

7. Groundwater Investigation and Remediation

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Lawrence Livermore National Laboratory (LLNL) 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, nature, and extent of the contamination and its source. Where necessary, remediation strategies are developed and evaluated through preparation for a Comprehensive Environmental Response, Compensation and Liability Act (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 on site. The sites differ in that Site 300, with an area of 28.3 km² (10.9 mi²), is much larger than the Livermore Site and has been divided into nine Operable Units (OUs) based on the nature and extent of contamination, and topographic and hydrologic considerations. The Livermore Site, at 3.3 km² (1.3 mi²), is effectively one OU.

7.1 Livermore Site Environmental Restoration 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 volatile organic compounds (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 (EPA) 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 (maximum contaminant level [MCLs]) are trichloroethylene (TCE), tetrachloroethene (PCE), 1,1-dichloroethylene, cis-1,2-dichloroethylene, 1,1-dichloroethane, 1,2-dichloroethane, 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.

7.1.1 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

7. Groundwater Investigation and Remediation

hills and seasonal surface water in the arroyos recharge 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 1,000 m in thickness and occupies an area of approximately 250 km². The alluvium, which is about 100 m thick, is the principal water-producing aquifer within the valley.

7.1.2 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 hydrostratigraphic units (HSUs) beneath the Livermore Site. HSUs are defined as sedimentary sequences whose permeable layers show evidence of being hydraulically interconnected and geochemically similar. 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. The large amounts of rainfall experienced during the winter of 2016 and spring of 2017 resulted in significant amounts of recharge, rising groundwater levels, increased yields at many extraction wells, and changes in the size and geometry of hydraulic capture areas and pumping-induced groundwater depressions across the site.

7.1.3 Remediation Activities and Monitoring Results

In 2017, LLNL maintained and operated 27 groundwater treatment facilities. The groundwater extraction wells and dual (groundwater and soil vapor) extraction wells produced more than 973 million L of groundwater and the treatment facilities (TFs) removed 32 kg of VOCs. Since remediation began in 1989, approximately 22.7 billion L of groundwater have been treated, resulting in removal of more than 1,713 kg of VOCs. Detailed flow and mass removal by treatment facility area is presented in Noyes et al. (2018).

LLNL also maintained and operated nine soil vapor treatment facilities (VTFs) in 2017. The soil vapor extraction wells and dual extraction wells produced more than 1.8 million m³ of soil vapor and the treatment facilities removed approximately 11 kg of VOCs. Since initial operation, nearly 23.6 million m³ of soil vapor has been extracted and treated, removing more than 1,597 kg of VOCs from the subsurface. Detailed flow and mass removal by treatment facility area are presented in Noyes et al. (2018).

Six treatment facilities remained offline in 2017:

- Treatment Facility A (TFA-East)
- Vapor Treatment Facility D (VTFD) Helipad

7. Groundwater Investigation and Remediation

- TF5475-1
- TF5475-3
- VTF5475
- TF518 North

TFA East remained off-line due to the lack of groundwater in extraction well W-254, the sole extraction well for this facility. VTFD Helipad remained off-line in support of the *in situ* bioremediation Enhanced Source Area Remediation (ESAR) treatability test at the TFD Helipad Source area. The four remaining facilities were discussed in LLNL (2009). With the U.S. EPA concurrence, restart of these four facilities has been deferred pending the results of ESAR treatability tests. LLNL continues to monitor groundwater for VOCs and tritium. See Noyes et al. (2018) for more information on the Livermore Site groundwater and soil vapor treatment facilities.

Restoration activities in 2017 at the Livermore Site continued to be primarily focused on enhancing and optimizing ongoing operations at treatment facilities, while continuing to evaluate technologies that could be used to accelerate cleanup of the Livermore Site source areas and to address the mixed-waste management issue discussed in the *Draft Focused Feasibility Study of Methods to Minimize Mixed Hazardous and Low Level Radioactive Waste from Soil Vapor and Ground Water Treatment Facilities at the Lawrence Livermore National Laboratory Site* (Bourne et al. 2010).

In 2017, the ESAR treatability tests continued at TFD Helipad (*in situ* bioremediation), TFE Eastern Landing Mat (thermally-enhanced remediation), and TFC Hotspot (emplacement of zero valent iron [ZVI] for *in situ* VOC destruction).

