6. Terrestrial Monitoring

Keala Cummings • Aaron Felish • Caleb Murphy• Lisa Paterson
• Reginald Ramirez • Tony Wegrecki • Amanda Werrell • Kent Wilson

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 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 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 on 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 radioactivity (distant locations unlikely to be impacted by LLNL operations) and areas that have the potential to be impacted by LLNL operations. Sampling locations also include areas with known contamination, such as the Livermore Water Reclamation Plant (LWRP) and explosives testing areas at Site 300.

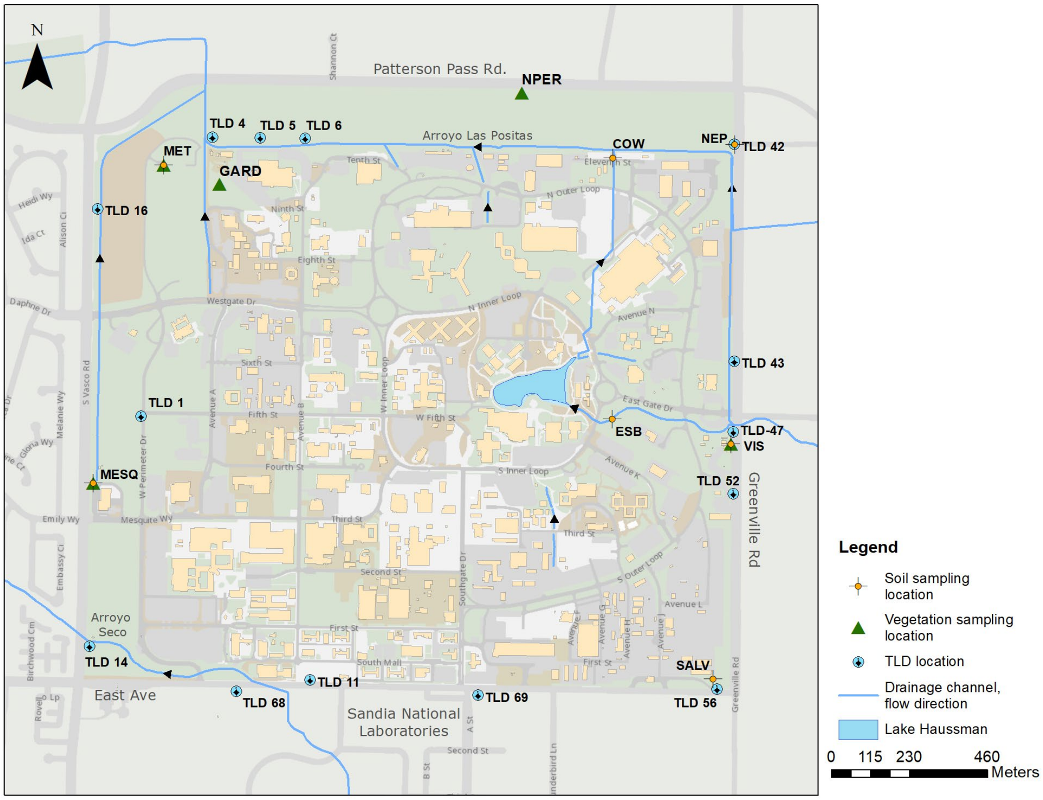

Figure 6-1. Soil, Vegetation, and TLD Sampling Locations, Livermore Site

Surface soil samples are collected from the top five centimeters of soil because aerial deposition is the primary pathway for potential radionuclide contamination. 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^2 areas are selected 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. At four of the sampling locations, a sample is taken at a depth of 15 cm 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

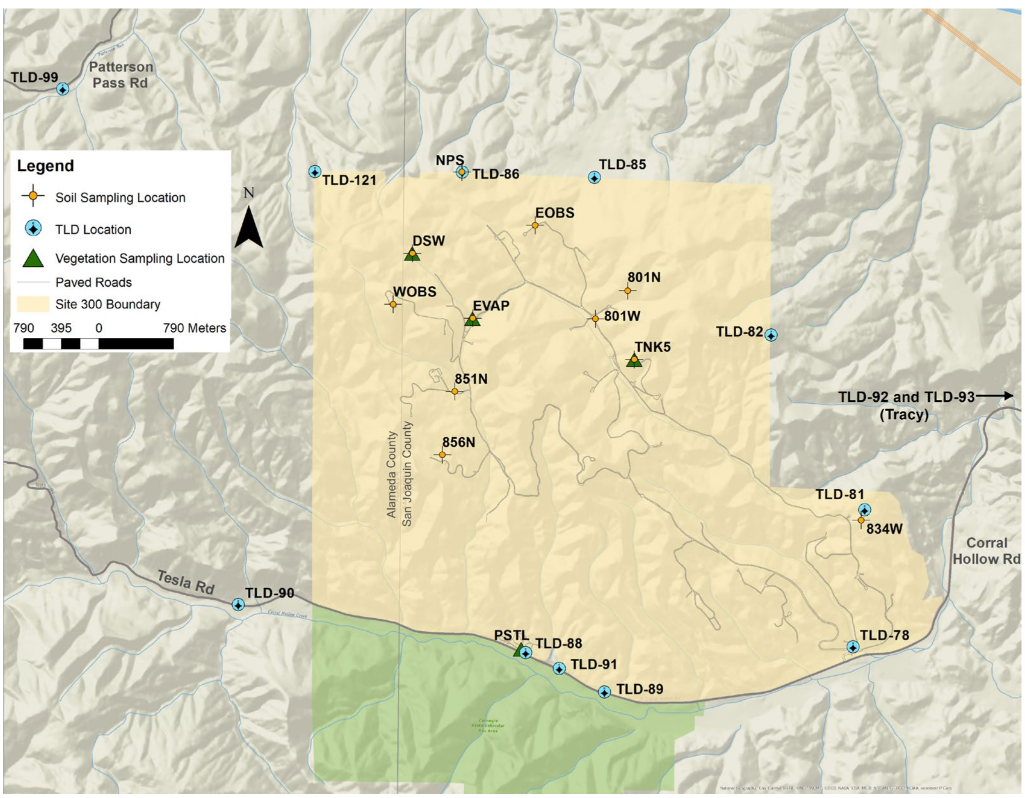

Figure 6-3. Soil, vegetation, and TLD Locations, Site 300 and Off-Site

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

Prior to radiochemical analysis by alpha and gamma spectrometry, the soil samples are dried, sieved, ground into a powder, 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 Analytical Results

