation and consists largely of finer-grained lacustrine and fluvial sediments.

## 3.2. Land and Resource Use

As presented in Section 3.1.1, the Livermore Site was converted from agricultural use by the U.S. Navy in 1942. LLNL was established in 1952 and continues its national security mission at the Livermore Site. Current LLNL property land use is restricted with the site remaining a secured DOE facility. This restriction is anticipated for the foreseeable future. Fencing around the Livermore Site perimeter controls access to the site. The site is heavily developed with large-scale experimental research and support facilities. A storm water drainage retention basin approximately 800 feet by 300 feet in size, is situated near the center of LLNL. This basin was constructed and lined in 1990 to prevent infiltration of ponded surface water (Coty et al., 2002).

Land immediately north of the Livermore Site is zoned for industrial use. To the west, the land is zoned for residential use. Sandia National Laboratories, California (SNL) is located south of the site. The area east of LLNL is zoned for agriculture and is currently used as pasture land (DOE, 2005). Water supply and ground water uses are discussed in Section 3.1.2.

## 3.3. History of Contamination

Initial hazardous materials releases occurred at the Livermore Site in the mid- to late-1940s when the site was the Livermore Naval Air Station (Thorpe et al., 1990). There is also evidence that localized spills, unlined landfills, and leaking tanks and impoundments contributed volatile organic compounds (VOCs), fuel hydrocarbons (FHCs), metals, and tritium to the ground water and unsaturated sediments in the post-Navy era. By 1987, a plume of VOCs had migrated offsite about 2,200 feet west of the current LLNL property. These historical operations resulted in placement of the Livermore Site on the EPA National Priorities List in 1987 because of ground water contamination by hazardous substances, as defined in Section 101(14) of CERCLA. In August 1987, the RWQCB adopted Site Cleanup Order No. 87-018 for various parts of the site. In June 1988, this order was superseded by Order No. 88-103 that considered the site as a whole and established a schedule for CERCLA investigations and remediation.

Historically, the following compounds have been detected in ground water beneath the Livermore Site at concentrations above drinking water standards:

- VOCs — trichloroethylene (TCE), perchloroethylene (PCE), 1,1-dichloroethylene (1,1-DCE), chloroform, cis-1,2-dichloroethylene (cis-1,2-DCE), trans-1,2-DCE, 1,1-dichloroethane (1,1-DCA), 1,2-dichloroethane (1,2-DCA), trichlorofluoromethane (Freon 11), and carbon tetrachloride.
- FHCs — benzene, ethyl benzene, toluene, and ethylene dibromide.
- Metals — chromium.
- Radionuclides — tritium.

As a result of remedial actions, ground water concentrations are currently below the Livermore Site cleanup standards for the following compounds:

- VOCs — trans-1,2-dichloroethylene (trans-1,2-DCE) and trichlorofluoromethane.
- FHCs — ethyl benzene, toluene, and ethylene dibromide.
- Metals — chromium.

## 3.4. Initial Response

In 1982, DOE/LLNL began environmental investigations at the Livermore Site when VOCs were discovered in drinking water wells. LLNL was placed on the Superfund National Priority

List (NPL) in 1987 because of VOCs in ground water and the presence of drinking water supply wells within 3 miles of the site (Thorpe et. al., 1990). Since then, over 1,800 boreholes have been drilled and 608 ground water monitor or extraction wells have been installed. The geologic and chemical data from these wells and boreholes have been used to characterize the site hydrogeology and to monitor temporal and spatial changes in saturation and dissolved contaminants. Site characterization activities have also included passive and active (i.e., vacuum-induced) soil vapor surveys.

Removal actions have been conducted when technically feasible at the following locations:

- Taxi Strip — The Taxi Strip area was a former radioactive solid and liquid waste and solvent storage and processing area near the current location of Trailer 5475 (Berg, et al., 1998; Buerer, 1983; Dreicer, 1985). In 1983, soil was excavated from the area down to depths of 34 feet below ground surface. About 3,000 cubic yards of soil was shipped offsite for disposal. The project was completed in May 1983.
- East Traffic Circle Landfill — A landfill containing paper, construction debris, capacitors, gardening debris, etc. was excavated in August through September 1984. About 160 capacitors were removed during this removal. Nearly 14,000 cubic yards of soil and debris removed containing VOCs and polychlorinated biphenyls (PCBs). All excavated materials were shipped and disposed offsite by September 1985 (McConachie et al., 1986).
- National Ignition Facility (NIF) Construction Site — During the NIF construction project, a cache of buried capacitors was discovered, which triggered further investigation and soil removal. Under an Emergency Removal Action (Bainer and Berg, 1998), 112 buried capacitors and 766 tons of contaminated soil were removed and disposed offsite in September 1997.
- East Traffic Circle residual soil clean up — Residual soil contamination from the East Traffic Circle Landfill removal was discovered in October 1998. Investigations and removal occurred during March through July 1999 under a time-critical removal action (Joma, 2000). Over 400 cubic yards of residual soil containing PCBs were removed and disposed offsite from May through July 1999.
- Building 212 — During demolition of Building 212 superstructure in April 2008, free-phase mercury and low-level radiological contamination was discovered along the northeast corner of the foundation. Approximately 4.5 cubic yards of soil containing mercury was removed from a trenched area under a time-critical work plan (LLNL, 2008; LLNL, 2009a). An additional investigation to characterize the distribution and concentration of mercury in soil occurred during 2010 (LLNL, 2010). During this investigation, all mercury concentrations in soil were found to be below the EPA industrial screening level of 34 mg/kg. Accordingly, no further removal action is planned at this time (LLNL, 2011).

## 3.5. Summary of Basis for Taking Action

Remedial actions were initiated at the Livermore Site to address potential human health impacts and minimize environmental exposure to these contaminants by site workers. The remedial actions were also initiated to remediate ground water to meet cleanup standards and to protect City of Livermore water supply wells located west of the site. The remedial action objectives for the LLNL Livermore Site are discussed in Section 4.1.

# 4. Remedial Actions

## 4.1. Remedy Selection

Regulatory actions including the ROD are presented in Table 1. Prior to issuing the ROD, a number of assumptions were made to aid in the selection of the remedy. The assumptions were based on information available at the time, and were fully expected to change with the addition of new data, wellfield performance, and unforeseen conditions. The initial assumptions and final determinations are documented in the Second Five-Year Review (Berg et al., 2002).

The following are the remedial action objectives (RAOs) for all contaminants originating at the Livermore Site:

- Prevent future human exposure to contaminated ground water and soil.
- Prevent further migration of contaminants in ground water.
- Reduce contaminant concentrations in ground water to levels below Maximum Contaminant Levels (MCLs), and reduce the contaminant concentrations in treated ground water to levels below state discharge limits.
- Prevent migration in the unsaturated zone of those contaminants that would result in concentrations in ground water above a MCL.
- Meet all existing permit discharge standards for treated water and soil vapor, and to treat vapor so that there are no measurable atmospheric releases from treatment systems.

The screening conducted for the Baseline Public Health Assessment (Layton et al., 1990) considered potential exposure pathways and concluded that ground water is the only viable pathway of exposure, and the inhalation risk from VOCs migrating from ground water offsite to the indoor breathing zone is insignificant. In addition, soil vapor surveys were conducted throughout the Laboratory during the Remedial Investigation, again indicating that the risk of exposure to VOCs through the inhalation pathway onsite is insignificant.

As discussed in the Second Five-Year Review, studies were conducted in 1991 to evaluate the VOC inhalation risk to building occupants (Berg et al., 2002). The results from this investigation corroborated previous studies that volatilization of VOCs from the unsaturated zone do not present a health risk at LLNL.

The following discusses the remedy selected for VOCs and tritium.

### 4.1.1. Ground Water Containing VOCs

The remedy selected in the ROD for ground water called for strategically placing extraction wells near contaminant plume margins to intercept and hydraulically control ground water from LLNL with VOC concentrations exceeding MCLs. In addition, ground water would be extracted from source areas to expedite cleanup. The ROD required 18 initial extraction locations and seven treatment facilities (TF), specifically TFA, TFB, TFC, TFD, TFE, TFF, and TFG. The total rate of ground water removal for this extraction plan was estimated to be about 350 gallons per minute (gpm). Since the ROD, TFF has been closed with regulatory concurrence, and the area encompassing the southeast corner of Livermore Site has been designated as TFH (Figure 2).

### 4.1.2. Soil Vapor Containing VOCs

The primary criterion for determining if an area required vadose zone cleanup was based on whether the contamination will impact ground water in concentrations above the MCL. The remedy selected in the ROD was to use vacuum-induced venting to extract contaminant vapors from the unsaturated sediments and to treat the vapors by catalytic oxidation. Subsequent to the ROD, an Explanation of Significant Differences (ESD) changed the treatment to granular activated carbon (GAC) (Dresen et al., 1993).

### 4.1.3. Tritium

The remedy selected in the ROD for ground water containing tritium was to minimize tritium migration, and to prevent influent to any treatment system from containing tritium in concentrations above the MCL. The approach for tritium in any media (ground water or soil vapor) was to keep it in the subsurface as much as possible where it will decay naturally.

As discussed in Section 8, DOE is currently evaluating alternative remedies to resolve mixed waste generation issues at facilities where tritium is present in the influent stream. The Focused Feasibility Study (FFS) (Bourne et al., 2010) includes an evaluation of new remedial alternatives (i.e., *in situ* technologies). The FFS also includes evaluation of improvements to existing facilities without altering the current remedial selection. DOE is currently field-testing or planning to field-test several of the alternatives discussed in the FFS. Depending on the results of the field tests and with regulatory concurrence, DOE may suggest changes in the future to the selected remedy for tritium at specific locations.

### 4.1.4. Remedy Changes

There have not been any remedy changes during the past five years. An ESD is required when significant, but not fundamental, changes are made to the final remedial action plan described in the ROD. Four ESDs have been previously prepared for changes to the remedies selected in the ROD. The four ESDs were prepared for changing: (1) catalytic oxidation to granular activated carbon for Vapor Treatment Facility F (Dresen et al., 1993); (2) replacing ultraviolet light/hydrogen peroxide and air stripping remediation with air stripping only at TFA and TFB (Berg et al., 1997a); (3) discharge requirements for metals based on wet season and dry season beneficial use (Berg et al., 1997b); and (4) the remedy to allow ground water containing both VOCs and tritium to be brought to the surface via a closed-loop treatment system to remediate the VOCs, and returning the tritiated water to the subsurface to decay naturally (Berg, 2000).

A treatability study was conducted in 2007 to evaluate the effectiveness of discharging ground water from offsite well W-404 to the Livermore Water Reclamation Plant. If adopted, that approach would have required an ESD. However as discussed in Section 8, DOE is currently evaluating ground water extraction alternatives for the TFA West area that do not require remedy changes.

## 4.2. Remedy Implementation

DOE has met or exceeded the remedy construction activities described in the ROD and remedial design reports. The ROD specified construction of seven ground water and two vapor facilities to treat VOCs. After installing four fixed treatment facilities, DOE began constructing and installing less expensive portable ground water treatment units for use at more locations than specified in the ROD. This increased cleanup flexibility and reduced capital cost. Since the start of ground water cleanup, DOE has constructed and operated 33 ground water treatment facilities and 11 vapor treatment facilities. Currently, 28 ground water facilities and 9 vapor facilities are maintained (Figure 2). In addition, the ROD specified 18 initial extraction locations (with one or more wells at these locations). Currently the Livermore Site has 93 ground water extraction wells, two ground water injection wells, 17 dual extraction wells, 32 vapor extraction wells, and one soil vapor injection well.

While implementing remedial actions to achieve RAOs for VOCs, DOE also continues to meet the objective of the ROD by keeping the tritium in the subsurface as much as possible (Section 4.1.3). All tritium activities in Livermore Site monitor wells are currently below the MCL. Even though mitigation actions are in place, minor tritium activities have been detected in some of the granular activated carbon from treatment facilities in tritium-contaminated areas (Bourne et al., 2010). Moisture from the soil vapor may contain tritium that can condense onto the carbon; low tritium activities from the ground water may also reside on the carbon. When tritium is detected in the granular activated carbon, it is handled as mixed waste.

During the first, second and third Five-Year Reviews, the remedial actions were found to be functioning as intended, and the current remediation network continues to function as intended. At the end of FY 2006, all milestones on the Remedial Action Implementation Plan milestone list were completed, constituting “build-out” as defined by DOE Environmental Management. As discussed in Section 8, several of the treatment facilities were secured and/or were shutdown due to budget shortfall during FY 2008.

Milestone construction activities followed the Remedial Project Managers’ priorities as documented in the Livermore Site Consensus Statement. A Livermore Site Consensus statement was signed in March 2009 to establish a schedule to systematically restart treatment facilities that were affected by the budget shortfall. DOE met the goals of the 2009 Consensus Statement and successfully started the facilities as scheduled. Consensus Statements were also signed in 2010 and 2011 to include additional milestones for the Livermore Site. The current Consensus Statement is included as Appendix A, and identifies the remediation priorities as:

1. Western site boundary (distal plumes).
2. Southern site boundary (distal plumes).
3. Internal source areas.

Engineered Plume Collapse (EPC) (Berg et al., 2002) was used to implement these priorities. For EPC, the first step is to hydraulically control and isolate the source, then remediate the high concentration distal plume, contain the plume leading edge, and lastly focus on source area remediation.

DOE, LLNL, and the regulatory agencies have long recognized that the sources control the long-term duration and cost of the site cleanup. A commitment to an ongoing evaluation of source technologies was made in the Second Five-Year Review (Berg et al., 2002). Some potential technologies have been identified. In April 2007, EPA's Office of Research and Development visited the site and favored thermal remediation technologies. As part of the ongoing Phased Source Remediation (PSR) strategy, the focus is now to test newer technologies that may accelerate the source area cleanup. The PSR strategy is to phase-in increasingly costly technologies, as needed, to remediate the source areas.

A Source Area Cleanup Technology Evaluation (SACTE) was conducted to help choose potentially effective source cleanup technologies. SACTE provides direct comparison of approaches to allow the appropriate cleanup technology to be matched to each source area, and to evaluate the cost effectiveness of the technology. SACTE was applied to all the Livermore Site source areas (Figure 3).

Various source remediation technologies were proposed as a series of pilot tests during FY 2007 as part of the Enhanced Source Area Remediation (ESAR) approach, taking advantage of existing infrastructure as much as possible. The proposed work scope for this source remediation focus included:

- Field-scale tests of heated air injection and dynamic operation flushing to enhance vadose zone and capillary fringe drying, help mobilize and extract contaminants, and enhance air permeability.
- Field-scale test to evaluate mechanical fracturing to enhance contaminant mass transfer in the saturated zone.
- Bench-scale and field-scale tests to evaluate *in situ* bioremediation and contaminant destruction in the saturated zone.

A key component of the pilot studies is evaluating potential long-term efficacy of the source area remediation technologies. As shown through the SACTE approach, many technologies may have a significant short-term benefit, but post-deployment contaminant rebound can extend the cleanup for long durations, deriving minimal cost benefit to deploying the technology.

This ESAR source work is the logical "next step" in source area cleanup conducted at the Livermore Site as part of the overall Phased Source Remediation (PSR) strategy. To date, the following has been implemented at the Livermore Site source areas:

- Excavation of four sources.
- Application of Electro-Osmosis to enhance mobility by applying a low voltage.
- Application of Dynamic Underground Stripping to volatilize contaminants by steam injection.
- Operation of vadose zone remediation systems at 11 sources.
- Hydraulic containment and advection-dominated ground water treatment at 15 sources.
- Vacuum-enhanced ground water extraction.

- Regulatory closure of two sources.
- One agreement for source “monitoring only”.
- Implementation of four field-scale tests under ESAR.

## 4.3. System Operation/ Operation and Maintenance

Table 3 presents information on each treatment facility. All facilities are performing as designed to remediate ground water or soil vapor. Treatment facilities TF5475-1, TF5475-3, VTF5475, and TF518 North were shut down during the review period and remain off pending resolution of mixed waste management issues (LLNL, 2009b). Monthly self-monitoring data show that the treatment facilities are removing contaminants from ground water and soil vapor, and treating the contaminants to concentrations below discharge levels. Adherence to substantive requirements has been consistent over the last five years with infrequent incidents promptly reported and corrected. All noncompliance issues have been and are documented in the Remedial Project Manager’s meeting summaries, the LLNL ground water project annual reports, and the annual LLNL storm water monitoring reports. Compliance issues over the last five years are summarized in Table 4.

Operation and Maintenance (O&M) requirements include:

- Mechanical O&M.
- Control and instrument calibration.
- Facility documentation and data collection.
- Maintaining the particulate filters, blowers, air strippers, and pumps.
- Replacing granular activated carbon and/or ion-exchange resin.
- Routinely inspecting and maintaining interlocks, extraction well pumps, pipelines, blowers, and sensors.

O&M procedures are contained in the following documents:

- Health and Safety Plan and Quality Assurance/Quality Control Plan for the O&M of the Treatment Facilities, contained within the Remedial Design documents.
- Operations and Maintenance Manual, Volume 1: Treatment Facility Quality Assurance and Documentation (LLNL, 2004).
- Operations and Maintenance Manual, Volume 2: Treatment Facility A (TFA) (Kawaguchi and Iyer, 2003).
- Operations and Maintenance Manual, Volume 3: Treatment Facility B (TFB) (Kawaguchi, 2004).
- Operations and Maintenance Manual, Volume 4: Treatment Facility C (TFC) (Van Noy, 2004).
- Operations and Maintenance Manual, Volume 5: Treatment Facility D (TFD) (Kawaguchi, 2005).

- Operations and Maintenance Manual, Volume 12: Portable Treatment Units (PTUs) (Martins, 2006).
- Operations and Maintenance Manual, Volume 13: Miniature Treatment Units (MTUs), Ground Water Treatment Units (GTUs), and Solar Treatment Units (STUs) (Martins, 2007).
- Compliance Monitoring Plan (Nichols et al., 1996).
- Contingency Plan (McKereghan et al., 1996).
- LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures (Goodrich and Lorega, 2009).
- Substantive Requirements and Monitoring and Reporting Program issued by the RWQCB.
- Permits to Operate issued by the Bay Area Air Quality Management District (BAAQMD).

Monitoring and optimizing the performance and efficiency of each treatment facility and associated well field is an essential component of O&M activities. DOE/ERD developed a process known as REVAL to ensure that each system operates in a safe and optimal manner to remove and treat contaminated soil vapor and ground water, and ultimately accomplish cleanup of the subsurface. The REVAL process is summarized in Appendix B.

Using the REVAL process, DOE/ERD continues to optimize treatment systems to meet subsurface cleanup goals, increase treatment system uptime and reliability, standardize equipment and instrumentation, and improve communication among disciplines. Some specific benefits of REVAL include:

- Standardizing wellhead designs for ground water, soil vapor, and dual extraction wells;
- Replacing bubbler systems with water level transducers to record more accurate water levels;
- Repositioning ground water and vapor flow rate measuring devices to increase data accuracy;
- Testing different types of blowers and blower configurations for soil vapor treatment systems;
- Upgrading ground water extraction well pumps to meet optimal target flow rates;
- Lowering ground water extraction well pumps meet optimal target flow rates and increase hydraulic capture and mass removal;
- Identifying extraction wells with declining performance that may require redevelopment;
- Performing hydraulic and pneumatic tests on extraction wells that may be used for well field optimization and long-term performance evaluation; and
- Improving the data acquisition system.

The budgeted and actual environmental restoration costs for the Livermore Site are tracked closely and are consistently within or near the allocated budget, with the exception noted below. Total project funding over the last five years, as authorized by DOE for cleanup at the Livermore Site, is presented in Table 5.

During FY 2008, a significant funding shortfall resulted in shutdown or run-to-failure of many treatment facilities. When funding was restored in July 2008, ERD developed the REVAL process, described above and in Appendix B, to restart facilities in a phased and deliberate fashion based on risk to human health and the environment, and importance to the cleanup effort. In accordance with the remedial objectives and selected remedies defined in the Livermore Site Record of Decision (DOE, 1992) and subsequent CERCLA documentation, western and southern site boundary control and offsite contaminant plume clean up were given the highest priority. Treatment facilities that hydraulically control higher-concentration ground water plumes that had the potential to move beyond the reach of existing cleanup infrastructure were also considered high priority.

## 4.4. Institutional/Land Use Controls

Institutional/land use controls are non-engineered actions or measures used to prevent or limit the potential for human exposure to contamination at the Livermore Site and to protect the integrity of the remedy. The general types of institutional/land use controls that are used to prevent human exposure to contamination at the Livermore Site include:

- Access controls – Measures such as fences, signs, and security forces that are used to prevent exposure by controlling and/or restricting access to areas of contamination.
- Administrative controls – Measures such as pre-construction review and controls for limiting or restricting access to contaminated areas and prohibitions on water supply well drilling.

The screening conducted for the Baseline Public Health Assessment considered potential exposure pathways and concluded that ground water is the only viable pathway of exposure. Current offsite access is restricted by the local water purveyor controlling water supply well installation. Since the site is a secured DOE facility, current and future onsite access to ground water will continue to be restricted. No water-supply wells are planned onsite, and any onsite drilling and excavation is first discussed with LLNL's Environmental Restoration Division.

Monitoring and inspection of the Livermore Site will be performed throughout the remediation period to determine whether the institutional/land use controls remain protective and consistent with all remedial action objectives. In addition, DOE will review facility and land use to evaluate changes in exposure pathway conditions that could affect the risk assessment assumptions and calculations.

In March 2007, the Department of Energy entered a letter (Holtzapple, 2007) into the Administrative Record for the Livermore Site Record of Decision that discusses the land use controls and requirements. This letter documents a prohibition from transferring any part of the Livermore Site with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition may be lifted if a risk assessment shows no unacceptable risk for residential or unrestricted land use and is agreed to by the DOE, the U.S.

EPA, DTSC, and the RWQCB. In the event that the site is transferred in the future, the DOE will execute a land use covenant at the time of transfer in compliance with Title 22, California Code of Regulations, Section 67391.1.

