Chapter

6

Lawrence Livermore National Laboratory

History and Mission

In 1942 a large property neighboring Livermore, California was converted from agricultural land to a training aircraft assembly facility for the Navy. Around 1951, the Atomic Energy Commission began construction of the Lawrence Livermore National Laboratory (LLNL) Site. The site was established in 1952 as the second nuclear weapons design center.[1] Historically, the site is known for the development, fabrication and testing of new weapons at the Nevada Test Site. The current mission of this research facility includes:

- Perform research, development and testing of nuclear weapons and other weapons systems, such as "Star Wars";
- Re-design and modify the design of several nuclear warheads;
- Testing of weapons through experiments and three-dimensional modeling;
- Other National Nuclear Security Administration Programs.

Location and Land

LLNL is composed of two sites that are not adjacent to one another: the Main Site and Site 300. Both sites are currently on the Superfund National Priorities List with the Main Site placed on the list in 1987 and Site 300 placed on the list in 1990. LLNL's Main Site is located on one square mile of land at the edge of Livermore, California, which is about 40 miles southeast of San Francisco (population 776,733) and San Jose (population 894,943). Existing facilities at the Main Site include a high explosives application facility, a plutonium facility, and a tritium facility. Site 300 is located 16 miles to the southeast of the Main Site. (See Figure 1.)

LLNL is owned by the Department of Energy (DOE) and operated by the University of California, Board of Regents. Some of the facilities and parking lots at the Main Site are shared with Sandia National Laboratory along the southern border. The Sandia National Laboratory provides engineering support to the lab and assembles nuclear warhead components for testing at the Nevada Test Site.

Main Site

The Main Site is situated on approximately 800 acres (>1 square mile) of land and is bordered by residential subdivisions on the western boundary approximately 3 miles from downtown Livermore. A plutonium facility at this site is authorized to house up to 1540 pounds of plutonium, which is the administrative limit for plutonium at the site. The administrative limit of LLNL for enriched uranium (>1% weight U-235) is 1100 pounds and for unenriched uranium (<1% weight U-235) is 6600 pounds.[2] The surface slopes gently and is heavily developed.[13] A storm water drainage retention basin, 800 feet by 300 feet located near the center of the site, was lined to prevent infiltration of ponded surface water to the groundwater below.[4]

Number of people living within 50 miles of LLNL: Greater than 6 million, including San Francisco and San Jose[5]

Employees at LLNL: 110 DOE. 6,403 Contractor Employees[6]

Site 300

The land for Site 300 was acquired in 1955 for the development and testing of high explosive materials and components of nuclear weapons. Site 300 is located on 7,150 acres (11 square miles) about 8.5 miles from Tracy, California; the land is hilly and consists primarily of undeveloped land, steep hills and deep ravines with soil highly susceptible to erosion and several earthquake faults.[7]

The primary function of Site 300 is to study the results of tests that simulate nuclear weapons explosions using the materials that are in a nuclear weapon, with surrogate materials substituted for fissile materials. In addition, this site is also used for high-explosive research, fabrication, and testing. Groundwater and soil contain materials used in nuclear bombs, such as tritium, depleted uranium, and some explosive compounds (RDX, HMX). The open space surrounding the site is used mainly for recreation and ranching.

A potential exposure to agriculture, and future development of adjacent areas results from the contamination of groundwater. Although the two sites are not adjacent to one another, contamination remains in the groundwater at both sites and in springs at Site 300. Groundwater flows freely beneath the surface of Site 300 due to the highly permeable interconnected coarse-grained sediments.[8]

Water Sources – Main Site

Surface Water

Four streams flow intermittently and merge at the base of Livermore Valley heading toward the San Francisco Bay: Arroyo Seco, Arroyo Las Positas, Arroyo Mocho, and Altamont Creek. Arroyo Mocho and Altamont Creek do not flow onsite.[9] From October to April, Arroyo Seco and Arroyo Las Positas travel through the site picking up contaminants, and recharging the groundwater during wet periods. Arroyo Seco is a deep channel that carries and contains the floodwaters from periodic storms. It is typically dry 6 months out of the year and carries only storm water drainage from the hills and from East Avenue.

Arroyo Las Positas is a narrow and shallow channel that is diverted along a storm ditch around the northern edge of the site and exits in the northwest corner of the site.[10] This stream typically carries only storm water runoff. Both streams join west of LLNL. Storm water is collected and channeled to these streams through gutters, culverts, and open ditches. These streams serve as a recharge to the groundwater during the wet periods. Sources of additional surface water onsite at LLNL include storm-water runoff, treated effluent from plant operations, and a drainage retention pond.