6.1.1.1 Livermore Valley

The 2022 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. 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 the LWRP sampling locations in 2022. The highest detected plutonium-239+240 concentration was 7.2 ± 0.26 mBq/dry g (0.19 pCi/dry g) at sampling location LWRP1. Americium-241 was also detected at this location at 3.30 ± 0.53 mBq/dry g (0.0891 pCi/dry g) and is most likely caused by the natural radiological decay of the trace levels of plutonium that were present in historical releases to the sewer.

6.1.1.2 Livermore Site

The 2022 radionuclide analyses data for the soil samples collected at the Livermore Site 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.

Sampling at location ESB, which is in the drainage area for the southeast quadrant of the Livermore Site, shows the effects of historical operation of solar evaporators for plutonium-containing liquid waste (which was discontinued in 1976). The measured value for plutonium-239+240 at this location was 1.60 ± 0.078 mBq/dry g (0.043 pCi/dry g).

All reported tritium results were within the range of previous data. Detected tritium concentrations ranged from 1.6 ± 1.5 Bq/L (43.2 ± 40.5 pCi/L) at sampling location VIS to 6.8 ± 1.9 Bq/L (183.6 ± 51.3 pCi/L) at sampling location NEP.

6.1.1.3 Site 300

The soils data for Site 300 for 2022 are provided in **Appendix A, Section A.8.**

The concentrations and distributions of all radionuclides observed in Site 300 soil are within the ranges reported in previous years. At most sampling locations, the uranium-235/uranium-238 (U235/U238) ratio reflects the natural ratio of 0.00725. It should be noted that there is significant uncertainty in calculating the ratio due to the difficulty of measuring low activities of uranium-238 by gamma spectrometry.

The data collected showed three sampling locations (801N, 801W, and 851N) that may indicate the presence of depleted uranium. The U235/U238 ratios ranged from 0.0044 ± 0.0020 µg/dry g to 0.0065 ± 0.0032 µg/dry g. The depleted uranium at Site 300 results from past use of uranium material in atmospheric explosive experiments.

6.1.2 Non-radiological Analytical Results

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

Detected beryllium concentrations were within the ranges previously reported. Detected concentrations ranged from 0.50 mg/kg at sampling location NPS to 1.0 mg/kg at sampling location 801N. The 801N sampling location is in an area that has historically been used for 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 2022 has not changed from previous years and remains insignificant. Most analytes of interest or concern were detected at background concentrations, in trace amounts, or could not be measured above detection limits.

The highest detected value for plutonium-239+240 was 7.20 ± 0.26 mBq/dry g (0.194 pCi/dry g) at sampling location WRP1. The detected concentration is approximately 1.5% 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 2022 are within the range of previous data and are generally representative of background levels. The U235/U238 mass ratios are indicative of depleted uranium located near the firing tables resulting from historical testing. The highest detected uranium-235 concentration was 0.037 ± 0.013 µg/dry g at sampling location EVAP and is well below the NCRP-recommended screening level for commercial sites (8.2 µg/dry g). The highest detected uranium-238 concentration was at sampling location 801N (8.4 ± 2.2 µg/dry g) and is also well below the NCRP-recommended screening level for commercial sites (313 µg/dry g).

A draft Remedial Investigation/Feasibility Study (RI/FS) was submitted for the Building 812 Operable Unit (OU 9) 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. Upon review of the draft RI/FS, DOE and the regulatory agencies agreed that additional characterization was needed prior to submitting an updated draft RI/FS. 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 2022. Upon completion, a draft and final RI/FS will be prepared. See **Chapter 7** for further details regarding this project.

6.2 Vegetation and Foodstuff Monitoring

Vegetation and foodstuff monitoring is conducted to monitor the potential radiation dose to the public through ingestion. The foodstuff product monitored is wine because it is the main agricultural product in the Livermore Valley surrounding LLNL.

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 then analyzed for tritiated water (HTO) using liquid scintillation techniques.

Wines for sampling in 2022 were purchased from a supermarket in Livermore. The wines represent the Livermore Valley, other regions of California, and the Chablis and Bordeaux regions in France. Wines were prepared for sampling using a method that separates the water fraction from the other wine components and were analyzed using an ultra-low-level scintillation counter.

6.2.1 Vegetation Monitoring Results

2022 median and mean concentrations of tritium in vegetation based on samples collected at the Livermore Site, the Livermore Valley, and Site 300 are shown in **Table 6-1.** See **Appendix A, Section A.9,** for quarterly tritium concentrations in plant water. The highest mean tritium concentration near the Livermore Site in 2022 was 7.7 Bq/L at the near location VIS by the east perimeter of the site. The highest mean concentration measured in the Livermore Valley was 5.3 Bq/L at ZON7. For Site 300, the highest mean concentration in 2022 was 38 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**). Since 1993, median concentrations at the far locations have been below the detection limit of approximately 2.0 Bq/L. Median concentrations at the intermediate locations have been below the detection limit since 1998, except in 2002, 2020, 2021, and 2022 when the median concentrations ranged from 2.1 Bq/L to 2.5 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 all sampling locations (DSW, EVAP, PSTL, and TNK5) were at or below the detection limit.

