Site Environmental Report for 2017

September 2018

Lawrence Berkeley National Laboratory
Environment, Health & Safety Division

LBNL-27170E-2018

DISCLAIMER

Department of Energy
Office of Science
Berkeley Site Office
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-1023
Berkeley, California 94720

SEP 18 2018

DISTRIBUTION

Subject: 2017 Site Environmental Report (SER) for the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL)

This report, prepared by LBNL for the U.S. Department of Energy, Berkeley Site Office (DOE/BSO), provides a comprehensive summary of the environmental program activities at LBNL for calendar year 2017. SERs are prepared annually for all DOE sites with significant environmental activities, and distributed to relevant external regulatory agencies and other interested organizations or individuals.

To the best of my knowledge, this report accurately summarized the results of the 2017 environmental monitoring, compliance, and restoration programs at LBNL. This assurance can be made based on the reviews conducted by DOE/BSO, and LBNL, as well as quality assurance protocols applied to monitoring and data analyses at LBNL.

A reader survey form is posted with the SER at the LBNL website to provide comments or suggestions for future versions of the report. Your response is appreciated.

Questions or comments regarding this report may also be made directly to DOE/BSO, by contacting Ms. Sue Fields of the Berkeley Site Office at (510) 486-5875, or by mail to the address above, or by email susan.fields@science.doe.gov .

Sincerely,

9/18/18

Paul Golan
Site Office Manager

Site Environmental Report for 2017

September 2018

Cover photo: Dramatic clouds over San Francisco Bay as viewed from the cafeteria at Berkeley Lab. Photograph by Kelly J. Owen, Strategic Communications Department.

This work was supported by the Director, Office of Science, U.S. Department of Energy, under Contract Number DE-AC02-05CH11231.

Table of Contents

Figures

Tables

Executive Summary

Lawrence Berkeley National Laboratory (LBNL, Berkeley Lab) is a multi-program scientific facility operated by the University of California (UC) for the U.S. Department of Energy (DOE). Berkeley Lab's research is focused on the physical, biological, environmental, and computational sciences with the objective of delivering scientific knowledge and discoveries pertinent to DOE's mission. This annual report describes environmental protection activities and potential impacts resulting from LBNL operations conducted in 2017. The format and content of this report satisfy the requirements of both DOE Order 231.1B, Administrative Change 1 (*Environment, Safety, and Health Reporting*) and the operating contract between UC and DOE (DOE Contract No. DE-AC02-05CH11231, also known as Contract 31).

Activities are planned and conducted with full regard to protecting employees, the public, and the environment, as well as complying with all applicable environmental, safety, and health laws and regulations. Berkeley Lab implements an Environmental Management System (EMS) to oversee these compliance activities and continually improve overall environmental performance while maintaining operational capability and sustaining its overall mission.

The effectiveness of the EMS and environmental programs is reviewed annually as part of the performance evaluation process of Contract 31. For fiscal year (FY) 2017, which began October 1, 2016, and ended September 30, 2017, the EMS was given a performance rating of B plus for its management of environmental activities (on a scale from A plus as the highest grade to F as the lowest). The measurement and rating system was developed jointly by Berkeley Lab, UC, and DOE. The FY 2017 rating was based on how Berkeley Lab met the objective in DOE's *FY 2017 Performance Evaluation and Measurement Plan* (Appendix B in Contract 31, Section J) of providing an efficient and effective EMS. Six significant accomplishments, which ranged from effective teaming on projects and with regulatory agencies to improved program assessment approaches, were factors in the rating.

The EMS was also graded through the federal Office of Management and Budget's annual EMS performance metrics, in which a reporting scorecard rates elements of the International Organization for Standardization (ISO) 14001 standard and the degree of integration between the EMS and Berkeley Lab's sustainable practices. Overall scores fall into one of three categories: green (highest), yellow (middle), or red (lowest). For FY 2017, Berkeley Lab received a score of green, as described in more detail in Chapter 2.

An overview of environmental protection and restoration programs is provided (Chapter 3), including information about compliance activities, operating permits, and regulatory agency inspections that occurred during 2017. Thirteen minor violations issued during City of Berkeley inspections of above and underground storage tanks, treatment units, and hazardous waste storage areas are discussed in this chapter.

This report also includes information on environmental monitoring performed in 2017 (Chapter 4). The results of these monitoring activities confirmed that groundwater cleanup actions continue to show improving conditions, and all emissions and discharges from LBNL operations were within environmental compliance release limits, with the exception of some stormwater discharges. Most stormwater discharges measured throughout the LBNL site fall within acceptable levels established by the state's stormwater permit; however, iron and aluminum exceeded

Numeric Action Levels. To reduce iron and aluminum discharge levels, Berkeley Lab is aggressively implementing controls such as construction of asphaltic berms and check dams to restrain and filter runoff to storm drains, and installation of filtration units in storm drain basins to collect sediment and absorb metal contaminants.

The radiological dose assessments (Chapter 5) performed in 2017 concluded that the maximum potential dose to a hypothetical resident from Berkeley Lab's airborne radionuclide releases was approximately 0.1% of the DOE and U.S. Environmental Protection Agency annual limit of 10 millirem per year (mrem/yr); the potential dose from all radiation sources at Berkeley Lab was approximately 0.06% of the average natural background radiation dose of 310 mrem/yr in the United States, and about 0.2% of the DOE annual limit of 100 mrem/yr from all sources.

Preface

Each year Lawrence Berkeley National Laboratory (LBNL, Berkeley Lab) prepares a Site Environmental Report that describes its environmental programs and performance for the most recent calendar year. This report provides an overview of Berkeley Lab, its Environmental Management System, and the status of environmental compliance programs, surveillance and monitoring activities, radiological dose assessment results, and quality assurance measures conducted in 2017. The document meets the reporting requirements of U.S. Department of Energy Order 231.1B, *Environment, Safety, and Health Reporting.*

This report was prepared under the direction of Ron Pauer, the environmental manager for the LBNL Environmental Services Group (ESG). Primary contributors to the report were David Baskin, Ned Borglin, David Diamond, Robert Fox, Zachary Harvey, John Jelinski, Maram Kassis, Ken Kievit, Jennifer Larson, Brendan Mulholland, Jeff Phillibar, Nancy Sutherland, Patrick Thorson, and Suying Xu.

The Site Environmental Report can be viewed or downloaded from the Environmental Publications page of the ESG website (https://ehs.lbl.gov/service/environmental-services/), where many of the documents cited in this report can also be found. Questions about the report can be directed to Ron Pauer at ropauer@lbl.gov or 510-486-7614. Feedback on the report can be provided via a short reader survey form that is also located on the ESG Publications page. Bound copies of Site Environmental Reports are available at the Berkeley Public Library, Oakland Public Library, and UC Berkeley Public Health Library.

1 Site Overview

Lawrence Berkeley National Laboratory (LBNL, Berkeley Lab) is a member of the national laboratory system supported by the U.S. Department of Energy (DOE) through its Office of Science. Under management by the University of California (UC), Berkeley Lab is a multidisciplinary scientific research facility where more than 3,000 scientists, engineers, support staff, and students work year-round, and several thousand more researchers visit each year. This chapter provides a description of the location and physical aspects of the main site.

1.1 LOCATION

Figure 1-1 shows the locations of the LBNL main site and nearby satellite facilities, which are in the eastern region of the San Francisco Bay Area, commonly known as the East Bay. The main site is situated on the ridges and in the draws of Blackberry and Strawberry Canyons in the East Bay Hills about 3 miles east of San Francisco Bay. The site occupies approximately 200 acres of land immediately east of the UC Berkeley campus, and straddles the border of the cities of Berkeley and Oakland in Alameda County.

Figure 1-1 LBNL Main Site and Satellite Facility Locations in the East Bay

The LBNL site and the majority of the land bordering it is owned by UC (see Figure 1-2). Most of the land to the south and east of the site is maintained in its natural state and adjoins wilderness and recreation areas. Nearby points of interest include UC Berkeley's Strawberry Canyon Recreational Area, Botanical Garden, Lawrence Hall of

Science, and East Bay Regional Park District's Tilden Regional Park. To the north of Berkeley Lab is a low-density residential neighborhood of single-family homes, and to the west and southwest is a highly urbanized area that includes the UC Berkeley campus, commercial zones, and residential areas. LBNL satellite facilities in Berkeley, Emeryville, Oakland, and Walnut Creek consist of leased buildings in developed urban areas.

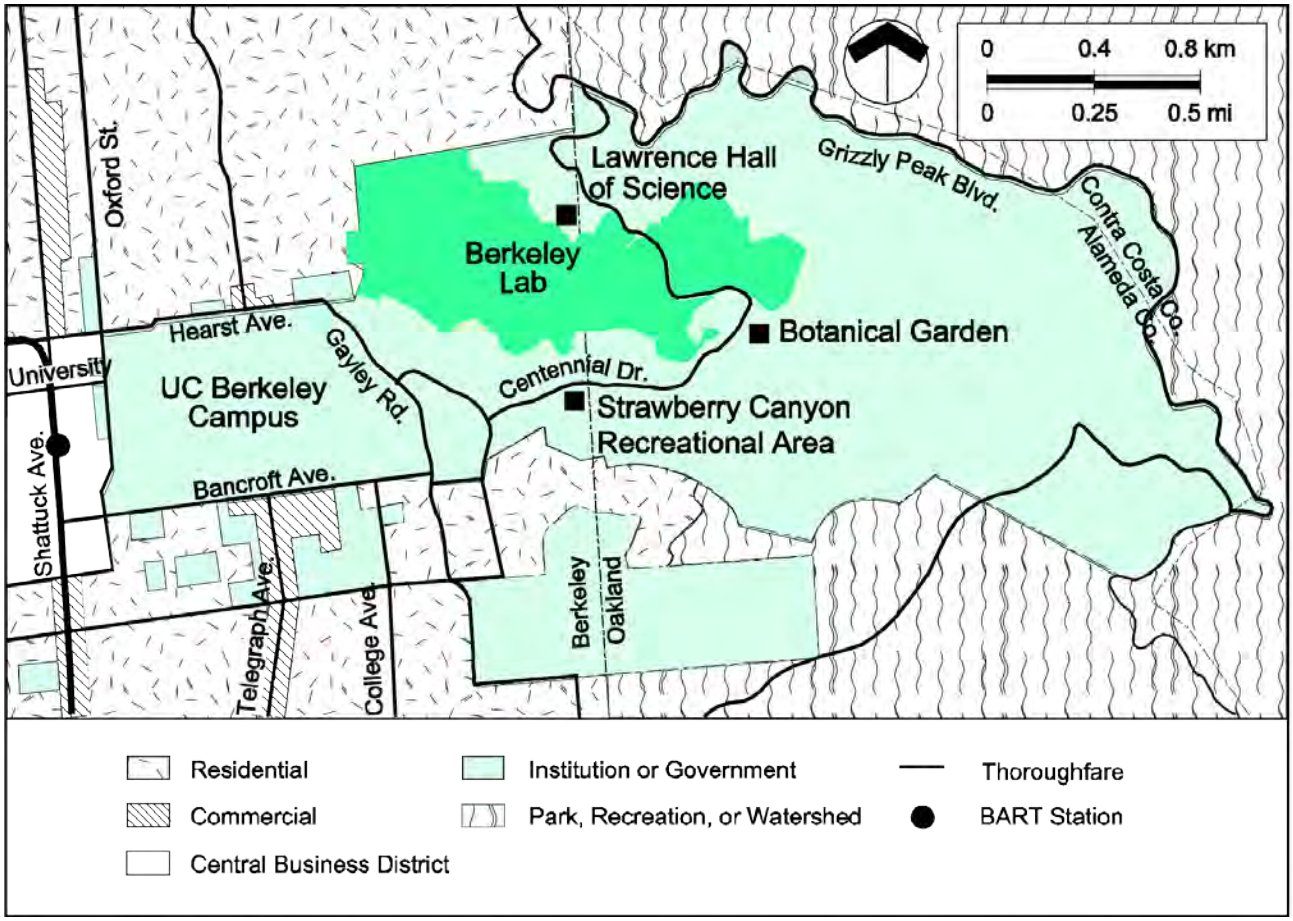

Figure 1-2 LBNL Main Site and Adjacent Land Use

1.2 ENERGY SUPPLY

Electricity and natural gas are the two sources of energy used to operate research and support facilities at Berkeley Lab. Nearly all electric power for the LBNL site is provided by the Western Area Power Administration, with a small amount of renewable power obtained from a solar power array located at Lawrence Livermore National Laboratory. Power purchases are arranged through DOE's Northern California Power Purchase Consortium, which serves the electric power needs of the DOE facilities in the San Francisco Bay Area: Berkeley Lab, Lawrence Livermore National Laboratory, and the SLAC National Accelerator Laboratory. Natural gas is provided by the Defense Logistics Agency and is transported through infrastructure belonging to the Pacific Gas and Electric Company. In 2017, renewable electricity energy consumption accounted for nearly half of total energy use by Berkeley Lab.

1.3 WATER SUPPLY

The East Bay Municipal Utility District (EBMUD) supplies domestic water, which originates in Sierra Nevada watershed lands and is conveyed to the Bay Area and ultimately to Berkeley Lab through a system of rivers, lakes, aqueducts, treatment plants, supply lines, and pumping stations. EBMUD tests the water for contaminants and treats it to meet disinfection standards required by the 1974 Safe Drinking Water Act. Three large tanks store water on site for emergencies. No water supply wells are located on site.

1.4 METEOROLOGY

The temperate climate at the main site – cool, dry summers and relatively warm, wet winters – is heavily influenced by the moderating effects of nearby San Francisco Bay and the Pacific Ocean to the west, and the East Bay Hills to the east. Temperatures typically range between 40 degrees Fahrenheit (°F) and 70°F, with an average annual temperature of 55°F. The temperature seldom exceeds 90°F or drops below 32°F. The maximum and minimum temperatures in 2017 were 105°F and 36°F, respectively.

Based on measurements taken on site beginning in the early 1960s, the precipitation total for a "water year" averages 29.11 inches of rain (with no record of measurable snow). Hydrologists and climatologists use the term *water year* to represent rainfall occurring between October 1 of one year and September 30 of the next year because it characterizes California's seasonal rainfall cycle better than a calendar year. The precipitation total for the 2016/2017 water year – at 46.3 inches – was the fourth wettest of the 55 seasons of measurements, and it ended 5 consecutive dry seasons.