The South Bay aqueduct, an integral part of California's water system, passes within 500 feet of both the LLNL Main Site and the Sandia Laboratory Site. It provides water for drinking, agricultural purposes, and groundwater recharge. Accidental airborne releases of toxic or radioactive substances from the Main Site have the potential to contaminate this aqueduct.[11]

Aquifer

Al groundwater beneath the Main Site is contained in the Spring and Mocho I hydrologic sub-basins and is semi-confined. The depth of the groundwater ranges from 25 feet to 120 feet beneath LLNL.[12]

Water Sources – Site 300

Surface Water

Many springs and creeks neighboring the site are contaminated. Corral Hollow Creek flows on the southern border of Site 300 and contains several ravines and intermittent springs contaminated by solvents.

Aquifer

Characterization beneath Site 300 is extremely difficult due to complex geology and hydrology. At least five different geologic formations and several fault zones exist beneath Site 300. As the groundwater follows the incline of the bedrock, the direction of the groundwater flow and the rate of movement vary. It is known that groundwater beneath Site 300 includes two regional aquifers and several perched aquifers. The regional aquifers consist of an upper and a lower aquifer and are known as the Livermore Formation. These aquifers are of great importance due to the climate and heavily populated areas that are increasingly growing closer to Site 300. There are a few areas offsite to the west that have yet to be fully characterized.[13]

Groundwater flow:
Main Site: Westward at a rate of 70 feet per year[14]
Site 300: Flow rates and direction vary with the terrain

Average Annual Precipitation: 14 inches per year for the Main Site and 10 inches per year for Site 300[15]

Differences arise in groundwater flow and surface patterns of the Main Site and Site 300 due to differences in terrain. Altamont Pass is located between the Main Site and Site 300. This Pass is windy and contains one of the largest windmill farms in the west.[16] Although the two sites are only 16 miles apart, groundwater flow and precipitation differ between the two sites.

LLNL is located in a semiarid climate with very permeable soils. The lack of groundcover allows for recharge to the groundwater from surface water and precipitation.[17] (Ground cover inhibits the flow of surface water.) Groundwater is used for agriculture and drinking water for the cities of Tracy, Livermore, and other neighboring regions.[18] Surrounding populations are increasing and contamination is a pressing concern for neighboring communities at both sites.

Contamination

Main Site

Contamination at the Main Site is significant. In 1987, the Environmental Protection Agency (EPA) added the site to the Superfund List, primarily due to numerous volatile organic compounds in a half-mile groundwater plume emanating from the site and heading westward towards Livermore's municipal drinking water wells. This plume contains Freon-113, trichloroethane, trichloroethene, dichloroethene, and dichloroethane. Also found in groundwater were benzene, toluene, carbon tetrachloride, chromium, and tritium in excess of drinking water standards.

The Main Site created transuranic waste, mixed low-level waste, and low-level waste primarily contaminated with trichloroethene and tritium. Liquids dumped into unlined lagoons, streams, or directly into the ground contaminated this area. Most of the contamination came from leaking tanks and disposal in unlined pits through the early-1960s with disposal in evaporation trays through the mid-1970s.[19] Contamination in nineteen different onsite areas has resulted from these poor waste management operations.

As of 2002, approximately 223 storage tanks are located onsite, 46 of which are underground and store hazardous materials.[20] In addition, an underground fuel tank, located in the southern part of the site, leaked 17,000 gallons of leaded gasoline. Twelve groundwater plumes contaminated with volatile organic compounds stretch beneath 85% of the site. The trichloroethylene plume is the most extensive in this area covering 1.4 square miles and serving as a potential threat to private and municipal wells.[21] In 1967, the largest release of plutonium to the sewer occurred (approximately 32 mCi). This release was then sent to the local wastewater reclamation facility, and the resulting sludge was distributed to an unknown number of people for their gardens.

Accidental releases have resulted in large amounts of radionuclides and hazardous materials emitted to the environment.[22] The first large airborne release occurred in 1965 with the release of 350,000 curies of tritium.[23] In 1970, 300,000 curies of tritium were released to the surrounding environment.[24] In 1973, it is believed that plutonium was released to the soil. In 1978, americium was improperly disposed of, and curium leaked from storage drums.[25] The Taxi Strip Area and a solar evaporator pond have also leaked tritium. In 1983, a drum containing 2 mCi of curium spilled onto the soil in the Waste Management Facility Compound. Five thousand curies and 1000 curies of tritium were released respectively in 1984 and 1985 from the Tritium Research Facility. Each accidental release has contributed further to groundwater contamination onsite and offsite. Most of these accidents were due to human error and have placed a large number of resources and people at great risk with the spread of contamination.[26] (See Figure 2.)

Initially, wastes were dumped into earthen pits. After 1962 the pits were replaced with solar evaporation trays where the radioactive liquid wastes were allowed to evaporate, and the remaining salts were rolled up in a plastic liner and then placed in 55-gallon drums.[27] In 1982 and 1983, four former pits in this area were excavated and backfilled. The evaporation of materials contributed to air pollution in addition to contamination that remained in the soil.

In 1984, the East Taxi Strip Circle Landfill was discovered and shortly after excavated and backfilled. This landfill was located near the east boundary of the Main Site. The radionuclide-contaminated waste was packaged into drums and transferred to the Waste Management Facility onsite. The state began investigations for suspected groundwater contamination at LLNL in 1984. At that time, perchloroethylene was discovered in a well offsite.