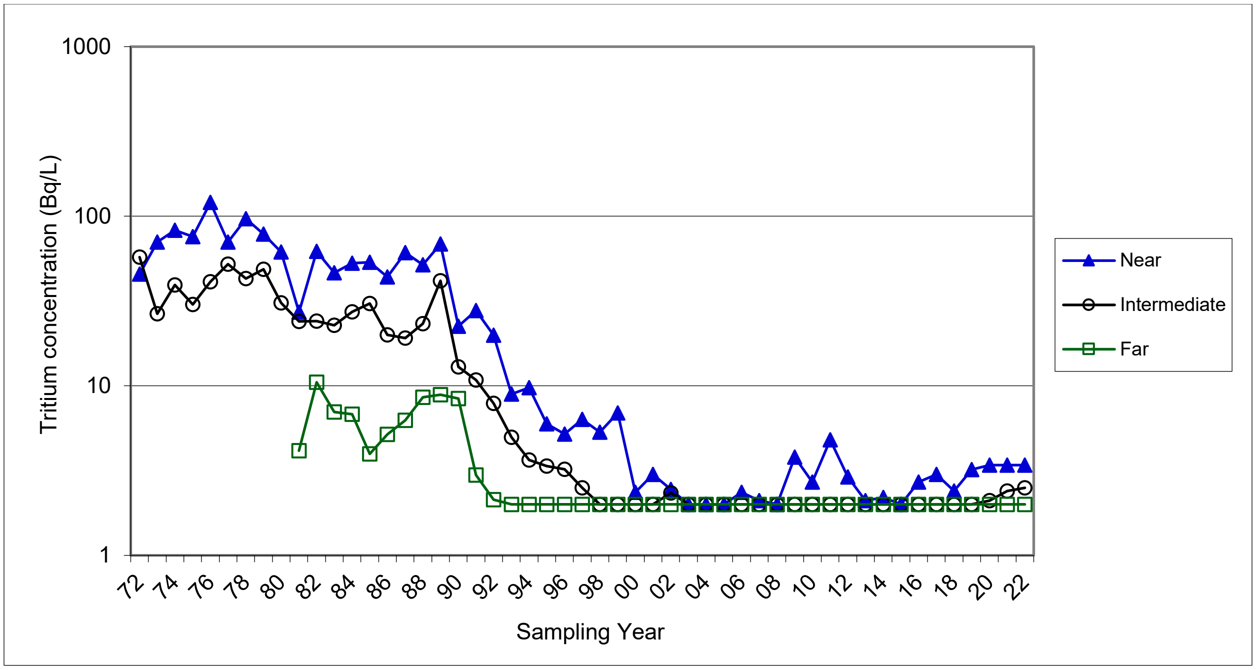

Figure 6-4. Median Tritium Concentrations in Livermore Site and Livermore Valley Plant Water Samples, 1972 – 2022

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.

Table 6-1. Median and Mean Concentrations of Tritium in Plant Water for the Livermore Site, Livermore Valley, and Site 300 in 2022

Sampling Locations		Concentration of Tritium in Plant Water (Bq/L)		Mean Annual Ingestion Dose [(a)] (nSv/y)
		Median	Mean	
NEAR (onsite or <1 km from Livermore Site perimeter)	AQUE	1.9	6.3	38
	GARD	2.6	3.4	20
	MESQ	3.0	3.6	22
	MET	3.4	3.8	23
	NPER	4.4	6.5	39
	VIS	5.1	7.7	46
INTERMEDIATE (1–5 km from Livermore Site perimeter)	I580	3.2	4.5	27
	TESW	2.0	2.0	12
	ZON7	3.8	5.3	32
FAR (>5 km from Livermore Site perimeter)	CAL	0.16	0.15	<10[(b)]
	FCC	1.2	1.2	<10[(b)]
Site 300	DSW[(c)]	1.2	38	[(d)]
	EVAP[(c)]	0.82	10	[(d)]
	PSTL	0.26	0.36	[(d)]
	TNK5	-0.27	0.15	[(d)]

Note: Table includes mean annual ingestion doses calculated for 2022.

(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 at these locations because there is no pathway dose to the public.

6.2.2 Wine Monitoring Results

Tritium concentrations in wines purchased in 2022 are shown in **Table 6-2.** The highest measured concentration in Livermore Valley wine was 3.5 Bq/L (94 pCi/L) from a wine made from grapes harvested in 2019. The highest measured concentration in California (other than the Livermore Valley) wine was 1.9 Bq/L (52 pCi/L) from a wine made from grapes harvested in 2018 from Sonoma County. The highest measured concentration in French wine was 2.3 Bq/L (63 pCi/L) from Petit Chablis appellation wine grapes harvested in 2020.

Based on analyses of wines purchased annually since 1977, tritium concentrations in the French wines are typically higher than tritium concentrations in the Livermore Valley wines. However, in 2022 the average tritium concentration in French wines was less than the average tritium concentration in Livermore Valley wines. Additionally, tritium concentrations in the California (other than the Livermore Valley) wines are typically lower than tritium concentrations in the Livermore Valley wines; this was also the case in 2022.

The Livermore Valley wines represent vintages from 2017, 2018, 2019 and 2021; the California wines represent vintages from 2018 and 2021; and the French wines represent vintages from 2018 and 2020. 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 2022, decay-corrected concentrations ranged from 1.8 to 4.3 Bq/L for Livermore Valley wine samples, 1.6 and 2.4 Bq/L for the two California wine samples, and 1.9 and 2.6 Bq/L for the two French wine samples.

