6. Terrestrial Monitoring

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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 onsite.

The LLNL terrestrial radioactivity-monitoring program is designed to measure any changes in environmental levels of radioactivity. All monitoring activities follow U.S. 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 and natural sources of radioactivity in air. 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 model 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

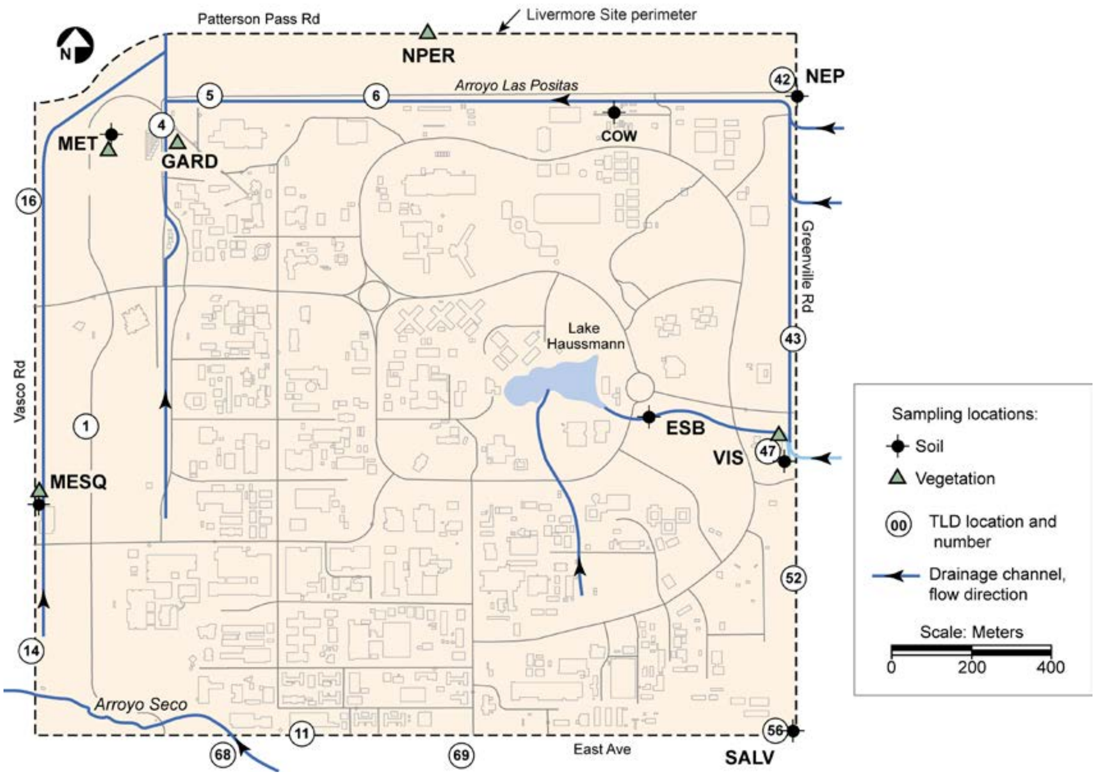

Figure 6-1. Soil, vegetation, and TLD sampling locations, Livermore Site.

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.

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.

