6. Terrestrial Monitoring

Paola Aquino • Pete Bergeron • Heather Byrnes
Caleb Murphy • Lisa Paterson • Anthony Wegrecki

Lawrence Livermore National Laboratory (LLNL) monitors several aspects of the terrestrial environment at the Livermore Site, Site 300, and in the vicinity of both sites. 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 also 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 operations 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 from 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 Brunckhorst (2019). 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 (ESA), the California Endangered Species Act (CESA), 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 operations) 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.

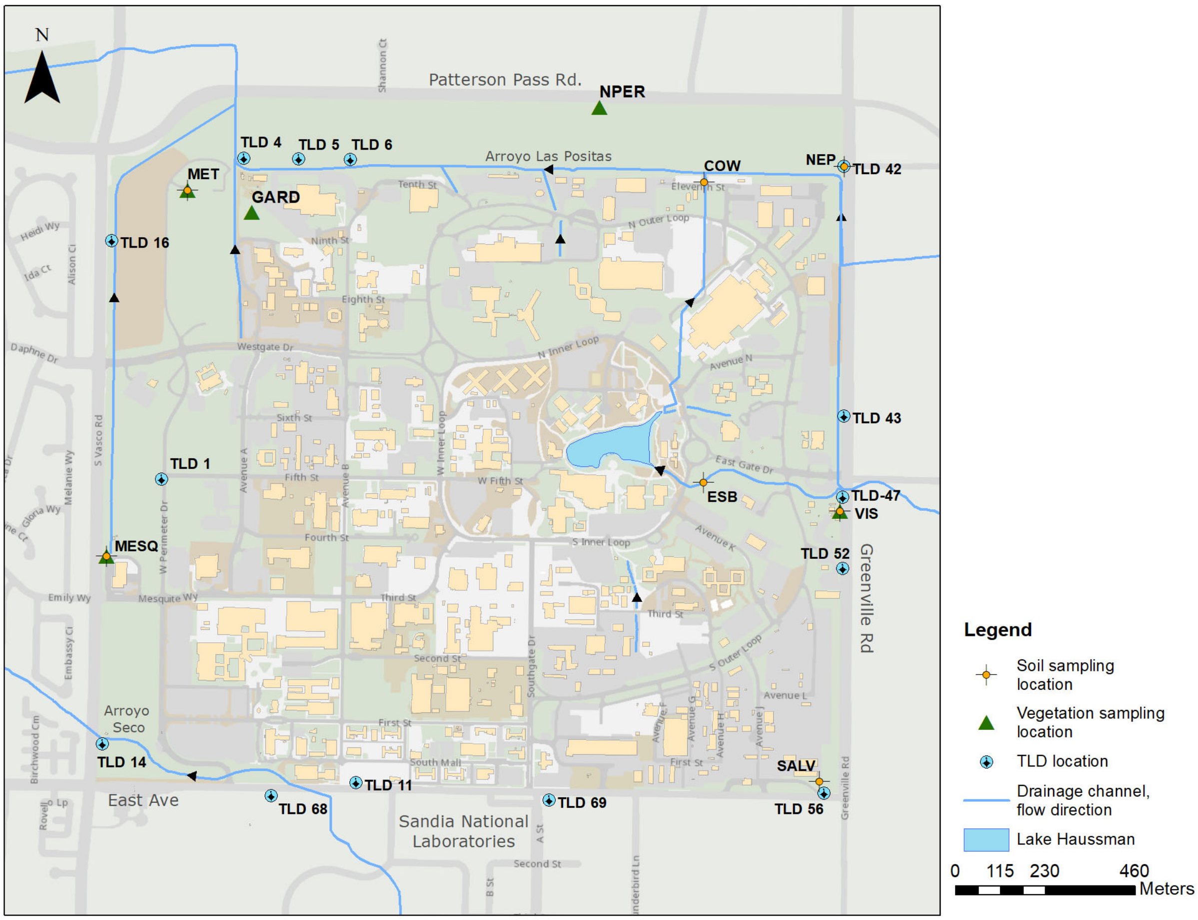

Figure 6-1. Soil, vegetation, and TLD sampling locations, Livermore Site.