Site 300

A rainy year at Site 300 enables the pits to fill with water. As the water infiltrates into the soil, contaminants are carried into the groundwater. Additional sources of contamination result from disposal into landfills, drywells, and wastewater lagoons. Primary facilities contributing to the releases include the General Services Area, High Explosives Process Area, Building 833 and 834, the Pit 6 and 7 Landfills, Building 850 Firing Table, and the Canyon behind Building 832. Some of the contamination has migrated offsite.[2] (See Figure 3.)

Contaminants of Potential Concern found in aquifers
Volatile Organic Compounds:
Benzene, carbon tetrachloride, chloroform, dibromide, 1-dichloroethene, 2-dichloroethene, 1-dichloroethane, 2-dichloroethane, ethylbenzene, ethylene, nitrate, perchlorate, perchloroethylene,
trichloroethene, trichloroethane, toluene, and trihalomethane
Metals:
Chromium and lead
Radionuclides:
Plutonium, tritium and uranium

The General Services Area includes support facilities for all of Site 300. This is an area of concern due to abandoned debris trenches and closed drywells where solvents were disposed. The contaminant plume that starts in this area originally spread roughly one mile off the site in an east-northeast direction.[29] Extensive pump-and-treat remediation has pulled the plume back near the site boundary, but not yet within the boundary. Trichloroethene contaminated plumes extend to the shallow alluvial aquifer in the Corral Hollow Basin and into the corresponding regional aquifer. Two water supply wells have been sealed to prevent vertical contaminant migration.

Contamination of the soil surrounding Building 834 has resulted from previous pipe leaks and spills, estimated at 550 gallons. Volatile organic compounds are found in the soil, bedrock, and groundwater, and the primary contaminant is TCE. Minor tetra 2-ethylbutylorthosilicate (T-BOS) and diesel fuel contamination are also present. Interim soil vapor and groundwater extraction are ongoing as a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) removal action. [30](See Figure 4.)

An area known as Pit 6 is located on 43 acres in the southern portion of Site 300 and consists of two former disposal areas for solid waste: the Pit 6 Landfill and Paper Canyon Area. Three unlined trenches and six unlined pits comprise the area. Bulk solid wastes including empty drums, capacitors, and wastes from biomedical experiments were disposed of in this area.[31] Despite the many items buried in this area, only TCE, nitrate, perchlorate, and tritium have migrated beyond the pit boundaries. No remedial actions have been conducted except for surface drains and placement of a compacted native soil cover.

The East Firing Area (EFA) and West Firing Area (WFA) of Site 300 encompass over 3,200 acres and are divided into four sub-areas consisting of the Pit 7 Complex, the Building 850/Doall Ravine Area, the Southern WFA, and the EFA. The area has been operating since 1955 for use in explosives experiments on seven outdoor gravel-covered firing tables. Contamination at Site 300 arises from high explosive detonations that release highly toxic beryllium and depleted uranium into the air. Winds then carry the contaminants to nearby surface water, soil and people.[32] In over 65 buildings in the study area, dynamics testing, linear accelerator research and other work has taken place.

Primary areas of contamination include groundwater plumes contaminated with tritium and uranium, firing tables with contaminated surface soil, two springs, and ten areas of subsurface soil contamination. Maximum concentrations of depleted uranium were measured at 50 pCi/g in soil and 120 pCi/L in groundwater. A rise in the water table in the 1980s saturated the fill and mobilized the tritium from Pits 3 and 5 enabling the release of tritium into the environment. Concentrations in groundwater were measured as high as 1.8 million pCi/L in 1984. TCE was also released from pit 5 into groundwater in concentrations of up to 15.6 ppb.

In December 1996, LLNL reported that a groundwater sample south of Pit 5 contained 1.3-1.4 million pCi/L of tritium, a five-fold increase from previous samples. The suspected cause is groundwater rising from beneath the pit, saturating the material, and mobilizing the tritium in the groundwater. It was also hypothesized that direct infiltration of the pit might be responsible. These are the same phenomena that mobilized the tritium in the early 1980's. Tritium was detected in the area containing the Building 850 Complex and firing table. Maximum concentrations detected in soil moisture were 15.0 million pCi/L. The maximum concentrations were 200,000 pCi/L in surface water, and 566,000 pCi/L in groundwater. Once the contaminated gravel and soil were removed from the firing tables and placed in pits 1 and 7, the pits were covered with engineered caps.

Remedial actions have included covering the landfills with compacted native clay soil. Capping impedes the flow of contaminants on the surface, but does not restrict the infiltration into the subsurface. Complete remediation is increasingly difficult due to the continued operation and the limited amount of money allotted for cleanup activities.