Wind patterns recorded at the on-site meteorological station change little from year to year, as shown by the "wind rose" graphical comparison on Figure 1-3. The wind rose on the left shows the distribution of wind patterns for 2017, while the one on the right summarizes the wind patterns at the site since 1994. The most common wind pattern occurs with westerly winds blowing off the bay and ocean. The other predominant wind pattern is associated with stormy weather when south-to-southeast winds precede a storm system, then shift to the west or northwest after it passes.

1.5 VEGETATION

Vegetation at Berkeley Lab and the area surrounding it comprises native plants, naturalized exotics, and ornamental species. Figure 1-4 presents an aerial view of the site's vegetation and ground cover. Extensive grazing and farming occurred in this region for about 150 years before Berkeley Lab development began in the 1930s. Vegetation is now managed in harmony with the local natural succession of native plant communities, as is evident in the less developed areas, where the wooded and savanna character is being maintained. Ornamental species are generally restricted to courtyards and areas adjacent to buildings. No known rare, threatened, or endangered plant species are present on site.

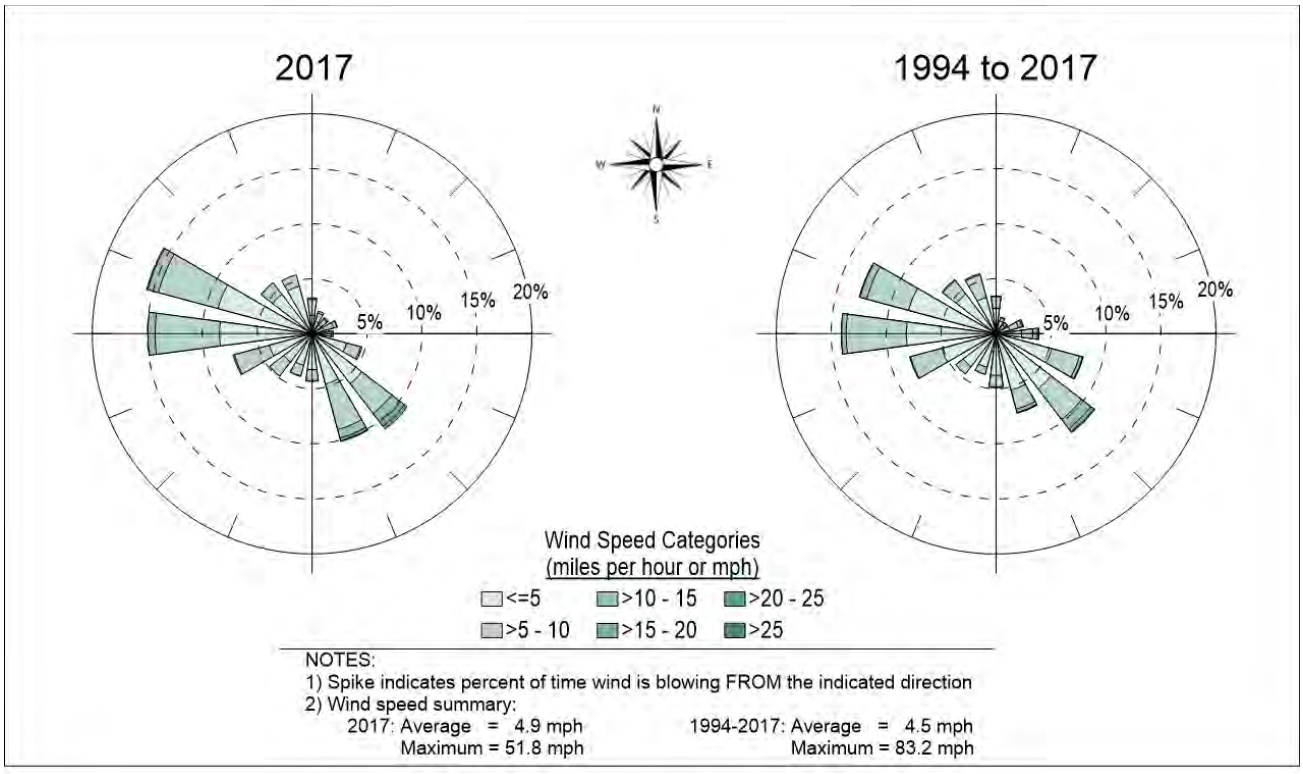

Figure 1-3 Annual Wind Patterns from 1994 to 2017

Figure 1-4 Vegetation at LBNL Site and the Surrounding Area

1.6 WILDLIFE

Wildlife is common at Berkeley Lab as the site is adjacent to large tracts of open space land owned by the East Bay Regional Park District and UC. More than 120 species of birds, mammals, reptiles, and amphibians are thought to inhabit or traverse the site. These species are typical of those found in disturbed (previously grazed) areas of mid-latitude California with a temperate climate. The most abundant large mammal is the Columbian black-tailed deer.

The following habitats on site are protected by environmental laws or LBNL land use policies for species at risk:

- A small area of about 1 acre on the south-facing slope of Blackberry Canyon may be inhabited by the arachnid Lee's micro-blind harvestman (*Microcina leei*). *M. leei* is extremely rare and considered a California "special animal."
- An approximately 5-acre area at the site's eastern boundary is included in the U.S. Fish and Wildlife Service's designated critical habitat for the Alameda whipsnake (*Masticophis lateralis euryxanthus*). This subspecies of the California whipsnake is listed as threatened under both federal and state law.

1.7 GEOLOGY

Three principal bedrock units underlie most of the site, as follows:

1. **Great Valley Group.** Marine mudstones, sandstones, and shales of this unit underlie the western and southern portions of the site. The permeability of these rocks is relatively low, so the rate of groundwater flow is also low.
2. **Orinda Formation.** Non-marine sedimentary rocks of this unit overlie the Great Valley Group and constitute the exposed bedrock underlying most of the site's developed area. The Orinda Formation consists primarily of sandstones, mudstones, and conglomerates deposited in fluvial and alluvial environments. The permeability of this formation is generally much lower than that of the underlying Great Valley Group or overlying Moraga Formation, so groundwater flow rates in this unit are also very low.
3. **Moraga Formation.** This unit consists of volcanic rocks that underlie most of the higher elevations, as well as much of the central developed area, which is commonly referred to as "Old Town." The Moraga Formation constitutes the main water-bearing unit at the site. Permeabilities and groundwater flows are significantly higher in this unit than in the Great Valley Group and the Orinda Formation.

In addition to the bedrock units described above, the Claremont Formation (primarily marine chert and shale) and the San Pablo Group (primarily marine sandstones) underlie small areas in the easternmost part of the site. In many areas of the site, the main bedrock units described above are overlain by unconsolidated surficial materials consisting primarily of soil, colluvium (sedimentary deposits that have accumulated by mass wasting processes on, or at the foot of, hill slopes), and artificial fill. Soil derived primarily from the bedrock units has accumulated to typical thicknesses of 3 or more feet across much of the site. Engineered cutting (i.e., excavation of rock and soil) and filling (i.e., placement of fill composed of compacted soils derived from nearby areas) of the hilly terrain has been necessary to provide suitable building sites for some building locations.

1.8 SURFACE WATERS

Berkeley Lab lies within the Strawberry Creek watershed. The two main creeks in this watershed receiving stormwater discharges from the LBNL site are the South Fork of Strawberry Creek (in Strawberry Canyon) and the North Fork of Strawberry Creek (in Blackberry Canyon). The creeks, which merge downstream from the LBNL site on the UC Berkeley campus, are shown on Figure 1-5, along with key tributaries on or near the site.

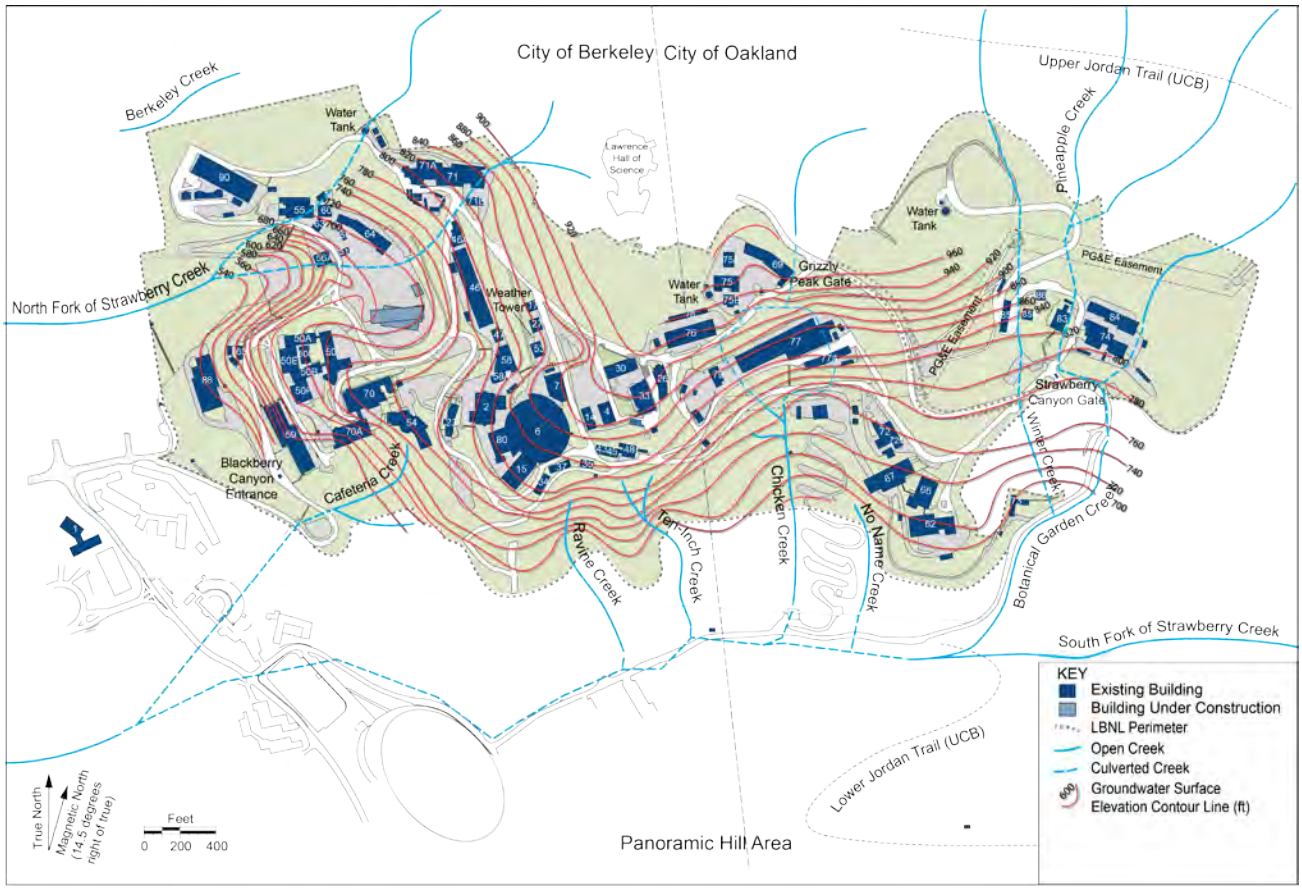

Figure 1-5 Surface Water Locations and Groundwater Elevations at Berkeley Lab

1.9 GROUNDWATER

Figure 1-5 also depicts groundwater elevation contours. The water table approximately mirrors surface topography, flowing from higher to lower elevation. Groundwater flow in the western portion of the site is generally westward toward Blackberry Canyon, while flow in other parts of the site is generally southward toward Strawberry Canyon. The depth to groundwater varies from the ground surface to 100 feet below the surface, depending on location.

2 Environmental Management System

2.1 BACKGROUND

DOE Order 436.1, *Departmental Sustainability* (DOE, 2011a), requires that DOE sites such as Berkeley Lab develop and maintain an Environmental Management System (EMS) that conforms to the ISO 14001 standard, *Environmental Management Systems – Requirements with Guidance for Use* (ISO, 2015). Berkeley Lab has established an EMS that ensures that environmental activities reduce environmental impacts and are well managed, cost-effective, and compliant. The EMS strives for continual improvement in environmental performance through the four-step "Plan-Do-Check-Act" framework for management systems.

DOE Order 436.1 also requires that a site's sustainability goals be integrated into the EMS. Berkeley Lab's Annual Site Sustainability Plan sets performance goals in the following areas:

- Greenhouse gas reduction
- Sustainable buildings
- Clean and renewable energy
- Water use efficiency and management
- Fleet management
- Sustainable acquisition
- Pollution prevention and waste reduction
- Energy performance contracts (accelerate investment in cost-effective energy conservation measures)
- Life-cycle stewardship of electronics
- Climate change resilience

In total, more than 30 sustainability goals are set forth in these areas by Executive Order 13693, *Planning for Federal Sustainability in the Next Decade*, issued in 2015. Berkeley Lab's Site Sustainability Plan each year is available online at http://sbl.lbl.gov/results/reports.html.

2.2 FRAMEWORK OF THE ENVIRONMENTAL MANAGEMENT SYSTEM

Key elements of the ISO 14001 standard that contribute to the framework of Berkeley Lab's EMS are described in the following subsections.

2.2.1 Leadership and Commitment

The mission of Berkeley Lab's Operations directorate is to anticipate and safely deliver exceptional operational services in support of the scientific mission of Berkeley Lab through effective and efficient infrastructure and programs. The framework for LBNL operations is defined in a collection of policies, the *Requirements and Policies Manual* (PUB-201), which covers a broad range of topics, including policies for EMS and specific environmental programs. The objective of the manual is to translate DOE and UC requirements and federal, state, and local requirements into actionable everyday language for LBNL employees.

The Environment/Health/Safety (EHS) Division of LBNL Operations is chartered with the mission of helping Berkeley Lab achieve its commitment to perform all work safely and in a manner that strives for the highest degree of protection for employees, guests, the public, and the environment.

The EMS specifically demonstrates Berkeley Lab's commitment to the following environmental practices:

- Complying with applicable environmental, public health, and resource conservation laws and regulations
- Preventing pollution, minimizing waste, and conserving natural resources
- Mitigating environmental hazards and cleaning up existing environmental problems
- Continually improving environmental performance while maintaining operational capability
- Sustaining Berkeley Lab's overall mission

These practices are incorporated into Berkeley Lab's *Environmental Management System Plan* (LBNL, 2012a), which provides guidance on implementing environmental policy in compliance with the ISO 14001 standard. An EMS "Core Team," consisting of representatives from various divisions at Berkeley Lab, assists with implementing the integrated environmental and sustainability goals. A link to the *Environmental Management System Plan* and related documents is available on the Environmental Services Group (ESG) website (https://ehs.lbl.gov/service/environmental-services/).