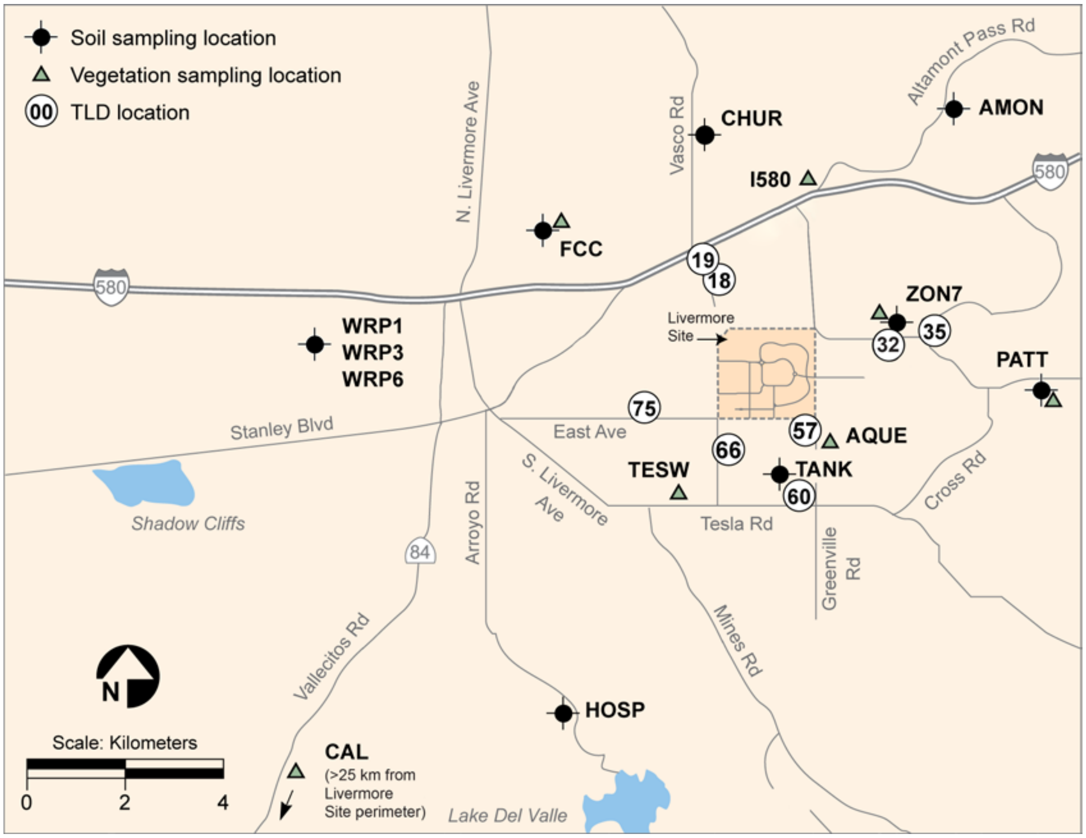

Figure 6-2. Soil, vegetation, and TLD locations, Livermore Valley.

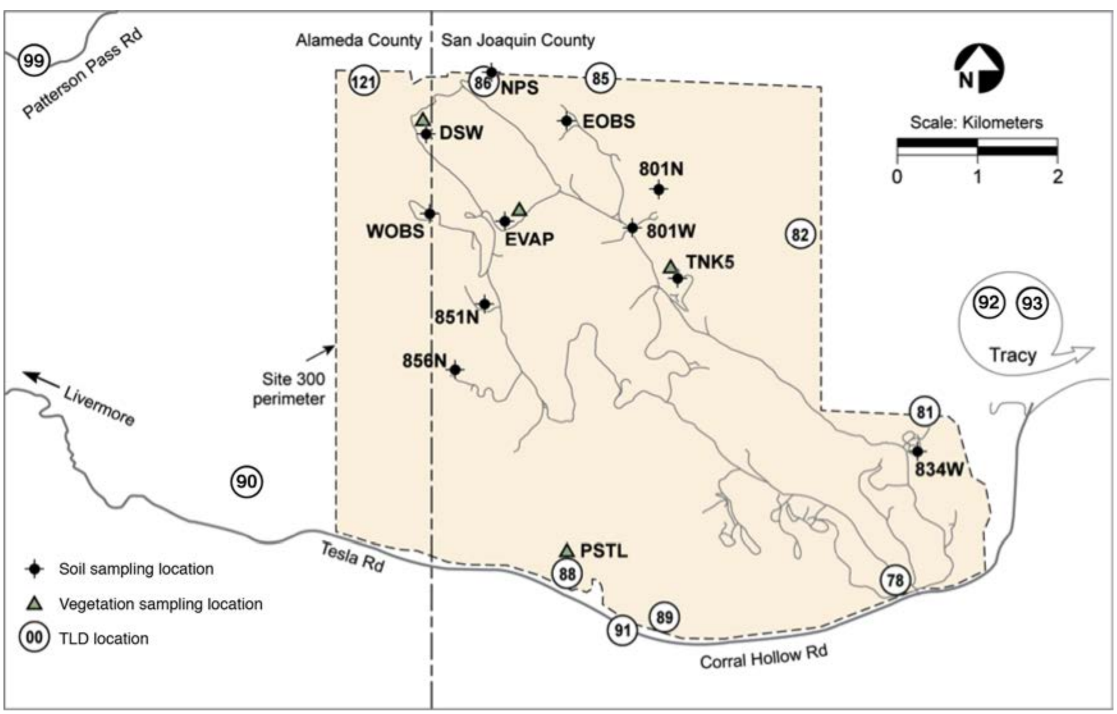

Figure 6-3. Soil, vegetation, and TLD locations, Site 300 and offsite.