The institutional controls were reviewed and are still effective for preventing exposure to contaminated media.

# 5. Progress Since Last Review

This section describes the Protectiveness Statement and recommendations and follow-up actions from the 2007 Five-Year Review. It also describes the status of the actions recommended in this previous review.

## 5.1. Protectiveness Statement from Last Review

The 2007 Five-Year Review stated that: "The remedy is functioning as intended and will be protective of human health and the environment for the site's industrial land use when cleanup levels are achieved. Exposure pathways are currently controlled, and both the Health and Safety Plan and Contingency Plan are in place, properly implemented, and are sufficient to control risks. A letter to file in the Administrative Record prohibits the transfer of the property with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition may be lifted if a risk assessment shows no unacceptable risk for residential or unrestricted land use and is agreed to by the DOE, the U.S. EPA, DTSC, and the RWQCB. In the event that the site is transferred in the future, the DOE will execute a land use covenant at the time of transfer in compliance with Title 22, California Code of Regulations, Section 67391.1."

DOE/LLNL are actively evaluating source areas cleanup technologies to reduce long-term operational costs and accelerate the time to cleanup. DOE/LLNL are committed to the Livermore Site remediation objectives of (1) preventing present day and future human exposure to contaminated ground water and soil, (2) preventing contaminant migration at concentrations above Maximum Contaminant Levels, (3) reducing contaminant concentrations in ground water to levels below the state and federal Maximum Contaminant Levels, and (4) minimizing contaminant migration in the unsaturated zone that would result in concentrations in ground water above a Maximum Contaminant Level."

No deficiencies in the remedy were identified during the 2007 Five-Year Review.

## 5.2. Recommendations and Follow-up Actions from the 2007 Five-Year Review

The following recommendations were developed during the Five-Year Review process in 2007:

1. Complete a source area cleanup technology evaluation (SACTE) on all sources.
2. Investigate thermal remediation technologies.

3. Evaluate bioremediation, oxidizers, and mechanical fracturing under site-specific conditions as possible source area remediation technologies for saturated sediments at the Livermore Site.
4. Test heated air injection and dynamic operations for the cleanup of contaminants residing in the vadose zone and capillary fringe.
5. Monitor increasing TCE concentration trends at piezometer SIP-191-002 to determine if further actions are warranted.
6. Conduct wellfield optimization and hydraulic testing of the TFB HSU-2 plume to determine if wellfield modifications are needed.
7. Conduct modeling to evaluate the need for hydraulic capture and treatment to prevent further westward migration of HSU-3A, 3B, and 4 plumes in the western TFE area.
8. Conduct modeling to evaluate the need for hydraulic capture and treatment to prevent further westward migration of the HSU-3A Freon 11 plume in western TFD area.
9. Investigate the source of the HSU-4 contamination at TFD Southeast where concentrations have remained relatively unchanged.
10. Monitor site-wide water level rises and any associated increases in source area concentrations to determine if treatment facility modifications are needed.
11. Monitor the increase in concentrations west of TF406 at well W-1519 and determine if there is the need to contain further westward migration of this dilute, low-concentration TCE plume.
12. Evaluate the need to expand the TF518 wellfield to include more of the western area.
13. Evaluate the need to actively remediate the area south and west of Trailer 5425.
14. Compare the inhalation risk methodology used for the Baseline Public Health Assessment with current methodologies to determine if the prior evaluation is sufficient or if additional modeling is warranted.

## 5.3. Results of Implemented Actions

The status of actions taken in response to the recommendations listed in Section 5.2 are as follows:

1. In 2007, DOE/LLNL increased its efforts to identify and evaluate innovative technologies that could help accelerate cleanup of source areas at the Livermore Site. These efforts, which fall under the heading of ESAR activities, include detailed hydrogeologic evaluation, numerical modeling, bench-scale laboratory tests, and field treatability tests. A data evaluation and numerical modeling analysis methodology called the SACTE analysis was developed by ERD to evaluate potential technologies to accelerate source area cleanup. The subsurface hydrogeochemical attributes of 21 source areas at the Livermore Site were catalogued and analyzed with respect to ground water flow and contaminant transport properties (Table 6). These site-specific attributes were used in the SACTE analysis to determine whether the cleanup technologies being considered for field-testing and implementation would be cost

effective and have a high likelihood of technical success. This analysis provided a means of directly comparing cleanup methods, thereby allowing appropriate technologies to be matched with individual source areas. The analysis also provided estimates of the long-term reduction in cleanup time (McNab et al., 2007).

Based on this analysis, four source areas were selected for conducting ESAR treatability tests: TFE Eastern Landing Mat (TFE-ELM); Trailer 5475 (T5475); TFE Hotspot (TFE-HS); and TFD Helipad. The four areas were selected in part because existing infrastructure could be used to reduce the overall cost of the treatability tests. The cleanup technologies and source areas selected for evaluation are:

- Dynamic well field operations (DWFO) for removing residual contamination in the vadose zone at T5475 and TFE-ELM. DWFO is intended to overcome rate-limited recovery from soil vapor extraction by periodically altering the subsurface flow patterns and eliminating stagnation zones.
- Thermally-enhanced remediation (TER) using hot air injection and ground water heating to accelerate contaminant mass removal from both the capillary fringe and the vadose zone at TFE-ELM.
- *In situ* bioremediation (ISB) for destruction of contaminant mass in the saturated zone at TFD Helipad.
- Pneumatic fracturing (PF) to enhance the permeability of low-permeability silt- and clay-rich source area sediments and accelerate mass removal at TFE Hotspot.

In 2007, new extraction wells were drilled at T5475 and the system was reconfigured for dynamic operation of the soil vapor extraction and air injection wells. In 2008, the ESAR activities in this area were discontinued due to mixed-waste handling issues. Field activities will resume pending the results of the Focused Feasibility Study (Bourne et al., 2010).

In 2007, DWFO was implemented at TFE-ELM's eastern soil vapor extraction wells and a significant reduction of soil vapor concentrations was observed.

In 2010, pneumatic fracturing was implemented at TFE-HS. Post-fracturing performance testing is currently underway to evaluate the effectiveness of this technology.

In 2010, the *in situ* bioremediation project at TFD Helipad was initiated and is currently in progress. Bioaugmentation of this site is expected to occur in early 2012.

In 2011, thermally-enhanced remediation at TFE-ELM's western wells was initiated and is currently in progress.

The SACTE results also provided a systematic approach to evaluate combinations of technologies either at the same time or in series. An example of a combination technology that can be implemented at the same time is zero-valent iron placement using pneumatic fracturing for *in situ* destruction of VOCs. An example of a combination technology in series is thermally-enhanced remediation followed by *in situ* bioremediation.

2. DOE has accumulated a significant knowledge base on thermal remediation technologies and their application for subsurface environmental remediation over the years. The Dynamic Underground Stripping Project (Aines et al., 1992) is a successful implementation of this technology at Livermore Site. DOE reviewed several thermal remediation technologies during the SACTE analysis and determined that the best approach to field-test these technologies for VOC remediation is to start with the least energetic thermal technology, and adjust the intensity of the thermal treatment overtime to determine the most effective method. We are currently testing thermally-enhanced remediation (TER) at the TFE-ELM. Results of this field test will be presented in the annual reports. The next level of intensity that could be considered is the Electrical Resistive Heating (ERH) technology.

3. In 2007, a bench-scale study was completed to evaluate the feasibility of *in situ* bioremediation and *in situ* chemical oxidation technologies at Livermore Site. These included two studies employing soil samples collected from the TFD Helipad well W-2304, designed to assess volatile organic compound (VOC) destruction efficacy using augmented bioremediation and chemical oxidants.

   Microcosm studies indicated that TCE, the major VOC of concern at this source area, is amenable to remediation via reductive dehalogenation if a suitable electron donor is introduced into the subsurface. Augmentation of the soil microbial population in a follow-on injection event is an essential component of this effort. Lactate and emulsified vegetable oil represent comparatively benign electron donors. Lactate was selected as the electron donor for the field-testing based on the microcosm study results.

   Potassium permanganate and activated persulfate injection also represent effective methods for treating TCE *in situ*. However, application of both chemicals results in apparent mobilization of trace metals. Hexavalent chromium, in particular, may constitute an adverse operational issue in the case of permanganate. These findings, combined with significant environmental safety and health (ES&H) handling issues that would be associated with these chemical oxidants, suggests that *in situ* treatment based on microbiological transformations would be a better solution.

   In 2010, the field-testing of *in situ* bioremediation began at the TFD Helipad and is currently in progress. The system includes four extraction wells (W-1650, W-1653, W-1655, and W-1657) and one central injection well (W-1552). Ground water is circulated in the subsurface between these wells, which creates a controlled subsurface environment for electron donor injection and bioaugmentation. Lactate (electron donor) injection was initiated in May 2011. The preliminary results indicate that a controlled injection of the electron donor creates favorable subsurface conditions in a short period of time. Several issues were encountered due to biofouling in the wells and subsurface. These issues have been mostly resolved and injection of lactate has resumed. Bioaugmentation is expected to begin in early 2012.

   In October 2010, an ESAR treatability test was conducted at the TFE-HS source area to assess whether pneumatic fracturing could enhance the permeability of low-permeability, silt- and clay-rich source area sediments. Pneumatic fracturing involves the application of high-pressure gas to the subsurface to initiate fracturing in targeted areas. Doing so would accelerate transfer of contaminant mass from the source area by improving the yield of soil vapor and ground water extraction. The treatability test included pneumatically fracturing the vadose and saturated zone in six boreholes at 3-foot intervals between 75 and 105 feet below ground surface (ft bgs) and emplacing an inert sand proppant in the propagated fractures. In addition, two tracer dyes were injected into one fracture borehole in conjunction with the proppant to visually enhance fracture documentation in the field. During the pneumatic fracturing activities, six digital bi-axial tilt meters were deployed to record ground movement near each of the injection boreholes during each fracture event.

Following pneumatic fracturing, two of the six fracture boreholes were completed as 2-inch inside diameter (ID) poly vinyl chloride (PVC) wells. The other four fracture boreholes were enlarged to install 4-inch ID PVC wells. All six wells, identified as W-2618, W-2619, W-2620A, W-2621, W-2622, and W-2623, are screened across the fracture interval (75 to 105 ft bgs). In addition, six confirmation borings were drilled to evaluate the extent, nature, and frequency of propagated fractures. The borings were continuously cored from approximately 72 to 107 ft bgs, and the cores were visually examined, described, and photographed to characterize fracture distribution based on the presence of sand proppant and tracer dyes. In addition, composite samples from all six cores were collected in one-foot intervals between approximately 72 ft bgs and 105 ft bgs to analyze for the tracers Fluorescein and Rhodamine WT. When well W-2012 was damaged during pneumatic fracturing, this well was sealed and replaced in October 2011.

Prior to the pneumatic fracturing, pneumatic testing was conducted at soil vapor extraction wells W-ETS-2008A, W-ETS-2008B, W-ETS-2009, W-ETS-2010A, W-ETS-2010B, and dual extraction well W-2105. Hydraulic testing was also conducted before fracturing at dual extraction well W-2105, extraction well W-2012, and piezometer SIP-ETS-601. These tests were repeated in 2011 and a comparison of the pre- and post-fracturing data will help quantify any changes in local hydraulic conductivity and storativity, in the hydraulic interconnectivity between wells, and in the improvement of the sediment permeability. Post-fracturing mass removal rates for TFE Hotspot and VTFE Hotspot will be compared with those recorded prior to pneumatic fracturing to quantify any improvements in mass removal rates. A summary report documenting the results of the test will be prepared once all data from the treatability test has been collected and analyzed.

4. In 2011, field-testing of thermally-enhanced remediation was initiated at TFE-ELM. The system includes one dual extraction well (W-1903) and two injection wells (W-1909 and W-2305) where heated air is injected to the vadose zone and ground water in the saturated zone is heated to temperatures below the boiling point of water. This technology requires less energy and can be deployed in wells where a high-temperature application, such as ERH, is not possible due to existing PVC well casings. Because W-2305 can be operated as an air injection/heating well or a dual extraction well, this system also allows for DWFO, further enhancing the recovery from the vapor phase. The system has been in operation since late 2011 and we are currently collecting performance data to evaluate the efficacy of TER. The results of the field-testing will be reported in the annual reports.

5. In northern TFC, where a ten-fold increase in TCE concentrations was observed at SIP-191-002 during the previous five year review, concentrations were essentially unchanged (47 ppb to 53 ppb) and remained well within the hydraulic capture area of TFC extraction well W-1104. VOC concentrations at downgradient monitor well W-556 continue to be below detection levels for all contaminants of concern. Accordingly, no further actions were taken.
6. Between 2006 and 2008, a series of hydraulic tests and wellfield optimization tasks were completed in the TFB area to evaluate hydraulic capture in HSU-2. After evaluating the field data and reviewing numerical modeling results, DOE proposed to drill two new extraction wells to more effectively capture the plume in this area. The new extraction wells, W-2501 and W-2502, were installed in late 2009 and will be operational by early 2012 (Figures 6 and 7). The wellfield optimization actions taken during 2008 significantly changed the previously increasing concentration trends observed at monitoring wells W-422 and W-1420 (Section 6.4.2). Ground water extraction from the new wells is expected to significantly improve the hydraulic capture and cleanup time of the TFB HSU-2 plume.
7. In 2011, LLNL developed two numerical models to evaluate the westerly migration of the VOC plumes in HSU-3A and HSU-3B. The primary objective of the modeling effort was to evaluate the benefit of connecting well W-276 to an existing or new treatment facility to increase hydraulic capture and reduce cleanup time. The modeling results indicate that there may be additional capture of the existing plumes in HSUs-3A and 3B. The results also indicate that the cleanup duration does not significantly improve when well W-276 is operational. As shown on Figure 8, the VOC plume in this area is not migrating west at a significant rate. DOE installed monitoring well W-2603 down gradient of well W-276 to closely monitor the westerly migration of the plume (Figure 8). In addition, the TFA ground water extraction well field would ultimately capture any portion of the plume that migrated further to the west. Numerical modeling was not necessary for the VOC plume in HSU-4 because the plume is currently within the capture zone of the existing extraction wells based on measured water level and concentration data.
8. Since 2006, the Freon 11 concentrations in HSU-3A wells have declined to levels below the MCL of 150 ppb due to active ground water remediation at TFD West. Westerly migration of the Freon 11 plume is not observed based on measured concentrations in monitoring wells. Therefore, numerical modeling was not necessary to evaluate the fate of this plume.
9. After remaining essentially unchanged for the previous 10 years, concentrations of TCE in the TFD Southeast HSU-4 extraction well W-314 declined from 140 ppb (July 2006) to 48 ppb (July 2011). The concentration decline suggests that ground water extraction is finally beginning to reduce concentrations in the HSU-4 source area. With falling concentrations and the FY 2008 budget shortfall (Section 8), the source area investigation at TFD Southeast became a lower priority for DOE and LLNL. Additional source area drilling there has been deferred until the REVAL process and ESAR treatability tests are completed at the Livermore site.

10. During 2008, when many treatment facilities and remedial well fields were shut down due to the budget shortfall, a significant water level rise was observed across the site in most HSUs (over 20 ft rise in HSU-4) as over-drafting of the aquifer due to remediation ceased. Livermore site source areas were carefully monitored for any rebound in concentrations during this time period. At TFD South, concentrations rose in HSU-4 extraction well W-1503 from 46 ppb (January 2008) to 550 ppb (January 2009). Once pumping resumed at the TFD South remedial well field, concentrations showed a rapid decline and concentrations at well W-1503 are currently 57 ppb (July 2011). Accordingly, no treatment facility modifications are needed at TFD South. Elsewhere, no significant source area concentration increases were observed that could be associated with this site-wide water level rise.

11. As shown on Figure 12, concentrations in the dilute TCE plume west of TF406 at well W-1519 declined slightly during the review period. TCE concentrations in this well decreased from 18 ppb to 12 ppb, suggesting that the area is being hydraulically controlled by TF406 and that additional remedial infrastructure is not needed at this time.

12. During 2010, an extensive direct-push drilling campaign was conducted in the VTF518 Perched Zone source area. Four permanent monitor wells, W-2604A, W-2604B, W-2605A, and W-2605B, were installed immediately north in the former B514 yard and 20 direct-push borings (B-2650 through B-2669) were advanced in the VTF518 Perched Zone area to profile the area lithology and acquire soil vapor samples to better delineate the VOC source in the area. While 79 soil vapor samples were collected and analyzed, attempts made to sample perched water were unsuccessful due to insufficient quantities of available water. An additional extraction well is planned for the area, and treatability tests will be conducted on western area soil vapor monitor wells to determine whether to expand the VTF518 Perched Zone wellfield to include this area.

13. In September 2006, a soil vapor monitor well and ground water monitor well (W-2216A and W-2216B) were installed in the T5425 area to investigate concentrations of VOCs associated with a former disposal pit located in the area. Ground water TCE concentrations at W-2216B were 270 ppb in March 2011. However, similar to the T5475 area, tritium is present well above background levels (i.e., 2150 pCi/L in SIP-ETS-302 in June 2010). Accordingly, active remediation of the T5425 area awaits resolution of the mixed waste management issues discussed in Section 8.

14. The Baseline Public Health Assessment (BPHA) document (Layton et al., 1990) included three vapor inhalation pathways for risk assessment. These pathways are based on offsite residential scenarios and consider: a) risk associated with inhalation of VOCs from shower air (indoor); b) from air downwind of sprinklers (outdoor); and c) air volatilizing to atmosphere from subsurface soil (outdoor). Although twenty years have passed, the approach and methodology used in the BPHA for the inhalation pathway evaluation is very robust, and would be considered sufficiently protective of human health when compared to recent guidance. The main difference between the approach used in 1990 and the recent guidance are the consideration given to onsite workers and direct migration of VOCs to indoor air from the subsurface soil and ground water. In

addition, toxicity characteristics of multiple VOCs have been modified since the BPHA was completed.

In 1991, in a response (Hoffman, 1991) to an EPA comment on the Draft Proposed Remedial Action Plan (Dresen et al., 1991), DOE/LLNL collected ambient air samples to confirm the conclusions of the BPHA; that volatilization of VOCs from the vadose zone and ground water do not present a health risk at LLNL. In order to address the worst-case scenario in which VOCs accumulate beneath buildings and trailers, and may result in an elevated exposure risk to occupants, five trailers (T5105, T5425, T5475, T5626 and T5627) were selected for ambient air sampling. These trailers are located on or very near areas where high levels of VOCs have been detected in the vadose zone and groundwater. Analytical results from the sampling indicated that only very low concentrations (< 5 ppb volume by volume, or v/v) of VOCs were detected beneath and around the trailers investigated. The results of this investigation support the conclusions of the BPHA; that volatilization of VOCs from the vadose zone and/or ground water do not present a health risk at LLNL.

In 2007, following EPA's recommendations, DOE/LLNL conducted a screening level analysis of the potential risk associated with the inhalation pathway at the Livermore Site. The analysis was based on new EPA guidance developed during the past ten years. TCE was used as an indicator compound because it comprises the majority of the VOC mass in ground water and also has the highest measured ground water concentration of any VOC onsite. The analysis included the inhalation pathway from impacted ground water to indoor air. At the time of the analysis, there were five locations where TCE concentrations in ground water exceeded the EPA, the San Francisco Regional Water Quality Control Board (SFRWQCB) and DTSC screening level of 1800 ppb for the inhalation pathway from ground water to indoor air. Three of these locations did not have nearby buildings: TFD Helipad, TFD East Traffic Circle, and TF518 Perched Zone (TF518-PZ). One location was beneath Building 419, which was unoccupied at the time and since has been demolished. Trailer 5475 (T5475) overlies the fifth location. At the time of the analysis, DOE/LLNL was actively remediating ground water and soil vapor beneath the T5475. Currently the soil vapor extraction system (VTF5475) is not active. However, the T5475 trailer complex does not have a foundation that is in contact with soil (there is approximately 3 ft of crawl space beneath T5475). In addition, the building has a Heat, Venting, and Air Conditioning (HVAC) system that creates positive interior air pressure, which mitigates soil vapor intrusion.

In 2011, EPA regional screening levels (RSLs – formerly Preliminary Remedial Goals - PRGs) were updated to incorporate the new toxicity characteristics for TCE. The RSL for the ground water to indoor air inhalation pathway remained at 1800 ppb. Currently, the ground water concentrations onsite exceed the RSL for TCE at the same five locations mentioned above. Ground water remediation continues at all of these sites, except at T5475 where ground water remediation only continues in zones where tritium is not present. The hiatus is temporary until mixed waste issues are resolved. However, volatilization of VOCs from the ground water does not present a health risk because the pathway for vapor intrusion into the trailer is not complete, very low concentrations of VOCs (<5 ppbv/v) were detected in 1991 when vapor samples were collected in the crawl space beneath the trailer complex, the concentrations in the subsurface have declined significantly since the 1991 vapor sampling, and DOE/LLNL plans to resume operation of the soil vapor treatment system at this location.

## 5.4. Status of Other Prior Issues

There are no other prior issues.

# 6. Five-Year Review Process

## 6.1. Notification of Review/Community Involvement

The report will be placed in the Administrative Record file and the Information Repositories located in the LLNL Discovery Center in Livermore, California, and in the Tracy Public Library in Tracy, California. Notice of its initiation and completion will be placed in the *Tri-Valley Times* and *The Independent* newspapers. The initial notice was published in the *Tri-Valley Times* and *The Independent* on March 8. Completed documents can also be accessed electronically at LLNL's Environmental Restoration Department electronic library web page at http://www-erd/library/ or the Environmental Community Relations web page at http://www-envirinfo.llnl.gov.

The draft and draft final Five-Year Review is also submitted to the community action group, Tri-Valley Communities Against a Radioactive Environment, for review.

