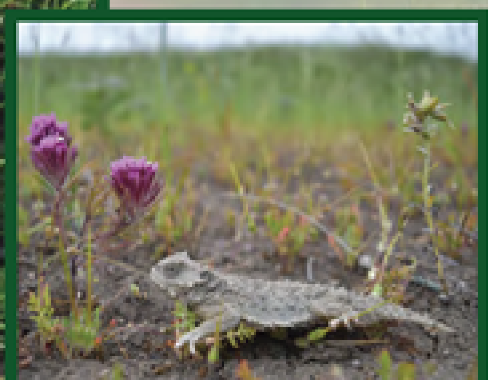
2018

SITE ANNUAL ENVIRONMENTAL REPORT



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Cover photography by Caleb Murphy

Top photo:
Coyote (*Canis latrans*)
Photo taken at Los Vaqueros Reservoir

Bottom left:
Burrowing Owl (*Athene cunicularia*)—California Species of Special Concern
Photo taken in Contra Costa County, Pittsburg, CA

Bottom right:
Coast Horned Lizard (*Phrynosoma blainvillii*)—California Species of Special Concern
Photo taken at LLNL Site 300

Artwork by Janet Orloff

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Lawrence Livermore National Laboratory
Environmental Report 2018

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Preface

The purposes of the *Lawrence Livermore National Laboratory Environmental Report 2018* are to record Lawrence Livermore National Laboratory's (LLNL's) compliance with environmental standards and requirements, describe LLNL's environmental protection and remediation programs, and present the results of environmental monitoring at the two LLNL sites—the Livermore Site and Site 300. The report is prepared for the U.S. Department of Energy (DOE) by LLNL's Environmental Functional Area. Submittal of the report satisfies requirements under DOE Order 231.1B, "Environment, Safety and Health Reporting," and DOE Order 458.1, "Radiation Protection of the Public and Environment."

The report is distributed electronically and is available at https://saer.llnl.gov/, the website for the LLNL annual environmental report. Previous LLNL annual environmental reports beginning with 1994 are also on the website. Some references in the electronic report text are underlined, which indicates that they are clickable links. Clicking on one of these links will open the related document, data workbook, or website.

The report begins with an executive summary, which provides the purpose of the report and an overview of LLNL's compliance and monitoring results. The first three chapters provide background information: Chapter 1 is an overview of the location, meteorology, and hydrogeology of the two LLNL sites; Chapter 2 is a summary of LLNL's compliance with environmental regulations; and Chapter 3 is a description of LLNL's environmental programs with an emphasis on the Environmental Management System including pollution prevention.

The majority of the report covers LLNL's environmental monitoring programs and monitoring data for 2018: effluent and ambient air monitoring and dose assessment (Chapter 4); waters, including wastewater, storm water runoff, surface water, rain, and groundwater (Chapter 5); and terrestrial, including soil, sediment, vegetation, foodstuff, ambient radiation, and special status wildlife and plants (Chapter 6). The remaining two chapters discuss LLNL's groundwater remediation program (Chapter 7), and quality assurance for the environmental monitoring programs (Chapter 8). Complete monitoring data, which are summarized in the body of the report, are provided in Appendix A.

The report uses Système International units, consistent with the federal Metric Conversion Act of 1975 and Executive Order 12770, "Metric Usage in Federal Government Programs" (1991). For ease of comparison to environmental reports issued prior to 1991, dose values and many radiological measurements are given in both metric and U.S. customary units. A conversion table is provided in the glossary.

The report is the responsibility of LLNL's Environmental Functional Area. Monitoring data were obtained through the combined efforts of the Environmental Functional Area; Environmental Restoration Department; Physical and Life Sciences Environmental Monitoring Radioanalytical Laboratory; and the Radiation Protection Functional Area.

Special recognition is given to the technologists who gathered the data—Gary Bear, Karl Brunckhorst, Ty Grace, Steven Hall, Terrance Poole, Lane Stephens, and Robert Williams; and to the data management personnel—Kimberly Swanson, Cheryl Paguia, Suzanne Chamberlain, Nancy Bowers, Lisa Graves, Della Burruss, Beth Schad, Courtney Scialabba, and Katelynn Keller. Special thanks to Jenny Hempel for proofreading, compositing, and distributing the report, and to Sharon Cornelious of the Technical Information Department for editing support.

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Executive Summary

Lawrence Livermore National Laboratory (LLNL) is a premier research laboratory that is part of the National Nuclear Security Administration (NNSA) within the U.S. Department of Energy (DOE). As a national security laboratory, LLNL is responsible for ensuring that the nation's nuclear weapons remain safe, secure, and reliable. The Laboratory also meets other pressing national security needs, including countering the proliferation of weapons of mass destruction and strengthening homeland security, and conducting major research in atmospheric, earth, and energy sciences, bioscience and biotechnology, and engineering, basic science, and advanced technology. The Laboratory is managed and operated by Lawrence Livermore National Security, LLC (LLNS), and serves as a scientific resource to the U.S. government and a partner to industry and academia.

LLNL operations have the potential to release a variety of constituents into the environment via atmospheric, surface water, and groundwater pathways. Some of the constituents, such as particles from diesel engines, are common at many types of facilities while others, such as radionuclides, are unique to research facilities like LLNL. All releases are highly regulated and carefully monitored, and engineering and administrative controls are applied to minimize releases.

LLNL strives to maintain a safe, secure, and efficient operational environment for its employees and neighboring communities. Experts in environment, safety, and health (ES&H) support all Laboratory activities. LLNL's radiological control program ensures that radiological exposures and releases are reduced to as low as reasonably achievable to protect the health and safety of its employees, contractors, the public, and the environment.

LLNL is committed to enhancing its environmental stewardship and managing the impacts its operations may have on the environment through a formal Environmental Management System (EMS). The Laboratory encourages the public to participate in matters related to the Laboratory's environmental impact on the community by soliciting citizens' input on matters of significant public interest and through various communications. The Laboratory also provides public access to information on its ES&H activities with websites and public meetings.

LLNL consists of two sites—an urban site in Livermore, California, referred to as the "Livermore Site," which occupies 1.3 square miles; and a rural Experimental Test Site, referred to as "Site 300," near Tracy, California, which occupies 10.9 square miles. In 2018, the Laboratory had a staff of approximately 7,500.

Purpose and Scope of the Environmental Report

The purposes of the *Environmental Report 2018* are to record LLNL's compliance with environmental standards and requirements, describe LLNL's environmental protection and remediation programs, and present the results of environmental monitoring. Specifically, the report discusses LLNL's EMS; describes significant accomplishments in pollution prevention; presents the results of air, water, vegetation, and foodstuff monitoring; reports radiological doses from LLNL operations; summarizes LLNL's activities involving special status wildlife, plants, and habitats; and describes the progress LLNL has made in remediating groundwater contamination.

Environmental monitoring at LLNL, including analysis of samples and data, is conducted according to documented standard operating procedures. Duplicate samples are collected and analytical results are reviewed and compared to internal acceptance standards.

This report is prepared for DOE by LLNL's Environmental Functional Area (EFA). Submittal of the report satisfies requirements under DOE Order 231.1B, "Environment, Safety and Health Reporting," and DOE Order 458.1, "Radiation Protection of the Public and Environment." The report is distributed in electronic form and is available to the public at https://saer.llnl.gov/, the website for the LLNL annual environmental report. Previous LLNL annual environmental reports beginning with 1994 are also on the website.

Regulatory Permitting and Compliance

LLNL undertakes substantial activities to comply with many federal, state, and local environmental laws. The major permitting and regulatory activities that LLNL conducts are required by the Clean Air Act (CAA); the Clean Water Act (CWA) and related state programs; the Emergency Planning and Community Right-to-Know Act (EPCRA); the Resource Conservation and Recovery Act (RCRA) and state and local hazardous waste regulations; the National Environmental Policy Act (NEPA); the Endangered Species Act (ESA); the National Historic Preservation Act (NHPA); the Antiquities Act; and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

Integrated Safety Management System and Environmental Management System

LLNL established its EMS to meet the requirements of the International Organization for Standardization (ISO) 14001:1996 in June 2004 and has remained certified since that time, updating to revised standards in June 2006 (14001:2004) and May 2018 (14001:2015). Every three years LLNL identifies, documents, and updates its environmental aspects and each year plans actions to address the most significant aspects identified. In FY2018, LLNL established 5 ES&H Action Plans to address environmental aspects including meeting all site sustainability goals, developing a municipal waste reduction strategy, reducing energy and water use in laboratories, leveraging electric vehicle charging infrastructure, and reducing risks associated with closed facilities and surrounding areas.

Pollution Prevention

A strong Pollution Prevention/Sustainability Program (P2S) is an essential supporting element of LLNL's EMS. LLNL operations have reduced the quantity and toxicity of waste generated, eliminated or reduced pollutant releases, and recycled common and unique materials.

Each year, LLNL submits nominations for the NNSA environmental awards program and DOE Sustainability awards programs, which recognize exemplary performance in integrating environmental stewardship practices to reduce risk, protect natural resources, and enhance site operation. In 2018 a nomination submitted in the Strategic Partnerships for Sustainability category won an NNSA Sustainability Award and an Honorable Mention from DOE. LLNL also won *USDA's Biopreferred 2018 Excellence in Biobased Procurement Award* for biobased purchases.

The P2S Program outreach efforts in 2018 included holding April 2018 Earth Day events; participation, with Sandia National Laboratory, in the 4^{th} annual Bike to Work Day; publishing articles in the LLNL online newsletter; and maintaining an internal P2S website and a green hotline for all LLNL employees.

Air Monitoring

LLNL operations involving radioactive materials had minimal impact on ambient air during 2018. Estimated nonradioactive emissions are low compared to local air district emission criteria.

Releases of radioactivity to the environment from LLNL operations occur through stacks and from diffuse area sources. In 2018, radioactivity released to the atmosphere was monitored at five facilities on the Livermore Site and one at Site 300. In 2018, 183.5 Ci (6,790 GBq) of tritium was released from the Tritium Facility, and 8.66 Ci (320 GBq) of tritium was released from the National Ignition Facility (NIF). The Contained Firing Facility (CFF) at Site 300 had measured stack emissions in 2018 for depleted uranium. A total of 1.2×10^{-7} Ci (4.4×10^{-6} GBq) of uranium-234, 1.1×10^{-8} Ci (4.1×10^{-7} GBq) of uranium-235, and 8.9×10^{-7} Ci (3.3×10^{-5} GBq) of uranium-238 was released in particulate form. The doses to the hypothetical, site-wide maximally exposed individual (SW-MEI) members at the Livermore Site and Site 300 are less than one percent of the annual National Emissions Standards for Hazardous Pollutants (NESHAPs), which is 100 µSv/y (10 mrem/y) total site effective dose equivalent. None of the other facilities monitored for gross alpha and gross beta radioactivity had emissions in 2018.

The magnitude of nonradiological releases (e.g., reactive organic gases/precursor organic compounds [ROGs/POCs], nitrogen oxides, carbon monoxide, particulate matter, sulfur oxides) is estimated based on specifications of equipment and hours of operation. Livermore Site air pollutant emissions were very low in 2018 compared to the daily releases of air pollutants from all sources in the entire Bay Area. For example, the average daily emission of NOx in the Bay Area was approximately 2.3×10^5 kg/d, compared to the estimated daily release from the Livermore Site of 37.5 kg/d, which is 0.016% of total Bay Area source emissions for NOx. The 2018 Bay Area Air Quality Management District (BAAQMD) estimate for ROGs/POCs daily emissions throughout the Bay Area was approximately 2.2×10^5 kg/d, while the daily emission estimate for 2018 from the Livermore Site was 15.7 kg/d, or 0.0071% of the total Bay Area source emissions for ROGs/POCs. Nonradiological releases from LLNL continue to be a very small fraction of releases from all sources in the Bay Area or San Joaquin County.

In addition to air effluent monitoring, LLNL samples ambient air for tritium, radioactive particles, and beryllium. Some samplers are situated specifically to monitor areas of known contamination; some monitor potential exposure to the public; and others, distant from the two LLNL sites, monitor the natural background. In 2018, ambient air monitoring data was used to determine source terms for resuspended plutonium-contaminated soil, resuspended fallout from previous atmospheric testing, or resuspended fallout from the Fukushima nuclear accident; and tritium diffusing from area sources at the Livermore Site and resuspended uranium-contaminated soil at Site 300. In 2018, radionuclide particulate, tritium, and beryllium concentrations in air at the Livermore Site and in the Livermore Valley were well below the levels that would cause concern for the environment or public health.

Water Monitoring

Water monitoring is carried out to determine whether any radioactive or nonradioactive constituents released by LLNL might have a negative impact on public health and the environment. Data indicate LLNL has good control of its discharges to the sanitary sewer, and discharges to the surface water and groundwater do not have any apparent environmental impact.

Permits, including one for discharging treated groundwater from the Livermore Site Ground Water Project, regulate discharges to the City of Livermore sanitary sewer system. During 2018, monitoring data under the LLNL Wastewater Discharge Permit #1250 (2017–18, 2018–19) demonstrated full compliance with all discharge limits, and most of the measured values were a small fraction of the allowed limits. All discharges to the Site 300 sewage evaporation pond and percolation ponds were within permitted limits, and groundwater monitoring related to this area showed no measurable impacts.

Under the current storm water Industrial General Storm Water Permit (IGP) (2014-0057-DWQ), the only regulated industrial activities at the Livermore Site and Site 300 are those related to Treatment, Storage, and Disposal Facilities (TSDF). This includes the Decontamination and Waste Treatment Facility (DWTF) and Area 612 Facilities at Livermore and B-883, Explosive and Waste Treatment Facility (EWTF), and Explosives Waste Storage Facility (EWSF) at Site 300. LLNL has five storm water runoff sampling locations at the Livermore Site and two at Site 300. Storm water runoff samples were collected for three storm events at the Livermore Site and one storm event at Site 300 in 2018. Samples were collected from all five required storm water locations at the Livermore Site and one required location, EWTF, at Site 300. Based on annual sample results, both the Livermore Site and Site 300 remain at Exceedance Response Action Level 2 for magnesium.

LLNL evaluated both sites for potential industrial sources of magnesium. The evaluation did not identify any significant sources of this metal as part of TSDF activities. Observations and data collected at both sites overwhelmingly pointed to aerial deposition of naturally occurring soils as the source of the high concentrations of this constituent in storm water runoff. Historical data of magnesium concentrations at upstream sample locations of the receiving waters show that the metal occurs at much higher concentrations than are measured at TSDF discharge locations.

The annual storm water reports for the Livermore Site, National Pollutant Discharge Elimination System (NPDES) General Permit 2014-0057-DWQ (Waste Discharge Identification Number [WDID] 2 01I025682) and Site 300, NPDES General Permit 2014-0057 (WDID 5S39I021179) are available through the Stormwater Multiple Applications and Report Tracking System (SMARTS) managed by the California State Water Resources Control Board.

In addition to the CERCLA-driven monitoring (i.e., for volatile organic compounds [VOCs]) conducted by LLNL's Environmental Restoration Department (ERD), extensive surveillance monitoring of groundwater occurs at and near the Livermore Site and Site 300. Groundwater from wells downgradient from the Livermore Site is analyzed for anions, hexavalent chromium, and radioactivity. To detect any off-site contamination quickly, the well water is sampled in the uppermost water-bearing layers. Near Site 300, monitored constituents in off-site groundwater include explosives residue, nitrate, perchlorate, metals, volatile and semivolatile organic compounds, tritium, uranium, and other (gross alpha and beta) radioactivity. With the exception of VOCs in wells monitored for the CERCLA compliance, the constituents of all off-site samples collected at both the Livermore Site and Site 300 were below allowable limits for drinking water.

Surface waters and drinking water are analyzed for tritium and gross alpha and gross beta radioactivity. In the Livermore Valley, the maximum tritium activity was less than 1% of the drinking water standard, and the maximum gross alpha and gross beta measurements were less than 8% of their respective drinking water standards. At Site 300, maintenance and the operation of drinking water and cooling systems resulted in permitted discharges without adverse impact on surrounding waters.

Terrestrial Radiological Monitoring

The impact of LLNL operations on surface soil in 2018 was insignificant. Soil is analyzed for plutonium, gamma-emitting radionuclides, and tritium. Plutonium concentrations in soil at the Livermore Water Reclamation Plant continued to be high relative to other sampled locations, but even this concentration was only 0.4% of the screening level for cleanup recommended by the National Council on Radiation Protection (NCRP). At Site 300, soils are analyzed for gamma-emitting radionuclides and beryllium. In 2018, uranium-235 and uranium-238 concentrations in soils at Site 300 were below NCRP-recommended screening levels.

Vegetation and Livermore Valley wine were sampled for tritium. In 2018, the median of concentrations in all off-site vegetation samples was below the lower limit of detection of the analytical method. For Livermore Valley wines purchased in 2018, the highest concentration of tritium was just 0.41% of the Environmental Protection Agency's (EPA's) standard for maximal permissible level of tritium in drinking water.

LLNL's extensive network of thermoluminescent dosimeters measures the natural terrestrial and cosmogenic background; in 2018, as in recent years, no impact from LLNL operations was detected.

Biota

Through monitoring and compliance activities in 2018, LLNL avoided most impacts to special status species and enhanced some habitats. LLNL studies, preserves, and tries to improve the habitat of five species at Site 300 that are covered by the federal or California Endangered Species Acts—California tiger salamander (*Ambystoma californiense*), California red-legged frog (*Rana draytonii*), Alameda whipsnake (*Masticophus lateralis euryxanthus*), valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*), and the large-flowered fiddleneck (*Amsinckia grandiflora*)—as well as species that are rare and otherwise of special interest. At Site 300, LLNL monitors populations of birds and rare species of plants and continues restoration activities for the four rare plant species known to occur at Site 300—the large-flowered fiddleneck, the big tarplant (*Blepharizonia plumosa*), the diamond-petaled California poppy (*Eschscholzia rhombipetala*), and shining navarretia (*Navarretia nigelliformis* ssp. *radians)*.

LLNL took several actions to control invasive species in 2018. Measures taken at the Livermore Site to control bullfrogs, which are a significant threat to California red-legged frogs, included dispatching adults and removing egg masses in Lake Haussmann and Arroyo Las Positas. To remove bullfrog tadpoles and invasive fish, the LLNL reach of Arroyo Las Positas was allowed to dry out in September of 2018 by temporarily halting groundwater discharges to the arroyo.

The 2018 radiological doses calculated for biota at the Livermore Site or Site 300 were far below screening limits set by DOE, even though highly conservative assumptions maximized the potential effect of LLNL operations on biota.

Radiological Dose

Annual radiological doses at the Livermore Site and Site 300 in 2018 were found to be well below the applicable standards for radiation protection of the public. Dose calculated to the SW-MEI for 2018 was 6.7×10^{-2} µSv (6.7×10^{-3} mrem) for the Livermore Site and 9.6×10^{-4} µSv (9.6×10^{-5} mrem) at Site 300. These doses are well below the federal NESHAPs of 100 µSv (10 mrem) and are significantly less than the doses from natural background radiation.

Groundwater Remediation

Groundwater at both the Livermore Site and Site 300 is contaminated from historical operations; the contamination, for the most part, is confined to each site. Groundwater at both sites is undergoing cleanup under the CERCLA. Remediation activities removed contaminants from groundwater and soil vapor at both sites, and documentation and investigations continue to meet regulatory milestones.

At the Livermore Site, contaminants include VOCs, fuel hydrocarbons, metals, and tritium, but only the VOCs in groundwater and saturated and unsaturated soils need remediation. Combinations of VOCs, nitrate, perchlorate, tritium, high explosives, depleted uranium, organosilicate oil, polychlorinated biphenyls, dioxins, furans, and metals have been identified for remediation at one or more of the nine Operable Units (OUs) at Site 300.

In 2018, concentrations continued to decrease in most of the Livermore Site VOC plumes due to active remediation and the removal of more than 44 kg of VOCs from both groundwater and soil vapor. Groundwater concentration and hydraulic data indicate subtle but consistent declines in the VOC concentrations and areal extent of the contaminant plumes in 2018.

In 2018 at Site 300, perchlorate, nitrate, the high explosive RDX, and organosilicate oil were removed from groundwater in addition to about 7.2 kg of VOCs. Each Site 300 OU has a different profile of contaminants, but overall, groundwater and soil vapor extraction and natural attenuation continue to reduce the mass of contaminants in the subsurface. Cleanup remedies have been fully implemented and are operational at eight of the nine OUs at Site 300. The CERCLA pathway for the last OU, Building 812, was negotiated with the regulatory agencies in 2011 and characterization activities continued. All milestones were met or renegotiated with the regulatory agencies (see **Chapter 2**).

Conclusion

LLNL's EMS provides a framework that integrates environmental protection into all work planning processes. The success of EMS is evidenced by LLNL's certification to the ISO 14001:2015 standard, coupled with a consistent record of good environmental stewardship and compliance. The combination of surveillance and effluent monitoring, source characterization, and dose assessment showed that the radiological dose to the hypothetical, maximally-exposed individual member of the public caused by LLNL operations in 2018 was substantially less than the dose from natural background. Potential dose to biota was well below DOE screening limits. LLNL demonstrated good compliance with permit conditions for releases to air and to water. Analytical results and evaluations of air and various waters potentially impacted by LLNL operations showed minimal contributions from LLNL operations. Remediation efforts at both the Livermore Site and Site 300 further reduced concentrations of contaminants of concern in groundwater and soil vapor.

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1. Introduction

Lawrence Livermore National Laboratory (LLNL) is a premier research laboratory that is part of the National Nuclear Security Administration (NNSA) within the U.S. Department of Energy (DOE). LLNL is managed and operated by Lawrence Livermore National Security, LLC (LLNS); the LLNS management team includes Bechtel National, University of California, BWX Technologies, and AECOM. LLNS manages LLNL under NNSA Contract Number DE-AC52-07NA27344.

As a national security laboratory, LLNL is responsible for ensuring that the nation's nuclear weapons remain safe, secure, and reliable. The Laboratory also meets other pressing national security needs, including countering the proliferation of weapons of mass destruction, strengthening homeland security, and conducting major research in atmospheric, earth, and energy sciences, bioscience and biotechnology, and engineering, basic science, and advanced technology. The Laboratory staff of approximately 7,500, serves as a scientific resource to the U.S. government and a partner to industry and academia.

1.1 Location

LLNL consists of two sites—an urban site in Livermore, California, referred to as the "Livermore Site," and a rural test site, referred to as "Site 300," near Tracy, California. See **Figure 1-1.**

Figure 1-1. Locations of the two LLNL sites—the Livermore Site and Site 300.

The Livermore Site, LLNL's general research site, is within the eastern limits of Livermore, a city with a population of about 90,000 in Alameda County.

The site occupies 1.3 mi^2, including the land that serves as a buffer zone along its north and west perimeters.

Within a 50-mi radius of the Livermore Site are cities such as Tracy and Pleasanton and the more distant (and more densely populated) cities of Oakland, San Jose, and San Francisco. Of the 7.7 million people within 50 mi of the Laboratory, only about 10% are within 20 mi.

Site 300, LLNL's Experimental Test Site, is located in the Altamont Hills of the Diablo Range in Central California and straddles the San Joaquin and Alameda county line. The site is 12 mi east of the Livermore Site and occupies 10.9 mi^2.

The city of Tracy, with a population of about 91,000, is approximately 6 mi to the northeast of Site 300 (measured from the northeastern border of Site 300 to Sutter Tracy Community Hospital). Of the 7.1 million people who live within 50 mi of Site 300, 95% are more than 20 mi away in large metropolitan areas, which include Oakland, San Jose, and Stockton.

1.2 Meteorology

The climate at both sites is characterized by mild, rainy winters and warm-to-hot, dry summers, with strong seasonal wind and rainfall patterns. Wind patterns at both sites tend to be dominated by the thermal draw of the warm San Joaquin Valley that results in wind blowing from the cool ocean toward the warm valley during the warm season, increasing in intensity as the valley heats up. During the winter, the wind blows from the northeast more frequently as cold, dense air spills out of the San Joaquin Valley. The meteorological conditions at Site 300 are also strongly influenced by higher elevation and more pronounced topological relief. Approximately 55% of the rain at both sites falls in January, February, and March and approximately 80% falls in the five months from November through March, with very little rain falling during the warmer months. For a detailed review of rainfall at LLNL, see Bowen (2007). For a detailed review of the climatology at LLNL, see Gouveia and Chapman (1989).

Meteorological towers at both the Livermore Site and Site 300 continuously gather data including wind speed, wind direction, rainfall, humidity, solar radiation, and air temperature. Temperature, rainfall, and wind speed data from the Livermore Site and Site 300 towers during 2018 are summarized in **Table 1-1.** Annual wind data for the Livermore Site and Site 300 are shown in **Figure 1-2.**

Table 1-1. Summary of temperature, rainfall, and wind speed data at the Livermore Site and Site 300 during 2018.

	Livermore Site		Site 300	
Temperature	**°C**	**°F**	**°C**	**°F**
Mean daily maximum	22.4	72.4	21.9	71.3
Mean daily minimum	7.9	46.1	12.9	55.3
Average	14.6	58.3	17.0	62.6
High	37.7	99.9	39.0	102.2
Low	-5.0	23.1	1.1	34.0
Rainfall	**cm**	**in.**	**cm**	**in.**
Total	30.4	11.9	25.3	9.9
Climatological normal [(a)]	34.8[(b)]	13.7[(b)]	27.3[(b)]	10.7[(b)]
Wind	**m/s**	**mph**	**m/s**	**mph**
Average speed	2.2	4.8	5.6	12.6
Peak gust speed	15.8	35.4	33.1	74.1

(a) Climatological normal is based on a 30-year period (1981–2010).

(b) 1981–2010 (Mean re-calculated every 10 years).

1.3 Topography

The Livermore Site is located in the southeastern portion of the Livermore Valley, a prominent topographic and structural depression oriented east–west within the Diablo Range. The most prominent valley in the Diablo Range, the Livermore Valley is bounded on the west by the Pleasanton Ridge and on the east by the Altamont Hills. The valley is approximately 14 mi long and varies in width generally between 2.5 and 7 mi. The highest elevation of the valley floor is 720 ft above sea level along its eastern margin near the Altamont Hills; it descends gradually to 300 ft at the southwestern corner. The valley floor is covered primarily by alluvial and floodplain deposits consisting of gravels, sands, silts, and clays with an average thickness of about 325 ft. Ephemeral waterways flowing through the Livermore Site include Arroyo Seco along the southwestern corner and Arroyo Las Positas along the eastern and northern perimeters.

Site 300 consists of a series of steep hills and ridges separated by intervening ravines oriented in a generally northwest–southeast direction. The Altamont Hills, where Site 300 is located, are part of the California Coast Range Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. The elevation of Site 300 ranges from about 1,740 ft above sea level at the northwestern corner of the site to approximately 490 ft in the southeastern portion. Corral Hollow Creek, an ephemeral stream that drains toward the San Joaquin Basin, runs along the southern and eastern boundaries of Site 300.

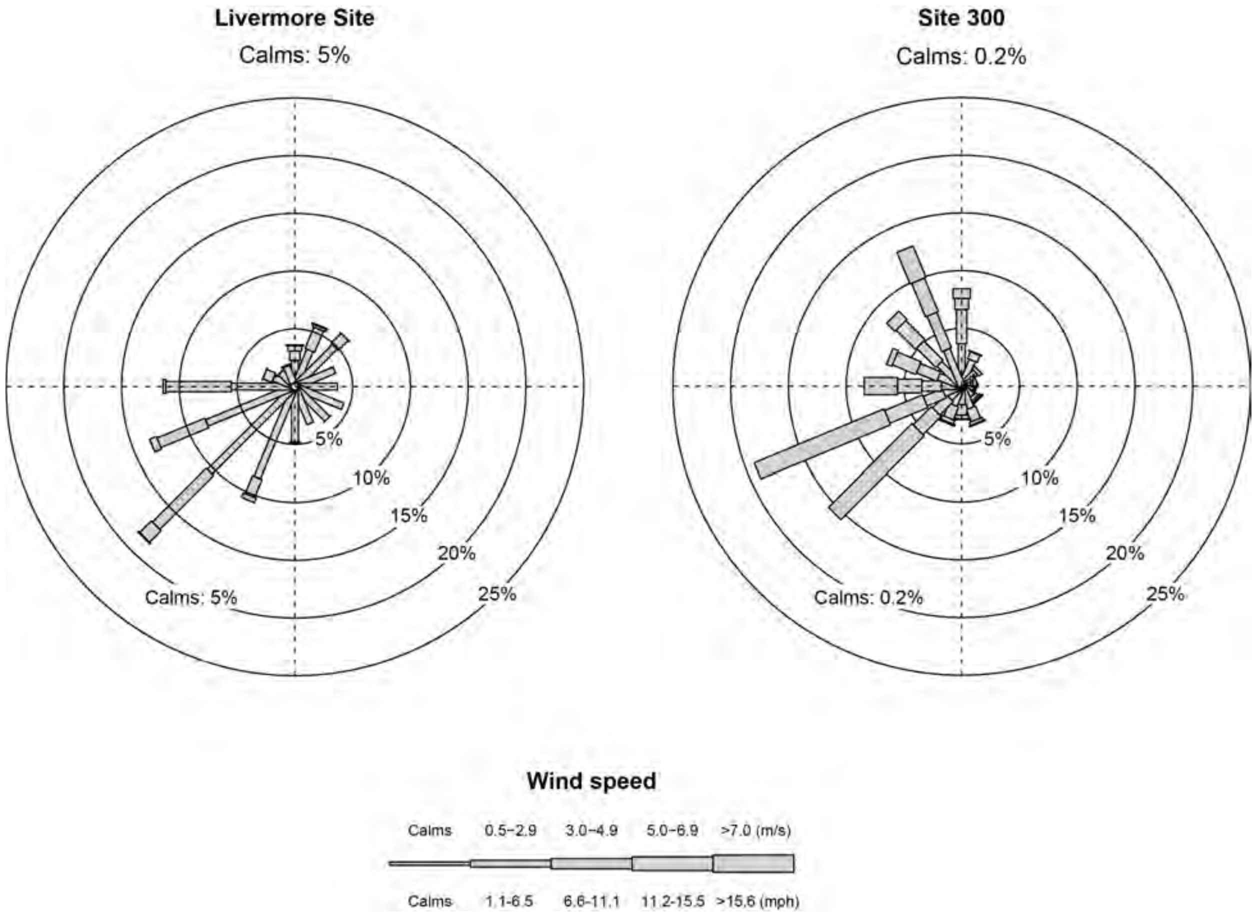

Figure 1-2. Wind roses showing wind direction and wind speed frequencies at the Livermore Site and Site 300 during 2018. The length of each spoke is proportional to the frequency at which the wind blows from the indicated direction. Different line widths of each spoke represent wind speed classes.

1.4 Hydrogeology

Geologically the Livermore Formation and overlying alluvial deposits contain the primary aquifers of the Livermore Valley groundwater basin. Natural recharge occurs primarily along the basin margins and arroyos during wet winters. In general, groundwater flows toward the central east–west axis of the valley and then westward through the central basin. Groundwater flow in the basin is primarily horizontal, although a significant vertical component probably exists along the basin margins under localized sources of recharge and near heavily used extraction or water production wells. Beneath the Livermore Site, the depth to the water table varies from about 35 to 125 ft below the ground surface. See Thorpe et al. (1990) for a detailed discussion of Livermore Site hydrogeology.

Site 300 is generally underlain by gently dipping sedimentary bedrock dissected by steep ravines. The bedrock primarily consists of interbedded sandstone, siltstone, and claystone. Groundwater occurs principally in the Neroly Formation upper and lower blue sandstone units and in the underlying Cierbo Formation. Significant groundwater is also locally present in permeable

Quaternary alluvium valley fill and underlying decomposed bedrock, especially during wet winters. Minor quantities of groundwater are present within perched aquifers in the unnamed Pliocene nonmarine unit. Perched aquifers contain unconfined groundwater separated from an underlying main body of groundwater by impermeable layers; normally these perched zones are laterally discontinuous. Recharge occurs predominantly in locations where saturated alluvial valley fill is in contact with underlying permeable bedrock or where permeable bedrock strata crop out along the canyon bottom because of structure or topography. The thick Neroly Formation lower blue sandstone unit, stratigraphically near the base of the formation, generally contains confined groundwater. Wells located in the southern part of Site 300 pump water from this aquifer, which is used for drinking and process supply. See Webster-Scholten et al. (1994) and Ferry et al. (2006) for a detailed discussion of Site 300 hydrogeology.

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2. Compliance Summary

Lawrence Livermore National Laboratory (LLNL) activities comply with federal, state, and local environmental regulations, internal requirements, Executive Orders, and U.S. Department of Energy (DOE) Orders as specified in Contract DE-AC52-07NA27344. This chapter provides an overview of LLNL's compliance programs and activities during 2018, as well as a listing of all active environmental permits.

2.1 Environmental Restoration and Waste Management

2.1.1 Comprehensive Environmental Response, Compensation and Liability Act

Ongoing remedial investigations and cleanup activities for legacy contamination of environmental media at LLNL fall under the jurisdiction of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), Title I of the Superfund Amendments and Reauthorization Act (SARA). CERCLA is commonly referred to as the Superfund law.

CERCLA compliance activities for the Livermore Site and Site 300 are summarized in **Sections 2.1.1.1** and **2.1.1.2**. Community relations activities conducted by DOE/LLNL are also part of these projects. See **Chapter 7** for more information on the activities and findings of the investigations.

2.1.1.1 Livermore Site Groundwater Project

The Livermore Site came under CERCLA in 1987 when it was placed on the National Priorities List. The Livermore Site Groundwater Project (GWP) complies with provisions specified in a Federal Facility Agreement (FFA) entered into by the U.S. Environmental Protection Agency (EPA), DOE, the California EPA's Department of Toxic Substances Control (DTSC), and the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB). As required by the FFA, the GWP addresses compliance issues by investigating potential contamination source areas (e.g., suspected old release sites, solvent-handling areas, leaking underground tank systems), monitoring water quality through an extensive network of wells, and remediating contaminated soil and groundwater. The primary soil and groundwater contaminants (constituents of concern) are common volatile organic compounds (VOCs), primarily trichloroethylene (TCE) and perchloroethylene (PCE). Background information on LLNL Livermore Site environmental characterization and restoration activities are presented in the *CERCLA Remedial Investigation Report for the LLNL Livermore Site* (Thorpe et al., 1990). The *LLNL Groundwater Project 2018 Annual Report* (Noyes et al., 2019) presents the current status of clean up at the Livermore Site.

Regulatory Milestones. In calendar year 2018, the following deliverables were submitted to the regulatory agencies:

- *Fourth Quarter 2017 Self-Monitoring Report*
- *LLNL Groundwater Project 2017 Annual Report*

- *First, Second, and Third Quarter 2018 Self-Monitoring Report*
- *Work Plans for Well and Borehole Drilling at the Livermore Site in Fiscal Year 2018*

Treatment Facilities. During 2018, the Livermore GWP maintained 27 groundwater and 8 soil vapor treatment facilities, and one skid-mounted soil vapor treatment test facility. The groundwater extraction wells and dual extraction wells extracted about 1,011 million L of groundwater during 2018. The dual extraction wells and soil-vapor extraction wells together removed approximately 2.5 million m^3 of soil vapor.

In 2018, the Livermore GWP treatment facilities removed about 44 kg of VOCs. Since remediation efforts began in 1989, more than 23.7 billion L of groundwater and approximately 26.1 million m^3 of soil vapor have been treated, removing about 3,355 kg of VOCs.

Livermore Site restoration activities in 2018 were focused on enhancing and optimizing ongoing operations at treatment facilities. Evaluation of technologies that may accelerate cleanup of the Livermore Site contaminant source areas and address areas of co-mingled VOC and low-level tritium plumes, also continued. Beneath the site, groundwater concentration and hydraulic data indicate subtle but consistent declines in VOC concentrations and areal extent of contaminant plumes in 2018. Hydraulic containment along the western and southern boundaries of the site was fully maintained in 2018, and progress was made toward interior plume and source area clean up. See Noyes et al. (2019) for more information.

Community Relations. Livermore Site community relations activities in 2018 included maintenance of information repositories and an administrative record; disseminating environment-related news releases and internal/external newsletter articles, responding to journalists' inquiries regarding the Livermore Site environmental cleanup; sending 391 letters to near neighbors living to the west of LLNL providing an update on the progress of the off-site groundwater plume cleanup; and two meetings with members of Tri-Valley Communities Against a Radioactive Environment (Tri-Valley CAREs) and the organization's scientific advisor as part of the activities funded by an EPA Technical Assistance Grant (TAG) (January and September 2018). DOE/LLNL conducted CERCLA community tours of the Livermore Site in March and April 2018. DOE/LLNL also conducted tours of environmental restoration activities and facilities upon request. In addition, DOE/LLNL environmental documents, letters, and public notices were posted on a public website: https://enviroinfo.llnl.gov/.

2.1.1.2 Site 300 Environmental Restoration Project

Remedial activities are ongoing at Site 300, which became a CERCLA site in 1990 when it was placed on the National Priorities List. Remedial activities are overseen by the EPA, the Central Valley Regional Water Quality Control Board (CVRWQCB), and DTSC, under the authority of an FFA for the site. Contaminants of concern at Site 300 include VOCs (primarily TCE), high-explosive compounds, tritium, depleted uranium, silicone-based oils, nitrate, perchlorate, polychlorinated biphenyls, dioxins, furans, and metals. The contaminants present in environmental media vary within the different environmental restoration operable units (OUs) at the site. See Webster-Scholten (1994) and Ferry et al. (1998) for background information on LLNL environmental characterization and restoration activities at Site 300. The *LLNL Site 300 2018 Annual Compliance Monitoring Report* (Buscheck et al., 2019) presents the current status of clean up at Site 300.

Regulatory Milestones. In calendar year 2018, the following deliverables were submitted to the regulatory agencies:

- *2017 Annual Compliance Monitoring Report*
- *Second Five-Year Review Report for OUs 3 and 8*
- *First Semester 2018 Compliance Monitoring Report*
- *Draft Focused Remedial Investigation/Feasibility Study for Perchlorate at the Building 850 Area*
- *Draft Remedial Investigation/Feasibility Study for the LLNL Site 300 Building 865 Study Area*
- *Work Plans for Well Drilling at Site 300 in Fiscal Year 2018*

All calendar year 2018 milestones were met or renegotiated with the regulatory agencies.

Treatment Facilities. During 2018, the Site 300 Environmental Restoration Project (ERP) operated 15 groundwater and 5 soil vapor treatment facilities at Site 300. The groundwater extraction wells and dual extraction wells extracted about 31.2 million L of groundwater during 2018. The dual extraction wells and soil-vapor extraction wells together removed 2.3 million m^3 of soil vapor.

In 2018, the Site 300 treatment facilities removed approximately 7.2 kg of VOCs, 0.072 kg of perchlorate, 1,500 kg of nitrate, 0.28 kg of the high explosive compound RDX, 0.0079 kg of silicone oils and 0.031 kg of uranium. Since groundwater remediation began in 1990, approximately 1,735 million L of groundwater and 35 million m^3 soil vapor have been treated, resulting in removal of approximately 630 kg of VOCs, 1.7 kg of perchlorate, 20,000 kg of nitrate, 2.7 kg of RDX, 9.5 kg of silicone oils, and 0.087 kg of uranium.

Site 300 restoration activities in 2018 were focused on enhancing and optimizing ongoing operations at treatment facilities, continuing bioremediation treatability studies, and characterization in the Building 812 OU. Groundwater concentration data indicate declines in contaminant concentrations in 2018 and progress toward off-site and on-site plume and source area cleanup. See Buscheck et al. (2019) for more information.

Community Relations. Site 300 community relations activities in 2018 included maintenance of information repositories and an administrative record, two meetings (January and September) with members of Tri-Valley CAREs and the organization's scientific advisor as part of the activities funded by an EPA TAG, and three CERCLA community tours of Site 300 (March, April, and May 2018). In addition, DOE/LLNL environmental documents, letters, and public notices were posted on a public website: https://enviroinfo.llnl.gov/.

2.1.2 Emergency Planning and Community Right-to-Know Act and Toxics Release Inventory Report

Title III of SARA, known as the Emergency Planning and Community Right-to-Know Act (EPCRA), requires owners and operators of facilities who handle certain hazardous chemicals on site to provide information on the release, storage, and use of these chemicals to organizations responsible for emergency response planning. Executive Order 13693, Planning for Federal Sustainability in the Next Decade, directs all federal agencies to comply with the requirements of the EPCRA, including SARA, Section 313, the Toxic Release Inventory (TRI) Program. EPCRA requirements and LLNL compliance are summarized in **Table 2-1.**

LLNL has reported lead release data via the Form R for Site 300 since 2002. The Form R is used for reporting TRI chemical releases and includes information about waste management and waste minimization activities. Over 99 percent of lead releases are associated with activities at the Site 300 Small Firearms Training Facility (SFTF). Data for the 2017 TRI Form R for lead at Site 300 was submitted to DOE/NNSA on May 8, 2018. Over the past several years, the lead releases have decreased due to increased use of frangible bullets.

Table 2-1. Compliance with EPCRA

EPCRA section	Brief description of requirement	LLNL action
302	Notify SERC of presence of extremely hazardous substances.	Originally submitted 05/87.
303	Designate a facility representative to serve as emergency response coordinator.	Last update submitted 04/23/15 to San Joaquin County for Site 300 and 04/14/15 to the LPFD for Livermore Site.
304	Report releases of certain hazardous substances to SERC and LEPC.	No EPCRA-listed extremely hazardous substances were released above reportable quantities in 2018.
311	Submit SDSs or chemical list to SERC, LEPC, and Fire Department.	Per the California Office of Emergency Services, the EPCRA Section 311 requirement is satisfied by the EPCRA Section 312 submittal and the filing of necessary amendments within 30 days of handling a previously undisclosed hazardous material subject to Section 312 inventory requirements.
312	Submit hazardous chemical inventory to local administering agency (county).	Submitted to San Joaquin County and the LPFD on 01/03/18 and 02/21/18, respectively.
313	Submit Form R to U.S. EPA and California EPA for toxic chemicals released above threshold levels.	Form R for lead for Site 300 submitted to DOE on 05/08/18, DOE forwarded it to U.S. EPA and California EPA on 06/05/18.

Note: See the **Acronyms and Glossary** section for acronym definitions.

2.1.3 California Accidental Release Prevention Program

The California Accidental Release Prevention (CalARP) Program is the combined federal and state program for the prevention of accidental release of regulated toxic and flammable substances. The goal of the combined program is to eliminate the need for two separate and distinct chemical risk management programs. The purpose of the CalARP program is to prevent accidental releases of substances that can cause serious harm to the public and the environment, to minimize the damage if releases do occur, and to satisfy Community Right-to-

Know laws. The CalARP program is implemented at the local government level by Certified Unified Program Agencies (CUPAs). The related federal regulations are the Clean Air Act (CAA) Section 112(r) and Title 40, Code of Federal Regulations, Part 68 (40 CFR Part 68).