Additional Livermore Site environmental restoration activities performed in 2017 included:

- Drilling and installation of four ground water monitoring wells in the TFD and TFE areas.
- Proper abandonment or decommissioning of thirteen obsolete wells in accordance with Alameda County Zone 7 Water Agency guidelines.
- Implementing treatment facility upgrades and remedial wellfield expansions using the Remediation Evaluation (REVAL) process at TFC Southeast and TFE West, and continuing the process at VTF518 Perched Zone.

Groundwater concentration and hydraulic data indicate subtle but consistent declines in the VOC concentrations and areal extent of the contaminant plumes in 2017. Hydraulic containment along the western and southern boundaries of the site was fully maintained in 2017, and progress was made toward interior plume and source area clean up. See Noyes et al. (2018) for the current status of cleanup progress.

7.1.4 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

7. Groundwater Investigation and Remediation

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 the Department of Energy (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, and of meeting regulatory standards for chemicals in water and soil, and other state and federal requirements.

7.2 Site 300 Environmental Restoration 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 off-site 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), *Final Remedial Investigation/Feasibility Study for the Pit 7 Complex at Lawrence Livermore National Laboratory Site 300* (Taffet et al. 2005), and the *Site-Wide Remediation Evaluation Summary Report for Lawrence Livermore National Laboratory Site 300* (Ferry et al. 2006). Another source of background information is <https://www-erd.llnl.gov/library/index.html>.

7.2.1 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.

7.2.2 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 OUs. Groundwater movement and contaminant migration in groundwater are discussed in the context of HSUs.

Groundwater contamination at Site 300 occurs in three types of HSUs:

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 silts and clay of the Tps/Tnsc₂ HSU.
3. Tertiary Neroly Formation bedrock including the Tnsc₂, Tnbs₂, Tnsc_{1a/b} UTnbs₁, Tnbs₁/Tnbs₀, and Tnsc₀ HSUs.

Groundwater in bedrock is typically present under confined conditions in the southern part 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. Water levels within Site 300 shallow water-bearing zones were recently in decline due to ground water pumping and limited recharge owing to the California drought. During 2017, shallow water-bearing zones throughout Site 300 were recharged by significant rainfall that occurred during the 2016-2017 winter season.

7.2.3 Remediation Activities and Monitoring Results

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

- Operating up to 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.

7. Groundwater Investigation and Remediation

- Removal of contaminated soil from source areas throughout the site.
- Installation of a drainage diversion system at the Pit 7 Complex to prevent groundwater from rising into the landfills and releasing contaminants in the waste.
- Remediation (consolidation and solidification) of 29,000 cubic yards of polychlorinated biphenyl (PCB)-, dioxin-, and furan-contaminated soil in a Corrective Action Management Unit (CAMU) at Building 850.
- Treatability studies for the *in situ* bioremediation of VOCs and perchlorate in groundwater.
- 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%, (3) the remediation of VOCs in groundwater in the Eastern General Services Area to meet cleanup standards, and (4) a reduction of maximum tritium activities in ground water emanating from the Building 850 area to below cleanup standards.

In 2017, the Site 300 Environmental Restoration Project operated 15 groundwater and five soil vapor treatment facilities extracting and treating approximately 28.6 million L of groundwater and 1.5 million m³ of contaminated soil vapor. The Site 300 treatment facilities removed nearly 6.5 kg of VOCs, 0.070 kg of perchlorate, 1,400 kg of nitrate, 0.13 kg of the high explosive compound RDX, 0.0036 kg of silicone oils, and 0.029 kg of uranium in 2017. Since groundwater remediation began in 1990, approximately 1,707 million L of groundwater and 32 million m³ soil vapor have been treated, resulting in removal of approximately 620 kg of VOCs, 1.7 kg of perchlorate, 19,000 kg of nitrate, 2.4 kg of RDX, 9.5 kg of silicone oils, and 0.056 kg of uranium. Tritium in groundwater continues to decay on site, reducing tritium activities in Site 300 groundwater. Detailed flow and mass removal by OU is presented in Buscheck et al. (2017).