## 6.2. Identification of Five-Year Review Team Members

The Five-Year Review of the Livermore Site was led by Phil Wong, Livermore Site Remedial Project Manager for the DOE/NNSA-Livermore Site Office. The following team members assisted in the review:

- Peter McKereghan, Program Leader, LLNS.
- Charles Noyes, Hydrogeologist, LLNS.
- Zafer Demir, Hydrogeologist, LLNS.
- Kayyum Mansoor, Hydrogeologist, LLNS.
- Valerie Dibley, Environmental Scientist, LLNS.
- Alexis Porubcan, Hydrogeologist, Weiss Associates.
- Mark Buscheck, Geologist, Weiss Associates.

## 6.3. Document Review

This Five-Year Review consisted of examining relevant project documents and site data:

- Record of Decision for the Lawrence Livermore National Laboratory, Livermore Site (U.S. DOE, 1992).

- CERCLA Remedial Investigation Report for the LLNL Livermore Site (Thorpe et al., 1990).
- First Five-Year Review for the Lawrence Livermore National Laboratory, Livermore Site (Berg et al., 1997).
- Second Five-Year Review for the Lawrence Livermore National Laboratory, Livermore Site (Berg et al., 2002).
- Third Five-Year Review for the Lawrence Livermore National Laboratory, Livermore Site (Berg et al., 2007).
- LLNL Ground Water Project 2010 Annual Report (Buscheck et al., 2011).
- LLNL Ground Water Project 2009 Annual Report (Buscheck et al., 2010).
- LLNL Ground Water Project 2008 Annual Report (Valett et al., 2009).
- LLNL Ground Water Project 2007 Annual Report (Karachewski et al., 2008).
- LLNL Ground Water Project 2006 Annual Report (Karachewski et al., 2007).
- LLNL Livermore Site Milestone Completion Report (Berg et al., 2007a).
- Preliminary Close-Out Report, LLNL Main Site (K. Setian, 2007).
- Draft Focused Feasibility Study of Methods to Minimize Mixed Hazardous and Low Level Radioactive Waste from Soil and Ground Water Treatment Facilities at the LLNL Livermore Site (Bourne et al., 2010).
- Resolution of Mixed Waste Management Issues Associated with Operation of Soil Vapor and Ground Water Treatment Facilities at LLNL, Livermore Site (LLNL, 2009b).
- Preliminary List of Alternatives for Treatment Facilities TF5475-1, TF5475-3, VTF5475, and TF518 North (McKereghan et al., 2009).
- LLNL Livermore Site Consensus Statement Schedules (McKereghan et al., 2010).
- Treatability Study Summary and Proposed Cleanup Alternatives for the TFA West Area LLNL Livermore Site (Noyes et al., 2009).
- Work Plan for a Time-Critical Removal Action of Mercury in Soil North of Building 212, LLNL Livermore Site (LLNL, 2008).
- Summary Report for the Delineation of Mercury in Soil at the Former Building 212 Facility, LLNL Livermore Site (LLNL, 2011).
- Baseline Public Health Assessment for CERCLA Investigations at the LLNL Livermore Site (Layton et al., 1990).

This Five-Year Review evaluates subsurface contaminant concentration and remediation system performance data collected through third quarter of calendar year 2011.

## 6.4. Data Review and Evaluation

The most complete and current data set was used for the following discussions. This includes ground water analytical results, water level measurements, borehole data, and treatment facility data. Due to the timing of this report, the most current data set was from third quarter 2011. Figures, mass calculations, and cleanup progress are reported using this data. Five-year trends compare progress since third quarter 2006.

### 6.4.1. Mass Removal

Through September 2011, more than 4.3 billion gallons of ground water and more than 470 million cubic feet of soil vapor have been treated since the onset of site cleanup in 1989. This treatment has resulted in the removal of more than 2,900 kilograms (kg) of VOCs from the beneath the Livermore Site and surrounding area. During this Five-Year Review period, about 250 kg of VOCs were removed from ground water and about 450 kg of VOCs from soil vapor (over 700 kg total).

In comparison to the prior Five-Year Review, this represents an approximate 40% decrease in VOC mass removed from ground water due to lower concentrations in distal plumes as they are cleaned up, as well as dewatering in the higher-concentration areas, which limits sustainable pumping rates. There is also an approximate 25% decrease in VOC mass removed from soil vapor due to declining concentrations in source areas as they are successfully cleaned up. The 2008 budget shortfall and operating fewer numbers of extraction wells since 2006, in part due to mixed waste management issues at idled treatment facilities (Section 8), were also factors in lower VOC mass removal rates.

Based on data collected during the past five years, new estimates of the remaining amounts of mass and pore volumes of VOCs exceeding MCLs in the subsurface were calculated for each hydrostratigraphic unit (Table 7). A hydrostratigraphic unit (HSU) is a sequence of sediments grouped together on the basis of hydraulic properties, geologic data, and chemical data.

The estimated remaining VOC mass in ground water changed from 670 kilograms (kg) in 2006 (Berg et al., 2007) to 478 kg in 2011 (Table 7), resulting in a reduction of about 190 kg, or approximately 30% removal of mass since 2006. However, during the same time interval, the total VOC mass removed at the ground water treatment facilities was about 250 kg. The difference is because the estimated mass only accounts for VOCs dissolved in ground water and does not include VOC mass adsorbed on to the sediments at the sources; however, extraction wells completed in source areas are removing significant amounts of adsorbed VOC mass. Thus the difference between the estimated mass reduction versus the actual mass removed highlights the progress toward source area cleanup over the last five years.

### 6.4.2. Chemical Trends

Chemical trends were compared over a five-year timeframe (third quarter 2006 to third quarter 2011) to evaluate the cleanup progress for this Five-Year Review. Over this five-year interval, the size and concentration of contaminant plumes at the Livermore Site have continued to decrease in areas with active ground water extraction and treatment. The following sections summarize key points of this trend analysis for the western margin, southern margin, and site interior. Figures 5 through 13 show the plume configuration at the time of the last Five-Year Review (third quarter 2006), as well as the third quarter 2011 status for HSUs-1B, 2, 3A, 3B, 4, and 5, respectively. Treatment facilities are identified on Figure 2.

### *6.4.2.1. Western Margin Chemical Trends*

The ongoing western margin cleanup strategy consists of hydraulically containing VOC plumes within the site boundary and collapsing the offsite contaminant plumes back on site toward their respective source areas. Concentrations continued to decline across the entire western margin. Highlights of VOC concentration trends over the last five years are discussed below by individual HSUs. Wells discussed in the text are shown on Figures 4 through 13.

<u>Hydrostratigraphic Unit 1B</u>

- Concentrations of all VOCs, including PCE, are now consistently remaining below their respective MCLs everywhere in the offsite TFA area for the first time since remediation began in 1989 (Figures 4 and 5). At monitor well W-1425, PCE concentrations have remained below 5 ppb for the last three quarters (Figure 4).
- As shown on Figure 5, VOC concentrations all along the western margin at TFA, TFB, and TFC exhibited a moderate eastward retreat in response to ground water extraction and treatment – no migration downgradient to the West was detected anywhere.
- The areal extent of concentrations within the western margin plumes continued to decrease between 2006 and 2011 (Figures 4 and 5). This was most noticeable in the TFB and northern TFC areas. At TFB, TCE concentrations at source area piezometer SIP-141-202 fell from 77 to 41 ppb. At TFC, TCE concentrations at W-1427 fell from 64 to 4 ppb. At TFA, PCE concentrations in source area well W-1214 fell from 97 to 49 ppb, while PCE concentrations at TFA extraction well W-254 declined from 77 to 32 ppb over the five-year period.
- In northern TFC, where a ten-fold increase in PCE concentrations had been observed at SIP-191-002 during the previous five year review, concentrations were essentially unchanged (47 to 53 ppb) and remained within the hydraulic capture area of extraction well W-1104.

<u>Hydrostratigraphic Unit 2</u>

- In the offsite TFA area, substantial concentration declines were observed in response to ground water extraction along the TFA Arroyo Seco pipeline, with the 5 ppb "VOCs above MCLs" contour retreating from large portions of the area. PCE concentrations fell from 13 to 2 ppb in monitor well W-654, and from 10 to 7 ppb, from 12 to 7 ppb, and from 10 to 6 ppb in offsite extraction wells W-904, W-457, and W-903, respectively (Figures 6 and 7).
- At the leading edge of the TFA offsite HSU-2 plume, PCE concentrations fell from 24 to 10 ppb at well W-404, largely as a result of the year-long treatability test that was conducted there during 2007 (Noyes et al., 2009).

  In the onsite TFA area, the 25 ppb "VOCs above MCLs" contour is no longer present, as concentrations continue to fall in response to pumping. At monitor well W-264, PCE concentrations fell from 44 to 6 ppb, while at extraction well W-605, PCE concentrations declined from 30 to 18 ppb.

  In the TFB area, concentrations remained largely unchanged except in the southern area, where the VOC plume contracted about 500 ft to the east (Figure 7). Previously, concentrations had begun to rise along the margin at wells W-422 and W-1420 (currently 13 and 8 ppb TCE, respectively). Based on a long-term hydraulic test, it was determined that new extraction wells were needed to ensure that further westward migration did not occur. Accordingly, extraction wells W-2501 and W-2502 were installed and will be activated during 2012.

#### *6.4.2.2. Site Interior and Southern Margin Chemical Trends*

Despite the budget shortfall in 2008, hydraulic containment was maintained at most of the sources areas within the site interior and along the southern margin throughout the period. Additionally, high-concentration distal plumes continued to be aggressively targeted for cleanup. From 2008 onward, most treatment facility construction was focused on improving existing ground water and soil vapor treatment facilities through the REVAL process (see Section 4.3). Highlights of VOC concentration trends over the last five years are discussed below. Wells discussed in the text are shown on Figures 7 through 16.

Hydrostratigraphic Unit 2

- The large, mobile Freon 11 plume north of TFD in HSU-2 has now been reduced to below its MCL (Figures 7 and 8). The remaining plume is being captured by treatment facilities TFD, TFD West, and TFC East. At well W-568, located close to the leading edge of the plume, concentrations of Freon 11 declined from 62 to 15 ppb during the review period. At this same location, a dilute TCE plume is present. While the plume appears to be increasing in size and concentration when compared to 2006, a review of chemical trends for wells in the area indicates that this is not the case, and that concentrations in area wells are either stable or declining. The increased size of the TCE plume depicted is interpreted to be a reflection of the natural variability in analytic results and does not reflect a long-term trend.
- At TFE Hotspot, TCE concentrations have declined by half due to soil vapor and ground water extraction and treatment there. TCE at piezometer SIP-ETS-601 declined from 740 to 370 ppb during the period (Figure 7).
- Continued ground water extraction and treatment at TFE East, TFE West, and TFG North resulted in extensive concentration declines in the mobile TCE plume emanating from the TFE Eastern Landing Mat source area. As shown on Figure 7, large portions of the plume were brought below the 5 ppb "VOCs above MCLs" contour, which contracted eastward over 500 ft. There was a substantial reduction in the size of the 50 ppb contour in the TFE area as well (Figure 7). TCE concentrations at well W-271 fell from 29 to 11 during the period, from 27 ppb to 5 at well W-353, while at piezometer SIP-331-001 TCE decreased from 11 ppb to 4 ppb. The apparent migration of the leading edge contaminant plume in TFG reflects new concentration data from a new well not included in the 2006 map. Concentrations at well W-1901-2 have actually declined since sampling began (from 18 ppb VOCs above MCLs, March 2009, to 13 ppb VOCs above MCLs, August, 2011), therefore no westward migration of the plume has actually occurred at this location during this period.
- HSU-2 VOC concentrations at other source areas, such as Building 518 Perched Zone, TF5475, and TFD East Traffic Circle South remained largely unchanged. ESAR technologies to help accelerate clean up in these fine-grained, low-permeability saturated source areas are currently being evaluated (Section 4).

Hydrostratigraphic Unit 3A

- In the TF5475 area, a dramatic decline in VOC concentrations was observed (Figure 9). A water level rise associated with the 2008 budget shortfall and temporary cessation of remediation allowed for ground water sampling of wells that had been dry for a decade or more. Specifically, TCE concentrations declined in the following piezometers:
  - SIP-ETS-215 concentrations fell from 1100 ppb (April 1998) to 80 ppb (May 2009),
  - SIP-ETS-214 concentrations dropped from 760 ppb (May 2001) to 4 ppb (June 2010),
  - and SIP-ETS-211 decreased from 550 ppb (April 1998) to 27 ppb (May 2009).

  This concentration decline is considered to be the result of long-term operations at VES01, which removed an estimated 240 kg of VOCs to date, and suggests that mass removal using vapor extraction in de-watered areas may be very effective.

  In western TFE, TCE concentrations declined slightly at well W-276 (91 to 77 ppb), where a previous concentration increase had raised concerns of uncontrolled westward plume migration. Ground water extraction at TF406 Northwest appears to be inhibiting further westward movement of the plume. TCE concentrations are below MCLs (5 ppb) in newly-installed HSU-3A monitor well W-2603, located downgradient of W-276.

- VOC concentrations remained relatively unchanged in the Building 419 source area (1500 to 1300 ppb TCE in well W-1414), where the implementation of cleanup awaits completion of the Building 419 Resource Conservation and Recovery Act (RCRA) closure.

  Sizeable declines were observed in two TFD source areas where soil vapor extraction and ground water extraction treatment are being implemented (Figures 8 and 9). In the TFD ETC South area, TCE concentrations decreased from 370 to 100 ppb at well W-1301, from 230 to 37 ppb at well W-2005, and from 260 to 100 ppb at well W-1408. In the TFD Hotspot area, TCE concentrations declined from 620 to 260 ppb in well W-2101 and from 63 to 4 ppb in W-2011.

- Elsewhere across the site, while the areal extent of the HSU-3A VOC plumes remained relatively unchanged, a gradual, systematic decline in concentrations was noted (Figures 8 and 9).

Hydrostratigraphic Unit 3B

- As evident on Figures 11 and 12, the geometry of the HSU-3B contaminant plumes changed very little over the last five years. Significantly, no migration to the west was observed anywhere across the site, suggesting that the hydraulic containment scheme in place continues to be effective.

- The most notable change observed was the collapse of the high concentration plume emanating from the TFD ETC South source area back towards that location in response to pumping at that facility and at TFD South (note the change in the areal extent of the 500 ppb contour on Figure 11). TCE concentrations at extraction well W-1601 fell from 330 to 260 ppb, while at area monitor wells W-1422 and W-1511, TCE concentrations declined from 100 to 20 ppb and from 390 to 330 ppb, respectively. In the TFD ETC South source area proper, little change in concentrations was noted.

Similarly, at TFE Southwest, VOC concentrations fell in response to pumping there. TCE concentrations declined from 88 to 54 ppb at monitor well W-356, while at extraction well W-1522, concentrations decreased from 140 to 78 ppb (Figure 11).

Hydrostratigraphic Unit 4

- Only subtle changes in the areal distribution of HSU-4 contaminants were observed during the review period. For example, a slight contraction of the VOC plume was noted in westernmost TFE, where TCE concentrations at well W-304 declined from 28 to 8 ppb.
- At TFD, TCE concentrations at extraction well W-351 rose from 100 to 590 ppb, while they fell at adjacent extraction well W-1206 from 29 to 18 ppb (Figures 13 and 14). This increase in concentrations may be related to the cessation of pumping at TFD Helipad extraction well W-1254 in 2007, allowing for the westward migration of contaminants towards well W-351. The shut-in of W-1254 was needed to stabilize ground water conditions for the TFH Helipad ESAR bioremediation treatability test (Section 4). Extraction wells W-351 and W-1206 appear to be effectively capturing this TCE plume as concentrations to the west at well W-1803-1 fell from 140 to 94 ppb during the review period.
- To the south at TFE Southwest, TCE concentrations in extraction well W-1520 rose from 72 to 260 ppb. TCE concentrations appear to be migrating northward out of the TF518 North area, where extraction at well W-1410 was halted because of increasing tritium activities in the facility effluent. Due to over-drafting, the plume is well contained within a large HSU-4 potentiometric depression (Figure 11, Buscheck et al., 2011), eliminating the possibility of westward migration of the TCE contaminant plume outside the control of existing treatment facilities (Figures 13 and 14).
- Very high VOC concentrations remain in the TFD Helipad source area, where TCE concentrations at well W-1253 were 2700 ppb in June 2011. A remedial strategy for this HSU-4 source area will be formulated based on the results of ongoing ESAR treatability tests (Section 4.2).

Hydrostratigraphic Unit 5

- Along the southern margin, VOCs are now below MCLs in all wells located on Sandia National Laboratories property as a result of ground water extraction at TF406 (Figures 15 and 16). Over the five-year review period, concentrations at well W-509 declined from 11 to 4 ppb. The steady, systematic decline in concentrations observed over the last 15 years eliminated the need to install a treatment facility at TF406 South.
- Concentrations in the dilute TCE plume west of TF406 at well W-1519 declined slightly during the review period. TCE concentrations in well W-1519 declined from 18 to 12 ppb, suggesting that the area is being hydraulically controlled by TF406 and that additional remedial infrastructure is not needed at this time.

  At T5475, concentrations declined in response to ground water extraction at well W-1108; TCE fell from 630 to 310 ppb. To the west at TFE East, TCE concentrations remained relatively stable but fell to the west at well W-1210 (from 54 to 34 ppb), suggesting effective hydraulic control was being achieved.

To the north, a new area of higher concentrations was discovered east of TFD South. Well W-2601, which had a TCE concentration of 120 ppb in 2010 and a very high sustainable yield (over 40 gpm), is proposed to be converted to a TFD South extraction well to clean up TCE in this area.

- Elsewhere in the TFH, TFE, and TFD areas, the areal distribution of HSU-5 concentrations remained largely unchanged during the review period (Figure 15).

## 6.5. Interviews and Site Inspection

DOE/LLNL currently meets every six weeks with the EPA, RWQCB, and DTSC Remedial Project Managers (RPMs) and twice a year with a community action group at Technical Assistance Grant Meetings to discuss remediation activities, issues, and cleanup status and progress.

There is a continuous presence of ERD staff at the Livermore Site that routinely inspect the: (1) extraction wellfield and treatment facilities weekly; and (2) monitoring wellfield during sampling activities. ERD staff conducts self-assessment inspections of facilities and DOE conducts quarterly inspections of remediation activities at the Livermore Site. The EPA performed the construction completion inspection on April 30, 2007 (Berg et al., 2007a, and Setian, 2007). In addition, the following inspections were conducted during the review period:

- March 15, 2007. The LLNL Environmental Safety & Health Team performed a formal self-assessment of PTU4 (TFE area), TF406-NW (GTU03), TF518-N (STU09), TF5475-1 (CRD1), TF5475-2 (GTU09), TF5475-3 (CRD2), VTF5475 (VES01), TFE-NW (PTU9), TFE-SE (MTU04), TFE-SW (MTU03), TFE-W (MTU05), TFE-HS (GTU07), VTFE-HS (VES12), TFA-E (STU06), TFG-N (MTU02), and T5999 Storage Tent.
- January 27, 2009. The EPA's contractor performed an inspection of the Livermore Site treatment facilities.
- June 9, 2010. DOE performed an assessment of Livermore Site treatment facilities and Building 212.

Operational issues and resulting corrective actions identified during routine inspections associated with the treatment systems and extraction wellfields are: (1) detailed in the treatment facility status spreadsheets sent to the regulators on a monthly basis; (2) discussed with the regulators at the RPM meetings; and (3) described in detail in the LLNL Ground Water Project Annual Reports.

# 7. Technical Assessment

The protectiveness of the remedy was assessed by determining if:

1. The remedy is functioning as intended at the time of the decision documents.
2. The assumptions used in the decision-making process are still valid.

3. Any additional information has been identified that would call the protectiveness of the remedy into question.

## 7.1. Remedy Function

The remedy was determined to be functioning as intended at the time of the decision documents because:

- Ground water and soil vapor extraction is reducing contaminant concentrations in the subsurface as discussed in Section 6.4.
- System operation procedures are consistent with requirements.
- Costs have generally been within budget, except when extra costs were incurred to address unanticipated problems or regulatory requests. Additional costs were incurred to startup facilities in an expedited manner after the budget shortfall in 2008 resulted in secured facilities or delays in repair.
- Ground water and soil vapor treatment systems are performing as designed and will continue to be operated and optimized. Examples of the types of optimization that may be considered include installing new extraction wells, adding higher capacity pumps to maximize yield and to increase hydraulic capture, and upgrading the treatment facilities to accommodate increased flow, where appropriate. DOE continues to optimize treatment systems to meet subsurface cleanup goals using the REVAL process discussed in Section 4.3 and Appendix B. DOE also continues to use the SACTE tool to help choose effective source cleanup technologies (Section 4.2).
- No early indicators of potential remedy failure were identified. While not a remedy failure, mixed waste management issues resulted in the temporary shutdown of four treatment facilities during the review period (Sections 4.2 and Section 8).
- Institutional controls are in place. No current or planned changes in land use at the site suggest that they are not or would not be effective.

## 7.2. Changes to Exposure Assumptions, Toxicity Data, Cleanup Levels, and Remedial Action Objectives

The assumptions used in the decision-making process were determined to still be valid because:

- There have been no changes in risk assessment methodologies or calculations that could call the protectiveness of the remedy into question.
- There have been no changes in exposure pathways that could call the protectiveness of the remedy into question.
- No new or previously unidentified unacceptable risk or hazard to human health or ecological receptors has been identified.
- There have been no changes in land, building, or water use.
- No new contaminants or sources have been identified. A hydrogeologic investigation is underway to determine whether the increasing tritium activities observed in TFE

Southwest and TF518 North influent are coming from a potential source at Building 419 or an as-yet-unidentified source nearby.