2.2.2 Environmental Aspects

As part of the "plan" step for a management system, ESG subject matter experts and the EMS Core Team periodically review environmental aspects associated with LBNL research and operations. An environmental aspect is any activity, product, or service that interacts, whether adversely or beneficially, with the environment. These environmental aspects serve as the master list of potential risks and opportunities to improve environmental compliance and stewardship under Berkeley Lab's EMS. When evaluating environmental aspects, reviewers consider change (e.g., planned or new developments) and new or modified activities, as well as abnormal conditions and reasonably foreseeable emergency situations. Federal, state, and local agency requirements are considered during the aspects review.

The current inventory of individual environmental aspects totals approximately 40 environmental aspects, which are grouped under two general categories, as follows:

1. Environmental compliance aspects
    a. Emissions from diesel-powered equipment
    b. Storing hazardous material in an aboveground storage tank
    c. Contaminated runoff into storm drain system
2. Materials and resources use
    a. Energy consumption
    b. Water consumption
    c. Life-cycle stewardship of electronics

In determining which aspects are significant, reviewers evaluate the following risk factors for each aspect: the likelihood of occurrence and the impact from occurrence. This approach is consistent with the *Risk Severity Guidelines for Issues Management* issued by Berkeley Lab's Office of Institutional Assurance and Integrity (OIAI)

and found in its *Risk Management Program Manual.* The approach also follows OIAI's definitions of low (1), moderate (2), and high (3) risk for likelihood of occurrence and impact of occurrence. Multiplying the numeric values for both risk factors results in a score. In general, an aspect with risk combinations of high-high and high-moderate, or a score of at least six (i.e., 3 x 2 = 6), from this first step in the process will likely be considered significant. When deciding on risk factors for these environmental aspects, reviewers may consider the life cycle of the activity or service, plus the potential impact on all facets of the environment, such as the following:

- Cost
- Duration
- Effect on Berkeley Lab's mission
- Effect on public image
- Potential for improvement
- Potential legal exposure

The next step is to foster a discussion between the reviewers and the EMS Program Manager on aspects found significant from the initial risk scoring so that their combined professional judgment can be used to determine a final classification (e.g., significant) for each aspect in this group. If any aspect is significant, the rationale for that rating will be documented and an Action Plan will be developed. If reviewers determine that additional information is needed to evaluate a particular product or activity, the EMS Program Manager can assign the responsibility for collecting that information to an appropriate reviewer.

2.2.3 Objectives and Plans to Achieve Them

As part of the "do" step for a management system, aspects deemed significant require development and maintenance of an Action Plan document to define the objective, target, strategy, and actions for reducing impacts to the environment. The Action Plans in place at the end of fiscal year (FY) 2017 are listed in Table 2-1, along with a summary of each plan's objective, target, and status.

These Action Plans are part of more than 30 sustainability goals mentioned in Section 2.1. Berkeley Lab's *Annual Site Sustainability Plan* (LBNL, 2017a) contains more details on changes, strategy, and actions for all sustainability goals.

2.2.4 Awareness and Communication

The success of the EMS depends on ongoing and multiple lines of communication. These lines vary depending on factors such as the level of environmental impact, the types of control, the degree to which an environmental concern vertically and horizontally permeates the organization, and the level of effort needed to promote environmental compliance or performance goals.

Table 2-1 Environmental Management Programs

Aspect/Activity	Objective(s)	Target(s)	Status at End of FY 2017
Energy Use	Implement sustainable practices to achieve energy efficiency.	Reduce energy use intensity 2.5% each year through end of FY 2025 (baseline: FY 2015).	Consumption was 2% below baseline.
Greenhouse Gas (GHG) Emissions	Track, report, and reduce GHG emissions from LBNL activities.	Reduce Scope 1[(a)] and 2 GHG emissions by 50% and selected Scope 3[(b)] emissions 25% by end of FY 2025 (baseline: FY 2008).	Scope 1 and 2 emissions were 27% below baseline. Scope 3 emissions were 49% below baseline.
Petroleum Use	Reduce vehicle fleet petroleum consumption.	Reduce fleet's annual petroleum consumption by 30% (baseline: FY 2014 fleet fuel consumption).	Consumption was 53% below baseline. Achieved by operating an E85 (85% ethanol, 15% unleaded gasoline) fueling station and maintaining a fleet that includes hybrid[(c)] vehicles, one electric/unleaded[(d)] vehicle, and numerous low-speed electric carts.
Solid Waste Diversion	Increase solid waste diversion.	Divert at least 50% of nonhazardous solid waste, excluding construction and demolition debris. Divert at least 50% of construction and demolition debris.	73% diversion for nonhazardous solid waste. 88% diversion for construction and demolition debris.
Stormwater Management	Return to baseline compliance status under California's General Permit for Storm Water Discharges Associated with Industrial Activity.	Maintain or reduce pollutant concentrations to below California Numeric Action Levels for the parameters being monitored under the General Industrial Permit.	Still at compliance Level 2 (see Section 4.2.2 for additional details).
Sustainable Acquisition	Increase procurement opportunities for environmentally sustainable products.	Increase the percentage of priority sustainable products purchased (baseline: FY 2012).	86% of new applicable subcontract actions were reviewed to ensure they included appropriate sustainable acquisition provisions and clauses.
Vehicle Parking	Reduce commute traffic through transportation demand management.	Optimize parking. Facilitate/promote non-single-occupant vehicle commuting. Enhance shuttle bus operations.	No metrics in place at present.
Water Use	Implement sustainable practices to reduce water use intensity.	Reduce potable water use consumption intensity 36% by end of FY 2025 (baseline: FY 2007). Reduce industrial/landscaping/agricultural water use 30% by end of FY 2025 (baseline: FY 2010). Update and execute annual Water Metering Plan.	Consumption was 6% below baseline. Berkeley Lab did not use external sources for industrial/landscaping/ agricultural water use in baseline year FY 2010 (no metric possible).

[a] Scope 1 and 2 emissions are direct and indirect GHG emissions from sources owned or controlled by Berkeley Lab. Scope 1 can include emissions from fossil fuels burned on site or entity-leased vehicles. Scope 2 can include emissions resulting from the generation of purchased electricity.

[b] Scope 3 emissions include indirect GHG emissions from sources not owned or directly controlled by Berkeley Lab, but related to Berkeley Lab's activities. The most common activity is GHG emissions associated with employee travel and commuting.

[c] A hybrid has both a gasoline engine and an electric motor powering the wheels simultaneously.

[d] The electric/unleaded vehicle uses electric power first, then switches to its gasoline engine to extend driving range.

EMS-related matters may be communicated in a number of ways at Berkeley Lab, as follows:

- Publication of the annual Site Environmental Report and Environmental Restoration Program Progress Report.
- Posting information (e.g., environmental documents and operating permits) on websites and lessons-learned databases.
- Articles in LBNL publications (e.g., *Today at Berkeley Lab*) prepared by ESG staff or EMS Core Team members.
- One-on-one or small-group conversations between colleagues affiliated with Berkeley Lab, DOE, and UC.
- Access to a webpage for LBNL employees and external parties to express environment, safety, and health concerns and interests.

Relationships established with colleagues over years of working together are also an excellent way to communicate EMS-related matters. These relationships may be within the Berkeley Lab community or external, such as with DOE and UC communities.

Whenever appropriate, articles on EMS topics are included in LBNL publications, such as *Today at Berkeley Lab*. Environmentally related articles may be prepared by ESG staff or EMS Core Team members. The LBNL community can also learn more about EMS program activities through occasional presentations provided by a Core Team member to groups such as the Safety Advisory Committee and Division Safety Coordinators.

LBNL employees and external parties are encouraged to visit the ESG website and submit questions or concerns about any environmental issue to ems@lbl.gov. Communications for members of the public may also be sent directly to Berkeley Lab's Government and Community Relations Office or Strategic Communications Office. The Government and Community Relations office also oversees Berkeley Lab's Community Advisory Group, which consists of LBNL staff and residents of communities adjacent to Berkeley Lab and which meets every other month for a total of five times a year. The group serves as a liaison between Berkeley Lab and the community for discussion of initiatives and activities, including issues related to the environment.

2.2.5 Monitoring, Measurement, Analysis, and Evaluation of Compliance

As part of the "check" step for a management system, Berkeley Lab's EMS is required by DOE to undergo a formal audit once every three years. The audit is conducted by a qualified party outside the control or scope of the EMS. The purpose of the audit is to verify that the EMS conforms to the ISO 14001 standard, as required by the Contractor Requirements Document of DOE Order 436.1, *Departmental Sustainability*. The next audit must be completed in time for the DOE Berkeley Site Office to declare that Berkeley Lab's EMS conforms to the ISO 14001 standard by October 2018, a date formally established by DOE.

Plans and procedures are prepared by EHS staff to comply with regulatory requirements for various environmental programs. For example, a Stormwater Pollution Prevention Plan details how Berkeley Lab will comply with California stormwater requirements. Similarly, a Spill Prevention, Control, and Countermeasure Plan (SPCC) describes measures that Berkeley Lab will take to prevent the discharge of oils into nearby waters, as regulated by both federal and state organizations.

ESG has developed an extensive set of internal procedures that describe how to implement one or more aspects of a program plan. For example, ESG Procedure 210, *SPCC Compliance Inspection for Petroleum Drum Storage Areas*, provides guidance on implementing part of the Spill Prevention, Control, and Countermeasure Plan.

Correspondence between regulatory agencies and Berkeley Lab is often critical for showing an environmental program's compliance status. ESG maintains an electronic record of correspondence between Berkeley Lab and regulatory agencies. The record, an Excel spreadsheet, is organized by fiscal year and can be accessed by everyone in the group.

Many of the monitoring records are found in an ESG database, which is used for storing sampling results from all environmental monitoring programs that are reported in Chapter 4 of this document. Other monitoring records, such as calibration results for monitoring instrumentation, are also maintained and available on a shared computer drive.

Records management is a line-management function at Berkeley Lab. The EMS Program Leader is responsible for the care, maintenance, disposition, and archiving of EMS-related records in accordance with Berkeley Lab's record management policies and procedures, as listed in PUB-201, LBNL *Requirements and Policies Manual*, Information Management section.

2.2.6 Management Review

As part of the "act" step for a management system, senior management of organizations involved in implementing the EMS meet periodically with the EMS Program Manager to review the program's status. The meetings are attended by a representative who reports to the Deputy Director for Research and one who reports to the Deputy Director for Operations. These senior representatives can then share relevant information with others in the Research and Operations areas who do not attend the management review meetings.

At a minimum, the review meetings cover the following topics cited in the ISO 14001 standard:

- Results of internal audits and evaluations of compliance with legal and other requirements
- Communications from external interested parties
- Berkeley Lab's environmental performance
- The extent to which objectives and targets have been met
- Status of corrective and preventive actions
- Follow-up actions from previous management reviews
- Changing circumstances, including developments in legal and other requirements
- Recommendations for improvement

With the requirement that the EMS be integrated with sustainability goals and Berkeley Lab now developing an ISO 50001 (Energy Management) program, the Lab's Chief Sustainability Officer now participates in management reviews. The management review for 2017 was originally scheduled for December after EMS and sustainability performance results for fiscal year 2017 could be compiled. Last-minute scheduling conflicts pushed the meeting into January 2018. Key topics discussed were program accomplishments such as completion of soil management plans and improved stormwater management practices, EMS performance reporting, the upcoming triennial external audit of the EMS, and the path to ISO 50001 certification.

2.3 ENVIRONMENTAL MANAGEMENT PERFORMANCE AND HIGHLIGHTS

At the end of the federal fiscal year, which begins October 1 and ends September 30 the following year, Berkeley Lab is required to report on the performance of its EMS. As discussed below, one report is required by the operating contract between DOE and UC (DOE Contract No. DE-AC02-05CH11231, also known as Contract 31; DOE, 2017a) that assesses performance for numerous functional areas. The second report is strictly limited to EMS activities and is required of all federal agencies and their contractors.

2.3.1 DOE's Evaluation of EMS Performance

Berkeley Lab received a score of B plus – on a scale ranging from A plus (best) to F (worst) – in DOE Berkeley Site Office's *Performance Evaluation Report of the University of California for Management and Operations of Science and Technology at the Lawrence Berkeley National Laboratory for the Period October 1, 2016 to September 30, 2017* (DOE, 2017b) for providing an effective and efficient EMS. This evaluation is based on objectives in DOE's *FY 2018 Performance Evaluation and Measurement Plan* (Section J, Appendix B in DOE, 2017); both the plan and report are required by Contract 31. The following activities and accomplishments contributed to earning a B plus performance rating:

- U.S. EPA Region 9 approved Berkeley Lab's request to use a streamlined approach to comply with their public dose assessment regulation for radiological air emissions through use of a single virtual stack. Previously, the dose assessment process collected information and evaluated radionuclide emissions from approximately 10 grouped stack locations. Use of the single virtual stack method resulted in significant savings in staff resources.
- To support redevelopment of the site involving areas of nonradiologically contaminated soil, Berkeley Lab updated its 2006 sitewide Soil Management Plan and submitted it to the California Department of Toxics Substances Control (DTSC) for approval. The updated plan streamlined requirements for assessing and managing soils generated during demolition and construction activities, improving the flexibility for on-site reuse of soils. Due to DTSC's regulatory jurisdiction, this plan is limited to non-radiological soil contamination. Requirements for managing radiologically contaminated soil at Berkeley Lab are under the jurisdiction of DOE, so an analogous soil management plan for this type of material was also prepared. The goals of both plans is to reduce cost and schedule impacts to demolition and construction projects resulting from soil management.
- Dedicated environmental project managers have been assigned to support large capital projects involving complex environmental assessment and remediation issues. In addition to supporting safe and compliant operations, these environmental managers are supporting the retirement of environmental risks from the Lab's overall liabilities and the reduction of impacts to new building construction. These environmental project managers are also capitalizing on recently set-up Master Agreements to quickly and efficiently procure necessary environmental subcontractor support so these projects can efficiently move forward.
- The EHS Division teamed effectively with Facilities Old Town Demolition Project staff and redirected substantial radiation protection, waste management, and environmental programmatic resources to complete Phase 1b scope within a very aggressive schedule.
- The Environment, Waste & Radiation Protection Department fostered a positive relationship with the DTSC team that is reviewing the Hazardous Waste Handling Facility permit renewal submission.