Remediation

Remediation strategies differ between the Main Site and Site 300. At the Main Site, remediation technologies include UV/hydrogen peroxide, air stripping, Dynamic Underground Stripping-Hydrous Pyrolysis/Oxidation and in-situ and ex-situ catalytic reduction for mixed halogens and tritium in groundwater.[33] The primary method of remediation used at the Main Site is pump-and-treat. This method maximizes plume capture and contaminant removal for over one billion gallons of contaminated groundwater. However, pump-and-treat does not remove tritium.[34]

Remediation technologies at Site 300 include landfill capping, pump-and-treat, excavation, treatability studies of a permeable barrier wall, phytoremediation, and ex-situ bioremediation.[35] A few methods of remediation are already in place onsite including pump-and-treat, in-situ microbial filters, and natural attenuation (for tritium).[36]

Objectives for cleanup of the Main Site include:

Prevent future human exposure to contaminated groundwater and soil;
Prevent further migration of contaminants in groundwater;
Reduce contaminant concentrations in groundwater to levels below requirements and reduce the contaminant concentrations in treated groundwater to levels below State discharge limits;
Prevent migration in the unsaturated zone of those contaminants that would result in concentrations in groundwater;
Meet all discharge standards of existing permits for treated water, and to treat vapor so that there are no measurable atmospheric releases from treatment systems.[37]

Challenges

The Proposed Plan for the cleanup of the site does not include a continued search for the location of Dense Non-Aqueous Phase Liquids (DNAPLs). One 55-gallon drum of DNAPLs can contaminate 11 billion gallons of water to the 5 ppb drinking water standard.[38] DNAPLs that remain in the soil or groundwater act as a continuing source of contamination as they slowly dissolve, preventing complete restoration of an area for many years.

Tritium, a contaminant not removed from the groundwater during cleanup, is allowed to decay in place. Low-level waste generated at the Main Site is removed and taken to the Nevada Test Site, and transuranic waste is shipped to the Waste Isolation Pilot Plant in New Mexico. No permanent waste disposal facilities are present at the Main Site. Treatment wastes are disposed of in several ways: by discharge to the sewer, offsite recycling and/or treatment, storage, or disposal offsite. The waste treatment for Site 300 involves burning explosives at the High Explosives Burn Pits.[39]

The spread of contaminants into the groundwater via recharge is problematic. Highly permeable soils and abundant uncovered acreage allow for surface drainage and an increased groundwater recharge surface area.[40] An increase to the recharge of the aquifer beneath Site 300 occurs through surface water runoff during storms. Infiltration of contaminants from the surface into the aquifer is enhanced with the excess water. Site 300 is in dire need of remediation so that other sources of surface water or groundwater are not affected further.

Earthquakes are a significant concern at both sites. Livermore Valley is crisscrossed with faults. Although many of these are considered “inactive,” several earthquakes have caused damage in the region. An earthquake in 1906 caused damage to the city of Livermore, and in 1980 an earthquake measuring 5.9 on the Richter scale caused severe damage to the Main Site, including the cracking of reinforced concrete structures. Any earthquake or tremor presents the risk of radionuclides and hazardous materials being transported further into the soil and groundwater.[41]

Radioactive and hazardous wastes are spread through many different routes. Complete remediation is key to the return of both sites to the previous state. Rapid growth of populated areas neighboring the Main Site and not far from Site 300 will require continued monitoring of contaminants and complicate the continued stewardship of the sites.

