8. Groundwater Investigation and Remediation

Lindee L. Berg, Leslie S. Ferry

During 2007, groundwater investigations and remediations under CERCLA continued at both the Livermore site and Site 300. Lawrence Livermore National Laboratory samples and analyzes groundwater from areas of known or suspected contamination. Portions of the two sites where soil or groundwater contains or may contain chemicals of concern are actively investigated to define the hydrogeology and nature and extent of the contamination and its source. Where necessary, remediation strategies are developed and evaluated in preparation for a CERCLA removal action or through the feasibility study process. An approved remedy for each area is developed in consultation with the regulatory agencies and the community.

This chapter reviews the distribution of contaminants in groundwater and the progress LLNL has made in removing contaminants from groundwater and from the unsaturated zone (soil vapor) at the Livermore site and Site 300. The sites are similar in that the contamination is, for the most part, confined to on site. The sites differ in that Site 300, with an area of 28.3 km^2 (10.9 mi^2), is much larger than the Livermore site and has been divided into eight operable units (OUs) based on the nature and extent of contamination, and topographic and hydrologic considerations. The Livermore site at 3.3 km^2 (1.3 mi^2) is effectively one OU.

8.1 Livermore Site Ground Water Project

Initial releases of hazardous materials occurred at the Livermore site in the mid-to-late 1940s during operations at the Livermore Naval Air Station (Thorpe et al. 1990). There is also evidence that localized spills, leaking tanks and impoundments, and landfills contributed VOCs, fuel hydrocarbons, metals, and tritium to the unsaturated zone and groundwater in the post-Navy era. The Livermore site was placed on the U.S. Environmental Protection Agency National Priorities List in 1987.

An analysis of all environmental media showed that groundwater and both saturated and unsaturated soils are the only media that require remediation (Thorpe et al. 1990). Compounds that currently exist in groundwater at various locations beneath the site at concentrations above drinking water standards (MCLs) are TCE, PCE, 1,1-dichloroethylene, chloroform, 1,2-dichloroethylene, 1,1-dichloroethane, 1,2-dichloroethane, trichlorotrifluoroethane (Freon-113), trichlorofluoromethane (Freon-11), and carbon tetrachloride. PCE is also present at low concentrations slightly above the MCL in off-site plumes that extend from the southwestern corner of the Livermore site. LLNL operates groundwater extraction wells in both on-site and off-site areas. In addition, LLNL maintains an extensive network of groundwater monitoring wells in the off-site area west of Vasco Road.

8.1.1 Physiographic Setting

The general topography of the Livermore site is described in **Chapter 1**. The Livermore Valley groundwater system consists of several semiconfined aquifers. Rainfall from the surrounding hills and seasonal surface water in the arroyos recharges the groundwater system, which flows toward the east-west axis of the valley.

The thickest sediments and aquifers are present in the central and western portions of the Livermore Valley, where they form an important resource for the Zone 7 Water Agency. These sediments comprise two aquifers: the Livermore Formation and overlying alluvium. The Livermore Formation averages about 1000 m in thickness and occupies an area of approximately 250 km^2. The alluvium, which is about 100 m thick, is the principal water-producing aquifer within the valley.

8.1.2 Hydrogeology of the Livermore Site

Sediments at the Livermore site are grouped into four grain-size categories: clay, silt, sand, and gravel. Groundwater flow beneath the site occurs primarily in alluvial sand and gravel deposits, which are bounded by lower permeability clay and silt deposits. The alluvial sediments have been subdivided into nine HSUs beneath the Livermore site. HSUs are defined as sedimentary sequences whose permeable layers show evidence of being hydraulically interconnected. Six of the nine HSUs contain contaminants at concentrations above their MCLs: HSU-1B, -2, -3A, -3B, -4, and -5 (Blake et al. 1995; Hoffman et al. 2003). HSU-1A, -6, and -7 do not contain contaminants of concern above action levels.