Collaboration with DTSC on the development of the Cost Reimbursement Agreement led to a final Agreement with reduced anticipated fees and mutual understanding of needs. The final Agreement was executed in June 2017 and the DTSC is proceeding with processing the permit application.

- Berkeley Lab continued to enhance the new Work Planning and Control program by including an on-the-job training module and integrating environmental hazards and controls into the system.

2.3.2 Federal Office of Management and Budget EMS Reporting Scorecard

The requirement for the EMS Reporting Scorecard originated from Executive Order 13423, *Strengthening Federal Environmental, Energy, and Transportation Management*, issued in 2007. This reporting is now associated with Executive Order 13693, *Planning for Federal Sustainability in the Next Decade*, issued in 2015. The federal Office of Management and Budget collects annual performance information online to measure performance against goals established in this executive order for five categories, as follows:

1. Environmental aspects
2. Environmental objectives
3. Operational controls
4. Compliance with regulatory requirements / corrective actions
5. EMS/Executive Order 13693 goals integration

The fifth category, EMS/Executive Order 13693 goals integration, is graded by responses to how a site has addressed the following 10 sustainability goals:

1. GHG reduction
2. Sustainable buildings
3. Clean & renewable energy
4. Water use efficiency & management
5. Fleet management
6. Sustainable acquisition
7. Pollution prevention & waste reduction
8. Electronic stewardship & data centers
9. Energy performance contracts
10. Climate change resilience

For FY 2017, Berkeley Lab reported that sustainability goals 1 through 8 were applicable and were addressed by the organization. Although goals 9 and 10 were not applicable, Berkeley Lab commented in its reporting that it will address goal 10 by performing a climate change vulnerability screening in 2018.

Based on collective ratings in the five Office of Management and Budget categories for the FY 2017 reporting period, Berkeley Lab's EMS program earned the highest score of "green." Each category is scored from A (best) to D (worst). A green score signifies that at least three A's and the rest B's were received. Berkeley Lab received five A's for the reporting period.

While the responses were not factored into the scoring of a site, the EMS Reporting Scorecard asked questions regarding EMS experiences in terms of best practices and effect on an organization's mission.

Regarding EMS best practices, Berkeley Lab noted that management review meetings now cover both environmental management and sustainability activities. This helps show the integration of the two as required by DOE Order 436.1, as well as simultaneously address the management review requirements of ISO 14001 (Environmental Management) and ISO 50001 (Energy Management). Another best practice mentioned – bringing in environmental project managers to coordinate environmental requirements for several large capital projects – has improved the effectiveness of environmental management through a single point of contact and prompter response to project questions.

Regarding Berkeley Lab's experiences with EMS and the effect on its mission, Berkeley Lab maintains strong environmental compliance programs that foster good relationships with the regulatory community and neighbors. Limiting distractions from compliance deficiencies help Berkeley Lab's research community focus on its research. One example mentioned was updating Berkeley Lab's soil management processes during the reporting period. The improvements made, with input from the regulatory oversight agency, will streamline the handling of potentially contaminated soil associated with areas of the site available for future development.

2.3.3 Accomplishments, Awards, and Recognition

The EPEAT Purchase Awards program honors organizations that show leadership in the procurement of sustainable IT products in four product categories: PCs and Displays, Imaging Equipment, Mobile Phones, and Televisions. The Green Electronics Council, the organization that manages the EPEAT ecolabel, recognized a total of 53 awardees that include national and local governments, financial institutions, healthcare organizations, K–12 schools, institutions of higher learning, and businesses from around the globe. Berkeley Lab was one of 10 four-star award recipients (the highest award category) in early 2018 for its efforts in 2017.

3 Environmental Program Summary

This chapter summarizes the status of environmental compliance programs and includes general regulatory requirements, permits issued by regulatory agencies, and audits and inspections conducted during the year.

3.1 ENVIRONMENTAL PERMITS

Certain activities or equipment require an operating permit issued by a government agency. Authorizations held by Berkeley Lab at the end of 2017 for 61 activities or equipment are summarized in Table 3-1 by permit type.

Table 3-1 Environmental Permits

Permit Type	Issuing Agency	Description (Section with Details)	Location
Air quality	BAAQMD[a]	Various activities or equipment with emissions to atmosphere (3.4.1.2)	Main Site
		Standby emergency generators (3.4.1.2)	Joint Genome Institute
CUPA[b] (permit and registration)	ACEH[c]	Hazardous Materials Business Plan and hazardous waste generator areas (3.4.2)	EmeryStation East
	CCHS[d]	Aboveground storage tanks (3.4.4.1) Hazardous Materials Business Plan and hazardous waste generator areas (3.4.2)	Joint Genome Institute
	COB[e]	Aboveground storage tanks (3.4.4.1) Fixed treatment units (3.4.3.1) Hazardous Materials Business Plan and hazardous waste generator areas (3.4.2) Underground storage tanks (3.4.3.3)	Main Site
		Hazardous Materials Business Plan and hazardous waste generator areas (3.4.2)	Berkeley West Biocenter
Hazardous waste	DTSC[f]	Hazardous Waste Handling Facility operations and hazardous waste generator areas (3.4.3.1)	Main Site
Stormwater	SWRCB[g]	Sitewide and construction stormwater discharges (3.4.4.3)	Main Site
Surface water and sediment	EBRPD[h]	Surface water and sediment sampling (4.2.1, 4.5.2)	Tilden Park
Wastewater	CCCSD[i]	Wastewater discharges to sanitary sewer (3.4.4.1)	Joint Genome Institute
	EBMUD[j]	Sitewide and operation-specific wastewater discharges to sanitary sewer (3.4.4.1)	Main Site

[a] Bay Area Air Quality Management District
[b] Certified Unified Program Agency
[c] Alameda County Environmental Health
[d] Contra Costa Health Services
[e] City of Berkeley
[f] Department of Toxic Substances Control
[g] State Water Resources Control Board
[h] East Bay Regional Park District
[i] Central Contra Costa Sanitary District
[j] East Bay Municipal Utility District

3.2 AUDITS AND INSPECTIONS

The regulatory agencies that enforce environmental requirements conduct periodic on-site inspections. Ten minor violation notices resulted from nine inspections in 2017. Information about these inspections is summarized in Table 3-2 and discussed in Sections 3.4.3.1, 3.4.3.3, and 3.4.4.1. The table includes the self-monitoring inspections conducted by Berkeley Lab as required by EBMUD wastewater discharge permits, since the self-monitoring results expose Berkeley Lab to potential regulatory actions.

Table 3-2 Summary of Environmental Audits, Inspections, and Appraisals

Organization	Inspection Type	Start Date	Violations
BAAQMD	Inspection of permitted soil vapor treatment system, paint spray booth, solvent wipe-cleaning operations, and a new generator	Jan. 18	0
	Gasoline Dispensing Facility (Building 76)	July 5	0
COB[a]	Aboveground storage tanks, fixed treatment units, and hazardous waste accumulation areas	June 7	10
	Underground storage tanks	Oct. 12	3
EBMUD	EBMUD inspection and sampling of the Hearst and Strawberry sanitary sewer outfalls	May 23	0
U.S. EPA[b]	RCRA inspection of the Hazardous Waste Handling Facility (Building 85) and waste accumulation areas in Buildings 67 and 77A	Sept. 12	0
LBNL	Self-monitoring inspections required by EBMUD for groundwater treatment units	Feb. 22 July 17	0 0
	Self-monitoring inspections required by EBMUD for the Building 77 fixed treatment unit	Sept. 21	0
	Self-monitoring inspections required by EBMUD for the Hearst and Strawberry sanitary sewer outfalls	March 8 Sept. 13	0 0

[a] Permitted under California's Certified Unified Program Agency.

[b] U.S. Environmental Protection Agency; COB and DTSC representatives also attended.

3.3 DOE-REPORTABLE ENVIRONMENTAL INCIDENTS

The DOE Occurrence Reporting Program tracks environmental incidents across the DOE complex. No environmentally related occurrence reports associated with LBNL activities occurred during 2017.

However, an external event, a wildland fire on land neighboring Berkeley Lab, occurred on the afternoon of August 2. Employees were instructed to evacuate the site, considering that the fire's movement was unpredictable, the Pacific Gas and Electric Company had given notification that electrical power to the site would be turned off to protect supply lines to the East Bay, and significant time would be required to complete an evacuation from the site. The fire burned 20 acres adjacent to the site; no injuries or property damage to Berkeley Lab were reported.

3.4 COMPLIANCE PROGRAMS

The primary federal laws driving LBNL compliance programs for federal, state, and local environmental regulations are the Clean Air Act, the Emergency Planning and Community Right-to-Know Act, the Resource Conservation and

Recovery Act (RCRA), the Clean Water Act, and the Toxic Substances Control Act. The federal and state laws impacting Berkeley Lab's environmental planning for future activities are the National Environmental Policy Act of 1969 and the California Environmental Quality Act of 1970. The sections below briefly describe each of these environmental laws and associated regulations, and highlight associated LBNL activities for this reporting year.

3.4.1 Clean Air Act

The Clean Air Act of 1970 is the key statutory reference for federal, state, and local air pollution control programs. Regulations are based on three categories of air pollutants, as follows:

1. Hazardous air pollutants (e.g., radionuclides, air toxics)
2. Criteria air pollutants (e.g., carbon monoxide, nitrogen oxides, particulate matter)
3. Ozone-depleting substances (e.g., chlorofluorocarbons, halons)

3.4.1.1 Radiological Emissions

LBNL research activities involving radionuclide emissions to the atmosphere must comply with the following regulations:

- Code of Federal Regulations (CFR), Title 40, Part 61, Subpart H, National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities (U.S. EPA, 1989)
- DOE Order 458.1, Administrative Change 3, Radiation Protection of the Public and the Environment (DOE, 2013)

The U.S. Environmental Protection Agency (U.S. EPA) administers the regulations in 40 CFR 61, *National Emission Standards for Hazardous Air Pollutants* (NESHAP), which limit the dose to the public from a facility's airborne radionuclide emissions to 10 millirem per year (mrem/yr). The estimated potential dose from LBNL activities in 2017 was approximately 0.10% of this limit.

Berkeley Lab documents its NESHAP review and compliance status annually; the *Radionuclide Air Emission Report for 2017* (LBNL, 2018) is the most recent report submitted to the U.S. EPA. The report is available on the Publications page of ESG's website (https://ehs.lbl.gov/service/environmental-services/).

3.4.1.2 Non-radiological Emissions

California's air pollution control program, led by the California Air Resources Board (CARB), created regional air districts to regulate air emissions sources (California Health and Safety Code, 1967). In the case of Berkeley Lab, the Bay Area Air Quality Management District (BAAQMD, "Air District") is responsible for administering and enforcing federal and state air quality requirements for most non-radiological air emission activities. CARB administers regulations on mobile sources such as vehicles, as well as regulations on certain toxic chemicals and greenhouse gases (GHGs).

At the end of 2017, Berkeley Lab held 35 operating permits issued by the Air District (BAAQMD, 2017); 33 permits cover activities and equipment at the main site, and 2 permits cover standby emergency diesel generators at the Joint Genome Institute (JGI) in Walnut Creek. Additionally, 11 industrial boilers with a combustion rating of at least 2 million BTUs per hour and less than 10 million BTUs per hour are registered with the Air District. This includes 4 industrial boilers registered in November 2017. All permits issued by the Air District are listed in Table 3-3.

Table 3-3 BAAQMD-Permitted Air Emission Sources

BAAQMD Permit Category	Description (No. of Permitted Sources)	Building	Abatement Type
Combustion equipment	Standby emergency generators (4)	64, 66, 67, 70	Catalytic converter
	Standby emergency generators (7)	30, 48, 50A, 59, 72, plus two portable units	Diesel particulate filter
	Standby emergency generators (16)	2, 33, 37 (2), 50B, 55, 62, 64, 68, 74, 77, 84B, 85, plus three portable units	None
	Standby emergency generators (2)	JGI	None
Gasoline dispensing	Fueling stations: unleaded and E85 (2)	76	Vapor recovery
Surface coating and painting	Paint spray booth (1)	77	Dry filter
Surface preparation and cleaning	Sandblast booth (1)	77	Baghouse
	Wipe-cleaning (1)	Sitewide	None
Miscellaneous	Soil vapor extraction system (1)	58	Activated carbon

E85 = 85% ethanol / 15% unleaded gasoline fuel blend

BAAQMD operating permits must be renewed annually. The renewal application process includes submitting usage information on permitted sources, as well as sitewide adhesive and sealant annual usage under a BAAQMD-approved alternative recordkeeping agreement for compliance with Regulation 8, Rule 51: Adhesive and Sealant Products. Information submitted in the application also satisfies requirements of the state's Air Toxics "Hot Spots" Information and Assessment Act of 1987 (California Health and Safety Code, 1987).

The Air District conducted two inspections in 2017 of permitted equipment or activities. The first inspection in January focused on the paint spray booth, the soil vapor extraction unit, and a newly permitted diesel generator, in addition to sitewide solvent wipe-cleaning operations. The second inspection occurred in July and focused strictly on the fuel dispensing facilities at Building 76. No violations were reported for either inspection.

CARB regulates sulfur hexafluoride (SF_6) emissions from gas-insulated switchgear by setting a maximum annual emission rate and requiring an annual usage report. SF_6 is a potent GHG having a global warming potential 23,900 times that of carbon dioxide. Berkeley Lab had 15 active SF_6-containing switches and breakers in service in 2017, and reported 20 pounds of SF_6 emissions from two of the switches for the year. Maintenance is performed every two years on switches at Berkeley Lab and includes testing for leaks. No leaks were detected for these two particular switches, although the vendor added 10 pounds of SF_6 to each unit because they were low by that amount.

CARB's Refrigerant Management Program regulates stationary non-residential refrigeration systems that use more than 50 pounds of a refrigerant with a high global warming potential by requiring use reporting and fee payment. Berkeley Lab's 51 refrigeration systems affected by this program are all on the main site.