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. At each sampling location, two, 1-m-square areas are chosen from which to collect the samples. 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.

The samples are collected for metals analyses, gross alpha, gross beta, and tritium activity. At four of the sampling locations, a 15-cm deep sample is taken for tritium analysis. This deeper sample enables laboratory extraction of sufficient pore water from the soil for tritium analysis.

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

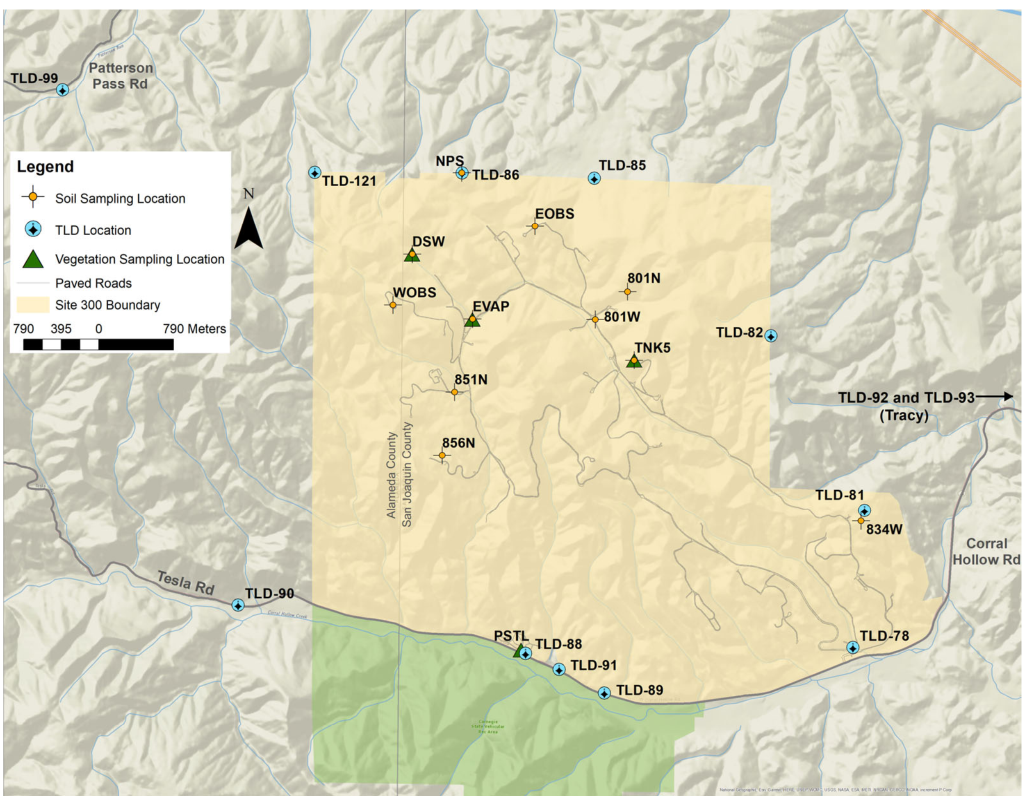

Figure 6-3. Soil, vegetation, and TLD locations, Site 300 and off-site.

Surface soil samples in the Livermore Valley were analyzed for plutonium and gamma-emitting radionuclides. Samples at selected locations were also 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

6.1.1.1 Livermore Valley

The 2019 radionuclide analyses data for the soil samples collected from the Livermore Valley sampling locations are provided in **Appendix A, Section A.8.**

The concentrations and distributions of all observed radionuclides 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 was 2.8 ± 0.26 mBq/dry g (7.6×10^{-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 2019. The highest detected plutonium-239+240 concentration (activity) was 7.70 ± 0.75 mBq/dry g (0.19 pCi/dry g) at sampling location L-WRP1. Americium 241 was also detected at this location, at 3.50 ± 0.51 mBq/dry g (9.5×10^{-2} pCi/dry g), and is most likely caused by the natural radiological decay of the trace concentrations of plutonium that were present in the historical releases to the sewer.