LLNL submitted a revised Livermore Site CalARP Level 1 risk management plan (RMP) in September 2016. The Livermore Site RMP includes lithium hydride, hydrofluoric acid, and nitric acid.

2.1.4 Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA) provides the framework at the federal level for regulating solid wastes, including wastes designated as hazardous. The California Hazardous Waste Control Law (HWCL) and California Code of Regulations (CCR) Title 22 set requirements for managing hazardous wastes and implementing RCRA in California. LLNL works with DTSC and CUPA to comply with these regulations and obtain hazardous waste permits.

The hazardous waste management facilities at the Livermore Site consist of permitted units in Area 612 and Building 625 plus Buildings 693, 695, and 696, which make up the Decontamination and Waste Treatment Facility (DWTF). Permitted waste-management units include container storage, tank storage, and various treatment processes (e.g., wastewater filtration, blending, and size reduction). LLNL submitted the permit renewal application to DTSC in April 2009, followed by submittal of the human health risk assessment (HHRA) in December 2010 as part of the permit renewal process. DTSC issued the Hazardous Waste Facility Permit on March 11, 2016. However, DTSC stayed the permit on April 29, 2016 to address three comments that were accepted on December 1, 2016. Resolution of the three appeal comments was in the DTSC appeal process as of December 31, 2018.

The hazardous waste management facilities at Site 300 consist of three operational RCRA-permitted facilities. The Explosives Waste Storage Facility (EWSF) and the Explosives Waste Treatment Facility (EWTF) are permitted to store and treat explosives waste, respectively. The Building 883 container storage area (CSA) is permitted to store routine facility-generated hazardous waste such as spent acids, bases, contaminated oil, and spent solvents. Site 300 has one post-closure permit for the RCRA-closed Building 829 High Explosives Burn Pits. DTSC issued the Hazardous Waste Facility Permit (HWFP) for EWSF, EWTF and the CSA on June 29, 2017. The HWFP is effective for 10 years, from August 7, 2017–August 7, 2027. DTSC issued the Building 829 post-closure permit on April 28, 2017. The post-closure permit is effective for 10 years, from April 27, 2017–April 27, 2027. Transportation of hazardous or mixed waste over public roads occurs by DTSC-registered transporters, including LLNL.

2.1.5 California Medical Waste Management Act

All LLNL medical waste management operations are conducted in accordance with the California Medical Waste Management Act (MWMA). The program is administered by the California Department of Public Health (CDPH) and is enforced by the Alameda County Department of Environmental Health (ACDEH) at the Main Site, and San Joaquin County

Environmental Health Department (SJCEHD) at Site 300. LLNL's medical waste permits are renewed on an annual basis and cover medical waste generation and treatment activities for the Biosafety Level (BSL) 2 facilities, and one BSL 3 facility. LLNL revised the BSL 2 and 3 Medical Waste Management Plans to incorporate new requirements pursuant to California Assembly Bill (AB) 333, which became effective in January 2016. The BSL 2 and 3 Medical Waste Management Plans and Emergency Action Plans were most recently submitted to the ACDEH in September 2018.

2.1.6 Radioactive Waste and Mixed Waste Management

LLNL manages radioactive waste and mixed waste in compliance with applicable sections of DOE Order 435.1, DOE Manual 435.1-1, DOE Notice 435.1, and the LLNL-developed Radioactive Waste Management Basis for the Lawrence Livermore National Laboratory (LLNL 2012), which summarizes radioactive waste management controls relating to waste generators and treatment and storage facilities.

2.1.7 Release of Property

LLNL does not release property (e.g., vehicles, equipment, or other materials) to the public with residual radioactivity above the limits specified in DOE Order 458.1. Pursuant to written procedures, items that are potentially contaminated or activated are either surveyed prior to the release to the public, or a process knowledge evaluation is conducted to verify that the material has not been exposed to radioactive material or to energy capable of inducing radioactivity in the material. In some cases, both a radiological survey and a process knowledge evaluation are performed. Excessed items that meet the requirements for unrestricted release are donated to interested state agencies, federal agencies, or universities; redeployed to other on-site users; or released to LLNL's Donation, Utilization and Sales group. In 2018, approximately 1,700 equipment release swipes were processed by LLNL's Radiological Measurements Laboratory; the equipment may have subsequently been used on-site or released to the public. Utilizing a graded approach, LLNL only keeps track of high value released items (e.g., those items worth greater than $100,000). In 2018, no high value items were released.

DOE issued a moratorium in January 2000 prohibiting the release of volume-contaminated metals and subsequently suspended the release of metals for recycling purposes from DOE radiological areas in July 2000. No metals subject to the moratorium or suspension were released from LLNL in 2018.

Excess property with residual radioactivity above the limits in DOE Order 458.1 is either transferred to other DOE facilities for reuse or transferred to LLNL's Radioactive and Hazardous Waste Management for disposal as radioactive waste. There were no releases of real property to the public in 2018.

2.1.8 Federal Facility Compliance Act

LLNL continues to work with DOE to maintain compliance with the Federal Facilities Compliance Act (FFCA) Site Treatment Plan (STP) for LLNL, which was signed in

February 1997. LLNL completed 5 milestones during 2018. An additional 69.4 m^3 of newly generated mixed waste was accepted into the approved storage facilities and added to the STP. LLNL removed approximately 37.8 m^3 of mixed waste from LLNL in 2018.

Reports and certification letters were submitted to DOE as required. LLNL continued the use of available commercial treatment and disposal facilities that are permitted to accept LLNL mixed waste. These facilities provide LLNL greater flexibility in pursuing the goals and milestones set forth in the STP.

2.1.9 Toxic Substances Control Act

The Federal Toxic Substances Control Act (TSCA) and implementing regulations found in 40 CFR Parts 700–789 govern the uses of newly developed chemical substances and TSCA- governed waste. In 2018, 4 containers of TSCA-regulated polychlorinated biphenyl (PCB) waste with an aggregate weight of 299 kilograms were transported to and disposed at the RCRA-permitted, Clean Harbors Treatment, Storage, and Disposal Facility in Aragonite, Utah, and EnergySolutions Treatment, Storage, and Disposal Facility in Clive, Utah.

2.2 Air Quality and Protection

2.2.1 Clean Air Act

All activities at LLNL are evaluated to determine the need for air permits or equipment registrations. Air permits are obtained from the Bay Area Air Quality Management District (BAAQMD) for the Livermore Site and from the San Joaquin Valley Air Pollution Control District (SJVAPCD) and/or BAAQMD for Site 300. The BAAQMD also administers a boiler registration program for natural gas fueled boilers with rated heat input capacities greater than 2 million British Thermal Units per hour (BTU/hr) and less than 10 million BTU/hr.

Both the BAAQMD and the SJVAPCD are overseen by the California Air Resources Board (CARB), which also oversees the statewide permitting for portable diesel fuel-driven equipment such as portable generators and portable air compressors. In addition, CARB presides over the state-wide registration of in-use off-road diesel vehicles (e.g., diesel-powered forklifts, loaders, backhoes, graders, and cranes), on-road heavy-duty diesel vehicles with a gross vehicle weight rating > 14,000 pounds (e.g., garbage trucks, street sweepers and bucket trucks) and large spark- ignition (LSI) engine vehicles (e.g., gasoline, propane and electric forklifts, scrubbers/sweepers and industrial tow tractors).

In 2018, LLNL operated 124 permitted air-pollutant emission sources at the Livermore Site and 35 permitted air-pollutant emission sources at Site 300. In addition, LLNL maintained the registrations for 36 natural gas boilers (and its commitments to replace boilers) with the BAAQMD at the Livermore Site and continued the registrations for 80 in-use off-road diesel vehicles, 16 on-road heavy-duty diesel vehicles, and 119 LSI engine vehicles with CARB at the Livermore Site and Site 300.

In 2018, LLNL continued to maintain a Synthetic Minor Operating Permit (SMOP) with the BAAQMD to ensure that facility-wide actual emissions of regulated air pollutants from the Livermore Site did not exceed federal CAA Title V emission limits. The source categories covered under the SMOP include solvents, fuel dispensing, remediation and wastewater, and combustion. LLNL was initially issued the SMOP by the BAAQMD in 2002 after it was determined that LLNL had the potential to emit regulated air pollutants in excess of federal CAA Title V emission limits, if all emission sources at the Livermore Site were to operate at maximum capacity. As a result, LLNL agreed to receive federally enforceable permit conditions in the SMOP that limit actual emissions of regulated air pollutants from sources rather than potential emissions from sources. As such, LLNL has been able to demonstrate through extensive monitoring and record keeping practices of emissions for sources, and meeting significantly reduced air pollutant emissions limits in the SMOP that its actual emissions are well below CAA Title V emission limits, and thus, LLNL is not a "major facility" of air pollutant emissions per 40 CFR Part 70.2.

On July 15, 2016, Site 300 was reclassified by SJVAPCD from a Title V Major Facility to a Minor Facility with potential to emit (PTE) of less than 10 tons per year for VOCs. As a Minor Facility, Site 300 is not mandated to tally the rolling 12-month emission as previously required by SJVAPCD. In addition, Site 300 is no longer subject to annual compliance inspections, but falls under a biennial schedule.

Under the authority of AB 32, the State of California adopted several regulations to reduce greenhouse gas emissions. California's Mandatory Reporting of Greenhouse Gas Emissions Regulation initially (for calendar years 2008-2011) required certain facilities to annually report greenhouse gas emissions from natural gas combustion when annual emissions exceeded 25,000 metric tons of CO_2 equivalent. The regulation was amended and the reporting threshold was lowered to 10,000 metric tons per year of CO_2 equivalent beginning with calendar year 2012.

Since 2008, the Livermore Site's annual greenhouse gas emissions from natural gas combustion have been slightly below 25,000 metric tons CO_2 equivalent. LLNL began reporting the Livermore Site's greenhouse gas emissions from natural gas combustion for calendar year 2012 and has reported each year since.

The CARB regulation to Reduce Greenhouse Gas Emissions from Semiconductor Operations applies to semiconductor (or related devices) operations that use fluorinated gases or fluorinated heat transfer fluids (HTF). The regulation aims to reduce fluorinated compound air emissions which are very potent greenhouse gases. Facilities with semiconductor operations using fluorinated gases or HTFs are required to report fluorinated gas emissions beginning with calendar year 2010 and each calendar year thereafter. In 2018 LLNL's annual emissions of fluorinated gases from semiconductor operations were below the 800 metric ton carbon dioxide equivalent (MT CO_2e) threshold. Facilities that exceed the 800 MT CO_2e threshold are required to meet strict emission standards for semiconductor operations.

Also, under the authority of AB 32, California has adopted regulations pertaining to sulfur hexafluoride (SF_6), because of its high global warming potential. LLNL was required to submit an annual report to CARB describing the research uses of SF_6 and the measures taken to control the SF_6 emissions from such research activities, and was required to keep records on the amounts of SF_6 contained in and used for electrical switchgear during calendar year 2018.

In addition, LLNL continues to implement reductions and controls to minimize CO_2 emissions. LLNL is replacing diesel engines, boilers, and hot water heaters on a continuing basis, and the new equipment is more efficient in terms of fuel use and air emissions, such as CO_2. Site 300 emissions of CO_2 are much lower than Livermore Site emissions, and there is no natural gas service at Site 300 that would generate CO_2 emissions.

The EPA has a mandatory reporting regulation for stationary emission sources, similar to California's regulation. LLNL is currently below the mandatory reporting threshold for the EPA of 25,000 metric tons per year at both the Livermore Site and Site 300.

2.2.2 National Emission Standards for Hazardous Air Pollutants, Radionuclides

To demonstrate compliance with 40 CFR Part 61, Subpart H (National Emission Standards for Hazardous Air Pollutants [NESHAPs] for radiological emissions from DOE facilities), LLNL monitors certain air-release points and evaluates the maximum potential dose to the public. The *LLNL NESHAPs 2018 Annual Report* (Wilson et al. 2019) reported that the estimated maximum radiological dose from radioactive air emissions were 6.7×10^{-2} µSv (6.7×10^{-3} mrem) for the Livermore Site and 9.6×10^{-4} µSv (9.6×10^{-5} mrem) for Site 300. The totals are well below the 100 µSv/y (10 mrem/y) site-wide dose limits defined by the NESHAPs regulation. The *LLNL NESHAPs 2018 Annual Report* is in Appendix D of this report.

2.3 Water Quality and Protection

LLNL complies with requirements of the Federal Clean Water Act (CWA), Porter-Cologne Water Quality Control Act, Safe Drinking Water Act (SDWA), the California Aboveground Petroleum Storage Act, Water Code, Health and Safety Code, and City of Livermore ordinances by complying with regulations and obtaining permits issued by the appropriate regulatory agencies whose mission is to protect water quality.

LLNL complies with the requirements of National Pollutant Discharge Elimination System (NPDES) and Waste Discharge Requirement (WDR) permits, and Water Quality Certifications issued by Regional Water Quality Control Boards (RWQCBs) and the State Water Resources Control Board (SWRCB) for discharges to waters of the U.S. and waters of the state. Discharges to the City of Livermore's sanitary sewer system are governed by permits issued by the Water Resources Division (WRD). The SDWA requires that LLNL register Class V injection wells with the EPA, and LLNL obtains permits from the Army Corps of Engineers (ACOE) for work in wetlands and waters of the U.S.

The CWA and California Aboveground Petroleum Storage Act require LLNL to have and implement Spill Prevention Control and Countermeasure (SPCC) plans for aboveground, oil-containing containers. The Livermore Pleasanton Fire Department (LPFD) and the San Joaquin County Environmental Health Department (SJCEHD) also issue permits for operating underground storage tanks (USTs) containing hazardous materials or hazardous waste (see **Table 2-2**). LLNL's USTs, for which permits are required, contain diesel fuel or gasoline; aboveground storage tanks, for which permits are not required, contain fuel, insulating oil, and process wastewater.

2.4 Other Environmental Statutes

2.4.1 National Environmental Policy Act and Floodplains and Wetland Assessments

The National Environmental Policy Act (NEPA) of 1969 is the U.S. government's basic environmental charter. When considering a proposed project or action at LLNL, DOE/NNSA must (1) consider how the action would affect the environment and (2) make certain that environmental information is available to public officials and citizens before decisions are made and actions are taken. The results of the evaluations and notice requirements are met through publication of "NEPA documents," such as environmental impact statements (EISs) and environmental assessments (EAs) under DOE NEPA Implementing Procedures in 10 CFR Part 1021.

In 2005, DOE/NNSA completed the Final Site-Wide Environmental Impact Statement for Continued Operation of Lawrence Livermore National Laboratory and Supplemental Stockpile Stewardship and Management Programmatic Environmental Impact Statement (2005 SWEIS) (U.S. DOE/NNSA 2005). In 2011, DOE/NNSA prepared a Supplement Analysis (SA) (DOE/EIS-0348-SA-03) of the 2005 SWEIS to consider whether the 2005 SWEIS should be supplemented, a new EIS should be prepared, or no further NEPA documentation is required (U.S. DOE/NNSA 2011). The SA concluded that a supplement to the 2005 SWEIS or a new SWEIS was not needed. Both the 2011 SA and the 2005 SWEIS are available online at https://enviroinfo.llnl.gov/nepa.

In 2018, no other EISs were completed. An EA was completed for the Proposed Construction and Operation of a Water Disinfection Facility at LLNL (DOE/EA-2081). Another EA was completed for the Proposed Increase in the Weight of Explosives Detonated at LLNL Experimental Test Site, Site 300 (DOE/EA-2076). This project is subject to permitting by the SJVAPCD and associated California Environmental Quality Act (CEQA) review. Several Categorical Exclusions under DOE NEPA Regulations (10 CFR Part 1021) were completed as follows:

- Remote Firing Facilities Office Trailer (NA-18-03)
- Small Firearms Training Facility Project (NA-18-04)
- Security Kiosk Canopy Installation (NA-18-02)

There were no proposed actions at LLNL that required separate DOE floodplain or wetlands assessments under DOE regulations in 10 CFR Part 1022.

2.4.2 National Historic Preservation Act

The National Historic Preservation Act (NHPA) provides protection and preservation of historic properties that are significant in the nation's history. LLNL resources subject to NHPA consideration range from prehistoric archeological sites to remnants of LLNL's own history of scientific and technological endeavors. The responsibility to comply with the provisions of the NHPA rests with DOE/NNSA as the lead federal agency in this undertaking. LLNL supports the agency's NHPA responsibilities with direction from DOE/NNSA.

In 2005, in consultation with DOE/NNSA, the California State Historic Preservation Officer (SHPO) formally determined that five archaeological resources, five individual buildings, two historic districts (encompassing 13 non-contiguous individual buildings), and selected objects in another building at LLNL are eligible for listing in the National Register of Historic Places (NRHP). In 2018, DOE consulted with the SHPO and the Advisory Council on Historic Preservation (ACHP) to remove Building 194 from the eligibility list. As final mitigation for loss of integrity of the facility for the period of historic significance, DOE and LLNL prepared an Historic American Engineering Report (HAER) documentation.

2.4.3 Antiquities Act of 1906

The Antiquities Act provides for protection of items of antiquities (i.e., archaeological sites and paleontological remains). The five NRHP-eligible archaeological sites noted in Section 2.4.2 are protected under the Antiquities Act. No paleontological remains subject to the provisions of the Antiquities Act were identified in 2018.

2.4.4 Endangered Species Act and Sensitive Natural Resources

LLNL meets the requirements of the Federal and State Endangered Species Acts (ESAs), the Eagle Protection Act, the Migratory Bird Treaty Act, and other applicable regulations as they pertain to endangered species, threatened species, and other special-status species (including their habitats) and designated critical habitats that exist at the LLNL sites.

On August 29, 2018 the U.S. Fish and Wildlife Service issued a sitewide biological opinion to DOE/NNSA for continued operations and maintenance of the LLNL Experimental Test Site, Site 300. Two projects, the Eastern General Services Area Well Decommissioning Project and the Tank 4 Road Repair Project, were completed under this biological opinion in 2018.

2.4.5 Federal Insecticide, Fungicide, and Rodenticide Act

LLNL complies with the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which provides federal control of the distribution, sale, and use of pesticides and requires that commercial users of pesticides are certified pesticide applicators. The California Department of Pesticide Regulation (DPR) has enforcement responsibility for FIFRA in California; DPR has in turn given enforcement responsibility to county departments of agriculture. All pesticides at LLNL are applied, stored, and used in compliance with FIFRA and other California, Alameda County, and San Joaquin County regulations governing the use of pesticides. The staff of the Landscape and Pest Management Shop at the Livermore Site and the Laborer/Gardener Shop at Site 300 includes certified pesticide applicators. These shops ensure that all storage and use of pesticides at LLNL is in accordance with applicable regulations. LLNL also reviews pesticide applications to ensure they do not result in impacts to water quality or special status species.

2.5 Environmental Permits, Inspections, and Occurrences

LLNL's various missions require a variety of permits. **Table 2-2** is a summary of active permits in 2018 at the Livermore Site and Site 300. The external agencies that issue the permits may also perform inspections required by the permits. **Table 2-3** lists environmental inspections and findings from both LLNL sites in 2018.

Notification of environmental occurrences is required under a number of environmental laws and regulations as well as DOE Order 232.2 (Occurrence Reporting and Processing of Operations Information). **Table 2-4** provides a list of environmental incidents reportable under DOE Order 232.2.

Table 2-2. Active permits in 2018 at the Livermore Site and Site 300

Type of permit	Livermore Site[(a)]	Site 300[(a)]
Hazardous waste	EPA ID No. CA2890012584. Hazardous Waste Facility Permit Number 99-NC-006 and RCRA Part A/B permit application—to operate hazardous waste management facilities. Agency–DTSC. Registered Hazardous Waste Hauler authorized to transport regulated wastes on public roadway. Permit number 1351. Agency–DTSC. Facility I.D. # 10697. Hazardous Waste Generator Program, On-site treatment of hazardous waste (tiered permitting) program: Conditionally Exempt Specified Wastestream, CE231-1, Hazardous Materials Business Program, Above Ground Petroleum Tank Program, and CA Accidental Release Program. Agency – LPFD CUPA.	EPA ID No. CA2890090002. Hazardous Waste Facility Permit and RCRA Part A/B permit application to operate CSA (Building 883), EWTF and EWSF. Agency–DTSC. EPA ID No. CA2890090002. Hazardous Waste Facility Post-Closure Permit and RCRA Site 300 Building 829 Post-Closure Operation Plan. Agency–DTSC. Facility I.D. # FA0003934 RCRA Hazardous Waste Generator category: waste generation in an amount equal to or more than 50 tons, but less than 250 tons. Agency–SJCEHD CUPA.
Medical waste	ACDEH issued a permit (PT0200461/PT0305526) that covers medical waste generation and treatment activities for BSL 2 facilities at B132 North and South, B150 Complex, B360 Complex, B663, and the BSL 3 facility.	Registered with SJCEHD as a Small Quantity Medical Waste Generator.
Air	BAAQMD issued 124 permits for operation of various types of equipment. BAAQMD conducted 87 compliance inspections of air sources and 1 asbestos compliance inspection. BAAQMD issued a revision to the SMOP in 2015, which was initially issued in 2002 to ensure the NOx and HAPs emissions from the site do not exceed federal Clean Air Act Title V emission limits. BAAQMD issued 3 Asbestos Removal and Demolition Permits. CARB renewed 3 permits and issued two new permits for the operation of portable diesel engines.	SJVAPCD issued 35 permits for operation of various types of equipment. SJVAPCD approved a Prescribed Burn Plan for the burning of 1,600 acres of grassland. SJVAPCD conducted 2 compliance inspections and 2 start-up inspections. SJVAPCD issued 3 air permits for operation for B-827 new ovens, ERD treatment facility and an emergency diesel generator. BAAQMD issued 2 permits for the operation of an emergency diesel generator. BAAQMD approved a Prescribed Burn Plan for the burning of 139.1 acres of grassland. CARB issued 1 permit for the operation of a portable auxiliary engine on street sweeper.
Underground Storage tanks	One operating permit (1016-09202018) issued by LPFD covering operation of 9 USTs from September 20, 2018–September 19, 2023.	One operating permit covering 3 underground petroleum storage tanks assigned individual permit numbers (PT0006785 [879TFUD01], PT0006530 [882TFUD01], and PT0007967 [879TFUG01]).
Sanitary sewer	Discharge Permit 1250[(b)] for discharges of wastewater to the sanitary sewer. Permit 1510G for discharges of groundwater from CERCLA restoration activities.	WDR R5-2008-0148 for operation of sewage evaporation pond.

Table 2-2. (cont.) Active permits in 2018 at the Livermore Site and Site 300

Type of permit	Livermore Site[a]	Site 300[a]
Water	WDR No. 88-075 for discharges of treated groundwater from Treatment Facility A to recharge basin. [c] NPDES General Permit 2014-0057-DWQ (Waste Discharge Identification Number [WDID] 2 01I025682) for discharge of storm water associated with industrial activities. NPDES General Permit 2009-0009-DWQ for discharges of storm water associated with construction activities affecting 0.4 hectares (1 acre) or more. FFA for groundwater investigation/remediation.	WDR No. 93-100 for post-closure monitoring requirements for two Class I landfills. WDR R5-2008-0148 for operation of sewage evaporation pond and discharges to percolation pits and septic systems. NPDES General Permit 2014-0057-DWQ (WDID 5S39I021179) for discharge of storm water associated with industrial activities. NPDES General Permit 2009-0009-DWQ for discharges of storm water associated with construction activities affecting 0.4 hectares (1 acre) or more. Regional Limited Threat General Order R5-2016-0076-025 and NPDES Permit No. CAG995002 for large volume discharges from the drinking water system. Domestic Water Supply Permit No. 01-10-16PA-003 FFA for groundwater investigation/remediation. Approximately 32 registered Class V injection wells.

Note: See the **Acronyms and Glossary** section for acronym definitions.

(a) Numbers of permits are based on actual permitted units or activities maintained and/or renewed by LLNL during 2018.

(b) Permit 1250 includes some wastewater generated at Site 300 and discharged at the Livermore Site.

(c) Recharge basin referenced in WDR Order No. 88-075 is located south of East Avenue within Sandia National Laboratories/California boundaries. The discharge no longer occurs; however, the agency has not rescinded the permit.

Table 2-3. Inspections of Livermore Site and Site 300 by external agencies in 2018

Medium	Description	Agency	Date	Finding
Air	Air pollutant emission sources (Livermore Site)	BAAQMD	01/09/18	No violations
			02/15/18	No violations
			04/04/18	No violations
			05/02/18	No violations
			05/31/18	No violations
			07/12/18	No violations
			08/15/18	No violations
			10/03/18	No violations
			10/10/18	No violations
			10/18/18	No violations
			11/29/18	No violations
	Synthetic Minor Operating Permit (SMOP) (Livermore Site)	BAAQMD	08/29/18	No violations
	Air pollutant emission sources (Site 300)	SJVAPCD	01/31/18	No violations
			10/16/18	No violations
			10/29/18	No violations
Hazardous Materials Business Plan	CUPA Inspection (Livermore Site)	LPFD	06/18/18-06/21/18	LPFD issued one action item concerning the hazardous materials inventory
	CUPA Inspection (Site 300)	SJCEHD	11/13/18, 11/14/18, 11/26/18	SJCEHD issued two violations for an incomplete site map and emergency response procedures.
Pesticides	Pest control records inspections (Livermore Site)	ACCDA	01/16/18	No violations
Sanitary sewer	Annual Inspection of the Sewer Monitoring Complex (Livermore Site)	WRD	10/10/18	No violations
	Categorical sampling/inspection Buildings 153 and 321C (Livermore Site)	WRD	03/13/18	No violations
			10/09/18	No violations
	Annual compliance sampling at the Sewer Monitoring Complex (Livermore Site)	WRD	10/10/18	No violations
	Café grease interceptor inspections, Building 125and 471 (Livermore Site)	WRD	10/09/18, 10/10/18	No violations

Table 2-3. (cont.) Inspections of Livermore Site and Site 300 by external agencies in 2018

Medium	Description	Agency	Date	Finding
Sanitary Sewer (cont.)	Quarterly BOD/total suspended solids (TSS) sampling at Outfall (Livermore Site)	WRD	02/13/18 05/22/18 08/16/18 10/24/18	No violations No violations No violations No violations
Storage tanks	Compliance with underground storage tank requirements and operating permits (Livermore Site)	LPFD	07/18/18 08/14/18	No violations
	Compliance with underground storage tank requirements and operating permits (Site 300)	SJCEHD	07/30/18	SJCEHD issued one violation for: Failure to maintain monitoring, maintenance, and follow up action records.
	CUPA Inspection (Livermore Site)	LPFD	06/18/18–06/21/18 12/27/18	No violations
	CUPA Inspection (Site 300)	SJCEHD	11/26/18	SJCEHD issued two violations for: Failure to properly close tanks when making a claim of permanently closed, and failure to keep records of procedures, inspections, or integrity tests for three years..
	361 TBD-01 and 361TFAD01 Tank Closures	LPFD	12/3/18	No violations
	133TFBD01 Tank Closure	LPFD	11/13/18	No violations
Waste	CUPA Inspection (Livermore Site)	LPFD	06/18/18–06/21/18	No violations
	CUPA Inspection, Site 300	SJCEHD	11/13/18 - 11/14/18, 11/26/18	SJCEHD issued one violation for: Failure to completely label a hazardous waste container (missing hazardous properties information on the waste label).
	Hazardous waste facilities Compliance Evaluation Inspection (CEI) (Livermore Site)	EPA	05/14/18	No violations
	Hazardous waste facilities Compliance Evaluation Inspection (CEI) (Site 300)	EPA/DTSC	06/05/18	No violations
	Medical Waste facilities inspection	ACDEH	08/22/18, 09/05/18	No violations

Table 2-3. (cont.) Inspections of Livermore Site and Site 300 by external agencies in 2018

Medium	Description	Agency	Date	Finding
Water	Permitted operations (Site 300 Drinking Water)	SWRCB	05/31/18	No violations
	Waste Discharge Requirements for sewage pond, percolation pits, and septic systems	CVRWQCB	05/19/18 11/05/18	No violations
	Closed Landfill Pit 1	CVRWQCB	05/19/18 11/05/18	No violations

Note: See the **Acronyms and Glossary** section for acronym definitions.

Table 2-4. Environmental Occurrences reported under the Occurrence Reporting System in 2018.

Date[a]	Occurrence category/group	Description
07/30/18	Report Level I Occurrence under Group 9(1) OR 2018-0022	On July 30, LLNL received a Notice of Violation from the SJCEHD as a result of an Underground Storage Tank (UST) inspection. The inspection report identified one minor violation associated with tank repair documentation: A contractor performing repairs submitted appropriate documentation to the County but failed to submit appropriate documentation to LLNL. This minor violation was corrected during the inspection.
11/26/18	Report Level I Occurrence under Group 9(1) OR 2018-0034	On November 26, 2018, LLNL received a Notice of Violation from the SJCEHD following a CUPA inspection of S300. The inspection report identified a total of five violations, including: Failure to properly label a container; failure to properly close a tank under SPCC criteria; failure to keep SPCC inspection records for three years; failure to submit a site map with required content; and failure to submit emergency response procedures for a release or threatened release.

Note: See the **Acronyms and Glossary** section for acronym definitions.

[a] Date the occurrence was categorized, not discovered.

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3. Environmental Program Information

Heather Ottaway

Lawrence Livermore National Laboratory (LLNL) is committed to enhancing its environmental stewardship and reducing any impacts its operations may have on the environment. This chapter describes LLNL's Environmental Management System (EMS) and Pollution Prevention/Sustainability Program (P2S).

3.1 Environmental Management System

LLNL continues to enhance its EMS through systematic process improvements and increased focus on establishing specific environmental objectives and performance measures contained in Environment, Safety & Health (ES&H) Action Plans. Progress toward goals is regularly measured and provided to senior management and other interested parties through a variety of means, including periodic senior management reports and the yearly update of this Environmental Report. The Laboratory's EMS has successfully maintained its International Organization for Standardization (ISO) 14001 registration since 2009 and is audited annually by a third-party internationally recognized ISO registrar for continued conformance and certification. In Fiscal Year (FY)18, the Laboratory successfully migrated to the revised 2015 ISO 14001 standard.

3.1.1 ES&H Action Plans

To better align with the revised 2015 ISO 14001 standard, a significant restructuring of the objectives setting process was implemented in FY18. In place of past Environmental Management Plans (EMPs), ES&H Action Plans were established to detail the objectives and track progress toward meeting environmental goals focused on decreasing climate impacts, conserving water, and reducing waste. Each ES&H Action Plan is championed by a senior manager who is responsible for developing objectives, assigning a process owner to lead the project successfully to meet objectives, providing adequate resources such as team members and data, holding the team accountable to goals and objectives, and presenting interim reviews to the senior management team. All ES&H Action Plans are reviewed and approved by the Laboratory deputy director. Senior managers championed nine ES&H Action Plans during FY18, five of which were specifically designed to address significant environmental aspects, the other action plans address health and safety objectives. **Table 3-1** lists the five ES&H Action Plans along with progress made in FY18 toward meeting the objectives and the status toward completion. The action plans in place also help to ensure that related U.S. Department of Energy (DOE) sustainability goals are addressed. LLNL's status toward meeting the DOE sustainability goals, along with planned actions (including ES&H Action Plans) to ensure continued progress toward attaining these goals can be found in the *LLNL FY18 Site Sustainability Plan* in **Appendix D.**

Table 3-1. ES&H Action Plan summary

Action Plan	Objectives	Related DOE SSP Goal Category
AP-01 Meet all Site Sustainability Plan (SSP) Goals	In the annual SSP, goals are evaluated for high, medium, or low risk of non-attainment as follows: Low risk – high feasibility goal will be met Medium risk – medium feasibility goal will be met High risk – low feasibility goal will be met.	All
AP-02 Develop a Municipal Waste Reduction Strategy	Continue working toward diversion of 100% of recyclable and compostable waste.	Waste Management
AP-03 Implement Smart Labs Initiative	Using available data and modeling, estimate the baseline annual kWh/ft^2 and water/ft^2 and identify opportunities for reduction, reuse, or recycling for in-scope Laboratory buildings.	Energy Management, Water Management, Waste Management
AP-04 Electric Vehicle Charging Infrastructure	Reduce scope 3 greenhouse gas (GHG) emissions by 3 metric tons of carbon dioxide equivalent ($MTCO_2e$) annually based on expected miles per gallon (MPG) and average miles driven per year for 10 government electric vehicles. Reduce scope 3 GHG emissions by 60 $MTCO_2e$ for personally owned vehicles (20 employees times 3 MTCO2e per vehicle) based on the average employee commute and average GHG savings from fully electric vehicles used in lieu of gas powered (assuming a commute distance of 45 miles per day for 230 days a gasoline car emits 3.9 $MTCO_2e$ annually; to charge an electric car for a 45-mile commute for 230 days results in 1.0 $MTCO_2e$ emitted annually).	Fleet Management
AP-07 Operational Stewardship	Address safety and environmental risks associated with closed facilities and trailers and surrounding areas that may contain hazardous and/or radioactive materials and equipment, and other potential hazards.	Waste Management

3.1.2 EMS Audits and Reviews

The Laboratory successfully completed one external third-party independent audit of its ISO 14001 EMS program (May 2018) with recommendations from the auditor to re-certify LLNL's ISO 14001:2015 registration through 2021. This independent audit was conducted by NSF International Strategic Registrations and validated the Laboratory's solid commitment to environmental stewardship.

3.1.2.2 Internal Assessments and Reviews

In November 2018, Senior Management Reviews of the EMS were conducted, reaffirming management commitment to LLNL's environmental policy and stewardship through the implementation of EMS. In February of 2018, an internal audit (Joint Functional Area Line Management Assessment [JFLMA]) was performed to assess if LLNL continues to meet the requirements of the standard. This audit used a management assessment model to ensure objectivity and impartiality were maintained during the process.

In accordance with LLNL's EMS, the Laboratory's environmental compliance is regularly evaluated through reviews of internal assessments including Management Self Assessments (MSAs); Management Observations and Inspections (MOIs); regulatory inspections; internal and external monitoring and compliance reports; and facility walk-throughs and work-control assessments. As a result of these reviews, LLNL identified specific practices and recommendations for corrective and preventive measures, demonstrating the Laboratory's commitment to environmental compliance.

3.2 Pollution Prevention/Sustainability Program

LLNL's P2S Program operates within the framework of the Integrated Safety Management System (ISMS) and EMS and in accordance with applicable laws, regulations, and DOE orders as required by contract. It encompasses stewardship and maintenance, waste stream analysis, reporting of waste generation and P2S accomplishments, and fostering of P2S awareness through presentations, articles, and events. The P2S Program supports institutional and directorate P2S activities via environmental teams and includes implementation and facilitation of source reduction and/or reclamation, recycling, and reuse programs for hazardous and nonhazardous waste; facilitation of sustainable acquisition; and preparation of P2S opportunity assessments.

The P2S Program at LLNL strives to systematically reduce all types of waste generated and eliminate or minimize pollutant releases to all environmental media from all aspects of the operations at the Livermore Site and Site 300. These efforts help protect public health and the environment by reducing or eliminating waste, improving resource usage, and reducing inventories and releases of hazardous chemicals. These efforts also benefit LLNL by reducing compliance costs and minimizing the potential for civil and criminal liabilities under environmental laws. In accordance with Environmental Protection Agency (EPA) guidelines and DOE policy, the P2S Program uses a hierarchical approach to waste reduction (i.e., source elimination or reduction, material substitution, reuse and recycling, and, lastly, treatment and disposal), which is applied to all types of waste. Radioactive and hazardous waste generation is tracked using Radioactive and Hazardous Waste Management's (RHWM's) HazTrack database (a system used to track all waste managed by RHWM). By reviewing the information in this database, program managers and P2S Program staff can monitor and analyze waste streams managed by RHWM to determine cost-effective improvements to LLNL operations. The P2S Program efforts primarily focus on opportunities to reduce routine waste from ongoing operations and non-routine waste from construction and demolition activities. Data on non-routine hazardous, transuranic, and radioactive waste can be found in the *2018 Annual Yearbook for the LLNL SW/SPEIS* (Quinly 2019).

3.2.1 Routine Hazardous, Transuranic, and Radioactive Waste

Routine waste listed in **Tables 3-2** and **3-3** includes waste from ongoing operations produced by any type of production, analysis, and research and development taking place at LLNL.

Table 3-2. Routine hazardous waste at LLNL, FY2014–2018

Waste Category	FY2014	FY2015	FY2016	FY2017	FY2018
Routine hazardous waste generated Metric Tons (MT)	202	170	142	110	167

Table 3-3. Routine transuranic and radioactive waste at LLNL, FY2014–2018

Waste Category	FY2014	FY2015	FY2016	FY2017	FY2018
Routine LLW generated (m^3)	896	860	284	318	353
Routine mixed waste generated (m^3)	31	19	25.5	14	38
Routine TRU/mixed TRU waste generated (m^3)	9.5	0.9	14	3.2	17

3.2.2 Diverted Waste

LLNL maintains an active waste-diversion program, encouraging recycling and reuse of both routine and non-routine waste, which prevents waste from going to the landfill. Site sustainability goals require separate accounting for construction/demolition and municipal solid wastes as reflected in **Tables 3-4** and **3-5**.

3.2.2.1 Municipal Solid Waste

Together, the Livermore Site and Site 300 generated 2,708 MT of routine nonhazardous solid waste in FY2018. This volume includes diverted waste (e.g., material diverted through recycling and reuse programs) and landfill waste.

Both sites combined diverted a total 2,019 MT of routine nonhazardous waste in FY2018, which represents a diversion rate of 75%. The portion of routine nonhazardous waste sent to landfill was 689 MT, see **Table 3-4**. In 2018, LLNL recycled 3,562 computers, monitors, laptops and tablets, which were resold or managed as universal waste. LLNL recycled 27 MT of large and small batteries, which were also managed as universal waste. LLNL also established a take back program for cell phones in which usable phones are refurbished for reuse and broken or otherwise unusable phones are shredded for recycling. In FY2018, LLNL sent 840 old cell phones through this program.

LLNL continued to expand recycling opportunities for plastics beyond the comingled recycling program. In 2018, 20.5 MT of plastics were recycled despite a declining plastics recycling market. The comingled recycling and composting program initiated in May 2011 was continued during 2018, diverting an estimated 44 MT of comingled recycling and 66 MT of compostable material from the landfill. To make separation easier for employees and decrease the amount of waste sent to landfill, the disposable foodservice products in the on-site cafeterias are compostable.

Table 3-4. Routine municipal waste in FY2018, Livermore Site and Site 300 combined

Destination	Waste Description	Amount in FY2018 (MT)
Diverted	Baled paper	59.5
	Corrugated cardboard	76
	Cooking grease (including grease traps)	25
	Mixed metals	754
	Scrap lead (Pb)	25
	Plastic	20.5
	Office paper	61
	Toner cartridges	12
	Greenwaste (chips, compost, mulch, clean wood)	876
	Comingled recycling	44
	Compost (food scraps, paper towels, food containers)	66
	TOTAL diverted	**2,019**
Landfill	Compacted (landfill)	689
	TOTAL landfill	**689**
	TOTAL routine nonhazardous waste	**2,708**

3.2.2.2 Construction and Demolition (C&D) Waste

C&D wastes include excavated soils, wastes and metals from construction, decontamination, and demolition activities. The Livermore Site and Site 300 generated a total of 829 MT of waste related to construction and demolition activities in FY2018. The two sites combined diverted 546 MT of non-routine nonhazardous solid waste through reuse or recycling, which represents a diversion rate of 66% in FY2018. Diverted C&D waste includes soil and concrete reused either on-site for other projects or as cover at Class II landfills. See **Table 3-5.**

Table 3-5. Construction and demolition waste in FY2018, Livermore Site and Site 300 combined

Destination	Waste Description	Amount in FY2018 (MT)
Diverted	Class II cover soil (reused on-site or as landfill cover)	13
	Class II concrete (reused at the landfill for roads, pads, etc. or as cover)	525
	Scrap metals (recycled)	8
	TOTAL diverted	**546**
Landfill	Construction and demolition (non-compacted landfill)	283
	TOTAL landfill	**283**
	TOTAL non-routine non-hazardous waste	**829**

3.2.3 Sustainable Acquisition

LLNL has a comprehensive Sustainable Acquisition program that includes preferential purchasing of recycled content and bio-based products. In 2018, the Sustainable Acquisition program continued to include a preference for Electronic Product Environmental Assessment Tool (EPEAT) registered computers and monitors, imaging equipment, and televisions. Eighty five percent of all desktop electronics, imaging equipment, and television purchases in FY2018 were EPEAT Bronze, EPEAT Silver or EPEAT Gold, indicating that the products meet or exceed the Institute of Electrical and Electronics Engineers (IEEE) environmental performance standards for electronic products (1680.1-2009; 1680.2-2012; 1680.3-2012).

Additional sustainable acquisition highlights can be found in the *LLNL FY18 Site Sustainability Plan* in **Appendix D.**

3.2.4 Pollution Prevention/Sustainability Activities

3.2.4.1 Environmental Stewardship Accomplishments and Awards

Each year, the P2S Program submits nominations for the National Nuclear Security Administration (NNSA) environmental awards and DOE Sustainability awards programs, which recognize exemplary performance in integrating environmental stewardship practices to reduce risk, protect natural resources, and enhance site operations. P2S also submits nominations for various other awards recognizing excellence in P2S projects.

LLNL submitted two award nominations to DOE and NNSA for work performed in FY2018. One nomination was submitted in the innovative approach category for its collaborative LLNL-DOE effort to incrementally replace LLNL’s fleet of gas-powered vehicles with electric vehicles. The project has already saved an estimated 179 metric tons of carbon dioxide equivalent ($MTCO_2e$). This nomination won both a DOE and NNSA Sustainability Award.

The other nomination was submitted in the Strategic Partnerships for Sustainability category for collaborative efforts between the two labs to expand sustainability opportunities, educate employees, and connect with the local community. This nomination won a NNSA Sustainability Award and an Honorable Mention from DOE.

LLNL also won *USDA's Biopreferred 2018 Excellence in Biobased Procurement Award* for biobased purchases. The food services program has converted all food service ware to biobased and compostable products, adopting biobased hot cups, cold cups, cutlery, lids, straws, takeout containers, napkins, soup cups, small sides/condiment containers, and to-go bags. The custodial division uses biobased hand soap and multipurpose cleaners Lab-wide.

3.2.4.2 High-Performance Sustainable Buildings and Energy Conservation

Four Leadership in Energy and Environmental Design (LEED) building certifications (B142, B264, B451, and B453) were completed in 2008–2011 and six initial building assessments using the DOE High Performance Sustainable Building (HPSB) assessment tool were completed in 2011–2012. The current number of occupied buildings over 5,000 square feet in the enduring inventory is 168, with a total square footage of 6,433,655. LLNL has set a goal of 15% existing buildings greater than 5,000 gross square feet which is 25 buildings with a total square footage of 965,048, being compliant with the guiding principles for HPSB by 2025. As of FY 2018, 12 buildings had been assessed using the LEED system, HPSB, or are CalGreen compliant—with a total square footage of 417,539. An additional 13 assessments based on building count and an additional 547,509 square feet based on square footage need to be assessed to achieve the 15% goal.