In 2016, 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 2016 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 2016 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 2016 was 1.8 mBq/dry g (4.9×10^{-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 2016. The highest detected plutonium-239+240 value at the LWRP in 2016 was 6.5 mBq/dry g (0.18 pCi/dry g). In addition, americium-241 was detected in one LWRP sample at a concentration of 3.5 mBq/dry g (9.5×10^{-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 2016 (3.5 Bq/L [95 pCi/L]) was 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 2016 are provided in **Appendix A**, **Section A.8**. The concentrations and the distributions of all radionuclides observed in Site 300 soil for 2016 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 2016, 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 0.0045. The amount of uranium-235 and uranium-238 in the sample were 0.032 µg/g (0.0025 Bq/g or 0.069 pCi/g) and 7.2 µg/g (0.089 Bq/g or 2.4 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 2016, 1.2 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 2016 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 2016 (6.5 mBq/dry g [0.18 pCi/dry g]), measured at LWRP, is 1.4% 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 2016 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 (0.0030 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 7.2 µg/g (0.089 Bq/g or 2.4 pCi/g) and was also well below the NCRP-recommended screening level for commercial sites (313 µg/g [3.9 Bq/g or 105 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 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 in 2016. 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.
- 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 2016 were purchased from a supermarket in Livermore. The wines represent the Livermore Valley, two other regions of California, 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 2016 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 2016 was 3.9 Bq/L at the near location VIS located on the east-central perimeter. For Site 300, the highest mean concentration for 2016 was 0.79 Bq/L at EVAP.

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 2003.

At Site 300, the median concentrations of tritium in vegetation at locations DSW, EVAP, PSTL and TNK5 were all less than the detection limit.

6.2.2 Wine Monitoring Results

Tritium concentrations in wines purchased in 2016 are shown in **Table 6-2**. The highest measured concentration in a Livermore Valley wine was 2.3 Bq/L (61 pCi/L) from a wine made from grapes harvested in 2012. The highest measured concentration in a California (other than the Livermore Valley) wine was 0.20 Bq/L (5.3 pCi/L) from a wine made from grapes harvested in 2014. The measured concentration in a Rhone Valley (France) wine was 1.0 Bq/L (28 pCi/L) from the wine grapes harvested in 2015, and the measured concentration in the Burgundy wine was 0.57 Bq/L (15 pCi/L) from wines made from grapes harvested in 2014.

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 among the Livermore Valley wines is slightly higher than the highest concentration among the European wines.

Table 6-1. Median and mean concentrations of tritium in plant water for the Livermore Site, Livermore Valley, and Site 300 sampled in 2016. The table includes mean annual ingestion doses calculated for 2016.

Sampling locations		Concentration of tritium in plant water (Bq/L)		Mean annual ingestion dose [(a)] (nSv/y)
		Median	Mean	
NEAR (on-site or <1 km from Livermore Site perimeter)	AQUE	0.94	0.97	<10[(b)]
	GARD	0.99	1.3	<10[(b)]
	MESQ	3.4	3.7	22
	MET	3.0	2.9	17
	NPER	1.8	2.8	17
	VIS	4.2	3.9	23
INTERMEDIATE (1–5 km from Livermore Site perimeter)	I580	0.60	0.38	<10[(b)]
	PATT	-0.32	-0.31	<10[(b)]
	TESW	0.34	0.62	<10[(b)]
	ZON7	1.8	2.2	13
FAR (>5 km from Livermore Site perimeter)	CAL	-0.38	-0.34	<10[(b)]
	FCC	0.10	0.097	<10[(b)]
Site 300	DSW[(c)]	-0.83	-0.54	[(d)]
	EVAP[(c)]	0.82	0.79	[(d)]
	PSTL	-0.78	-0.82	[(d)]
	TNK5	-0.010	0.18	[(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 2012, 2014, and 2015; the California wines represent vintage from 2014 and 2015; and the Rhone Valley and Burgundy region wines represent vintage from 2015 and 2014, respectively. 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 2016, decay-corrected concentrations for Livermore Valley wine samples ranged from 0.91 to 2.9 Bq/L; for the two California wine samples, 0.14 and 0.22 Bq/L; and for the Rhone Valley and Burgundy wine samples, 0.65 and 1.1 Bq/L, respectively.