Except for sampling location L-ESB, all reported tritium concentrations (activities) were within the range of previous data. At L-ESB, tritium was detected at 5.0 ± 1.5 Bq/L (135 pCi/L). In 2018, tritium was detected a L-ESB at 14.0 Bq/L (378 pCi/L).

6.1.1.2 Site 300

The soils data for Site 300 for 2019 are provided in **Appendix A, Section A.8.**

The concentrations (activities) and distributions of all radionuclides observed in Site 300 soil lie within the ranges reported in previous years. At the majority of the sampling locations, the uranium-235/uranium-238 (U235/U238) ratio 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.

There were two sampling locations (3-EOBS and 3-TNK5) that appeared to show the presence of depleted uranium. The U235/U238 ratios were 0.018 ± 0.017 and 0.012 ± 0.011, respectively. The amounts of uranium-235 and uranium-238 in the two samples were 0.022 ± 0.0093 µg/dry g and 1.2 ± 1.0 µg/dry g; and 0.022 ± 0.014 µg/dry g and 1.8 ± 1.1 µg/dry g, respectively. Depleted uranium at Site 300 results from the previous use of the material in atmospheric explosive experiments.

6.1.2 Nonradiological Monitoring Results

Monitoring for beryllium is only conducted at Site 300 (see **Figure 6-3**) and has been since 1991. The nonradiological soils data for Site 300 are provided in **Appendix A, Section A.8.**

Detected beryllium concentrations were within the ranges previously reported. The highest detected concentration in 2019, 1.00 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 (0.57 to 1.0 mg/kg) 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 2019 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 detected value for plutonium-239+240 was 7.70 ± 0.75 mBq/dry g (0.208 pCi/dry g), at sampling location L-WRP1. The detected concentration (activity) is 1.6% 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 2019 are within the range of previous data and are generally representative of background or naturally occurring levels. The U235/U238 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 uranium-235 concentration (3-DSW sampling location), was 0.037 ± 0.014 µg/dry g; and was well below the NCRP-recommended screening level for commercial sites of 8.2 µg/dry g. The highest uranium-238 concentration (3-801N sampling location), was 5.7 ± 1.5 µg/dry g; and was also well below the NCRP-recommended screening level for commercial sites of 313 µg/dry g.

A Draft Remedial Investigation/Feasibility Study (RI/FS) was submitted for the Building 812 Operable Unit (OU) in 2008 (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 2019. 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, TESW, and ZON7) are in the Livermore Valley and 1 to 5 km from the Livermore Site perimeter.
- 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 2019 were purchased from a supermarket in Livermore. The wines represent the Livermore Valley, two other regions of California, and the Rhone Valley and Burgundy regions 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 2019 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 2019 was 7.1 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 5.4 Bq/L at ZON7. For Site 300, the highest mean concentration for 2019 was 85 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 EVAP, PSTL and TNK5 were less than the detection limit. The median concentrations of tritium in vegetation at location DSW was 4.8 Bq/L.