Table 6-2. Tritium in Retail Wine, 2022[a, b]

Sample	Concentration by Area of Production (Bq/L)		
	Livermore Valley	California	Europe
1	1.30 ± 0.48	1.90 ± 0.52	2.30 ± 0.53
2	2.80 ± 0.53	1.50 ± 0.50	1.50 ± 0.51
3	1.80 ± 0.50	-	-
4	1.80 ± 0.50	-	-
5	3.50 ± 0.55	-	-
6	1.90 ± 0.50	-	-
Dose (nSv/y)[c]	5.0	2.7	3.3

(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 2022 sampling. Concentrations are those measured in March 2023.

(c) Calculated based on consumption of 52 L wine per year at maximum concentration. Doses account for organically bound tritium (OBT) and 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 2022, was 46 nSv (4.6 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 that 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 (including OBT) from LLNL operations in 2022 is 92 nSv/y (9.2 µrem/y). This maximum dose is about 1/33,000 of the average annual background dose in the United States from natural sources and about 1/110 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 2022, the highest concentration of tritium (3.5 Bq/L [94 pCi/L]) was just 0.47% 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 2022 would have resulted in a dose of 35 nSv/y (3.5 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 [59 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 (including the contribution of OBT) from drinking Livermore Valley wines in 2022, even at the high consumption rate of one liter per day and at the highest observed concentration, would be about 1/290 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 one (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 2022, 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 (surrogate for gross alpha), and strontium-90 (surrogate for gross beta).

For the LLNL assessment, the maximum concentration of each radionuclide measured in soil and storm water run-off samples at 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 because the maximum concentrations in the media originate from different locations within a large area. This 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 2022, the total sum of the fractions for the aquatic ecosystem animals was 0.079 with the limiting concentrations from radionuclides in water. The total sum of the fractions for the terrestrial ecosystem animals and plants was 0.16 with the limiting concentrations from radionuclides in soil. These fractions for both ecosystems are below one. Therefore, 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 to detect radiation exposure that may be attributed to LLNL operations. This monitoring is conducted using TLDs, which are placed in the following areas: 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 where 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 ($^nLi_2B_4O_7$). For the purposes of gamma radiation dose monitoring, 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 American National Standards Institute (ANSI) recommendations.

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 91-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 2022 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 and then averaging the annual sums for that area. For a typical year, if data is missing for any quarters at a particular location, the annual dose at that location is taken as four times the average of the results available.

Table 6-4. 5-Year Annual Ambient Radiation Dose Summary with Standard Deviation (SD) in Units of mSv and Numbers of Samples [(a)]

Area	Measurement	Year				
		2018	**2019**	**2020[(b) (c)]**	**2021**	**2022**
Livermore Site	Dose ± 1 SD (mSv)	0.581 ± 0.014	0.578 ± 0.015	0.665 ± 0.018	0.631 ± 0.016	0.634 ± 0.018
	Number of Samples	54	55	28	56	54
Livermore Valley	Dose ± 1 SD (mSv)	0.570 ± 0.035	0.547 ± 0.037	0.724 ± 0.12	0.634 ± 0.078	0.613 ± 0.040
	Number of Samples	31	31	14	31	32
Site 300	Dose ± 1 SD (mSv)	0.691 ± 0.029	0.689 ± 0.029	0.818 ± 0.078	0.776 ± 0.031	0.750 ± 0.037
	Number of Samples	30	29	14	33	34
Site 300 off-site	Dose ± 1 SD (mSv)	0.680 ± 0.13	0.658 ± 0.11	0.944 ± 0.18	0.732 ± 0.13	0.755 ± 0.21
	Number of Samples	7	7	3	8	7
Tracy	Dose ± 1 SD (mSv)	0.639 ± 0.039	0.643 ± 0.034	0.750 ± 0.091	0.595 ± 0.20	0.703 ± 0.06
	Number of Samples	8	8	4	7	4

(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.

(b) In 2020, the method for calculating the quarterly doses was updated to better reflect recommendations in ANSI/HPS N13.37-2014 (R2019), resulting in higher annual averages.

(c) In 2020, there are fewer samples than other years because one set of TLDs was deployed for an extended period. Due to COVID-19 pandemic restrictions, the first quarter TLDs were in the field for three quarters. The reported results still represent the entire calendar year.

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 2022 indicate there were no detectable elevations in ambient radiation dose resulting from LLNL operations. Radiation doses for each area are consistent with those of previous years.

In 2020, the method for calculating the quarterly doses was updated to better reflect recommendations in ANSI/HPS N13.37-2014 (R2019), resulting in higher annual averages. If these were calculated using previous methods, the results for 2020, 2021, and 2022 would be 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 special 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*), which is listed as threatened under the ESA and is a 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 threatened under both the ESA and CESA and has been observed in areas adjacent to the Livermore Site. Portions of the Livermore Site are considered potential upland habitat for the California tiger salamander due to the proximity of known observations and breeding pools. There is no breeding habitat for the California tiger salamander at the Livermore Site. The Swainson's hawk (*Buteo swainsoni*), a species listed under the CESA but not the federal ESA, is also known to occur at the Livermore Site.

Five species 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*). All of Site 300 is designated critical habitat for the California red-legged frog and portions of Site 300 are critical habitat for the large-flowered fiddleneck and the Alameda whipsnake. 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 the San Joaquin kit fox has been observed in proximity to Site 300, potential impacts to this species should be considered. Three additional species are listed under the CESA, but not the federal ESA, and are known to occur at Site 300. Two species listed as threatened under the CESA, the tricolored blackbird (*Agelaius tricolor*) and the Swainson's hawk, regularly occur at Site 300. A third species, the California-endangered willow flycatcher (*Empidonax traillii*), was observed at Site 300 once and is expected to occur infrequently as a migrant in riparian habitat 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 SSC are listed in **Appendix B.** A similar list for the Livermore Site is available in Appendix I of the Draft Sitewide Environmental Impact Statement for Continued Operations of the Lawrence Livermore National Laboratory (SWEIS) (DOE 2022).