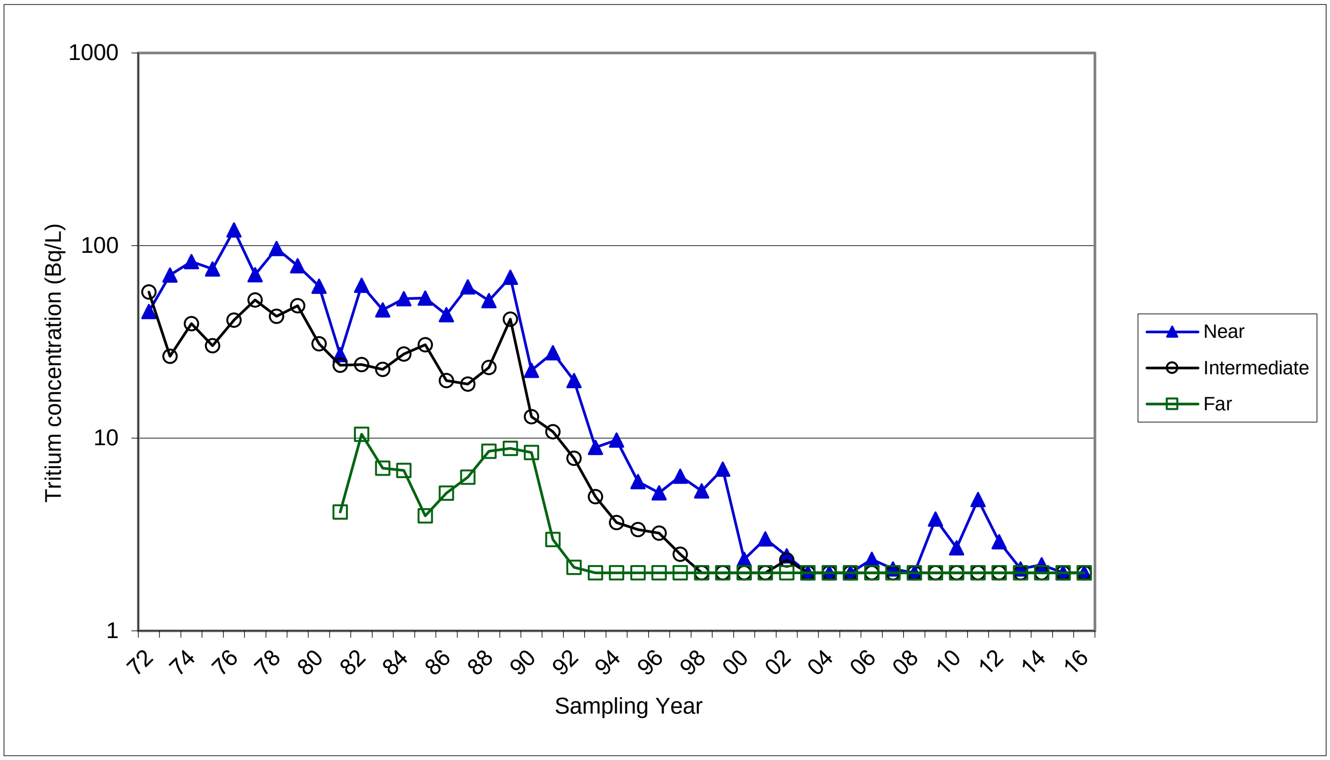

Figure 6-4. Median tritium concentrations in Livermore Site and Livermore Valley plant water samples, 1972 to 2016.

Table 6-2. Tritium in retail wine, 2016[a, b].

Sample	Concentration by area of production (Bq/L)		
	Livermore Valley	**California**	**Europe**
1	1.4 ± 0.54	0.20 ± 0.51	1.0 ± 0.54
2	2.3 ± 0.57	0.13 ± 0.51	0.57 ± 0.52
3	1.1 ± 0.54		
4	1.4 ± 0.55		
5	0.88 ± 0.54		
6	0.84 ± 0.54		
Dose (nSv/y)[c]	3.3	0.28	1.4

(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 2016 sampling. Concentrations are those measured in January 2017.

(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 2016, was 23 nSv (2.3 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 2016, including OBT, is 46 nSv/y (4.6 µrem/y). This maximum dose is about 1/65,000 of the average annual background dose in the United States from all natural sources and about 1/220 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 2016, the highest concentration of tritium (2.3 Bq/L [61 pCi/L]) was just 0.31% of the 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 2016 would have resulted in a dose of 23 nSv/y (2.3 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 (1.3 Bq/L [35 pCi/L]) would have been

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

1.8 nSv/y (0.18 µrem/y). Both doses account for the added contribution of OBT(2).