Three new buildings are currently planned for construction over the next several years with the goal of achieving LEED certification. This will contribute approximately 60,000 square feet to the assessed and/or certified totals, bringing the total to 477,539 square feet.

Applying best practices continues to help reduce LLNL's energy intensity and GHG emissions. These best practices include alerting facility managers of excessive use in their facilities, updating and adapting equipment operating schedules to meet the changing requirements of occupants, providing staff with the training and tools they need, and tracking energy use and comparing against expected performance. LLNL's Site 200 and Site 300 each have a site-wide direct digital control (DDC) system that is used to control temperatures, pressures, and humidity in many buildings. The system is state-of-the-art and as of the end of 2018 had approximately 581 high-speed, connected digital processors in 46 buildings with several more installations planned.

LLNL has also implemented many on-going sustainability efforts to increase the energy efficiency of data center facilities including the installation of Cold Aisle Containment systems, increasing ambient temperatures and reducing occupancy lighting in several key data center facilities, server consolidation, and server virtualization (i.e., using software to divide one physical server into multiple isolated virtual environments). LLNL continues to identify and decommission data centers that are no longer needed.

Additional information on energy conservation goals can be found in the *LLNL FY18 Site Sustainability Plan* in **Appendix D.**

3.2.5 Pollution Prevention/Sustainability Employee Training and Awareness Programs

The P2S Program conducted awareness activities during the year. Articles on pollution prevention were published in Newsline (LLNL's internal online newsletter) and Attune 360, the Environment, Safety, and Health Newsletter; and the P2S Program continued to provide support for implementation of green events. The P2S Program continues to conduct training for purchasing staff on Sustainable Acquisition requirements, and a Green Hotline continues to provide support for employees with questions, suggestions, or ideas regarding LLNL's pollution prevention and waste diversion endeavors, as well as other environmental issues.

The P2S Program also holds events each year to celebrate and bring awareness to Earth Day. In April 2018 an Earth Day celebration was held with neighboring Sandia National Laboratory (SNL/CA). It was a collaborative effort between both Labs, multiple departments within SNL/CA, local city and county agencies providing information about composting, recycling and water conservation; and local green office product vendors featuring green products and promoting green purchasing practices. Nearly 20 scientific vendors were on-site for LLNL and SNL/CA scientists to connect and share information, problem solve, and collaborate with scientists from companies around the country. There was also electronic waste recycling and paper shredding for both Labs' employees. A wildlife expert conducted a native bird walk throughout the SNL/CA site. Several hundred people attended the event.

In May, LLNL, SNL/CA, and Livermore Laboratory Employee Services Association (LLESA) (a non-profit employee services group that supports both sites) hosted a joint Bike to Work and Share Your Ride event for the 4th consecutive year. This event is held in conjunction with other cities in the San Francisco Bay Area and helps both sites promote alternative commute options for employees. On the morning of Bike to Work Day LLESA and volunteers from LLNL and SNL/CA set up an energizer station where cyclists check in and enjoy refreshments, this station is included in the overall San Francisco Bay Area Bike to Work Day outreach and was one of 142 stations supported in the region this year. It is in an open area where it serves local Livermore residents as well. Local agencies were invited to provide local transportation information at the energizer station. The energizer station also provides an opportunity to gather data on the number of employees who commute by bike or ride share.

The P2S Program used this event as an opportunity to gather data on the number of bike commuters, commute distance, number of days per month each bike commuter rides to work, and the number of first-time bike commuters (**Table 3-6**). These data help LLNL calculate Scope 3 greenhouse gas reductions realized through employee alternative commuting and to better direct outreach on available alternative commute options.

Table 3-6. Bike to work day attendee details

	FY2017	FY2018
Total participants	158	174
Number of pledges	99	100
Pledges who checked in	59 (59%)	67 (67%)
Number of first-time riders	5	22
Average round trip mileage	11.3	10.8
Total round trip mileage	1,769	1,838
Average number of bike commuting days per month	11.8	13.1

LLNL and SNL also collaborated to hold a monthly Farmers’ Market at the Sandia Open Campus, which is open to the public, on the last Tuesday of each month between May and October. The September market was dedicated to sustainability topics outreach.

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4. Air Monitoring and Dose Assessment

Kent Wilson • Heather Byrnes • Wilfred Montemayor • Anthony Wegrecki

Lawrence Livermore National Laboratory (LLNL) performs continuous air sampling to evaluate its compliance with local, state, and federal laws and regulations and to ensure that human health and the environment are protected. Federal environmental air quality laws and U.S. Department of Energy (DOE) regulations include Title 40, Code of Federal Regulations, Part 61 (40 CFR 61), Subpart H—the National Emission Standards for Hazardous Air Pollutants (NESHAPs) section of the Clean Air Act; applicable portions of DOE Order 458.1; and American National Standards Institute (ANSI) standards (N13.1-1969, 1999 [reaffirmed 2011]). The *Environmental Radiological Effluent Monitoring and Environmental Surveillance* (DOE 2015) handbook provides the guidance for implementing DOE Order 458.1.

The U.S. Environmental Protection Agency (EPA) Region IX has enforcement authority for LLNL compliance with radiological air emission regulations. Enforcement authority for the Clean Air Act regulations, pertaining to nonradiological air emissions, belongs to two local air districts: The Bay Area Air Quality Management District (BAAQMD) and the San Joaquin Valley Air Pollution Control District (SJVAPCD).

4.1 Air Effluent Monitoring

Air effluent monitoring of atmospheric discharge points is in place for compliance with 40 CFR Part 61, Subpart H and is used to determine the actual radionuclide releases from individual facilities during routine and nonroutine operations and to confirm the operation of facility emission control systems. Subpart H requires continuous monitoring of facility radiological air effluents if the potential off-site (fence-line) dose equivalent is greater than 1 µSv/y (0.1 mrem/y), as calculated using the U.S. EPA-mandated air dispersion dose model, CAP88-PC, without credit for emission control devices. The results of monitoring air discharge points provide the actual emission source information for modeling, which is used to ensure that the NESHAPs standard of 100 µSv/y (10 mrem/y) total site effective-dose equivalent from the airborne pathway is not exceeded. See **Appendix D** for the *LLNL 2018 NESHAPs Annual Report* (Wilson et al., 2019).

The air effluent sampling program measures only radiological emissions. For LLNL operations with nonradiological discharges, LLNL obtains permits and registrations from local air districts (i.e., BAAQMD and SJVAPCD) for stationary emission sources and from the California Air Resources Board (CARB) for portable emission sources such as diesel air compressors and generators and for off-road diesel vehicles. Current permits and registrations do not require monitoring of air effluent but do require monitoring of equipment inventory, equipment usage, material usage, and/or record keeping during operations. Based on air toxics emissions inventory and risk assessment required by the California Air Toxics "Hot Spots" Information and Assessment Act of 1987, BAAQMD and SJVAPCD have ranked LLNL as a low-risk facility for nonradiological air emissions.

4.1.1 Air Effluent Radiological Monitoring Results

In 2018, LLNL measured releases of radioactivity from air exhausts at five facilities at the Livermore Site and at one facility at Site 300. Air effluent monitoring locations at the Livermore Site and Site 300 are shown in **Figures 4-1** and **4-2**, respectively.

Three facilities had measurable emissions in 2018. A total of 183.5 Ci (6,790 GBq) of measured tritium was released from the stack exhausts at the Tritium Facility. Of this, approximately 78% of tritium was released as vapor (HTO). The remaining 22% released was gaseous tritium (HT).

The National Ignition Facility (NIF) released a total of 8.66 Ci (320 GBq) of tritium from the stack exhaust in 2018. Of this, approximately 31% of tritium was released as HTO. The remaining 69% was released as HT. In the first part of 2018, the glycol bubbler that measures tritium emissions was at the vendor being repaired for a faulty heat controller. The bubbler was back online continuously monitoring the stack effluent as of February 13, 2018.

A Monte Carlo probability simulation was developed to estimate the amount of HT and HTO for all non-monitored days. The estimate was based on 10,000 iterations each for HT and HTO. The highest values were used as a conservative approach in comparison to the straight mean (applying the average of measured emissions as an estimate). The total estimated amount of tritium released through February 13, 2018 was 0.277 Ci (10.2 GBq).

Of the 8.66 Ci (320 GBq) of tritium released from the stack effluent in 2018, 5.53 Ci was from an unplanned event on June 11, 2018. The bubbler was online and captured the release. See **Appendix D** for the *LLNL 2018 NESHAPs Annual Report*, Section 5 (Wilson et al. 2019) for a description of the event.

The Contained Firing Facility (B801A) at Site 300 had measured depleted uranium stack emissions in 2018 consisting of 1.2×10^{-7} Ci (4.4×10^{-6} GBq) of uranium-234, 1.1×10^{-8} Ci (4.1×10^{-7} GBq) of uranium-235, and 8.9×10^{-7} Ci (3.3×10^{-5} GBq) of uranium-238 in particulate form.

None of the other facilities monitored for radionuclides had reportable emissions in 2018. The data tables in **Appendix A, Section A.1** provide summary results of all air effluent monitored facilities and include upwind locations (control stations), which are used for gross alpha and gross beta background comparison to stack effluent gross alpha and gross beta results.

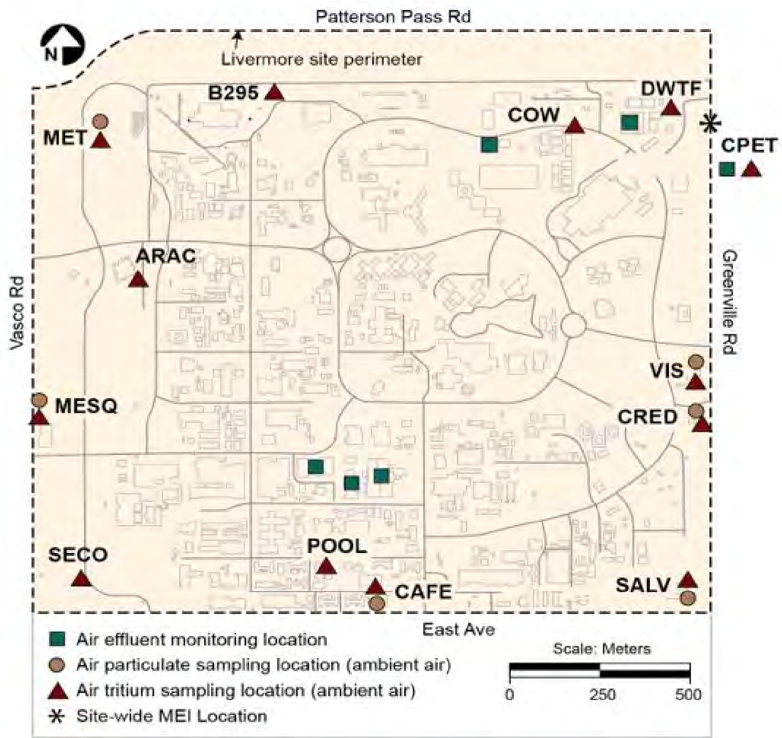

Figure 4-1. Air effluent and ambient air monitoring locations at the Livermore Site, 2018.

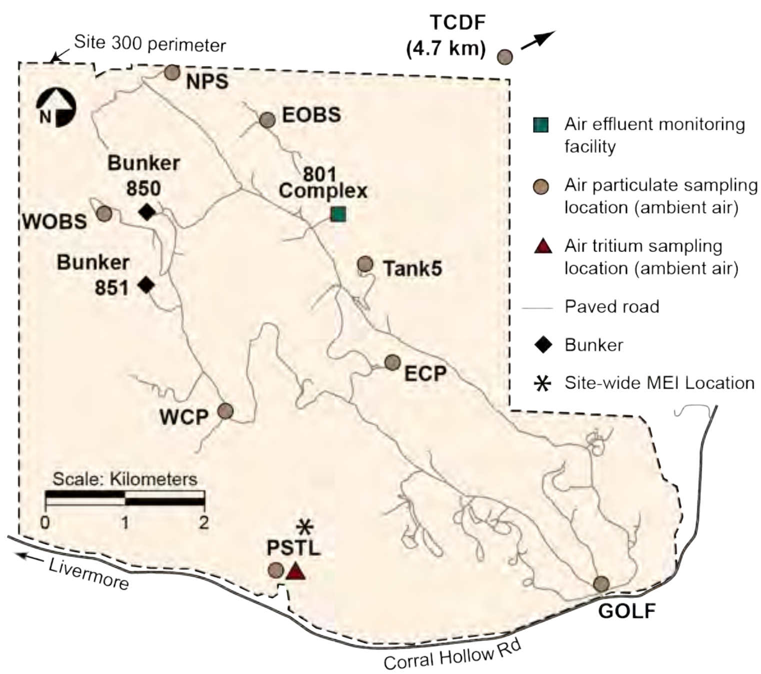

Figure 4-2. Air effluent and ambient air monitoring locations at Site 300, 2018.

4.1.2 Nonradiological Air Releases and Impact on the Environment

In 2018, the Livermore Site emitted approximately 102.9 kg/d of regulated air pollutants as defined by the Clean Air Act, including nitrous oxides (NOx), sulfur oxides (SOx), particulate matter (PM10), carbon monoxide (CO), and reactive organic gases/precursor organic compounds (ROGs/POCs) (see **Table 4-1**). The stationary emission sources that released the greatest amount of regulated pollutants at the Livermore Site were natural gas fired boilers, internal combustion engines (such as diesel generators), solvent cleaning, and surface coating operations (such as painting). Pollutant emission information was primarily derived from monthly material and equipment usage records.

Table 4-1. Nonradioactive air emissions, Livermore Site and Site 300, 2018.

	Estimated releases (kg/d)	
Pollutant	**Livermore Site**	**Site 300**
ROGs/POCs	15.7	0.17
Nitrogen oxides	37.5	1.72
Carbon monoxide	43.3	0.43
Particulates (PM10)	4.7	0.34
Sulfur oxides	1.7	0.08
Total	102.9	2.74

Livermore Site air pollutant emissions were very low in 2018 compared to the daily releases of air pollutants from all sources in the entire Bay Area. For example, the average daily emission of NOx in the Bay Area is estimated to be 2.3×10^5 kg/d, compared to the estimated daily release from the Livermore Site of 37.5 kg/d, which is 0.016% of total Bay Area source emissions for NOx. The 2018 BAAQMD estimate for ROGs/POCs daily emissions throughout the Bay Area was approximately 2.2×10^5 kg/d, while the daily emission estimate for 2018 from the Livermore Site was 15.7 kg/d, or 0.0071% of the total Bay Area source emissions for ROGs/POCs.

Certain operations at Site 300 require permits from the SJVAPCD. The estimated daily air pollutant emissions during 2018 from operations (permitted and exempt stationary sources) at Site 300 are listed in **Table 4-1**. The stationary emission sources that release the greatest amounts of regulated air pollutants at Site 300 include internal combustion engines (such as diesel-powered generators), a gasoline-dispensing facility, and general research operations. Combustion pollutant emissions, including NOx, CO, PM10, SOx, and ROGs/POCs decreased in 2018. The diesel-powered generators were the primary source of the pollutants.

4.2 Ambient Air Monitoring

LLNL conducts ambient air monitoring at on- and off-site locations to determine whether airborne radionuclides or beryllium are being released to the environs in measurable quantities by LLNL operations. Ambient air monitoring also serves to verify the air concentrations predicted by air dispersion modeling and to determine compliance with NESHAPs regulations.

Beryllium is the only nonradiological emission from LLNL that is monitored in ambient air. LLNL requested and was granted a waiver by the BAAQMD for source-specific monitoring and record keeping for beryllium operations, provided that LLNL can demonstrate that monthly average beryllium concentrations in air are well below regulatory limits of 10,000 pg/m^3. LLNL meets this requirement by sampling for beryllium at perimeter locations.

Based on air-dispersion modeling using site-specific meteorological data, the ambient air samplers, particularly those on the site perimeters, have been placed to monitor locations where elevated air concentrations due to LLNL operations may occur. Sampling locations for each monitoring network are shown in **Figures 4-1**, **4-2**, and **4-3**.

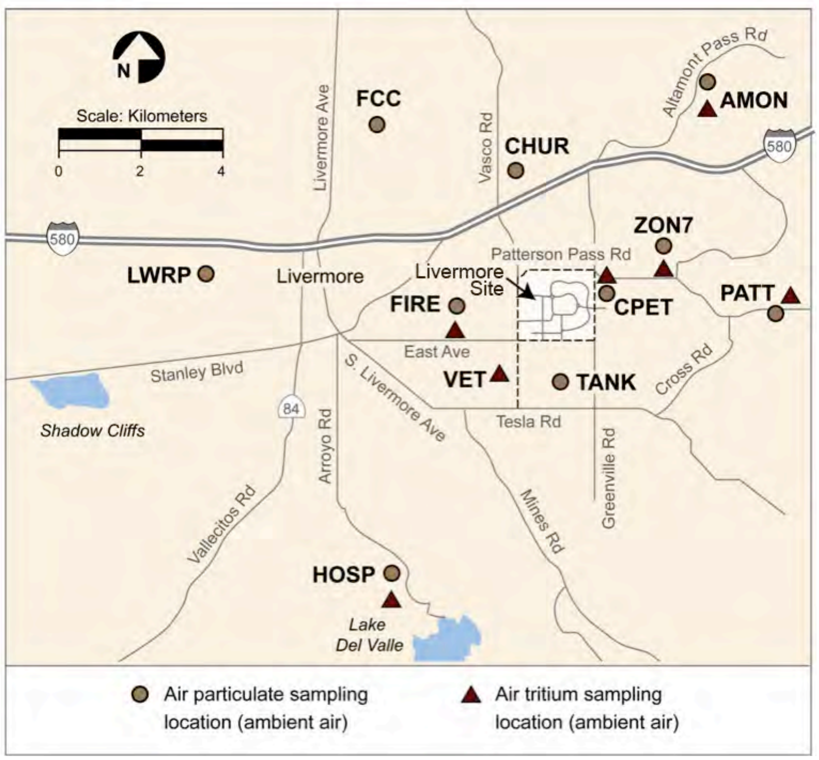

Figure 4-3. Air particulate and tritium monitoring locations in the Livermore Valley, 2018.

4.2.1 Ambient Air Radioactive Particulates

Composite samples for the Livermore Site and Site 300 were analyzed by gamma spectroscopy for an environmental suite of gamma-emitting radionuclide concentrations in air that include fission products, activation products, actinides, and naturally occurring isotopes. The isotopes detected at both sites in 2018 were beryllium-7 (cosmogenic), lead-210, and potassium-40, all of which are naturally occurring in the environment. The January composite sample at Site 300 was positive for thorium-228, which is naturally occurring.

Composite samples were analyzed by alpha spectroscopy for plutonium-239+240, which was detected in 7 out of 206 samples taken in 2018. Detections at the Livermore Site, Site 300, and

Livermore off-site locations for plutonium-239+240 are attributed to a number of factors that include: resuspension of plutonium-contaminated soil (see **Chapter 6**), resuspended fallout from previous atmospheric testing, or resuspended fallout from the Fukushima nuclear accident.

The derived concentration standard (DCS), which complements DOE Order 458.1, specifies the concentrations of a radionuclide that can be inhaled continuously 365 days a year without exceeding the DOE primary radiation protection standard for the public, which is 1 mSv/y (100 mrem/y) effective dose equivalent.

The DCS was formerly published in DOE Order 5400.5 (Radiation Protection of the Public and the Environment) in 1993. The current radiation protection standards approach, which has changed from the previously adopted 1993 guidance, uses age and gender specific attributes for the population subgroups of members of the public subject to exposure incorporating more sophisticated biokinetic and dosimetric information from the International Commission on Radiological Protection (ICRP).

The highest values and percentage of the DCS for the plutonium-239+240 detections were as follows:

- Livermore Site perimeter: 21.8 nBq/m^3 (0.59 aCi/m^3), 0.00024% of the DCS.
- Livermore off-site locations: 18.0 nBq/m^3 (0.49 aCi/m^3), 0.0002% of the DCS.
- Site 300 composite: 18.6 nBq/m^3 (0.50 aCi/m^3), 0.00021% of the DCS.

Uranium-235 and uranium-238 were detected at all sample locations. Uranium ratios, which can be calculated by mass or by atom, are used to determine the type of uranium present in the environment. Natural uranium has a mathematical uranium-235/uranium-238 ratio of 0.00725, and depleted uranium has a typical uranium-235/uranium-238 ratio of 0.002. The annual median uranium-235/uranium-238 isotopic ratios for 2018 at the Livermore Site and off-site location were:

- Livermore Site perimeter composite: 0.00722.
- Off-site TCDF (located 4.7 km northeast from Site 300): 0.00726.

The annual uranium-235/uranium-238 isotopic ratio medians are consistent with naturally occurring uranium.

Site 300 has not had atmospheric depleted uranium shots since September 2007. However, there are still areas of depleted uranium contaminated soil. Wind-driven resuspension as well as soil disturbance from construction-type activities and fire road maintenance showed a depleted uranium signature in one sample at the location of the site-wide maximally exposed individual (SW-MEI) (see **Figure 4-2**). The uranium-235 to uranium-238 isotopic ratio was 0.0065; this results in approximately 18% depleted uranium with the other 82% of the uranium naturally occurring.

All of the individual uranium-235 and uranium-238 results, including samples showing a depleted uranium signature, were less than one tenth of one percent of the DCS as shown in **Appendix A**, **Section A.2**.

All locations were sampled for gross alpha and gross beta. The primary sources of alpha and beta activities are naturally occurring radioisotopes. Routine isotopic gamma results indicate the activities are the result of naturally occurring isotopes (uranium, radium, and lead), which are also routinely found in local soils. See **Appendix A, Section A.2**.

4.2.2 Ambient Air Tritium Concentrations

LLNL emits tritium to the air from multiple sources. These sources include monitored stack sources, such as the Tritium Facility and NIF, unmonitored stack sources having minor emissions of tritium, and area sources. Area (diffuse) sources include stored containers of tritium waste or tritium-contaminated equipment from which HTO diffuses into the atmosphere. LLNL does not directly measure diffuse emissions, but estimates the radiation dose to the public from these sources given measurements taken using the ambient air tritium sampling network. The ambient air tritium sampling network measures HTO concentrations in the air from all sources. This information, along with measured stack emissions, is used to provide an estimate of the dose to the public from diffuse area tritium emissions. The approach used to characterize the area emission sources is stated in the *LLNL NESHAPs 2018 Annual Report* (Wilson et al., 2019). See **Appendix D** for a copy of this report. The biweekly air tritium data that are provided in **Appendix A**, **Section A.2** are summarized in **Table 4-2**.

Table 4-2. Ambient air tritium sampling summary for 2018.

Sampling location	Detection frequency[(a)]	Concentration (mBq/m^3)				Median as % of DCS[(d)]	Mean dose[(e)](nSv)
		Mean	Median	IQR[(b)]	Maximum[(c)]		
Livermore Site perimeter	295 of 309	179	43.7	50.4	26,700	0.00056	42.0
Livermore Valley	125 of 160	38.3	20.4	23.8	710	0.00026	8.98
Site 300	16 of 26	10.8	10.5	10.7	22.9	0.00013	<5

(a) Detection frequency indicates the number of samples that measure less than 100% of 2-Sigma uncertainty (see Chapter 8).

(b) IQR = Interquartile Range

(c) The maximum concentration in 2018 wss 0.34% of the DCS.

(d) Median as a percent of DCS is not used when the median is a negative value (see Chapter 8)

(e) Based on an annual breathing rate of 8103 m^3 and inhalation dose conversion factor of 1.93×10^{-11} Sv/Bq (DOE-STD-1196-2011). Dose due to HTO absorption through skin is accounted for. It is estimated as equaling one-half of the dose due to inhalation (2001 Environmental Report, Appendix A).

For a location at which the mean concentration is at or below the minimal detectable concentration, dose from tritium is assumed to be less than 5 nSv/y (0.5 µrem/y).

4.2.3 Ambient Air Beryllium Concentrations and Impact on the Environment

LLNL measures the monthly concentrations of airborne beryllium at the Livermore Site, Site 300, and at the off-site sampler northeast of Site 300. The highest value recorded at the Livermore Site perimeter in 2018 for airborne beryllium was 19 pg/m^3. This value is 0.19% of the BAAQMD ambient concentration limit for beryllium (10,000 pg/m^3). There is no regulatory requirement to monitor beryllium in San Joaquin County; however, LLNL analyzes samples from three Site 300 perimeter locations as a best management practice. The highest value recorded at the Site 300 perimeter in 2018 was 22 pg/m^3 and the highest value at the off-site location was 25 pg/m^3. These data are similar to data collected from previous years.

Beryllium is naturally occurring and has a soil concentration of approximately 1 part per million. The sampled results are believed to be from naturally occurring beryllium that was resuspended from the soil and collected by the samplers. Even if the concentrations of beryllium detected were from LLNL activities, the amount is still less than one percent of the BAAQMD ambient air concentration limit.

4.3 Radiological Air Dose Assessment

Dose is assessed for two types of receptors. First is the dose to the SW-MEI member of the public. Second is the collective or "population" dose received by people who reside within 80 km of either of the two LLNL sites.

In 2018, the SW-MEI at the Livermore Site was located at the Integrative Veterinary Care facility (CPET) about 35 m outside the site's eastern perimeter. The SW-MEI at Site 300 was located on the site's south-central perimeter (PSTL), which borders the Carnegie State Vehicular Recreation Area. The two SW-MEI locations are shown in **Figures 4-1** and **4-2**. **Table 4-3** shows average doses received in the United States from exposure to sources of radiation as well as the collective dose for people residing within 80 km of the Livermore Site.

Table 4-3. Radiation doses from ubiquitous background and man-made sources of radiation.

Source category (a)	Individual dose (µSv) (b, c)	Collective dose (d) (person-Sv) (e)
Natural radioactivity (f)		
Cosmic radiation	330	2,570
Terrestrial radiation	210	1,640
Internal (food and water consumption)	290	2,260
Radon and Thoron	2,280	17,800
Medical radiation procedures	3,000	23,400
Consumer	130	1,010
Industrial plus occupational	8	62

(a) From National Council on Radiation Protection and Measurements, Report No. 160, Table 8.1 (NCRP 2009).

(b) 1 µSv = 0.1 mrem.

(c) This dose is an average over the U.S. population.

(d) The collective dose is the combined dose for all individuals residing within an 80-km radius of LLNL (approximately 7.8 million people for the Livermore Site and 7.1 million for Site 300), calculated with respect to distance and direction from each site. The Livermore Site population estimate of 7.8 million people was used to calculate the collective doses for the source categories.

(e) 1 person-Sv = 100 person-rem.

(f) These values vary with location.

The annual radiological doses from all air emissions at the Livermore Site and Site 300 in 2018 were found to be well below the applicable standards for radiation protection of the public, in particular the NESHAPs 100 µSv/y (10 mrem/y) site-wide standard. Using an EPA-mandated computer model and LLNL site-specific meteorology appropriate to the two sites, the doses to the LLNL SW-MEI members of the public from LLNL operations in 2018 were:

- Livermore Site: 6.7×10^{-2} µSv (6.7×10^{-3} mrem).
- Site 300: 9.6×10^{-4} µSv (9.6×10^{-5} mrem).

The collective effective dose equivalent (EDE) attributable to LLNL airborne emissions in 2018 was calculated to be 0.0047 person-Sv (0.47 person-rem) for the Livermore Site and 2.8×10^{-7} person-Sv (2.8×10^{-5} person-rem) for Site 300. These doses include potentially exposed populations of 7.8 million people for the Livermore Site and 7.1 million people for Site 300 living within 80 km of the site centers.

The doses to the SW-MEI, which represent the maximum doses that could be received by members of the public where there is a residence, school, business, or office, resulting from Livermore Site and Site 300 operations in 2018, were less than one percent of the NESHAPs 100 µSv/y (10 mrem/y) site-wide standard.

LLNL operations involving radioactive materials had minimal impact on ambient air during 2018. The measured radionuclide particulate and tritium concentrations in ambient air at the Livermore Site and Site 300 were all less than one percent of the DOE primary radiation protection standard for the public (DCS). The SW-MEI doses from both sites for 2018 are much less than one-tenth of one percent of the total dose from sources of natural radioactivity shown in **Table 4-3.**

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5. Water Monitoring Programs

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• Crystal Rosene • Lane Stephens • Michael Taffet • Kent Wilson

Lawrence Livermore National Laboratory (LLNL) monitors water systems including wastewaters, storm water, and groundwater, as well as rainfall and local surface water. Water systems at the two LLNL sites (the Livermore Site and Site 300) operate differently. For example, the Livermore Site is serviced by a publicly owned treatment works but Site 300 is not, resulting in different methods of treating and disposing of sanitary wastewater at the two sites. Many drivers determine the appropriate methods and locations of the various water monitoring programs, as described below.

In general, water samples are collected according to written, standardized procedures appropriate for the medium (LLNL's *Environmental Monitoring Plan*, Gallegos 2016). Sampling plans are prepared by the LLNL network analysts who are responsible for developing and implementing monitoring programs or networks. Network analysts decide which analytes are sampled (see **Appendix B**) and at what frequency, incorporating any permit-specified requirements. Except for analyses of certain sanitary sewer and retention tank analytes, analyses are usually performed by off-site, California-certified contract analytical laboratories.

5.1 Sanitary Sewer Effluent Monitoring

In 2018, the Livermore Site discharged an average of 1.4 million L/d (368,054 gal/d) of wastewater to the City of Livermore sewer system or 6.7% of the total flow into the City's system. This volume includes wastewater generated by Sandia National Laboratories/California (SNL) and a very small quantity from Site 300. In 2018, SNL generated approximately 12% of the total effluent discharged from the Livermore outfall. Wastewater from SNL and Site 300 is discharged to the LLNL collection system and combined with LLNL sewage before it is released at a single point to the municipal collection system.

LLNL's effluent contains both domestic waste and process wastewater and is discharged in accordance with Wastewater Discharge Permit (Permit #1250) requirements administered by the Water Resources Division (WRD) of the City of Livermore, and the City of Livermore Municipal Code, as discussed below. Most of the process wastewater generated at the Livermore Site is collected in retention tanks and discharged to LLNL's collection system following characterization and approval from LLNL's Environmental Functional Area (EFA) Water Team Staff Wastewater Discharge Authorization Record (WDAR) approval process.

5.1.1 Livermore Site Sanitary Sewer Monitoring Complex

Permit #1250 requires continuous monitoring of the effluent flow rate and pH. Samplers at the Sewer Monitoring Station (SMS) collect flow-proportional composite samples and instantaneous grab samples that are analyzed for metals, radioactivity, total toxic organics, and other water-quality parameters.

5.1.1.1 Radiological Monitoring Results

Department of Energy (DOE) orders and federal regulations establish the standards of operation at LLNL (see **Chapter 2**), including the standards for sanitary sewer discharges. Primarily the standards for radioactive material releases are contained in sections of DOE Order 458.1.

For sanitary sewer discharges, DOE Order 458.1 provides the criteria DOE has established for the application of best available technology to protect public health and minimize degradation of the environment. These criteria (the Derived Concentration Technical Standards [denoted as DCSs by DOE]) limit the concentration of each radionuclide discharged to publicly owned treatment works. If the measured monthly average concentration of a radioisotope exceeds its concentration limit, LLNL is required to improve discharge control measures until concentrations are again below the DOE limits.

The DOE Order 458.1 sanitary sewer discharge numerical limits include the following annual discharge limits for radioactivity: tritium, 185 GBq (5 Ci); carbon-14, 37 GBq (1 Ci); and all other radionuclides combined, 37 GBq (1 Ci). The radioisotopes with the potential to be found in sanitary sewer effluent at LLNL and their discharge limits are discussed below. All analytical results are provided in **Appendix A**, **Section A.3**.

LLNL determines the total radioactivity contributed by tritium, gross alpha emitters, and gross beta emitters from the measured radioactivity in the monthly effluent samples. As shown in **Table 5-1**, the 2018 combined release of alpha and beta sources was 0.390 GBq (0.011 Ci), which is 1.1% of the corresponding DOE Order 458.1 limit (37 GBq [1.0 Ci]). The tritium total was 5.5 GBq (0.15 Ci), which is 2.9% of the DOE Order 458.1 limit (185 GBq [5 Ci]).

Table 5-1. Estimated total radioactivity in LLNL sanitary sewer effluent, 2018.

Radioactivity	Estimate based on effluent activity (GBq)	MDC[(a)] (GBq)
Tritium	5.462	0.730
Gross alpha	0.014	0.103
Gross beta	0.376	0.085

(a) Minimum detectable concentration.

Discharge limits and a summary of the measurements of tritium in the sanitary sewer effluent from LLNL and the Livermore Water Reclamation Plant (LWRP) are reported in LLNL monthly reports. The maximum daily concentration for tritium was 0.067 Bq/mL (1.80 pCi/mL).

Complete calendar year 2018 data for measured concentrations of cesium-137 and plutonium-239 in the sanitary sewer effluent from LLNL, the LWRP, and in LWRP sludge are reported in the LLNL March 2019 Report (Stephens 2019). Cesium and plutonium results are from monthly composite samples of LLNL and LWRP effluent and from quarterly composites of LWRP sludge. For 2018, the annual total discharges of cesium-137 and plutonium-239 were far below the DOE DCSs. Plutonium discharged in LLNL effluent is ultimately concentrated in LWRP sludge. The highest plutonium concentration observed in 2018 sludge was 0.07 mBq/g (0.002 pCi/g), which is many times lower than the National Council on Radiation Protection and Measurements (NCRP) recommended soil screening limit of 470 mBq/g (12.7 pCi/g) for commercial or industrial property.

LLNL also compares annual discharges with historical values to evaluate the effectiveness of ongoing discharge control programs. **Table 5-2** summarizes the radioactivity in sanitary sewer effluent over the past 10 years. During 2018, a total of 5.46 GBq (0.15 Ci) of tritium was discharged to the sanitary sewer. While this is moderately higher than tritium activities discharged during the past 10 years, this amount is in a similar range to historical values, well within regulatory limits, and fully protective of the environment.

Table 5-2. Historical radioactive liquid effluent releases from the Livermore Site, 2008–2018.

Year	Tritium (GBq)	Plutonium-239+240 (GBq)
2008	0.83	5.52×10^{-6}
2009	1.01	5.93×10^{-6}
2010	1.47	5.25×10^{-6}
2011	1.37	2.00×10^{-6}
2012	1.57	7.00×10^{-6}
2013	1.94	5.91×10^{-5}
2014	1.54	3.21×10^{-5}
2015	2.21	1.10×10^{-5}
2016	0.64	$9.38 \text{ x } 10^{-6}$
2017	4.50	1.44×10^{-5}
2018	5.46	$8.7 \text{ x } 10^{-6}$

5.1.1.2 Nonradiological Monitoring Results

LLNL monitors sanitary sewer effluent for chemical and physical parameters at different frequencies depending on the intended use of the result. For example, LLNL's wastewater discharge permit requires LLNL to collect monthly grab samples and 24-hour composites, weekly composites, and daily composites. Once a month, a 24-hour, flow-proportional composite is collected and analyzed; this is referred to as the monthly 24-hour composite in the discussion below. The weekly composite refers to the flow-proportional samples collected over a 7-day period continuously throughout the year. The daily composite refers to the flow-proportional sample collected over a 24-hour period, also collected continuously throughout the year.

A summary of the analytical results from the permit-specified monthly composite sampling program is presented in **Table 5-3**. The permit also requires that grab samples of effluent be collected on a monthly and quarterly basis and analyzed for total toxic organic (TTO) compounds. Samples for cyanide and metals are collected quarterly. Results from LLNL's 2018 sanitary sewer effluent monitoring program are provided in **Appendix A**, **Section A.3**.

Table 5-3. Summary of analytical results for permit-specified monthly, 24-hour composite sampling of the LLNL sanitary sewer effluent, 2018.

Parameter (mg/L)	Detection frequency[(a)]	Minimum	Maximum	Median
Biochemical oxygen demand	12 of 12	43	120	61
Total dissolved solids	12 of 12	270	1000	740
Total suspended solids	12 of 12	31	84	41

(a) The number of times an analyte was positively identified, followed by the number of samples that were analyzed.

As previously noted, grab samples of LLNL's sanitary sewer effluent are collected monthly for TTO analysis (permit limit = 1.0 mg/L) and quarterly for cyanide and metals analysis. In 2018, LLNL did not exceed any of these discharge limits. Results from the monthly TTO analyses for 2018 show that no priority pollutants, listed by the U.S. Environmental Protection Agency (EPA) as toxic organics, were identified in LLNL effluent above the 10 µg/L permit-specified reporting limit. As shown in **Appendix A**, **Section A.3**, one non-regulated organic compound, acetone, was identified in monthly grab samples at concentrations above the 10 µg/L permit-specified reporting limit.

5.1.2 Categorical Processes

The EPA has established pretreatment standards for categories of industrial processes that the EPA has determined are major contributors to point-source water pollution. These federal standards include prescribed sampling, self-monitoring, reporting, and numerical limits for the discharge of category-specific pollutants. At LLNL, the categorical pretreatment standards are incorporated into Permit #1250.

The processes at LLNL that are determined to be regulated under the Categorical Standards may change as programmatic requirements dictate. Categorical processes identified at LLNL (from both the Metal-Finishing Category, 40 CFR 433, and the Electrical and Electronic Components Category, 40 CFR 469) are listed in Permit #1250.

Only processes that discharge to the sanitary sewer require semiannual sampling, inspection, and reporting. During 2018, two processes discharged wastewater to the sanitary sewer: semiconductor processes located in the Building 153 (microfabrication facility), and the abrasive jet machining located in Building 321C. In 2018, LLNL analyzed compliance samples for all regulated parameters from both processes and demonstrated compliance with all federal categorical and local discharge limits. As a further environmental safeguard, LLNL sampled the wastewater in each wastewater tank designated as receiving regulated waste, prior to each discharge to the sanitary sewer. These monitoring data were reported to the WRD in July 2018 and January 2019 Semiannual Wastewater Point-Source Monitoring Reports (Rosene, 2018; 2019).

In addition, WRD source control staff performed their required annual inspection and sampling of the two discharging categorical processes in October 2018. The compliance samples were analyzed for all regulated parameters, and the results demonstrated compliance with all federal and local pretreatment limits.

If any of the non-discharging regulated processes were to discharge process wastewater to the sanitary sewer, they would be regulated under 40 CFR Part 433 and reported in the Semiannual Wastewater Point-Source Monitoring Report. Currently, wastewater from these processes is either recycled on-site or contained for eventual removal and appropriate disposal by Radioactive and Hazardous Waste Management (RHWM).

5.1.3 Discharges of Treated Groundwater

LLNL's groundwater discharge permit (1510G, 2017–2018) allows treated groundwater from the Livermore Site Ground Water Project (GWP) to be discharged in the City of Livermore sanitary sewer system (see **Chapter 7** for more information on the GWP). During 2018, there were no discharges (from on-site-or off-site locations) to the sanitary sewer from the Environmental Restoration Department GWP activities. When such discharges occur, permit compliance is maintained by Treatment Facility Operators through the systematic use of engineering and administrative controls, including WDARs generated for each discharge. This information is reported to the City of Livermore.

5.1.4 Environmental Impact of Sanitary Sewer Effluent

During 2018, no discharges exceeded any discharge limits for either radioactive or nonradioactive materials to the sanitary sewer. The data are comparable to the lowest historical LLNL values. All the values reported for radiological releases are a fraction of their corresponding limits.

The data demonstrate that LLNL continues to have excellent control of both radiological and nonradiological discharges to the sanitary sewer. Monitoring results for 2018 reflect an effective year for LLNL's wastewater discharge control program and indicate no adverse impact to the LWRP or the environment from LLNL sanitary sewer discharges.

5.2 Site 300 Sewage Ponds and Site 300 Waste Discharge Requirements

Wastewater samples were collected from the influent to the Site 300 sewage evaporation pond at a location internal to the evaporation pond itself, and at the effluent from the evaporation pond prior to flow to the sewage percolation pond. All samples were obtained in accordance with the written, standardized procedures summarized in Gallegos (2016).

5.2.1 Sewage Evaporation and Percolation Ponds

Sanitary effluent (nonhazardous wastewater) generated at buildings in the General Services Area at Site 300 is managed in a lined evaporation pond. Occasionally, during winter rains, treated wastewater may discharge into an unlined percolation pond where it enters the ground and the shallow groundwater. Although this potential exists, it did not occur during 2018.

In September 2008, Waste Discharge Requirement (WDR) 96-248 was replaced by WDR R5-2008-0148, a new permit issued by the Central Valley Regional Water Quality Control Board (CVRWQCB) for discharges to ground at Site 300.

Under the terms of this Monitoring and Reporting Program (MRP), LLNL submits semiannual and annual monitoring reports detailing its Site 300 discharges of domestic and wastewater effluent to sewage evaporation and percolation ponds in the General Services Area, and cooling tower blow down to percolation pits and septic systems, and mechanical equipment discharges to percolation pits located throughout the site.

The monitoring data collected for the 2018 semi-annual and annual reports shows compliance with all MRP and permit conditions and limits (Chan 2019a). All networks were in compliance with the permit requirements. Compliance certification accompanied this report, as required by federal and state regulations.

5.2.2 Environmental Impact of Sewage Ponds

There were no discharges from the Site 300 sewage evaporation pond to the percolation pond. Groundwater monitoring related to this area indicated there were no measurable impacts to the groundwater from the sewage pond operations (Chan 2019a).

5.3 Storm Water Compliance and Surveillance Monitoring

The State Water Quality Control Board issued a new Storm Water Industrial General Permit (IGP) (2014-0057-DWQ) that took effect July 1, 2015. LLNL modified the storm water monitoring plan for both sites to achieve compliance with this new permit. Storm water monitoring at both sites also follows the requirements in the U.S. DOE handbook *Environmental Radiological Effluent Monitoring and Environmental Surveillance* (U.S. DOE 2015) and meets the applicable requirements of DOE Order 458.1. **Appendix B** includes the current list of analyses conducted on storm water, including analytical methods and typical reporting limits. See **Figures 5-1** and **5-2** for storm water sampling locations for the Livermore Site and Site 300, respectively.

For construction projects that disturb one acre of land or more, LLNL also meets storm water compliance monitoring requirements of the California National Pollutant Discharge Elimination System (NPDES) General Permit for Storm Water Discharges Associated with Construction Activity (Order Number 2009-0009-DWQ) (SWRCB, 2009). The Energy Independence and Security Act, Section 438 specifically calls for federal development that has a footprint that exceeds 5,000 square feet to maintain or restore predevelopment hydrology.