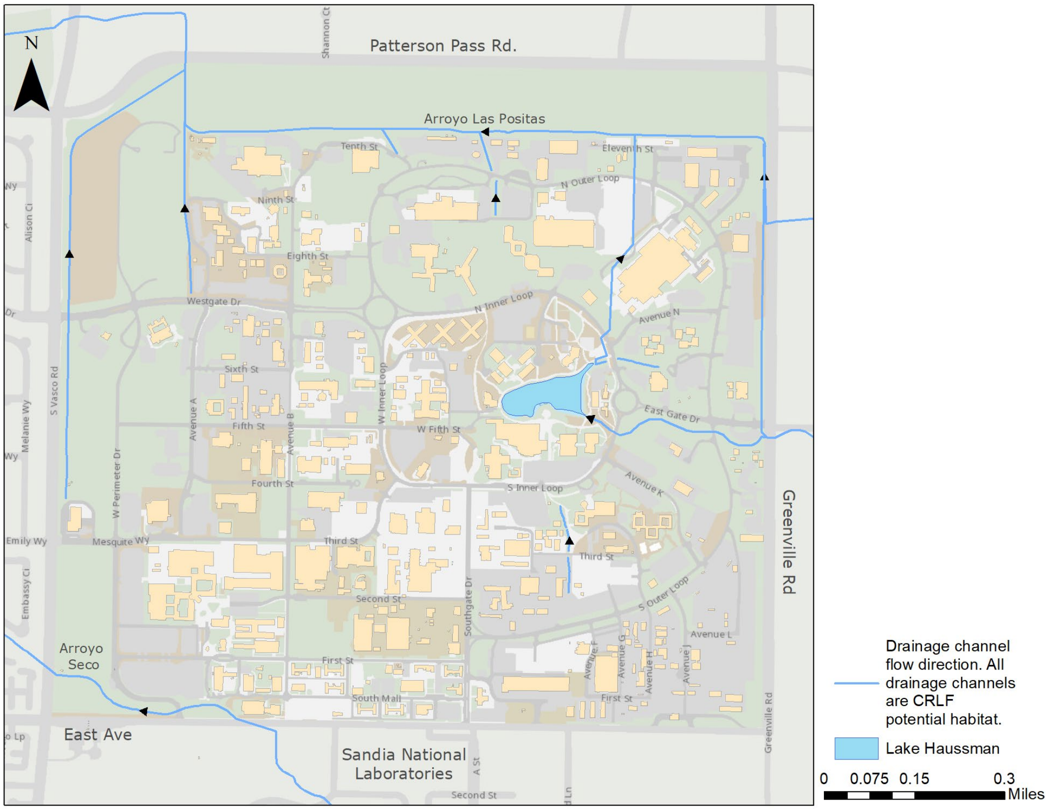

Figure 6-5. Potential California Red-Legged Frog Aquatic Habitat, Livermore Site

Including the endangered large-flowered fiddleneck, four rare plant species and three uncommon plant species are known to occur at Site 300. The four rare species include the large-flowered fiddleneck, the big tarplant (*Blepharizonia plumosa*), the diamond-petaled California poppy (*Eschscholzia rhombipetala*), and the shining navarretia (*Navarretia nigelliformis* ssp. *radians*) – all have a California Rare Plant Rank (CRPR) of 1B (CNPS 2022). A fifth species, the round-leaved filaree *(California macrophylla),* was previously considered rare, but its status was downgraded and is no longer considered rare (CNPS 2022).

The three uncommon plant species – California androsace (*Androsace elongata* subsp. *acuta*), stinkbells (*Fritillaria agrestis*), and hogwallow starfish (*Hesperevax caulescens*) – have a CRPR of 4.2 (CNPS 2022). Past surveys have failed to identify any rare plants at the Livermore Site (Preston 1997, 2002).