Since 2010, at the end of each fiscal year, Berkeley Lab has submitted a report to DOE on its annual GHG emissions. The current requirement for this reporting is Executive Order 13693, *Planning for Federal Sustainability*

in the Next Decade. The order contains more than 30 sustainability goals, including those for GHG emissions and fleet activities. More information on these sustainability goals is available in the *Lawrence Berkeley National Laboratory Annual Site Sustainability Plan* (LBNL, 2017a).

LBNL facilities do not emit GHGs in quantities that exceed reporting thresholds under other regulations such as the U.S. EPA's Greenhouse Gas Reporting Program and California's Assembly Bill 32, the California Global Warming Solutions Act of 2006.

3.4.2 Emergency Planning and Community Right-to-Know Act

The Emergency Planning and Community Right-to-Know Act (EPCRA), which was passed in 1986 as Title III of the Superfund Amendments and Reauthorization Act (SARA), establishes requirements for emergency planning, notification, and reporting. In California, the requirements of SARA Title III are incorporated into the state's Hazardous Materials Release Response Plans and Inventory law (California Health and Safety Code, 1985).

As a federal facility, Berkeley Lab is subject to EPCRA Toxic Release Inventory reporting requirements. If annual usage exceeds threshold quantities (i.e., 10,000 pounds for the chemicals used at Berkeley Lab), a U.S. EPA Form R must be submitted. As in previous years, Berkeley Lab determined in 2017 that no chemical usage exceeded the chemical-specific Toxic Release Inventory criterion for a listed substance; therefore, preparation of a Form R was not required. Table 3-4 summarizes Berkeley Lab's assessments of highest chemical usage quantities since 2007.

Table 3-4 Trends in Highest Quantities of Chemicals Subject to EPCRA Toxic Release Inventory Reporting

	Quantity Used per Year (pounds)									
Substance	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Chlorofluorocarbons	206	169	142	319	183	61	132	87	327	390
Methanol	117	181	147	88	103	172	127	100	130	126
Nitric acid	667	614	592	634	633	633	556	78	90	90

The City of Berkeley, Alameda County Environmental Health, and Contra Costa Health Services are the local administering agencies for certain hazardous materials regulations that fall under the requirements of EPCRA and the corresponding state law. Berkeley Lab complies with applicable federal hazardous materials reporting requirements, and each year it voluntarily submits Hazardous Materials Business Plans (HMBPs) that meet state requirements, even though it is not subject to state hazardous materials regulations.

Each HMBP provides the following information:

- All hazardous materials present in amounts exceeding the state's aggregate threshold quantities per building (i.e., 55 gallons for liquids, 500 pounds for solids, and 200 cubic feet for compressed gases)
- Emergency plans
- Procedures
- Training
- Facility maps

The HMBP for each facility listed below is updated each year and submitted electronically to the California Environmental Reporting System (http://cers.calepa.ca.gov/):

- LBNL main site
- Berkeley West Biocenter
- EmeryStation East (Joint BioEnergy Institute and the Advance Biofuels Process Demonstration Unit)
- Joint Genome Institute

The HMBPs are also available on the Publications page of ESG's website (https://ehs.lbl.gov/service/environmental-services/).

3.4.3 Resource Conservation and Recovery Act

The 1976 Resource Conservation and Recovery Act (RCRA) is an amendment to the earlier Solid Waste Disposal Act of 1965 that was enacted to create a management system to regulate waste from "cradle to grave." In 1984, the Hazardous and Solid Waste Amendments were added to the Solid Waste Disposal Act to reduce or eliminate the generation and disposal of hazardous wastes. Between 1984 and 1988, RCRA was further expanded to regulate underground storage tanks and leaking waste storage facilities.

RCRA's primary goals are to protect the public from harm caused by waste disposal, to clean up spilled or improperly stored wastes, and to encourage reuse, reduction, and recycling. RCRA impacts the following LBNL operations:

- Treatment and storage of hazardous waste (including the hazardous component of mixed waste)
- Investigation and cleanup of historical releases of hazardous chemicals to the environment
- Storage of petroleum products in underground storage tanks

3.4.3.1 Hazardous Waste

In California, the Department of Toxic Substances Control (DTSC) administers the hazardous waste program. The state's program incorporates the provisions of both the federal and state hazardous waste laws (California Health and Safety Code, 1972) and includes permitting and enforcement elements.

The state's permitting program for hazardous waste treatment and storage facilities has five tiers, which are listed in Table 3-5 in order of decreasing regulatory complexity. Berkeley Lab has activities falling under three of the tiers.

Table 3-5 Overview of California's Tiered Permitting Program

Program Tier	Regulatory Agency	LBNL Facilities Under Each Program Tier
Full permit	DTSC	Hazardous Waste Handling Facility
Standardized permit	DTSC	–
Permit-by-rule	City of Berkeley	FTU 006, FTU 007
Conditional authorization	City of Berkeley	FTU 004, FTU 005
Conditional exemption	City of Berkeley	–

FTU = fixed treatment unit

NOTE: See Table 3-6 for details on each FTU

The Hazardous Waste Handling Facility operates under a DTSC-issued full permit (the highest tier), which authorizes storage and treatment of certain hazardous and mixed wastes at the facility. The expiration date for this permit, which is valid for 10 years, was December 2016. In June 2016, Berkeley Lab submitted an application to DTSC to renew the permit. DTSC determined in July of that same year that the application was administratively complete. In January 2018, Berkeley Lab was notified that DTSC had completed its technical review and had issued a First Notice of Deficiency (NOD) letter requesting additional information on 32 items. As of this writing, Berkeley Lab has responded to the NOD letter and awaits DTSC's feedback. In the meantime, the existing permit remains effective and enforceable. When the application is complete, DTSC will prepare a draft permit that will involve a public comment period prior to issuing a final permit.

Administration and enforcement for the three lower tiers are delegated to the City of Berkeley under California's Certified Unified Program Agency (CUPA) program. Four fixed treatment units (FTUs) operate at Berkeley Lab under a hazardous wastewater treatment permit issued by the City of Berkeley at the permit-by-rule and conditional authorization tiers. This permit is renewed annually as part of the HMBP submission process for the main site. The City of Berkeley now issues electronic permits with relevant information on these permitted activities available on the California Environmental Reporting System (http://cers.calepa.ca.gov/).

FTU treatment types and operational throughput are summarized in Table 3-6. The FTU serving Buildings 70A and 70F treats over 75% of all FTU wastewater generated on site, and recycles approximately 60% of that by diverting it to a nearby cooling tower to replace the water consumed by the cooling process. Nearly 310,000 gallons of water was recycled in this manner in 2017. This wastewater treatment process reached a milestone in early November 2017 when the 3 millionth gallon of water was recycled since this process began in 2011.

Table 3-6 Summary of Fixed Treatment Unit Operations

FTU	Building No.	Treatment Types	Approx. Quantity of Wastewater Treated in 2017 (gallons)
004	70A/70F	Acid neutralization	503,250 (308,550 estimated recycled)
005	2	Acid neutralization	123,150
006	77	Metals precipitation and acid neutralization	11,675
007	67	Acid and alkaline neutralization	49,800

Berkeley Lab also sends hazardous, universal, mixed, medical, and radioactive waste generated at its operating locations to permitted off-site facilities for disposal. The state's Medical Waste Management Act (California Health and Safety Code, 1991) regulates the disposal of medical waste. DOE orders define low-level radioactive waste requirements. Mixed waste is subject to both California regulations and DOE orders and is managed at Berkeley Lab in accordance with the Site Treatment Plan for mixed waste (DOE, 1995).

In June 2017, the City of Berkeley conducted a three-day CUPA inspection of the main site. The inspection of wastewater treatment systems subject to California's Tiered Permitting Program and satellite waste accumulation areas resulted in five violations as follows:

1–3. Failure to obtain an assessment of the tank by a professional engineer every five years for the wastewater treatment unit at Buildings 2, 70A, and 77.
4. Improperly labeled hazardous waste containers were found in a single room in both Buildings 67 and 84.
5. Open hazardous waste containers were found in multiple rooms of Building 67.

The corrective action status of these five violations, plus five other minor violations pertaining to aboveground storage tanks (see Section 3.4.4.1), was documented to the City of Berkeley in a letter dated September 20, 2017.

In September, representatives of the U.S. EPA, accompanied by representatives of DTSC and the City of Berkeley, inspected hazardous waste and mixed waste storage units at the Hazardous Waste Handling Facility (Building 85). The inspection also covered the Molecular Foundry (Building 67) and Building 77A, including the plating/cleaning shop, the wastewater treatment system, and select 90-day hazardous waste storage areas and satellite accumulation areas. No violations were cited from this inspection.

3.4.3.2 Corrective Action Program

Berkeley Lab is currently in the Corrective Measures Implementation phase of the RCRA Corrective Action Program. This phase consists of operating, maintaining, and monitoring the environmental restoration measures approved by DTSC in the *Corrective Measures Study Report for Lawrence Berkeley National Laboratory* (LBNL, 2005). These measures are intended to reduce or eliminate the potentially adverse effects to human health or the environment caused by past releases of chemicals to soil and groundwater at Berkeley Lab.

The following DTSC-approved corrective measures are being used to clean up contaminated groundwater:

- **In situ soil flushing** involves extracting contaminated groundwater from the subsurface, cleaning the water on site using granular activated carbon (GAC), and then recirculating the treated groundwater by injecting it into the subsurface. In situ soil flushing increases the rate at which soil contaminants dissolve into the groundwater and promotes the flow of contaminated groundwater toward locations where it can be extracted and cleaned.
- **Groundwater capture and treatment** consists of extracting groundwater in the downgradient portions of groundwater contaminant plumes to minimize further migration, cleaning the extracted groundwater on site using GAC, and then either injecting the treated water into the subsurface, if needed for soil flushing, or discharging the treated water to the sanitary sewer system.
- **Hydrogen Release Compound (HRC®)**, an environmentally safe polylactate ester formulate, has been injected into certain contaminated areas to enhance the natural biodegradation of volatile organic compounds (VOCs).
- **Monitored natural attenuation** (i.e., reliance on natural processes) is also being used at some locations within the context of a controlled and monitored site cleanup approach.

In December, Berkeley Lab finalized the *Soil Management Plan for Lawrence Berkeley National Laboratory* (LBNL, 2017b), which replaced the plan prepared in 2006. The new Soil Management Plan and the *Groundwater Monitoring and Management Plan* (LBNL, 2006) describe the nature and extent of contamination, the controls used to reduce potential risk to human health and the environment from contaminants in soil and groundwater,

and the requirements for ongoing groundwater and surface water monitoring. These plans, as well as other RCRA Corrective Action Program documents prepared by Berkeley Lab, are available to the public at the main branch of the Berkeley Public Library and on the Environmental Restoration Program website at https://ehs.lbl.gov/resource/environmental-restoration-program/.

3.4.3.3 Underground Storage Tanks

In the early 1980s, California began addressing groundwater contamination from leaking underground storage tanks (USTs) through a rigorous regulatory and remediation program (California Health and Safety Code, 1983). The state program for USTs containing hazardous materials addresses permitting, construction, design, monitoring, recordkeeping, inspection, accidental releases, financial responsibility, and tank closure, and it satisfies the provisions of the federal RCRA requirements (42 USC §6991, 1988). The City of Berkeley is the local administering agency for UST regulations that apply to Berkeley Lab's main site. Six permitted USTs located on site contain either diesel or unleaded gasoline, as listed in Table 3-7 and shown on Figure 3-1. Berkeley Lab has removed nine USTs since 1993 following the regulatory closure process; no USTs were removed in 2017.

Table 3-7 Underground Storage Tanks Requiring Operating Permits

Registration ID	Location (Building)	Contents	Capacity (Gallons)	Year Installed
Fiberglass tanks, double-walled				
TK-3-2	2	Diesel	4,000	1988
TK-4-2	2	Diesel	1,000	1988
TK-1-85	85	Diesel	2,500	1995
Glasteel tanks, double-walled, with fiberglass-reinforced plastic corrosion protection				
TK-1-55	55	Diesel	1,000	1986
TK-5-76	76	Unleaded gasoline	10,000	1990
TK-6-76	76	Diesel	10,000	1990

In October, the City of Berkeley conducted an inspection of the six permitted USTs at the main site. Three minor violations were cited, as follows:

1. The audible alarm failed for UST systems at Building 76 and Building 2.
2. Secondary containment test results were not delivered to the City within the 30-day limit due to a delay by the vendor conducting this testing.
3. The UST Designated Operator monthly inspection report did not include verification (i.e., checkbox not marked on form) that all facility employees have been trained as required by state UST regulations (23 CCR §2715(f)), even though all employees were up to date with their training.

After the inspection, Berkeley Lab sent the City of Berkeley a letter showing the next monthly inspection report with the training section checkmarked complete, as required by the UST designated operator.