- No remedy byproducts have been identified.
- On April 19, 2003, the California Code of Regulations, Title 22, Section 67391.1 was adopted that contains requirements for imposing legal limitations on future site uses and activities through a land use covenant. However, there is no impact on the protectiveness of the remedy related to this new requirement for a land use covenant at the time of property transfer.
- There have been no changes in location-, chemical-, or action-specific ARARs or to-be-considered requirements.
- Changes in toxicity and other contaminant characteristics: On September 28, 2011, EPA released updated toxicity values and contaminant characteristics for trichloroethylene (TCE) in the Integrated Risk Information System (IRIS) (EPA, 2011). Currently, the only significant impact of this change is presumed to be on the assessment of risk for the vapor inhalation pathway. No risk was identified associated with the inhalation pathway in the Baseline Public Health Assessment (Layton et al., 1990) for offsite locations. Subsequent sampling beneath trailers T5105, T5425, T5475, T5626 and T5627 (near source areas) (Berg et al., 2002) indicate that the inhalation pathway does not pose a risk for on-site workers. DOE-LLNL will review the impact of changes with the regulators and assess the need for further evaluation.
- The review found progress toward meeting the RAOs.

Table 8 presents Livermore Site Record of Decision Cleanup Standards and current ground water Maximum Contaminant Levels.

## 7.3. Other Information

No additional information was identified that would call the protectiveness of the remedy into question:

- The Health and Safety Plan and Site-Wide Contingency Plan are in place, sufficient to control risks, and properly implemented.
- No unanticipated events (i.e., natural disasters, new contaminants discovered, etc.) occurred that would call the protectiveness of the remedy into question.
- No additional information has been identified that would call the protectiveness of the remedy into question.

# 8. Issues

During FY 2008, the Livermore Site Project experienced a severe budget reduction that necessitated a dramatic reduction in both staff and cleanup activities at the site. Consequently, ESAR treatability tests begun in 2007 were put on hold and existing ground water and soil vapor treatment operations were significantly curtailed for the year. The shutdown of ground water and vapor extraction facilities were prioritized so as to minimize the potential for uncontrolled plume migration and to ensure the continued protectiveness of the site remedies. In addition, available resources for treatment facility operations were allocated so as to meet the priorities for site remediation established in the March 2009 Consensus Statement and the contingency plan (McKereghan et al., 1996), namely 1) western plume capture, 2) southern plume capture, and 3) internal source control/mass removal. A detailed analysis of post-shutdown ground water concentration data indicates that this approach appears to have been successful. Other than a temporary rise in concentrations at TFD South (which returned to pre-shutdown concentrations once pumping resumed there), no significant increases in concentration or uncontrolled migration of site plumes related to the shutdown have been observed, indicating no reduction in the protectiveness of the site remedies. As ground water extraction was curtailed during the shutdown, water levels recovered across the site, rising more than 20 ft within HSU-4, for example. An unanticipated benefit of the shutdown was that site monitor wells that had become dry due to over-drafting of the aquifer could now be sampled. While no significant concentration rises were observed across the site, a dramatic decrease in ground water concentrations was recorded at the T5475 source area. Soil vapor extraction appears to have been a very effective means of removing T5475 HSU-3A mass and lowering concentrations (see Section 6.4.2.2 for additional discussion).

When funding was restored in July 2008, ERD developed a process to restart facilities in a phased and deliberate fashion based on risk to human health and the environment, and importance to the cleanup effort. The ESAR treatability tests were also restarted. Due to the budget shortfall, both the mass removed and the volume of ground water and soil vapor treated during the review period were less than otherwise would have been the case.

DOE and LLNL are seeking resolution of mixed waste management issues that have resulted in the temporary shutdown of four treatment facilities during the review period: TF5475-1, T5475-3, VTF5475, and TF518 North (Figure 2). The four facilities are discussed in a Draft FFS document submitted to the regulatory agencies in September 2010 (Bourne et al., 2010). Restart of these facilities through selection and implementation of the proposed alternatives has been put on hold pending the results of the ESAR treatability tests at the Livermore Site (Section 4.2).

DOE and LLNL are planning to extend the TFA Arroyo Seco Pipeline to accelerate cleanup at the leading edge of the TFA offsite PCE plume. The community has expressed concerns regarding exposure to sediments containing radioactive materials if construction of the pipeline extension was to proceed. Extensive sampling and studies of the area have not found plutonium in soil above the EPA action levels (ATSDR, 2000; ATSDR, 2003; Barreau et al., 2002).

# 9. Recommendations and Follow-up Actions

The following recommendations were developed by DOE/LLNL during the fourth Five-Year Review process:

1. Implement a strategy to accelerate cleanup of the PCE plume in the TFA West area, most likely through an Arroyo Seco Pipeline extension.
2. Complete ESAR treatability tests currently underway at the Livermore Site, as well as ZVI emplacement using pneumatic fracturing, and where applicable, formulate a plan

for implementing successful, cost-effective technologies at appropriate source areas to accelerate cleanup there.

3. Resolve the mixed waste management issues that have resulted in the temporary shutdown of four treatment facilities. Implement alternate treatment technologies or restart clean up operations at these four locations based on the findings of the FFS and the ESAR treatability tests being conducted at the Livermore Site. Also, begin implementing cleanup in the T5425 source area, where appropriate, and expand cleanup in the Building 511 and 514 source area.
4. Evaluate the need for additional HSU-4 source area delineation at TFD Southeast, in light of declining concentrations in this area.
5. Complete a hydrogeologic investigation to determine the source of increasing tritium activities observed in TFE Southwest and TF518 North influent, and conduct tests in HSU-4 to evaluate recirculation of water in the subsurface to control tritium migration in the Southeastern corner of the site (Building 419,412, 511, and 411 areas).
6 Once the VTF518 Perched Zone source delineation analysis has been completed, evaluate the need to expand the TF518 wellfield to include more of the western area.
7. Once the RCRA closure of Building 419 is complete and a resolution of the mixed waste management issues has been reached, continue delineating the source and begin implementing clean up measures there.
8. There is currently no funding identified to perform additional demolition of Building 212. As site usage is not expected to change and mercury concentrations detected in soil are below the U. S. EPA Industrial Regional Screening Levels, LLNL recommends leaving mercury-impacted soil in place. The need for additional soil sampling will be reviewed pending further demolition of the Building 212 foundation or if planned site usage changes.

No other follow-up actions were identified related to this Five-Year Review.

DOE will: (1) estimate costs and the timeframe necessary to accomplish the new work scope; (2) prioritize new work scope and present these priorities to the regulatory agencies; (3) incorporate the new work scope into upcoming fiscal year budget requests; and (4) develop a schedule for implementing the work. Testing and implementation of alternate clean up technologies beyond the approved remedy will depend on funding received during the upcoming five-year period. Completion dates for the recommendations and follow-up actions are presented in the Five-Year Review Summary form.

# 10. Protectiveness Statement

The remedy is protective of human health and the environment for the site's industrial land use. The remedy protects human health because exposure pathways that could result in unacceptable risk to onsite workers are being controlled by the implementation of institutional controls, the Health and Safety Plan, and the Contingency Plan.

A letter to file in the Administrative Record prohibits the transfer of the property with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition may be lifted if a risk assessment shows no unacceptable risk for residential or unrestricted land use and is agreed to by the DOE, the U.S. EPA, DTSC, and the RWQCB. In the event that the site is transferred in the future, the DOE will execute a land use covenant at the time of transfer in compliance with Title 22, California Code of Regulations, Section 67391.1.

DOE/LLNL are actively evaluating source areas cleanup technologies to reduce long-term operational costs and shorten the time to cleanup. DOE/LLNL are committed to the Livermore Site remediation objectives of (1) preventing present day and future human exposure to contaminated ground water and soil, (2) preventing contaminant migration at concentrations above MCLs, (3) reducing contaminant concentrations in ground water to levels below the state and federal MCLs, and (4) minimizing contaminant migration in the unsaturated zone that would result in concentrations in ground water above a MCL.

# 11. Next Review

The next review will be conducted in 2017, within five years of the completion of this Five-Year Review.

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# 13. Acronyms and Abbreviations

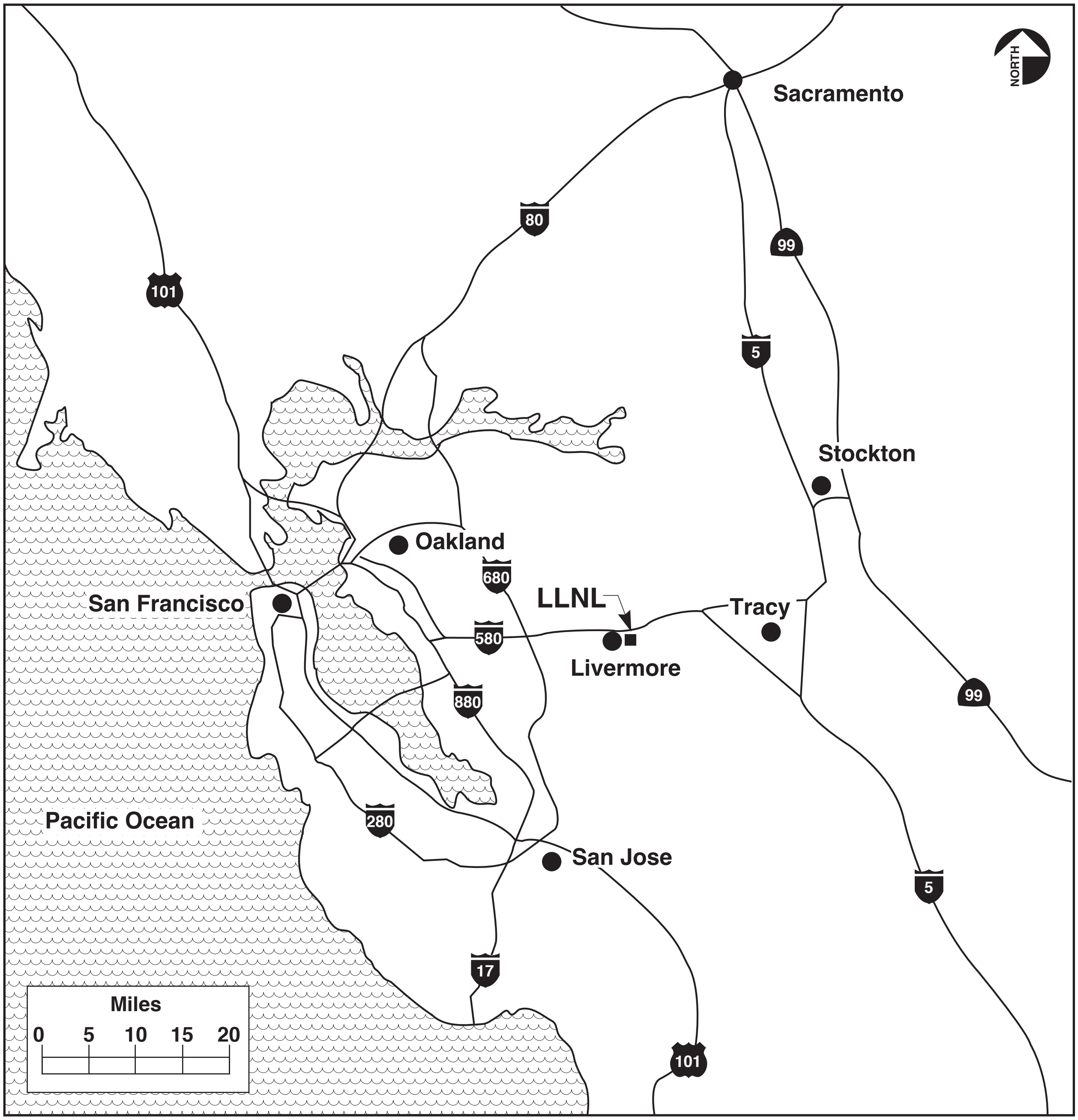
| | |
|---|---|
| **1,1-DCA** | 1,1-dichloroethane |
| **1,2-DCA** | 1,2-dichloroethane |
| **1,1-DCE** | 1,1-dichloroethylene |
| **1,2-DCE** | 1,2-dichloroethylene |
| **AEC** | Atomic Energy Commission |
| **CERCLA** | Comprehensive Environmental Response, Compensation, and Liability Act |
| **CFR** | Code of Federal Regulations |
| **CRD** | Catalytic Reductive Dehalogenation |
| **DOE** | U.S. Department of Energy |
| **DTSC** | California Department of Toxic Substances Control |
| **DWFO** | Dynamic well field operations |
| **ELM** | Eastern Landing Mat |
| **EM** | Environmental Management |
| **EPA** | U.S. Environmental Protection Agency |
| **ERH** | Electrical resistive heating |
| **ESAR** | Enhanced Source Area Remediation |
| **ESD** | Explanation of Significant Differences |
| **ETC** | East Traffic Circle |
| **ETCN** | East Traffic Circle North |
| **ETCS** | East Traffic Circle South |
| **ETS** | East Taxi Strip |
| **FFA** | Federal Facility Agreement |
| **FFS** | Focused Feasibility Study |
| **FHC** | Fuel hydrocarbon |
| **Freon 11** | Trichlorofluoromethane |
| **FY** | Fiscal year |
| **GAC** | Granular Activated Carbon |
| **GTU** | GAC Treatment Unit |
| **HSU** | Hydrostratigraphic Unit |
| **ID** | Inside diameter |
| **ISB** | *In situ* based bioremediation |

| | |
|---|---|
| **kg** | Kilograms |
| **LLNL** | Lawrence Livermore National Laboratory |
| **LWRP** | Livermore Water Reclamation Plant |
| **MCL** | Maximum Contaminant Level |
| **Mgal** | Millions of gallons |
| **MTU** | Miniature Treatment Unit |
| **NIF** | National Ignition Facility |
| **NCP** | National Oil and Hazardous Substance Pollution Contingency Plan |
| **NNSA** | National Nuclear Security Administration |
| **O&M** | Operations and Maintenance |
| **PCB** | Polychlorinated biphenyl |
| **PCE** | Perchloroethylene |
| **PF** | Pneumatic fracturing |
| **ppb** | Parts per billion |
| **PSR** | Phased Source Remediation |
| **PTU** | Portable Treatment Unit |
| **PVC** | Poly vinyl chloride |
| **ROD** | Record of Decision |
| **ROI** | Return on Investment |
| **RWQCB** | California Regional Water Quality Control Board |
| **SACTE** | Source Area Cleanup Technology Evaluation |
| **SARA** | Superfund Amendments and Reauthorization Act |
| **SNL** | Sandia National Laboratories |
| **STU** | Solar Treatment Unit |
| **TCE** | Trichloroethylene |
| **TER** | Thermally-enhanced remediation |
| **TF** | Treatment Facility |
| **TF406** | Treatment Facility 406 |
| **TF5475** | Treatment Facility 5475 |
| **TF518** | Treatment Facility 518 |
| **TFA** | Treatment Facility A |
| **TFB** | Treatment Facility B |
| **TFC** | Treatment Facility C |

| | |
|---|---|
| **TFD** | Treatment Facility D |
| **TFE** | Treatment Facility E |
| **TFF** | Treatment Facility F |
| **TFG** | Treatment Facility G |
| **TFH** | Treatment Facility H |
| **UV** | Ultraviolet light |
| **VES** | Vapor extraction system |
| **VOC** | Volatile organic compound |
| **VTF406** | Vapor Treatment Facility 406 |
| **VTF511** | Vapor Treatment Facility 511 |
| **VTF518** | Vapor Treatment Facility 518 |
| **VTF5475** | Vapor Treatment Facility 5475 |
| **VTFE** | Vapor Treatment Facility E |
| **VTFD** | Vapor Treatment Facility D |
| **ZVI** | Zero valent ion |

# Figures

# List of Figures




ERD-S3R-11-0162

**Figure 1. Location of the LLNL Livermore Site.**

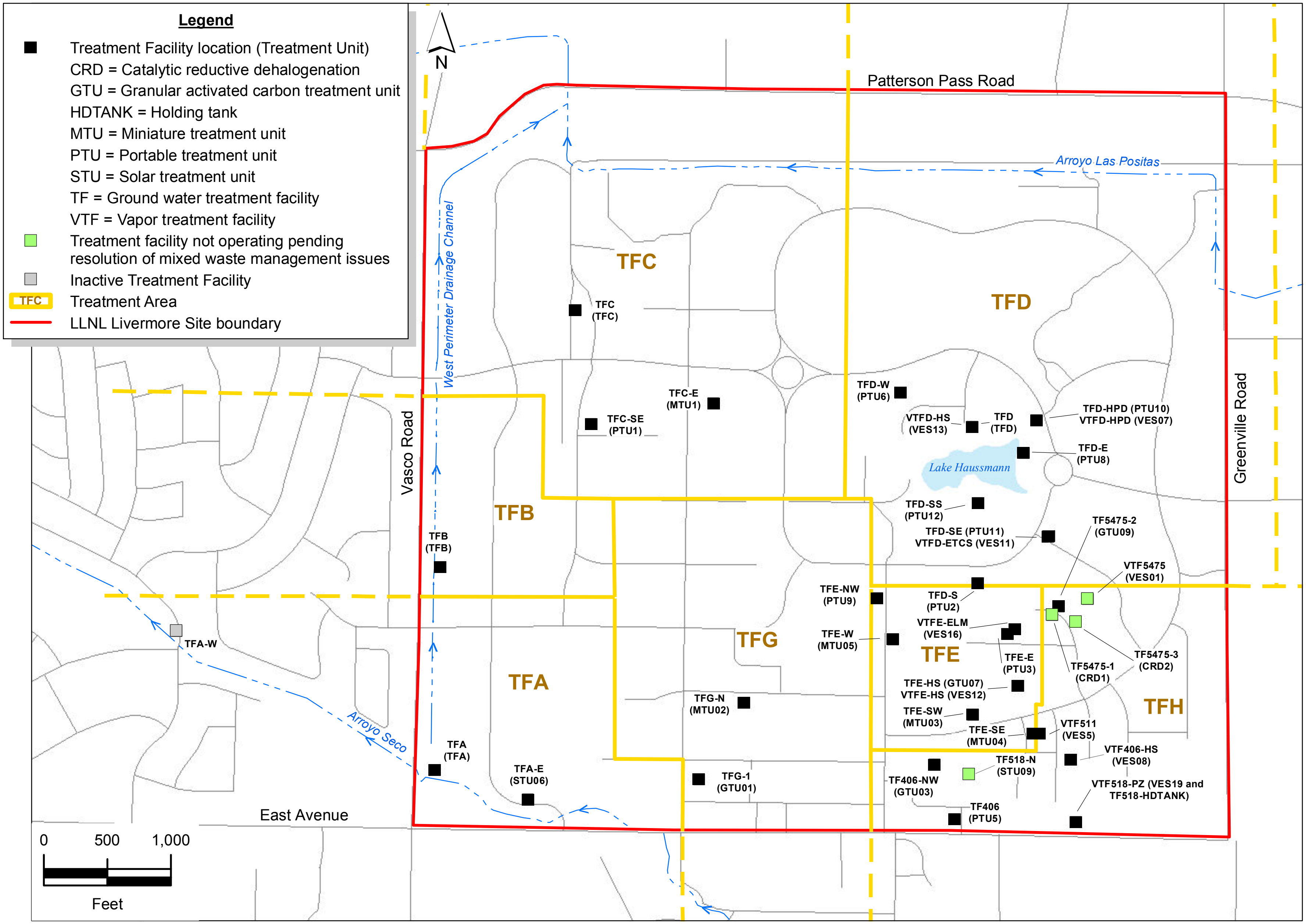



**Figure 2. Livermore Site treatment areas and treatment facility locations.**

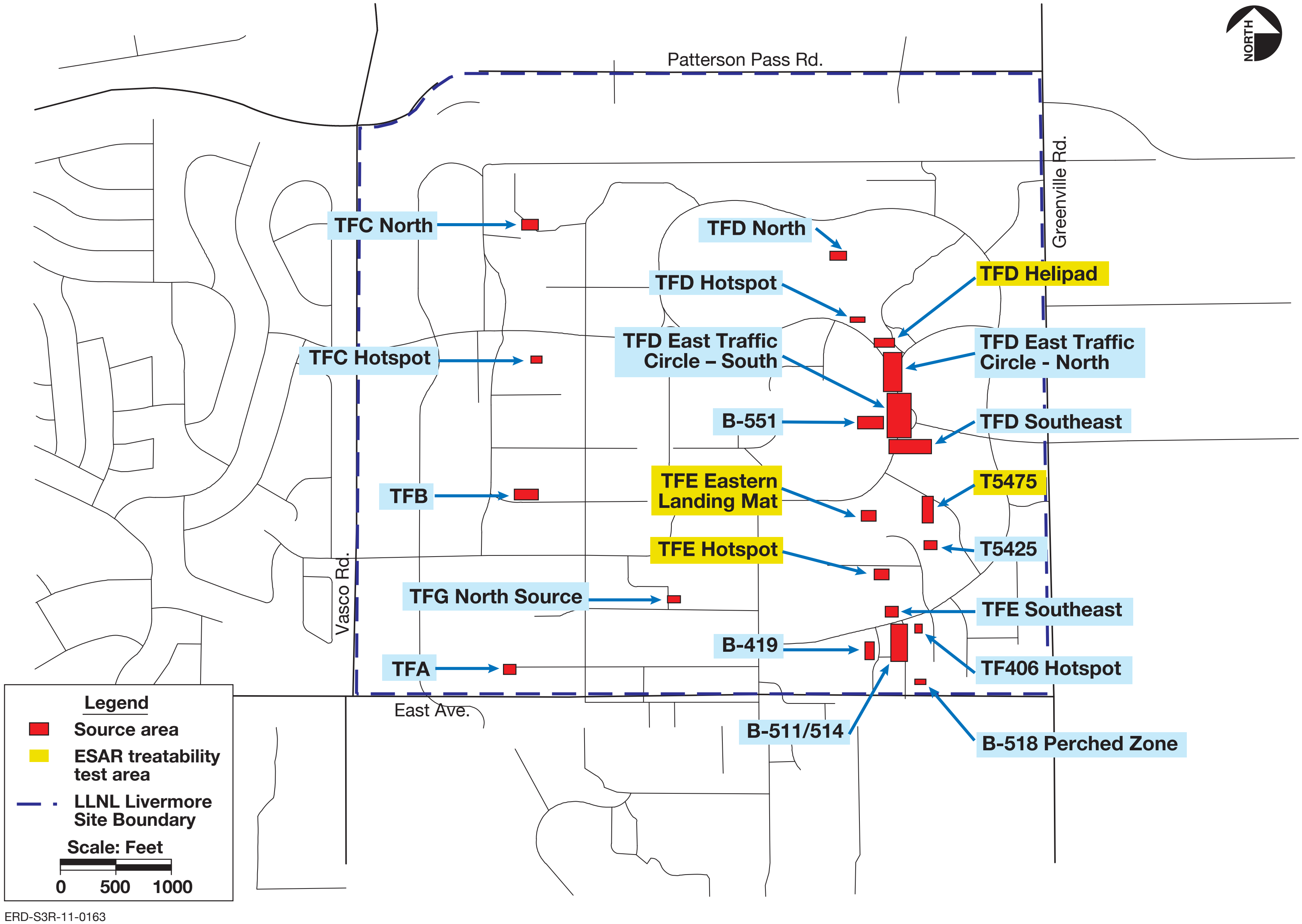



**Figure 3. Livermore Site source areas. Locations where enhanced source area remediation (ESAR) treatability tests are being conducted are highlighted in yellow.**