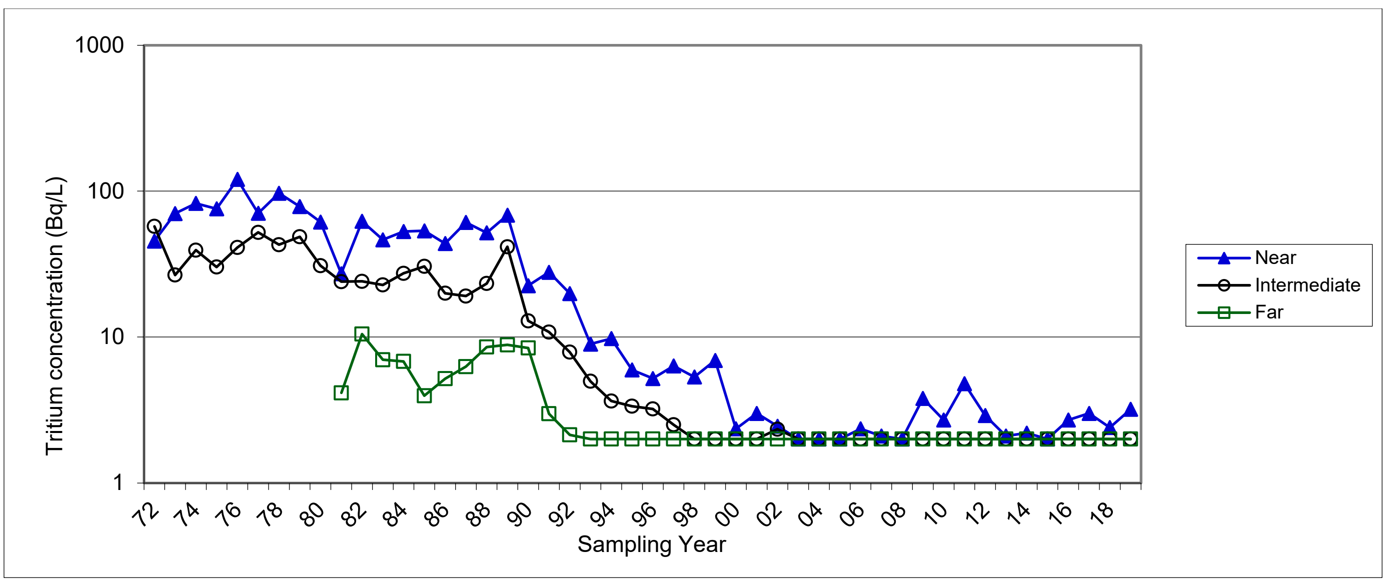

Figure 6-4. Median tritium concentrations in Livermore Site and Livermore Valley plant water samples, 1972 to 2019.

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 6-1. Median and mean concentrations of tritium in plant water for the Livermore Site, Livermore Valley, and Site 300 sampled in 2019.

Note: The table includes mean annual ingestion doses calculated for 2019.

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	3.8	5.5	33
	GARD	2.6	2.6	16
	MESQ	1.9	1.9	<10(b)
	MET	1.5	1.2	<10(b)
	NPER	6.0	6.2	37
	VIS	5.8	7.1	43
INTERMEDIATE (1–5 km from Livermore Site perimeter)	I580	1.6	1.8	<10(b)
	TESW	1.4	1.5	<10(b)
	ZON7	5.0	5.4	32
FAR (>5 km from Livermore Site perimeter)	CAL	0.36	0.24	<10(b)
	FCC	1.6	1.2	<10(b)
Site 300	DSW(c)	4.8	85	(d)
	EVAP(c)	1.1	2.1	(d)
	PSTL	0.67	0.67	(d)
	TNK5	0.50	0.48	(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.

6.2.2 Wine Monitoring Results

Tritium concentrations in wines purchased in 2019 are shown in **Table 6-2.** The highest measured concentration in a Livermore Valley wine was 2.5 Bq/L (68 pCi/L) from a wine made from grapes harvested in 2016. The highest measured concentration in a California (other than the Livermore Valley) wine was 1.9 Bq/L (51 pCi/L) from a wine made from grapes harvested in 2018 from Mendocino County. The highest measured concentration in a French wine was 2.9 Bq/L (77 pCi/L) from Rhone Valley 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 typical relationship was observed in this year's analysis.

The Livermore Valley wines represent vintages from 2011, 2014, 2015 and 2016; the California wines represent vintage from 2017 and 2018; and the French wines represent vintage from 2015. 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 2019, decay-corrected concentrations ranged from 1.7 to 3.9 Bq/L for Livermore Valley wine samples; 1.4 and 2.0 Bq/L for the two California wine samples; and 3.7 and 2.4 Bq/L for the French wine samples.

Table 6-2. Tritium in retail wine, 2019[(a, b)].