[1] Makhijani et al. *Nuclear Wastelands,* 1995: 202.
[2]Inga Olson of Tri-Valley CAREs. *Email.* November 15, 2001.
[3]PM Strauss & Associates of Tri-Valley CAREs. *Email*. October 3, 2001.
[4] US DOE. "Environmental Impact Statement", DOE/EIS-0157: 4.17 <http://nepa.eh.doe.gov/eis/eis0157EIS0157_417.html>.
[5] Estimated from the US Census 2000. <http://factfinder.census.gov/servlet/BasicFactsServlet>.
[6] Schwartz, S.I., "Lawrence Livermore National Laboratory", <http://nuclearfiles.org/sites/llnl.html>, 1998
[7] Coyle et al. *Deadly Defense: Military Radioactive Landfills*, 1988, 54.
[8]US DOE. "NDAA Report to Congress on Long-term Stewardship", January 2001: 41.
[9] "LLNL Comprehensive Site Plan: Surface and Groundwater", <www.llnl.gov/comp_plan/water.html> .
[10] "LLNL Comprehensive Site Plan: Surface and Groundwater", <www.llnl.gov/comp_plan/water.html> .
[11] IngaOlson of Tri -Valley CAREs. *Email.* November 15, 2001.
[12]US DOE. <https://denix.cecer.army.mil/denix/Public/Library/Remedy/LLPT/llnl02.html>.
[13] US DOE. "Environmental Impact Statement", DOE/EIS-0157: 4.17, <http://nepa.eh.doe.gov/eis/eis0157EIS0157_417.html>.
[14]US DOE. <https://denix.cecer.army.mil/denix/Public/Library/Remedy/LLPT/llnl02.html>.
[15]US DOE. "Vadose Zone Fact Sheet: Lawrence Livermore National Laboratory Main Site", September 2000. <http://www.em.doe.gov/vadose/contents.html>.
[16] Inga Olson of Tri-Valley CAREs. *Email.* November 15, 2001.
[17] "LLNL Comprehensive Site Plan: Surface and Groundwater", <www.llnl.gov/comp_plan/water.html>.
[18] PM Strauss & Associates of Tri-Valley CAREs. *Email.* October 3, 2001.
[19]Coyle et al. *Deadly Defense: Military Radioactive Landfills*, 1988: 55.
[20] US EPA. "Record of Decision", EPA/ROD/R09-92/081, August 5, 1992: 2.1.
[21]US DOE. "NDAA Report to Congress on Long-term Stewardship", January 2001: 41.
[22] US DOE. "Baseline Environmental Management Report", 1996, <http://www.em.doe.gov/bemr96/llml.html>.
[23] Lawrence Livermore Lab. "EIR", December 22, 1986.
[24] US DOE. "Baseline Environmental Management Report", 1996, <http://www.em.doe.gov/bemr96/llml.html>.
[25] US DOE. "Baseline Environmental Management Report", 1996, <http://www.em.doe.gov/bemr96/llml.html>.
[26] US DOE. "Baseline Environmental Management Report", 1996, <http://www.em.doe.gov/bemr96/llml.html>.
[27] PM Strauss & Associates of Tri-Valley CAREs. *Email.* October 3, 2001.
[28] US DOE. "Baseline Environmental Management Report", <http://www.em.doe.gov/bemr96/llml.html>.
[29]Strauss, Peter. "Community Guide: Lawrence Livermore National Laboratory Site 300 Superfund Cleanup", December 1997: 32.
[30] US DOE. "Baseline Environmental Management Report", <http://www.em.doe.gov/bemr96/llml.html>.
[31] Strauss, Peter. *Email.* October 3, 2001.
[32] Coyle et al. *Deadly Defense: Military Radioactive Landfills*, 1988:57
[33] Inga Olson of Tri-Valley CAREs. *Email.* November 15, 2001.
[34] US DOE. *NDAA Report to Congress on Long-term Stewardship*, January 2001: 40.
[35] Inga Olson of Tri-Valley CAREs. *Email.* November 15, 2001.
[36] US DOE. *NDAA Report to Congress on Long-term Stewardship*, January 2001:41.
[37] US EPA. "Record of Decision", EPA/ROD/RO9-92/081, August 5, 1992: 2.4.
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[39] US DOE. "Baseline Environmental Management Report", <http://www.em.doe.gov/bemr96/llml.html>.
[40] US DOE. "Environmental Impact Statement", DOE/EIS-0157: 4.17, <http://nepa.eh.doe.gov/eis/eis0157EIS0157_417.html>.
[41] Coyle et al. *Deadly Defense: Military Radioactive Landfills*, 1988: 54.