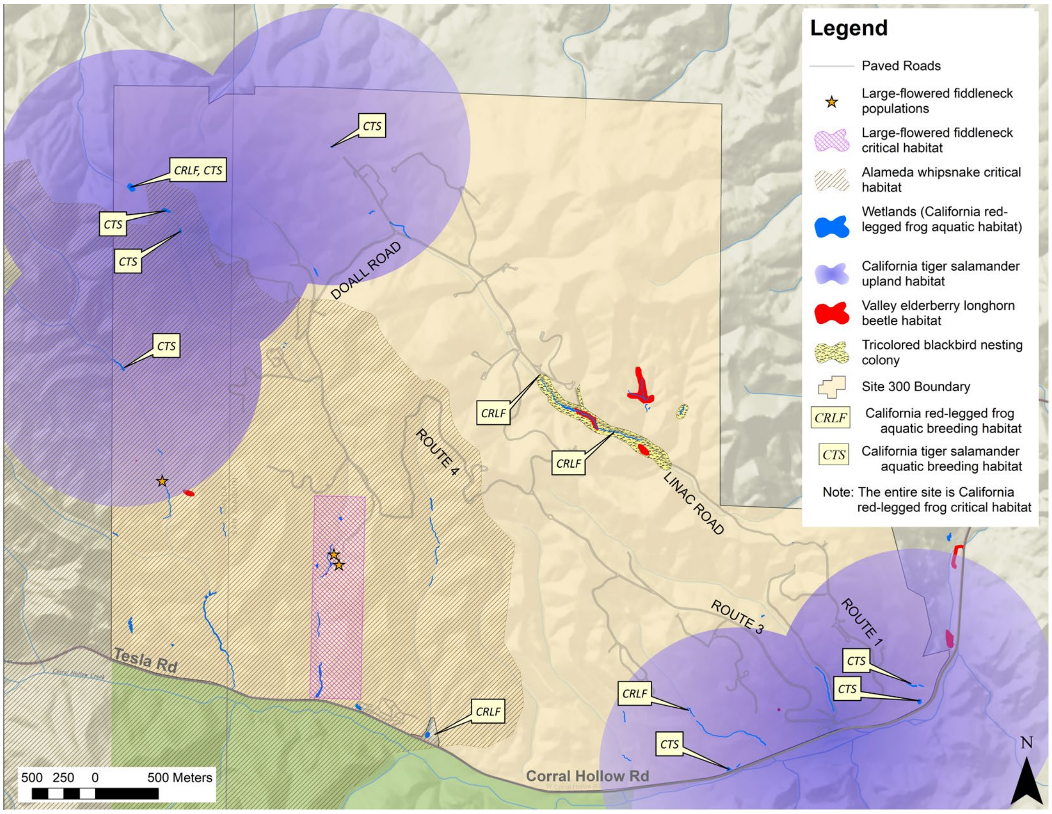

Figure 6-6. Protected Habitat for Species Listed Under the Federal and California Endangered Species Acts, Site 300

6.5.1 Surveillance Monitoring

6.5.1.1 Avian Monitoring

LLNL conducts seasonal nesting bird surveys and monitoring to ensure compliance with the Migratory Bird Treaty Act and prevent impacts to nesting birds.

Livermore Site Nesting Bird Surveys. LLNL conducted routine site-wide breeding raptor surveys during the 2022 nesting bird season at the Livermore Site. Two pairs of Swainson's hawks nested at the Livermore Site in 2022 – one failed and one successfully fledged one nestling. The nest failure was located on the southern edge of the site along East Avenue in a tree on Sandia National Laboratory (SNL) property. The second nest, which fledged one nestling, was located at the northern perimeter of the Livermore Site along Arroyo Las Positas. While white-tailed kites are typically observed at the Livermore Site, no white-tailed kite nests were discovered in 2022. Three common raven nests located near B581, B362, and the on-site substation successfully fledged young. Two red-tailed hawk nests were known on-site – one along East Avenue and one at the corner of Greenville Road and Lupin Way. Both nests are presumed to have fledged a single nestling based on observations and typical nest timing for the species (Preston and Beane, 2020). One red-shouldered hawk nest near B481 failed during the nestling stage.

Site 300 Burrowing Owl Bird Surveys. Sitewide surveys for nesting burrowing owls (*Athene cunicularia)* were conducted at Site 300 in 2022. The burrowing owl is protected by the federal Migratory Bird Treaty Act and is a California SSC. Sitewide burrowing owl surveys are conducted annually to ensure nesting owls are not impacted by site operations and maintenance. Five nesting burrowing owl pairs were observed at Site 300 in 2022. Compared to 2021, the number of nesting pairs decreased in 2022. The five nesting pairs in 2022 were observed to successfully rear at least 11 fledglings. In 2021, the six successful burrowing owl pairs reared at least six fledglings. Although there were fewer pairs in 2022, they were overall more successful than the 2021 breeding population.

Site 300 Nesting Bird Surveys. In addition to the burrowing owl monitoring described above, nesting raptor and corvid locations were recorded at Site 300 on a weekly basis during the nesting bird season and during construction monitoring in 2022. Nesting raptor surveys were conducted in areas of programmatic activity and do not include remote areas of the site. Incidental observations of nesting raptors in remote areas of Site 300 were also recorded during fire trail surveys, but these survey results do not represent the distribution of raptors throughout Site 300. The following were observed during these surveys: five pairs of nesting red-tailed hawks, one pair of nesting great-horned owls (*Bubo virginianus*), five pairs of common ravens, and one barn owl nest. Four of the five suspected red-tailed hawk nests fledged successfully, the great-horned owl pair was observed to rear one fledgling, three of the five common raven nests successfully fledged in 2022, and the fate of the barn owl nest was unknown.

Site 300 Tricolored Blackbird Surveys. Tricolored blackbirds regularly nest in the wetland habitat located within the Elk Ravine riparian corridor at Site 300. LLNL biologists annually monitor tricolored blackbird nesting success at this location. In 2022, only incidental tricolored blackbird surveys were conducted. These surveys indicated that tricolored blackbirds were present in Elk Ravine in March 2022. Although observations of nest-building behaviors were observed, no birds were detected in early April, suggesting that nesting attempts were not successful in 2022.

6.5.1.2 Amphibian Monitoring

Livermore Site California red-legged frog monitoring. In 2021, LLNL conducted extensive diurnal and nocturnal surveys for California red-legged frogs in Arroyo Las Positas, Arroyo Seco, Lake Haussmann, and drainages throughout the site in support of SWEIS data collection. In 2022, routine diurnal and nocturnal surveys for California red-legged frogs were conducted. Diurnal surveys for California red-legged frog egg masses were also conducted at the Livermore Site in 2022. No California red-legged frogs or egg masses were observed during 2022 survey efforts.

Although no California red-legged frogs were observed at the Livermore Site in 2022, this species has been observed infrequently over the last several years, indicating that the California red-legged frog continues to be an uncommon resident of the Livermore Site. Two juvenile California red-legged frogs were observed in Lake Haussmann in the fall of 2014, which is evidence of successful California red-legged frog reproduction. Although no evidence of

California red-legged frog reproduction has been observed since 2014, adult California red-legged frogs have continued to be infrequently observed.

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 was conducted; no California red-legged frogs were observed at the Livermore Site during these years. There were multiple sightings of adult California red legged frogs in 2019. Two sightings occurred in Arroyo Las Positas – one during a non-routine survey inspection and the other during a routine amphibian survey during breeding season. An additional observation occurred at Lake Haussmann during invasive wildlife control in the summer of 2019. One adult California red-legged frog was observed within Arroyo Las Positas during 2020.