	Concentration by area of production (Bq/L)		
Sample	**Livermore Valley**	**California**	**Europe**
1	1.30 ± 0.56	1.90 ± 0.57	2.90 ± 0.60
2	2.10 ± 0.58	1.30 ± 0.55	1.90 ± 0.57
3	2.20 ± 0.58		
4	2.40 ± 0.59		
5	2.50 ± 0.58		
6	2.40 ± 0.55		
Dose (nSv/y)[(c)]	3.5	2.7	4.1

(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 2019 sampling. Concentrations are those measured in February 2020.

(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 2019, was 43 nSv (4.3 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 2019, including OBT, is 86 nSv/y (8.6 µrem/y). This maximum dose is about 1/35,000 of the average annual background dose in the United States from all-natural sources and about 1/120 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 2019, the highest concentration of tritium (2.5 Bq/L [68 pCi/L]) was just 0.34% of the Environmental Protection Agency (EPA) 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 2019 would have resulted in a dose of 25 nSv/y (2.5 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 (2.2 Bq/L [58 pCi/L]) would have been 3.1 nSv/y (0.31 µrem/y). Both doses account for the added contribution of OBT [2].

The potential dose from drinking Livermore Valley wines in 2019, including the contribution of OBT, even at the high consumption rate of one liter per day, and the highest observed concentration, would be about 1/400 of a single dose from a panoramic dental x-ray.

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

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).

6.3 Biota Dose

Potential dose to biota resulting from LLNL operations is calculated according to DOE Standard 1153-2019, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (U.S. DOE 2019). 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 and riparian 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 2019, radionuclides considered for dose contribution 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 considered for dose contribution 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 2019, the total sum of the fractions for the aquatic ecosystem animals was 0.23 with the limiting concentrations from nuclides in water. The total sum of the fractions for the terrestrial ecosystem animals and plants was 0.15 with the limiting concentrations from radionuclides in 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 and recommendations of the American National Standards Institute (ANSI).

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 2019 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)]

		Year				
Area	**Measurement**	**2015**	**2016**	**2017**	**2018**	**2019**
Livermore Site	Dose ± 1 SD (mSv)	0.560 ± 0.016	0.566 ± 0.016	0.565 ± 0.014	0.581 ± 0.014	0.578 ± 0.015
	Number of Samples	56	56	55	54	55
Livermore Valley[(a)]	Dose ± 1 SD (mSv)	0.535 ± 0.039	0.541 ± 0.040	0.549 ± 0.039	0.570 ± 0.035	0.547 ± 0.037
	Number of Samples	32	32	31	31	31
Site 300	Dose ± 1 SD (mSv)	0.672 ± 0.033	0.663 ± 0.035	0.673 ± 0.036	0.691 ± 0.029	0.689 ± 0.029
	Number of Samples	35	31	28	30	29
Site 300 off-site	Dose ± 1 SD (mSv)	0.639 ± 0.12	0.638 ± 0.10	0.664 ± 0.091	0.680 ± 0.13	0.66 ± 0.11
	Number of Samples	8	6	7	7	7
Tracy	Dose ± 1 SD (mSv)	0.623 ± 0.024	0.618 ± 0.017	0.626 ± 0.039	0.639 ± 0.039	0.643 ± 0.034
	Number of Samples	8	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 2019 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 ESA or 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*), an ESA threatened species and CDFW species of special concern (SSC), is known to occur at the Livermore Site (see **Figure 6-5**). The California tiger salamander (*Ambystoma californiense*) is listed as an ESA and CESA threatened species and has 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 (*Masticophis 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.