Cleanup remedies have been fully implemented and are operational in eight of the nine OUs at Site 300 to date (the General Services Area, Building 834, Pit 6 Landfill, High Explosives Process Area, Building 850/Pit 7 Complex, Building 854, Building 832 Canyon OUs, and OU 8, which is comprised of four site-wide subareas). The CERCLA pathway for the last OU, Building 812, was negotiated with the regulatory agencies in 2011. At Building 812, characterization activities were initiated in 2011 and continued in 2012, 2013, 2014, 2015, 2016, and 2017. These activities included:

- Sampling surface soil, ground water, and surface water for chemical and radiological analysis.
- Sampling plants and invertebrates for uranium analysis.
- Drilling and hand augering additional boreholes, collecting samples for chemical analysis, and conducting High Purity Germanium (HPGe) detector gamma radiation

7. Groundwater Investigation and Remediation

surveying for uranium-238 in subsurface soil to better determine its vertical extent subsurface soil.

- Gamma radiation surveying with a sodium iodide (NaI) detector to better define the extent of uranium-238 in Building 812 surface soil.
- Surface water discharge and velocity monitoring.
- Analyzing the chemical and radiological data collected to determine the nature and extent of contamination.
- Sampling and analyzing soil from potential non-impacted areas at Site 300 to develop updated background concentrations and activities of metals and radionuclides.
- Commencing contaminant fate and transport modeling and a baseline risk assessment using the chemical data as input.

The results of the characterization activities are being analyzed and will be presented in a Remedial Investigation/Feasibility Study for the Building 812 OU.

Additional Site 300 Environmental Restoration Project activities performed in 2017 included:

- Installing three new groundwater monitor wells in the Building 832 area.
- Installing two new groundwater monitor wells in the Building 834 area.
- Installing five new groundwater monitor wells in the Building 854 area.
- Closing five former groundwater monitor wells and three former groundwater extraction wells in the Eastern General Services Area.
- Inspecting and maintaining the Pit 7 drainage diversion system and Building 850 Corrective Action Management Unit.
- Continuing the Building 850 *In Situ* Perchlorate Bioremediation Treatability Test, while awaiting rebound in perchlorate concentrations in groundwater.
- Continuing planning of the expansion of an *in situ* bioremediation treatment zone in the T2 area of Building 834 that included hydraulic testing of two wells and includes implementing a small-scale recirculation cell using ethyl lactate.
- Completing upgrades of the Building 834 source ground water and soil vapor treatment facility by field testing and converting an existing groundwater monitor well to an extraction well, in the Leachfield area.
- Converting the Building 817 source groundwater treatment facility to an extraction-only facility with extracted groundwater transported to the 815 source facility for treatment.
- Conducting hydraulic tests of three wells at 854-SRC in order to evaluate the injection capacity of a planned ethyl lactate injection well for proposed *in situ* bioremediation treatment of perchlorate in 854-SRC groundwater.
- Continuing upgrades of the Central General Services Area groundwater and soil vapor treatment facilities.

7. Groundwater Investigation and Remediation

- Continuing upgrades of the Building 830 source ground water and soil vapor treatment facilities.
- Conducting hydraulic testing of extraction, monitor, and potential injection wells at Building 832 Canyon.
- Beginning upgrades of the Building 854 distal ground water and soil vapor treatment facilities.
- Drilling 14 boreholes and collecting and analyzing surface and subsurface soil samples to investigate potential VOCs, semivolatile organic compounds (SVOCs), PCBs, metals, high explosives (HE) compounds, and diesel in soil and rock to complete characterization at four potential or suspected chemical release sites in the Building 812 firing table area.
- Collecting surface soil samples at a potential background reference area (BRA) in the northwest corner of Site 300 and analyzing the samples for uranium isotopes.

All calendar year 2017 Site 300 milestones were met or renegotiated with the regulatory agencies (see **Chapter 2**).

Groundwater concentration and hydraulic data collected and analyzed for Site 300 during 2017 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 2017 is available in the *2017 Annual Compliance Monitoring Report for LLNL Site 300* (Buscheck et al. 2018)

7.2.4 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 and radionuclides in water and soil, and preventing contaminant migration in groundwater to the extent technically and economically feasible.

These actions include:

- Groundwater and soil vapor extraction and treatment.
- Source control through the capping of lagoons and landfills, removal and remediation of contaminated soil, and hydraulic drainage diversion.
- Monitored natural attenuation.
- Monitoring and institutional controls.

These remedies are selected by DOE and the regulatory agencies with public input.