Under the industrial storm water permit, LLNL is required to collect and analyze samples at specified locations two times during the period from July 1 to December 31 and two times during the period from January 1 to June 30, if specific criteria are met and the sampling window coincides with regular working hours. The State storm water reporting period is offset from the reporting period in this *Environmental Report*. Runoff samples were collected for three storm events at the Livermore Site and one storm event at Site 300 in 2018. Samples were collected from all five required storm water locations at the Livermore Site and one required location, EWTF, at Site 300. Samples were collected at Livermore Site on 1/8/2018, 2/26/2018 and 3/1/2018, and at Site 300 on 1/8/2018. All other precipitation events at Site 300 and Livermore Site during 2018 were not qualifying and could not be sampled in compliance with the permit. LLNL is required to visually inspect the storm drainage system during up to four qualifying storm events to observe runoff quality and once each month during dry periods to identify any dry weather flows. Annual facility inspections are performed to ensure that the Best Management Practices (BMPs) for controlling storm water pollution are implemented and adequate.

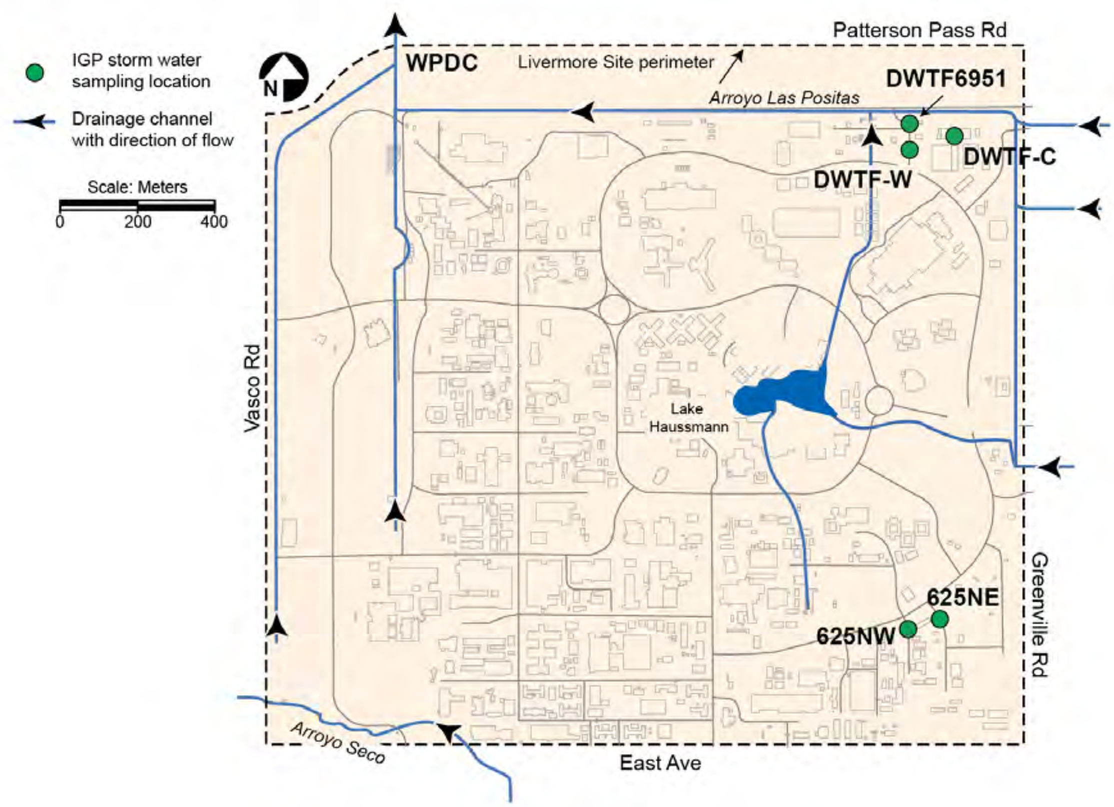

Figure 5-1. Storm water sampling locations, Livermore Site, 2018.

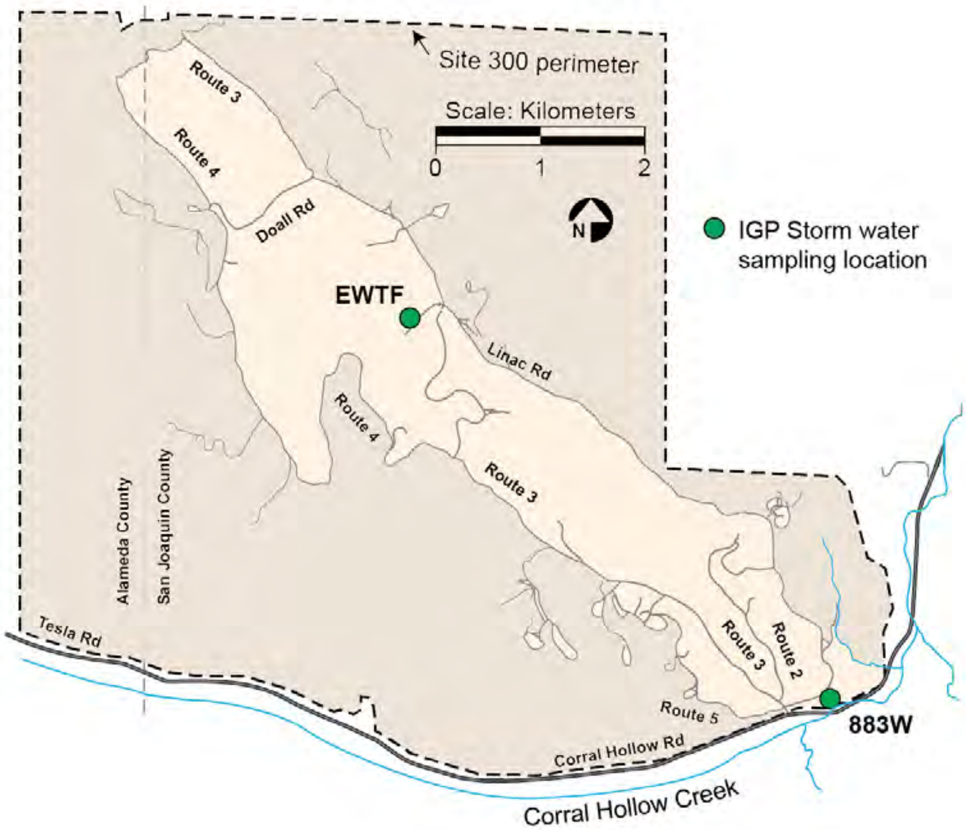

Figure 5-2. Storm water sampling locations, Site 300, 2018.

5.3.1 Storm Water Inspections

Each principal directorate at LLNL conducts an annual inspection of its facilities to verify implementation of BMPs and to ensure that those measures are adequate. LLNL's principal associate directors identified some minor corrections to the BMPs and certified in 2018 that their facilities complied with the provisions of LLNL's Storm Water Pollution Prevention Plans (SWPPPs). LLNL submits storm water analytical results to the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) and to the CVRWQCB through an online database called the Storm Water Multiple Application and Report Tracking System (SMARTS) for each Qualifying Storm Event (QSE).

For each construction project permitted by Order Number 2009-0009-DWQ, LLNL or designated subcontractors conduct visual monitoring of construction sites before, during, and after storms to assess the effectiveness of the BMPs. Annual compliance certifications, if necessary, summarize the inspections.

5.3.2 Storm Water Compliance

LLNL is required to meet the requirements of the new IGP. There are two types of Numeric Action Levels (NALs) in the new permit.

Annual NAL exceedance – occurs when the average of all the analytical results for a parameter from samples taken within a reporting year exceeds an annual NAL value for that parameter.

Instantaneous maximum NAL exceedance – occurs when two or more analytical results for Total Suspended Solids (TSS), Oil and Grease (O&G) or pH from samples taken within a reporting year exceed the instantaneous maximum NAL value (or are outside the NAL pH range).

An NAL exceedance is determined as follows:

a. For annual NALs, an exceedance occurs when the average of all analytical results from all samples taken at a facility during a reporting year for a given parameter exceeds an annual NAL value listed in Table 2 of the General Permit; or

b. For the instantaneous maximum NALs, an exceedance occurs when two or more analytical results from samples taken for any parameter within a reporting year exceed the instantaneous maximum NAL value (for Total Suspended Solids, and Oil and Grease), or are outside of the instantaneous maximum NAL range (for pH) listed in Table 2 of the General Permit.

Please refer to **Appendix A, Tables A.4.1** to **A.4.4**. for storm water sample analytical results. Both the Livermore Site and Site 300 remain at Exceedance Response Action Level 2 for magnesium. LLNL has provided data and analysis that show the exceedance of magnesium is due to aerial deposition from natural sources, not industrial activities at LLNL.

Storm water visual observations and BMP inspections indicated that LLNL's storm water program continues to protect water quality.

A full report of storm water runoff samples for the January 1, 2018 to June 30, 2018 is available in the 2018 Annual Storm Water Reports for the Livermore Site and Site 300 in SMARTS. A report of storm water compliance for the Livermore Site and Site 300 from July 1, 2018 to December 31, 2018 will be available in SMARTS after July 15, 2019.

5.4 Groundwater

LLNL conducts surveillance monitoring of groundwater in the Livermore Valley and at Site 300 through networks of wells and springs that include off-site private wells and on-site DOE Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) wells. To meet the goal of maintaining a comprehensive, cost-effective monitoring program, LLNL determines the number and locations of surveillance wells, the analytes to be monitored, the frequency of sampling, and the analytical methods to be used. A wide range of analytes is monitored to assess the impact, if any, of current LLNL operations on local groundwater resources. Because surveillance monitoring is geared to detecting substances at very low concentrations in groundwater, contamination can be detected before it significantly impacts groundwater resources. Groundwater monitoring wells at the Livermore Site, in the Livermore Valley, and at Site 300 are included in LLNL's *Environmental Monitoring Plan* (Gallegos 2016).

Beginning in January 2003, LLNL implemented a new CERCLA comprehensive compliance monitoring plan at Site 300 (Ferry et al. 2002) that adequately covers the DOE requirements for on-site groundwater surveillance. In addition, LLNL continues two additional surveillance networks to supplement the CERCLA compliance monitoring plan and provide additional data to characterize potential impacts of LLNL operations. LLNL monitoring related to CERCLA activities is described in **Chapter 7**. Additional monitoring programs at Site 300 comply with numerous federal and state controls such as state-issued permits associated with closed landfills containing solid wastes and with continuing discharges of liquid waste to sewage ponds and percolation pits; the latter are discussed in **Section 5.2.1**. Compliance monitoring is specified in WDRs issued by the CVRWQCB and in landfill closure and post-closure monitoring plans. (See **Chapter 2**, **Table 2-2** for a summary of LLNL permits.)

The WDRs and post-closure plans specify wells and discharges to be monitored, constituents of concern (COCs) and parameters, frequency of measurement, inspections, and the frequency and form of required reports. These monitoring programs include quarterly, semiannual, and annual monitoring of groundwater, monitoring of various influent waste streams, and visual inspections. LLNL performs the maintenance necessary to ensure the physical integrity of closed facilities, such as those that have undergone CERCLA or Resource Conservation and Recovery Act (RCRA) closure, and their monitoring networks.

During 2018, representative samples of groundwater were obtained from monitoring wells in accordance with the *LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures* (Goodrich and Lorega 2016). The procedures cover sampling techniques and information concerning the parameters monitored in groundwater. Different sampling techniques were applied to different wells depending on whether they were fitted with submersible pumps or had to be bailed. All the chemical and radioactivity analyses of groundwater samples were performed by California-certified analytical laboratories. For comparison purposes only, some of the results were compared with drinking water limits (maximum contaminant levels [MCLs]).

5.4.1 Livermore Site and Environs

5.4.1.1 Livermore Valley

LLNL has monitored tritium in water hydrologically downgradient of the Livermore Site since 1988. HTO (tritiated water) is potentially the most mobile groundwater contaminant from LLNL operations. Groundwater samples were obtained during 2018 from 16 of 17 water wells in the Livermore Valley (see **Figure 5-3**) and measured for tritium activity, well 16B1 was out of service and could not be sampled.

Tritium measurements of Livermore Valley groundwater are provided in **Appendix A**, **Section A.5**. The measurements continue to show very low activities compared with the 740 Bq/L (20,000 pCi/L) MCL established for drinking water in California. The maximum tritium activity estimated off-site was in the groundwater at well 12A2, located about 9.0 km (5.6 mi) west of LLNL (see **Figure 5-3**). The estimated activity at well 12A2 was less than 3.1±2.2 Bq/L (83.8 pCi/L) in 2018, less than 0.5% of the MCL.

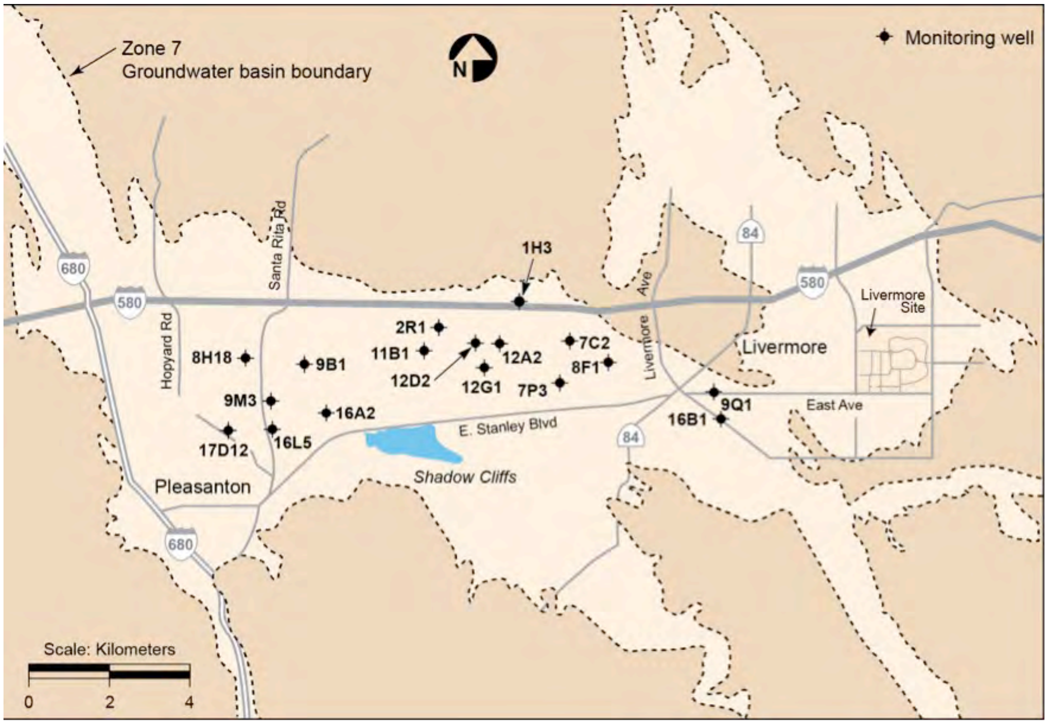

Figure 5-3. Off-site tritium monitoring wells in the Livermore Valley, 2018.

5.4.1.2 Livermore Site Perimeter

LLNL's groundwater surveillance monitoring program was designed to complement the Livermore Site GWP (see **Chapter 7**). The intent of the program is to monitor for potential groundwater contamination from LLNL operations. The perimeter portion of the surveillance groundwater monitoring network uses three upgradient (background) monitoring wells (wells W-008, W-221, and W-017) near the eastern boundary of the site and seven downgradient monitoring wells located near the western boundary (wells 14B1, W-121, W-151, W-1012, W-571, W-556, and W-373) (see **Figure 5-4**). As discussed in **Chapter 7**, the alluvial sediments have been divided into nine hydrostratigraphic units (HSUs), which are water bearing zones that exhibit similar hydraulic and geochemical properties. The nine HSUs dip gently westward. Screened intervals (depth range from which groundwater is drawn) for these monitoring wells range from the shallow HSU-1B to the deeper HSU-5. Two of the background wells, W-008 and W-221, are screened partially in HSU-3A; well W-017 is considered a background well for the deeper HSU-5. To detect contaminants as quickly as possible, the seven western downgradient wells (except well 14B1, screened over a depth range that includes HSU-2, HSU-3A, and HSU-3B) were screened in shallower HSU-1B and HSU-2, the uppermost water-bearing HSUs at the western perimeter. These perimeter wells were sampled and analyzed at least once during 2018 for general minerals (including nitrate) and for certain radioactive constituents, with the exception being well W-571 which was not sampled due to a pump failure. Analytical results for the Livermore Site perimeter wells are provided in **Appendix A**, **Section A.5**. Although there have been variations in these concentrations since regular surveillance monitoring began in 1996, the concentrations detected in the 2018 groundwater samples from the upgradient wells represent current background values.

Historically, chromium (VI) had been detected above the MCL (50 µg/L) in groundwater samples from western perimeter well W-373; however, concentrations of this analyte first dropped below the MCL in 2002. The 2018 sample from this location showed a concentration of 36 µg/L; a value consistent with the range of chromium (VI) concentrations (5 µg/L to 52 µg/L) detected at well W-373 since 2002. Groundwater samples collected in 2018 from the nearby wells W-556 and W-1012, also along the western perimeter of the LLNL Site, showed chromium (VI) concentrations of 20 µg/L and 10 µg/L, respectively.

From 1996 through 2004, concentrations of nitrate detected in groundwater samples from downgradient well W-1012 were greater than the MCL of 45 mg/L. The nitrate concentration detected in the 2018 sample from this well (21 mg/L) was again, as in the past 12 years, below the MCL. During 2018, concentration of nitrate in the on-site shallow background well W-221 was 54 mg/L. Detected concentrations of nitrate in western perimeter wells ranged from 14 mg/L (in well W-373) to 50 mg/L (in well W-151), a range consistent with results reported in previous years.

During 2018, gross alpha, gross beta, and tritium were detected occasionally in LLNL's Site perimeter wells, at levels consistent with the results from recent years; however, the concentrations again remain below drinking water MCLs.

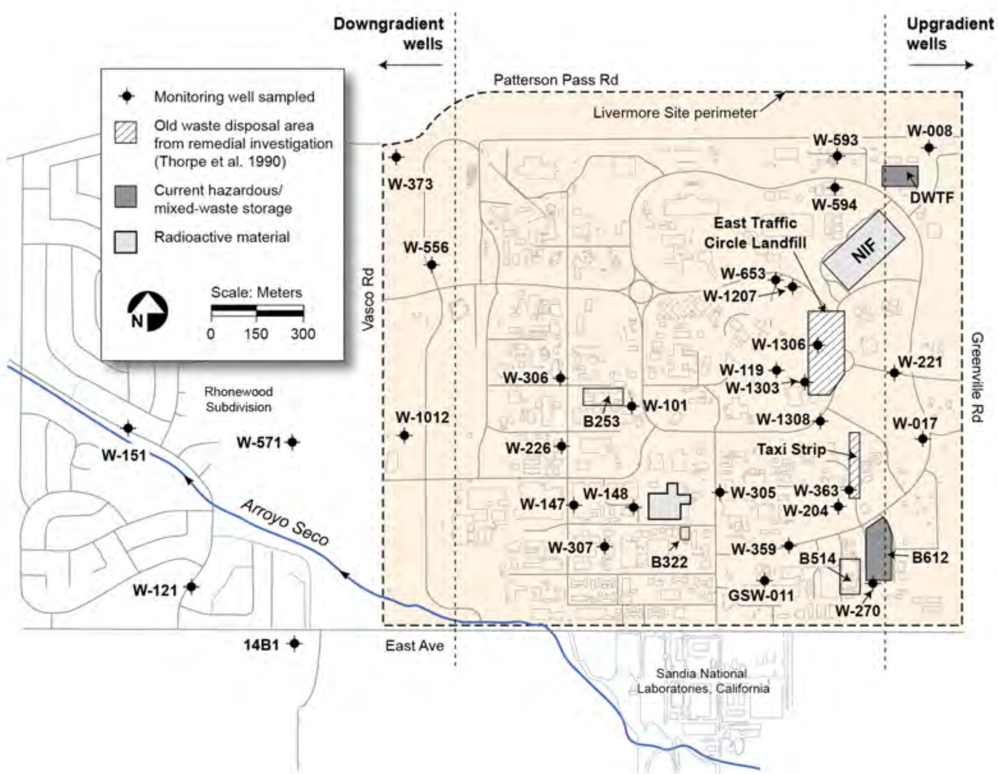

Figure 5-4. Routine surveillance groundwater monitoring wells at the Livermore Site, 2018.

5.4.1.3 Livermore Site

Groundwater sampling locations within the Livermore Site include areas where releases to the ground may have occurred in the recent past, where previously detected COCs have low concentrations that do not require CERCLA remedial action, and where baseline information needs to be gathered for the area near a new facility or operation. Wells selected for monitoring are screened in the uppermost aquifers and are downgradient from and as near as possible to the potential release locations. Well locations are shown in **Figure 5-4**. All analytical results are provided in **Appendix A**, **Section A.5**.

The Taxi Strip and East Traffic Circle Landfill areas (see **Figure 5-4**) are two potential sources of historical groundwater contamination. Samples from monitoring wells screened in HSU-2 (W-204) and HSU-3A (W-363) downgradient from the Taxi Strip area were analyzed in 2018 for copper, lead, zinc, and tritium. Samples from monitoring wells screened at least partially in HSU-2 (W-119, W-1207, W-1303, W-1306, and W-1308) within and downgradient from the East Traffic Circle Landfill were analyzed for the same elements as the Taxi Strip area. Concentrations of tritium remained well below the drinking water MCLs at all seven locations, and none of the trace metals (copper, lead, zinc) were detected in any of these seven monitoring wells during 2018.

Near the National Ignition Facility (NIF), LLNL measures pH, conductivity, and tritium concentration of nearby groundwater to establish a baseline. During 2018, tritium analyses were conducted on groundwater samples collected from wells W-653 and W-1207 (screened in HSU-3A and HSU-2, respectively) downgradient of NIF. Samples were also obtained downgradient from the Decontamination and Waste Treatment Facility (DWTF) from wells W-593 and W-594 (screened in HSU-3A and HSU-2, respectively) during 2018 and were analyzed for tritium. Monitoring results from the wells near NIF and DWTF showed no detectable concentrations of tritium, above the limit of sensitivity of the analytical method, in the groundwater samples collected during 2018.

The former storage area around Building 514 and the hazardous waste/mixed waste storage facilities around Building 612 are also potential sources of contamination. The area and facilities are monitored by wells W-270 and W-359 (both screened in HSU-5), and well GSW-011 (screened in HSU-3A). During 2018, groundwater from these wells was sampled and analyzed for gross alpha, gross beta, and tritium. No significant contamination was detected in the groundwater samples collected downgradient from these areas in 2018.

Groundwater samples are obtained annually from monitoring well W-307 (screened in HSU-1B), downgradient from Building 322. Soil samples previously obtained from this area showed concentrations elevated above the Livermore Site's background levels for total chromium, copper, lead, nickel, zinc, and occasionally other metals. LLNL removed contaminated soils near Building 322 in 1999 and replaced them with clean fill. The area was then paved over, making it less likely that metals would migrate from the site. In 2018, concentration of metals at well W-307 were within typical concentrations reported in recent years. The concentration of manganese in 2018 (which had shown some questionable fluctuations in 2012 and 2013) remained below the analytical reporting limit. LLNL will continue to track these results as additional data become available.

Groundwater samples were obtained downgradient from a location where sediments containing metals (including cadmium, chromium, copper, lead, mercury, and zinc) had accumulated in a storm water catch basin near Building 253. In 2018, the samples obtained from monitoring wells W-226 and W-306 (screened in HSU-1B and HSU-2, respectively) again contained dissolved chromium at concentrations above the analytical reporting limit, but these concentrations remained low and essentially unchanged from recent years.

Additional surveillance groundwater sampling locations, established in 1999, are in areas surrounding the Plutonium Facility and Tritium Facility. Potential contaminants include plutonium and tritium from these facilities, respectively. Plutonium is much more likely to bind to the soil than migrate into the groundwater. Tritium, as HTO, can migrate into groundwater if spilled in sufficient quantities. Upgradient of these facilities, well W-305 is screened in HSU-2. Downgradient wells W-101, W-147, and W-148 are screened in HSU-1B; however, as in 2012 through 2017, well W-101 was dry and could not be sampled in 2018. In August 2000, elevated tritium activity was detected in the groundwater sampled at well W-148 (115 ± 5.0 Bq/L [3100 ± 135 pCi/L]). The activity was most likely related to local infiltration of storm water containing elevated tritium activity. Tritium activities in groundwater in this area had remained at or near the same level through 2005, but samples collected from well W-148 in 2006 through 2018 have shown significantly lower values—a downward trend ranging from approximately one-fifth to one-half of the August 2000 value due to the natural decay and dispersion of tritium. LLNL continues to collect groundwater samples from these wells periodically for surveillance purposes, primarily to demonstrate that tritium concentrations remain below MCLs.

5.4.2 Site 300 and Environs

For surveillance and compliance groundwater monitoring at Site 300, LLNL uses DOE CERCLA wells and springs on-site and private wells and springs off-site. Representative groundwater samples are obtained at least once per year at every monitoring location; they are routinely measured for various elements (primarily metals), a wide range of organic compounds, general radioactivity (gross alpha and gross beta), uranium activity, and tritium activity. Groundwater from the shallowest water-bearing zone is the target of most of the monitoring because it would be the first to show contamination from LLNL operations at Site 300.

Brief descriptions of the Site 300 groundwater monitoring networks that are reported in this chapter are given below. (All analytical data from 2018 are included in **Appendix A**, **Section A.6**.)

5.4.2.1 Elk Ravine Drainage Area

The Elk Ravine drainage area, a branch of the Corral Hollow Creek drainage system, includes most of northern Site 300 (see **Figure 5-5**). Storm water runoff in the Elk Ravine drainage area collects in arroyos and quickly infiltrates into the ground. Groundwater from wells in the Elk Ravine drainage area is monitored for COCs to determine the impact of current LLNL operations on the system of underground flows that connect the entire Elk Ravine drainage area. The area contains eight closed landfills, known as Pits 1 through 5 and 7 through 9, and firing tables where explosives tests are conducted. None of these closed landfills have a liner, which is consistent with the disposal practices when the landfills were constructed. The following descriptions of monitoring networks within Elk Ravine begin with the headwaters area and proceed downstream. (See **Chapter 7** for a review of groundwater monitoring in this drainage area conducted under CERCLA.)

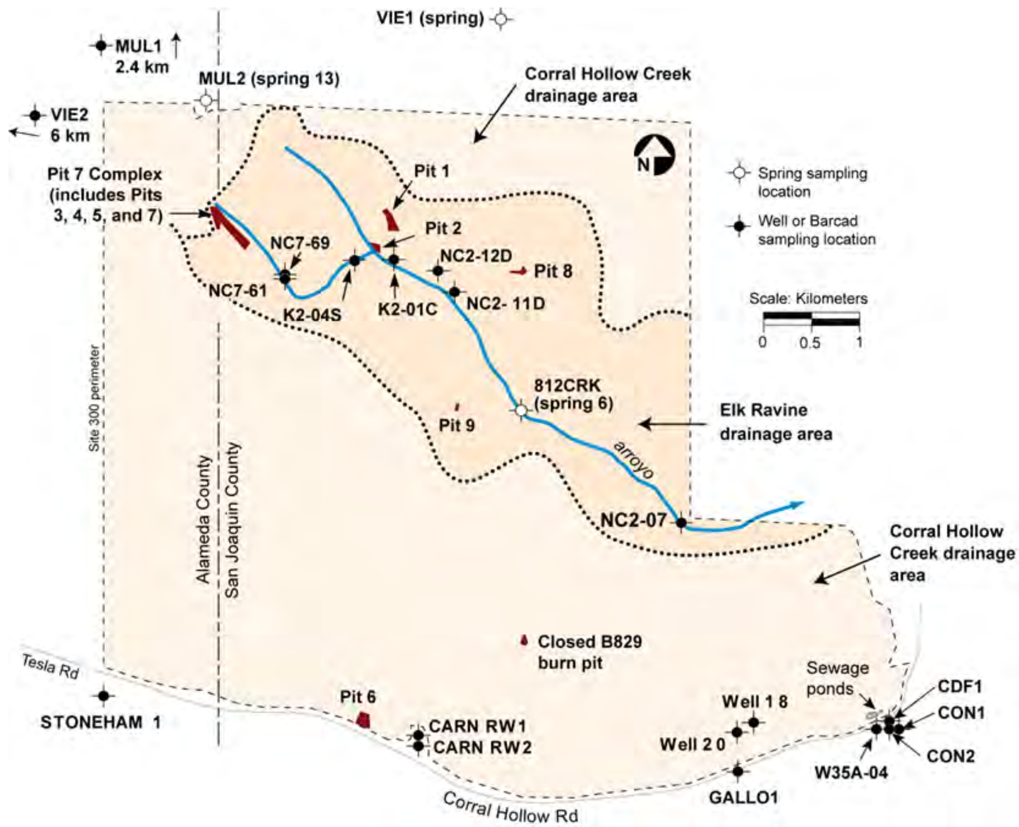

Figure 5-5. Surveillance groundwater wells and springs at Site 300, 2018.

Pit 7 Complex The Pit 7 landfill was closed in 1992 in accordance with U.S. EPA and California Department of Health Services (now Department of Toxic Substances Control, or DTSC) approved RCRA Closure and Post-Closure Plans using the LLNL CERCLA Federal Facility Agreement (FFA) process. From 1993 until 2009, monitoring requirements were specified in WDR 93-100, administered by the CVRWQCB (1993, 1998), and in *LLNL Site 300 RCRA Closure and Post-Closure Plans—Landfill Pits 1 and 7* (Rogers/Pacific Corporation 1990). An Amendment to the Interim Record of Decision (ROD) for the Pit 7 Complex (Site 300 U.S. DOE, 2007) was signed in 2007 under CERCLA. The remedial actions specified in the Interim ROD, including a hydraulic drainage diversion system, extraction and treatment of groundwater, and Monitored Natural Attenuation for tritium in groundwater were implemented in 2008. In 2010, detection monitoring and reporting for the Pit 7 complex was transferred to CERCLA. Analytes and frequencies of sampling are documented in the CERCLA Compliance Monitoring Plan and Contingency Plan for Site 300 (Dibley et al. 2009). The objective of this monitoring continues to be the early detection of any new release of COCs from Pit 7 to groundwater.

For compliance purposes, during 2018 LLNL obtained annual or more frequent groundwater samples from the Pit 7 detection monitoring well network. Samples were analyzed for tritium, volatile organic compounds (VOCs), fluoride, high explosive compounds (HMX and RDX), nitrate, perchlorate, uranium (isotopes or total), metals, lithium, and polychlorinated biphenyls (PCBs). A detailed account of Pit 7 compliance monitoring conducted during 2018, including well locations, maps of the distribution of COCs in groundwater, and analytical data tables is summarized in the CERCLA Site 300 Annual Compliance Monitoring Report (CMR), that was submitted to the regulatory agencies by the LLNL Environmental Restoration Department (Buscheck et al., 2019).

Elk Ravine. Groundwater samples were obtained on various dates in 2018 from the widespread Elk Ravine surveillance monitoring network shown in **Figure 5-5** (NC2-07, NC2-11D, NC2-12D, NC7-61, NC7-69, 812CRK [SPRING6], K2-04S, K2-01C). Monitoring at well K2-04D ceased in 2014 due to a pump becoming stuck in the well, and LLNL will decommission well K2-04D. Samples from NC2-07 were analyzed for inorganic constituents (mostly metallic elements), general radioactivity (gross alpha and beta), tritium and uranium activity, and explosive compounds (HMX and RDX). Samples from the remaining wells were analyzed only for general radioactivity.

No new release of COCs from LLNL operations in Elk Ravine to groundwater is indicated by the chemical and radioactivity data obtained during 2018. The major source of contaminated groundwater beneath Elk Ravine is from historical operations in the Building 850 firing table area (Webster-Scholten 1994; Taffet et al. 1996). Constituents that are measured as part of the Elk Ravine drainage area surveillance monitoring network are listed in **Appendix B.**

The tritium activity for well NC7-61 was 470 ± 91 Bq/L in 2018, compared to the higher value of 580 ± 110 Bq/L in 2017. This tritium activity remains elevated with respect to the background concentrations. Tritium, as HTO, has been released in the past in the vicinity of Building 850. The majority of the Elk Ravine surveillance-network tritium measurements made during 2018 support earlier CERCLA studies showing that the tritium in the plume is diminishing over time because of natural decay and dispersion (Ziagos and Reber-Cox 1998). CERCLA modeling studies indicate that the tritium will decay to background levels before it can reach a site boundary.

Groundwater surveillance measurements of gross alpha, gross beta and uranium radioactivity in Elk Ravine are low and are indistinguishable from background levels. (Note that gross beta measurements do not detect the low-energy beta emission from tritium decay.) Additional detections of nonradioactive elements including arsenic, barium, chromium, selenium, and vanadium are all within the natural ranges of concentrations typical of groundwater elsewhere in the Altamont Hills.

Pit 1. The Pit 1 landfill was closed in 1993 in accordance with a DTSC approved RCRA Closure and Post-Closure Plan using the LLNL CERCLA FFA process. Monitoring requirements are specified in WDR 93-100, which is administered by the CVRWQCB (1993, 1998, and 2010), and in Rogers/Pacific Corporation (1990). The main objective of this monitoring is the early detection of any release of COCs from Pit 1 to groundwater. LLNL obtained groundwater samples quarterly during 2018 from the Pit 1 monitoring well network. Samples were analyzed for inorganic COCs (mostly metallic elements), general radioactivity (gross alpha and beta), activity of certain radioisotopes (tritium, radium, uranium, and thorium), explosive compounds (HMX and RDX), and VOCs (EPA Methods 601 and 8260). Additional annual analyses were conducted on groundwater samples for extractable organics (EPA Method 625), as well as pesticides and PCBs (EPA Method 608). Compliance monitoring showed no new releases at Pit 1 in 2018; a detailed account of Pit 1 compliance monitoring during 2018, including well locations and tables and graphs of groundwater COC analytical data, can be found in Chan (2019b).

5.4.2.2 Corral Hollow Creek Drainage Area

Pit 6. Compliance monitoring requirements for the closed Pit 6 landfill in the Corral Hollow Creek drainage area are specified in Ferry et al. (1998, 2002). Two Pit 6 groundwater monitoring programs, which operate under CERCLA, ensure compliance with all regulations. They are (1) the Detection Monitoring Plan (DMP), designed to detect any new release of COCs to groundwater from wastes buried in the Pit 6 landfill, and (2) the Corrective Action Monitoring Plan (CAMP), which monitors the movement and fate of historical releases. To comply with monitoring requirements, LLNL collected groundwater samples monthly, quarterly, semiannually, and annually during 2018 from specified Pit 6 monitoring wells. Groundwater wells were analyzed for VOCs, tritium, beryllium, mercury, total uranium, gross alpha/beta, perchlorate, and nitrate.

During 2018, no new contaminant releases from Pit 6 were detected. A detailed account of Pit 6 compliance monitoring conducted during 2018, including well locations, tables of groundwater analytical data, and maps showing the distribution of COC plumes, is summarized in the Site 300 Annual CMR (Buscheck et al., 2019).

Building 829 Closed High Explosives Burn Facility. Compliance monitoring requirements for the closed burn pits in the Corral Hollow Creek drainage area are specified in DTSC (2017). As planned for compliance purposes, LLNL obtained groundwater samples during 2018 from the three wells in the Building 829 monitoring network. Groundwater samples from these wells, screened in the deep regional aquifer, were analyzed for inorganics (mostly metals), turbidity, explosive compounds (HMX, RDX, and TNT), VOCs (EPA Method 624), extractable organics (EPA Method 625), and general radioactivity (gross alpha and gross beta).

During 2018, the only COC detections above their respective statistical limits were manganese and zinc detected in well W-829-22 and zinc detected in well W-829-15; however, LLNL concluded that these detections were not evidence of release from the closed burn pit. The zinc data for the routine sample and two independent retests were inconclusive due to zinc being present in the field blanks during all three sampling events. For the manganese detected at well

W-829-22, one of the two independent retests exceeded the statistical limit for manganese, which validated the initial detection of manganese. However, given the natural presence of manganese in the deep regional aquifer beneath the B-829 Facility, as well as the history of W-829-22 showing no previous detections of this constituent, LLNL concluded that the detection of manganese is from naturally occurring sources and not evidence of a release from the closed burn pit. LLNL will continue annual monitoring of zinc and manganese.

Among the inorganic constituents, perchlorate was not detected above its reporting limit in any sample. With the exception of barium in well W-829-1915 (which remains below its statistical limit, but at a level approximately twice the originally calculated background concentration) and manganese in well W-829-1938 (which is approximately 60% of the originally calculated background concentration), the metal COCs that were detected showed concentrations that are not significantly different from background concentrations for the deep aquifer beneath the High Explosives Process Area. LLNL will continue to track these results as additional data become available.

There were no organic or explosive COCs detected above reporting limits in any samples. All results for the radioactive COCs (gross alpha and gross beta) were below their statistical limit values. For a detailed account of compliance monitoring of the closed burn pit during 2018, including well locations and tables and graphs of groundwater COC analytical data, see Diaz (2019).

Water Supply Well. Water supply well 20, located in the southeastern part of Site 300 (**Figure 5-5**), is a deep, high-production well. The well is screened in the Neroly lower sandstone aquifer ($Tnbs_1$) and can produce up to 1,500 L/min (396 gal/min) of potable water. As planned for surveillance purposes, LLNL obtained groundwater samples quarterly during 2018 from well 20. Groundwater samples were analyzed for inorganic COCs (mostly metals), VOCs, general radioactivity (gross alpha and gross beta), and tritium activity. Quarterly measurements of groundwater from well 20 do not differ significantly from previous years. As in past years, the primary potable water supply well at Site 300 showed no evidence of contamination. Gross alpha, gross beta and tritium activities were very low and are indistinguishable from background level activities.

5.4.2.3 Off-site Surveillance Wells and Springs

As planned for surveillance purposes, during 2018 LLNL obtained groundwater samples from one off-site spring (MUL2) and ten off-site wells (MUL1, VIE2, CARNRW1, CARNRW2, CDF1, CON1, CON2, GALLO1, STONEHAM1, and W35A-04) **(Figure 5-5)**. VIE1 is an off-site spring that is sampled for surveillance purposes; however, VIE1 was dry in 2018 and could not be sampled. With the exception of one well, all off-site monitoring locations are near Site 300. The exception, well VIE2, is located at a private residence 6 km west of the site. It represents a typical potable water supply well in the Altamont Hills.

Samples from CARNRW2 and GALLO1 were analyzed at least quarterly for inorganic constituents (mostly metals), general radioactivity (gross alpha and beta), tritium activity, explosive compounds (HMX and RDX), and VOCs (EPA method 502.2). Additional annual analyses were conducted for uranium activity and extractable organic compounds (EPA Method 625) for samples collected from CARNRW2 only. In addition, CARNRW1 and CON2 samples were analyzed for VOCs; samples from well CARNRW1 were also sampled for perchlorate and tritium.

Groundwater samples were obtained once (annually) during 2018 from the remaining off-site surveillance monitoring locations: MUL1, MUL2, and VIE1 (north of Site 300); VIE2 (west of Site 300); and STONEHAM1, CON1, CDF1, and W-35A-04 (south of Site 300). Samples were analyzed for inorganic constituents (metals, nitrate, and perchlorate), general radioactivity (gross alpha and gross beta), tritium and uranium activity, explosive compounds (HMX and RDX), VOCs, and extractable organic compounds (EPA Method 625).

Generally, no constituents attributable to LLNL operations at Site 300 were detected in the off-site groundwater samples. Radioactivity measurements in samples collected from off-site groundwater wells are generally indistinguishable from naturally occurring activities.

5.5 Other Monitoring Programs

5.5.1 Rainwater

Because air moisture containing HTO is rapidly entrained and washed out locally during rain events, rainwater is collected in rain gauges at fixed locations at both the Livermore Site and Site 300 to provide information about storms that are sampled for runoff. The collected rainwater is analyzed for tritium activity by EPA Method 906.0, which is a liquid scintillation counting method. The tritium activity of each sample is measured and the analytical results compared to the EPA drinking water MCL of 740 Bq/L (20,000 pCi/L) for tritium. In calendar year 2018, the rain gauges were placed at the sample locations SALV, MET, DWTF, and SECO at the Livermore Site as shown in **Figure 5-6**. The samples for calendar year 2018 were collected after the January, February, and March storms.

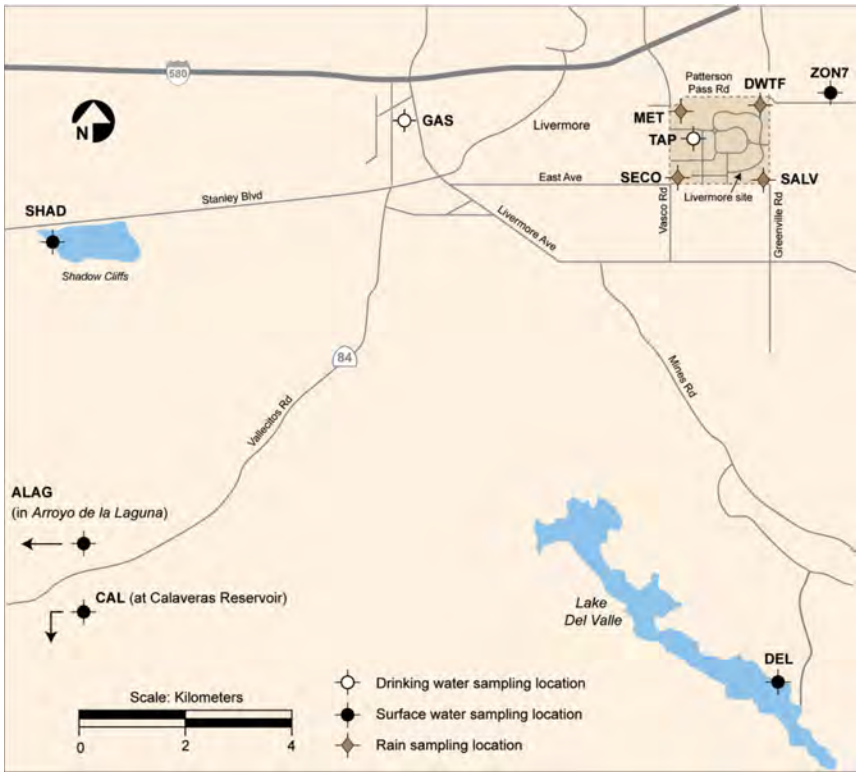

Figure 5-6. Livermore Site and Livermore Valley sampling locations for rain, surface water, and drinking water, 2018.