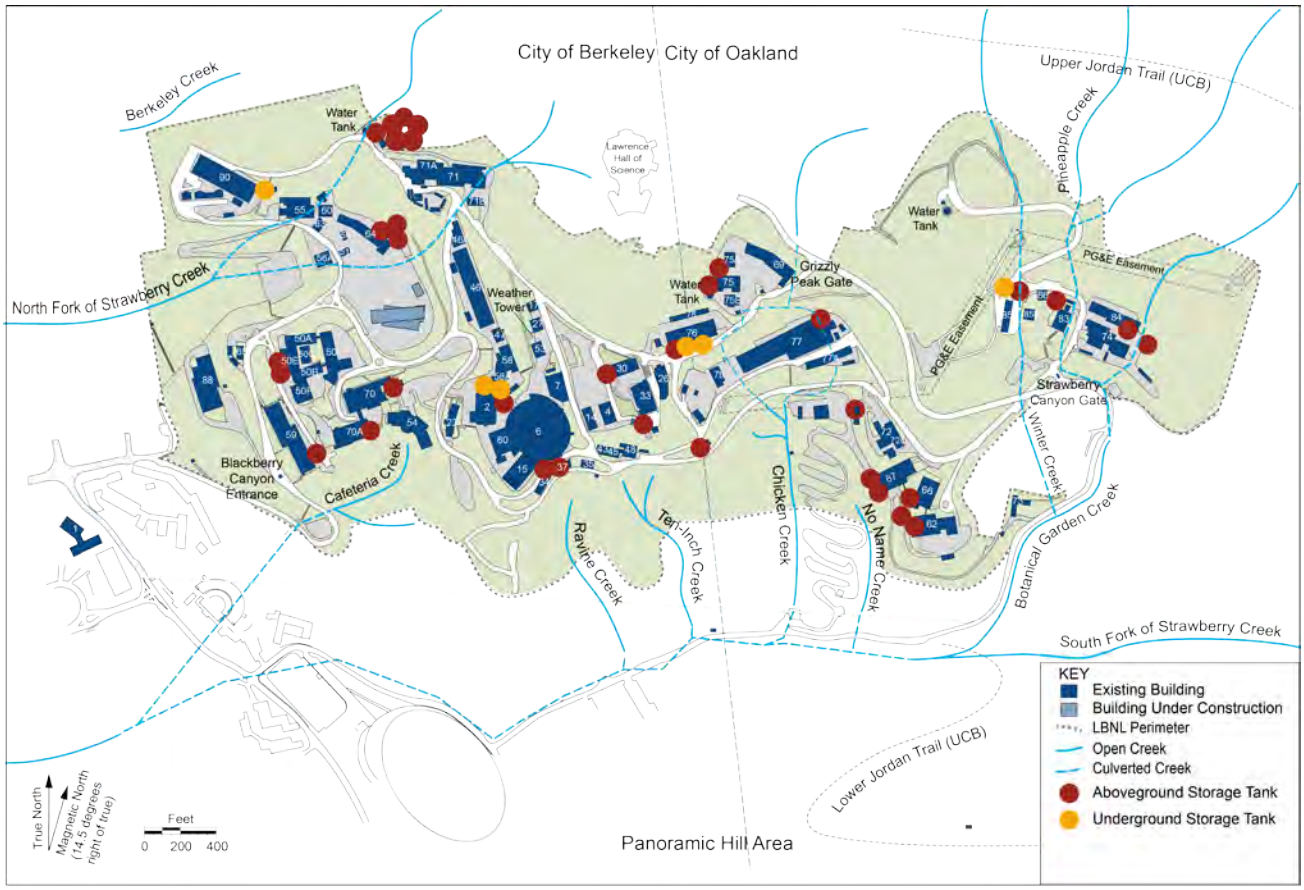

Figure 3-1 Locations of Petroleum-Containing Aboveground and Underground Storage Tanks

3.4.4 Clean Water Act

The 1972 Clean Water Act regulates the discharge of pollutants from both point and nonpoint sources to the waters of the United States by establishing pollutant discharge standards and limitations, as well as a permit and licensing system to enforce the standards. California is authorized by the U.S. EPA to administer the principal components of the federal water quality management program.

The California Porter-Cologne Water Quality Control Act (California Water Code, 1969) established a comprehensive statewide system for regulating water use and provided for a three-tiered system of regulatory administration and enforcement:

- California State Water Resources Control Board (SWRCB, "State Water Board")
- nine Regional Water Quality Control Boards
- local governments

For the LBNL main site, the agencies responsible for regulatory programs are the San Francisco Bay Regional Water Quality Control Board (herein referred to as the RWQCB) for stormwater discharges, and EBMUD for drinking water supply and wastewater discharges. For JGI, which is located in Walnut Creek, the responsible agency for both wastewater and stormwater discharges is the Central Contra Costa Sanitary District.

3.4.4.1 Aboveground Storage Tanks

Aboveground storage tanks (ASTs) fall under the authority of the Clean Water Act, which, together with the state's Aboveground Petroleum Storage Act (California Health and Safety Code, 1989), outlines the applicable regulatory requirements for ASTs containing chemicals or hazardous materials. At Berkeley Lab, these requirements apply to petroleum storage tanks for standby emergency diesel generators, storage drums at waste accumulation areas, and storage drums at product distribution areas. The City of Berkeley is responsible for administering and enforcing the regulations that apply to ASTs at the main site. Berkeley Lab has 32 of these tanks registered with the city. Their locations are shown on Figure 3-1.

Under the authority of the Clean Water Act, Berkeley Lab is required to prepare a Spill Prevention, Control, and Countermeasure (SPCC) Plan for petroleum-containing aboveground tanks. Berkeley Lab maintains an SPCC Plan for the main site with the goal of preventing and, if needed, mitigating spills or leaks from petroleum-containing tanks (LBNL, 2017c). These ASTs are provided with secondary containment or spill kits to capture any potential leaks. A 4,000-gallon AST at the JGI facility supports two standby emergency generators, and JGI maintains a separate SPCC Plan for this AST (LBNL, 2014b).

The three-day CUPA inspection in June by the City of Berkeley discussed in Section 3.4.3.1 also included Berkeley Lab's aboveground petroleum storage tanks and resulted in five minor violations associated with the SPCC for the main site as follows.

1. Not amending the SPCC Plan within six months of changes that affect the facility's discharge potential, and having the amendment certified by a professional engineer.
2. Not referencing in the SPCC Plan the on-site location for detailed piping diagrams.
3. Not fulfilling an implementation schedule cited in the previous SPCC Plan (prepared in 2012) to update monthly and annual AST inspection forms (LBNL, 2012c).
4. Not addressing in the SPCC Plan the type of oil and storage capacity of each container and total storage volume in a waste accumulation area.
5. Not ensuring that a professional engineer makes all required attestations in the SPCC Plan.

In the letter to the City of Berkeley dated September 20 (mentioned in Section 3.4.3.1), Berkeley Lab committed to updating its SPCC Plan to correct these deficiencies by the end of October; the updated plan was certified by a professional engineer by the end of September.

3.4.4.2 Wastewater

EBMUD is the local publicly owned treatment works that regulates all industrial and sanitary discharges to its treatment facilities. Berkeley Lab holds EBMUD wastewater discharge permits for the following discharge activities at the main site:

- General sitewide wastewater (EBMUD, 2017a)
- Treated groundwater from hydraugers and groundwater extraction wells (EBMUD, 2016)
- Treated rinse water from the metal finishing operations in the Ultra-High Vacuum Cleaning Facility at Building 77 (EBMUD, 2017b)
- Treated rainwater from the Old Town Demolition Project (EBMUD, 2017c)

Permits specify standard terms and conditions, individual discharge limits and provisions, and monitoring and reporting requirements. Berkeley Lab submits periodic self-monitoring reports specified under each permit, and in 2017 no wastewater discharge limits were exceeded. A summary of monitoring results is provided in Chapter 4.

EBMUD periodically inspects the site's sanitary sewer discharge without notice. The agency collected wastewater samples from both the Strawberry and Hearst sewer outfalls in late May and early June, respectively. No discharge violations were measured during the inspections or in the associated wastewater sampling results.

An eighth treatment system was added to the groundwater treatment systems permit in December 2016. This permit has no expiration date.

Both the sitewide wastewater and the Building 77 Ultra-High Vacuum Cleaning Facility wastewater discharge permits were renewed by EBMUD in 2017. Both permits require annual self-monitoring, which is reported in Chapter 4. The sitewide permit also requires annual certification by Berkeley Lab that it is in compliance with the radiological limits of the permit. The permit for the Building 77 facility requires that both a Toxic Organics Management Plan and a Slug Discharge Plan be maintained. The requirements for these two plans are incorporated into a single work authorization activity for metal finishing operations under Berkeley Lab's Work Planning and Control program. The two plans outline facility management practices designed to eliminate the accidental release of toxic organics – or any other pollutant – to the sanitary sewers or external environment by emphasizing secondary containment and other appropriate spill prevention practices. The work authorization activity also includes emergency response procedures.

Berkeley Lab also holds a special EBMUD permit for discharging treated rainwater collected within excavations at the Old Town Demolition Project site. Treatment consists of using a zeolite media bed to reduce metals, particulate filter cartridges to collect sediment, and activated charcoal to remove polychlorinated biphenyls (PCBs), total petroleum hydrocarbons, and VOCs that may have accumulated in the rainwater runoff collected at the site. This permit is valid for one year and includes conditions regarding compliance with all EBMUD Wastewater Control Ordinance discharge limits and self-monitoring requirements. EBMUD approved Berkeley Lab's request to renew the permit for another year in January 2017.

Berkeley Lab also holds a Class III Industrial User Permit for general wastewater discharged from the JGI facility in Walnut Creek. The Central Contra Costa Sanitary District renewed this permit in late 2017, effective through December 2021. The permit specifies requirements for inspections and reporting. No monitoring is required.

3.4.4.3 Stormwater

Berkeley Lab's stormwater releases are permitted under the statewide General Permit for Stormwater Discharges Associated with Industrial Activities (SWRCB, 2014), commonly referred to as the Industrial General Permit. Although the State Water Board issues this permit, it is administered and enforced locally by the RWQCB. Under this permit, Berkeley Lab has implemented a Stormwater Pollution Prevention Plan (SWPPP) (LBNL, 2016d), which includes the site's Stormwater Monitoring Implementation Plan (LBNL, 2016c).

The purpose of the SWPPP is to identify sources of pollution that could affect the quality of stormwater discharges, and to describe the practices implemented to reduce pollutants in these discharges. The *Stormwater Monitoring Implementation Plan* describes the rationale for selecting sampling locations, collecting and analyzing samples, and

ensuring the quality and reporting of the results. Together, these documents represent Berkeley Lab's plan and procedures for identifying, monitoring, and reducing pollutants in its stormwater discharges.

The annual report covering stormwater activities for the 2016/2017 season was submitted by the July 15 deadline using the State Water Board's online Stormwater Multiple Application and Report Tracking System (smarts.waterboards.ca.gov). The annual report includes results from the annual compliance evaluation, a summary of any changes made to the SWPPP, and analytical results for all sampling events during the reporting season. Under modifications to the Industrial General Permit that took effect at the beginning of the 2016/2017 season, Berkeley Lab began the year at the "Level 1" compliance level given the previous season's elevated levels of aluminum and iron. However, because levels of aluminum and iron continued to exceed Numeric Action Levels for these parameters, the State Water Board changed Berkeley Lab's status to compliance "Level 2" for the 2017/2018 season. Berkeley Lab conducted an evaluation to determine whether additional measures could be implemented to lower pollutant levels, and an Exceedance Response Action Level 2 report was submitted to the State Water Board. The sampling results are discussed in more detail in Section 4.2.2.

Stormwater releases from construction activity disturbing one or more acres of soil are regulated under the state's General Permit for Stormwater Discharges Associated with Construction Activities (SWRCB, 2012), also referred to as the Construction General Permit. During 2017, two projects at Berkeley Lab required coverage under the Construction General Permit program:

1. Old Town Demolition Project
2. Integrative Genomics Building (IGB) and Modular Utility Plant (MUP) Project within the Bayview area

Similar to the Industrial General Permit, each of these projects required a SWPPP and an annual report. Unlike the Industrial General Permit, no stormwater sampling was required, but project site inspections were required (i.e., prior to predicted rain event on a business day, during extended rain events, post rain events, and quarterly non-stormwater discharge). Inspection logs were included in the annual report. Both projects were compliant with their permit requirements for 2017.

Coverage for the Old Town Demolition Project has been in place since May 2015, while coverage for the IGB/MUP Project became effective in July 2016.

3.4.5 Toxic Substances Control Act

The objective of the Toxic Substances Control Act (TSCA) of 1976 is to minimize the exposure of humans and the environment to chemicals used in manufacturing, processing, commercial distribution, and disposal activities. TSCA establishes a protocol for evaluating chemicals before they are introduced to the marketplace, then regulating their use once they are approved for manufacturing. TSCA regulations are administered by the U.S. EPA.

PCBs are the principal substances at Berkeley Lab currently subject to TSCA regulations. The only remaining equipment containing TSCA-regulated PCBs is four large low-voltage capacitors in Building 88. These capacitors remain in use and contain an estimated 375 pounds of regulated PCB dielectric fluid, which is below the annual reporting threshold to the U.S. EPA for this substance.

In 2014, PCBs were detected in soil samples collected during a preliminary environmental hazard assessment of the Old Town area in preparation for demolition of Buildings 5 and 16. Efforts to characterize the extent of PCB

contamination continued into 2017 under the regulatory authority of U.S. EPA Region 9. Cleanup efforts of this contamination began in early 2017 under a cleanup plan approved by the U.S. EPA. More information on the Old Town Demolition Project is found in Section 3.5.1 of this report. In addition, characterization and cleanup efforts are documented in the LBNL Environmental Restoration Program's progress reports, which are available at the main branch of the Berkeley Public Library and on the program's website at https://ehs.lbl.gov/resource/environmental-restoration-program/.

3.4.6 National Environmental Policy Act and California Environmental Quality Act

The National Environmental Policy Act (NEPA) of 1969 and the California Environmental Quality Act (CEQA) of 1970 require that potential environmental impacts of proposed actions be considered in the decision-making process by the designated lead agency. At Berkeley Lab, environmental staff provide information and technical support to DOE and UC to assist with complying with NEPA and CEQA requirements.

In 2017, DOE determined that two proposed federally supported activities at Berkeley Lab met the criteria for a categorical exclusion under NEPA. Review documents for each are available at the following DOE website: http://science.energy.gov/bso/nepa-documents/. No environmental assessments under NEPA were prepared for LBNL activities. A final Environmental Impact Report was prepared under CEQA and certified under delegated authority by the Berkeley Lab Director. The report, which examined the Building 59 upgrade and the installation and operation of the NERSC-9 Project, is available online at http://www.lbl.gov/community/nersc-9-project/. Four additional activities were determined to be categorically exempt under CEQA.

3.5 SPECIAL PROJECTS

In 2017, Berkeley Lab conducted two projects that involved significant environmental activities: the Old Town Demolition Project and the IGB/MUP Project.

3.5.1 Old Town Demolition Project

Berkeley Lab is in the process of demolishing selected buildings in the central portion of the site known as Old Town, and completing remediation of soil containing PCBs and/or radionuclides. Soil cleanup verification surveys and sampling were conducted as demolition progressed, as discussed below.

3.5.1.1 Regulatory Oversight

The U.S. EPA requires cleanup and disposal of materials contaminated by PCBs in accordance with the Toxic Substances Control Act, codified at 40 CFR 761, *Polychlorinated Biphenyls Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions*. PCB cleanup conducted in 2017 was in conformance with the *Application for Cleanup of Polychlorinated Biphenyls, Old Town Demolition Phase I Project* (DMS, 2016) as amended (LBNL, 2016e), which was approved by the U.S. EPA in 2016 (U.S. EPA, 2016a).