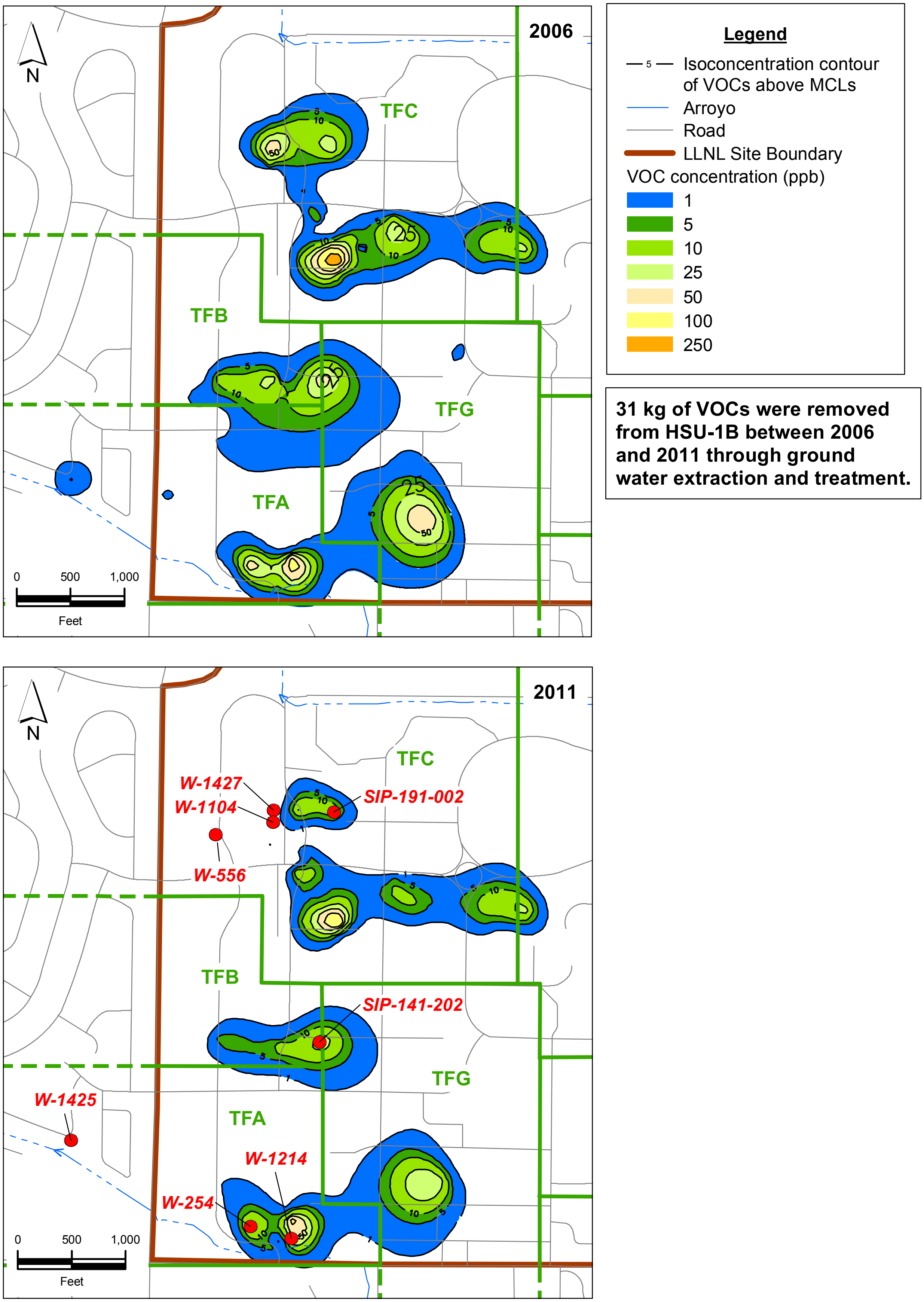



**Figure 4. Time-series isoconcentration maps of VOCs above MCLs based on wells completed within Hydrostratigraphic Unit 1B (HSU-1B) for 2006 and 2011.**

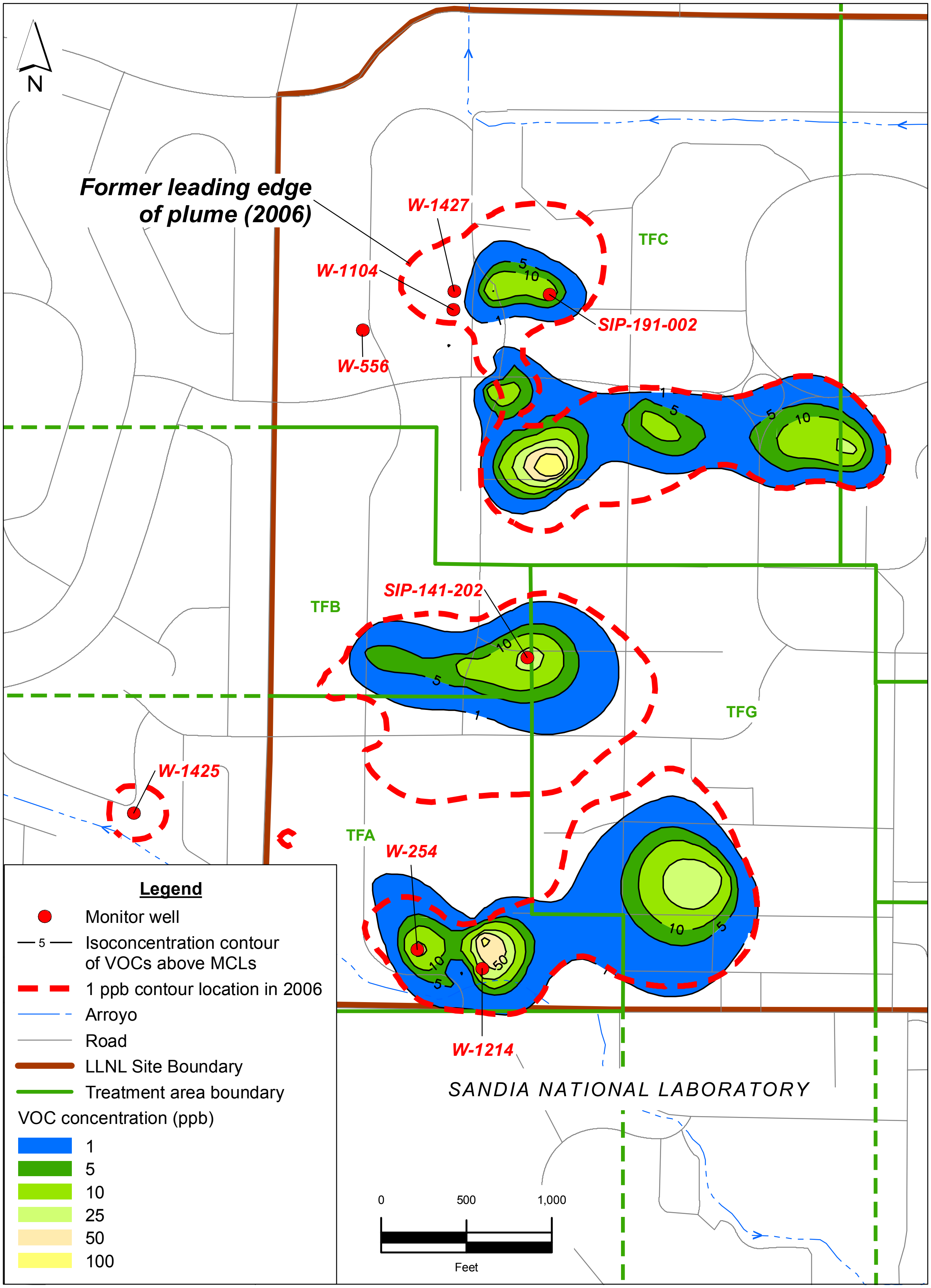



**Figure 5. TFA and TFB area HSU-1B isoconcentration contour map of VOCs above MCLs showing the eastward retreat of the plume between 2006 and 2011.**

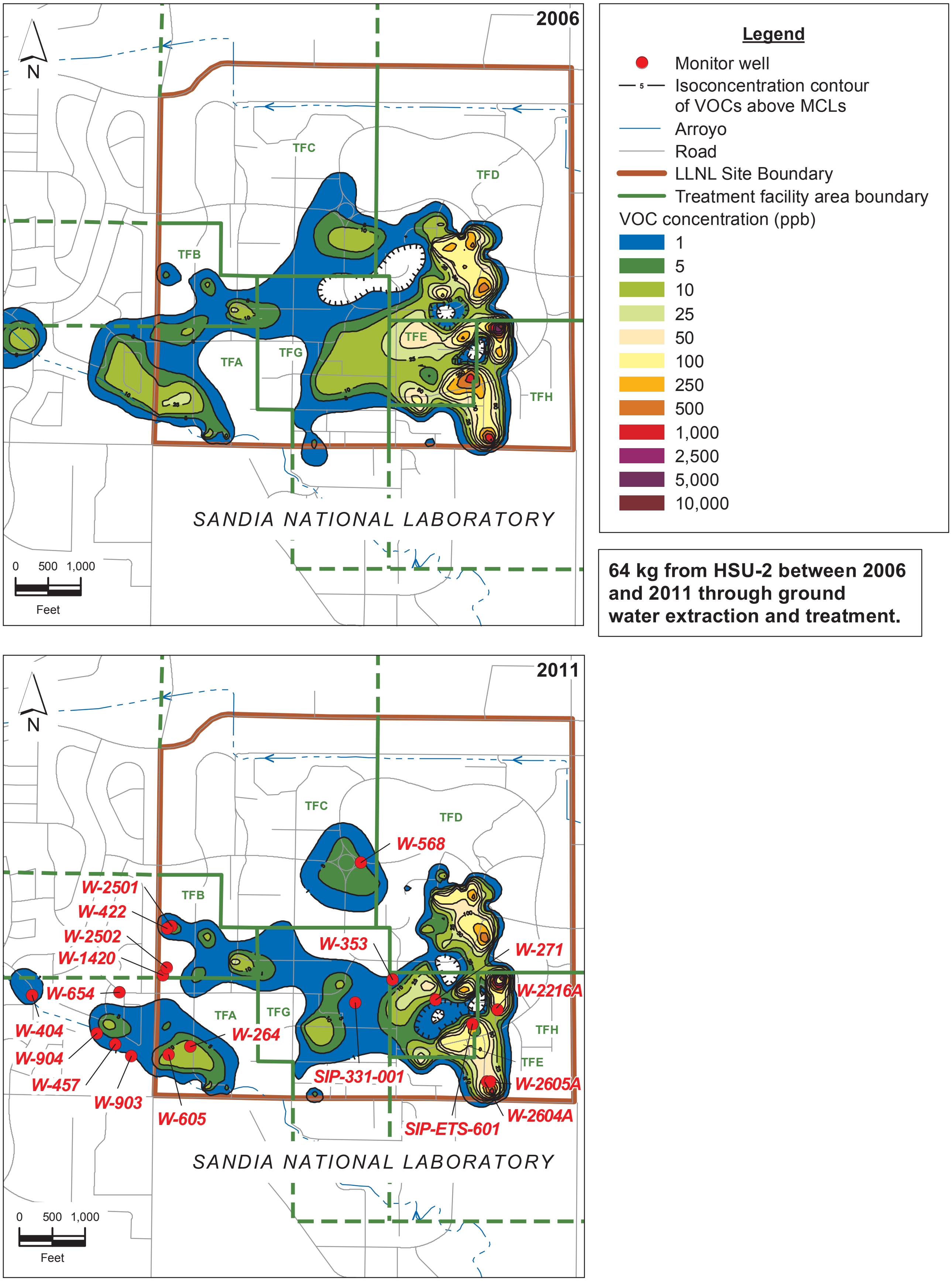



**Figure 6. Time-series isoconcentration maps of VOCs above MCLs based on wells completed within Hydrostratigraphic Unit 2 (HSU-2) for 2006 and 2011.**

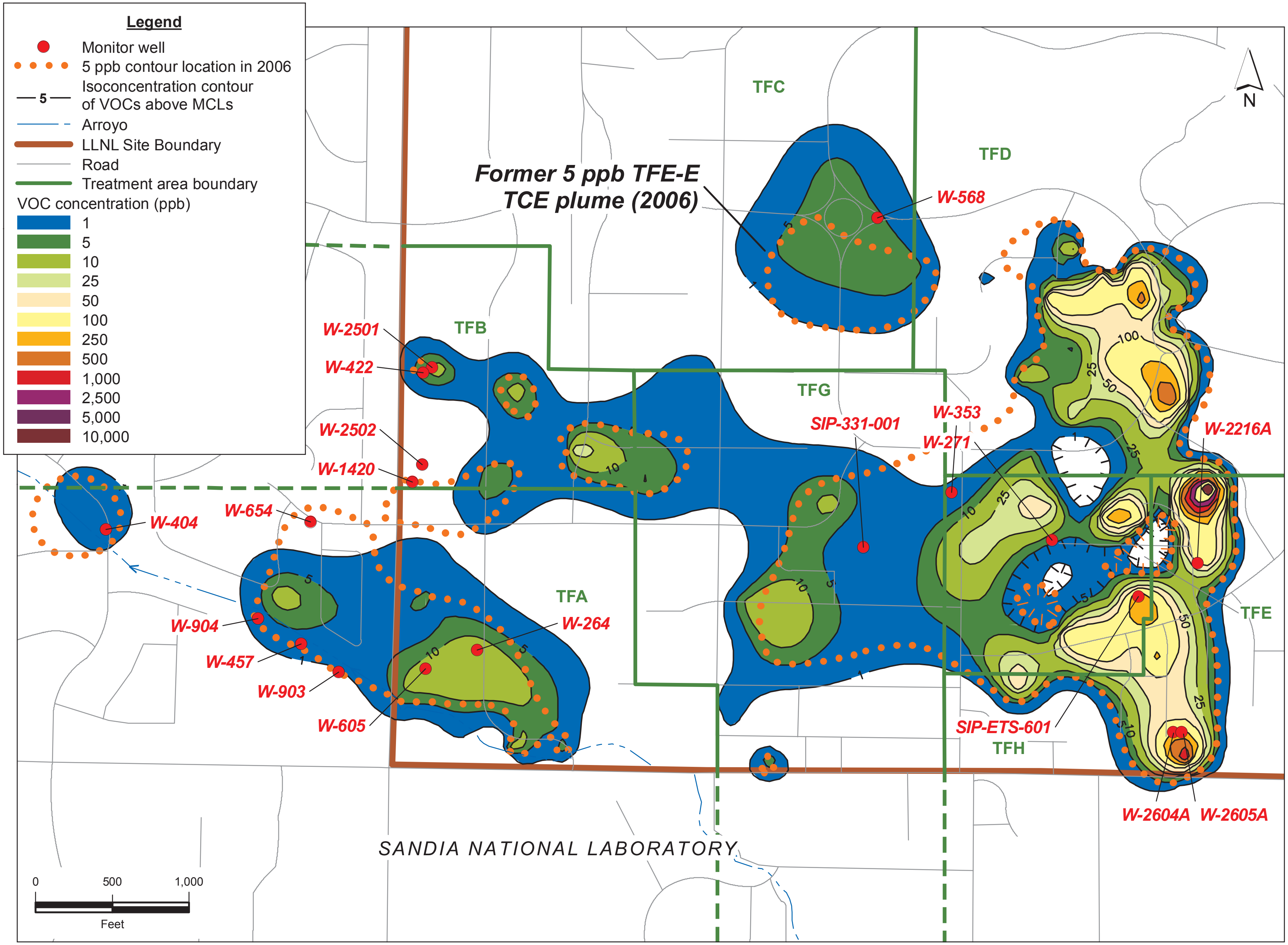



**Figure 7. HSU-2 isoconcentration contour map of total VOCs above MCLs showing the retreat of the 5 ppb contour, particularly in the TFA, TFB, TFG, and TFE areas, between 2006 and 2011.**

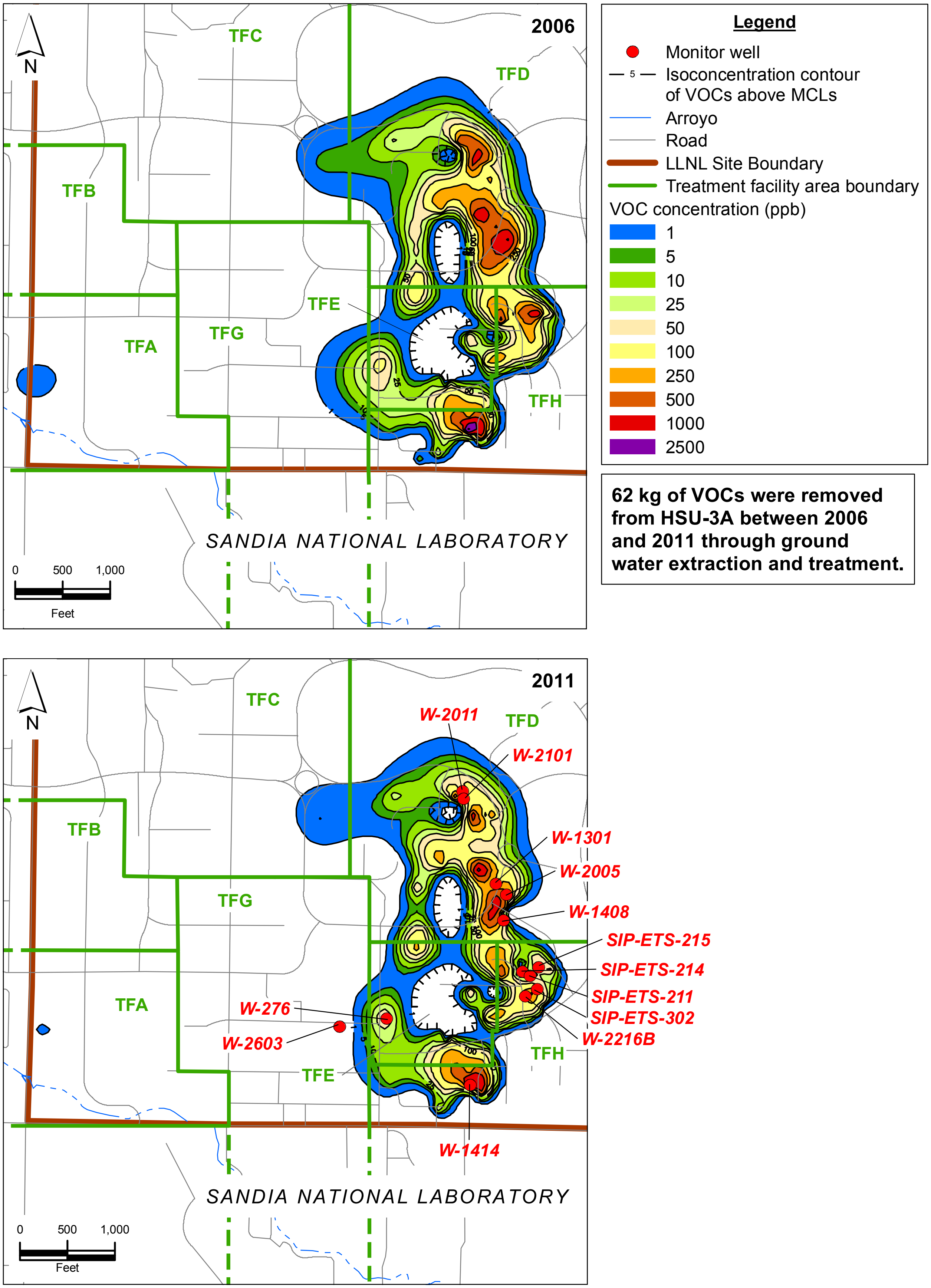



**Figure 8. Time-series isoconcentration maps of VOCs above MCLs based on wells completed within Hydrostratigraphic Unit 3A (HSU-3A) for 2006 and 2011.**