In 2021 observations of the American bullfrog (*Lithobates catesbeianus*), a non-native invasive species, decreased dramatically at the Livermore Site. Lawrence Livermore National Security (LLNS) continued minimal operations in 2021 due to the COVID-19 pandemic, which reduced the amount of treated groundwater discharge and water flow into Arroyo Las Positas. There continued to be a dramatic decline of American bullfrogs across the site in 2022. Additionally, confirmed sightings of a North American river otter (*Lontra canadensis)* were made in Lake Haussmann, which may have contributed to declining bullfrog numbers.

Site 300 amphibian monitoring. LLNL conducts routine monitoring for the presence and breeding success of special status amphibians at Site 300 including the California red-legged frog and the California tiger salamander. Due to drought conditions, many Site 300 wetlands and seasonal pools remained dry in 2022. Therefore, few observations of California red-legged frogs and California tiger salamanders were made in 2022.

LLNL conducted diurnal and nocturnal surveys within suitable aquatic habitat for California red-legged frogs throughout the site (Pools A, CP, CR, HC1, M1a, M1b, M2, M3, O, OS, S, SG, and an artificial impoundment – Pit 7 v-ditch).

During the 2022 surveys, one adult California red-legged frog and one egg mass were observed in Pools M1a and M1b. Tadpoles, which were determined to be California red-legged frogs based on size, were present during later surveys at this location. Pools S and SG had no inundation present during the 2022 survey period and additional surveys were suspended at these locations. Pool M3 did not retain inundation long enough to allow for successful amphibian breeding in 2022. There were no observations of California red-legged frog egg masses, tadpoles, subadults, or adults at any of the other surveyed locations in 2022.

Diurnal surveys were also conducted to monitor the breeding success of California tiger salamanders at several seasonal pools at Site 300. In 2022, diurnal surveys were conducted at nine seasonal pools (Pools A, H, M2, HC1, S, OS, M3, Lower Pool D, and Upper Pool D) and an artificial impoundment (Pit 7 v-ditch). These pools regularly support California tiger salamander breeding in years with average or above average rainfall. Although California tiger salamander eggs were recorded in Pool OS and in the Pit 7 v-ditch, neither location held water for long enough for larval salamanders to survive to become adults. No California tiger salamanders of any life-stage were found in any of the other surveyed locations due to insufficient inundation.

6.5.1.3 Rare Plant Monitoring

Large-Flowered Fiddleneck. This species has recently been known to occur in only four native populations. This includes two populations at Site 300 (the Drop Tower and Draney Canyon populations), a population located on mitigation property owned by the Contra Costa Water District, and a newly discovered population located near Antioch on property recently acquired by the East Bay Regional Park District. No large-flowered fiddleneck plants have been observed at Draney Canyon on Site 300 since a landslide occurred there in 1997. The Drop Tower native population also contained no large-flowered fiddleneck plants in 2022.

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 and seedlings in established plots within the population. As a result of enhancement efforts, the size of the experimental population fluctuates. Seeds were last planted in November 2012 and 280 seedlings were planted in January 2017. The Drop Tower experimental population contained approximately 25 large-flowered fiddleneck plants in the spring of 2022.

Big Tarplant. The distribution of big tarplant was mapped at Site 300 using a handheld global positioning system (GPS) from September – November 2022. Approximately 8,000 – 26,000 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 recently occurred. As is typical with annual plant species, the abundance of big tarplants varies significantly from year to year depending on environmental conditions. For example, while the Site 300 big tarplant population was estimated to contain approximately 2,700 individual plants in 2014, there were approximately 214,000 big tarplants 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. Four populations of this species are known to occur at Site 300; these populations are referred to as Sites 1 – 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 population in 2015 was attributed to less dense annual grass coverage due to drought conditions. In contrast, only four diamond-petaled California poppies were observed at Site 300 in 2017. The mean number of diamond-petaled California poppy plants observed at Site 300 from 2004 – 2021 is 5,829. This includes the high population of approximately 46,000 plants in 2015, which is approximately 44,500 more than the second highest population number recorded in 2021. The median number of diamond-petaled California poppy plants observed at Site 300 from 2004 – 2021 is 845. In 2022, approximately 1,708 diamond-petaled California poppies were observed in all Site 300 populations.

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 the region. At the Livermore Site, the American bullfrog is a significant threat to California red-legged frogs. At Site 300, the feral pig (*Sus scrofa*) threatens numerous protected habitat types. The exotic largemouth bass (*Micropterus salmoides*) has been successfully removed from Lake Haussmann at the Livermore Site since 2017.

At the Livermore Site, bullfrog control measures were implemented from May – September 2021. Adult bullfrogs were dispatched to Lake Haussmann and Arroyo Las Positas. Typically, bullfrog egg masses would also be removed, but no egg masses were observed in 2022. Additionally, to remove bullfrog tadpoles and invasive fish, the LLNL reach of Arroyo Las Positas was allowed to dry out in September 2022 by temporarily halting groundwater discharges to the arroyo.

At Site 300, feral pig control measures were implemented from March – October 2022. Adults and associated litters were dispatched. Site 300 continues to protect its critical habitats and rare species by implementing consistent swine control practices.

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 implements 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.