The highest measured tritium activity, 2.3 Bq/L, was for the March 1 storm and was measured at the SECO location. This activity is less than 1% of the EPA established drinking water standard. All analytical results are provided in **Appendix A, Section A.7.**

In calendar year 2018, LLNL collected samples at three on-site locations at Site 300, ECP, PSTL, and GOLF (see **Figure 5-7**) for the January storm. All of the sample locations for the storm were non-detections for tritium. All analytical results are provided in **Appendix A, Section A.7.**

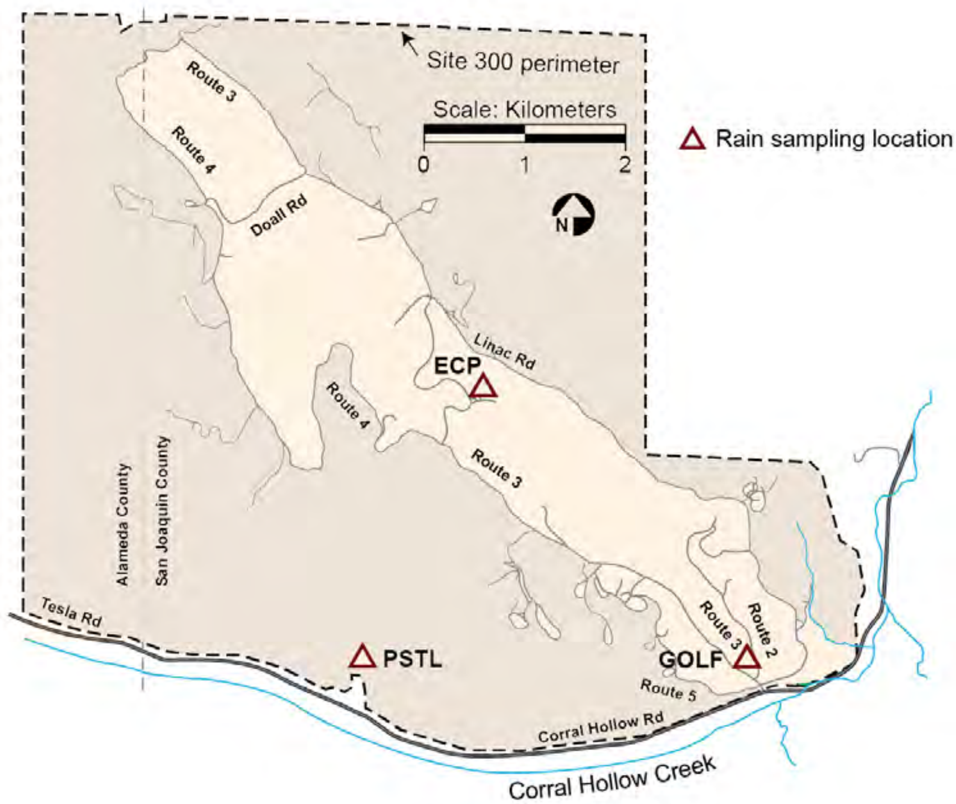

Figure 5-7. Rainwater sampling locations at Site 300, 2018.

5.5.2 Livermore Valley Surface Waters

LLNL conducts additional surface water surveillance monitoring in support of DOE Order 458.1. Surface and drinking water near the Livermore Site and in the Livermore Valley were sampled at the locations shown in **Figure 5-6** in 2018. Off-site sampling locations DEL, ALAG, SHAD, and ZON7 are surface water bodies; of these, DEL and ZON7 are also drinking water sources. The Springtown pond (DUCK) is an artificial duck pond that was removed by the City of Livermore in 2018 and therefore the location was removed from the surface water sampling plan. GAS and TAP are drinking water outlets; radioactivity data from these two sources are used to calculate drinking water statistics (see **Table 5-4**).

Samples are analyzed according to written, standardized procedures summarized in Gallegos (2016). LLNL sampled the two drinking water outlets semiannually and the other locations annually in 2018. All locations were sampled for tritium, gross alpha, and gross beta. All analytical results are provided in **Appendix A**, **Section A.7.**

The median activity for tritium in all water location samples was estimated to be below the analytical laboratory's minimum detectable activities, or minimum quantifiable activities. The maximum tritium activity detected in any sample collected in 2018 was 1.49 Bq/L (40.3 pCi/L), which is less than 1% of the drinking water MCL. Median activities for gross alpha and gross beta radiation in all water samples were less than 8% of their respective MCLs. Historically, concentrations of gross alpha and gross beta radiation in drinking water sources have fluctuated around the Laboratory's minimum detectable activities. At these very low levels, the counting error associated with the measurements is nearly equal to, or in many cases greater than, the calculated values so that no trends are apparent in the data. The maximum activities detected for gross alpha and gross beta occurred in samples collected at GAS (gross alpha at 0.1080 Bq/L [2.92 pCi/L]) and SHAD (gross beta at 0.1360 Bq/L [3.68 pCi/L]). These maximum values were less than 20% and 8% of their respective gross alpha and gross beta drinking water MCLs (see **Table 5-4**).

Table 5-4. Radioactivity in surface and drinking waters in the Livermore Valley, 2018.

Location	Metric	Tritium (Bq/L)[(a)]	Gross alpha (Bq/L)[(a)]	Gross beta (Bq/L)[(a)]
All locations	Median	0.78	0.0416	0.0504
	Minimum	-4.66	-0.0008	0.0343
	Maximum	1.49	0.1080	0.1360
	Interquartile range	2.30	0.0248	0.0377
Drinking water outlet locations	Median	-2.21	0.0385	0.0446
	Minimum	-4.66	0.0017	0.0343
	Maximum	0.98	0.1080	0.0648
	Drinking water MCL	740	0.555	1.85

(a) A negative number means the sample radioactivity was less than the background radioactivity

5.5.3 Lake Haussmann Monitoring

Lake Haussmann, formerly the Drainage Retention Basin, is an artificial water body that has a 45.6 million L (37 acre-feet) capacity. It is in the central portion of the Livermore Site and receives storm-water runoff and treated groundwater discharges. LLNL continues to modify monitoring of Lake Haussmann based on changing regulatory drivers. In 2015, LLNL discontinued sampling at Lake Haussmann as part of LLNL's adjustments to Livermore Site sampling to meet the requirements of the most recent California Industrial General Permit for storm water discharges. Storm Water Compliance and Surveillance Monitoring information is in **Section 5.3**.

5.5.4 Site 300 Drinking Water System Discharges

In 2018, LLNL maintained coverage under General Order R5-2016-0076-025, NPDES Permit No. CAG995001 for occasional large volume discharges from the Site 300 drinking water system that may reach surface water drainage courses. The monitoring and reporting program that LLNL developed for these discharges was approved by the CVRWQCB. Discharges with the potential to reach surface waters that are subject to these sampling and monitoring requirements are:

- Drinking water storage tank discharges
- System-flush and line-dewatering discharges
- Dead-end flush discharges

Complete monitoring results from 2018 are detailed in the quarterly self-monitoring reports to the CVRWQCB. All 2018 releases from the Site 300 drinking water system quickly percolated into the drainage ditches or dry streambeds and did not reach Corral Hollow Creek, the potential receiving water.

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6. Terrestrial Monitoring

Heather Byrnes • Caleb Murphy
• Lisa Paterson • Anthony Wegrecki • Kent Wilson

Lawrence Livermore National Laboratory (LLNL) monitors several aspects of the terrestrial environment. LLNL measures the radioactivity present in soil, vegetation, and wine, and the gamma radiation exposure at ground-level receptors from terrestrial and atmospheric sources. LLNL monitors the abundance and distribution of rare plants and protects special habitats on-site.

The LLNL terrestrial radioactivity-monitoring program is designed to measure any changes in environmental levels of radioactivity. All monitoring activities follow U.S. Department of Energy (DOE) guidance criteria. On-site monitoring activities detect radioactivity released from LLNL that may contribute to radiological dose to the public or to biota; monitoring at distant locations not impacted by LLNL operations detects naturally occurring background radiation and is used to evaluate the impact of operations.

Terrestrial pathways from LLNL operations leading to potential radiological dose to the public include resuspension of soils, infiltration of constituents of runoff water through arroyos to groundwater, ingestion of locally grown foodstuffs, and external exposure to contaminated surfaces. Potential ingestion doses are calculated from measured concentrations in vegetation and wine. Doses from exposure to ground-level external radiation are obtained from thermoluminescent dosimeters (TLDs). Potential dose to biota is calculated using a screening method that requires knowledge of radionuclide concentrations in soils and surface water.

Sampling for all media is conducted according to written, standardized procedures summarized in Gallegos (2016). Sampling locations for soils, vegetation and direct radiation for the Livermore Site, the Livermore Valley, and Site 300 are illustrated in **Figures 6-1, 6-2,** and **6-3,** respectively.

LLNL also monitors the abundance and distribution of special status plant and wildlife species, and conducts research relevant to the protection of rare plants and animals. Biota monitoring and research on LLNL property is conducted to ensure compliance with requirements of the U.S. Endangered Species Act, the California Endangered Species Act, the Eagle Protection Act, the Migratory Bird Treaty Act, and other applicable regulations as they pertain to endangered, threatened, and other special status species, their habitats, and designated critical habitats that exist at both LLNL sites.

6.1 Soil Monitoring

Soil sampling locations were selected to represent both background concentrations (distant locations unlikely to be affected by LLNL activities) and areas that have the potential to be affected by LLNL operations. Sampling locations also include areas with known contaminants, such as the Livermore Water Reclamation Plant (LWRP) and explosives testing areas at Site 300.

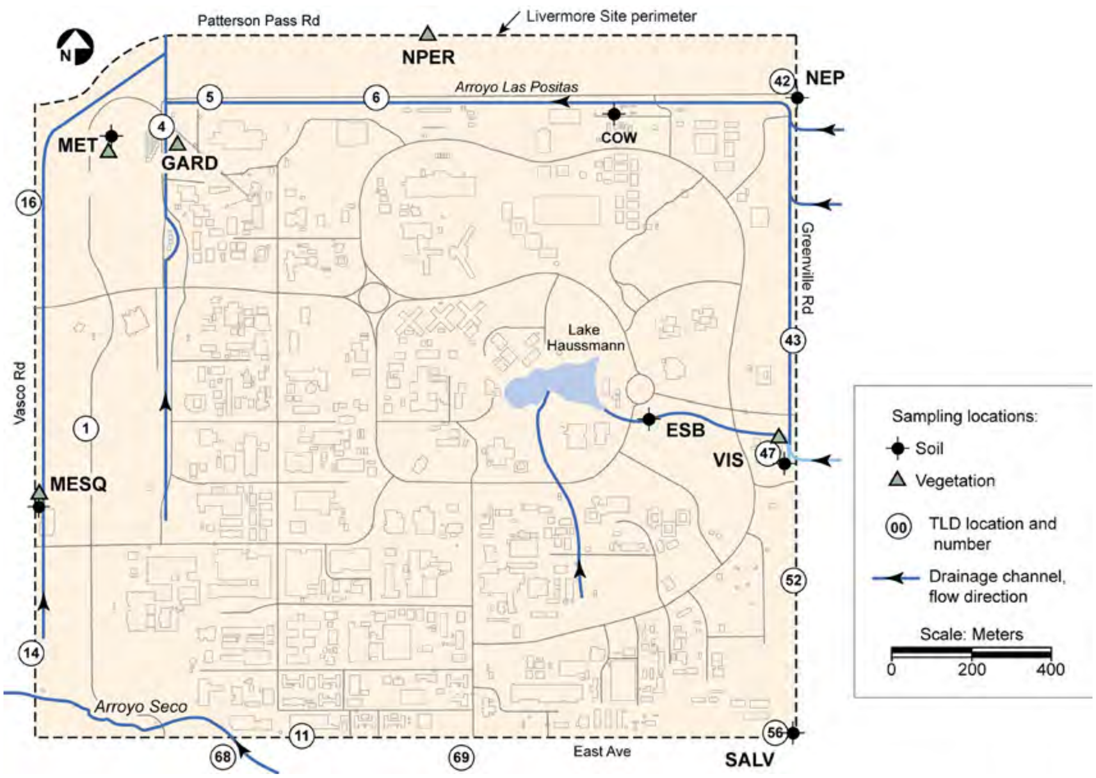

Figure 6-1. Soil, vegetation, and TLD sampling locations, Livermore Site.

Surface soil samples are collected from the top 5 cm of soil because aerial deposition is the primary pathway for potential contamination, and resuspension of materials from the surface into the air is the primary exposure pathway to nearby human populations. Two, 1 m squares are chosen from which to collect the sample. Each sample is a composite consisting of 10 subsamples that are collected at the corners and center of each square using an 8.25 cm-diameter, stainless steel core sampler.

Additional samples are collected for tritium, gross alpha, gross beta, and metals analyses. At four sample locations, a 15-cm deep sample is taken for tritium analysis at one of the subsample grid points; this deeper sample enables laboratory extraction of sufficient water from the soil for tritium analysis.

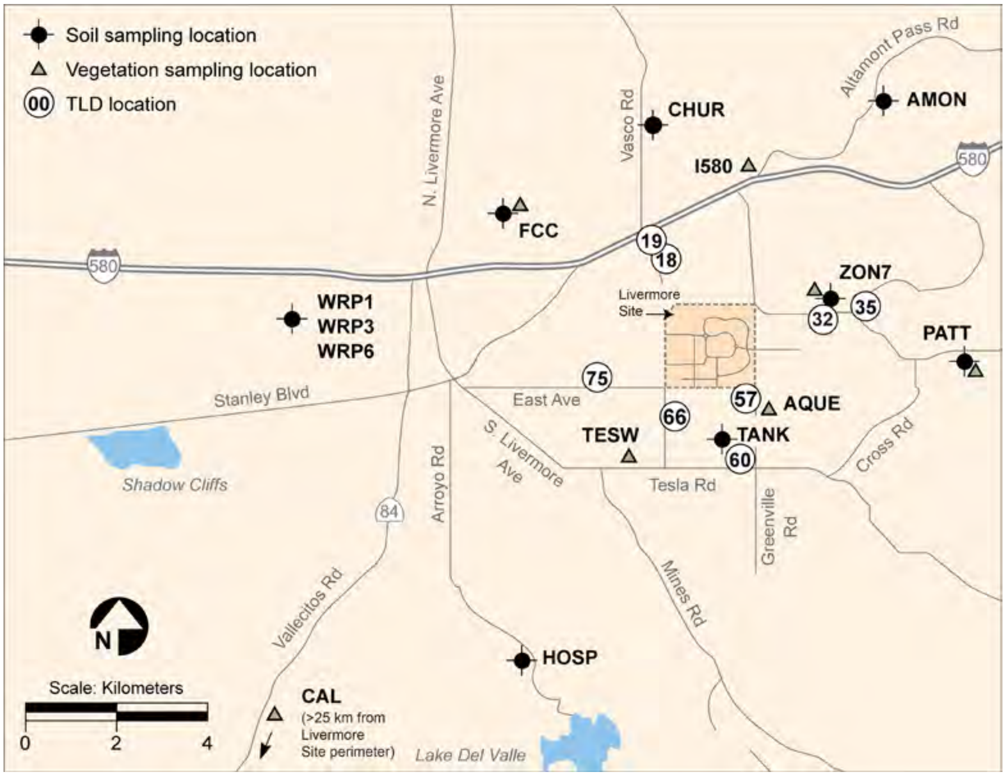

Figure 6-2. Soil, vegetation, and TLD locations, Livermore Valley.

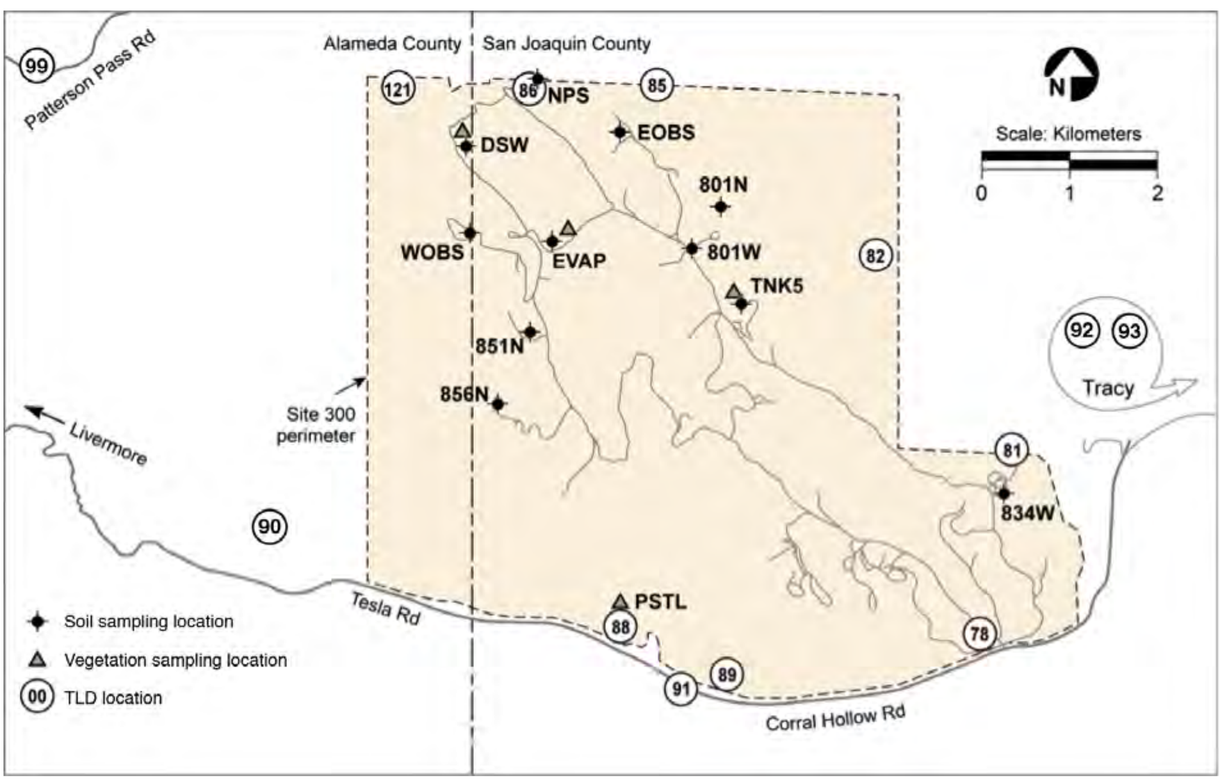

Figure 6-3. Soil, vegetation, and TLD locations, Site 300 and offsite.

In 2018, surface soil samples in the Livermore Valley were analyzed for plutonium and gamma-emitting radionuclides; samples at selected locations were analyzed for tritium, gross alpha, and gross beta. Samples from Site 300 were analyzed for gamma-emitting radionuclides and beryllium.

Prior to radiochemical analysis by alpha and gamma spectrometry, the surface soil is dried, sieved, ground, and homogenized. The plutonium content of a 100 g sample aliquot is determined by alpha spectrometry. Other sample aliquots (300 g) are analyzed by gamma spectrometry using a high-purity germanium (HPGe) detector for a suite of radionuclides, including fission products, activation products from neutron interactions on steel, actinides, and natural products.

Tritium is analyzed by liquid scintillation counting of the water extracted from the sample. For beryllium, 10 g subsamples are analyzed by atomic emission spectrometry.

6.1.1 Radiological Monitoring Results

The 2018 data on the concentrations of radionuclides in surface soil from the Livermore Valley sampling locations are provided in **Appendix A, Section A.8.**

The concentrations and distributions of all observed radionuclides in soil for 2018 are within the ranges reported in previous years and generally reflect worldwide fallout and naturally occurring concentrations. Slightly higher values at and near the Livermore Site have been attributed to historical operations (Silver et al. 1974), including the operation of solar evaporators for plutonium-containing liquid waste in the southeast quadrant of the site. LLNL ceased operating the solar evaporators in 1976 and has not engaged in any open-air treatment of plutonium-containing waste since then. Sampling at location ESB, which is in the drainage area for the southeast quadrant of the Livermore Site, shows the effects of the historical operation of solar evaporators. The measured value for plutonium-239+240 at this location in 2018 was 2.0 mBq/dry g (5.4×10^{-2} pCi/dry g). Elevated levels of plutonium-239+240 resulting from an estimated 1.2×10^{9} Bq (32 mCi) plutonium release to the sanitary sewer in 1967 and earlier releases were again detected at LWRP sampling locations in 2018. The highest detected plutonium-239+240 value at the LWRP in 2018 was 6.1 mBq/dry g (0.17 pCi/dry g). In addition, americium-241 was detected in one LWRP sample at a concentration of 3.4 mBq/dry g (9.2×10^{-2} pCi/dry g) and was most likely caused by the natural radiological decay of the trace concentrations of plutonium-241 that were present in the historical releases to the sewer.

The highest detected value for tritium in 2018 was 14.0 Bq/L (378 pCi/L) at location ESB, which is downwind of the Tritium Facility. This value is consistent with measured tritium emissions associated with the Tritium Facility's operations, as described in **Chapter 4.** All tritium concentrations were within the range of previous data.

The soils data for Site 300 for 2018 are provided in **Appendix A, Section A.8.** The concentrations and the distributions of all radionuclides observed in Site 300 soil for 2018 lie within the ranges reported in previous years. At the majority of the sampling locations, the ratio of uranium-235 to uranium-238 reflects the natural ratio of 0.00725. There is significant uncertainty in calculating the ratio due to the difficulty of measuring low activities of uranium-238 by gamma spectrometry. In 2018, there was one sample that showed the presence of depleted uranium located at the 801N sampling location that had a uranium-235 to uranium-238 mass ratio of 0.0043. The amount of uranium-235 and uranium-238 in the sample were 0.028 µg/g (0.0022 Bq/g or 0.060 pCi/g) and 6.7 µg/g (0.083 Bq/g or 2.23 pCi/g). Depleted uranium values at Site 300 result from the previous use of depleted uranium in atmospheric explosive experiments.

6.1.2 Nonradiological Monitoring Results

Nonradiological monitoring for beryllium at Site 300 is conducted at all soil sampling locations (see **Figure 6-3**). The beryllium results for soils at Site 300 were within the ranges reported since sampling began in 1991. The highest value in 2018, 0.99 mg/kg, was found in an area that has historically been used for explosives testing. This value is much lower than the 110 mg/kg detected in 2003. The range of results reflects the varied concentrations of beryllium in the soil from previous explosives testing.

6.1.3 Environmental Impact on Soil

6.1.3.1 Livermore Site

Routine surface soil sample analyses indicate that the impact of LLNL operations on this medium in 2018 has not changed from previous years and remains insignificant. Most analytes of interest or concern were detected at background concentrations or in trace amounts or could not be measured above detection limits.

The highest value for plutonium-239+240 in 2018 (2.0 mBq/dry g [0.054 pCi/dry g]), measured at LWRP, is 0.4% of the National Council on Radiation Protection (NCRP) recommended screening limit of 470 mBq/g (12.7 pCi/g) for property used for commercial purposes (NCRP 1999).

LLNL has investigated the presence of radionuclides in local soils frequently over the years including possible impacts of the distribution to the public of sludge contaminated by the 1967 plutonium release (see Table 6-5 in the *Environmental Report 2006* [Mathews et al. 2007] for a list of previous studies). The studies have consistently shown that the concentrations of radionuclides in local soils are below levels of health concern. In fact, the concentrations are of such low levels of health concern that the Agency for Toxic Substances and Disease Registry (ATSDR) (2003) strongly recommended against further study of local soils for the purpose of identifying locations where plutonium-contaminated sludge from the 1967 release may remain.

6.1.3.2 Site 300

The concentrations of radionuclides and beryllium detected in soil samples collected at Site 300 in 2018 are within the range of previous data and are generally representative of background or naturally occurring levels. The uranium-235 to uranium-238 mass ratios are indicative of depleted uranium located near the firing tables. They result from the fraction of the firing table operations that dispersed depleted uranium from historical testing. The highest measured uranium-235 concentration, located at the EVAP sampling location, was 0.038 µg/g (0.003 Bq/g or 0.081 pCi/g) and was well below the NCRP-recommended screening level for commercial sites (8.2 µg/g [0.65 Bq/g or 17.5 pCi/g]). The highest measured uranium-238 concentration, located at the 801N sampling location, was 6.7 µg/g (0.08 Bq/g or 2.2 pCi/g) and was also well below the NCRP-recommended screening level for commercial sites (313 µg/g [3.9 Bq/g or 104 pCi/g]).

In 2008, a Draft Remedial Investigation/Feasibility Study (RI/FS) was submitted for the Building 812 Operable Unit (OU) (Taffet et al. 2008). This RI/FS specified the nature and extent of contamination, risk assessment, and remedial alternatives for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cleanup of the OU. In 2011, the Environmental Restoration Department (ERD) began additional characterization of soil and surface water in the Building 812 OU. Further characterization activities continued into 2018. Upon completion of characterization, a Draft/Final RI/FS will be prepared. See **Chapter 7** for further details regarding this project.

6.2 Vegetation and Foodstuff Monitoring

Vegetation sampling locations at the Livermore Site (see **Figure 6-1**) and in the Livermore Valley (see **Figure 6-2**) are divided for comparison into the following three groups:

- Near locations (AQUE, GARD, MESQ, NPER, MET, and VIS) are on-site or less than 1 km from the Livermore Site perimeter.
- Intermediate locations (I580, PATT, TESW, and ZON7) are in the Livermore Valley and 1 to 5 km from the Livermore Site perimeter. The PATT sampling location is no longer available to LLNL and was discontinued after collecting the first quarter sample.
- Far locations (FCC and CAL) are more than 5 km from the Livermore Site perimeter; FCC is about 5 km away and CAL is more than 25 km away. Both locations are generally upwind of the Livermore Site.

Tritium in vegetation due to LLNL operations is most likely to be detected at the near and intermediate locations and is highly unlikely to be detected at the far locations.

Site 300 has four monitoring locations for vegetation (PSTL, TNK5, DSW, and EVAP) (see **Figure 6-3**). Vegetation at locations DSW and EVAP exhibit variable tritium concentrations due to occasional uptake of contaminated groundwater by the roots. At the other two locations, TNK5 and PSTL, the only likely potential source of tritium uptake is the atmosphere, although groundwater in the vicinity of PSTL is contaminated with low levels of tritium.

Vegetation is sampled and analyzed quarterly. Water is extracted from vegetation by freeze-drying and analyzed for tritiated water (HTO) using liquid scintillation techniques.

Wines for sampling in 2018 were purchased from supermarkets in Pleasanton and Livermore. The wines represent the Livermore Valley, two other regions of California, and the Rhone Valley region in France. Wines were prepared for sampling using a method that separates the water fraction from the other components of the wine and were analyzed using an ultra-low-level scintillation counter.

6.2.1 Vegetation Monitoring Results

Median and mean concentrations of tritium in vegetation based on samples collected at the Livermore Site, in the Livermore Valley, and Site 300 in 2018 are shown in **Table 6-1.** See **Appendix A, Section A.9,** for quarterly tritium concentrations in plant water. The highest mean tritium concentration at the Livermore Site during 2018 was 9 Bq/L at the near location VIS on the east-central perimeter of the site. The highest mean concentration measured in the Livermore Valley was 34 Bq/L at ZON7. For Site 300, the highest mean concentration for 2018 was 190 Bq/L at DSW.

Median concentrations of tritium in vegetation at sampling locations at the Livermore Site and in the Livermore Valley have decreased noticeably since 1989 (see **Figure 6-4**). Median concentrations at the far locations have been below the detection limit of approximately 2.0 Bq/L since 1993. Median concentrations at the intermediate locations have been below the detection limit since 1998, except in 2002 when the median concentration was 2.3 Bq/L. Median concentrations at the near locations have been at or slightly above the detection limit since 2012.

At Site 300, the median concentrations of tritium in vegetation at locations PSTL and TNK5 were less than the detection limit. The median concentrations of tritium in vegetation at locations DSW and EVAP were 166 Bq/L and 4.8 Bq/L, respectively.

6.2.2 Wine Monitoring Results

Tritium concentrations in wines purchased in 2018 are shown in **Table 6-2.** The highest measured concentration in a Livermore Valley wine was 3.0 Bq/L (81 pCi/L) from a wine made from grapes harvested in 2011. The highest measured concentration in a California (other than the Livermore Valley) wine was 2.5 Bq/L (67 pCi/L) from a wine made from grapes harvested in 2014 from San Diego County. The highest measured concentration in a Rhone Valley (France) wines was 1.3 Bq/L (7.2 pCi/L) from the wine grapes harvested in 2015.

Analyses of the wines purchased annually since 1977 have typically demonstrated the following relationships: Tritium concentrations in the Rhone Valley wines are typically higher than tritium concentrations in the Livermore Valley wines. Tritium concentrations in the California (other than the Livermore Valley) wines are typically lower than tritium concentrations in the Livermore Valley wines. This year, however, the highest measured tritium concentration was found in Livermore Valley wines followed by California wines and then Rhone River Valley wines.

Table 6-1. Median and mean concentrations of tritium in plant water for the Livermore Site, Livermore Valley, and Site 300 sampled in 2018.

Note: The table includes mean annual ingestion doses calculated for 2018.

Sampling locations		Concentration of tritium in plant water (Bq/L) Median	Mean	Mean annual ingestion dose [a] (nSv/y)
NEAR (onsite or <1 km from Livermore Site perimeter)	AQUE	1.8	1.8	<10[b]
	GARD	2.1	1.9	<10[b]
	MESQ	2.2	2.2	13
	MET	1.5	1.4	<10[b]
	NPER	2.4	2.9	17
	VIS	3.4	9	54
INTERMEDIATE (1–5 km from Livermore Site perimeter)	I580	1.0	1.4	<10[b]
	TESW	2.2	1.8	<10[b]
	ZON7	2.0	34	200
FAR (>5 km from Livermore Site perimeter)	CAL	1.2	1.7	<10[b]
	FCC	1.6	1.3	<10[b]
Site 300	DSW[c]	170	190	[d]
	EVAP[c]	4.8	7.9	[d]
	PSTL	0.41	0.50	[d]
	TNK5	1.2	1.1	[d]

(a) Ingestion dose is based on conservative assumptions that an adult's diet is exclusively vegetables with this tritium concentration, and that meat and milk are derived from livestock fed on grasses with the same concentration of tritium. See **Table 6-3**.

(b) When concentrations are less than the detection limit (about 2.0 Bq/L), doses can only be estimated as being less than the dose at that concentration.

(c) Plants at these locations are rooted in areas of known subsurface contamination.

(d) Dose is not calculated because there is no pathway to dose to the public.

The Livermore Valley wines represent vintages from 2011, 2014, 2015 and 2016; the California wines represent vintage from 2014 and 2016; and the Rhone Valley region wines represent vintage from 2015 and 2016. Tritium concentrations must be decay-corrected to the year of harvest to correlate with tritium concentrations in air and soil to which the grape was exposed. In 2018, decay-corrected concentrations ranged from 1.8 to 4.5 Bq/L for Livermore Valley wine samples; 0.49 and 3.19 Bq/L for the two California wine samples; and 1.5 and 1.3 Bq/L for the Rhone Valley wine samples.

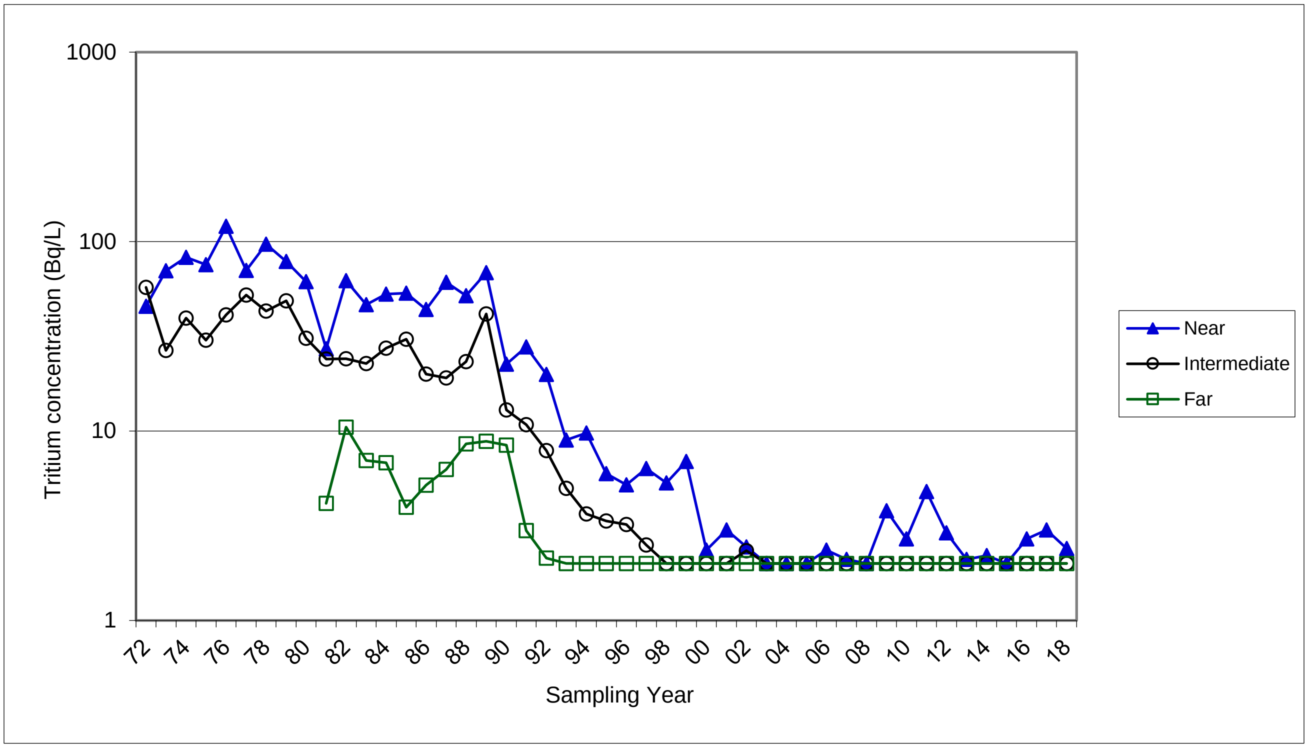

Figure 6-4. Median tritium concentrations in Livermore Site and Livermore Valley plant water samples, 1972 to 2018.
Note: When median values are below the lower limit of detection (2.0 Bq/L [54 pCi/L]), values are plotted as 2.0 Bq/L to eliminate meaningless variability.

Table 6-2. Tritium in retail wine, 2018[a, b].

	Concentration by area of production (Bq/L)		
Sample	**Livermore Valley**	**California**	**Europe**
1	1.4 ± 0.53	0.43 ± 0.54	1.3 ± 0.56
2	3.0 ± 0.56	2.5 ± 0.60	1.1 ± 0.56
3	2.4 ± 0.60		
4	2.1 ± 0.54		
5	1.5 ± 0.53		
6	1.7 ± 0.53		
Dose (nSv/y)[c]	4.3	3.5	1.8

(a) Radioactivity is reported here as the measured concentration and an uncertainty (±2σ counting error).

(b) Wines from a variety of vintages were purchased and analyzed for the 2018 sampling. Concentrations are those measured in February 2019.

(c) Calculated based on consumption of 52 L wine per year at maximum concentration. Doses account for contribution of organically bound tritium (OBT) as well as of HTO.

6.2.3 Environmental Impact on Vegetation and Wine

6.2.3.1 Vegetation

Hypothetical annual ingestion doses for mean concentrations of tritium in vegetation are shown in **Table 6-1.** These hypothetical doses, from ingestion of HTO in vegetables, milk, and meat, were calculated from annual mean measured concentrations of HTO in vegetation using the transfer factors from **Table 6-3** based on U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 (U.S. NRC 1977). The hypothetical annual ingestion dose, based on the highest observed mean HTO concentration in vegetation for 2018, was 200 nSv (20 µrem).

Table 6-3. Bulk transfer factors used to calculate inhalation and ingestion doses from measured concentrations in air, vegetation, and drinking water.

Exposure pathway	Bulk transfer factors[(a)] times observed mean concentrations
Inhalation and skin absorption	230 $nSv \cdot y^{-1} \cdot Bq^{-1}\ m^3$ × concentration in air (Bq/m^3)
Drinking water	15 $nSv \cdot y^{-1} \cdot Bq^{-1} \cdot L$ × concentration in drinking water (Bq/L)
Food ingestion	6 $nSv \cdot y^{-1} \cdot Bq^{-1} \cdot L$ × concentration in vegetation (Bq/L) [(b)], factor obtained by summing contributions of 1.3 $nSv \cdot y^{-1} \cdot Bq^{-1} \cdot L$ for vegetables, 1.4 $nSv \cdot y^{-1} \cdot Bq^{-1} \cdot L$ for meat and 3.3 $nSv \cdot y^{-1} \cdot Bq^{-1} \cdot L$ for milk

(a) See Sanchez et al. (2003), Appendix C, for the derivation of bulk transfer factors. The bulk transfer factors found in Sanchez et al. (2003) Appendix C have been updated with current DOE-accepted dose coefficients of 2.11×10^{-11} Sv/Bq for ingestion and of 1.93×10^{-11} Sv/Bq for inhalation found in U.S. DOE (2011).

(b) For vegetation dose calculations, the assumption is that the vegetation is 100% water; therefore, Bq/L equals Bq/kg fresh weight.

Doses calculated based on Regulatory Guide 1.109 neglect the contribution from OBT. However, according to a panel of tritium experts, "the dose from OBT that is ingested in food may increase the dose attributed to tritium by not more than a factor of two, and in most cases by a factor much less than this" (ATSDR 2002, p. 27). Thus, the maximum estimated ingestion dose from LLNL operations for 2018, including OBT, is 400 nSv/y (5.4 µrem/y). This maximum dose is about 1/7,500 of the average annual background dose in the United States from all natural sources and about 1/25 the dose from a panoramic dental x-ray. Ingestion doses of Site 300 vegetation were not calculated because neither people nor livestock ingest vegetation at Site 300.

6.2.3.2 Wine

For Livermore Valley wines purchased in 2018, the highest concentration of tritium (3.0 Bq/L [81 pCi/L]) was just 0.41% of the Environmental Protection Agency's (EPA's) standard for maximal permissible level of tritium in drinking water (740 Bq/L [20,000 pCi/L]). Drinking one liter per day of the Livermore Valley wine with the highest concentration purchased in 2018 would have resulted in a dose of 30 nSv/y (3.0 µrem/y). A more realistic dose estimate, based on moderate drinking (one liter per week) [(1)] at the mean of the Livermore Valley wine concentrations (2.0 Bq/L [55 pCi/L]) would have been 2.8 nSv/y (0.28 µrem/y). Both doses

1 Moderate consumption is higher than the average consumption of wine in California (15.7 L/yr) (Avalos 2005).

account for the added contribution of OBT [(2)].

The potential dose from drinking Livermore Valley wines in 2018, including the contribution of OBT, even at the high consumption rate of one liter per day, and the highest observed concentration, would be about 1/340 of a single dose from a panoramic dental x-ray.

6.3 Biota Dose

Potential dose to biota resulting from LLNL operations is calculated according to DOE Standard 1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (U.S. DOE 2002). RESRAD-BIOTA computer code is used to complete these calculations.

Limits on absorbed dose to biota are 10 mGy/day (1 rad/day) for aquatic animals and terrestrial plants, and 1 mGy/day (0.1 rad/day) for terrestrial animals. In the RESRAD-BIOTA code, each radionuclide in each medium (e.g., soil, sediment, and surface water) is assigned a Biota Concentration Guide (BCG). Measured radionuclide concentrations in the soil and water media are divided by the BCG, and the resulting fractions for each medium are summed for each ecosystem (aquatic and terrestrial). For aquatic and riparian animals, the sum of the fractions for water exposure is added to the sum of the fractions for sediment exposure. Similarly, fractions for water and soil exposures are summed for terrestrial animals. If the sum of the fractions for the aquatic and terrestrial systems are each less than 1 (i.e., the dose to the biota does not exceed the screening limit), then the site has passed the screening analysis for protection of biota.

6.3.1 Estimate of Dose to Biota

At LLNL in 2018, radionuclides contributing to dose to biota from soil were americium-241, cesium-137, hydrogen-3 (tritium), potassium-40, plutonium-238, plutonium-239+240, thorium-232, uranium-235, uranium-238, and strontium-90 (based on gross beta). Radionuclides contributing to dose to biota from water were tritium, plutonium-239 (based on gross alpha) and strontium-90 (based on gross beta).

For the LLNL assessment, the maximum concentration of each radionuclide measured in soil and the storm water run-off samples, considering both the Livermore site and Site 300, were used in the dose screening calculations for the terrestrial and aquatic fractions. This approach resulted in a conservative assessment, given that the maximum concentrations in the media originate from different locations within a large area. It accounts for the exposure at both the Livermore Site and Site 300 and no plant or animal would likely be exposed to both simultaneously.

For 2018, the total sum of the fractions for the aquatic ecosystem animals was 0.059 with the limiting concentrations from nuclides in water. The total sum of the fractions for the terrestrial ecosystem animals and plants was 0.40 with the limiting concentrations from radionuclides in

2 Dose from wine was calculated based on the measured concentration of HTO multiplied by 1.3 to account for the potential contribution of OBT that was removed so that the tritium in wine could be counted using liquid scintillation counting. The ingestion dose coefficient for HTO is 2.1×10^{-11} Sv/Bg per U.S. DOE (2011).

soil. These fractions for both ecosystems are well below 1 showing that, even using the most conservative assumptions, LLNL’s impacts on biota are minimal.

6.4 Ambient Radiation Monitoring

Motivated by DOE Order 458.1, LLNL’s ambient radiation monitoring program monitors trends in average ambient dose from gamma radiation in order to detect radiation exposure that may be attributed to LLNL operations. This monitoring is conducted using TLDs. The areas in which TLDs are placed are the Livermore Site perimeter (**Figure 6-1**), the Livermore Valley (**Figure 6-2**); Site 300, and the Site 300 vicinity including Tracy (**Figure 6-3**). In each area, there are multiple TLD locations at which individual TLDs are placed.

6.4.1 Ambient Radiation Monitoring Methods

Exposure to external gamma radiation is measured using Panasonic UD-814-A1 TLDs. These TLDs contain three crystal elements of thulium-activated calcium sulfate ($CaSO_4$: Tm) and one element of lithium borate phosphor ($^{n}Li_2B_4O_7$). For the purposes of gamma radiation dose monitoring, though, only the three $CaSO_4$ elements are considered. TLDs are placed approximately one meter above ground and deployed and retrieved quarterly, consistent with DOE guidance.

When gamma radiation interacts with the TLD, energy is trapped within the structure of the TLD crystal. Upon heating, the trapped energy is released in the form of light. Measurements of the light are converted to radiation exposure, in milliroentgen (mR), based on a calibration standard of 662 keV cesium-137 gamma energy. Radiation exposure measurements are then converted to dose, in milliSieverts (mSv; 1 mSv = 100 mrem), and normalized to represent a standard 90-day quarter. The result is the estimated dose to the public due to external gamma radiation for the duration of one quarter.

6.4.2 Ambient Radiation Monitoring Results

Table 6-4 presents the annual dose (in mSv) for 2018 and the previous four years for the Livermore Site perimeter, the Livermore Valley, Site 300, and the Site 300 vicinity including Tracy. Tabular data for each sampling location are provided in **Appendix A, Section A.9.** The annual dose for each area is obtained by summing the quarterly doses from each TLD location, then averaging the annual sums for that area. If data is missing for any quarters at a particular location, the annual dose at that location is taken as four times the average of the results available.