Berkeley Lab, the DOE Berkeley Site Office, and the U.S. EPA met three times in 2017 to discuss progress of the PCB cleanup. During a meeting in April, Berkeley Lab led a tour of the project site to observe ongoing soil excavation and to visit waste accumulation areas and a water treatment system used for treatment of water that has accumulated in excavations at the project area.

Berkeley Lab keeps DTSC informed of interactions with the U.S. EPA and the progress of PCB characterization and cleanup. Berkeley Lab also keeps DTSC apprised of any new non-PCB contaminants detected in soil within the demolition project area. In 2016, Berkeley Lab submitted to DTSC a report on sampling for mercury at the eastern edge of the project boundary. The report was updated in June 2017 to address DTSC's comments (Weiss, 2017). In July, DTSC notified Berkeley Lab that the mercury characterization effort required no additional action (DTSC, 2017b).

When activities described by the U.S. EPA-approved Berkeley Lab PCB cleanup plan are completed, Berkeley Lab will submit a report to the U.S. EPA with a copy to DTSC documenting the PCB cleanup. Berkeley Lab also plans to submit a report to DTSC documenting the concentrations of non-radiological contaminants other than PCBs remaining in soil. Refer to Section 3.4.5 for more information.

Berkeley Lab also interfaces with the DOE Berkeley Site Office regarding cleanup of radiological contaminants in concrete and soil at the Project area. In October, Berkeley Lab submitted a final status survey report to the DOE Berkeley Site Office to document compliance with the dose-based standards of DOE Order 458.1, *Radiation Protection of the Public and the Environment* (DOE, 2013). The report covered cleanup completed at former Building 5 and its radiological waste yard (Perma-Fix, 2017). The DOE Berkeley Site Office released these areas from radiological controls (BSO issued formal approval of the final status survey results in April 2018). Berkeley Lab submitted additional final status survey reports in late 2017 to the DOE Berkeley Site Office documenting cleanup completed at Building 52 and along segments of the retaining wall at Building 5.

EBMUD issued a special discharge permit to discharge rainwater to the sanitary sewer that accumulated in excavations during the demolition (EBMUD, 2017c). The rainwater was treated prior to discharge. As required by the permit, quarterly discharge logs of the treated water and self-monitoring results of PCB congeners were submitted to EBMUD. In 2017, approximately 147,380 gallons of stormwater was pumped into holding tanks and treated in accordance with the requirements of this permit before being discharged to the sanitary sewer. Stormwater discharged from the Old Town Demolition Project area in 2017 was covered under the state's Construction General Permit. These permits are discussed in Sections 3.4.4.2 and 3.4.4.3, respectively.

3.5.1.2 Demolition Progress

The following demolition work was completed during 2017:

- **Former Building 5 and Radiological Waste Yard.** Radiological surveys and soil sampling were conducted along a retaining wall northeast of former Building 5 to demonstrate compliance with the dose-based standard of DOE Order 458.1. Elevated levels of europium were detected in soil near the retaining wall, and the impacted soil was excavated. Verification surveys and samples indicated that a small area requires additional cleanup.

  A subsurface concrete radiological decontamination pit was removed from beneath Room 150 of former Building 5 in 2016. In May 2017, the pit and gravel inside it were sampled for waste characterization. The gravel was found to contain PCBs at concentrations greater than 500 mg/kg and some radioactivity contamination. In September, additional samples were collected of soil adhering to the exterior of the pit to confirm that PCBs had not migrated from inside the pit to soil beneath it. The PCB concentrations in

these samples were less than the cleanup goal of 0.94 mg/kg approved by the U.S. EPA for the project area. The decontamination pit, the gravel inside, and waste associated with the pit were disposed of as mixed low-level radioactive waste, as described in Section 3.5.1.3.

Partial backfilling of areas released from radiological controls by the DOE Berkeley Site Office began in December and continued into 2018.

- **Former Building 16 and 16A Area.** Demolition of the building slab of former Building 16 was completed in 2017, along with PCB cleanup in soil at the south end of the building beneath Room 101, and radiological cleanup at the north side of the building. In July, Berkeley Lab submitted results of the verification sampling and requested concurrence from the U.S. EPA that the PCB cleanup was complete beneath Room 101. The U.S. EPA concurred in August that cleanup was complete, but it requested that Berkeley Lab collect additional samples to the east of the excavation once the utility corridor at this location was demolished in order to determine whether PCBs had migrated eastward, as one verification sample on the east side of the excavation contained PCBs at 2.1 mg/kg. This sampling occurred in early 2018.

  Contaminated soil was also removed in 2017 from the western side of the former building and cleanup verification samples were collected. Sampling results showed that soil with metals at concentrations greater than screening levels established for the project in the *Sampling and Analysis Plan for PCBs – Above-Slab Building Characterization* (DMS, 2015) had been removed, and that PCB cleanup was complete in the area except for one location at the northwest end of the excavation where PCB concentrations were greater than the cleanup goal of 0.94 mg/kg. Additional PCB cleanup was conducted in early 2018.

- **Former Buildings 52 and 52A Area and the former Electrical Pad.** PCB cleanup in the area to the west of former Building 52 began in February and was completed in October. In November, final verification sampling results were submitted to the U.S. EPA, along with a request for concurrence that PCB cleanup was complete in this area. After the U.S. EPA concurred that cleanup was complete in December, the excavation at this area was backfilled later that month.

  In March, PCB cleanup began beneath and to the west of former Building 52A and along a perforated drain pipe removed between former Buildings 52 and 52A. The cleanup continued into 2018.

  In May, PCB cleanup was completed at the former electrical pad and at a storm drain running along the south side of former Building 52 toward former Building 16A. Sampling results and a request for concurrence that cleanup was complete at these areas were submitted to U.S. EPA in July. Concurrence came from the U.S. EPA in August.

  Elevated concentrations of PCBs were detected in soil beneath a corroded storm drain pipe running along the northern side of former Building 52. After the pipe was removed, three rounds of excavation and verification sampling were completed in 2017. PCBs remained in the northeast corner of the excavation, which was backfilled to prevent sidewall sloughing that could have undermined the eastern hillside. Additional investigation to determine the lateral and vertical extent of the PCB contamination began in early 2018.

3.5.1.3 Waste Status

In 2017, a total of 8,587,577 pounds of waste was transported to the following treatment, storage, and disposal facilities:

- **Nevada National Security Site (near Las Vegas, Nevada):** 5,396,392 pounds of low-level radiological waste; 6% had PCB concentrations greater than 50 mg/kg, 62% of the waste was PCB remediation waste with PCB concentrations less than 50 mg/kg, and the remainder was non-PCB low-level radiological waste.
- **Potrero Hills Landfill (Suisun City, California):** 2,119,160 pounds of PCB remediation waste with PCB concentrations less than 50 mg/kg (not radiologically impacted); approximately 55% of the waste was soil, the rest was debris.
- **Chemical Waste Management (Kettleman Hills, California):** 785,533 pounds of PCB remediation waste with PCBs concentrations greater than 50 mg/kg.
- **Chemical Waste Management of the Northwest (Arlington, Oregon):** 186,197 pounds of nonradiologically impacted PCB remediation waste; 77% had PCB concentrations greater than 50 mg/kg.
- **PermaFix Northwest (Richland, Washington):** 40,000 pounds of low-level radioactive (non-PCB) waste.
- **Waste Control Specialists (Andrews, Texas):** 57,000 pounds of low-level radiological waste soil, hazardous for mercury or lead, and 14,595 pounds of mixed waste (PCB remediation waste with greater than 50 mg/kg PCBs and low-level radiological waste) including the decontamination pit beneath Room 150 of former Building 5.
- **Materials and Energy Corporation (Oak Ridge, Tennessee):** 2,595 pounds of PCB remediation waste (PCB concentrations less than 50 mg/kg) containing mercury subject to RCRA.

No concrete or soil waste generated during the cleanup in 2017 was reused or recycled.

3.5.2 Integrative Genomics Building and Modular Utility Plant Project

Site preparation activities continued for construction of the IGB and MUP at the southeastern portion of the Bayview Area, which is the former Bevatron site. The IGB/MUP Project is shown as "Building Under Construction" on figures used in this report, such as Figure 3-1. In preparing the construction site, Berkeley Lab conducted characterization, demolition or excavation, and off-site disposal of soil and concrete from the following areas:

- Soil from the IGB and MUP building footprints.
- Soil from excavations associated with new utilities.
- Concrete from the top of the existing retaining wall to meet project elevation requirements.
- Concrete from pre-existing subsurface features encountered during construction activities.

Characterization and off-site disposal activities in 2017 were performed in conformance with both the *Sampling and Analysis Plan for Characterization of Soil and Concrete Building 91 Integrative Genomics Building and Building 91U Modular Utility Plant* (Northgate, 2017b) and the *Soil Management Plan, Building 91 Integrative Genomics Building and Building 91U Modular Utility Plant* (LBNL, 2016b).

3.5.2.1 Characterization

Samples of concrete and soil were collected and analyzed for both radiological and non-radiological constituents. The analytical results for non-radiological constituents indicated that the materials were all nonhazardous; the

radiological data indicated that the material was indistinguishable from background. These analytical data, which are summarized in the *Characterization Report for Excavated Soil and Concrete Building 91 Integrative Genomics Building and Building 91U Modular Utility Plant* (Northgate, 2017a), were used to characterize materials for final off-site disposition.

3.5.2.2 Disposal

Using the characterization data, special waste applications were submitted to Waste Connections for its approval. In 2017, approximately 500 cubic yards of materials were shipped in covered trucks under nonhazardous waste manifests to Waste Connections' Potrero Hills Landfill in Suisun City, California.

4 Environmental Monitoring

Berkeley Lab's environmental monitoring programs assess the impact of its emissions on public health and the environment, which is important for measuring environmental stewardship performance and demonstrating compliance with requirements established by federal, state, and local agencies. These programs also confirm adherence to DOE environmental protection policies and support environmental management decisions. The comprehensive *Environmental Monitoring Plan* (LBNL, 2013b) provides the basis and current scope for each program. This chapter presents summaries of 2017 sampling and monitoring results for the following media and processes:

- Stack air
- Surface water
- Wastewater
- Groundwater
- Soil and sediment
- Vegetation and foodstuffs
- Penetrating radiation monitoring
- Radiological clearance of property

4.1 STACK AIR

Berkeley Lab's air monitoring program is designed to measure the impacts from radiological air emissions. The program consists of emissions sampling and monitoring to measure contaminants in building exhaust systems. The program meets the U.S. EPA and DOE requirements discussed in Section 3.4.1.1.

Various radionuclides are used in Berkeley Lab's radiochemical and biomedical research programs, and radioactive materials are generated by particle accelerators. These research and accelerator operations may produce very small amounts of airborne radionuclides, which are typically emitted through a stack via a building's exhaust system. Berkeley Lab is required to assess the potential impacts from radionuclide emissions where radionuclides are used or generated. If the dose from potential emissions exceeds U.S. EPA Region 9–approved thresholds listed in Table 4-1, Berkeley Lab must follow U.S. EPA–approved methods for measuring emissions by sampling or monitoring stacks through which emissions are released. *Sampling* is the collection of radionuclides on a filter or absorbent media, and subsequent analysis of the filters or media at an analytical laboratory, and *monitoring* is the continuous measurement of radionuclides in real time.

Each year, all locations using radionuclides are evaluated for their potential to emit radionuclides, then compared with the thresholds listed in Table 4-1. In 2017, all potential doses were found to be less than 0.1 mrem/yr, indicating that the applicable requirements are either Category 3, which requires periodic sampling, or Category 4, which requires dose evaluation but no sampling or monitoring. At some locations, Berkeley Lab follows a more conservative approach that may include either real-time monitoring to better characterize emissions, or more frequent sampling than required. In 2017, sampling was performed on a total of 17 stacks, and real-time monitoring was performed on four others. Sampling and monitoring locations are shown on Figure 4-1.

Table 4-1 U.S. EPA–Approved Radionuclide Emissions Measurement Approach

Category	AEDE (mrem/yr)	Requirements
Noncompliant	AEDE ≥ 10	Reduction or relocation of the source and re-evaluation before authorization
1	10 > AEDE ≥ 1	Continuous sampling with weekly collection and real-time monitoring for short-lived radionuclides
2	1 > AEDE ≥ 0.1	Continuous sampling with monthly collection or real-time monitoring for short-lived radionuclides
3	0.1 > AEDE ≥ 0.01	Periodic sampling 25% of the year
4	0.01 > AEDE	Potential dose evaluation before project starts and when project changes; no sampling or monitoring required