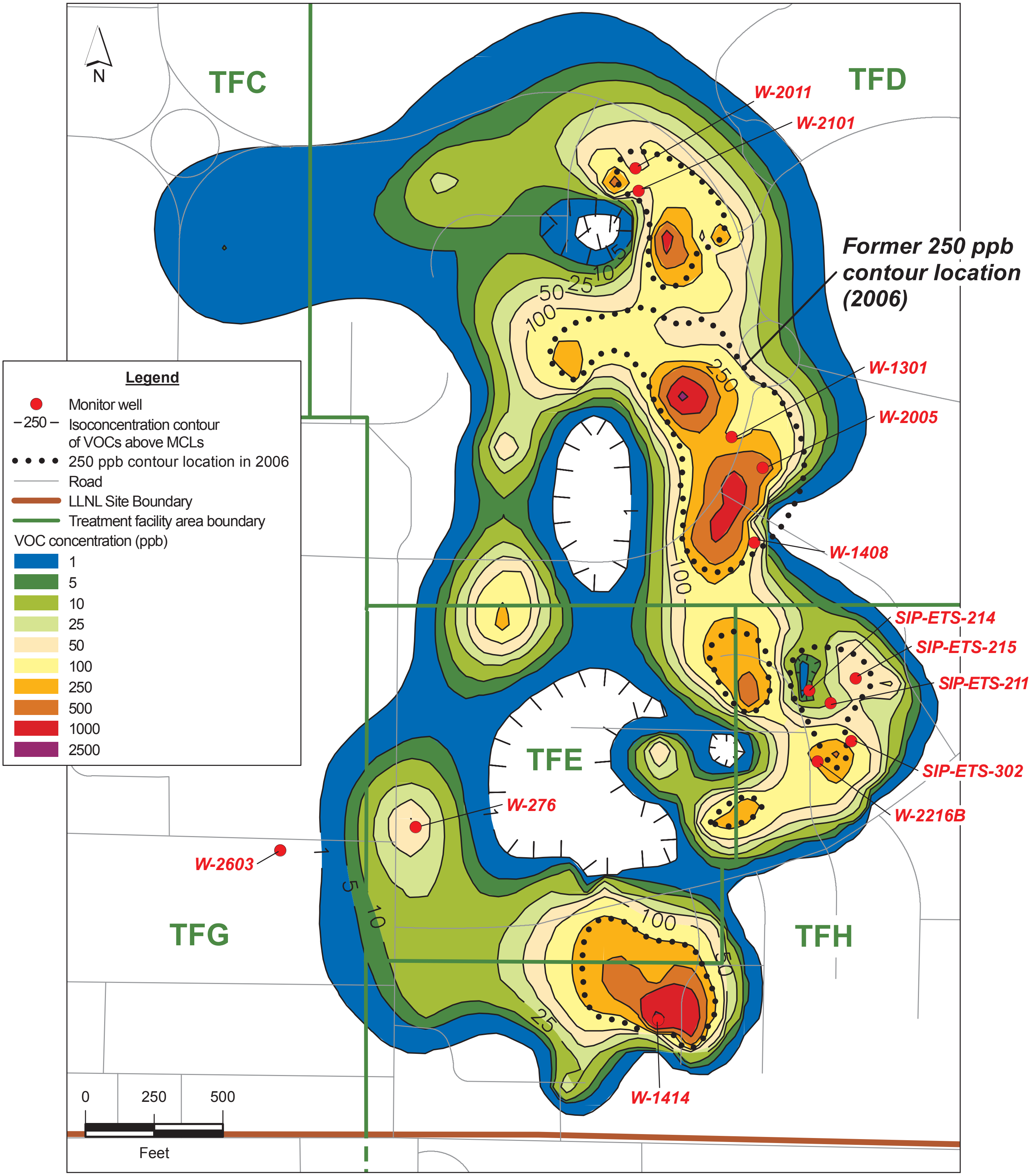



**Figure 9. HSU-3A isoconcentration contour map of total VOCs above MCLs showing the retreat of the 250 ppb contour, particularly in the TFD and TFH areas, between 2006 and 2011.**

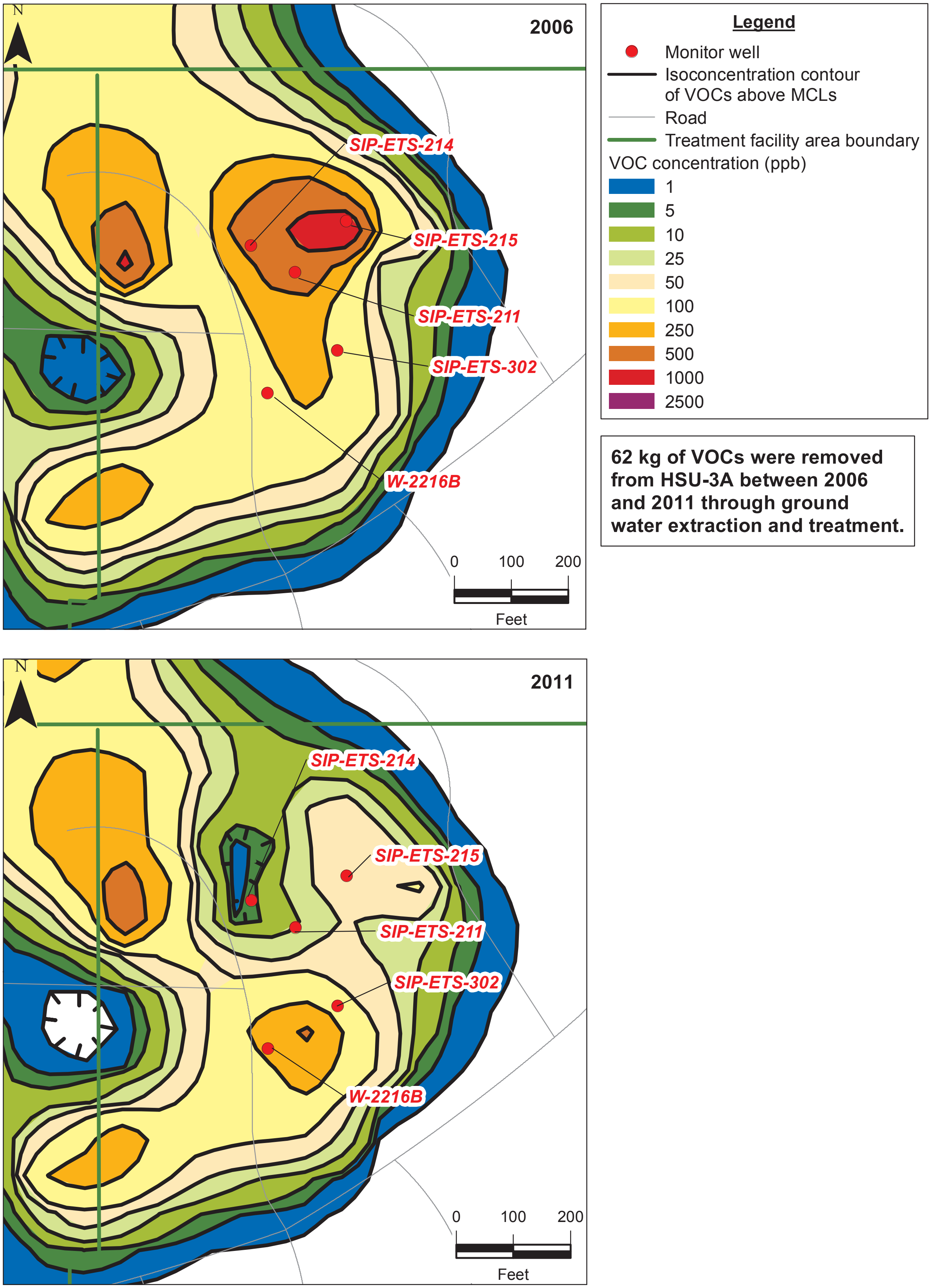



**Figure 10. Time-series isoconcentration maps of VOCs above MCLs based on wells completed within Hydrostratigraphic Unit 3A (HSU-3A) for 2006 and 2011 showing cleanup progress in the T5475 source area by soil vapor extraction using VES01.**

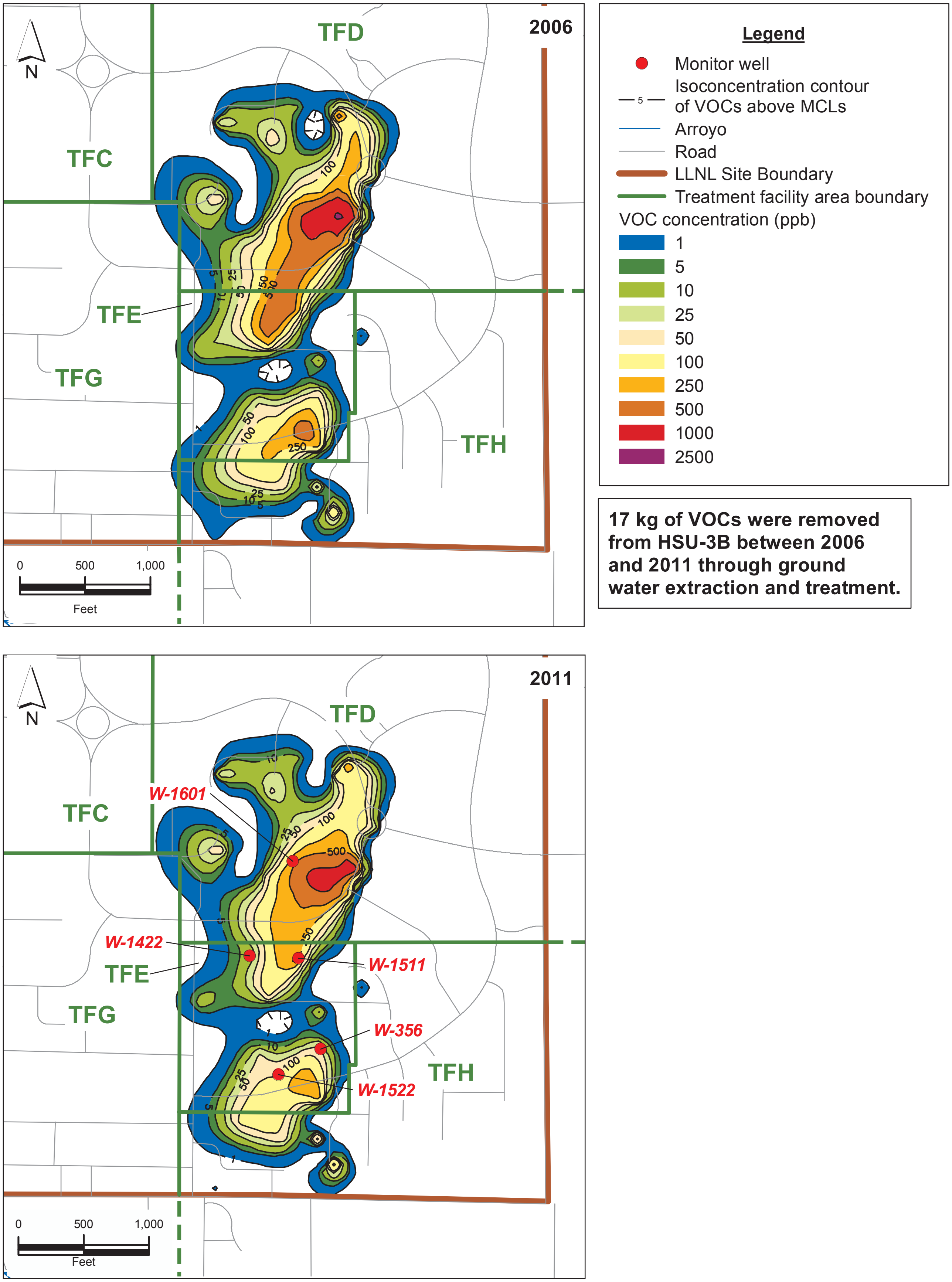



**Figure 11. Time-series isoconcentration maps of VOCs above MCLs based on wells completed within Hydrostratigraphic Unit 3B (HSU-3B) for 2006 and 2011.**

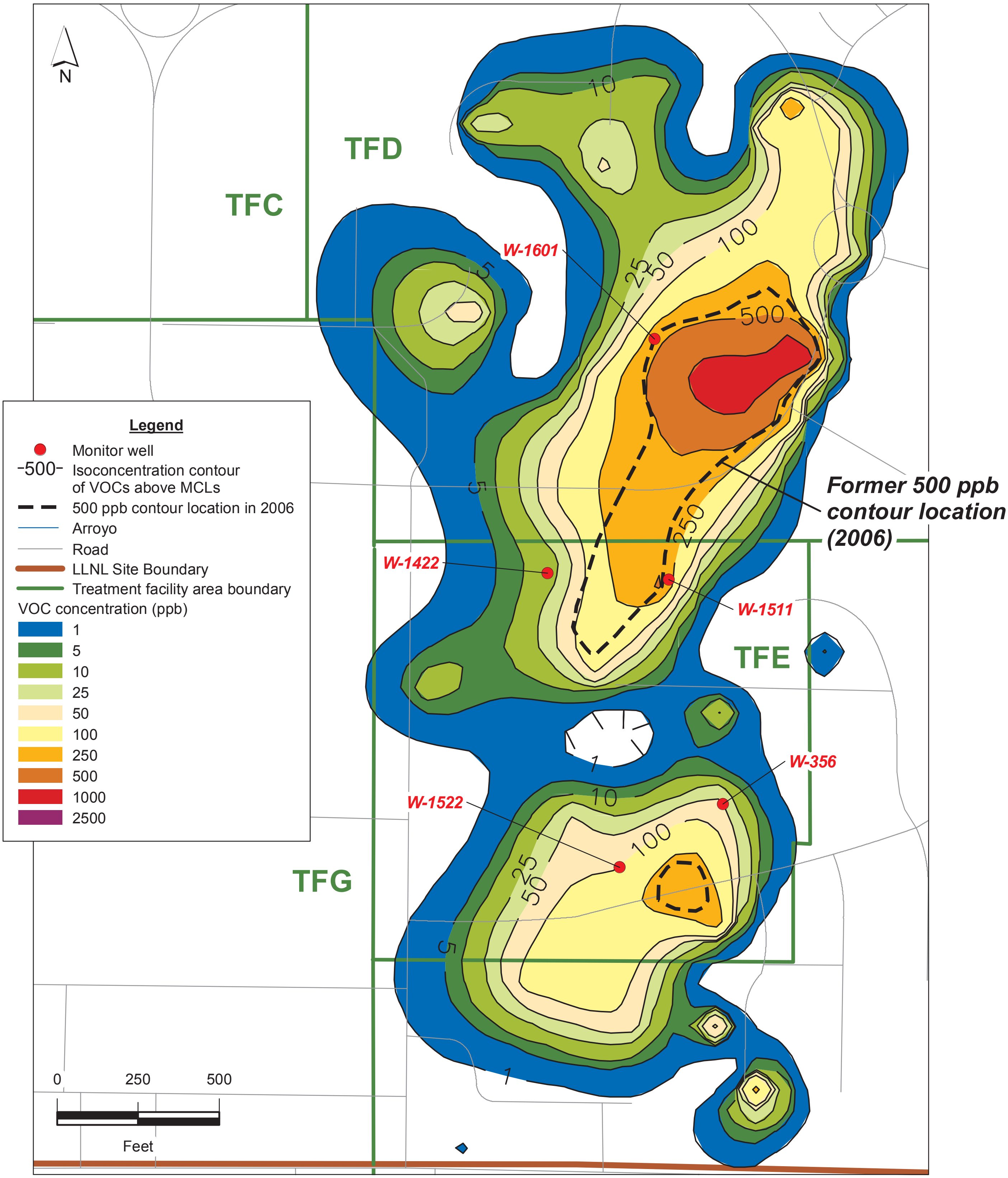



**Figure 12. HSU-3B isoconcentration contour map of the total VOCs above MCLs showing the retreat of the 500 ppb contour in the TFD and TFE areas between 2006 and 2011.**

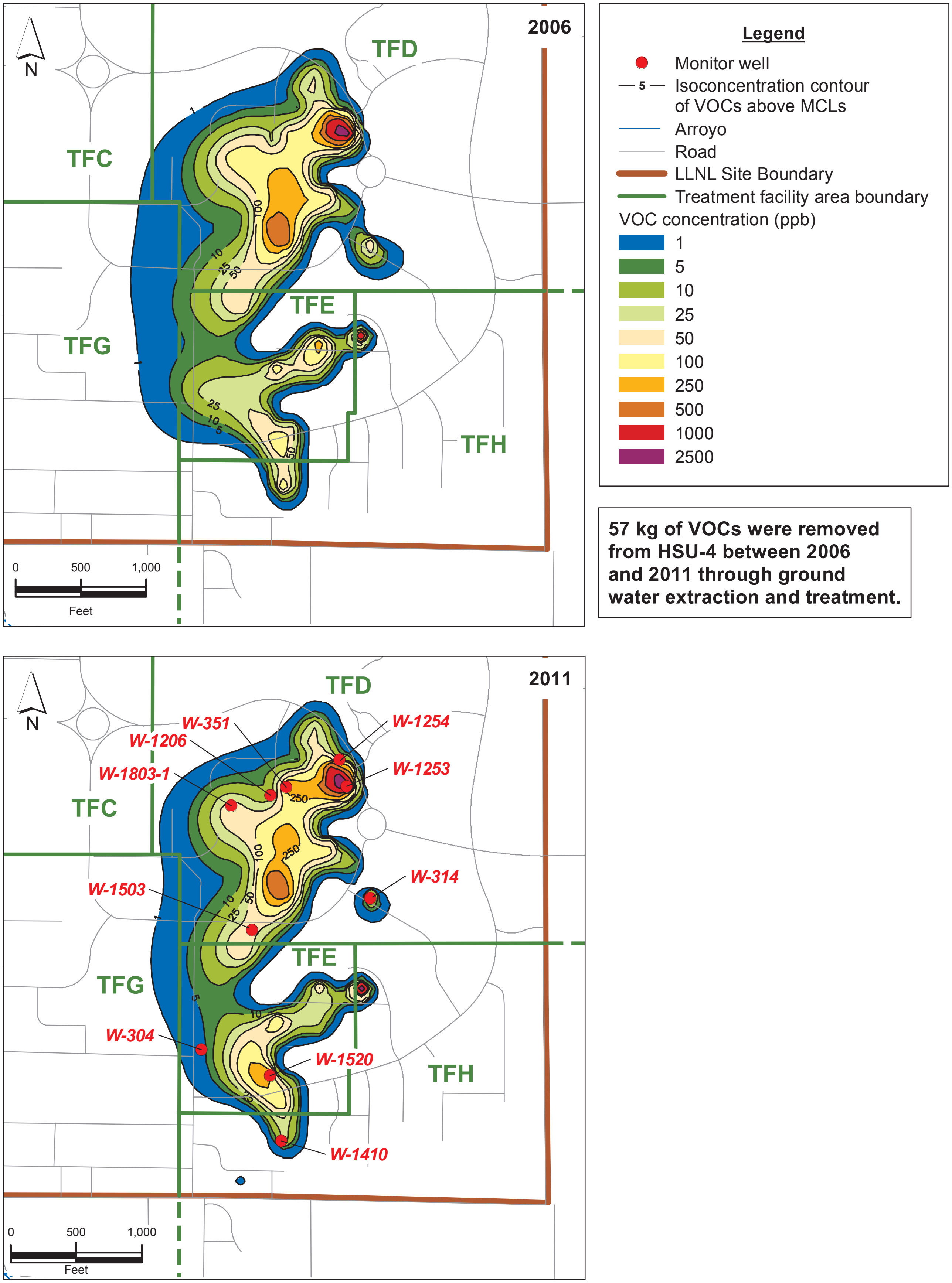



**Figure 13. Time-series isoconcentration maps of VOCs above MCLs based on wells completed within Hydrostratigraphic Unit 4 (HSU-4) for 2006 and 2011.**

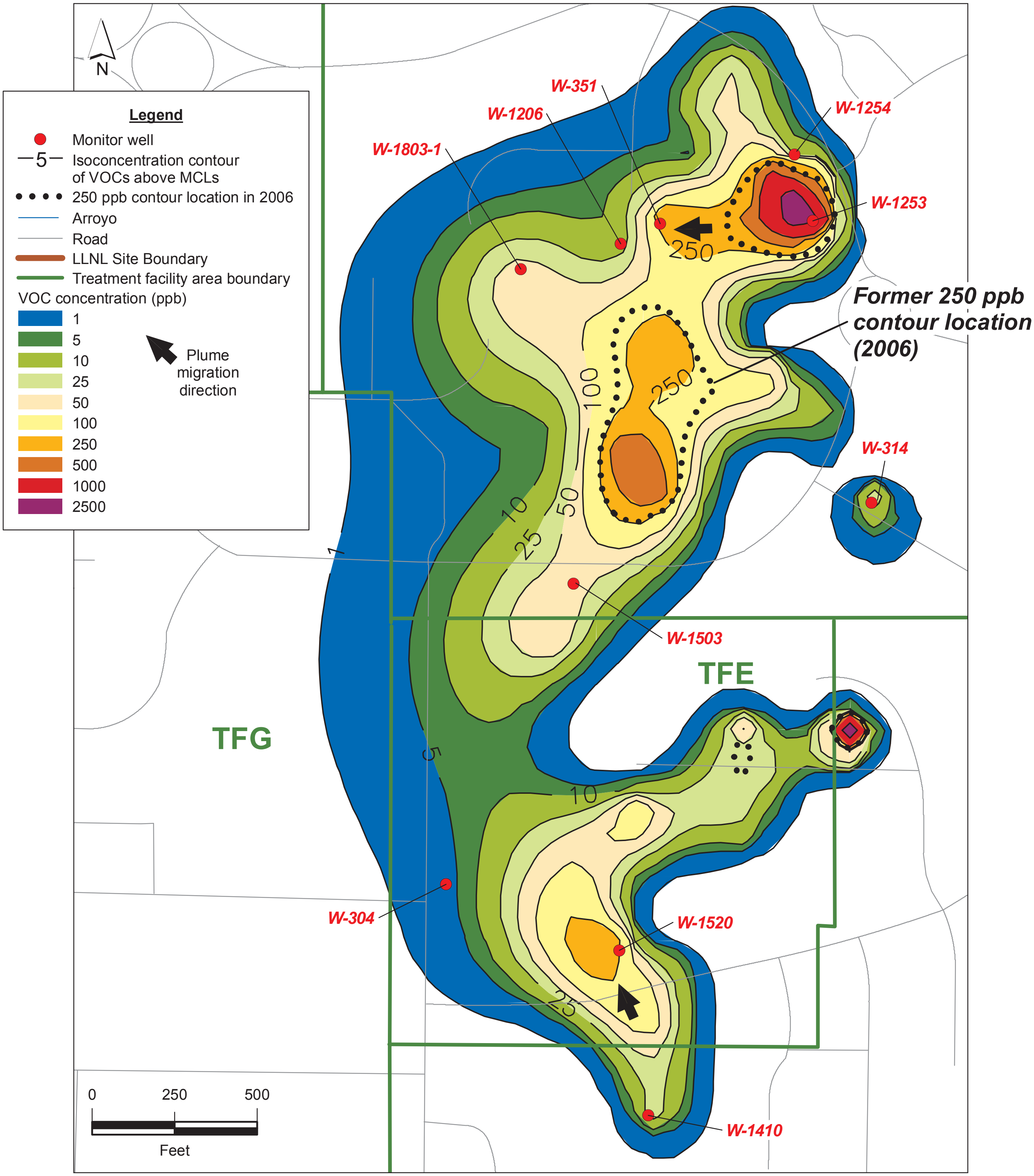



**Figure 14. HSU-4 isoconcentrataion contour map of total VOCs above MCLs showing the westward (TFD) and northward (TFE) movement of the plume as reflected by the 250 ppb contour, between 2006 and 2011. In both locations, movement is toward pumping-induced ground water depressions developed around HSU-4 ground water extraction wells.**