Table 6-4. 5-year annual ambient radiation dose summary with standard deviation (SD) in units of mSv and numbers of samples. [(a)]

Area	Measurement	Year 2014	2015	2016	2017	2018
Livermore Site	Dose ± 1 SD (mSv)	0.568 ± 0.015	0.560 ± 0.016	0.566 ± 0.016	0.565 ± 0.014	0.581 ± 0.014
	Number of Samples	56	56	56	55	54
Livermore Valley[(a)]	Dose ± 1 SD (mSv)	0.552 ± 0.039	0.535 ± 0.039	0.541 ± 0.040	0.549 ± 0.039	0.570 ± 0.035
	Number of Samples	32	32	32	31	31
Site 300	Dose ± 1 SD (mSv)	0.689 ± 0.031	0.672 ± 0.033	0.663 ± 0.035	0.673 ± 0.036	0.691 ± 0.029
	Number of Samples	31	35	31	28	30
Site 300 off-site	Dose ± 1 SD (mSv)	0.649 ± 0.13	0.639 ± 0.12	0.638 ± 0.10	0.664 ± 0.091	0.680 ± 0.13
	Number of Samples	7	8	6	7	7
Tracy	Dose ± 1 SD (mSv)	0.618 ± 0.051	0.623 ± 0.024	0.618 ± 0.017	0.626 ± 0.039	0.639 ± 0.039
	Number of Samples	6	8	8	8	8

(a) The number of samples may change from year to year for the same location if TLD data is rejected or the TLD is damaged or missing at the time of collection.

Some natural variation in exposure and dose is expected. For example, the Neroly Formation in and around Site 300 contains naturally occurring thorium that increases the external radiation dose at Site 300 relative to the Livermore Valley.

6.4.3 Environmental Impact from Laboratory Operations

TLD measurements for 2018 indicate there were no detectable elevations in ambient radiation dose as a result of LLNL operations. Radiation doses for each area are consistent with those of previous years.

6.5 Special Status Wildlife and Plants

Special status wildlife and plant monitoring at LLNL focuses on species considered to be rare, threatened, or endangered (including species listed under the federal Endangered Species Act [ESA] or California Endangered Species Act [CESA]) and species considered of concern by the California Department of Fish and Wildlife (CDFW) and the U.S. Fish and Wildlife Service (USFWS).

The California red-legged frog (*Rana draytonii*), a threatened species, is known to occur at the Livermore Site (see **Figure 6-5**). Because California tiger salamanders (*Ambystoma californiense*) have been observed within 1.1 km of the Livermore Site, portions of the Livermore Site are considered potential upland habitat for the California tiger salamander. There is no known historic or occupied breeding habitat for the California tiger salamander at the Livermore Site.

Five species that are listed under the federal ESA are known to occur at Site 300—the California tiger salamander, California red-legged frog, Alameda whipsnake (*Masticophus lateralis euryxanthus)*, valley elderberry longhorn beetle (*Desmocerus californicus dimorphus)*, and the large-flowered fiddleneck (*Amsinckia grandiflora*). Although there are no recorded observations of the federally endangered San Joaquin kit fox (*Vulpes macrotis mutica*) at Site 300, this species is known to have historically occurred in the adjacent Carnegie and Tracy Hills areas (USFWS 1998). Because of the proximity of known observations of San Joaquin kit fox to Site 300, it is necessary to consider potential impacts to San Joaquin kit fox during activities at Site 300.

Three additional species that are listed under the CESA, but not the federal ESA, are also known to occur at Site 300. Two species that are listed as threatened under the CESA, the tricolored blackbird (*Agelaius tricolor*) and the Swainson's hawk (*Buteo swainsoni*), regularly occur at Site 300. A third species, the California-endangered willow flycatcher (*Empidonax traillii*), has been observed at Site 300 once.

Protected habitat for species listed under the federal and California ESAs at Site 300 is shown in **Figure 6-6.**

Vertebrate species and rare invertebrate species known to occur at Site 300, including state and federally listed species and other species of special concern are listed in **Appendix C.** A similar list has not been prepared for the Livermore Site.

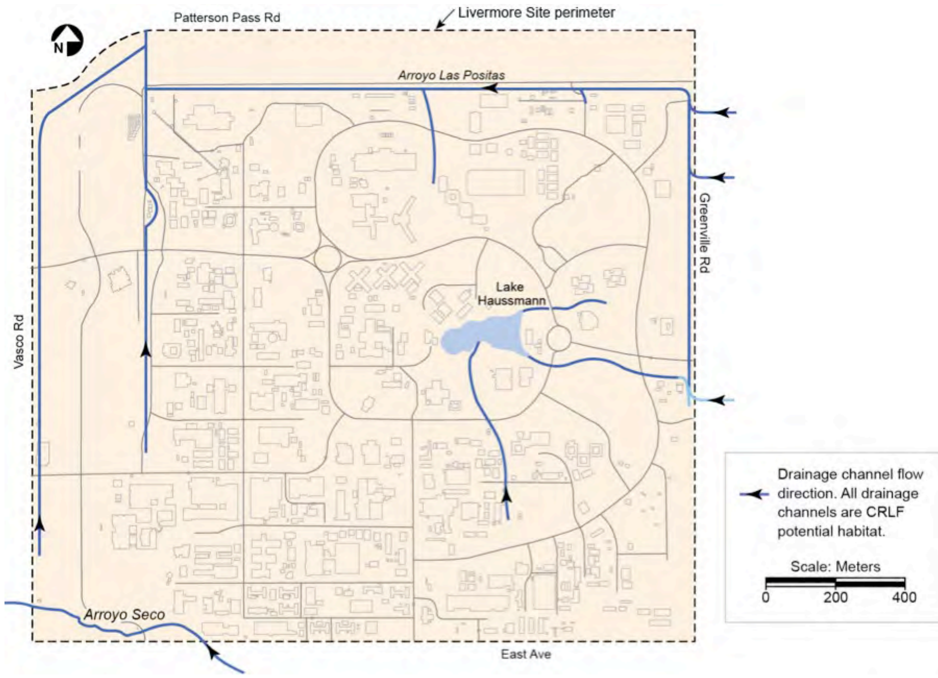

Figure 6-5. Potential California red-legged frog aquatic habitat, Livermore Site.

Including the federally endangered large-flowered fiddleneck, four rare plant species and three uncommon plant species are known to occur at Site 300. The four rare species—the large-flowered fiddleneck, the big tarplant (*Blepharizonia plumosa*), the diamond-petaled California poppy (*Eschscholzia rhombipetala*), and shining navarretia (*Navarretia nigelliformis* ssp. *radians*)—all have a California Rare Plant Rank (CRPR) of 1B (CNPS 2019). A fifth species, the round-leaved filaree *(California macrophylla),* was previously considered rare, but its status was recently downgraded, and this species is no longer considered rare (CNPS 2019).

The three uncommon plant species—California androsace (*Androsace elongata* subsp. *acuta*), stinkbells (*Fritillaria agrestis*), and hogwallow starfish (*Hesperevax caulescens*)—have a CRPR of 4 (CNPS 2018). Past surveys have failed to identify any rare plants on the Livermore Site (Preston 1997, 2002).

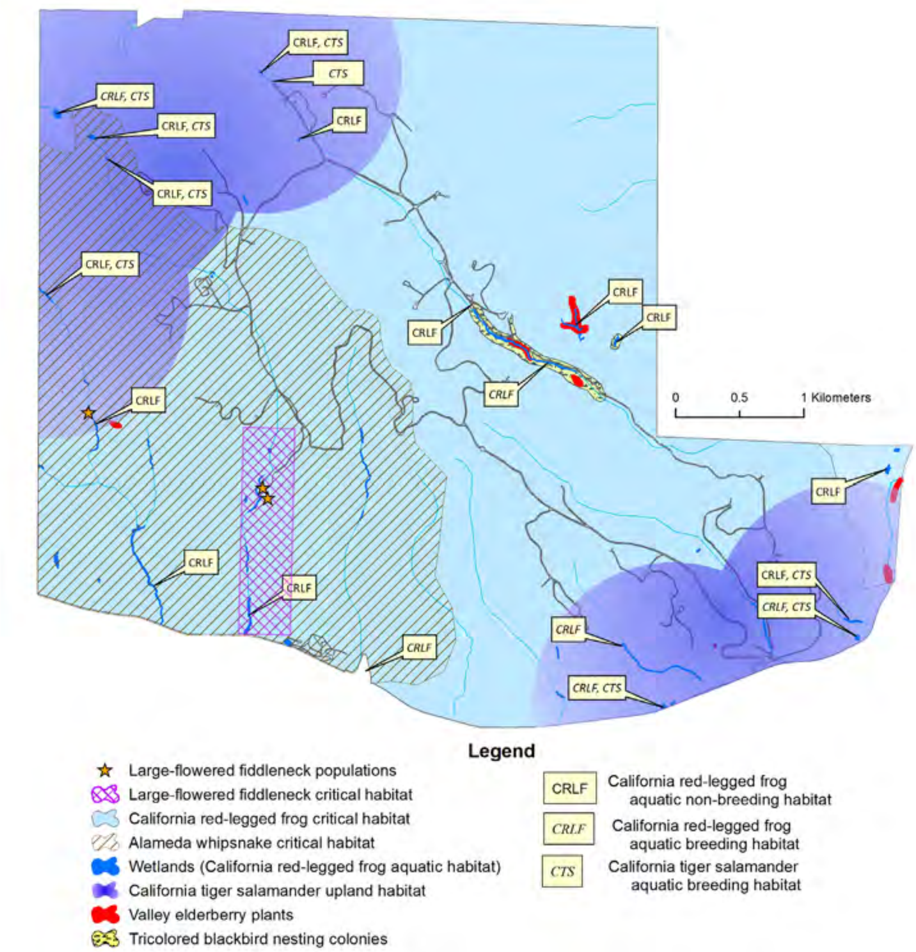

Figure 6-6. Protected habitat for species listed under the federal and California Endangered Species Acts at Site 300.

6.5.1 Surveillance Monitoring

6.5.1.1 Avian Monitoring

Nesting bird surveys and monitoring ensure LLNL activities comply with the Migratory Bird Treaty Act and do not result in impacts to nesting birds.

Livermore Site Nesting Bird Surveys. LLNL conducted site-wide breeding raptor surveys in 2018 at the Livermore Site. White-tailed kites frequently nest in the trees along the north, east, and south perimeters of the Livermore Site. Two white-tailed kite nests successfully fledged a total of three young at the Livermore Site in 2018. One great-horned owl nest and two barn owl nests successfully fledged young at the Livermore Site in 2018. There was one successful red-tailed hawk nest at the Livermore Site that fledged two young and a second successful nest just outside the eastern boundary of the Livermore Site that fledged one young. Of two American kestrel nests at the Livermore Site, one nest successfully fledged three young and the status of the second nest was not determined. One turkey vulture nest located near the center of the Livermore Site successfully fledged one young in 2018.

Site 300 Burrowing Owl Bird Surveys. Sitewide surveys for nesting burrowing owls were conducted at Site 300 in 2018. Twenty-five nesting burrowing owl pairs were observed at Site 300 in 2018. Although there was an increase in the number of nesting pairs in 2018 compared to 2017, these pairs were less successful and produced fewer fledglings. In 2018, 15 of the 25 nesting pairs (60%) successfully reared at least one fledgling, and in 2017 13 out of 14 (92%) nesting burrowing owl pairs were successful. The 15 successful nesting pairs observed in 2018 reared at least 55 fledglings. This is an average of three to four fledglings per successful nest. In 2017, the 13 successful burrowing owl pairs reared at least 60 fledglings. This is an average of four to five nestlings per natal burrow.

Site 300 Nesting Bird Surveys. In addition to burrowing owl monitoring described above, nesting raptor locations were recorded at Site 300 during fire trail surveys and pre-activity monitoring conducted in 2018. Nesting raptor surveys were also conducted within the Corral Hollow Creek riparian corridor adjacent to the eastern and southern perimeter of Site 300 in the spring of 2018 prior to the start of the ESGA well decommissioning project. During these surveys, three pairs of nesting red-tailed hawks and one pair of nesting great-horned owls were observed. Nest success was not monitored.

Site 300 Tricolored Blackbird Surveys. Tricolored blackbirds regularly nest in wetland habitat located the Elk Ravine riparian corridor at Site 300. Each year LLNL biologists monitor tricolored blackbird nesting success at this location. Early in April 2018, 300-500 tricolored blackbirds were observed at the nesting colony in Elk Ravine, but no tricolored blackbird fledglings were observed in Elk Ravine in 2018. Survey results indicate that the colony did not successfully reproduce in Elk Ravine in 2018 and relocated to another location before the end of the breeding season.

6.5.1.2 Amphibian Monitoring

Livermore Site California red-legged frog monitoring. In 2018, LLNL continued nocturnal surveys for California red-legged frogs in Arroyo las Positas, Arroyo Seco, and Lake Haussmann. No California red-legged frogs were observed during these surveys. Two juvenile California red-legged frogs were observed in Lake Haussmann in the fall of 2014. Two adult California red-legged frogs were observed during maintenance activities in Arroyo las Positas in the fall of 2016. These are the most recent observations of California red-legged frogs at LLNL’s Livermore Site. In 2018 the American bullfrog, (*Lithobates catesbeianus*) a non-native invasive species, continued to be abundant at the Livermore Site. Diurnal surveys for California red-legged frog egg masses were also conducted at the Livermore Site in 2018. No California red-legged frog egg masses were observed in Arroyo las Positas, Arroyo Seco, or Lake Haussmann in 2018.

Site 300 Amphibian monitoring. At Site 300, California red-legged frog visual encounter surveys continued in Pool M1a and b (mid-Elk Ravine) and successful breeding of adults and metamorphosis of tadpoles was recorded in this spring-fed drainage (2005–2018). Diurnal surveys are also routinely conducted at several seasonal pools at Site 300 to monitor the breeding success of California tiger salamanders and California red-legged frogs in these locations. In 2018, diurnal surveys were conducted at nine seasonal pools (Pool A, Pool H, Pool M2, Pool

HC1, Pool S, Pool OS, Pool M3, Lower Pool D and Upper Pool D). These pools regularly support California tiger salamander breeding in years with average or above average rainfall, and adult California red-legged frogs are occasionally observed at these pools during the wet season. In 2018, seasonal pools at Site 300 did not become inundated for a long enough duration to allow for amphibian breeding due to below average rainfall.

6.5.1.3 San Joaquin Kit Fox Monitoring

In the fall of 2018, subcontract biologists conducted San Joaquin kit fox surveys with scent detection dogs along the northern western and eastern perimeters of Site 300. No sign of San Joaquin kit fox was observed at Site 300 during these surveys.

6.5.1.4 Rare Plant Monitoring

Large-Flowered Fiddleneck. This species has recently been known in only three native populations. This includes two populations at Site 300 (the Drop Tower and Draney Canyon populations) and a population located on mitigation property owned by the Contra Costa Water District. No large-flowered fiddleneck have been observed at Draney Canyon since a landslide at that site in 1997. The Drop Tower native population also contained no large-flowered fiddleneck plants in 2018.

LLNL established an experimental population of the large-flowered fiddleneck at Site 300 beginning in the early 1990s. LLNL maintains the experimental population by periodically planting large-flowered fiddleneck seedlings and seeds in established plots within the population. The size of the experimental population fluctuates as a result of these enhancement efforts. Two-hundred and eighty large-flowered fiddleneck seedlings were planted in this experimental population in 2017, and seeds were last planted at this population in November of 2012. Largely as a result of planting seedlings in January of 2017, the Drop Tower experimental population contained approximately 130 large-flowered fiddleneck plants in the spring of 2018.

Big Tarplant. The distribution of big tarplant was mapped at Site 300 using a handheld global positioning system (GPS) in September through November 2018. Between approximately 14,500 and 45,000 big tarplants were observed at Site 300 during these surveys. This is an average annual population size. While this species is extremely rare throughout its range, it can be abundant at Site 300, especially in or near areas where prescribed burns are routinely conducted and where wildfires have occurred. As is typical with annual plant species, the abundance of big tarplant varies greatly between years depending on environmental conditions. For example, while the Site 300 big tarplant population was estimated to contain no more than 2,700 individual plants in 2014, there were up to 214,000 big tarplants found at Site 300 in 2010.

Diamond-Petaled California Poppy. Although the species is not listed under the federal or California ESAs, it is extremely rare and is currently known to occur only at Site 300 and in a few locations in Contra Costa and San Luis Obispo Counties. Currently four populations of this species are known to occur at Site 300; these population locations are referred to as Site 1 through 4. Site 3 was discovered in 2004 and typically contains the largest population of this rare species. As with the big tarplant and other annual plants, the number of diamond-petaled California poppy plants present in these populations is expected to vary from year to year. In 2015, approximately 46,100 diamond-petaled California poppies were observed within all Site 300 populations. The 2015 population was the largest observed since sitewide monitoring began in 2004. The relatively large diamond-petaled California poppy population in 2015 was likely attributable to annual grass cover, which was much less dense than average as a result of drought conditions. In contrast, only 4 diamond-petaled California poppies were observed at Site 300 in 2017. The median number of diamond-petaled California poppy plants observed at Site 300 between 2004 and 2018 is 606. In 2018, 931 diamond-petaled California poppies were observed in all Site 300 populations. This is slightly higher than the median population size observed between 2004 and 2018.

6.5.2 Invasive Species Control Activities

Invasive species control is an important part of LLNL’s effort to protect special status species at both sites. Prevention of additional colonization by invasive species is also important to protect native species throughout our region. The American bullfrog is a significant threat to California red-legged frogs at the Livermore Site, and the feral pig (*Sus scrofa*) threatens numerous protected habitat types at Site 300. The exotic fish, largemouth bass (*Micropterus salmoides*), has been successfully removed from Lake Haussmann at the Livermore Site.

At the Livermore Site, bullfrog control measures were implemented between May and September 2018. Bullfrog control measures included dispatching adults and removing egg masses in Lake Haussmann and Arroyo Las Positas. To remove bullfrog tadpoles and invasive fish, the LLNL reach of Arroyo Las Positas was allowed to dry out in September 2018 by temporarily halting groundwater discharges to the arroyo.

At Site 300, feral pig control measures were implemented between March and May 2018. Feral swine control measures included dispatching both adults and associated litters. Site 300 continues to protect its critical habitats and rare species as a result of consistent swine control practices onsite.

6.5.3 Habitat Enhancement Projects and Compliance Activities

6.5.3.1 Power Pole Modifications for Migratory Bird Protection

To minimize adverse impacts to migratory birds, Site 300 implemented an avian protection policy to support avian-friendly transmission lines, insulators, power poles, and other features that are designed to minimize collision and electrocution fatalities of birds of prey.

Between 2014 and 2017, over fifty power poles were modified for bird protection at Site 300 as part of a site-wide revitalization project. These bird-friendly modifications included creating safe perch sites and limiting access to areas with possible electrical hazards; specifically, the following actions were taken:

1. Dropping the cross arm to create an elevated center pole perch.
2. Running underarm (under cross arm) conductor jumpers away from perch sites.
3. Adding elevated center phase conductors with kingpins above perch sites.

4. Upgrading cross arm geometry to "straight line" conductors on line and buck (multi-directional) poles thereby avoiding extra conductor infrastructure.
5. Cleaning-up wiring (i.e., wire removal or guards) or adding bushing covers to switch poles.
6. Installing long ten-foot cross arms to increase the separation between phases.

6.5.3.2 Arroyo Las Positas Maintenance and Habitat Management

LLNL annually conducts maintenance and habitat management within the Arroyo Las Positas at LLNL's Livermore Site. Maintenance was conducted in two 300-foot and one 200-foot reaches of Arroyo Las Positas at LLNL's Livermore Site in September 2018. This is the fourth consecutive year work was conducted as part of this project. The goals of this project are to reduce the potential for flooding of LLNL facilities and improve habitat value for the federally threatened California red-legged frog and other native species. All work in the channel of Arroyo Las Positas is monitored by a Service Approved Biologist. In 2018, no California red-legged frogs were observed during diurnal and nocturnal pre-activity and monitoring surveys in this location. This project includes planting willows and cottonwoods to eventually shade the arroyo, reducing cattail growth that will in turn reduce the need for maintenance. In addition, willow and cottonwoods will provide cover that can be utilized by the California red-legged frog and other native wildlife. After the 2015, 2016, and 2018 maintenance was completed, willows and cottonwoods were planted along the south bank of the arroyo. The survivorship of planted willows and cottonwoods was monitored in 2018, and the survivorship of planted willows and cottonwoods met requirements for this project.

6.5.3.3 Elk Ravine Habitat Enhancement Pools

In late August 2005, LLNL implemented a habitat enhancement project for California red-legged frogs at Site 300 in accordance with a 2002 USFWS biological opinion (BO), Army Corps of Engineers (ACOE), and Regional Water Quality Control Board (RWQCB) permits. California red-legged frogs were translocated to the new habitat enhancement pools in Elk Ravine (Pool M1a and b) in February and March 2006. In the summer of 2014, both pools were dredged to remove extra sediment thus increasing the depths to the original 8-10 ft. improving the value of this habitat for California red-legged frog breed. During dredging operations, overgrown vegetation (including cattails, nettles and willows) was also removed to increase breeding habitat suitability. Vegetation in Pool M1a and b continued to recover from a wildfire that occurred in early June of 2015. No impacts to California red-legged frog breeding were observed as a result of this wildfire. Monitoring demonstrated that California red-legged frogs successfully reproduced in these pools in 2006 through 2018.

6.5.3.4 Pool M2 Habitat Enhancement

A series of three ephemeral pools (Pool A, Pool H, and Pool M2), located in the northwest corner of Site 300, provide breeding habitat of the California tiger salamander. Pool A and Pool H are seasonal pools that have supported California tiger salamander breeding for many years. A habitat enhancement project was conducted at Pool M2 in 2005 to improve the suitability of this pool for California tiger salamander breeding. A second habitat enhancement project was conducted at the Pool M2 in 2013 when the clay liner of this pool was augmented to limit infiltration or loss of water through the bottom of the pool. In 2006, 2010, 2011, 2015, 2016, and 2017, Pool M2 filled and California tiger salamanders successfully reproduced at this location. In 2007, 2008, 2009, 2012, 2013, 2014, and 2018 the pool received inadequate inundation and evaporated before the salamander larvae could reach maturity and leave the pool.

6.5.3.5 Pool HC1 Habitat Enhancement

In 2006, LLNL completed culvert replacement projects at two Site 300 locations (the Oasis and Round Valley) where unpaved fire trails cross intermittent drainages. The Oasis site has been disturbed by feral pigs and does not currently provide suitable habitat for California tiger salamander or California red-legged frog breeding. Monitoring was not conducted at the Oasis in 2018. The 2006 Round Valley project included the creation of a pool upstream of the project area, known as Pool HC1, in part as mitigation for the impacts at the Oasis site and to serve as enhanced habitat for protected amphibian species.

An additional habitat enhancement project was conducted at Pool HC1 in 2012. The clay liner of this pool was augmented in the fall of 2012 in an effort to limit infiltration or loss of water through the bottom of the pool. In 2016, Pool HC1 filled completely and California tiger salamander eggs and larvae were observed in the pool. In 2017, Pool HC1 initially filled but the pool did not hold water long enough for salamander larva to successfully mature. Seasonal pools at Site 300, including Pool HC1, received inadequate inundation in 2018 and evaporated before the salamander larvae could reach maturity and leave the pool.

6.5.3.6 Pool M3 Habitat Enhancement

In the fall of 2014, LLNL completed the formal set aside of 48.5 acres and enhancement of the Pool M3 breeding site for California tiger salamanders. In 2016, California tiger salamanders successfully reproduced in this pool. This represented the second successful breeding attempt in Pool M3 since completion of its restoration activities conducted in 2014. In 2017, California tiger salamander eggs were observed at Pool M3, but the pool did not hold water for long enough for salamander larva to mature. In the summer of 2017, the clay liner at Pool M3 was enhanced in an effort to increase the hydroperiod of this pool. In 2018, Pool M3 did not fill to a depth or duration to allow for California tiger salamander reproduction. This was not unexpected because none of the seasonal pools at Site 300 filled for the duration necessary to allow for California tiger salamander breeding in 2018 because of low annual rainfall.

6.5.4 Environmental Impacts on Special Status Wildlife and Plants

Through monitoring and compliance activities in 2018, LLNL has been able to avoid significant impacts on special status wildlife and plants. Habitat enhancement, avian protection, and invasive species control efforts resulted in benefits to protected species. LLNL continues to monitor and maintain several restoration sites, habitat enhancements, and conservation set asides that are beneficial to native plants and animals at the Livermore Site or Site 300 and ensures the protection of listed and special status species.

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7. Groundwater Investigation and Remediation

Mark Buscheck • Charles Noyes

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 of a Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) removal action or through the CERCLA 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 km^2 (10.9 mi^2), 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 km^2 (1.3 mi^2), 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 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 km^2. 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.

7.1.3 Remediation Activities and Monitoring Results

In 2018, LLNL maintained and operated 27 groundwater treatment facilities. The groundwater extraction wells and dual (groundwater and soil vapor) extraction wells produced 1,011 million L of groundwater and the treatment facilities (TFs) removed about 32 kg of VOCs. Since remediation began in 1989, approximately 23.7 billion L of groundwater have been treated, resulting in removal of more than 1,746 kg of VOCs. Additional information concerning flow and mass removal by treatment facility area is presented in Noyes et al. (2019).

LLNL also maintained and operated eight soil vapor treatment facilities (VTFs) in 2018. The soil vapor extraction wells and dual extraction wells produced more than 2.5 million m^3 of soil vapor and the treatment facilities removed approximately 12 kg of VOCs. Since initial operation, nearly 26.1 million m^3 of soil vapor has been extracted and treated, removing more than 1,609 kg of VOCs from the subsurface. Additional information concerning flow and mass removal by treatment facility area is presented in Noyes et al. (2019).

Five treatment facilities remained offline in 2018:

- Vapor Treatment Facility D (VTFD) Helipad
- TF5475-1
- TF5475-3
- VTF5475
- TF518 North

VTFD Helipad remained offline 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. (2019) for more information on the Livermore Site groundwater and soil vapor treatment facilities.

Restoration activities in 2018 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 2018, 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 2018 included:

- Drilling and installation of three ground water monitoring wells in the TFD and TFE areas.
- Proper abandonment or decommissioning of fourteen 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 VTF518 Perched Zone.
- Continued reevaluation of the inhalation risk for VOCs potentially migrating from the subsurface into indoor ambient air, including sampling of a prioritized list of buildings.

Groundwater concentration and hydraulic data indicate subtle but consistent declines in the VOC concentrations and areal extent of the contaminant plumes in 2018. Hydraulic containment along the western and southern boundaries of the site was fully maintained in 2018, and progress was made toward interior plume and source area clean up. See Noyes et al. (2019) 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 of all site workers. LLNL's environmental restoration project is committed to preventing present and future human exposure to contaminated soil, soil vapor, and groundwater, preventing further contaminant migration of concentrations above drinking water standards, reducing concentrations of contaminants in groundwater and soil vapor, 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 EPA 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).

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/$Tnsc_2$ HSU.
3. Tertiary Neroly Formation bedrock including the $Tnsc_2$, $Tnbs_2$, $Tnsc_{1a/b}$ $UTnbs_1$, $Tnbs_1$/$Tnbs_0$, and $Tnsc_0$ 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 2018, shallow water-bearing zones throughout Site 300 declined nominally in response to less than average rainfall that occurred during the 2017-2018 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.
- 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 2018, the Site 300 Environmental Restoration Project operated 15 groundwater and 5 soil vapor treatment facilities extracting and treating approximately 31.2 million L of groundwater and 2.3 million m^3 of contaminated soil vapor. The Site 300 treatment facilities removed nearly 7.2 kg of VOCs, 0.072 kg of perchlorate, 1,500 kg of nitrate, 0.28 kg of the high explosive compound RDX, 0.0079 kg of silicone oils, and 0.031 kg of uranium in 2018. Since groundwater remediation began in 1990, approximately 1,735 million L of groundwater and 35 million m^3 soil vapor have been treated, resulting in removal of approximately 630 kg of VOCs, 1.7 kg of perchlorate, 20,000 kg of nitrate, 2.7 kg of RDX, 9.5 kg of silicone oils, and 0.087 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. (2019).

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, 2017, and 2018. 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 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.

The results of the characterization activities are being analyzed and will be presented in a Remedial Investigation/Feasibility Study for the Building 812 OU and a document summarizing the updated background concentration ranges for metals and radionuclides in Site 300 soil.

Additional Site 300 Environmental Restoration Project activities performed in 2018 included:

- Installing two new groundwater monitor wells in the Building 832 area.
- Installing one new extraction well in the Pit 7 area.
- Installing one new groundwater monitor well in the Building 854 area.
- Installing two new groundwater monitor wells in the Building 865 area.
- Closing ten former groundwater monitor 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 evaluation of a next phase of VOC treatment in the T2 area of Building 834.
- Continuing upgrades of the Central General Services Area groundwater and soil vapor treatment facilities.
- Continuing upgrades of the Building 832 source ground water and soil vapor treatment facilities.
- Continued reevaluation of the inhalation risk for VOCs potentially migrating from the subsurface into indoor ambient air, including sampling of a prioritized list of buildings.

All calendar year 2018 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 2018 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 2018 is available in the *2018 Annual Compliance Monitoring Report for LLNL Site 300* (Buscheck et al. 2019).

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.
- Monitoring natural attenuation.
- Monitoring and institutional controls.

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

8. Quality Assurance

Tyler Jackson • Chris Campbell

Quality assurance (QA) is a system of activities and processes put in place to ensure that products or services meet or exceed customer specifications. Quality control (QC) consists of activities used to verify that deliverables are of acceptable quality and meet criteria established in the quality planning process.

8.1 Quality Assurance Activities

Nonconformance reporting and tracking is a formal process used to ensure that problems are identified, resolved, and prevented from recurring. The Lawrence Livermore National Laboratory (LLNL) Environmental Functional Area (EFA) and Environmental Restoration Department (ERD) track problems using the LLNL Institutional Tracking System (ITS). ITS items are initiated when items or activities are identified that do not comply with procedures or other documents that specify requirements for EFA operations or that cast doubt on the quality of regulatory reports, integrity of samples, or data, and that are not covered by other reporting or tracking mechanisms. Nonconformances involving EFA are captured and used to provide trending information for environmental compliance evaluations. There were no laboratory data nonconformances affecting the quality of data used for reporting purposes documented in 2018. Many minor sampling or data problems are resolved without generating an ITS item. The LLNL quality assurance requirements stipulate that laboratories generating data must have a formal nonconformance program to track and document issues in their analyses. Such programs are separate from the LLNL ITS.

LLNL averts sampling problems by requiring formal and informal training on sampling procedures. Errors that occur during sampling generally do not result in lost samples but may require extra work on the part of laboratory or sampling and data management personnel to correct the errors.

LLNL addresses commercial analytical laboratory problems as they arise. Many of the problems concern minor documentation errors and are corrected soon after they are identified. Other problems, such as missed holding times, late analytical results, incorrect analysis, and typographical errors on data reports, account for the remaining issues and are not tracked as nonconformances. These problems are corrected by the commercial laboratory reissuing reports or correcting paperwork and do not affect associated sample results.

LLNL participates in the Department of Energy Consolidated Auditing Program (DOECAP). Annual on-site visits to commercial laboratories under contract to LLNL are part of the auditing program to ensure that accurate and defensible data are generated. The audit program is based on DOECAP requirements under The National Environmental Laboratory Accreditation Conference (NELAC) Institute (TNI). All commercial laboratories used by LLNL are LLNL-qualified vendors and are National Environmental Laboratory Accreditation Program (NELAP) certified or California Department of Health Services Environmental Laboratory accredited. Audit reports, checklists, and Corrective Action Plans are maintained under the DOECAP program for commercial labs.

The following six areas pertain to the services provided by a particular external analytical laboratory:

- QA management systems and general laboratory practices
- Organic analyses
- Inorganic and wet chemistry analyses
- Radiochemical analyses
- Laboratory information management systems and electronic deliverables
- Hazardous and radioactive materials management

LLNL has qualified auditors under the national DOECAP program in the areas of quality assurance, organic chemistry, inorganic chemistry, laboratory information management, and hazardous material management.

In FY2018, the laboratories certified by the State of California operating at LLNL as government owned and contractor operated were not internally assessed, but are subject to assessment by the State of California under the Environmental Laboratory Accreditation Program (ELAP).

Analytical laboratories routinely perform QC tests to document and assess the quality and validity of their sample results. Each set of data received from the analytical laboratory is systematically evaluated and compared to establish measurement-quality objectives before the results can be authenticated and accepted into the monitoring database. Categories of measurement quality objectives include accuracy, precision, and comparability. When possible, quantitative criteria are used to define and assess data quality.

8.2 Analytical Laboratories and Laboratory Intercomparison Studies

In 2018, LLNL had Blanket Service Agreements (BSAs) with six commercial analytical laboratories. All analytical laboratory services used by LLNL are provided by facilities certified by the State of California. LLNL works closely with these analytical laboratories to minimize problems and ensure that QA/QC objectives are maintained.

LLNL uses the results of nationally recognized intercomparison performance evaluation program data to identify and monitor trends in performance and to draw attention to the need to improve laboratory performance. If a laboratory performs unacceptably for a particular test in two consecutive performance evaluation studies, LLNL may stop work and select another laboratory to perform the affected analyses until the original laboratory has demonstrated that the problem has been corrected. If an off-site laboratory continues to perform unacceptably or fails to prepare and implement acceptable corrective action responses, the LLNL Supply Chain Management Department formally notifies the laboratory of its unsatisfactory performance. If the problem persists, the off-site laboratory’s BSA could be terminated for that test. If an on-site laboratory continues to perform unacceptably, use of that laboratory could be suspended until the problem is corrected. In 2018, all contracted commercial labs were successful in participation in performance evaluation studies and where there were individual failures to perform, the commercial labs were verified to have corrective actions in place.

Although laboratories are also required to participate in laboratory intercomparison programs, permission to publish their accreditation results for comparison purposes was not granted for 2018. To obtain DOE Mixed Analyte Performance Evaluation Program (MAPEP) reports that include the results from all participating laboratories, see https://www.id.energy.gov/resl/mapep/mapepreports.html. MAPEP is a DOE program and the results are publicly available from laboratories that choose to participate.

8.3 Duplicate Analyses

Duplicate (collocated) samples are distinct samples of the same matrix collected as closely as possible to the same point in space and time. Collocated samples that are processed and analyzed by the same laboratory provide information about the precision of the entire measurement system, including sampling, homogeneity, handling, shipping, storage, preparation, and analysis. Collocated samples that are processed and analyzed by different laboratories provide information about the precision of the entire measurement system that also captures interlaboratory variation (U.S. EPA 1987). Collocated samples may also identify errors such as mislabeled samples or data entry errors. **Tables 8-1**, **8-2**, and **8-3** present summary statistics for collocated sample pairs, grouped by sample matrix and analyte. Samples from both the Livermore Site and Site 300 are included. **Tables 8-1** and **8-2** are based on data pairs in which both values are considered “detections” as described in **Section 8.4**. **Table 8-3** is based on data pairs in which either or both values are considered “nondetections” (see **Section 8.4**).

Table 8-1. Quality assurance collocated sampling: Summary statistics for analytes with more than eight pairs in which both results were above the reporting limit.

Media	Analyte	N [(a)]	%RSD [(b)]	Slope	r^2 [(c)]	Intercept
Air	Gross alpha	12	27.8	0.803	0.86	1.77×10^{-5} Bq/m^3
Air	Gross beta	50	17.6	0.937	0.88	3.36×10^{-5} Bq/m^3
Air	Beryllium [(e)]	16	10.4	0.661	0.88	1.47 pg/m^3
Air	U235 by mass	10	8.21	1.11	0.98	-4.29×10^{-9} µg/m^3
Air	U238 by mass	10	9.75	1.1	0.97	-5.22×10^{-7} µg/m^3
Air	Tritium	43	26.9	0.991	0.87	0.0107 Bq/m^3
Direct radiation	90 day Rad dose	22	2.18	1.02	0.94	-0.345 mrem
Ground water	Gross alpha [(d)]	11	37.1	0.909	0.63	-0.00274 Bq/L
Ground water	Gross beta [(d)]	33	21.9	0.816	0.67	0.0531 Bq/L
Ground water	Arsenic	28	15.2	1.02	0.98	-0.000464 mg/L
Ground water	Barium	14	3.52	0.955	1	0.000895 mg/L
Ground water	Carbon tetrachloride [(e)]	44	12.6	0.55	0.29	3.02 µg/L
Ground water	Chloroform	76	8.2	0.935	0.93	0.563 µg/L
Ground water	1,1-Dichloroethane	21	8.16	0.992	1	0.0579 µg/L
Ground water	1,2-Dichloroethane	30	8.93	1	1	0.0244 µg/L
Ground water	1,1-Dichloroethene	71	13.3	1.06	0.99	-0.086 µg/L
Ground water	cis-1,2-Dichloroethene	50	10.6	0.887	1	3 µg/L

Media	Analyte	N [(a)]	%RSD [(b)]	Slope	r^2 [(c)]	Intercept
Ground water	1,2-Dichloroethene (total)	35	11.1	0.889	1	4.38 µg/L
Ground water	Freon 113	56	30	1.04	0.86	0.62 µg/L
Ground water	Nitrate (as NO3)	66	3.79	1	0.99	-0.41 mg/L
Ground water	Perchlorate	38	15.4	0.963	0.98	0.715 µg/L
Ground water	Tetrachloroethene	85	10.3	0.941	0.99	1.22 µg/L
Ground water	Trichloroethene	190	9.43	0.953	1	33.2 µg/L
Ground water	Trichlorofluoromethane	13	19.2	1.21	0.89	0.0909 µg/L
Ground water	Tritium	32	8.21	0.976	0.99	35.1 Bq/L
Ground water	Total Uranium	11	2.61	1	1	0.00248 Bq/L
Ground water	Total Uranium mass	11	1.4	1.01	1	0.193 µg/L
Ground water	U234	11	4.25	1.01	1	-0.00361 Bq/L
Ground water	U234+U233	27	14.6	0.955	0.99	0.0159 Bq/L
Ground water	U235	11	0.858	0.999	1	-1.13×10^{-5} Bq/L
Ground water	U235+U236	20	27.4	1.13	0.98	-0.00133 Bq/L
Ground water	U238	37	9.61	0.996	1	0.00323 Bq/L
Ground water	U238 by mass	11	1.64	1.01	1	0.0411 µg/L
Sewer	Gross beta [(d)]	12	10.5	0.796	0.61	0.000123 Bq/mL
Sewer	Tritium [(d)]	20	15.4	1.03	0.7	-0.000841 Bq/mL

(a) Number of collocated pairs included in regression analysis.

(b) 75th percentile of percent relative standard deviations (%RSD) where %RSD = $\left(\frac{200}{\sqrt{2}}\right)\frac{|x_1 - x_2|}{x_1 + x_2}$ and x_1 and x_2 are the reported concentrations of each routine–collocated pair.

(c) Coefficient of determination.

(d) Outside target range of slope or r^2 because of high variability.

(e) Outside target range of slope or r^2 because of outliers.

Table 8-2. Quality assurance collocated sampling: Summary statistics for selected analytes with eight or fewer pairs in which both results were above the reporting limit.

Media	Analyte	N [(a)]	Minimum ratio	Maximum ratio
Aqueous	Gross alpha	1	0.68	0.68
Aqueous	Gross beta	1	0.88	0.88
Aqueous	Uranium 234 and 233 (in activity)	1	1.1	1.1
Aqueous	Uranium 235 and 236 (in activity)	1	1	1
Aqueous	Uranium 238 (in activity)	1	1.3	1.3
Other water	Gross beta	1	2.4	2.4
Runoff (from rain)	Gross alpha	1	0.77	0.77
Runoff (from rain)	Gross beta	2	1	1.2
Runoff (from rain)	Tritium	2	1	1.1
Vegetation	Tritium	4	0.78	1.4
Wine	Tritium	2	0.9	0.92

(a) Number of collocated pairs used in ratio calculations.

Table 8-3. Quality assurance collocated sampling: Summary statistics for analytes with at least four pairs in which one or both results were below the reporting limit.

Media	Analyte	Number of inconsistent pairs (a)	Number of pairs	Percent of inconsistent pairs
Air	Tritium	2	8	25
Ground water	Gross alpha	1	24	4.2
Ground water	Carbon tetrachloride	1	308	0.32
Ground water	Chloroform	1	276	0.36
Ground water	Total Coliform	1	4	25
Ground water	1,2-Dichloroethane	1	322	0.31
Ground water	1,1-Dichloroethene	2	281	0.71
Ground water	Trichlorotrifluoroethane	2	296	0.68
Ground water	Manganese	1	6	17
Ground water	Tetrachloroethene	3	267	1.1
Ground water	Zinc	1	29	3.4
Sewer	Tritium	1	44	2.3

(a) Inconsistent pairs are those for which one of the results is more than twice the reporting limit of the other.

(b) Does not include count of pairs where both results were detections.

When there were more than eight data pairs with both results in each pair considered detections, precision and regression analyses were performed; those results are presented in **Table 8-1**. When there were eight or fewer data pairs with both results considered detections, the ratios of the individual data pairs for selected analytes were calculated; the minimum and maximum ratios are given in **Table 8-2.** When either of the results in a pair is considered a nondetection, then for consistency the other result should be also be a nondetection, or less than two times the reporting limit. **Table 8-3** identifies the sample media and analytes for which at least one pair failed this criterion. Media and analytes with fewer than four pairs are not included.

Precision is measured by the %RSD; see the EPA's *Data Quality Objectives for Remedial Response Activities: Development Process*, Section 4.6 (U.S. EPA 1987). Acceptable values for %RSD vary greatly with matrix, analyte, and analytical method; however, lower values represent better precision. The results for %RSD given in **Table 8-1** are the 75th percentile of the individual precision values. 95% of the pairs have %RSD of 35% or better.

Regression analysis consists of fitting a straight line to the collocated sample pairs. Good agreement is indicated when the data lie close to a line with a slope equal to 1 and an intercept equal to 0, as illustrated in **Figure 8-1.** Allowing for normal analytical and environmental variation, the slope of the fitted line should be between 0.7 and 1.3, and the absolute value of the intercept should be less than the detection limit. The coefficient of determination (r^2) should be greater than 0.8. These criteria apply to pairs in which both results are considered above the detection limit.