The potential dose from drinking Livermore Valley wines in 2016, including the contribution of OBT, even at the high consumption rate of one liter per day, and the highest observed concentration, would be about 1/440 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 2016, radionuclides contributing to dose to biota from soil and sediment were americium-241, cesium-137, hydrogen-3 (tritium), potassium-40, plutonium-238, plutonium-239, 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 2016, the total sum of the fractions for the aquatic ecosystem animals was 0.112. Nearly all of the impact was due to water exposure. The total sum of the fractions for the terrestrial ecosystem animals and plants was 0.468. Nearly all of the impact was due to concentrations of radionuclides

(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).

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 attributable to LLNL operations. This monitoring is conducted using TLDs. The locations at which TLD's are placed are the Livermore Site perimeter (**Figure 6-1**), the Livermore Valley (**Figure 6-2**), Site 300 (**Figure 6-3**) and the Site 300 vicinity, including Tracy (**Figure 6-3**). At each location, there are multiple TLD locations at which individual TLD's 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 ($^nLi_2B_4O_7$). 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 2016 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 location is obtained by summing the quarterly doses from each TLD location, then averaging the annual sums.

Table 6-4. Annual ambient radiation dose with standard deviation (SD) in units of mSv and numbers of samples.

Location	Measurement	Year				
		2012	2013	2014	2015	2016
Livermore Site	Dose ± 1 SD (mSv)	0.563 ± 0.016	0.580 ± 0.017	0.568 ± 0.015	0.560 ± 0.016	0.566 ± 0.016
	Number of Samples	56	56	56	56	56
Livermore Valley[(a)]	Dose ± 1 SD (mSv)	0.566 ± 0.022	0.573 ± 0.027	0.552 ± 0.039	0.535 ± 0.039	0.541 ± 0.040
	Number of Samples	88	86	32	32	32
Site 300	Dose ± 1 SD (mSv)	0.670 ± 0.030	0.691 ± 0.036	0.689 ± 0.031	0.672 ± 0.033	0.663 ± 0.035
	Number of Samples	34	36	31	35	31
Site 300 off-site	Dose ± 1 SD (mSv)	0.638 ± 0.12	0.658 ± 0.13	0.649 ± 0.13	0.639 ± 0.12	0.638 ± 0.10
	Number of Samples	8	8	7	8	6
Tracy	Dose ± 1 SD (mSv)	0.629 ± 0.023	0.632 ± 0.024	0.618 ± 0.051	0.623 ± 0.024	0.618 ± 0.017
	Number of Samples	8	8	6	8	8

(a) Number of locations reduced from 88 to 32 in year 2014 as need for number of sampling locations decreased.

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 2016 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. California threatened Swainson's hawks (*Buteo swainsoni*) and California-endangered willow flycatchers (*Empidonax traillii*) have also been observed at Site 300. The willow flycatcher is not known to nest at Site 300. In December of 2014, the tricolored blackbird was given emergency protection under the CESA. Although the California Fish and Game Commission allowed the emergency listing of the tricolored blackbird to expire in June of 2015, the Commission advanced the tricolored blackbird to candidacy under the CESA in December 2015. As a candidate species, the tricolored blackbird receives the same protection afforded to species listed as threatened or endangered under the CESA. The USFWS is also currently reviewing a petition to list the tricolored blackbird under the federal ESA. Tricolored blackbirds nest in Elk Ravine at Site 300.

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.