8.1.3 Remediation Activities and Monitoring Results

In 2007, LLNL operated 29 groundwater treatment facilities. The 95 groundwater extraction wells and 27 dual extraction wells produced more than 1.1 billion L of groundwater and the treatment facilities removed nearly 71 kg of VOCs. Since remediation began in 1989, approximately 12.9 billion L of groundwater have been treated, resulting in removal of more than 1317 kg of VOCs. Detailed flow and mass removal by treatment facility area is presented in Karachewski et al. (2008).

LLNL also operated 9 soil vapor treatment facilities in 2007. The 31 soil vapor extraction wells and 27 dual extraction wells produced more than 1.5 million m^3 of soil vapor and the treatment facilities removed more than 247 kg of VOCs. During the second quarter of 2007, approximately 104 kg of VOCs were removed from soil vapor. This is the first time that more than 100 kg of VOCs has been removed during a single quarter. Since initial operation, over 8.9 million m^3 of soil vapor has been extracted and treated, removing more than 1300 kg of VOCs from the subsurface. Detailed flow and mass removal by treatment facility area is presented in Karachewski et al. (2008).

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 Enhanced Source Area Remediation (ESAR) activities, include detailed hydrogeologic evaluation, numerical modeling, bench-scale laboratory tests, and field pilot tests. A data evaluation and numerical modeling analysis methodology called the Source Area Cleanup Technology Evaluation (SACTE) analysis was developed to evaluate potential technologies to accelerate source area cleanup. The subsurface hydrogeochemical attributes of all 21 source areas at the Livermore site were catalogued and analyzed with respect to groundwater flow and contaminant transport. The SACTE analysis then used those site-specific attributes 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.

Based on the SACTE analysis, three source areas were selected for conducting ESAR pilot tests in 2007: TFE Eastern Landing Mat, Trailer 5475, and TFD Helipad. The three areas were selected in part because existing infrastructure could be used to reduce the overall cost of the pilot tests. The cleanup technologies selected for evaluation were dynamic wellfield operations for removing residual contamination in the vadose zone, hot air injection and groundwater heating for accelerating contaminant mass removal from both the capillary fringe and the vadose zone, and chemical oxidation and bioremediation for in situ destruction of contaminant mass in the saturated zone. ESAR activities in the three source areas are discussed in Karachewski et al. (2008).

Groundwater concentration and hydraulic data collected and analyzed during 2007 continued to provide evidence for the collapse of off-site contaminant plumes and hydraulic containment along the western and southern boundaries of the site, as well as progress towards cleanup of interior plumes and source areas. This is consistent with the longer-term trends detailed in the 2007 *Third Five-Year Review for the Lawrence Livermore National Laboratory, Livermore Site* (Berg et al. 2007) that show steady cleanup in both off-site and on-site areas.

8.1.4 Environmental Impacts

LLNL strives to reduce risks arising from chemicals released to the environment, to conduct all its restoration activities to protect environmental resources, and to preserve the health and safety of all site workers. LLNL's environmental restoration project is committed to preventing present and future human exposure to contaminated soil and groundwater, preventing further contaminant migration of concentrations above drinking water standards, reducing concentrations of contaminants in groundwater, and minimizing contaminant migration from the unsaturated zone to the underlying groundwater.

Remedial solutions that have been determined to be most appropriate for individual areas of contamination are implemented. The selected remedial solutions, which include groundwater and soil vapor extraction and treatment, have been agreed upon by DOE and the regulatory agencies with public input and are designed to achieve the goals of reducing risks to human health and the environment and satisfying remediation objectives, regulatory standards for chemicals in water and soil, and other state and federal requirements.

8.2 Site 300 CERCLA Project

A number of contaminants were released to the environment during past LLNL Site 300 operations including waste fluid disposal to dry wells, surface spills, piping leaks, burial of debris in unlined pits and landfills, detonations at firing tables, and discharge of rinse water to unlined lagoons. Environmental investigations at Site 300 began in 1981. As a result of these investigations, VOCs, high explosive compounds, tritium, depleted uranium, organosilicate oil, nitrate, perchlorate, polychlorinated biphenyls, dioxins, furans, and metals were identified as contaminants of concern in soil, rock, groundwater, or surface water. This contamination is confined within the site boundaries with the exception of VOCs that are present in three monitor wells near the southern site boundary. LLNL maintains an extensive network of on-site and off-site wells to monitor this contamination. All characterized contaminant release sites that have a CERCLA pathway have been assigned to one of nine OUs based on the nature, extent, and sources of contamination, and topographic and hydrologic considerations. Site 300 was placed on the U.S. Environmental Protection Agency National Priorities List in 1990. Cleanup activities began at Site 300 in 1982 and are ongoing.