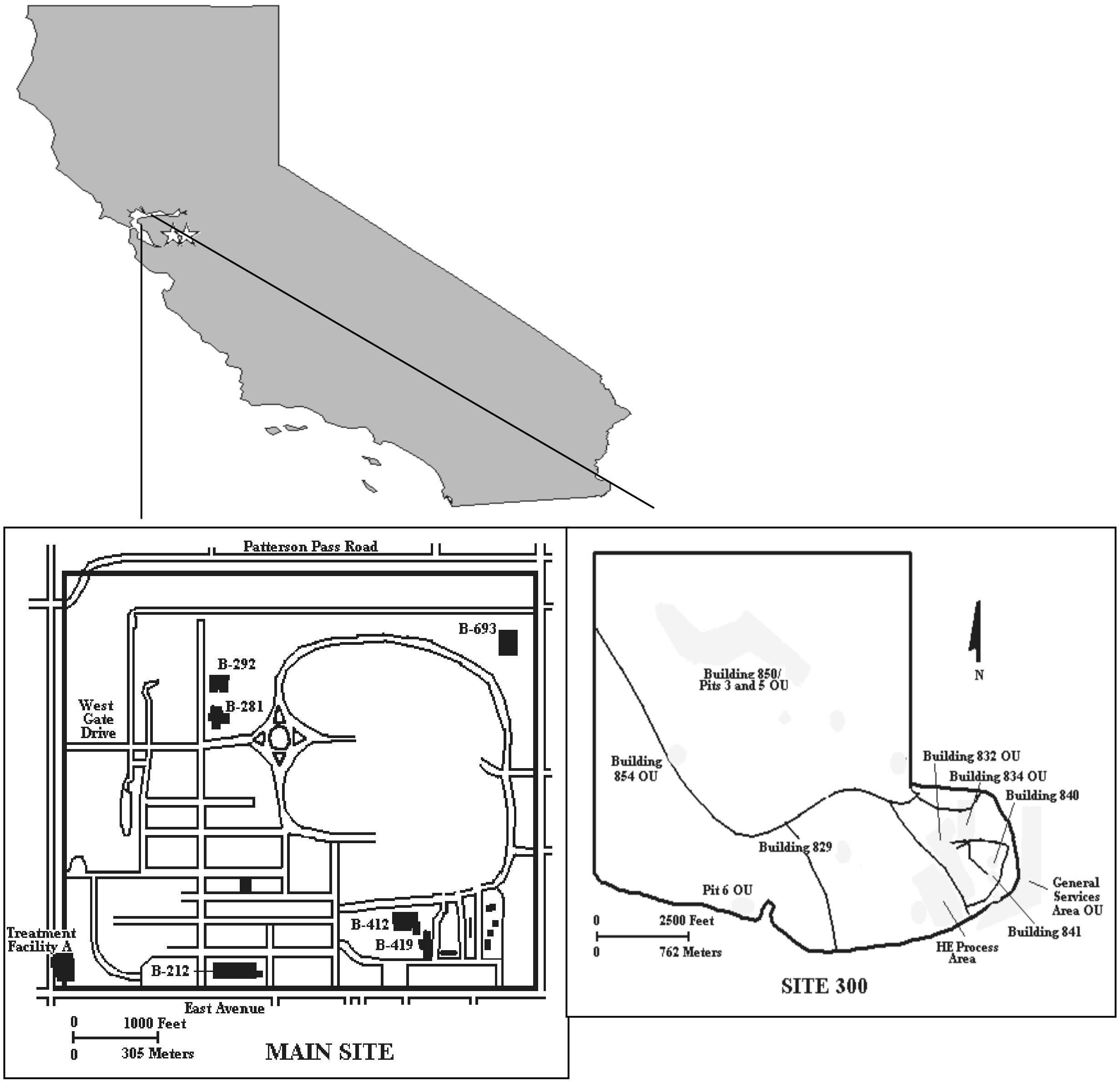
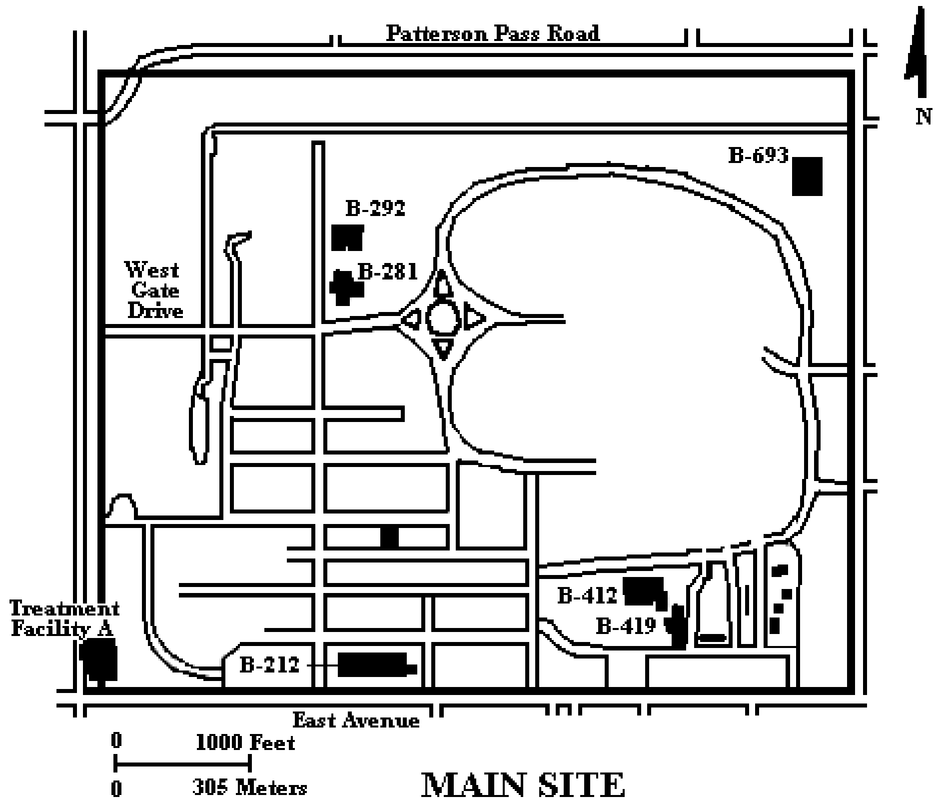


Figure 1: Location of LLNL Main Site and Site 300. The Main Site is adjacent to residences. Site 300 is located 8.5 miles from the town of Tracy.