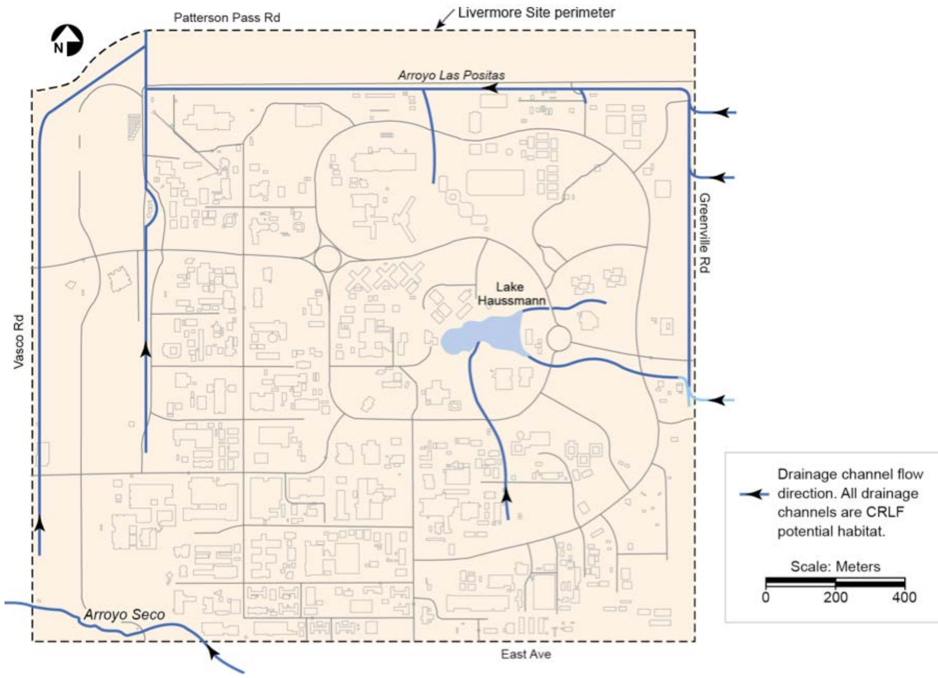

Figure 6-5. Potential California red-legged frog aquatic habitat, Livermore Site.

Including the federally endangered large-flowered fiddleneck, five rare plant species and three uncommon plant species are known to occur at Site 300. The five rare species—the large-flowered fiddleneck, the big tarplant (*Blepharizonia plumosa*), the round-leaved filaree *(California macrophylla),* the diamond-petaled California poppy (*Eschscholzia rhombipetala*), and adobe navarretia (*Navarretia nigelliformis* ssp. *radians*)—all have a California Rare Plant Rank (CRPR) of 1B (CNPS 2017).

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 2017). Past surveys have failed to identify any rare plants on the Livermore Site (Preston 1997, 2002).

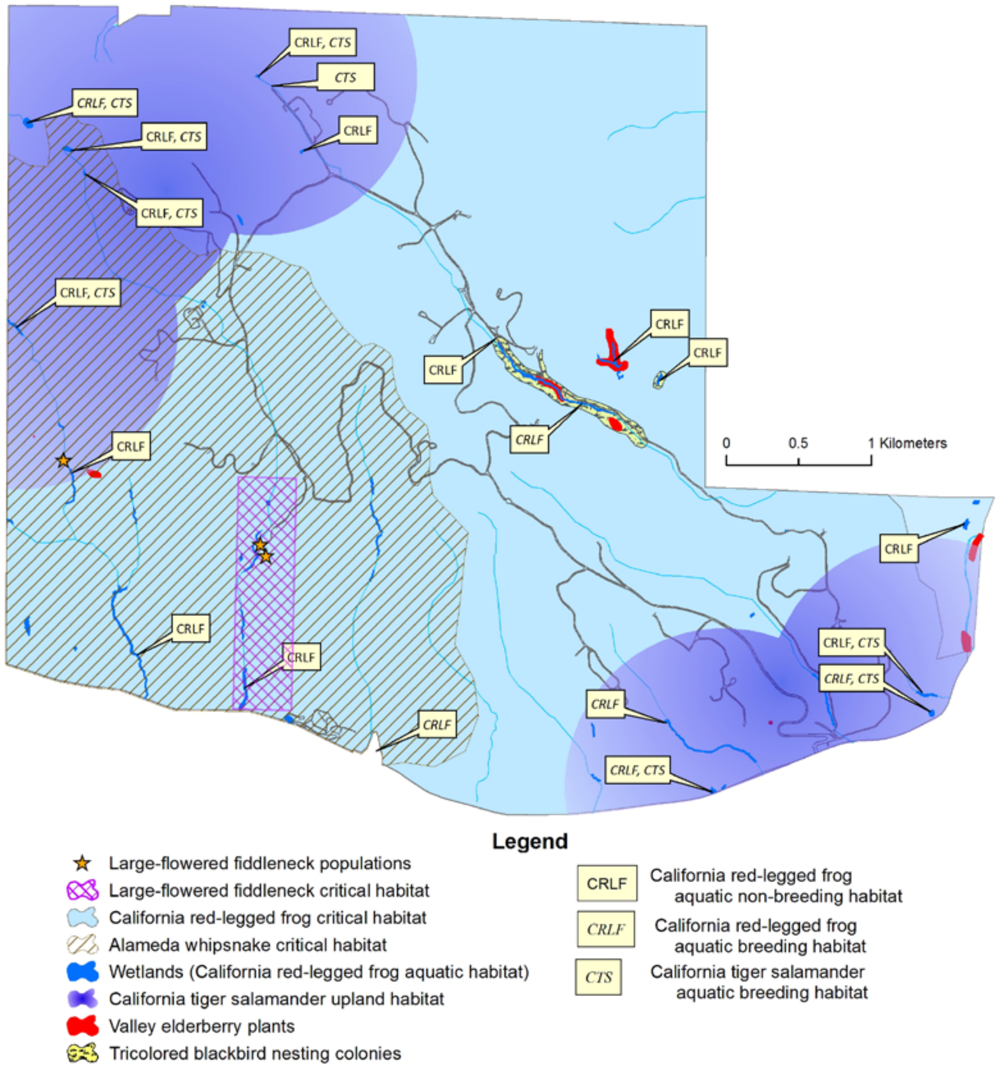

Figure 6-6. Protected habitat for species listed under the federal and California Endangered Species Acts at Site 300.