Background information for LLNL environmental characterization and restoration activities at Site 300 can be found in Webster-Scholten (1994) and the *Site-Wide Remediation Evaluation Summary Report for Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2006).

8.2.1 Physiographic Setting and Geology of Site 300

Site 300 is located in the southeastern Altamont Hills of the Diablo range. The topography of Site 300 consists of a series of steep hills and canyons generally oriented northwest to southeast. The site is underlain by gently dipping sedimentary bedrock dissected by steep ravines. The bedrock consists of interbedded conglomerates, sandstones, siltstones, and claystones of the late Miocene Neroly Formation (Tn), and a Pliocene nonmarine unit (Tps). The bedrock units are locally overlain by mid- to late-Pleistocene terrace deposits and late-Pleistocene to Holocene floodplain, ravine fill, landslide, and colluvial deposits.

The bedrock within Site 300 has been slightly deformed into several gentle, low-amplitude folds. The locations and characteristics of these folds, in combination with the regional fault and fracture patterns, locally influence groundwater flow within the site.

8.2.2 Contaminant Hydrogeology of Site 300

Site 300 is a large and hydrogeologically diverse site. Due to the steep topography and structural complexity, stratigraphic units and groundwater contained within many of these units are discontinuous across the site. Consequently, site-specific hydrogeologic conditions govern the occurrence and flow of groundwater and the fate and transport of contaminants beneath each OU.

An HSU is a water-bearing zone that exhibits similar hydraulic and geochemical properties. At Site 300, HSUs have been defined consisting of one or more stratigraphic intervals that compose a single hydraulic system within one or more OU. Groundwater movement and contaminant migration in groundwater are discussed in the context of HSUs.

Groundwater contamination at Site 300 occurs in three types of water-bearing zones:

1. Quaternary deposits including the alluvium and weathered bedrock (Qal/WBR HSU), alluvial terrace deposits (Qt), and landslide deposits (Qls HSU).
2. Tertiary perched groundwater in fluvial sands and gravels (Tpsg HSU) and semilithified silts and clay of the Tps HSU.
3. Tertiary Neroly Formation bedrock including the $Tnsc_2$, $Tnbs_2$, $Tnsc_{1b}$ $Tnbs_1$, $Tnbs_0$, and $Tnsc_0$ HSUs.

Groundwater in bedrock is typically present under confined conditions in the southern half of the site but is often unconfined elsewhere. Recharge occurs where saturated alluvial valley fill is in contact with underlying permeable bedrock, and where bedrock strata crop out.

8.2.3 Remediation Activities and Monitoring Results

Cleanup activities were initiated at Site 300 in 1982 and are underway or are in the process of being implemented at all nine OUs. These activities include:

- Operating 20 groundwater and soil vapor extraction and treatment facilities.
- Capping and closing four landfills, six high explosives rinse water lagoons and one high explosives burn pit.
- Removal and/or closure of numerous dry wells throughout the site.
- Removal of contaminated soil from source areas throughout the site.
- Installation and sampling of over 680 groundwater monitor wells to track plume migration and remediation progress.

These remediation efforts have resulted in (1) the elimination of risk to on-site workers from contaminant exposure at eight locations throughout Site 300, (2) a reduction in maximum concentrations of the primary contaminant (VOCs) in Site 300 groundwater by 50% to 99%, and (3) the remediation of VOCs in the eastern General Services Area to meet cleanup standards.