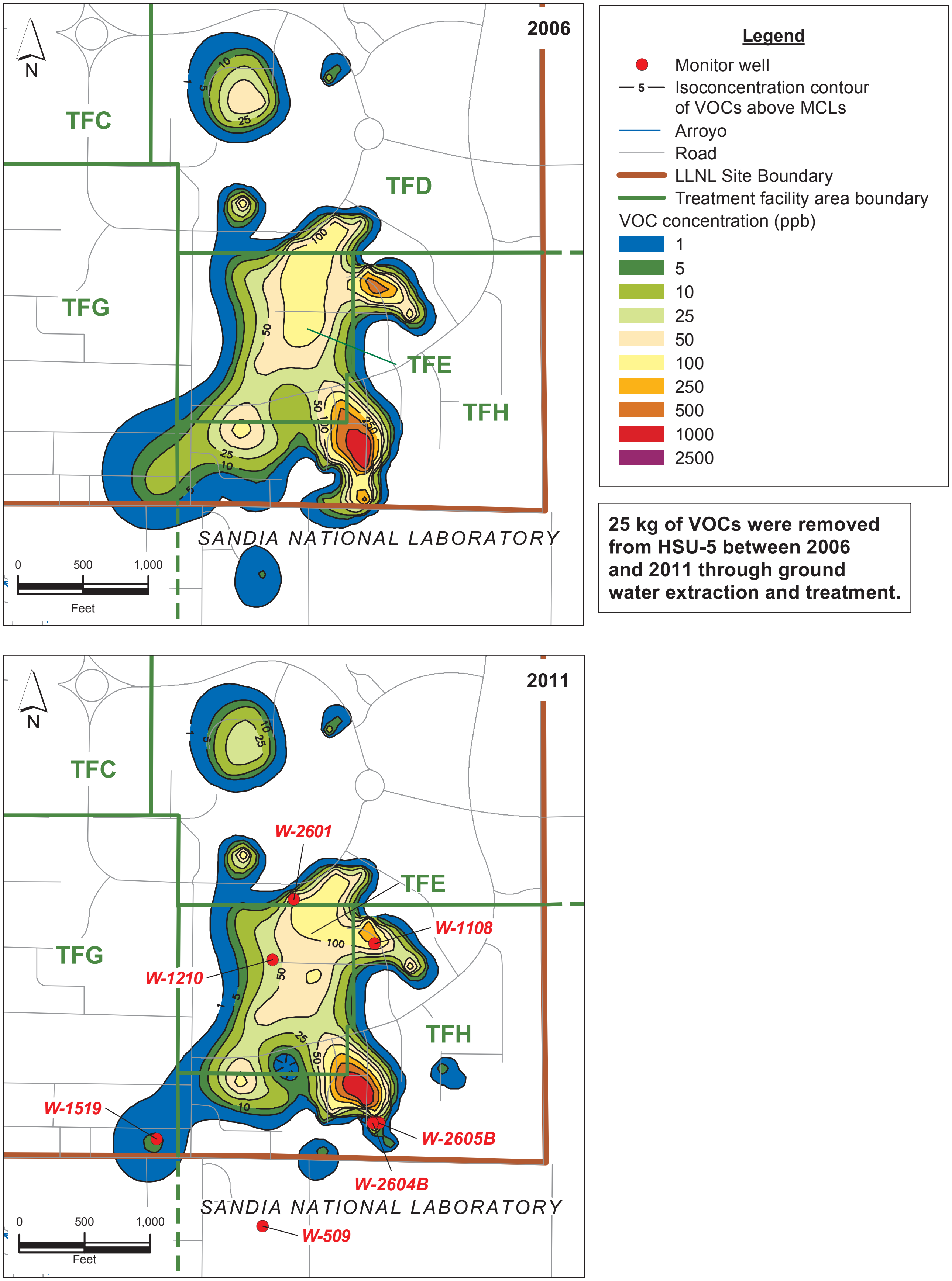



**Figure 15. Time-series isoconcentration maps of VOCs above MCLs based on wells completed within Hydrostratigraphic Unit 5 (HSU-5) for 2006 and 2011.**

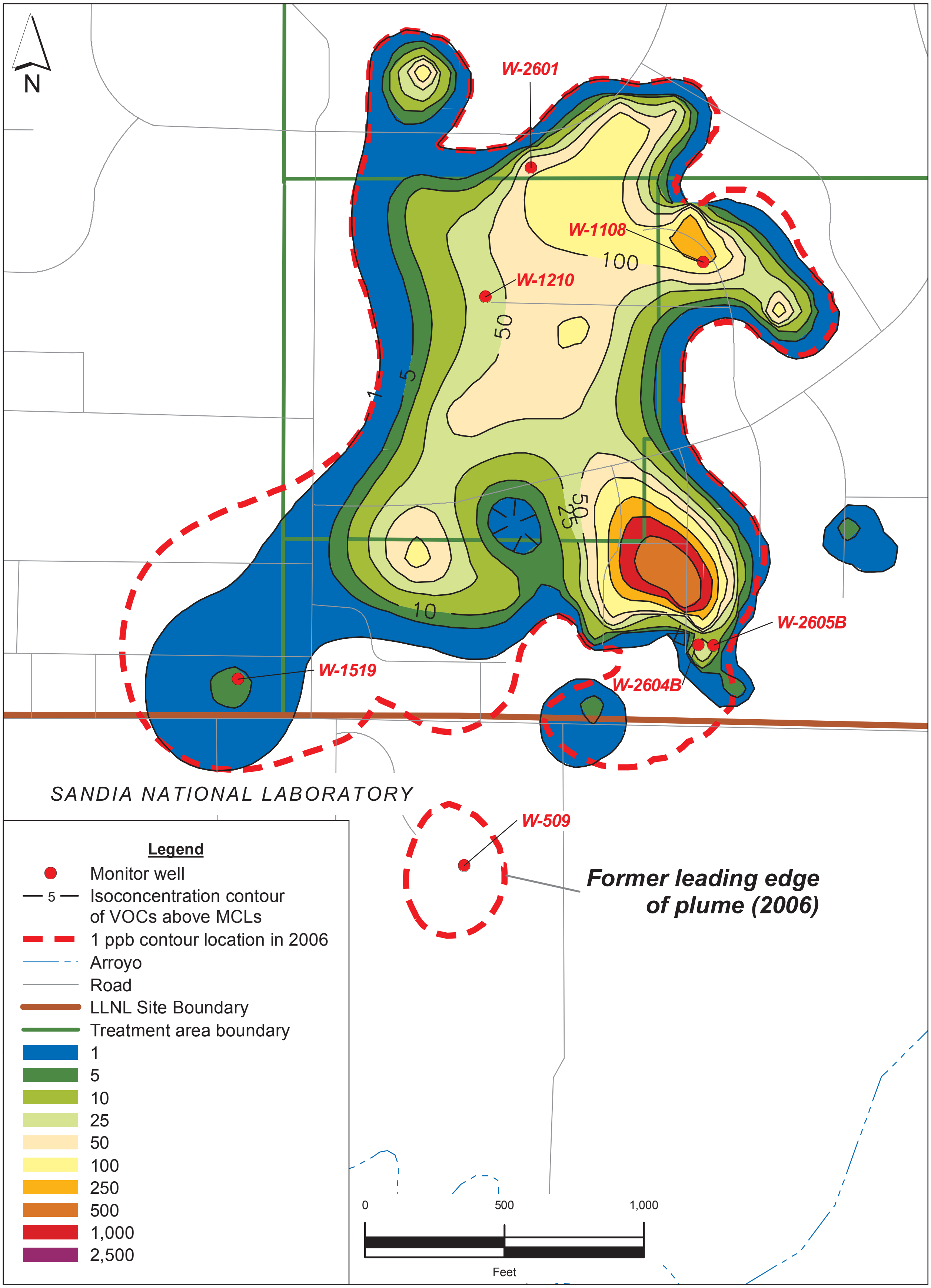



**Figure 16. TFH area HSU-5 isoconcentration map of total VOCs above MCLs showing the northward retreat of the plume between 2006 and 2011.**

# Tables

# List of Tables

**Table 1. Livermore Site chronology of events.**

| Date | Event |
|---|---|
| 1942–1949 | Site used as U.S. Navy Air Station; first release of hazardous materials. |
| 1950s | Undocumented releases of radioactive and hazardous materials to soil. |
| 1960s | Landfills, evaporation ponds, and disposal pits constructed. |
| 1970s | DOE/LLNL began environmental investigations. |
| 1982–1983 | Excavation of four disposal pits containing debris, and disposed of about 3,000 cubic yards of contaminated soil containing volatile organic compounds and radionuclides from the East Taxi Strip area (now referred to as that Trailer 5475 area). |
| 1983 | DOE/LLNL discovers ground water contamination on- and off-site, and notifies regulatory agencies. |
| 1984–1985 | Excavation and removal of about 14,000 cubic yards of soil and debris, and 160 buried capacitors from the East Traffic Circle Landfill. |
| 1987 | Livermore Site named to the National Priorities List (Superfund). |
| 1988 | Federal Facility Agreement signed by DOE and regulatory agencies. |
| 1989 | DOE/LLNL established Community Work Group. |
| 1989 | DOE/LLNL initiated the Remedial Investigation. |
| 1992 | Record of Decision signed determining scope and remedies of cleanup. |
| 1993 | Completed Explanation of Significant Differences for a change in the vapor treatment at Treatment Facility F. |
| 1994 | LLNL developed hydrostratigraphic unit analysis for more effective cleanup. |
| 1995 | State closure of Treatment Facility F vadose zone cleanup. |
| 1995 | DOE/LLNL achieved hydraulic control of contaminated plumes at the western site boundary. |
| 1996 | State "No Further Action" for the Treatment Facility F fuel hydrocarbon contamination. |
| 1996 | DOE/LLNL implemented Engineered Plume Collapse strategy using portable treatment units. |
| 1997 | First five-year review concluded cleanup ahead of schedule. |
| 1997 | Removed approximately 766 tons of contaminated soil and 112 buried capacitors containing polychlorinated biphenyls at the site of the National Ignition Facility. |

**Table 1. Livermore Site chronology of events. (Continued)**

| Date | Event |
|---|---|
| 1997 | Completed Explanation of Significant Differences for a change in the ground water treatment at Treatment Facilities A and B. |
| 1997 | Completed Explanation of Significant Differences for a change in metals discharge requirements. |
| 1999 | Removed more than 400 cubic yards of residual contaminated soil containing polychlorinated biphenyls at the East Traffic Circle. |
| 1999 | Cumulatively treated more than 1 billion gallons of contaminated ground water. |
| 2000 | Completed Explanation of Significant Differences for a design change for Treatment Facility 5475. |
| 2002 | Second five-year review concluded remedy is functioning as intended and is protective of human health and the environment. |
| 2003 | Cumulatively treated more than 2 billion gallons of contaminated ground water. |
| 2005 | Cumulatively removed more than 2 tons of VOC contaminant mass from the subsurface. |
| 2006 | Cumulatively treated more than 3 billion gallons of contaminated ground water. |
| 2007 | Preliminary Close-out Report issued by the EPA. |
| 2007 | Third five-year review concluded remedy is functioning as intended and is protective of human health and the environment. |
| 2008 | Conducted Time-Critical Removal Action of Mercury in Soil North of Building 212. |
| 2009 | Cumulatively removed more than 3 tons of VOC contaminant mass from the subsurface. |
| 2010 | Cumulatively treated more than 4 billion gallons of contaminated ground water. |

**Table 2. Project highlights since the third five-year review.**

| Date | Event |
|---|---|
| **January 2007** | **Initial start-up of Treatment Facility (TF) A West began January 16, 2007.** |
| **April 2007** | **On April 30, 2007, Environmental Protection Agency's (EPA) contractor conducted an inspection of the Livermore Site treatment facilities: TFA East (STU06), TFB Main, TFC Southeast (PTU1), VTFD East Traffic Circle South (VES11), TFE Southeast (MTU04), TFG-1 (GTU01), VTF511/419 (VES14), TF5475-2 (GTU09), TF5475-1 (CRD1) and TF5475-3 (CRD2), and Lake Haussmann.** |
| **July 2007** | **Performed a tracer test with Hetch Hechy water at TFD Helipad *in situ* bioremediation test site.** |
| **July 2007** | **The TFE ELM Enhance Source Area Remediation (ESAR) Pilot Study was activated on July 26, 2007.** |
| **July 2007** | **TF5475-1 was shut down due to mixed waste disposal issues.** |
| **August 2007** | **TF5475-3 was shut down due to mixed waste disposal issues.** |
| **August 2007** | **Preliminary Close-out Report issued by the EPA.** |
| **August 2007** | **The Third Five-Year Review was approved.** |
| **September 2007** | **Modifications for the TF5475 ESAR Pilot Study were completed in September 2007.** |
| **October 2007** | **VTF5475 was shut down due to mixed waste disposal issues.** |
| **November 2007** | **Submitted Draft Explanation of Significant Difference (ESD) for Well W-404 to the regulatory agencies by the November 15, 2007, milestone.** |
| **January 2008** | **Treatability test at TFA West (W-404) was terminated.** |
| **February 2008** | **TF518 North was shutdown due to mixed waste disposal issues.** |
| **February 2008** | **Livermore Site Environmental Restoration Project experienced a significant funding shortfall (>$6M) that resulted in the loss of approximately 60% of the technical staff, and 28 of the 38 groundwater and soil vapor treatment facilities either being shut down, remaining shut down, or run-to-failure. All ESAR activities were also stopped.** |
| **July 2008** | **A draft work plan for a Time-Critical Removal Action of Mercury in Soil North of Building 212 was submitted to the regulators for review.** |
| **July 2008** | **Budget shortfall was restored.** |
| **August 2008** | **The final work Plan for a Time Critical soil Removal Action for the mercury at Building 212 was distributed on August 4, 2008. Excavation began on August 19, 2008.** |
| **October 2008** | **Initiated the Remedial Evaluation Process (REVAL) to restart treatment facility operations.** |

**Table 2. Project highlights since the third five-year review. (Continued)**

| Date | Event |
|---|---|
| December 2008 | Completed the REVAL process at TF406 and TFA East and began normal operations. |
| January 2009 | EPA notified DOE of fines and penalties for violating Federal Facilities Agreement due to the budget shortfall. |
| January 2009 | The excavation area at Building 212 was lined and filled with clean soil on January 13, 2009, and capped with concrete on January 14, 2009. |
| February 2009 | Restarted operations at TFA and TFC Southeast ahead for the March 31, 2009 milestone. |
| February 2009 | The Building 212 Soil Removal Project Status Report was submitted. |
| March 2009 | Remedial Action Implementation Plan Table 5, milestone list was updated with 32 new milestones and regulatory agencies signed new Consensus Statement. |
| March 2009 | Restarted operations at TFE Hotspot and VTF406 Hotspot ahead for the March 31, 2009 milestone. |
| April 2009 | Restarted TFC East and TFD South ahead of the June 30, 2009 milestone. |
| April 2009 | Submitted Summary of Mixed Waste Management Efforts to regulatory agencies (April 30, 2009). |
| June 2009 | Met remaining third Quarter FY2009 Treatment Facility Restart Milestones for TFD, TFE Southeast, TF406 Northwest, TF5475-2, and VTF511 ahead of the June 30, 2009 milestone. |
| August 2009 | Restarted TFG North, VTFE Hotspot, TFE East, and VTFD ETC South ahead of the September 30, 2009 milestone. |
| September 2009 | Restarted VTFD Hotspot and VTFE ELM ahead of the September 30, 2009 milestone. |
| September 2009 | Restarted TFD Helipad, VTFD Helipad, and TF518 Perched Zone (PZ) ahead of the December 31, 2009 milestone. |
| September 2009 | Restarted VTF518 PZ ahead of the March 31, 2010 milestone. |
| September 2009 | Submitted schedule for bioremediation treatability test at TFD/VTFD Helipad; submitted schedules to upgrade TF5475-2, TF518-PZ, and VTF518-PZ; submitted schedules for the focused feasibility studies (FFS) for TF518 North, TF5475-1, TF5475-3, and VTF5475; and submitted the treatability summary report with cleanup alternatives for TFA West by the September 30, 2009 milestones. |
| December 2009 | Submitted FFS list of alternatives for TF5475-1, TF5475-3, VTF5475 and TF518 North to regulatory agencies by the December 18, 2009 milestone. |
| February 2010 | Submitted Draft Work Plan for the Delineation of Mercury in Soil at the Building 212 Facility by the February 2, 2010 milestone. |

**Table 2. Project highlights since the third five-year review. (Continued)**

| Date | Event |
|---|---|
| April 2010 | Remedial Action Implementation Plan Table 5, milestone list was updated with 12 new milestones and regulatory agencies signed new Consensus Statement. |
| April 2010 | Submitted Draft Final Work Plan for the Delineation of Mercury in Soil at the Building 212 Facility to regulatory agencies by the April 30, 2010 milestone. |
| April 2010 | Presented plan for TFD Helipad *in situ* bioremediation treatability test to regulatory agencies by the April 30, 2010 milestone. |
| May 2010 | Submitted Final Work Plan for the Delineation of Mercury in Soil at the Building 212 Facility by the May 29, 2010 milestone. |
| June 2010 | Initiated soil sampling for delineating the extent of mercury in soil at the former Building 212. |
| August 2010 | The Cone Penetrometer Test (CPT) survey of the Building 518 perched zone source area was completed. |
| September 2010 | Submitted Draft FFS for TF5475-1, TF5475-3, VTF5475 and TF518 North to regulatory agencies and the Technical Assistance Grant group by the September 13, 2010 milestone. |
| September 2010 | Drilling and collection of subsurface soil samples from around and beneath Building 419 conducted as part of the Building 419 RCRA Closure Project. |
| September 2010 | Well abandonment activities at the former Gas Pad area were completed. |
| September 2010 | A direct-push CPT survey was performed in an area encompassing the former Buildings 514 and 412 and existing Building 511, 411, and 419. |
| October 2010 | Held meeting to present the planned TFA West Pipeline Extension to the neighboring community by the October 7, 2010 milestone. |
| October 2010 | Initiated TFE Hotspot (TFE-HS) ESAR pneumatic fracturing project. |
| October 2010 | TFD Helipad *in situ* bioremediation test and TFE ELM thermally-enhanced remediation reinitiated. |
| December 2010 | Completed subsurface pneumatic fracturing, tracer dye injection, and well construction at TFE Hotspot source area. |
| November 2010 | Demolition of Building 419 began on November 29, 2010. |
| January 2011 | Completed CPT survey at TFC Hotspot. |
| March 2011 | Submitted Building 212 Status Report. |
| April 2011 | Performed dye-tracer injection test at TFD Helipad *in situ* bioremediation test site. |
| May 2011 | Submitted the Draft Addendum to Remedial Design Report No. 1 for the TFA Arroyo Seco pipeline expansion to regulatory agencies and the Technical Assistance Grant group by the May 1, 2011 milestone. |

**Table 2. Project highlights since the third five-year review. (Continued)**

| Date | Event |
|---|---|
| **July 2011** | **Remedial Action Implementation Plan Table 5, milestone list was updated and regulatory agencies signed new Consensus Statement.** |
| **August 2011** | **Submitted the Draft Final Addendum to Remedial Design Report No. 1 to the regulatory agencies by the August 31, 2011 milestone.** |
| **September 2011** | **Hydraulic testing of Hydrostratigraphic Unit 4 (HSU4) began on September 13, 2011.** |
| **September 2011** | **Submitted the Final Addendum to Remedial Design Report No. 1.** |

**Table 3. Livermore Site treatment facility summary.**

| Facility[a] | Media treated | Contaminants | Facility type[b] | Current technologies | Operating dates |
|---|---|---|---|---|---|
| TFA | Ground water | VOCs | Fixed | Air stripping | April 1989 – present[c] |
| TFA East | Ground water | VOCs | STU | Granular activated carbon (GAC) | August 1999 – present[c] |
| TFA West[d] | Ground water | VOCs | LWRP | Filtered ground water to sanitary sewer | January 2007 – January 2008 |
| TFB | Ground water | VOCs; hexavalent chromium | Fixed | Air stripping; ion exchange | July 1990 – present |
| TFC | Ground water | VOCs; hexavalent chromium | Fixed | Air stripping; ion exchange | October 1993 – present |
| TFC Southeast | Ground water | VOCs; hexavalent chromium | PTU | Air stripping; ion exchange | January 1997 – present[c] |
| TFC East | Ground water | VOCs; hexavalent chromium | MTU | Air stripping; ion exchange | April 2002 – present[c] |
| TFD | Ground water | VOCs | Fixed | Air stripping | September 1994 – present[c] |
| TFD West | Ground water | VOCs | PTU | Air stripping | April 1997 – present |
| TFD East | Ground water | VOCs | PTU | Air stripping | September 1997 – present |
| TFD Southeast | Ground water | VOCs | PTU | Air stripping | March 1998 – present |
| TFD South | Ground water | VOCs | PTU | Air stripping | June 1999 – present[c] |
| TFD Helipad[e] | Ground water | VOCs | PTU | Air stripping | September 1999 – December 2010[c] |
| TFD Southshore | Ground water | VOCs | PTU | Air stripping | June 2000 – present |
| TFD area (STU10)[d] | Ground water | VOCs | STU | GAC | March 2000 – September 2002 |
| VTFD Helipad[e] | Soil vapor | VOCs | VES | GAC | June 2004 – November 2010[c] |
| VTFD ETC South | Soil vapor | VOCs | VES | GAC | July 2005 – present[c] |
| VTFD Hotspot[f] | Soil vapor | VOCs | VES | GAC | September 2005 – October 2010[c] |
| TFE East | Ground water | VOCs | PTU | Air stripping | November 1996 – present[c] |
| TFE Northwest | Ground water | VOCs | PTU | Air stripping | June 1998 – present |
| TFE North (using PTU4)[g] | Ground water | VOCs | PTU | Air stripping | December 1998 – February 2003 |
| TFE Southwest | Ground water | VOCs | MTU | Air stripping | June 2000 – present |
| TFE Southeast | Ground water | VOCs | MTU | Air stripping | March 2001 – present[c] |