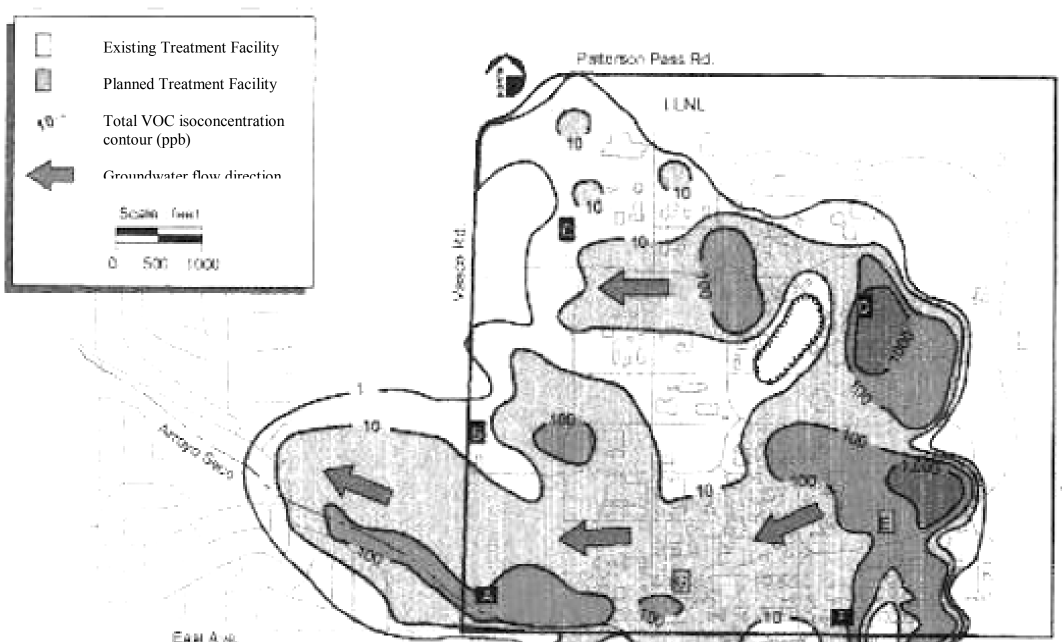


Figure 2. This type of two-dimensional contaminant plume map was used initially for preliminary planning of LLNL pump-and-treat groundwater cleanup.