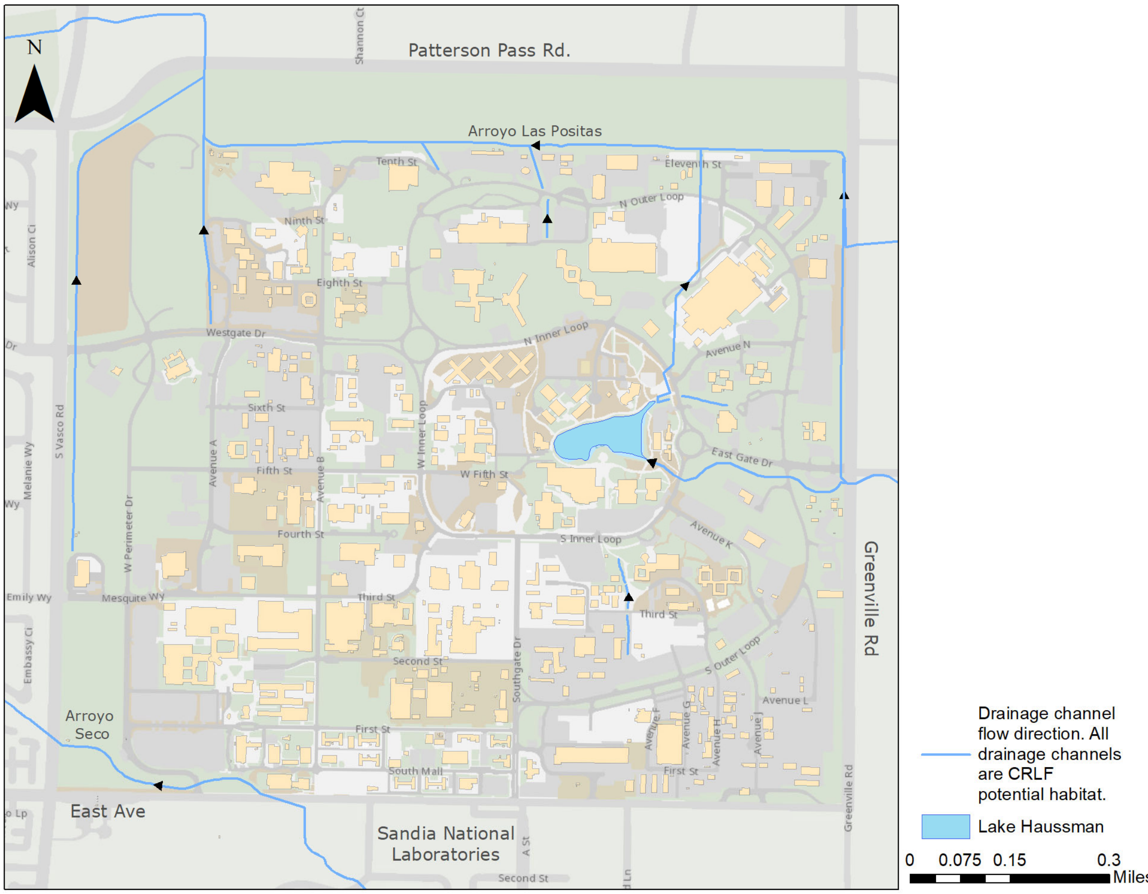

Figure 6-5. Potential California red-legged frog aquatic habitat, Livermore Site.

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 2020). A fifth species, the round-leaved filaree *(California macrophylla),* was previously considered rare, but its status was recently downgraded and is no longer considered rare (CNPS 2020).

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 2020). Past surveys have failed to identify any rare plants on the Livermore Site (Preston 1997, 2002).