6.5.1 Habitat Enhancement Projects and Compliance Activities

6.5.1.1 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) and 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 February and March 2006. Monitoring demonstrated that California red-legged frogs successfully reproduced in these pools in 2006 through 2016. In the summer of 2014, both pools were dredged to remove extra sediment thus increasing the depths to the original 8-10 ft.; coincidentally, the spring that feeds these pools had stopped flowing at that time due to the drought. During dredging operations, overgrown vegetation (including cattails, nettles and willows) was removed to increase breeding habitat suitability. Normal flow resumed in these pools with the onset of fall rains in 2015, and California red-legged frogs successfully reproduced in the pools in 2016.

6.5.1.2 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 June and November 2011, seven power poles onsite caused bird of prey deaths by electrocution.

Between 2014 and 2016, 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.

6.5.1.2 Arroyo Las Positas Maintenance and Habitat Management

A maintenance and habitat management project was conducted within the Arroyo Las Positas at LLNL’s Livermore Site in September and November of 2016. The goals of this project were 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 was monitored by a Service Approved Biologist. Although no California red-legged frogs were observed during diurnal and nocturnal pre-activity and monitoring surveys in this location, two California red-legged frogs were found during monitoring of the maintenance activities. Both frogs were safely relocated outside of the work area. After the 2016 maintenance was completed, willows and cottonwoods were planted along the south bank of the arroyo. The purpose of the willow and cottonwood planting is 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. To provide California red-legged frogs with a mosaic of habitat types, including open water, emergent wetland, and riparian, one 300-foot maintenance zone was not planted with willows or cottonwoods in 2016. The maintenance zone was left without willows to provide a basking zone for wildlife.

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 (*Lithobates catesbeianus*) 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 through September 2016. 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 of 2016 by temporarily halting groundwater discharges to the arroyo.

At Site 300, feral swine control measures were implemented between March and April 2016. 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 Surveillance Monitoring

6.5.3.1 Avian and Bat Monitoring

Nesting Bird Surveys. Nesting bird surveys ensure LLNL activities comply with the Migratory Bird Treaty Act and do not result in impacts to nesting birds. LLNL conducted site-wide breeding raptor surveys in 2016 at the Livermore Site. White-tailed kites frequently nest in the trees along the north, east, and south perimeters of the Livermore Site. One white-tailed kite nest successfully fledged four young at the Livermore Site in 2016. One great-horned owl nest successfully fledged young at the Livermore Site in 2016, and there was a successful red-tailed hawk nest just outside the eastern boundary of the Livermore Site.

Sitewide monitoring for nesting raptors was not conducted at Site 300 in 2016. No red-tailed hawk nests occurred in the trees within the prescribed burn plots along Corral Hollow Road; therefore, no mitigation or avoidance measures were necessary to protect these nest sites. Five of the seven nest platforms installed in the fall of 2015 to encourage raptor/raven pairs (to build nests away from power pole structures) fledged young. One nest platform north of B801 fledged three baby red-tailed hawks which is a very productive nest site. Similar to the 2015 effort, several new nest platforms were established in onsite areas of avian concern and protection at the end the year.

Passive Acoustic Monitoring. Passive acoustic monitoring to identify bat species was conducted winter and spring of 2016 at the Site 300 meteorological tower. This study is a continuation of monitoring conducted in 2015. During this monitoring, 1,012 bat calls were recorded. These calls were analyzed by a trained biologist and using acoustic software. Two bat species which are California species of special concern were detected at Site 300 during active acoustic surveys conducted in 2002: the pallid bat *(Antrozous pallidus)* and the western red bat *(Lasiurus blossevillii).* Although the pallid bat and western red bat were not detected in 2015 or 2016, these findings do not demonstrate a change from 2002. Differences in survey location, timing, and equipment are likely to account for the change in detections compared to 2002 surveys. (Drennan and Tortosa 2016)

6.5.3.2 Amphibian Research and Monitoring

Livermore Site. In 2016, 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 2016, the American bullfrog (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 2016. No California red-legged frog egg masses were observed in Arroyo las Positas, Arroyo Seco, or Lake Haussmann in 2016.