From 2014 – 2022, over 50 power poles have been modified for bird protection at Site 300 as part of a site-wide revitalization project. These bird-friendly modifications include creating safe perch sites and limiting access to areas with possible electrical hazards. Specifically, the following actions have been 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 online 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 conducts annual maintenance and habitat management within the Arroyo Las Positas at the Livermore Site to reduce potential flooding of LLNL facilities and to improve the habitat value for the federally threatened California red-legged frog and other native species. Maintenance was conducted in three 300-foot reaches of Arroyo Las Positas in September 2022. For the eighth consecutive year, willows and cottonwoods were planted to eventually shade the arroyo and reduce cattail growth, which will also reduce the need for future maintenance. Additionally, willows and cottonwoods will provide cover that can be utilized by the California red-legged frog and other native wildlife. All work conducted within the channel of Arroyo Las Positas is monitored by a biologist approved by the USFWS to conduct monitoring under the Arroyo Las Positas Biological Opinion. In 2022, no California red-legged frogs were seen or heard during a diurnal pre-activity and monitoring survey at this location. After the 2015 – 2016 and 2018 – 2022 maintenance was completed, willows and cottonwoods were planted along the south bank of the arroyo. The 2022 survivorship of planted willows and cottonwoods met project requirements. Two maintenance sections received plantings for the first time during 2022 maintenance. Willow and cottonwood coverage, as a dominant vegetation type, increased from 16.1% in 2015 to 41.4% in 2022. By implementing invasive tree species removal, she-oak (*Casaurina* sp.) coverage has been reduced to 6.5% of the total length of the project site in 2022 compared to 15% 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) and permits issued by the Army Corps of Engineers (ACOE) and the Regional Water Quality Control Board (RWQCB). California red-legged frogs were translocated to the new habitat enhancement pools in Elk Ravine (Pools M1a and M1b) in February and March 2006. In the summer of 2014 and fall of 2021, both pools were dredged to remove extra sediment. This increased pool depths to the original 8 – 10 feet, improving the value of this habitat for California red-legged frog breeding. During dredging operations, overgrown vegetation (including cattails, nettles, and willows) was removed to increase breeding habitat suitability. Monitoring demonstrated that California red-legged frogs successfully reproduced in these pools from 2006 – 2019. No California red-legged frog eggs or tadpoles were encountered within the mitigation pools at mid Elk Ravine in 2020 and 2021 due to drought conditions. In 2022, one California red-legged frog adult, tadpoles, and one egg mass were observed within Elk Ravine (Pools M1a and M1b). Although California red-legged frogs were not observed to reproduce in the habitat enhancement pools in 2019 or 2020, they were able to successfully find breeding habitat in Elk Ravine upstream of Pools M1a and M1b in 2020. California red-legged frog adults, tadpoles, and one egg mass were observed within Pool CR in Elk Ravine upstream of Pools M1a and M1b in 2020.

6.5.3.4 Pool M2 Habitat Enhancement

Three ephemeral pools (Pools A, H, and M2) located in the northwest corner of Site 300 provide California tiger salamander breeding habitat. Pools A and 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 in 2013 at Pool M2 when the clay liner of this pool was augmented to limit infiltration or loss of water through the bottom of the pool. Pool M2 was filled in 2006, 2010 – 2011, and 2015 – 2017 and California tiger salamanders successfully reproduced at this location. In 2007 – 2009, 2012 – 2014, 2018, and 2020 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 Pools M2, H, A, and HC1. Additionally, Pools M2 and A had sightings of California tiger salamander larvae. Although California tiger salamander larvae were observed in all three pools, only Pools A and HC1 were inundated long enough for these larvae to mature into adult salamanders. In 2021 and 2022, no California tiger salamanders, eggs, or larvae were observed in any of these pools and no pools held enough water for salamanders to undergo metamorphosis.

6.5.3.5 Pool HC1 Habitat Enhancement

In 2006, LLNL completed culvert replacement projects within Draney Canyon at Site 300 (the Oasis and Round Valley) where unpaved fire trails crossed intermittent drainages. In 2006, a pool was created within the channel of Draney Canyon to provide California red-legged frog breeding habitat. The Oasis pool was disturbed by feral pigs soon after its construction and no longer holds water to a depth to support California red-legged frog reproduction. Amphibian surveys were conducted at the Oasis in 2020. Although California red-legged frog reproduction was not observed at the Oasis, adult and subadult frogs were found during 2020 surveys. The 2006 Round Valley project included the creation of Pool HC1 to mitigate 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 to limit infiltration or loss of water through the bottom of the pool. In 2016, Pool HC1 completely filled and California tiger salamander eggs and larvae were observed. In 2017, Pool HC1 initially filled but did not hold water long enough for salamander larvae 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 held water long enough for California tiger salamanders to undergo metamorphosis during the season. However, Pool HC1 did not hold water long enough for California tiger salamanders to undergo metamorphosis during the 2020 – 2022 seasons and no salamander eggs or larvae were observed in these years.

6.5.3.6 Pool M3 Habitat Enhancement

In the fall of 2014, LLNL formally set aside 48.5 acres and completed the enhancement of the Pool M3 breeding site for California tiger salamanders. In 2016, California tiger salamanders successfully reproduced in this pool, which represented the second successful breeding attempt since completion of the 2014 restoration activities. In 2017, California tiger salamander eggs were observed at Pool M3, but the pool did not hold water long enough for salamander larvae to mature. In the summer of 2017, the clay liner at Pool M3 was enhanced to increase the hydroperiod of this pool. From 2019 – 2022 Pool M3 did not fill to a depth or duration suitable for California tiger salamander reproduction.

6.5.4 Environmental Impacts on Special Status Wildlife and Plants

In 2022, LLNL avoided significant impacts to special status wildlife, plants, and their habitats by conducting monitoring and implementing avoidance and minimization measures. Habitat enhancement, avian protection, and invasive species control efforts benefited protected species. LLNL continues to monitor and maintain several restoration sites, habitat enhancements, and conservation areas that are beneficial to native plants and animals at the Livermore Site and Site 300 to ensure the protection of listed and special status species.

This page is intentionally left blank.