Figure 2: Main Site Map and Groundwater Contamination

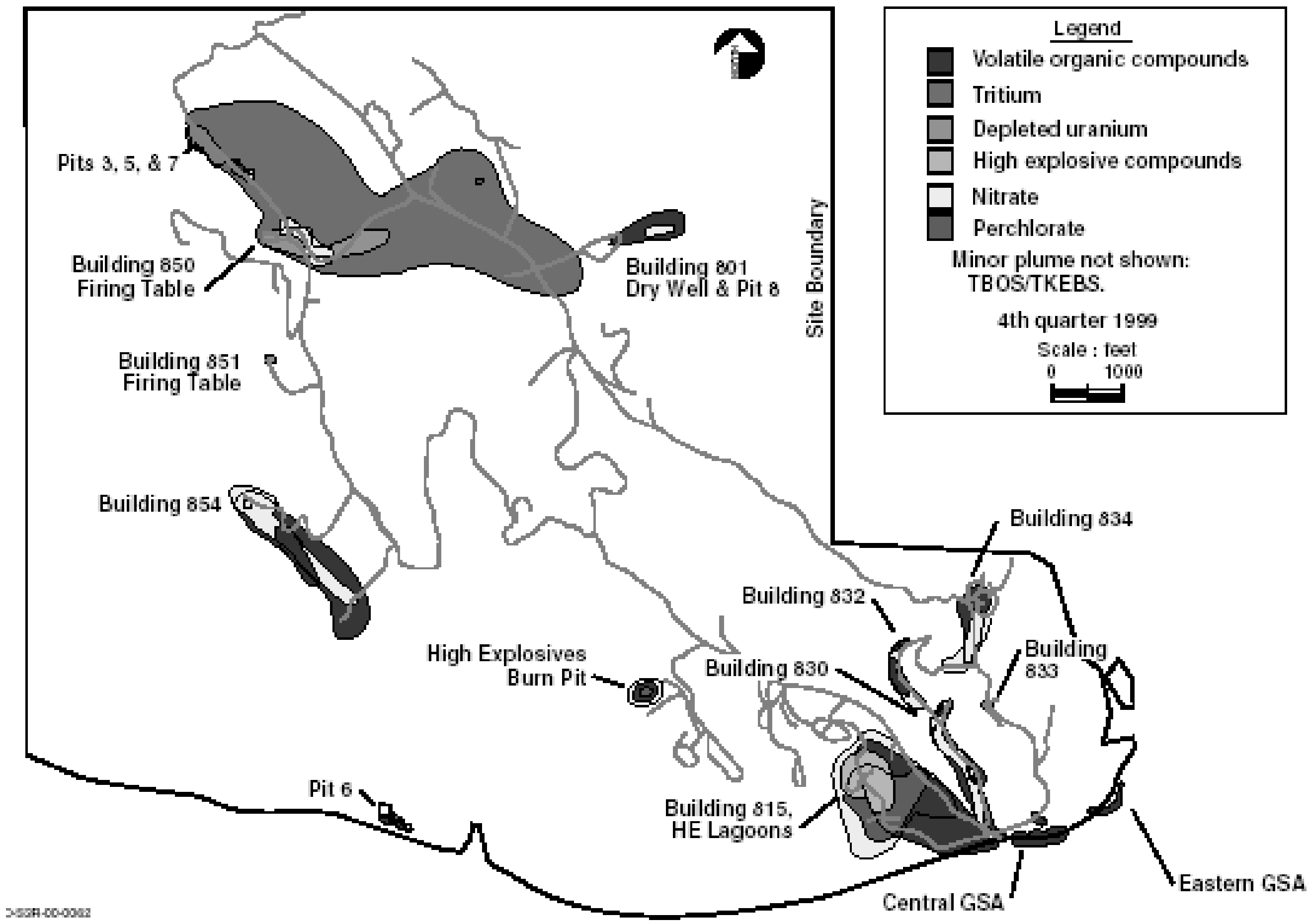


Figure 3: Area 300 Site Map and Groundwater Contamination
Source:http://www-envirinfo.llnl.gov/AR-138470.pdf

Figure 4: Close-up of Building 834 VOC Contamination
Source: http://www-envirinfo.llnl.gov/AR-144919.pdf

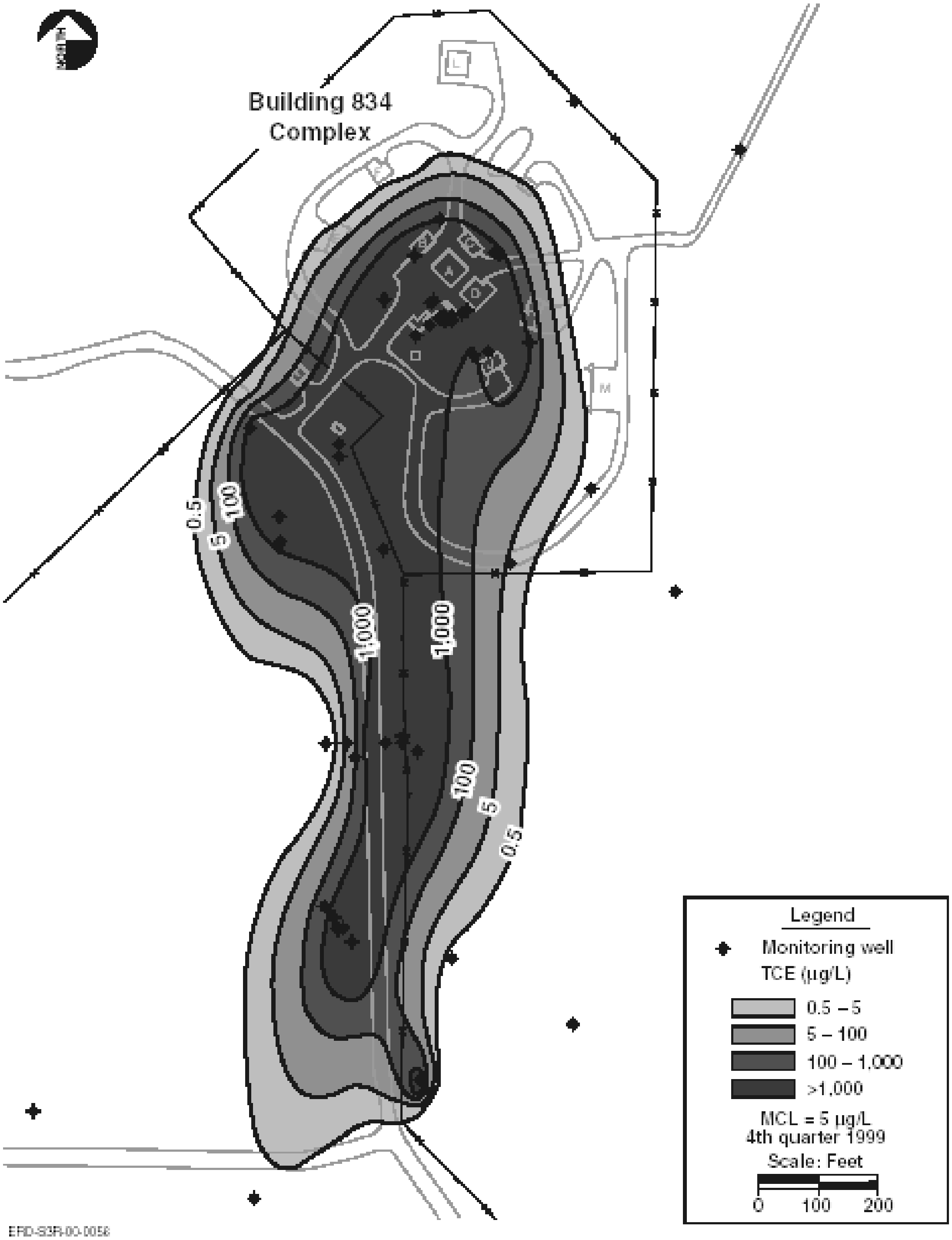


Figure 5: Close-up of Building 834 TCE Contamination
Source: http://www-envirinfo.llnl.gov/AR-138470.pdf