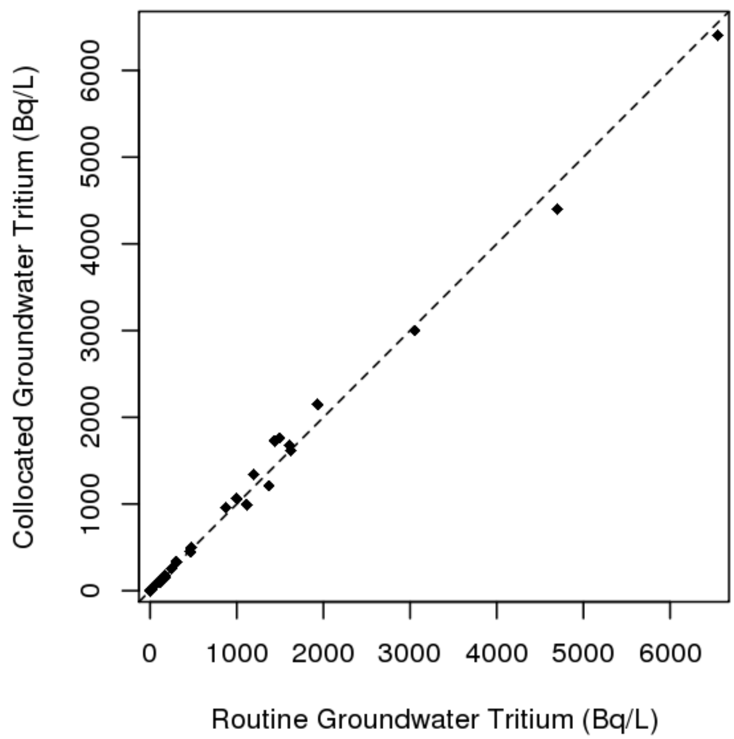

Figure 8-1. Example of good agreement between collocated sample results using groundwater tritium concentrations.

Collocated sample comparisons are more variable when the members of the pair are analyzed by different methods or with different criteria for analytical precision. For example, radiological analyses using different counting times or different laboratory aliquot sizes will have different amounts of variability. Different criteria are rarely, if ever, used with collocated sample pairs in LLNL environmental monitoring sampling. Different criteria are sometimes used in special studies if more than one agency is involved and each sets its own analytical criteria.

Data sets that do not meet LLNL regression analysis criteria fall into one of two categories: outliers and high variability. Outliers can occur because of data transcription errors, measurement errors, or real but anomalous results. Of the 35 data sets reported in **Table 8-1**, two did not meet the target for acceptability because of outliers. **Figure 8-2** illustrates a set of collocated pairs with one outlier.

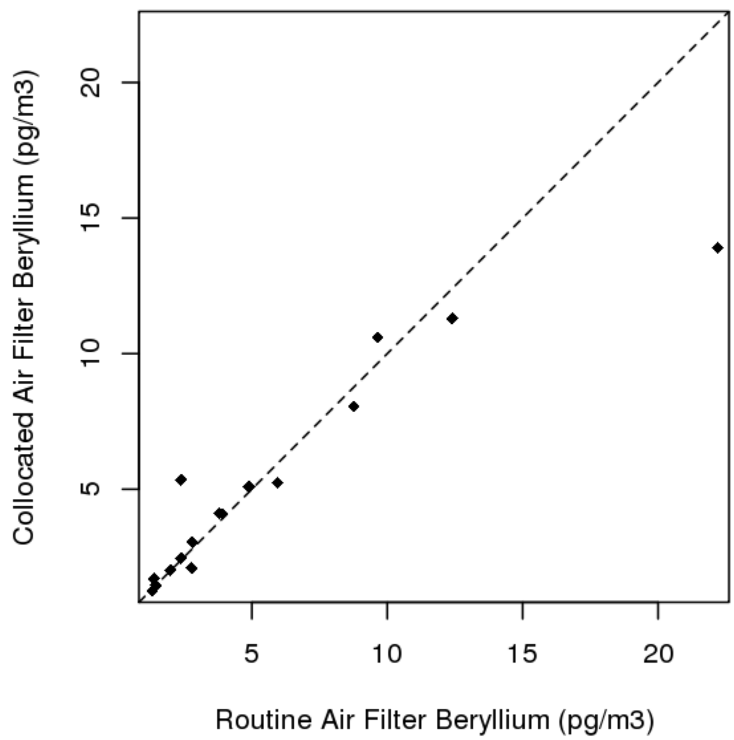

Figure 8-2. Example of data with one outlier using collocated air filter beryllium measurements.

The second category, high variability, occurs when the measurement process inherently has substantial variability (see **Figure 8-3** for an example). This tends to occur at extremely low environmental concentrations. Low concentrations of radionuclides on particulates in air highlight this effect because a small change in the number of radionuclide-containing particles on an air filter can significantly affect results. Analyses of total organic carbon and total organic halides in water are particularly difficult to control. Of the 35 data sets listed in **Table 8-1**, four show sufficient variability in the results to make them fall outside the target range.

8.4 Data Presentation

The data tables in **Appendix A** were created using computer scripts that retrieve data from a database, convert the data into Système International (SI) units when necessary, calculate summary statistics, format the data, organize the data into rows and columns, and present a draft table. The tables are then reviewed by the responsible analyst before inclusion in the Appendix. Analytical laboratory data and values calculated from the data are normally displayed with two, or at most three, significant digits. Significant trailing zeros may be omitted.

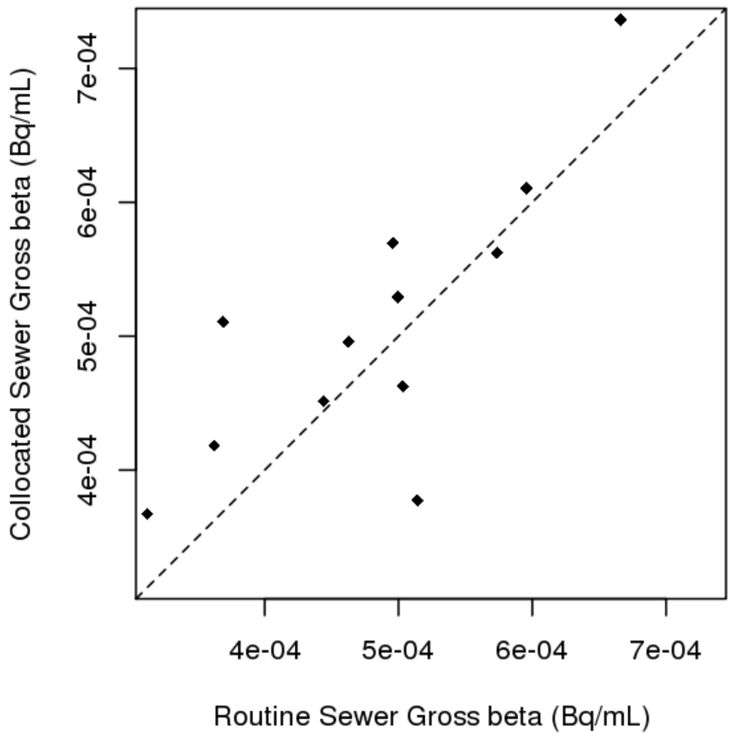

Figure 8-3. Example of high variability using collocated sewer effluent gross beta concentrations.

8.4.1 Radiological Data

Most of the data tables in **Appendix A** that have radiological data display the result plus or minus (±) an associated 2σ (two sigma) uncertainty. This measure of uncertainty represents intrinsic variation in the measurement process, most of which is due to the random nature of radioactive decay (see **Section 8.6**). The uncertainties are not used in summary statistic calculations. Any radiological result exhibiting a 2σ uncertainty greater than or equal to 100% of the result is considered a nondetection, whereas any radiological result exhibiting a 2σ uncertainty less than 100% of the result is considered a detection, whether above or below the analytical contract reporting limit.

Some radiological results are derived from the number of sample counts minus the number of background counts inside the measurement apparatus. In such cases, samples with a concentration at or near background sometimes have more background counts than sample counts, and thus a negative value. Such results are reported in the data tables and used in the calculation of summary statistics.

Some data tables provide a limit-of-sensitivity value instead of an uncertainty when the radiological result is below the detection criterion. Such results are displayed with the limit-of-sensitivity value in parentheses.

8.4.2 Nonradiological Data

Nonradiological data reported by the analytical laboratory as being below the analytical contract reporting limit is displayed in tables with a less-than symbol (<) and referred to as a "nondetection." Reporting limit values are used in the calculation of summary statistics, as explained below.

8.5 Statistical Comparisons and Summary Statistics

Standard statistical comparison techniques such as regression analysis, *t*-tests, and analysis of variance are used where appropriate to determine the statistical significance of trends or differences between means. When a statistical comparison is made, the results are described as either "statistically significant" or "not statistically significant." Other uses of the word "significant" in this report do not imply that statistical tests have been performed but relate to the concept of practical significance and are based on professional judgment.

Summary statistics are calculated according to Gallegos (2016). The usual summary statistics are the median, which is a measure of central tendency, and interquartile range (IQR), which is a measure of dispersion (variability). However, data tables may present other measures at the discretion of the analyst. In this report, at least four values are required to calculate the median and at least six values are required to calculate the IQR.

The median indicates the middle of the data set (i.e., half of the measured results are above the median, and half are below). The IQR is the range that encompasses the middle 50% of the data set. The IQR is calculated by subtracting the 25th percentile of the data set from the 75th percentile of the data set. When necessary, the percentiles are interpolated from the data. Different software vendors may use slightly different formulas for calculating percentiles. Radiological data sets that include values less than zero may have an IQR greater than the median.

Summary statistics are calculated from values that, if necessary, have already been rounded, such as when units have been converted from picocuries (pCi) to Becquerels (Bq), and are then rounded to an appropriate number of significant digits. The calculation of summary statistics may be affected by the presence of nondetections. A nondetection of the form "less than the reporting limit" indicates that a measured value is not available; instead, the best information available is that the actual value is less than the contract reporting limit. Adjustments to the calculation of the median and IQR for data sets that include such nondetections are described below.

For data sets with all measurements above the reporting limit and radiological data sets that include reported values below the reporting limit, all reported values, including any below the reporting limit, are included in the calculation of summary statistics.

For data sets that include one or more values reported as “less than the reporting limit,” the reporting limit is used as an upper bound value in the calculation of summary statistics.

If the number of values is odd, the middle value (when sorted from smallest to largest) is the median. If the middle value and all larger values are detections, the middle value is reported as the median. Otherwise, the median is assigned a less-than (<) sign.

If the number of values is even, the median is halfway between the middle two values (i.e., the middle two when the values are sorted from smallest to largest). If both of the middle two values and all larger values are detections, the median is reported. Otherwise, the median is assigned a less-than (<) sign.

If any value used to calculate the 25th percentile is a nondetection, or any value larger than the 25th percentile is a nondetection, the IQR cannot be calculated and is not reported.

The median and the IQR are not calculated for data sets with no detections.

8.6 Reporting Uncertainty in Data Tables

Measurement uncertainties associated with results from analytical laboratories are represented in two ways. The first of these, significant digits, derives from the resolution of the measuring device. For example, if an ordinary household ruler with a metric scale is used to measure the length of an object in centimeters, and the ruler has tick marks every one-tenth of a centimeter, the length can reliably and consistently be measured to the nearest tenth of a centimeter (i.e., to the nearest tick mark). An attempt to be more precise is not likely to yield reliable or reproducible results because it would require a visual estimate of a distance between tick marks. The appropriate way to report a measurement using this ruler would be, for example, 2.1 cm, which would indicate that the “true” length of the object is nearer to 2.1 cm than to 2.0 cm or 2.2 cm (i.e., between 2.05 and 2.15 cm). A measurement of 2.1 cm has two significant digits. Although not stated, the uncertainty is considered to be ± 0.05 cm. A more precise measuring device might be able to measure an object to the nearest one-hundredth of a centimeter; in that case a value such as “2.12 cm” might be reported. This value would have three significant digits and the implied uncertainty would be ± 0.005 cm. A result reported as “3.0 cm” has two significant digits. That is, the trailing zero is significant and implies that the true length is between 2.95 and 3.05 cm—closer to 3.0 than to 2.9 or 3.1 cm.

When performing calculations with measured values that have significant digits, all digits are used. The number of significant digits in the calculated result is the same as that of the measured value with the fewest number of significant digits.

Most unit conversion factors do not have significant digits. For example, the conversion from milligrams to micrograms requires multiplying by the fixed (constant) value of 1,000. The value 1,000 is exact; it has no uncertainty and therefore the concept of significant digits does not apply.

The second method of representing uncertainty is based on random variation. For radiological measurements, there is variation due to the random nature of radioactive decay. As a sample is measured, the number of radioactive decay events is counted and the reported result is calculated from the number of decay events that were observed. If the sample is recounted, the number of decay events will almost always be different because radioactive decay events occur randomly. Uncertainties of this type are reported as 2σ (two sigma) uncertainties. A ± 2σ uncertainty represents the range of results expected to occur approximately 95% of the time if a sample were to be recounted many times. A radiological result reported as, for example, "2.6 ± 1.2 Bq/g," would indicate that with approximately 95% confidence, the "true" value is in the range of 1.4 to 3.8 Bq/g (i.e., 2.6 – 1.2 = 1.4 and 2.6 + 1.2 = 3.8).

When necessary, radiological results are converted from pCi to Bq by multiplying by 0.037. This introduces additional digits that are not significant and should not be shown in data tables (for example, 5.3 pCi/g × 0.037 Bq/pCi = 0.1961 Bq/g). The initial value, 5.3, has two significant digits, so the value 0.1961 would be rounded to two significant digits, that is, 0.20. However, the rounding rule changes when there is a radiological uncertainty associated with a radiological result. In this case, data are presented according to the method recommended in Multi-Agency Radiological Laboratory Analytical Protocols (MARLAP) Section 19.3.7 (U.S. NRC/U.S. EPA 2004). First the uncertainty is rounded to the appropriate number of significant digits, after which the result is rounded to the same number of decimal places. For example, suppose a result and uncertainty after unit conversion are 0.1961 ± 0.05436, and the appropriate number of significant digits is two. First, 0.05436 is rounded to 0.054 (two significant digits) and 0.054 has three decimal places, so 0.1961 is then rounded to three decimal places, i.e., 0.196. These would be presented in the data tables as 0.196 ± 0.054.

When rounding a value with a final digit of "5," the software used to prepare the data tables implements the ISO/IEC/IEEE 60559:2011 rule, which is "go to the even digit." For example, 2.45 would be rounded down to 2.4, and 2.55 would be rounded up to 2.6.

The software that prepares the data tables pays careful attention to the details of rounding for significant digits. It should be noted, however, that these details are of little practical significance. For example, if a result of 5.6 is incorrectly rounded to 5.5 or 5.7, the introduced "error" is less than 2% (0.1/5.6 = 0.018). Such an error will rarely have any effect on the interpretation of the data with respect to human health or environmental impact.

A common activity in environmental monitoring is to compare measurements in an attempt to determine whether the objects being measured are "the same" or "different." For example, measurements of tritium concentration in each of two wine bottles could be compared; if they are not the same, there might be an indication of differences between the regions in which the grapes were grown. Comparisons between samples, particularly for radiological results, must take into account the uncertainty in the measurements of each sample. As mentioned above, the uncertainty interval indicates that the "true" value of the material being measured is not known exactly, but is probably somewhere within the interval. A comparison of measured values, not taking into account the uncertainty intervals, might suggest that the objects being measured are "different," but such a conclusion is not supported when the uncertainty intervals overlap.

8.7 Quality Assurance Process for the Environmental Report

Unlike the preceding sections, which focused on standards of accuracy and precision in data acquisition and reporting, this section describes the actions that are taken to ensure the accuracy of this data-rich environmental report, the preparation of which involves many operations and many people. The key elements that are used to ensure accuracy are described here.

Analytical laboratories send reports electronically, which are loaded directly into a database. This practice should result in perfect agreement between the database and data in printed reports from the laboratories. In practice, however, laboratory reporting is not perfect, so the EFA and ERD Data Management Teams (DMTs) carefully check incoming data throughout the year to make sure that electronic and printed reports from the laboratories agree. This aspect of QC is essential to the environmental report's accuracy. In addition, EFA and ERD technical staff review the analytical laboratories' internal QC results to make sure that analytical QA standards have been met, and to identify potential errors. When necessary, analytical laboratories are asked to review results or reanalyze samples. Results that do not meet QA standards may be flagged as suspect or rejected.

As described in **Section 8.4**, computer scripts are used to pull data from the database directly into the format of the table, including unit conversion and summary statistic calculations. All of the data tables contained in **Appendix A** were prepared in this manner. For these tables, it is the responsibility of the appropriate analyst to check each year that the table is up-to-date (e.g., new locations/analytes added, old ones removed), that the data agree with the data he or she has received from DMT, and that any summary calculations have been done correctly.

For this 2018 environmental report, LLNL staff checked tables and figures in the body of the report. Forms to aid in the QC of tables and figures were distributed along with the appropriate figure, table, and text, and a coordinator kept track of the process. Items that were checked included clarity and accuracy of figure captions and table titles; data accuracy and completeness; figure labels and table headings; units; significant digits; and consistency with text. Completed QC forms and the corrected figures or tables were returned to the report editor, who, in collaboration with the responsible author, ensured that corrections were made.

There are multiple levels of document review performed to ensure the accuracy and clarity of this report. Authors, scientific editors, and the DOE Livermore Field Office (LFO) all participate in multiple review cycles throughout document production.

8.8 Errata

Appendix E contains the protocol for errata in LLNL *Environmental Reports* and the errata for *LLNL Site Annual Environmental Report 2017*

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Acronyms and Glossary

Symbols and Units of Measure

ºC	degree centigrade
ºF	degree Fahrenheit
σ	sigma
aCi	attocurie (10^{-18} Ci)
µBq	microbecquerel (10^{-6} Bq)
µg/g	microgram per gram (10^{-6} g/g)
µg/L	microgram per liter (10^{-6} g/L)
µg/m^3	microgram per cubic meter (10^{-6} g/m^3)
µrem	microrem (10^{-6} rem)
µSv/y	microsievert per year
Bq	becquerel (*See also* definition in **Key Terms** section.)
Bq/g	becquerel per gram
Bq/kg	becquerel per kilogram
Bq/L	becquerel per liter
Bq/m^3	becquerel per cubic meter
Bq/mL	becquerel per milliliter
Ci	curie (*See also* definition in **Key Terms** section.)
cm	centimeter
ft	foot
g	gram
gal	gallon
gal/d	gallon per day
gal/min	gallon per minute
GBq	gigabecquerel (10^{9} Bq)
in.	inch
keV	kiloelectronvolt (10^{3} eV) (*See also* definition of "electronvolt" in **Key Terms** section.)
kg	kilogram (10^{3} g)
kg/d	kilogram per day (10^{3} g/d)
km	kilometer (10^{3} m)
L	liter
L/d	liter per day
L/y	liter per year
m	meter
mBq	millibecquerel (10^{-3} Bq)
mBq/g	millibecquerel per gram (10^{-3} Bq/g)
mBq/dry g	millibecquerel per dry gram (10^{-3} Bq/dry g)
mBq/m^3	millibecquerel per cubic meter (10^{-3} Bq/m^3)
mCi	millicurie (10^{-3} Ci)
mg/L	milligram/liter (10^{-3} g/L)
mi	mile
mph	mile per hour
mR	milliroentgen (10^{-3} R) (*See also* definition of "roentgen" in **Key Terms** section.)
mrem	millirem (10^{-3} rem) (*See also* definition of "rem" in **Key Terms** section.)
mrem/y	millirem per year (10^{-3} rem/y)
m/s	meter per second
mSv	millisievert (10^{-3} Sv)
mSv/y	millisievert per year (10^{-3} Sv/y)

MT	metric ton
nBq	nanobecquerel (10^{-9} Bq)
nSv	nanosievert (10^{-9} Sv)
nSv/y	nanosievert per year (10^{-9} Sv/y)
pCi	picocurie (10^{-12} Ci)
pCi/g	picocurie per gram (10^{-12} Ci/g)
pCi/dry g	picocurie per dry gram (10^{-12} Ci/dry g)
pCi/L	picocurie per liter (10^{-12} Ci/liter)
person-Sv	person-sievert (*See also* definition in **Key Terms** section.)
person-Sv/y	person-sievert/year
pg/L	picogram per liter (10^{-12} g/L)
pg/m^3	picogram per cubic meter (10^{-12} g/m^3)
Sv	sievert (*See also* definition in **Key Terms** section.)
TBq	terabecquerel (10^{12} Bq)

Acronyms and Abbreviations

%RSD	Percent relative standard deviation
ACCDA	Alameda County Community Development Agency
ACDEH	Alameda County Department of Environmental Health
ACHP	Advisory Council on Historic Preservation
ACOE	Army Corps of Engineers
AFV	alternative fuel vehicle
ALARA	as low as reasonably achievable
APHIS	Animal and Plant Health Inspection Service
ATSDR	Agency for Toxic Substances and Disease Registry
BAAQMD	Bay Area Air Quality Management District (*See also* definition in **Key Terms** section.)
BCG	Biota Concentration Guide
BGS	Below Ground Surface
BO	biological opinion
BSA	Blanket Service Agreement
BSL	Biosafety Level
BWXT	BWX Technologies
CAA	Clean Air Act
CalARP	California Accidental Release Prevention
CAMP	Corrective Action Monitoring Plan
CAMU	Corrective Action Management Unit
CARB	California Air Resources Board
CCR	California Code of Regulations
CDC	Centers for Disease Control
CDFW	California Department of Fish and Wildlife
CDPH	California Department of Public Health
CEI	Compliance Evaluation Inspection
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980 (*See also* definition in **Key Terms** section.)
CFF	Contained Firing Facility
CFR	Code of Federal Regulations
CNPS	California Native Plant Society
CO	carbon monoxide

COC	constituent of concern
COD	chemical oxygen demand
CSA	container storage area
CUPA	Certified Unified Program Agencies
CVRWQCB	Central Valley Regional Water Quality Control Board (*See also* definition in **Key Terms** section.)
CWA	(Federal) Clean Water Act
CWG	Community Working Group
DCS	Derived Concentration Technical Standard
DMP	Detection Monitoring Plan
DMT	Data Management Team
DOE	(U.S.) Department of Energy (*See also* definition in **Key Terms** section.)
DOECAP	(U.S.) Department of Energy Consolidated Auditing Program
DOT	(U.S.) Department of Transportation
DPR	(California) Department of Pesticide Regulation
DRB	Drainage Retention Basin
DTSC	(California Environmental Protection Agency) Department of Toxic Substances Control
DWTF	Decontamination and Waste Treatment Facility
E85	Vehicle fuel, 85% ethanol and 15% gasoline
EA	environmental assessment
EDE	effective dose equivalent (*See also* definition in **Key Terms** section.)
EDO	Environmental Duty Officer
EFA	Environmental Functional Area
EIS	environmental impact statement
ELAP	Environmental Laboratory Accreditation Program
EMP	Environmental Management Plan
EMS	Environmental Management System
EPA	Environmental Protection Agency (*See also* definition in **Key Terms** section.)
EPCRA	Emergency Planning and Community Right-to-Know Act of 1986 (*See also* definition in **Key Terms** section.)
EPEAT	Electronic Product Environmental Assessment Tool
EPL	effluent pollutant limit
EPP	Environmentally Preferable Purchasing
ERD	(LLNL) Environmental Restoration Department
ERP	Environmental Restoration Project
ES&H	Environment, Safety and Health
ESA	Endangered Species Act
ESAR	Enhanced Source Area Remediation
EWSF	Explosives Waste Storage Facility
EWTF	Explosives Waste Treatment Facility
FFA	Federal Facility Agreement (*See also* definition in **Key Terms** section.)
FFCA	Federal Facilities Compliance Act
FGC	Federal Green Challenge
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FY	fiscal year (*See also* definition in **Key Terms** section.)
GPS	global positioning system
GPs	Guiding principles
GSA	(U.S.) General Services Administration
GSF	Gross square feet
GWP	(Livermore Site) Ground Water Project
HABS/HAER	Historic American Building Survey/Historic American Engineering Report

HAP	hazardous air pollutant
HHRA	Human health risk assessment
HPGe	high-purity germanium
HSU	hydrostratigraphic unit
HT/TT	tritiated hydrogen gas
HTO/TTO	tritiated water or tritiated water vapor
HWCL	Hazardous Waste Control Law (*See also* definition in **Key Terms** section.)
ICRP	International Commission on Radiological Protection
IEEE	Institute of Electrical and Electronics Engineers
IGP	Industrial General Permit
ILA	industrial, landscaping, and agricultural
IQR	Interquartile range (*See also* definition in **Key Terms** section.)
ISMS	Integrated Safety Management System
ISO	International Organization for Standardization
ITS	Institutional Tracking System
JFLMA	Joint Functional Area Line Management Assessment
LEED	Leadership in Energy and Environmental Design
LEED-EB	Leadership in Energy and Environmental Design for Existing Buildings
LEPC	Local Emergency Planning Committee
LFO	Livermore Field Office
LFPD	Livermore Pleasanton Fire Department
LLNL	Lawrence Livermore National Laboratory
LLNS	Lawrence Livermore National Security, LLC
LLW	Low Level Waste
LWRP	Livermore Water Reclamation Plant
MAPEP	Mixed Analyte Performance Evaluation Program
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols
MCL	maximum contaminant level (*See also* definition in **Key Terms** section.)
MDC	minimum detectable concentration
MOIs	Management, Observation, and Inspections
MRP	Monitoring and Reporting Program
MSAs	Management Self Assessments
MWMA	Medical Waste Management Act
MWMP	Medical Waste Management Plan
NAI	sodium iodide
NAL	numeric action level
NCRP	National Council on Radiation Protection and Measurements
NELAP	National Environmental Laboratory Accreditation Program
NEPA	National Environmental Policy Act (*See also* definition in **Key Terms** section.)
NESHAPs	National Emissions Standards for Hazardous Air Pollutants
NHPA	National Historic Preservation Act
NIF	National Ignition Facility
NNSA	National Nuclear Security Administration
NOV	Notice of Violation
NOx	nitrous oxides
NPDES	National Pollutant Discharge Elimination System (*See also* definition in **Key Terms** section.)
NRHP	National Register of Historic Places
O&B	Operations & Business Principal Directorate
OBT	organically bound tritium
ODS	ozone depleting substance

ORNL	Oak Ridge National Laboratory
OU	Operable Unit
P2S	pollution prevention/sustainability
PA	Programmatic Agreement
PEP	Performance Evaluation Plan
PCB	polychlorinated biphenyl
PCE	perchloroethylene (or perchloroethene); also called tetrachloroethylene or tetrachloroethene
PM-10	particulate matter with diameter equal to or less than 10 micrometer
POCs	Precursor organic compounds (*See also* definition in **Key Terms** section.)
PPMRP	Pollution Prevention and Monitoring and Reporting Program
PQL	practical quantitation limit (*See also* definition in **Key Terms** section.)
PRAD	(LLNL) Permits and Regulatory Affairs Division
PUE	Power Utilization Effectiveness
PV	Photovoltaic
PVC	polyvinyl chloride
QA	quality assurance (*See also* definition in **Key Terms** section.)
QC	quality control (*See also* definition in **Key Terms** section.)
RCRA	Resource Conservation and Recovery Act of 1976 (*See also* definition in **Key Terms** section.)
REC	Renewable Energy Credit
REVAL	Remediation Evaluation Process
RHWM	(LLNL) Radioactive and Hazardous Waste Management Division
RMP	risk management plan
RL	reporting limit
RMP	risk management plan deleted in
ROD	Record of Decision
ROGs	reactive organic gases (*See also* definition in **Key Terms** section.)
RPM	Remedial Project Managers
RWQCB	Regional Water Quality Control Board (*See also* definition in **Key Terms** section.)
SARA	Superfund Amendment and Reauthorization Act of 1986 (*See also* definition in **Key Terms** section.)
SDS	Safety Data Sheet
SDWA	Safe Drinking Water Act
SERC	State Emergency Response Commission
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board (*See also* definition in **Key Terms** section.)
SFTF	Small Firearms Training Facility
SHPO	State Historic Preservation Officer
SI	Système International d'Unités (*See also* definition in **Key Terms** section.)
SJCEHD	San Joaquin County Environmental Health Department (*See also* definition in **Key Terms** section.)
SJCOES	San Joaquin County, Office of Emergency Services
SJVAPCD	San Joaquin Valley Air Pollution Control District (*See also* definition in **Key Terms** section.)
SMARTS	Storm Water Multiple Application and Report Tracking System
SMOP	Synthetic Minor Operating Permit
SMS	(LLNL) Sewer Monitoring Station
SOx	sulphur oxides
SPCC	Spill Prevention Control and Countermeasure
STP	Site Treatment Plan
SVOCs	semi-volatile organic compounds

SW-MEI	site-wide maximally exposed individual member (of the public) (*See also* definition in **Key Terms** section.)
SWPPP	Storm Water Pollution Prevention Plan
SWRCB	State Water Resources Control Board
TAG	Technical Assistance Grant
TCE	trichloroethene (or trichloroethylene)
TDS	Total Dissolved Solids
TEF	toxicity equivalency factor
TEQ	toxicity equivalency
TF	treatment facility
TLD	thermoluminescent dosimeter (*See also* definition in **Key Terms** section.)
TNI	The NELAC Institute
TRI	Toxics Release Inventory
Tri-Valley CAREs	Tri-Valley Communities Against a Radioactive Environment
TRU	transuranic (waste) (*See also* definition in **Key Terms** section.)
TSCA	Toxic Substances Control Act
TSDF	Treatment, Storage, and Disposal Facility
TSF	Terascale Simulation Facility
TSS	total suspended solids (*See also* definition in **Key Terms** section.)
TTO	total toxic organic (compounds)
UCD	under dispenser containment
USTs	underground storage tanks
USFWS	U.S. Fish and Wildlife Service
USGBC	U.S. Green Building Council
VOC	volatile organic compound (*See also* definition in **Key Terms** section.)
VTF	vapor treatment facility
WAA	waste accumulation area (*See also* definition in **Key Terms** section.)
WDAR	Waste Discharge Authorization Requirement
WDR	Waste Discharge Requirement
WRD	Water Resources Division (*See also* definition in **Key Terms** section.)

Metric and U.S. Customary Unit Equivalents

	From metric unit to U.S. customary equivalent unit		From U.S. customary unit to metric equivalent unit	
Category	**Metric**	**U.S.**	**U.S.**	**Metric**
Length	1 centimeter (cm)	0.39 inches (in.)	1 inch (in.)	2.54 centimeters (cm)
	1 millimeter (mm)	0.039 inches (in.)		25.4 millimeters (mm)
	1 meter (m)	3.28 feet (ft)	1 foot (ft)	0.3048 meters (m)
		1.09 yards (yd)	1 yard (yd)	0.9144 meters (m)
	1 kilometer (km)	0.62 miles (mi)	1 mile (mi)	1.6093 kilometers (km)
Volume	1 liter (L)	0.26 gallons (gal)	1 gallon (gal)	3.7853 liters (L)
		8.11×10^{-7} acre-feet	1 acre-foot	1.23×10^{6}liters (L)
	1 cubic meter (m^3)	35.32 cubic feet (ft^3)	1 cubic foot (ft^3)	0.028 cubic meters (m^3)
		1.35 cubic yards (yd^3)	1 cubic yard (yd^3)	0.765 cubic meters (m^3)
Weight	1 gram (g)	0.035 ounces (oz)	1 ounce (oz)	28.3 gram (g)
	1 kilogram (kg)	2.21 pounds (lb)	1 pound (lb)	0.454 kilograms (kg)
	1 metric ton (MT)	1.10 short ton (2000 pounds)	1 short ton (2000 pounds)	0.90718 metric ton (MT)
Area	1 hectare (ha)	2.47 acres	1 acre	0.40 hectares (ha)
Radioactivity	1 becquerel (Bq)	2.7×10^{-11} curie (Ci)	1 curie (Ci)	3.7×10^{10} becquerel (Bq)
Radiation dose	1 gray (Gy)	100 rad	1 rad	0.01 gray (Gy)
Radiation dose equivalent	1 sievert (Sv)	100 rem	1 rem	0.01 sievert (Sv)
Temperature	^{o}Fahrenheit = (^{o}Centigrade x 1.8) + 32		^{o}Centigrade = (^{o}Fahrenheit – 32) / 1.8	

Multiplying Prefixes

Symbol	Prefix	Factor	Symbol	Prefix	Factor
y	yocto	10^{-24}	da	deca	10^{1}
z	zepto	10^{-21}	h	hecto	10^{2}
a	atto	10^{-18}	k	kilo	10^{3}
f	femto	10^{-15}	M	mega	10^{6}
p	pico	10^{-12}	G	giga	10^{9}
n	nano	10^{-9}	T	tera	10^{12}
µ	micro	10^{-6}	P	peta	10^{15}
m	milli	10^{-3}	E	exa	10^{18}
c	centi	10^{-2}	Z	zetta	10^{21}
d	deci	10^{-1}	Y	yotta	10^{24}

Key Terms

Absorbed dose. Amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material, in which the absorbed dose is expressed in units of rad or gray (1 rad = 0.01 gray).

Accuracy. Closeness of the result of a measurement to the true value of the quantity measured.

Action level. Defined by regulatory agencies, the level of pollutants which, if exceeded, requires regulatory action.

Alluvium. Sediment deposited by flowing water.

Alpha particle. Positively charged particle emitted from the nucleus of an atom, having mass and charge equal to those of a helium nucleus (two protons and two neutrons).

Ambient air. Surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures; for monitoring purposes, it does not include air immediately adjacent to emission sources.

Analyte. Specific component measured in a chemical analysis.

Aquifer. Saturated layer of rock or soil below the ground surface that can supply usable quantities of groundwater to wells and springs, and be a source of water for domestic, agricultural, and industrial uses.

Bay Area Air Quality Management District (BAAQMD). Local agency responsible for regulating stationary air emission sources (including the LLNL Livermore Site) in the San Francisco Bay Area.

Becquerel (Bq). SI unit of activity of a radionuclide, equal to the activity of a radionuclide having one spontaneous nuclear transition per second.

Beta particle. Negatively charged particle emitted from the nucleus of an atom, having charge, mass, and other properties of an electron.

Categorical discharge. Discharge from a process regulated by EPA rules for specific industrial categories.

Central Valley Regional Water Quality Control Board (CVRWQCB). Local agency responsible for regulating ground and surface water quality in the Central Valley.

Comingled recycling. Single-stream (also known as “fully **commingled**” or “single-sort”) **recycling** refers to a system in which all paper fibers, plastics, metals, and other containers are mixed in a collection truck, instead of being sorted by the depositor into separate commodities.

Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). Administered by EPA, this federal law**,** also known as Superfund, requires private parties to notify the EPA of conditions that threaten to release hazardous substances or after the release of hazardous substances, and undertake short-term removal and long-term remediation.

Cosmic radiation. Radiation with very high energies originating outside the earth’s atmosphere; it is one source contributing to natural background radiation.

Curie (Ci). Unit of measurement of radioactivity, defined as the amount of radioactive material in which the decay rate is 3.7×10^{10} disintegrations per second or 2.22×10^{12} disintegrations per minute; one Ci is approximately equal to the decay rate of 1 gram of pure radium.

Depleted uranium. Uranium having a lower proportion of the isotope uranium-235 than is found in naturally occurring uranium. The masses of the three uranium isotopes with atomic weights 238, 235, and 234 occur in depleted uranium in the weight-percentages 99.8, 0.2, and 5×10^{-4}, respectively. Depleted uranium is sometimes referred to as D-38 or DU.

Derived concentration technical standard (DCS). Concentrations of radionuclides in water and air that could be continuously consumed or inhaled for one year and not exceed the DOE primary radiation standard to the public (100 mrem/y EDE).

Dose. Energy imparted to matter by ionizing radiation; the unit of absorbed dose is the rad, equal to 0.01 joules per kilogram for irradiated material in any medium.

Dose equivalent. Product of absorbed dose in rad (or gray) in tissue and a quality factor representing the relative damage caused to living tissue by different kinds of radiation, and perhaps other modifying factors representing the distribution of radiation, etc. expressed in units of rem or sievert (1 rem = 0.01 sievert).

Dosimeter. Portable detection device for measuring the total accumulated exposure to ionizing radiation.

Downgradient. In the direction of groundwater flow from a designated area; analogous to downstream.

Effective dose equivalent (EDE). Estimate of the total risk of potential effects from radiation exposure, it is the summation of the products of the dose equivalent and weighting factor for each tissue. The weighting factor is the decimal fraction of the risk arising from irradiation of a selected tissue to the total risk when the whole body is irradiated uniformly to the same dose equivalent. These factors permit dose equivalents from nonuniform exposure of the body to be expressed in terms of an effective dose equivalent that is numerically equal to the dose from a uniform exposure of the whole body that entails the same risk as the internal exposure (ICRP 1980). The effective dose equivalent includes the committed effective dose equivalent from internal deposition of radionuclides and the effective dose equivalent caused by penetrating radiation from sources external to the body, and is expressed in units of rem (or sievert).

Effluent. Liquid or gaseous waste discharged to the environment.

Electronvolt (eV). A unit of energy equal to the amount of kinetic energy gained by an electron when it passes through a potential difference of 1 volt in a vacuum.

Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA). Act that requires facilities that produce, use, or store hazardous substances to report releases of reportable quantities or hazardous substances to the environment.

Environmental impact statement (EIS). Detailed report, required by the National Environmental Policy Act, on the environmental impacts from a federally approved or funded project. An EIS must be prepared by a federal agency when a “major” federal action that will have “significant” environmental impacts is planned.

Federal facility. Facility that is owned or operated by the federal government, subject to the same requirements as other responsible parties when placed on the Superfund National Priorities List.

Federal facility agreement (FFA). Negotiated agreement that specifies required actions at a federal facility as agreed upon by various agencies (e.g., EPA, RWQCB, DOE).

Fiscal year (FY). LLNL’s fiscal year is from October 1 through September 30.

Freon-11. Trichlorofluoromethane.

Freon-113. 1,1,2-trichloro-1,2,2-trifluoroethane; also known as CFC 113.

Gamma ray. High-energy, short-wavelength, electromagnetic radiation emitted from the nucleus of an atom, frequently accompanying the emission of alpha or beta particles.

Groundwater. All subsurface water.

Groundwater dual extraction well: Extraction of groundwater using a downhole pump with concurrent application of vacuum to the well. Groundwater and soil vapor are removed in separate pipe manifolds and treated.

Hazardous waste. Waste that exhibits ignitability, corrosivity, reactivity, and/or EP-toxicity (yielding toxic constituents in a leaching test), and waste that does not exhibit these characteristics but has been determined to be hazardous by EPA. Although the legal definition of hazardous waste is complex, according to EPA the term generally refers to any waste that, if managed improperly, could pose a threat to human health and the environment.

(California) Hazardous Waste Control Law (HWCL). Legislation specifying requirements for hazardous waste management in California.

Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX). High-explosive compound.

Inorganic compounds. Compounds that either do not contain carbon or do not contain hydrogen along with carbon, including metals, salts, and various carbon oxides (e.g., carbon monoxide and carbon dioxide).

International Commission on Radiological Protection (ICRP). International organization that studies radiation, including its measurement and effects.

Interquartile range (IQR). Distance between the top of the lower quartile and the bottom of the upper quartile, which provides a measure of the spread of data.

Isotopes. Forms of an element having the same number of protons in their nuclei, but differing numbers of neutrons.

Lake Haussmann. Man-made, lined pond used to capture storm water runoff and treated water at the Livermore site. Formerly called Drainage Retention Basin (DRB).

Less than detection limits. Phrase indicating that a chemical constituent was either not present in a sample, or is present in such a small concentration that it cannot be measured by a laboratory's analytical procedure, and therefore is not identified or not quantified at the lowest level of sensitivity.

Livermore Water Reclamation Plant (LWRP). City of Livermore's municipal wastewater treatment plant, which accepts discharges from the LLNL Livermore site.

Low-level waste. Waste defined by DOE Order 5820.2A, which contains transuranic nuclide concentrations less than 100 nCi/g.

Maximum contaminant level (MCL). Highest level of a contaminant in drinking water that is allowed by the U.S. Environmental Protection Agency or California Department of Health Services.

Metric units. Except for temperature for which specific equations apply, U.S. customary units can be determined from metric units by multiplying the metric units by the U.S. customary equivalent. Similarly, metric units can be determined from U.S. customary equivalent units by multiplying the U.S. customary units by the metric equivalent. (*See also* **Metric and U.S. Customary Unit Equivalents** table in this Glossary.)

Mixed waste. Waste that has the properties of both hazardous and radioactive waste.

National Environmental Policy Act (NEPA). Federal legislation enacted in 1969 that requires all federal agencies to document and consider environmental impacts for federally funded or approved projects and the legislation under which DOE is responsible for NEPA compliance at LLNL.

National Pollutant Discharge Elimination System (NPDES). Federal regulation under the Clean Water Act that requires permits for discharges into surface waterways.

Nuclear Regulatory Commission (NRC). Federal agency charged with oversight of nuclear power and nuclear machinery and applications not regulated by DOE or the Department of Defense.

Nuclide. Species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons, number of neutrons, and energy content; or, alternatively, by the atomic number, mass number, and atomic mass. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable length of time.

Part A permit. Application submitted by generators in the RCRA permitting process.

Part B permit. Second, narrative section submitted by generators in the RCRA permitting process that covers in detail the procedures followed at a facility to protect human health and the environment.

Perched aquifer. Aquifer that is separated from another water-bearing stratum by an impermeable layer.

Person-Sievert (person-Sv). The product of the average dose per person times the number of people exposed. 1 person-Sv = 100 person-rem.

pH. Measure of hydrogen ion concentration in an aqueous solution. The pH scale ranges from 0 to 14. Acidic solutions have a pH less than 7; basic solutions have a pH greater than 7; and neutral solutions have a pH of 7.

Pliocene. Geological epoch of the Tertiary period, starting about 12 million years ago.

PM-10. Fine particulate matter with an aerodynamic diameter equal to or less than 10 micrometers.

Point source. Any confined and discrete conveyance (e.g., pipe, ditch, well, stack).

Practical quantitation limit (PQL). Level at which the laboratory can report a value with reasonably low uncertainty (typically 10–20% uncertainty).

Pretreatment. Any process used to reduce a pollutant load before it enters the sewer system.

Quality assurance (QA). System of activities whose purpose is to provide the assurance that standards of quality are attained with a stated level of confidence.

Quality control (QC). Procedures used to verify that prescribed standards of performance are attained.

Quaternary. Geologic era encompassing the last 2 to 3 million years.

Rad. Unit of absorbed dose and the quantity of energy imparted by ionizing radiation to a unit mass of matter such as tissue, and equal to 0.01 joule per kilogram, or 0.01 gray.

Radioactive decay. Spontaneous transformation of one radionuclide into a different nuclide (which may or may not be radioactive), or de-excitation to a lower energy state of the nucleus by emission of nuclear radiation, primarily alpha or beta particles, or gamma rays (photons).

Radioactivity. Spontaneous emission of nuclear radiation, generally alpha or beta particles, or gamma rays, from the nucleus of an unstable isotope.

Radionuclide. Unstable nuclide. See also **nuclide** and **radioactivity**.

Reactive organic gases/precursor organic compounds (ROGs/POCs). Classes of chemicals that are precursors to the production of ozone and the photochemical formation of smog.