In 2007, LLNL operated 15 groundwater and 5 soil vapor treatment facilities. About 34 million L of groundwater were extracted and treated during 2007. The 18 dual and 2 soil vapor extraction wells removed 1.5 million m^3 of contaminated soil vapor. The Site 300 treatment facilities removed nearly 62 kg of VOCs, 0.1 kg of perchlorate, 390 kg of nitrate, 0.16 kg of the high explosive compound RDX and 0.029 kg of silicone oils (TBOS/TKEBS). Since groundwater remediation began in 1990, approximately 1351 million L of groundwater has been treated, resulting in removal of more than 510 kg of VOCs, 0.7 kg of perchlorate, 5300 kg of nitrate, 0.94 kg of RDX, and 9.4 kg of silicone oils. Detailed flow and mass removal by OU is presented in Dibley et al. (2008).

Construction and buildout of the selected cleanup remedies in the Pit 6 Landfill, High Explosives Process Area, Building 854, and Building 832 Canyon OUs was completed in 2007. Construction was completed for the cleanup remedies at General Services Area, Building 834, and Site-Wide OUs in previous years. Therefore, cleanup remedies have been fully implemented and are operational in seven of the nine OUs at Site 300 to date.

Groundwater concentration and hydraulic data collected and analyzed for Site 300 during 2007 provided evidence of continued progress in reducing contaminant concentrations in Site 300 soil vapor and groundwater, controlling and cleaning up contaminant sources, and mitigating risk to on-site workers. A more detailed description of remediation progress at the Site 300 OUs in 2007 is available in the *2007 Annual Compliance Monitoring Report for LLNL Site 300* (Dibley et al. 2008).

8.2.4 Planned Cleanup Activities

In 2007, a cleanup remedy was selected by the regulatory agencies and DOE for the Pit 7 Complex area in the *Final Amendment to the Interim Site-Wide Record of Decision for the Pit 7 Complex* at *Lawrence Livermore National Laboratory Site 300* (U.S. DOE 2007). In addition, construction began on a drainage diversion system to prevent releases from the Pit 7 Complex landfills and on an extraction and treatment system to remove uranium, VOCs, perchlorate, and nitrate from groundwater in this area. Institutional controls to prevent exposure, and monitoring of contaminants in groundwater are already underway at the Pit 7 Complex.

Cleanup remedies have not yet been selected to address PCB-, dioxin-, and furan-contaminated soil at Building 850; soil and groundwater contamination in Building 812 OU; and for Freon contamination in Building 865 groundwater. In 2007, the *Draft Engineering Evaluation/Cost Analysis for PCB-, Dioxin-, and Furan-contaminated Soil at the Building 850 Firing Table* (Dibley et al. 2007) was submitted to the regulatory agencies. This document presents alternatives for the soil cleanup for regulatory and public consideration and input. The final remedy is scheduled to be selected in an Action Memorandum in 2008. In 2008, a Remedial Investigation/Feasibility Study is scheduled to be submitted for the Building 812 OU. This document will present the results of remedial investigation to characterize contamination and the risk assessment, and present alternatives for the cleanup of soil and groundwater in the Building 812 area for regulatory and public consideration and input. The results of the remedial investigation at Building 865 are still being reviewed by the regulatory agencies.[(1)]

8.2.5 Environmental Impacts

LLNL strives to reduce elevated risks arising from chemicals released to the environment at Site 300, to conduct its activities to protect ecological resources, and to protect the health and safety of site workers. LLNL's cleanup remedies at Site 300 are designed and implemented to achieve the goals of reducing risks to human health and the environment and satisfying remediation action objectives, meeting cleanup standards for chemicals in water and soil, and preventing contaminant migration in groundwater to the extent technically and economically feasible. These remedies are selected by DOE and the regulatory agencies with public input. These actions include groundwater and soil vapor extraction and treatment; source control through the capping of lagoons and landfills, removal of contaminated soil, and hydraulic drainage diversion; and monitored natural attenuation, monitoring, and institutional controls.

(1) See the Environmental Community Relations website for the status of planned activities. Go to www-envirinfo.llnl.gov and click on "Recently completed environmental documents".