Pool M1a and b. 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 (2005–2016). In early June of 2015, a mylar balloon contacting high voltage distribution wires resulted in a wildfire that caused this area to be burned. No impacts to the Pool M1a and b red-legged frog population were noted. In 2016, the vegetation impacted by the June 2015 quickly recovered.

Pool M2. In 2006, 2010, 2011, 2015, and 2016, Pool M2 filled and California tiger salamanders successfully reproduced at this location. In 2007, 2008, 2009, 2012, 2013, and 2014 the pool received inadequate inundation and evaporated before the salamander larvae could reach maturity and leave the pool. A habitat enhancement project was conducted at the Pool M2 in 2013. The clay liner of this pool was augmented in the fall of 2013 to limit infiltration or loss of water through the bottom of the pool.

Round Valley and Oasis Pools. 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 2006 Round Valley project included the creation of a pool upstream of the project area in part as mitigation for the impacts at the Oasis site and to serve as enhanced habitat for protected amphibian species. The Round Valley pool did not receive enough water during the 2007 through 2015 winters to pool and afford potential breeding habitat for amphibians. The Oasis site has been disturbed by feral pigs and does not currently provide suitable habitat for California red-legged frog breeding.

An additional habitat enhancement project was conducted at the Round Valley Pool 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.

Pool M3. 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. Visual encounter surveys were performed in the spring of 2016. In 2016, California tiger salamanders successfully reproduced in this pool. This represents the second successful breeding attempt in Pool M3 since completion of its restoration activities conducted in 2014.

California tiger salamander. With the exception of pools D and lower D, eggs and larvae of the California tiger salamander were incidentally encountered in all pools sampled for large branchiopods.

6.5.3.3 Rare Plant Research and Monitoring

Large-Flowered Fiddleneck. This species has recently been known from 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 (the Etchelet population). 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 2016.

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 seeds in established plots within the population. The size of the experimental population fluctuates as a result of these seed bank enhancement efforts. Large-flowered fiddleneck seeds were last planted at LLNL's experimental population in November of 2012. The Drop Tower experimental population contained approximately 51 large-flowered fiddleneck plants in the spring of 2016.

Big Tarplant. The distribution of big tarplant was mapped at Site 300 using a handheld global positioning system (GPS) in September through November 2016. Between approximately 14,000 and 44,000 big tarplants were observed at Site 300 during these surveys. This is comparable to abundance of this species in 2015 when between 16,000 and 60,000 individual big tarplants were observed. 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 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.

A spring census of Site 300 diamond-petaled California poppy populations was conducted annually in 2000 through 2016. In 2016, only 11 diamond-petaled California poppies were observed in all four populations, the smallest population observed since surveys began. In 2015, a total of approximately 46,100 diamond-petaled California poppies were observed within all Site

300 populations. The 2015 population was one of the largest observed since 2004. The relatively large diamond-petaled California poppy population in 2015 was likely attributable to annual grass cover in 2015, which was much less dense than average as a result of drought conditions.

Round-Leaved Filaree. Six populations of round-leaved filaree are known to occur at Site 300. All populations occur in the northwest portion of the site. This species thrives in the disturbed soils of the annually graded fire trails at Site 300, but also occurs in grasslands. Of the six known Site 300 populations, four occur on fire trails and two occur in grasslands. A census was conducted of three of these six populations in 2016. These three populations contained approximately 12,000 round-leaved filaree in 2016. This is an increase from 2015, when five populations were estimated to contain 8,900 round-leaved filaree plants.

6.5.3.4 Large Branchiopod Surveys

In 2016, wet and dry season surveys for large branchiopods were conducted at six seasonal pools in Site 300. Pools D, lower D, M2, H, A, and HC1 were sampled from January 14, 2016 through October 20, 2016. Field surveys and soil analysis followed the protocols outlined in the *U.S. Fish and Wildlife Service Survey Guidelines for the Listed Large Branchiopods* (2015). No federal or state listed branchiopods were observed in wet season surveys or found within the soils during dry season surveys. One species of branchiopod, the California fairy shrimp (*Linderiella occidentalis*), was identified in pools D, Lower D, A, H, and M2.

6.5.4 Environmental Impacts on Special Status Wildlife and Plants

Through monitoring and compliance activities in 2016, 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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