Regional Water Quality Control Board (RWQCB). California regional agency responsible for water quality standards and the enforcement of state water quality laws within its jurisdiction. California is divided into nine RWQCBs; the Livermore site is in the San Francisco Bay Region, and Site 300 is in the Central Valley Region.

Rem. Unit of radiation dose equivalent and effective dose equivalent describing the effectiveness of a type of radiation to produce biological effects; coined from the phrase “roentgen equivalent man,” and the product of the absorbed dose (rad), a quality factor (Q), a distribution factor, and other necessary modifying factors. 1 rem = 0.01 sievert.

Resource Conservation and Recovery Act of 1976 (RCRA). Program of federal laws and regulations that govern the management of hazardous wastes, and applicable to all entities that manage hazardous wastes.

Risk assessment. Qualitative and quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence and/or use of specific pollutants.

Roentgen (R). Unit of measurement used to express radiation exposure in terms of the amount of ionization produced in a volume of air.

San Francisco Bay Regional Water Quality Control Board (SFBRWQCB). Local agency responsible for regulating ground and surface water quality in the San Francisco Bay Area.

San Joaquin County Environmental Health Department (SJCEHD). Local agency that enforces underground-tank regulations in San Joaquin County, including Site 300.

San Joaquin Valley Air Pollution Control District (SJVAPCD). Local agency responsible for regulating stationary air emission sources (including Site 300) in San Joaquin County.

Sanitary waste. Most simply, waste generated by routine operations that is not regulated as hazardous or radioactive by state or federal agencies.

Saturated zone. Subsurface zone below which all rock pore-space is filled with water; also called the phreatic zone.

Sensitivity. Capability of methodology or instrumentation to discriminate between samples having differing concentrations or containing varying amounts of analyte.

Sievert (Sv). SI unit of radiation dose equivalent and effective dose equivalent, that is the product of the absorbed dose (gray), quality factor (Q), distribution factor, and other necessary modifying factors. 1 sievert = 100 rem.

Sigma (σ) denotes the standard deviation of a statistical distribution.

Site-wide maximally exposed individual (SW-MEI). Hypothetical person who receives, at the location of a given publicly accessible facility (such as a church, school, business, or residence), the greatest LLNL-induced effective dose equivalent (summed over all pathways) from all sources of radionuclide releases to air at a site. Doses at this receptor location caused by each emission source are summed, and yield a larger value than for the location of any other similar public facility. This individual is assumed to continuously reside at this location 24 hours per day, 365 days per year.

Specific conductance. Measure of the ability of a material to conduct electricity; also called conductivity.

Superfund. Common name used for the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). California has also established a “State Superfund” under provisions of the California Hazardous Waste Control Act.

Superfund Amendments and Reauthorization Act (SARA). Enacted in 1986, these laws amended and reauthorized CERCLA for five years.

Surface impoundment. A facility or part of a facility that is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials, although it may be lined with man-made materials. The impoundment is designed to hold an accumulation of liquid wastes, or wastes containing free liquids, and is not an injection well.

Système International d'Unités (SI). International system of physical units which include meter (length), kilogram (mass), kelvin (temperature), becquerel (radioactivity), gray (radioactive dose), and sievert (dose equivalent).

Thermoluminescent dosimeter (TLD). Device used to measure external beta or gamma radiation levels, and which contains a material that, after exposure to beta or gamma radiation, emits light when processed and heated.

Total dissolved solids (TDS). Portion of solid material in a waste stream that is dissolved and passed through a filter.

Total suspended solids (TSS). Total mass of particulate matter per unit volume suspended in water and wastewater discharges that is large enough to be collected by a 0.45-micron filter.

Tritium. Radioactive isotope of hydrogen, containing one proton and two neutrons in its nucleus, which decays at a half-life of 12.3 years by emitting a low-energy beta particle.

Transuranic waste (TRU). Material contaminated with alpha-emitting transuranium nuclides, which have an atomic number greater than 92 (e.g., plutonium-239), half-lives longer than 20 years, and are present in concentrations greater than 100 nCi/g of waste.

Universal waste. Hazardous waste that is widely produced by households and many different types of businesses. Universal waste includes televisions, computers and other electronic devices as well as batteries, fluorescent lamps, mercury thermostats, and other mercury-containing equipment. California's Universal Waste Rule allows individuals and businesses to transport, handle, and recycle universal waste in a manner that differs from the requirements for most hazardous wastes.

Unsaturated zone. Portion of the subsurface in which the pores are only partially filled with water and the direction of water flow is vertical; is also referred to as the vadose zone.

U.S. Department of Energy (DOE). Federal agency responsible for conducting energy research and regulating nuclear materials used for weapons production.

U.S. Environmental Protection Agency (EPA). Federal agency responsible for enforcing federal environmental laws. Although some of this responsibility may be delegated to state and local regulatory agencies, EPA retains oversight authority to ensure protection of human health and the environment.

Vadose zone. Partially saturated or unsaturated region above the water table that does not yield water to wells.

Volatile organic compound (VOC). Liquid or solid organic compounds that have a high vapor pressure at normal pressures and temperatures and thus tend to spontaneously pass into the vapor state.

Waste accumulation area (WAA). Officially designated area that meets current environmental standards and guidelines for temporary (less than 90 days) storage of hazardous waste before pickup by the Radioactive and Hazardous Waste Management Division for off-site disposal.

Wastewater treatment system. Collection of treatment processes and facilities designed and built to reduce the amount of suspended solids, bacteria, oxygen-demanding materials, and chemical constituents in wastewater.

Water Resources Division: The City of Livermore governmental organization dedicated to meeting Livermore's water, wastewater, and storm water utility needs.

Water table. Water-level surface below the ground at which the unsaturated zone ends and the saturated zone begins, and the level to which a well that is screened in the unconfined aquifer would fill with water.

Weighting factor. Tissue-specific value used to calculate dose equivalents which represents the fraction of the total health risk resulting from uniform, whole-body irradiation that could be contributed to that particular tissue.

Zone 7. Common name for the Alameda County Flood Control and Water Conservation District, Zone 7, which is the water agency for the Livermore–Amador Valley with responsibility for regional flood control and drinking water supply.

APPENDIX A
Data Tables

The data tables listed in this appendix are accessible at https://saer.llnl.gov/, the website for the LLNL annual environmental report.

A.1 Air Effluent (Chapter 4)

A.1.1 Summary of gross alpha and gross beta (µBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 235, 2018

A.1.2 Summary of tritium in air effluent samples (Bq/m^3) from the monitored emission points at Livermore Site, Building 331, 2018

A.1.3 Summary of gross alpha and gross beta (µBq/m^3) in air effluent samples from the monitored emission points at Livermore Site, Building 332, 2018

A.1.4 Summary of gross alpha and gross beta (uBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 581, 2018

A.1.5 Summary of representative gamma suite for radioactive particulate (uBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 581, 2018

A.1.6 Summary of tritium in air effluent samples (Bq/m^3) from the monitored emission point at Livermore, Building 581, 2018

A.1.7 Summary of tritium exchange on particulate filter (Bq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 581, 2018

A.1.8 Summary of Iodine-131 (uBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 581, 2018

A.1.9 Summary of gross alpha and gross beta (µBq/m^3) in air effluent samples from the monitored emission point at Livermore Site, Building 695, 2018

A.1.10 Summary of gross alpha and gross beta (µBq/m^3) in air effluent samples from the monitored emission point at Site 300, Building 801, 2018

A.2 Ambient Air (Chapter 4)

A.2.1(a) Bi-weekly gross alpha concentrations (µBq/m^3) from air particulate samples from the Livermore perimeter locations, 2018

A.2.1(b) Bi-weekly gross beta concentrations (µBq/m^3) from air particulate samples from the Livermore perimeter locations, 2018

A.2.2 Tritium concentrations (mBq/m^3) in air on the Livermore Site, 2018

A.2.3 Beryllium concentration (pg/m^3) in air particulate samples at the Livermore Site and Site 300, 2018

A.2.4 Plutonium-239+240 concentrations (nBq/m^3) in air particulate samples from the Livermore perimeter and Site 300 perimeter composite, 2018

A.2.5 Uranium mass concentrations (pg/m^3) and atom ratios in air particulate samples from Livermore Site (composite) and Site 300 onsite and offsite locations, 2018

A.2.6(a) Bi-weekly gross alpha concentrations (µBq/m^3) from air particulate samples from the Livermore Valley downwind locations, 2018

A.2.6(b) Bi-weekly gross beta concentrations (µBq/m^3) from air particulate samples from the Livermore Valley downwind locations, 2018

A.2.7 Tritium concentrations (mBq/m^3) in air, Livermore Valley, 2018

A.6 Site 300 Groundwater (Chapter 5)

A.7 Other Water (Chapter 5)

A.8 Soil (Chapter 6)

A.9 Ambient Radiation (Chapter 6)

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APPENDIX B
EPA Methods of Environmental Water Analysis

Table B-1. Inorganic constituents of concern in water samples, the analytical methods used to determine their concentrations, and their contractual reporting limits.

Constituent of concern		Analytical method	Reporting limit [(a,b)]
Metals and minerals (mg/L)	All alkalinities	SM 2320B or E310.1	1
	Aluminum	EPA 200.7 or 200.8	0.05 or 0.2
	Ammonia nitrogen (as N)	EPA 350.1 or SM 4500-NH3 D	0.03 or 0.1
	Antimony	EPA 200.7 or 200.8	0.1, 0.5 or 0.005
	Arsenic	EPA 200.7 or 200.8	0.05 or 0.002
	Barium	EPA 200.7 or 200.8	0.025 or 0.01
	Beryllium	EPA 200.7, 200.8 or 6010B	0.0005 or 0.0002
	Boron	EPA 200.7 or 6010B	0.05
	Bromide	EPA 300.0	0.5
	Cadmium	EPA 200.7 or 200.8	0.0005
	Calcium	EPA 200.7	0.5
	Chloride	EPA 300.0	0.5
	Chromium	EPA 200.7 or 200.8	0.01 or 0.001
	Chromium(VI)	EPA 218.6 or 7196	0.001 or 0.002
	Cobalt	EPA 200.7, 200.8 or 6010B	0.025, 0.05 or 0.5
	Copper	EPA 200.7, 200.8 or 6010B	0.001, 0.01 or 0.05
	Cyanide	EPA 335.4 or 4500-CN	0.02 or 0.003
	Diesel	8015DRO	50
	Fluoride	EPA 300.0	0.05
	Gas	EPA-8015B	50
	Hardness, total (as $CaCO_3$)	SM 2320B, Calc	1
	Iron	EPA 200.7 or 200.8	0.1
	Lead	EPA 200.7 or 200.8	0.002 or 0.005
	Magnesium	EPA 200.7 or 200.8	0.002 or 0.5
	Manganese	EPA 200.7 or 200.8	0.01 or 0.03
	Mercury	EPA 245.2 or 245.1	0.0002
	Molybdenum	EPA 200.7 or 200.8	0.025
	Nickel	EPA 200.7 or 200.8	0.002, 0.005 or 0.1
	Nitrate (as NO_3)	EPA 353.2, 300.0 or SM 4500-NO3	0.3 or 0.5
	Nitrite (as NO_2)	EPA 353.2, 300.0 or SM 4500-NO2	0.3 or 0.5
	Salinity	SM2520B	2
	Ortho-phosphate	EPA 300.0, SM 4500-P E or E365.1	0.05
	Perchlorate	EPA 314.0	4
	Potassium	EPA 200.7 or 200.8	1 or 0.5
	Selenium	EPA 200.7, 200.8 or 6010B	0.05 or 0.002
	Silver	EPA 200.7 or 200.8	0.01, 0.001 or 0.0005
	Sodium	EPA 200.7	1 or 0.1
	Sulfate	EPA 300.0	1
	Surfactants	SM 5540C or EPA 425.1	0.5
	Thallium	EPA 200.7 or 200.8	0.1 or 0.001

B. EPA Methods of Environmental Water Analysis

Table B-1. Inorganic constituents of concern in water samples, the analytical methods used to determine their concentrations, and their contractual reporting limits.

Constituent of concern		Analytical method	Reporting limit [a,b]
	Total dissolved solids	EPA 160.1 or SM 2540C	1
	Total suspended solids	EPA 160.2 or SM 2540D	1
	Vanadium	EPA 200.7 or 200.8	0.01, 0.02
	Zinc	EPA 200.7 or 200.8	0.02 or 0.05
General indicator parameters	pH (pH units)	EPA 150.1 or SM 4500HB	1
	Biochemical oxygen demand (mg/L)	SM 5210B	2
	Conductivity (umhos/cm)	EPA 120.1 or SM2510B	none
	Chemical oxygen demand (mg/L)	EPA 410.4 or SM5220D	5 or 20
	Dissolved oxygen (mg/L)	EPA 360.1 or SM 4500-O G	0.05
	Total organic carbon (mg/L)	EPA 9060 or SM 5310C	1
Radioactivity (Bq/L)	Gross alpha	EPA 900	0.074
	Gross beta	EPA 900	0.11
Radioisotopes (Bq/L)	Tritium	EPA 906	3.7
	Plutonium 239/240	EM-P558	0.00037

(a) The number of decimal places displayed in this table vary by constituent. These variations reflect regulatory agency permit stipulations, or the applicable analytical laboratory contract under which the work was performed, or both.

(b) These reporting limits are for water samples with low concentrations of dissolved solids. If higher concentrations are present, limits are likely to be higher.

Table B-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical methods.

Constituent of concern	Reporting limit (µg/L) [(a,b)]
EPA Method 1664	
Oil & Grease	5000
EPA Method 547	
Glyphosate	20
EPA Method 608	
Aldrin	0.05
BHC, alpha isomer	0.05
BHC, beta isomer	0.05
BHC, delta isomer	0.05
BHC, gamma isomer (Lindane)	0.05
Chlordane	0.2
Dieldrin	0.1
Endosulfan I	0.05
Endosulfan II	0.1
Endosulfan sulfate	0.1
Endrin	0.1
Endrin aldehyde	0.1
Heptachlor	0.05
Heptachlor epoxide	0.05
Methoxychlor	0.5
4,4’-DDD	0.1
4,4’-DDE	0.1
4,4’-DDT	0.1
Toxaphene	1
PCB 1016	0.2
PCB 1221	0.2
PCB 1232	0.2
PCB 1242	0.2
PCB 1248	0.2
PCB 1254	0.2
PCB 1260	0.2
EPA Method 624	
1,1,1-Trichloroethane	1
1,1,2,2-Tetrachloroethane	1
1,1,2-Trichloroethane	1
1,1-Dichloroethane	1
1,1-Dichloroethene	1
1,2-Dichlorobenzene	1
1,2-Dichloroethane	1
1,2-Dichloroethene (total)	1
1,2-Dichloropropane	1
1,3-Dichlorobenzene	1
1,4-Dichlorobenzene	1

Constituent of concern	Reporting limit (µg/L) [(a,b)]
2-Butanone	20
2-Chloroethylvinylether	20
2-Hexanone	20
4-Methyl-2-pentanone	20
Acetone	10
Acrolein	5
Acroylonitrile	5
Benzene	1
Bromodichloromethane	1
Bromoform	1
Bromomethane	2
Carbon disulfide	1
Carbon tetrachloride	1
Chlorobenzene	1
Chloroethane	2
Chloroform	1
Chloromethane	2
cis-1,2-Dichloroethene	1
cis-1,3-Dichloropropene	1
Dibromochloromethane	1
Dibromomethane	1
Dichlorodifluoromethane	2
Ethylbenzene	1
Freon 113	1
Methylene chloride	1
Styrene	1
Tetrachloroethene	1
Toluene	1
Total xylene isomers	2
trans-1,2-Dichloroethene	1
trans-1,3-Dichloropropene	1
Trichloroethene	0.5
Trichlorofluoromethane	1
Vinyl acetate	1
Vinyl chloride	1
EPA Method 625	
1,2,4-Trichlorobenzene	5
1,2-Dichlorobenzene	5
1,3-Dichlorobenzene	5
1,4-Dichlorobenzene	5
2-Butanone	20
2-Chloroethylvinylether	20
2-Hexanone	20

Table B-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical methods.

Constituent of concern	Reporting limit (μg/L) [(a,b)]
EPA Method 625 (cont.)	
4-Methyl-2-pentanone	20
Acetone	10
Acrolein	5
Acroylonitrile	5
Benzene	1
Bromodichloromethane	1
Bromoform	1
Bromomethane	2
Carbon disulfide	1
Carbon tetrachloride	1
Chlorobenzene	1
Chloroethane	2
Chloroform	1
Chloromethane	2
cis-1,2-Dichloroethene	1
cis-1,3-Dichloropropene	1
Dibromochloromethane	1
Dibromomethane	1
Dichlorodifluoromethane	2
Ethylbenzene	1
Freon 113	1
Methylene chloride	1
Styrene	1
Tetrachloroethene	1
Toluene	1
Total xylene isomers	2
trans-1,2-Dichloroethene	1
trans-1,3-Dichloropropene	1
Trichloroethene	0.5
Trichlorofluoromethane	1
Vinyl acetate	1
Vinyl chloride	1
EPA Method 625	
1,2,4-Trichlorobenzene	5
1,2-Dichlorobenzene	5
1,3-Dichlorobenzene	5
1,4-Dichlorobenzene	5
2,4,5-Trichlorophenol	5
2,4,6-Trichlorophenol	5
2,4-Dichlorophenol	25
2,4-Dimethylphenol	5

Constituent of concern	Reporting limit (μg/L) [(a,b)]
2,4-Dinitrotoluene	5
2,6-Dinitrotoluene	5
2-Chloronaphthalene	5
2-Chlorophenol	5
2-Methylphenol	5
2-Methyl-4,6-dinitrophenol	25
2-Methylnaphthalene	5
2-Nitroaniline	25
3,3'-Dichlorobenzidine	10
3-Nitroaniline	25
4-Bromophenylphenylether	5
4-Chloro-3-methylphenol	10
4-Chloroaniline	10
4-Chlorophenylphenylether	5
4-Nitroaniline	25
4-Nitrophenol	25
Acenaphthene	25
Acenaphthylene	5
Benzo[a]a nthracene	5
Benzo[a]p yrene	5
Benzo[b]f luoranthene	5
Benzo[g,h,i]p erylene	5
Benzo[k]fluoranthene	5
Benzoic acid	25
Benzyl alcohol	10
Bis(2-chloroethoxy)methane	5
Bis(2-chloroisopropyl)ether	5
Bis(2-ethylhexyl)phthalate	5
Butylbenzylphthalate	5
Chrysene	5
Di-n-butylphthalate	5
Di-n-octylphthalate	5
Dibenzo[a,h]a nthracene	5
Dibenzofuran	5
Diethylphthalate	5
Dimethylphthalate	5
Fluoranthene	5
Hexachlorobenzene	5
Hexachlorobutadiene	5
Hexachlorocyclopentadiene	5
Hexachloroethane	5
Indeno[1,2,3-c,d]p yrene	5

Table B-2. Organic constituents of concern in water samples and their contractual reporting limits of concentration, sorted by analytical methods.

Constituent of concern	Reporting limit (µg/L) [(a,b)]
EPA Method 625 (cont.)	
Isophorone	5
m- and p-Cresol	5
N-Nitroso-di-n-propylamine	5
o-Dichlorobenzene	5
Naphthalene	5
Nitrobenzene	5
Pentachlorophenol	5
Phenanthrene	5
Phenol	5
Pyrene	5
EPA Method 8330	
HMX(c)	5 or 1
RDX(d)	5

(a) The number of decimal places displayed in this table vary by constituent. These variations reflect regulatory agency permit stipulations, the applicable analytical laboratory contract under which the work was performed, or both.

(b) These reporting limits are for water samples with low concentrations of dissolved solids. If higher concentrations are present, limits are likely to be higher.

(c) HMX is octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.

(d) RDX is hexahydro-1,3,5-trinitro-1,3,5-triazine.

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APPENDIX C
Wildlife Survey Results

Table C-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[a]	Source
Invertebrates	Valley Elderberry Longhorn Beetle	*Desmocerus californicus dimorphus*	FT	Arnold 2002
	California linderiella	*Linderiella occidentalis*		Weber 2002
	California Clam Shrimp	*Cyzicus californicus*		Weber 2002
Amphibians	Arboreal Salamander	*Aneides lugubris*		Woollett 2005
	California Tiger Salamander	*Ambystoma californiense*	FT, ST	LLNL 2002
	California Slender Salamander	*Batrachoseps attenuatus*		Burkholder 2008
	California Newt	*Taricha torosa torosa*		Woollett 2005
	California Red-legged Frog	*Rana draytonii*	FT, CDFW: SSC	LLNL 2002
	Sierran Treefrog	*Pseudacris sierra*		LLNL 2002
	Western Spadefoot	*Spea hammondii*	CDFW: SSC	LLNL 2002
	California Toad	*Anaxyrus boreas halophilus*		LLNL 2002
Reptiles	Western Pond Turtle	*Actinemys marmorata*	CDFW: SSC	Woollett 2005
	Alameda Striped Racer (Whipsnake)	*Coluberlateralis euryxanthus*	FT, ST	Swaim 2002
	San Joaquin Coachwhip	*Masticophis flagellum ruddocki*	CDFW: SSC	LLNL 2002
	Blainville's (Coast) Horned Lizard	*Phrynosoma blainvillii*	CDFW: SSC	LLNL 2002
	California Legless Lizard	*Anniella pulchra pulchra*	CDFW: SSC	Swaim 2002
	Common Side-blotched Lizard	*Uta stansburiana*		LLNL 2002; Swaim 2002
	California Whiptail	*Aspidoscelis tigris munda*		LLNL 2002; Swaim 2002
	Northwestern Fence Lizard	*Sceloporus occidentalis occidentalis*		LLNL 2002; Swaim 2002
	Western Skink	*Plestiodon skiltonianus*		LLNL 2002; Swaim 2002
	Gilbert's Skink	*Plestiodon gilberti*		LLNL 2002; Swaim 2002
	Forest Alligator Lizard	*Elgaria multicarinata multicarinata*		LLNL 2002; Swaim 2002
	Western Yellow-Bellied Racer	*Coluber constrictor mormon*		LLNL 2002; Swaim 2002
	Pacific Gophersnake	*Pituophis catenifer catenifer*		LLNL 2002; Swaim 2002
	California Kingsnake	*Lampropeltis californiae*		LLNL 2002; Swaim 2002
	California Nightsnake	*Hypsiglena ochrorhyncha nuchalata*		LLNL 2002; Swaim 2002
	Glossy Snake	*Arizona elegans*		LLNL 2002; Swaim 2002
	Long-nosed Snake	*Rhinocheilus lecontei*		LLNL 2002; Swaim 2002

Table C-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source
Reptiles (cont.)	Western Black-headed Snake	*Tantilla planiceps*		Swaim 2002
	Pacific Ring-necked Snake	*Diadophis punctatus amabilis*		Woollett 2005
	California Striped Racer	*Coluber lateralis lateralis*		LLNL 2002; Swaim 2002
	Northern Pacific Rattlesnake	*Crotalus oreganus oreganus*		LLNL 2002; Swaim 2002
Birds	Pied-billed Grebe	*Podilymbus podiceps*	MBTA	LLNL 2003
	Double-crested Cormorant	*Phalacrocorax auritus*	MBTA, DFWWL	LLNL 2003
	Great Egret	*Ardea alba*	MBTA	LLNL 2003
	Bufflehead	*Bucephala albeola*	MBTA	LLNL 2003
	Common Goldeneye	*Bucephala clangula*	MBTA	LLNL 2003
	Mallard	*Anas platyrhynchos*	MBTA	LLNL 2003
	Northern Shoveler	*Anas clypeata*	MBTA	LLNL 2003
	Cinnamon Teal	*Anas cyanoptera*	MBTA	LLNL 2003
	American White Pelican	Pelecanus erythrorhynchos	MBTA	GANDA 2016
	Turkey Vulture	*Cathartes aura*	MBTA	LLNL 2003
	Golden Eagle	*Aquila chrysaetos*	BGEPA, MBTA, CAFPS, DFWWL, BCC	LLNL 2003
	Red-shouldered Hawk	*Buteo lineatus*	MBTA	LLNL 2003
	Rough-legged Hawk	*Buteo lagopus*	MBTA	LLNL 2003
	Ferruginous Hawk	*Buteo regalis*	MBTA, DFWWL, BCC	LLNL 2003
	Red-tailed Hawk	*Buteo jamaicensis*	MBTA	LLNL 2003
	Swainson's Hawk	*Buteo swainsoni*	MBTA, ST, BCC	LLNL 2003
	White-tailed Kite	*Elanus leucurus*	MBTA, CAFPS	LLNL 2003
	Osprey	*Pandion haliaetus*	MBTA, DFWWL	LLNL 2003
	Cooper's Hawk	*Accipiter cooperii*	MBTA, DFWWL	LLNL 2003
	Sharp-shinned Hawk	*Accipiter striatus*	MBTA, DFWWL	LLNL 2003
	Northern Harrier	*Circus cyaneus*	MBTA, CDFW: SSC	LLNL 2003
	Prairie Falcon	*Falco mexicanus*	MBTA, DFWWL, BCC	LLNL 2003
	Peregrine Falcon	*Falco peregrinus*	MBTA, CAFPS	GANDA 2016
	American Kestrel	*Falco sparverius*	MBTA	LLNL 2003
	Wild Turkey	*Meleagris gallopavo*		LLNL 2003
	California Quail	*Callipepla californica*		LLNL 2003
	Virginia Rail	*Rallus limicola*	MBTA	U.S. DOE and UC 1992

Table C-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source
Birds (cont.)	Sora	*Porzana carolina*	MBTA	Woollett 2009
	Killdeer	*Charadrius vociferus*	MBTA	LLNL 2003
	American Avocet	*Recurvirostra americana*	MBTA	Scott 2002
	Greater Yellowlegs	*Tringa melanoleuca*	MBTA	LLNL 2003
	Wilson's Snipe	*Gallinago delicata*	MBTA	LLNL 2003
	Mourning Dove	*Zenaida macroura*	MBTA	LLNL 2003
	Eurasian Collared-dove	*Streptopelia decaocto*		Woollett 2017
	Rock Pigeon	*Columba livia*		U.S. DOE and UC 1992
	Greater Roadrunner	*Geococcyx californianus*	MBTA	LLNL 2003
	Barn Owl	*Tyto alba*	MBTA	LLNL 2003
	Long-billed curlew	*Numenius americanus*	MBTA, CDFW: SSC , BCC	Woollett 2014
	Short-eared Owl	*Asio flammeus*	MBTA, CDFW: SSC	LLNL 2003
	Long-eared Owl	*Asio otus*	MBTA, CDFW: SSC	LLNL 2003
	Great Horned Owl	*Bubo virginianus*	MBTA	LLNL 2003
	Burrowing Owl	*Athene cunicularia*	MBTA, CDFW: SSC, BCC	LLNL 2003
	Western Screech Owl	*Megascops kennicottii*	MBTA	LLNL 2003
	Common Poorwill	*Phalaenoptilus nuttallii*	MBTA	LLNL 2003
	White-throated Swift	*Aeronautes saxatalis*	MBTA	LLNL 2003
	Allen's Hummingbird	*Selasphorus sasin*	MBTA, BCC	U.S. DOE and UC 1992
	Rufous Hummingbird	*Selasphorus rufus*	MBTA, BCC	LLNL 2003
	Costa's Hummingbird	*Calypte costae*	MBTA, BCC	LLNL 2003
	Anna's Hummingbird	*Calypte anna*	MBTA	LLNL 2003
	Northern Flicker	*Colaptes auratus*	MBTA	LLNL 2003
	Nuttall's Woodpecker	*Picoides nuttallii*	MBTA, BCC	LLNL 2003
	Acorn Woodpecker	*Melanerpes formicivorus*	MBTA	U.S. DOE and UC 1992
	Lewis's Woodpecker	*Melanerpes lewis*	MBTA	LLNL 2018
	Ash-throated Flycatcher	*Myiarchus cinerascens*	MBTA	LLNL 2003
	Cassin's Kingbird	*Tyrannus vociferans*	MBTA	LLNL 2003
	Western Kingbird	*Tyrannus verticalis*	MBTA	LLNL 2003
	Western Wood-pewee	*Contopus sordidulus*	MBTA	U.S. DOE and UC 1992
	Willow Flycatcher	*Empidonax traillii*	SE, MBTA, BCC,	van Hattem 2005
	Pacific-slope Flycatcher	*Empidonax difficilis*	MBTA	LLNL 2003
	Black Phoebe	*Sayornis nigricans*	MBTA	LLNL 2003
	Say's Phoebe	*Sayornis saya*	MBTA	LLNL 2003

C. Wildlife Survey Results

Table C-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source
Birds (cont.)	Loggerhead Shrike	*Lanius ludovicianus*	MBTA, CDFW: SSC, BCC	LLNL 2003
	California (Western) Scrub Jay	*Aphelocoma californica*	MBTA	LLNL 2003
	American Crow	*Corvus brachyrhynchos*	MBTA	LLNL 2003
	Common Raven	*Corvus corax*	MBTA	LLNL 2003
	Horned Lark	*Eremophila alpestris*	MBTA	LLNL 2003
	Tree Swallow	*Tachycineta bicolor*	MBTA	LLNL 2003
	Cliff Swallow	*Petrochelidon pyrrhonota*	MBTA	LLNL 2003
	Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	MBTA	LLNL 2003
	Oak Titmouse	*Baeolophus inornatus*	MBTA, BCC	LLNL 2003
	Bushtit	*Psaltriparus minimus*	MBTA	LLNL 2003
	House Wren	*Troglodytes aedon*	MBTA	LLNL 2003
	Rock Wren	*Salpinctes obsoletus*	MBTA	LLNL 2003
	Bewick's Wren	*Thryomanes bewickii*	MBTA	LLNL 2003
	Ruby-crowned Kinglet	*Regulus calendula*	MBTA	LLNL 2003
	Hermit Thrush	*Catharus guttatus*	MBTA	LLNL 2003
	Swainson's Thrush	*Catharus ustulatus*	MBTA	LLNL 2003
	Blue-gray Gnatcatcher	*Polioptila caerulea*	MBTA	LLNL 2019
	Western Buebird	*Sialia mexicana*	MBTA	LLNL 2003
	Mountain Bluebird	*Sialia currucoides*	MBTA	LLNL 2003
	American Robin	*Turdus migratorius*	MBTA	LLNL 2003
	Varied Thrush	*Ixoreus naevius*	MBTA	LLNL 2003
	California Thrasher	*Toxostoma redivivum*	MBTA	LLNL 2003
	Northern Mockingbird	*Mimus polyglottos*	MBTA	LLNL 2003
	European Starling	*Sturnus vulgaris*		LLNL 2003
	Cedar Waxwing	*Bombycilla cedrorum*	MBTA	LLNL 2003
	Phainopepla	*Phainopepla nitens*	MBTA	LLNL 2003
	MacGillivray's Warbler	*Geothlypis tolmiei*	MBTA	LLNL 2003
	Common Yellowthroat	*Geothlypis trichas*	MBTA	LLNL 2003
	Wilson's Warbler	*Cardellina pusilla*	MBTA	LLNL 2003
	Orange-crowned Warbler	*Oreothlypis celata*	MBTA	LLNL 2003
	Yellow Warbler	*Setophaga petechia*	MBTA, CDFW: SSC, BCC	LLNL 2003

Table C-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source
Birds (cont.)	Yellow-rumped Warbler	*Setophaga coronata*	MBTA	LLNL 2003
	Black-throated Gray Warbler	*Setophaga nigrescens*	MBTA	LLNL 2003
	Western Tanager	*Piranga ludoviciana*	MBTA	LLNL 2003
	Song Sparrow	*Melospiza melodia*	MBTA	LLNL 2003
	Lincoln's Sparrow	*Melospiza lincolnii*	MBTA	LLNL 2003
	Fox Sparrow	*Passerella iliaca*	MBTA	LLNL 2003
	White-crowned Sparrow	*Zonotrichia leucophrys*	MBTA	LLNL 2003
	Golden-crowned Sparrow	*Zonotrichia atricapilla*	MBTA	LLNL 2003
	Dark-eyed Junco	*Junco hyemalis*	MBTA	LLNL 2003
	Black-throated Sparrow	*Amphispiza bilineata*	MBTA	LLNL 2003
	California Towhee	*Melozone crissalis*	MBTA	LLNL 2003
	Vesper Sparrow	*Pooecetes gramineus*	MBTA	U.S. DOE and UC 1992
	Lark Sparrow	*Chondestes grammacus*	MBTA	LLNL 2003
	Bell's Sparrow	*Artemisiospiza belli*	MBTA	LLNL 2003
	Savannah Sparrow	*Passerculus sandwichensis*	MBTA	LLNL 2003
	Grasshopper Sparrow	*Ammodramus savannarum*	MBTA, CDFW: SSC	LLNL 2003
	Rufous-crowned Sparrow	*Aimophila ruficeps*	MBTA	LLNL 2003
	Lazuli Bunting	*Passerina amoena*	MBTA	LLNL 2003
	Blue Grosbeak	*Passerina caerulea*	MBTA	LLNL 2003
	Black-headed Grosbeak	*Pheucticus melanocephalus*	MBTA	U.S. DOE and UC 1992
	Bullock's Oriole	*Icterus bullockii*	MBTA	LLNL 2003
	Brown-headed Cowbird	*Molothrus ater*	MBTA	LLNL 2003
	Red-winged Blackbird	*Agelaius phoeniceus*	MBTA	LLNL 2003
	Tricolored Blackbird	*Agelaius tricolor*	BCC, MBTA, , ST	LLNL 2003
	Western Meadowlark	*Sturnella neglecta*	MBTA	LLNL 2003
	Brewer's Blackbird	*Euphagus cyanocephalus*	MBTA	LLNL 2003
	Lesser Goldfinch	*Spinus psaltria*	MBTA	LLNL 2003
	House Finch	*Haemorhous mexicanus*	MBTA	LLNL 2003
	Merlin	*Falco columbarius*	MBTA	Woolett 2011
Mammals	Broad-footed Mole	*Scapanus latimanus*		Woollett 2011
	Pallid Bat	*Antrozous pallidus*	CDFW: SSC, WBWGH	Rainey 2003

Table C-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source
Mammals (cont.)	Western Red Bat	*Lasiurus blossevillii*	CDFW: SSC, WBWGH	Rainey 2003
	Hoary Bat	*Lasiurus cinereus*		Rainey 2003
	California Myotis	*Myotis californicus*		Rainey 2003
	Yuma Myotis	*Myotis yumanensis*		Rainey 2003
	Canyon Bat	*Parastrellus hesperus*		Rainey 2003
	Brazilian Free-tailed Bat	*Tadarida brasiliensis*		Rainey 2003
	Audubon's (Desert) Cottontail	*Sylvilagus audubonii*		LLNL 2002; Clark et al. 2002
	Black-tailed Jackrabbit	*Lepus californicus*		LLNL 2002; Clark et al. 2002
	California Ground Squirrel	*Ostospermophilus beecheyi*		LLNL 2002
	Botta's Pocket Gopher	*Thomomys bottae*		LLNL 2002; West 2002
	Heermann's Kangaroo Rat	*Dipodomys heermanni*		LLNL 2002; West 2002
	California Pocket Mouse	*Chaetodipus californicus*		LLNL 2002; West 2002
	San Joaquin Pocket Mouse	*Perognathus inornatus*		Clark et al. 2002
	California Vole	*Microtus californicus*		LLNL 2002; West 2002
	House Mouse	*Mus musculus*		LLNL 2002; West 2002
	Dusky-footed Woodrat	*Neotoma fuscipes*		LLNL 2002; West 2002
	Brush Mouse	*Peromyscus boylii*		LLNL 2002; West 2002
	Deer Mouse	*Peromyscus maniculatus*		LLNL 2002; West 2002
	Western Harvest Mouse	*Reithrodontomys megalotis*		LLNL 2002; West 2002
	Red Fox	*Vulpes vulpes*		Woollett 2005
	Gray Fox	*Urocyon cinereoargenteus*		Woollett 2005
	Coyote	*Canis latrans*		LLNL 2002; Clark et al. 2002
	Raccoon	*Procyon lotor*		LLNL 2002; Orloff 1986
	Long-tailed Weasel	*Mustela frenata*		LLNL 2002; Orloff 1986
	Striped Skunk	*Mephitis mephitis*		LLNL 2002; Orloff 1986
	Western Spotted Skunk	*Spilogale gracilis*		LLNL 2002; Orloff 1986
	American Badger	*Taxidea taxus*	CDFW: SSC	LLNL 2002; Clark et al. 2002
	Bobcat	*Lynx rufus*		LLNL 2002; Clark et al. 2002

Table C-1. Site 300 wildlife species list. Includes species for which there are verified observations; it is not intended to be a complete list of Site 300 species.

Taxa	Common Name	Scientific Name	Regulatory Status[(a)]	Source
Mammals (cont.)	Mountain Lion	*Puma concolor*		LLNL 2002
	Mule Deer	*Odocoileus hemionus*		LLNL 2002; Clark et al. 2002
	Wild Pig	*Sus scrofa*		LLNL 2002; Clark et al. 2002

(a) BCC = U.S. Fish and Wildlife Service Birds of Conservation Concern (US Fish and Wildlife Service 2008)

BGEPA = Bald and Golden Eagle Protection Act

CAFPS = California Department of Fish and Wildlife Fully Protected Species (CA Fish and Game Code Section 3511)

CDFW:SSC = California Species of Special Concern (CA Dept. of Fish and Wildlife, Special Animals List,November 2018)

Candidate CESA = Candidate for listing under the California Endangered Species Act

DFWWL = California Department of Fish and Wildlife Taxa to Watch

FT = Threatened under the Federal Endangered Species Act

MBTA = Migratory Bird Treaty Act

SE = Endangered under the State Endangered Species Act

ST = Threatened under the State Endangered Species Act

WBWGH = Western Bat Working Group High Priority

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APPENDIX D
Extra Resources

The documents listed below are accessible at https://saer.llnl.gov, the website for the LLNL annual environmental report.

LLNL FY18 Site Sustainability Plan

Howing, B. (2017). *Lawrence Livermore National Laboratory FY2018 Site Sustainability Plan*. Livermore, CA: Lawrence Livermore National Laboratory, LLNL-AR-742010.

LLNL Ground Water Project 2018 Annual Report

Noyes, C., A. Porubcan, E. Yeh, K. Quamme, and Z. Demir (2019). *LLNL Ground Water Project 2018 Annual Report*. Livermore, CA: Lawrence Livermore National Laboratory, UCRL-AR-126020-18.

LLNL NESHAPs 2018 Annual Report

Wilson, K., H. Byrnes, , and A. Wegrecki (2019). *LLNL NESHAPs 2018 Annual Report.* Livermore, CA: Lawrence Livermore National Laboratory, UCRL-AR-113867-19.

Site 300 Compliance Monitoring Program for the Closed Building 829 Facility Annual Report 2018

Diaz, S. (2019). *Lawrence Livermore National Laboratory Experimental Test Site 300 Compliance Monitoring Program for the Closed Building 829 Facility Annual Report 2018.* Livermore, CA: Lawrence Livermore National Laboratory, UCRL-AR-143121-18.

Site 300 2018 Compliance Monitoring Annual Report

Buscheck, M., T. Carlsen, S. Chamberlain, Z. Demir, S. Gregory, E Edwards, S. Harris, J. McKaskey, J. Radyk, M. Taffett, A. Verce (2019). *2018 Annual Compliance Monitoring Report for Lawrence Livermore National Laboratory Site 300.* Livermore, CA: Lawrence Livermore National Laboratory, UCRL-AR-206319-18.

Site 300 Compliance Monitoring Report for Waste Discharge Requirement Order No. R5-2008-0148 Second Semester/Annual Report 2018

Chan, A. (2019). *LLNL Experimental Test Site, Site 300 Compliance Monitoring Report for Waste Discharge Requirement (WDR) Order No. R5-2008-0148, Second Semester/Annual Report 2018*. Livermore, CA: Lawrence Livermore National Laboratory, LLNL-AR-411431-19-3.

Site 300 Compliance Monitoring Program for Closed Landfill Pit 1 Fourth Quarter Report 2018

Chan, A. (2019). *LLNL Experimental Test Site 300 Compliance Monitoring Program for Closed Pit 1 Landfill, Fourth Quarter Report for 2018*. Livermore, CA: Lawrence Livermore National Laboratory, UCRL-10191-18-4.

Supplementary Topics on Radiological Dose

Sanchez, L., P.E. Althouse, N.A. Bertoldo, R.G. Blake, S.L. Brigdon, R.A, Brown, C.G. Campbell, T. Carlson, E. Christofferson, L.M. Clark, G.M. Gallegos, A.R. Grayson, R.J. Harrach, W.G. Hoppes, H.E. Jones, J. Larson, D. Laycak, D.H. MacQueen, S. Mathews, M. Nelson, L. Paterson, S.R. Peterson, M.A. Revelli, M.J. Taffet, P.J. Tate, R. Ward, R.A. Williams, and K. Wilson (2003). *Environmental Report 2002*. Livermore, CA: Lawrence Livermore National Laboratory, UCRL-50027-02, Appendix D.

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APPENDIX E
Errata

Protocol for Errata in LLNL Environmental Reports

The primary form of publication for the LLNL Environmental Report is electronic: the report is posted on the Internet. A limited number of copies are printed and distributed, including to local libraries. If errors are found after publication, the Internet version is corrected. Because the printed versions cannot be corrected, errata for these versions are published in a subsequent report. In this way, the equivalency of all published versions of the report is maintained.

In 1998, LLNL established the following protocol for post-publication revisions to the environmental report: (1) the environmental report website must clearly convey what corrections, if any, have been made and provide a link to a list of the errata, (2) the Internet version must be the most current version, incorporating all corrections, and (3) the electronic and printed versions must be the same in that the printed version plus errata, if any, must provide the same information as the Internet version.

LLNL environmental reports from 1994 through 2018 can be accessed at https://saer.llnl.gov/

Record of Changes to Environmental Report 2016

The following changes have been made to the Internet version of *Environmental Report 2017*.

- Change the electronic version of 2017 report: Section 5.2.1 remove last sentence "Although this potential exists, it did not occur during 2017."
- Change the electronic version of 2017 report: Section 5.2.2: Replace:
  "There were no discharges from the Site 300 sewage evaporation pond to the percolation pond. Groundwater monitoring related to this area indicated there were no measurable impacts to the groundwater from the sewage pond operations (Blake 2018)." with
  "There were discharges from the Site 300 sewage evaporation pond to the percolation pond on two separate occasions. On February 9, 2017, approximately 150,000 gallons of effluent was released into the overflow pond and on February 22, 2017, approximately 110,000 gallons of additional effluent was released to the overflow pond to prevent a potential uncontrolled release from the sewage evaporation pond.

  Because of heavy rains during the 2016/2017 winter and accumulated sludge in the bottom of the evaporation pond, the sewage evaporation pond was at risk of an uncontrolled release over the bank of the pond into the watershed. To prevent an uncontrolled release, effluent was released through a discharge pipe into the adjacent overflow percolation pond."

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