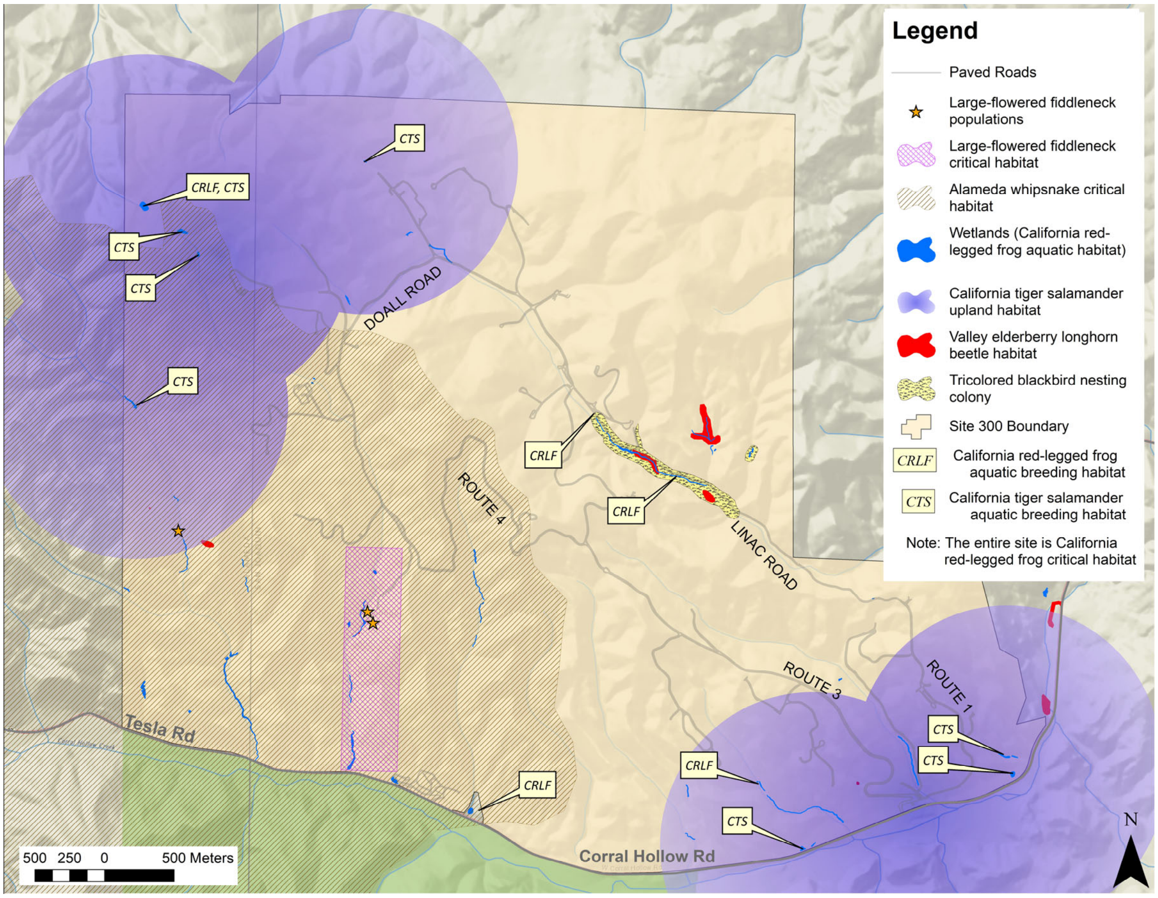

Figure 6-6. Protected habitat for species listed under the federal and California Endangered Species Acts at Site 300.

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 2019 at the Livermore Site. White-tailed kites (*Elanus leucurus)* 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 six young at the Livermore Site in 2019 (one pair of white-tailed kites double clutched and had 3 successful fledglings). Two pairs of great-horned owl (*Bubo virginianus)* nests successfully fledged four young at the Livermore Site in 2019. There was one successful red-tailed hawk (*Buteo jamaicensis)* nest at the Livermore Site that fledged one young. The two American kestrel (*Falco sparverius)*nests at the Livermore Site, were deemed as active as both adult pairs were active around the nest throughout the breeding season. Although, no fledglings were visually observed. One turkey vulture (*Cathartes aura)* nest located at T5475 of the Livermore Site successfully fledged two young in 2019.