**Table 3. Livermore Site treatment facility summary. (Continued)**

| Facility[a] | Media treated | Contaminants | Facility type[b] | Current technologies | Operating dates |
|---|---|---|---|---|---|
| TFE West | Ground water | VOCs | MTU | Air stripping | April 2001 – present |
| VTFE-Eastern Landing Mat | Soil vapor | VOCs | VES | GAC | September 2003 – present[c] |
| VTFE Hotspot | Soil vapor | VOCs | VES | GAC | August 2005 – present[c] |
| TFE Hotspot | Ground water | VOCs | GTU | GAC | August 2005 – present[c] |
| TFF[g] | Ground water | FHCs; VOCs | Fixed | UV/oxidation; air stripping | February 1993 – September 1995 |
| VTFF[g] | Soil vapor | FHCs | VES | GAC with steam regeneration | February 1993 – September 1995 |
| TF406 | Ground water | VOCs | PTU | Air stripping | August 1996 – present[c] |
| TF406 Northwest | Ground water | VOCs | GTU | GAC | July 2002 – present[c] |
| VTF406 Hotspot | Soil vapor | VOCs | VES | GAC | August 2005 – present[c] |
| TFG-1 | Ground water | VOCs | GTU | GAC | April 1996 – present |
| TFG North | Ground water | VOCs | MTU | Air stripping | July 2003 – present[c] |
| VTF511 | Soil vapor | VOCs | VES | GAC | September 2006 – present[c] |
| VTF518[g] | Soil vapor | VOCs | VES | GAC | September 1995 – May 2001 |
| TF518[g] | Ground water | VOCs | MTU | Air stripping | January 1998 – June 2000 |
| TF518 North[h] | Ground water | VOCs | STU | GAC | January 2000 – February 2008 |
| VTF518 Perched Zone[i] | Soil vapor | VOCs | VES | GAC | September 2004 – present[c] |
| TF5475-1[h] | Ground water | VOCs, tritium | CRD | Catalytic Reductive Dehalogenation (CRD) | September 1998 – July 2007 |
| VTF5475[h] | Soil vapor | VOCs, tritium | VES | GAC | January 1999 – October 2007 |
| TF5475-2 | Ground water | VOCs | GTU | GAC | March 1999 – present[c] |
| TF5475-3[h] | Ground water | VOCs, tritium | CRD | CRD | September 2000 – August 2007 |

**Notes appear on the following page.**

**Table 3. Livermore Site treatment facility summary. (Continued)**

**Notes:**

| | |
|---|---|
| **CRD =** | **Catalytic reductive dehalogenation.** |
| **FHCs =** | **Fuel hydrocarbons.** |
| **GTU =** | **GAC Treatment Unit.** |
| **LWRP =** | **Livermore Water Reclamation Plant.** |
| **MTU =** | **Miniature Treatment Unit.** |
| **PTU =** | **Portable Treatment Unit.** |
| **STU =** | **Solar Treatment Unit.** |
| **VES =** | **Vapor Extraction System.** |

[a] **Existing facility locations are shown on Figure 2.**

[b] **Facility abbreviations.**

[c] **Facility operation was affected by the 2008 budget shortfall.**

[d] **Facility is shut down due to regulatory concerns. A pipeline extension has been proposed.**

[e] **Facility is shut down due to an *in situ* bioremediation treatability test.**

[f] **Vapor system is shut down, however ground water extraction continues from the TFD-HS area.**

[g] **Facility is no longer in operation.**

[h] **Facility is shut down pending the results of the Focused Feasibility Study and Enhanced Source Area Remediation treatability tests.**

[i] **Water is collected from this facility into a bubble and treated in batches at TFB.**

**Table 4. Compliance issue summary 2007-2011.**

| Facility | Issue | Resolution and/or Lessons Learned |
|---|---|---|
| TFB | Ground water was inadvertently extracted from well W-655 and pumped to TFB while the air stripper was offline in February 2008. Approximately 250 gallons of untreated ground water was discharged to the ground. About 125 gallons of the total volume infiltrated into the dirt. Water did not reach the drainage ditch near TFB, and the quantity discharged was insufficient to reach ground water. The Regional Water Quality Control Board (RWQCB) was notified. | The cause of the spill was a defective digital output module. The extraction well pumps were manually secured while the digital output module was replaced and corrections were made to the control system. |
| TFD-HPD | TFD Helipad was shut down following the accidental release of untreated ground water from a burst pipe associated with extraction well W-1254 in September 2009. Approximately 3,360 gallons of ground water with an estimated total of 1.3 grams of VOCs were discharged to the ground surface. As the untreated ground water potentially flowed offsite, the RWQCB was notified. The volume of ground water and mass of VOCs released were below permit limits. | The appropriate repairs were made and the facility was restarted. |
| TFD-HPD | A line from well W-1254, which supplies untreated ground water to TFD Helipad, broke and discharged approximately 300 gallons in October 2010. As the discharge traveled north, some water soaked into the ground. The remaining water reached a storm drain (protected by an adsorbent pig), which flowed into Lake Haussmann. There, it presumably blended with water flowing from the lake and discharged to Arroyo Las Positas. Although the untreated ground water contained low concentrations of trichloroethylene (TCE, about 50 ppb), the TCE level was below reporting limits and reportable quantities.<br>This release was reported to the RWQCB. | The appropriate repairs were made and the facility was restarted. |
| TFD-S | In May 2008, TFD South was briefly started for compliance sampling. A break in the piping from extraction well W-1503 went unnoticed and approximately 50 gallons of untreated ground water was discharged. Approximately 40 gallons was discharged onto asphalt, 5 gallons to the storm drain, and 5 gallons to the unpaved ground. Total VOCs spilled were about 10.3 milligrams. The RWQCB was informed. | The facility was shut down and the leak was repaired. |

**Table 4. Compliance issue summary 2007-2011. (Continued)**

| Facility | Issue | Resolution and/or Lessons Learned |
|---|---|---|
| TFD-SE | Water was observed flowing out of a broken pipe associated with TFD Southeast in September 2011. An estimated 200 gallons of untreated groundwater containing TCE was released to soil and asphalt. The water was released onto the soil under the PVC piping, flowed northward across the asphalt pathway and into the soil along the dry channel/settlement basin. The amount of hazardous constituents contained in the released ground water was below the established reportable quantities. | |
| TFD-SS | TFD Southshore effluent exceeded VOC discharge limits in April 2007 (7.29 ppb total VOCs), and the facility was shut down. | The air stripper was cleaned and the air-flow rate meter was adjusted. |
| TFD-SS | A coupling on the TFD Southshore treated water discharge pipe failed in September 2010. Up to 18,000 gallons of treated water were released to the ground surface. Approximately 80% of this discharge flowed into a loading dock drain, which is connected to the LLNL sanitary sewer system. The remaining approximately 3,750 gallons of treated ground water flowed into a grassy area adjacent to Lake Haussmann. A courtesy notification was sent to the RWQCB. | The appropriate repairs were made and the facility was restarted. |
| TFE-NW | In May 2008 at TFE Northwest, a LLNL electrician accidentally broke a valve on well W-1211 influent pipeline. The facility automatically shut down due to low flow. Approximately 30 gallons of untreated water was discharged to asphalt prior to the shutdown. Total VOCs spilled were about 1.5 milligrams. The RWQCB was notified. | The valve was replaced and the facility restarted. |
| TF5475-2 | TF5475-2 effluent exceeded VOC discharge limits in December 2006 (194,000 gallons at 20.9 ppb total VOCs), January 2007 (126,000 gal, 40.0 ppb total VOCs) and February 2007 (20,200 gal, 39.1 ppb total VOCs). This condition was noticed and the facility was shut down on February 6, 2007. | All carbon canisters were replaced with fresh carbon before operations resumed. The primary cause was inattention to analytical results and lack of notification to management. To ensure compliance with effluent discharge requirements, ERD strengthened its monitoring program for all aqueous-phase carbon systems to improve periodic sampling between carbon canisters and timely notification of VOC breakthrough between carbon canisters. |

**Table 5. Total project funding authorized by DOE for fiscal years 2007-2011 for cleanup of the Livermore Site.**

| Fiscal year | Funding ($K) |
|---|---|
| 2007 | 12,556 |
| 2008 | 12,272 |
| 2009 | 12,097 |
| 2010 | 11,065 |
| 2011 | 11,033 |

**Table 6. Livermore Site Source Area Cleanup Technology Evaluation (SACTE) Summary.**

| No | Source Area | Level of Source Area Characterization | Source Area Cleanup Technology Evaluation Summary |
|---|---|---|---|
| 1 | TFA | Moderate | Hydraulic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 2 | TFB | Moderate | Hydraulic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 3 | TFC Hotspot | High | Hydraulic and pneumatic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 4 | TFC North | Very Low | Hydraulic access to contaminants is likely limited; Mass-transfer limitations control cleanup time. |
| 5 | TFD Hotspot | High | Hydraulic and pneumatic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 6 | TFD North | Low | Hydraulic access to contaminants exists; Mass-transfer limitations are not likely to control cleanup time. |
| 7 | TFD Helipad | High | Hydraulic access to contaminants partially exists; Mass-transfer limitations control cleanup time. **ESAR Treatability study for *in situ* bioremediation.** |
| 8 | TFD East Traffic Circle North | Moderate | Hydraulic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 9a | TFD East Traffic Circle South (HSU-2/3A) | Moderate | Hydraulic and pneumatic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 9b | TFD East Traffic Circle South (HSU-3B) | Low | Hydraulic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 9c | TFD East Traffic Circle South (HSU-4) | Low | Hydraulic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 10 | TFD B551 | Very low | Hydraulic access to contaminants is likely limited; Mass-transfer limitations may control cleanup time. |
| 11 | TFE Eastern Landing Mat | High | Hydraulic and pneumatic access to contaminants partially exists; Mass-transfer limitations control cleanup time. **ESAR Treatability study for thermally enhanced remediation and dynamic well-field operation.** |

**Table 6. Livermore Site Source Area Cleanup Technology Evaluation (SACTE) Summary. (Continued)**

| No | Source Area | Level of Source Area Characterization | Source Area Cleanup Technology Evaluation Summary |
|---|---|---|---|
| 12 | TFE Hotspot | High | Hydraulic access to contaminants is limited; Mass-transfer limitations control cleanup time. **ESAR Treatability study for pneumatic fracturing.** |
| 13 | TFE Southeast | Low | Hydraulic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 14 | TFG North | Very low | Hydraulic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 15 | TFH T5475 | High | Hydraulic and pneumatic access to contaminants partially exists; Mass-transfer limitations control cleanup time. **ESAR Treatability study for dynamic well-field operation.** |
| 16 | TFH T5425 | Low | Hydraulic and pneumatic access to contaminants is likely limited; Mass-transfer limitations control cleanup time. |
| 17 | TFH B419 | High | Hydraulic and pneumatic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 18 | TFH B511/B514 | Moderate | Hydraulic and pneumatic access to contaminants is limited; Mass-transfer limitations control cleanup time. |
| 19 | TFH TF406 Hotspot | Low | Pneumatic access to contaminants is partially limited; Mass-transfer limitations may control cleanup time. |
| 20 | TFH B518 Perched Zone | High | Hydraulic and pneumatic access to contaminants is limited; Mass-transfer limitations control cleanup time. |

**Notes:**

**ESAR = Enhanced Source Area Remediation.**

**Table 7. Estimated volume and mass of VOCs remaining in saturated hydrostratigraphic units (HSUs) in the vicinity of the Livermore Site.[a]**

| HSU | Estimated pore volume containing VOCs greater than 5 ppb (Mgal) | Estimated VOC mass dissolved in ground water (kg) |
|---|---|---|
| HSU-1A | 0.1 | <0.002 |
| HSU-1B | 480 | 41 |
| HSU-2 | 1,400 | 210 |
| HSU-3A | 260 | 95 |
| HSU-3B | 83 | 27 |
| HSU-4 | 59 | 22 |
| HSU-5 | 240 | 83 |
| Total | 2,522.1 | 478 |

**Notes:**

HSU = Hydrostratigraphic unit.

kg = Kilograms.

Mgal = Millions of gallons.

ppb = Parts per billion.

VOC = Volatile organic compound.

[a] Based on data through September 2011. Numbers are rounded to two significant digits as there is uncertainty in estimating mass remaining in the subsurface.

**Table 8. Livermore Site Record of Decision Cleanup Standards and current ground water Maximum Contaminant Levels.**

| Constituent | 1992 Record of Decision Cleanup Standards | 2012 Maximum Contaminant Levels (Federal and California[e]) |
|---|---|---|
| Tetrachloroethene | 5 µg/L | 5 µg/L |
| Trichloroethene | 5 µg/L | 5 µg/L |
| 1,1-Dichloroethene | 6 µg/L | 6[e] µg/L |
| cis-1,2- Dichloroethene | 6 µg/L | 6[e] µg/L |
| trans-1,2- Dichloroethene | 10 µg/L | 10[e] µg/L |
| 1,1- Dichloroethane | 5 µg/L | 5 µg/L |
| 1,2- Dichloroethane | 0.5 µg/L | 0.5[e] µg/L |
| Carbon tetrachloride | 0.5 µg/L | 0.5[e] µg/L |
| Total Trihalomethanes[a] | 100[a] µg/L | 80 µg/L |
| Benzene | 1.0 µg/L | 1.0[e] µg/L |
| Ethyl benzene | 680 µg/L | 300[e] µg/L |
| Toluene | 1,000 µg/L | 1,000 µg/L |
| Xylenes (total) | 1,750[b] µg/L | 1,750[e] µg/L |
| Ethylene dibromide | 0.02 µg/L | 0.05 µg/L |
| Chromium+3 | 50 (total Cr)[c] µg/L | 50 (total Cr)[e] µg/L |
| Chromium+6 | 50 (total Cr)[c] µg/L | 50 (total Cr)[e] µg/L |
| Lead | 15[d] µg/L | 15[d] µg/L |
| Tritium | 20,000 pCi/L | 20,000[f] pCi/L |

**Notes:**

[a] **Total trihalomethanes (THMs); includes chloroform, bromoform, chlorodibromomethane, and bromodichloromethane.**

[b] **MCL is for either a single isomer or the sum of the ortho, meta, and para isomers.**

[c] **National Interim Primary Drinking Water Regulation for total chromium is presently 50 ppb, but will increase to 100 ppb in July 1992. No MCLs exist for Cr+3 or Cr+6.**

[d] **National Primary Drinking Water Regulation Enforceable Action Level (Federal Register, volume 56, number 110, June 7, 1991, p. 26460).**

[e] **California Maximum Contaminant Levels in Drinking Water, California Code of Regulations (CCR Title 22).**

[f] **Gross beta MCL is 4 millirem/year annual dose equivalent to the total body or any internal organ.**

# Appendix A

# Livermore Site June 2011 Consensus Statement

# Consensus Statement for the Environmental Restoration of the Lawrence Livermore National Laboratory Livermore Site June 2011

The parties to this Consensus Statement – U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA), the San Francisco Bay Regional Water Quality Control Board, and Department of Toxic Substances Control – are those parties that entered into the Federal Facility Agreement (FFA) of November 2, 1988, for the Lawrence Livermore National Laboratory (LLNL) Livermore Site. This Consensus Statement does not amend the existing FFA.

**Consensus Statement History**

In a July 1994 Consensus Statement, the parties agreed to the following Livermore Site ground water cleanup priorities:

1. Western plume capture.
2. Southern plume capture.
3. Internal source control/mass removal.

Since then, the regulatory agencies agreed that DOE/LLNL had addressed western and southern plume capture (items 1 and 2 above), and had begun to address internal source control (item 3). DOE/LLNL and the regulatory agencies also agreed to use portable ground water treatment units instead of permanent facilities and pipelines to reduce cleanup time and cost. Engineered Plume Collapse (EPC) and Phased Source Remediation (PSR) strategies were adopted that incorporated distal plume cleanup, hydraulic control of source areas, and source area remediation. EPC and PSR are intended to accelerate cleanup consistent with the remediation strategy described in the Record of Decision (ROD). Treatment facilities are located to remediate the distal plumes as well as to more rapidly remove volatile organic compound (VOC) mass and eliminate downgradient movement of the plumes. Hydraulic control and cleanup of source areas are the focus of new remediation activities while western and southern plume capture, cleanup, and compliance monitoring continue with the objective of continuing operation until cleanup standards are achieved.

At the end of fiscal year 2006 (FY 2006), all milestones on the Remedial Action Implementation Plan schedule were completed, constituting "build-out" as defined by DOE, Office of Environmental Management (EM). The Livermore Site project remains the responsibility of DOE, but has been transferred internally from EM to the National Nuclear Security Administration (NNSA) in FY 2007. The NNSA is a semi-autonomous agency within DOE.

Additional milestones have been identified by DOE and the regulatory agencies and a new schedule has been developed identifying key milestones as described below.

**Current Consensus**

The following change is proposed to the Remedial Action Implementation Plan (RAIP) Table 5 milestone list. Seventeen new milestones have been added to Table 5 and have completion dates scheduled from May 2011[1] through November 30, 2013. The new milestones include: submitting the quarterly Self Monitoring Reports, Annual Reports, and Draft, Draft Final, and Final Five-Year Review, and receiving regulatory comments on the Draft Five-Year Review. In addition, the following four existing milestones dates have been changed: receiving regulatory comments on Draft Focused Feasibility Study (FFS) for TF5475-1, TF5475-3, VTF5475 and TF518 North, and submitting the Draft Final and Final FFS documents and the Interim Summary report for TFD Helipad *in situ* bioremediation treatability test to regulatory agencies.

The signatures of the Remedial Project Managers below demonstrate that the parties have reached consensus to the milestones on the May 2011 amendment to the Remedial Action Implementation Plan Table 5. Priorities and milestones can be reviewed at any time at the request of any of the parties. Any changes must be agreed by all parties.

[1] The 5/31/11 milestone for the First Quarter 2011 Self Monitoring Report has been completed and is included in Completed Milestones summary table.

The following parties agree to this Consensus Statement:

6/29/11
Date

Phillip W. Wong
Remedial Project Manager
Livermore Site Office
U.S. Department of Energy

6/29/11
Date

Kathy Setian
Remedial Project Manager
U.S. Environmental Protection Agency

6/29/11
Date

Jacinto Soto
Remedial Project Manager
California Environmental Protection Agency
Department of Toxic Substance Control

6/29/11
Date

Agnes Farres
Remedial Project Manager
California Environmental Protection Agency
Regional Water Quality Control Board
San Francisco Bay Region

# Appendix B

# The Remediation Evaluation (REVAL) Process

# Appendix B

# The Remediation Evaluation (REVAL) Process

DOE/ERD developed the REVAL process, to systematically evaluate treatment facilities. The process was designed to conduct the following activities at each facility:

- Track maintenance and repair work that was required for each facility;
- Document existing facility, pipeline and extraction well conditions;
- Standardize equipment and instrumentation;
- Collect groundwater analytical data from extraction and performance monitoring wells to assess potential rebound during the hiatus in operations;
- Collect information on the specific capacity of extraction wells; and
- Collect subsurface hydraulic and pneumatic interference information during extraction well field startup.

**Table B-1. Summary of the Remedial Evaluation (REVAL) Process.**

| REVAL Process Step | Description of Activities |
|---|---|
| 1 - Project Initiation | The project is initiated with a document that identifies the project personnel and details individual roles and responsibilities. The document also refers to all applicable site safety and security procedures, standard operating procedures, and all relevant regulatory documentation. |
| 2 - Remedial System Review/Design | The hydrogeologist reviews the effectiveness of the extraction well field and recommends adjustments. The engineering team performs a treatment facility assessment to identify necessary repairs, modifications, and recommend upgrades. During this step, all facility design, operation, and maintenance documentation is reviewed and updated as necessary. |
| 3 - Facility Repairs, Modifications, and Construction | The engineering team performs the necessary repairs and modifications to the facility and documents "as-built" drawings. |
| 4 - Initial Well Field Sampling | The hydrogeologist identifies the extraction and monitoring wells that require sampling. Field personnel sample these wells prior to the startup of the facility. The analytical results are used to evaluate potential rebound in concentrations while the facility was shutdown. |
| 5 - Facility Testing and Verification | The engineering team performs testing and verification of the treatment facility components. The facility is then operated on a day-only (test) basis until all facility systems are verified. Once all the interlocks are verified, the facility is run on a 24-hour basis. |
| 6 - Extraction Well Field Startup | The hydrogeologist prepares an extraction well field startup plan using data gathered during the testing and verification step. The startup plan includes specific capacity testing of each well followed by a phased startup of the entire extraction well field to determine hydraulic or pneumatic interference. |
| 7 - Project Completion, Verification and Review | The project is completed and the facility is continuously operated beginning with this step. A feedback meeting is held to review lessons learned and to apply them to the next project. |

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