Site 300 Burrowing Owl Bird Surveys. Sitewide surveys for nesting burrowing owls (*Athene cunicularia)* were conducted at Site 300 in 2019. Twenty nesting burrowing owl pairs were observed at Site 300 in 2019. There was a decrease in the number of nesting pairs in 2019 compared to 2018. In 2019, 12 of the 20 nesting pairs (60%) successfully reared at least one fledgling, and in 2018, 15 out of 25 (60%) nesting burrowing owl pairs were successful. The 12 successful nesting pairs observed in 2019 reared at least 32 fledglings. This is an average of three to four fledglings per successful nest. In 2018, the 15 successful burrowing owl pairs reared at least 55 fledglings. This is an average of three to four 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 on a weekly basis during the nesting bird season and during construction monitoring conducted in 2019. 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 2019 prior to the start of the ESGA well decommissioning project. During these surveys, 10 pairs of nesting red-tailed hawks, two pairs of nesting great-horned owls and two pairs of nesting common ravens (*Corvus corax)* were observed. There was a total of 10 red tailed hawk pairs which successfully reared 17 red tailed hawk fledglings The great horned owl nest within the CDFW eco reserve reared one successful fledgling.

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 2019, 300-500 tricolored blackbirds were observed at the nesting colony in Elk Ravine, but no tricolored blackbird fledglings were observed in Elk Ravine in 2019. Survey results indicate that the colony did not successfully reproduce in Elk Ravine in 2019 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 2019, 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. In 2017 and 2018 ongoing California red-legged frog monitoring and invasive species control were conducted, no California red-legged frogs were observed at the Livermore site. There were multiple sightings of adult California red legged frogs in 2019. Two sightings were in Lake Haussmann and Arroyo Las Positas during invasive wildlife control in the summer of 2019. The other California red legged frog sighting was along Arroyo Las Positas during a non-routine survey inspection. In 2019 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 2019. No California red-legged frog egg masses were observed in Arroyo las Positas, Arroyo Seco, or Lake Haussmann in 2019.

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 (2005–2019). 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 2019, 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. California tiger salamander eggs were observed at several seasonal pools at Site 300 in 2019 including Pools A, H, M2, and HC1. In addition, western spadefoot toads (*Spea hammondii)*, a California Species of Special Concern, successfully reproduced within Pool OS. Pools A and HC1 were the only ones that were inundated long enough for metamorphosis.

6.5.1.3 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 2019.

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 January 2017, and seeds were last planted at this population in November of 2012. Largely as a result of planting seedlings in 2017, the Drop Tower experimental population contained approximately 190 large-flowered fiddleneck plants in the spring of 2019.

Big Tarplant. The distribution of big tarplant was mapped at Site 300 using a handheld global positioning system (GPS) in September through November 2019. Between approximately 95,020 and 208,342 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 tarplants 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 2019 is 683. In 2019, 759 diamond-petaled California poppies were observed in all Site 300 populations. This is slightly higher than the median population size observed between 2004 and 2019.

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 2019. 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 2019 by temporarily halting groundwater discharges to the arroyo.

At Site 300, feral pig control measures were implemented between April and October 2019. 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 on-site.

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 reaches of Arroyo Las Positas at LLNL's Livermore Site in September 2019. This is the fifth 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 2019, one California red-legged frog was visually observed during a diurnal pre-activity and monitoring survey in this location. A second adult California red-legged frog was observed within the arroyo during dewatering and invasive species control efforts. 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, 2018, and 2019 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 2019, and the survivorship of planted willows and cottonwoods met requirements for this project. For the first time since project initiation, willows planted during the first two years of this project (2014 and 2015) have grown enough to be considered the dominant vegetation type in some areas. Willow and cottonwood coverage, as a dominant vegetation type, increased to 24.4% in 2019. By implementing invasive tree species tree removal, *Casaurina* sp., coverage has been reduced to 7.5% of the total length of the project site in 2019 compared to 15.0% in 2015.

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 2019.

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. In 2019, California tiger salamander eggs were observed in Pool M2, H, A and HC1. Furthermore, Pools M2 and A had sightings of California tiger salamander larvae. Although, Pools A and HC1 were the only ones that were inundated long enough for metamorphosis.

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 2019. 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. In 2019, Pool HC1 and A, held water long enough for California tiger salamanders to undergo metamorphosis during the season.

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 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 2019, Pool M3 did not fill to a depth or duration to allow for California tiger salamander reproduction.

6.5.4 Environmental Impacts on Special Status Wildlife and Plants

Through monitoring and compliance activities in 2019, 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.