AEDE = annual effective dose equivalent

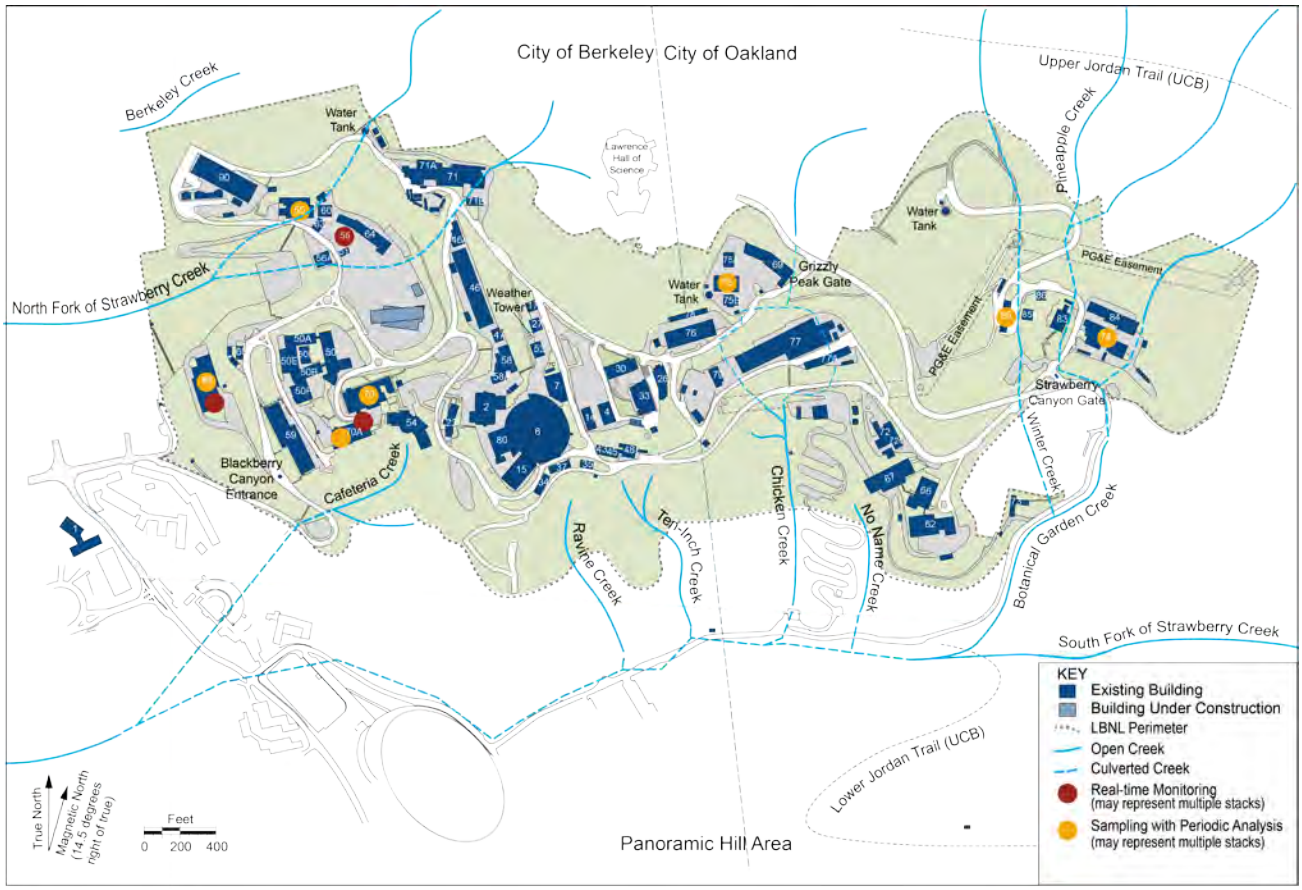

Figure 4-1 Building Exhaust Sampling and Monitoring Locations

Stack exhaust samples were analyzed for five radiological parameters: gross alpha, gross beta, carbon-14, iodine-125, and tritium. Real-time stack air monitoring systems measured alpha emitters and positron emitters. The positron emitter fluorine-18 (half-life of 1.8 hours) was the predominant radionuclide emitted, accounting for nearly 99.8% of the emitted activity. The Building 56 glovebox was the main source of fluorine-18 emissions, at 3.19 curies (Ci). Additional details on stack emissions are available in Berkeley Lab's *Radionuclide Air Emission*

Report for 2017 (LBNL, 2018), which was submitted to the U.S. EPA, and is available on the Publications page of ESG's website (https://ehs.lbl.gov/service/environmental-services/). For information on the estimated dose from radionuclide emissions, see Chapter 5.

4.2 SURFACE WATER

Surface water quality is evaluated at and around Berkeley Lab by sampling creek water and stormwater.

4.2.1 Creek Sampling

The sampled creeks either flow through or originate within the LBNL site. The following creeks are sampled within the Strawberry Creek watershed (from west to east on Figure 4-2):

- North Fork of Strawberry Creek
- Cafeteria Creek
- Ravine Creek
- Ten-Inch Creek
- Chicken Creek
- No Name Creek
- Winter Creek, which is sampled at two locations (inflow and outflow points to the site)
- Upper Botanical Garden Creek

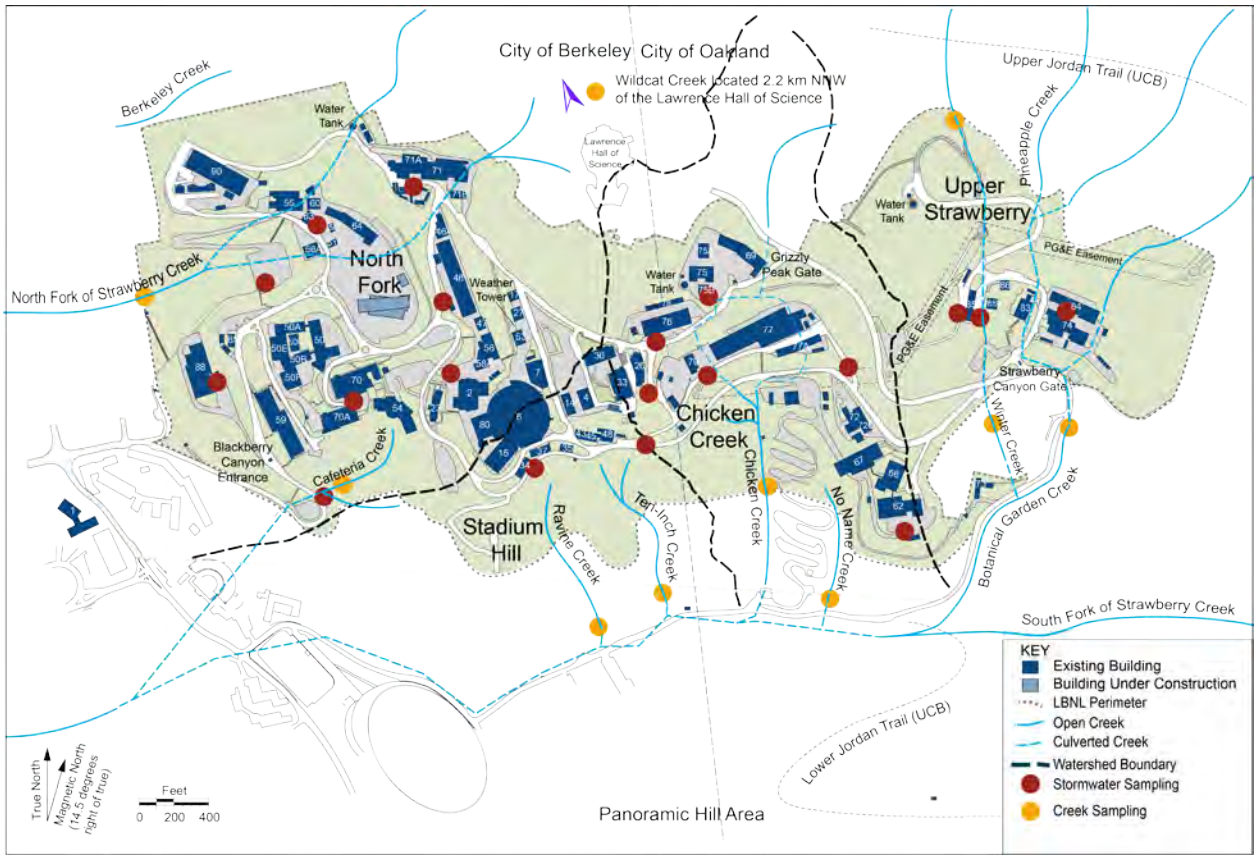

Figure 4-2 Surface Water Sampling Locations

To establish background water quality values for the region, samples were also collected semiannually from Wildcat Creek at a location in Tilden Regional Park approximately 1.4 miles north-northwest of UC's Lawrence Hall of Science. Wildcat Creek originates in Tilden Regional Park and flows in a northwest direction away from Berkeley Lab.

Samples from the following subset of creeks were collected semiannually and analyzed for gross alpha, gross beta, and for tritium in accordance with DOE Order 458.1 requirements: Chicken Creek, the North Fork of Strawberry Creek, Wildcat Creek, and Winter Creek (inflow and outflow points). Samples from these locations were also analyzed for the following specific radionuclides using gamma emission spectroscopy: actinium-228, bismuth-214, cesium-134, cesium-137, europium-152, iron-59, lead-214, potassium-40, radium-226, thallium-208, and uranium-238.

Although LBNL surface waters are not used as a source of public drinking water, Berkeley Lab evaluates creek water results against conservative Maximum Contaminant Level (MCL) drinking water standards, as well as water quality objectives as stated in the *Water Quality Control Plan for the San Francisco Bay Basin* (commonly known as the Basin Plan; RWQCB, 2015). The federal and state MCL values for drinking water are as follows (U.S. EPA, 1976; RWQCB, 2016):

- gross alpha – 15 picocuries per liter (pCi/L)
- gross beta – 50 pCi/L
- tritium – 20,000 pCi/L

Laboratory analysis reported 24 of the 27 sample results as below detectable levels. As shown in Table 4-2, three samples had detectable levels of gross alpha or gross beta, although these were less than 20% of the federal and state MCL values for drinking water. Naturally occurring radioactive materials, such as potassium-40, uranium-238, thorium-232, and their daughter products, are believed to contribute the majority, if not all, of the detectable gross alpha and gross beta results. Tritium was not detected in any of the samples.

Table 4-2 Detectable Radiological Results from 2017 Creek Sampling

Activity	MCL[a] (pCi/L)	Creek	Sample (pCi/L)	% of MCL
gross alpha	15	Winter Creek	2.6	17.3
		Chicken Creek	2.26	15.1
gross beta	50	Chicken Creek	3.8	7.6

[a] MCL = Maximum Contaminant Level for drinking water, in picocuries per liter (pCi/L)

Using gamma spectroscopy for specific radionuclides, the results indicated that 79 of the 94 analyses (84%) were below detectable levels. Radiological activities for the remaining samples with detectable results were consistently low and within historical environmental levels monitored by Berkeley Lab.

Creek samples were also analyzed for PCBs, VOCs, and metals. No PCBs or VOCs were detected, but the following metals were detected: aluminum, antimony, arsenic, barium, chromium, copper, iron, lead, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc. Metals concentrations were within historical

levels for Berkeley Lab, well below the water quality objectives listed in the Basin Plan, and well below the drinking water standard.

In addition, the first samples of the year collected from Chicken Creek, the North Fork Strawberry Creek, Wildcat Creek, and Winter Creek were analyzed for the following general indicator parameters: pH, chemical oxygen demand, oil and grease, total suspended solids, and nitrate plus nitrite. The results were within historical levels for the site.

4.2.2 Stormwater Sampling

Berkeley Lab's *Stormwater Monitoring Implementation Plan* describes the sampling rationale, sampling locations (see Figure 4-2), and analytical parameters for each specific industrial activity (LBNL, 2016c). The Industrial General Permit also requires visual observation of the surface water runoff from each qualifying storm event, dry weather visual observations of non-stormwater discharges once per month, and an annual sitewide inspection.

Under the terms of the Industrial General Permit, Berkeley Lab must conduct stormwater sampling each reporting year during four storm events that meet a set of permit-specific conditions. Two of the sampling events typically occur within the first half of each reporting year (July 1–December 31), with the remaining two then taking place during the second half of each reporting year (January 1–June 30). Because the Site Environmental Report is based on the calendar year, the sampling events discussed here are based on results from two stormwater reporting years: the second half of 2016/2017 and the first half of 2017/2018.

As identified by industrial activities listed in Berkeley Lab's SWPPP, samples must be analyzed for the following nine parameters:

1. aluminum
2. chemical oxygen demand
3. copper
4. iron
5. pH
6. nitrate plus nitrite
7. oil and grease
8. total suspended solids
9. zinc

The 2015/2016 reporting year was the first under a significantly modified Industrial General Permit, which initially set all facilities in the state operating under this permit at the "Baseline" compliance level, the least stringent of three compliance levels. To remain at the Baseline level, a facility would need to maintain the average results for each sampled parameter below that parameter's Numeric Action Level established by the State Water Board. The results from the four sampling events for the first reporting year under the new permit showed that two of the nine parameters sampled by Berkeley Lab, aluminum and iron, exceeded their Numeric Action Levels of 0.750 and 1.000 mg/L, respectively. This resulted in a change in compliance status from Baseline to Level 1 for the 2016/2017 reporting year. In the subsequent reporting year (2017/2018), sample results again showed that averages for

aluminum (at 1.271 mg/L) and iron (at 1.75 mg/L) were above their respective Numeric Action Levels, causing Berkeley Lab's status to change again to compliance Level 2.

The change in compliance level prompted Berkeley Lab to identify additional stormwater controls to implement in order to prevent future exceedances of Numeric Action Levels. These additional controls fell into the two categories of administrative and structural/treatment controls. Administrative controls were in the areas of updated procedures and expanding stormwater training for Laboratory staff, vendors, and contractors. Structural/treatment controls included additional asphaltic berms and check dams, and enhanced filtration for metal treatment. This also meant updating the SWPPP to include the additional stormwater controls, then submitting an Exceedance Response Action Level 2 report to the State Water Board outlining actions taken for the site.

With additional best management practices in place to address aluminum and iron for the 2017/2018 reporting year, Berkeley Lab was successful in collecting samples during the only qualifying storm event that occurred before December 31. Unlike the preceding two reporting years, the results for all nine parameters were below their Numeric Action Levels for this first sampling event, holding promise that the newly added controls would provide similar results for the remaining sampling events for the reporting year and return Berkeley Lab to the Baseline compliance level. The results for the entire 2017/2018 reporting year will be reported in the Site Environmental Report for 2018.

4.3 WASTEWATER

As required by permits issued by EBMUD, Berkeley Lab samples wastewater discharges at its two monitoring stations downstream of the main site. Sampling is also conducted to assess permit compliance for discharges of treated water from hydraugers, groundwater extraction wells, and the Building 77 Ultra-High Vacuum Cleaning Facility. For the current reporting year, all monitoring results were below EBMUD discharge limits. Monitoring results, an overview of monitoring locations, and a summary of any sanitary sewer spills are discussed in the following subsections.

4.3.1 Wastewater Monitoring Locations

As discussed in Section 3.4.4.2, Berkeley Lab holds EBMUD wastewater discharge permits for general sitewide activities, metal finishing operations in the Ultra-High Vacuum Cleaning Facility at Building 77, and treated groundwater operations at eight locations. Each permit specifies periodic monitoring and reporting requirements.

Berkeley Lab's sanitary sewer system, shown on Figure 4-3, has two monitoring stations, each located near the outfall of one of the two main sewer system branches:

1. The Hearst Monitoring Station is located at the head of Hearst Avenue below the western edge of Berkeley Lab immediately before the connection to the City of Berkeley's sewer main. Discharges from Berkeley Lab's western and northern areas flow through this monitoring station.
2. The Strawberry Monitoring Station is located next to Centennial Drive in lower Strawberry Canyon. Discharges from Berkeley Lab's eastern and southern areas, as well as from several upstream UC Berkeley

campus facilities, are routed through this monitoring station before tying into UC-owned piping downstream and then into the City of Berkeley's sewer system.

4.3.2 Hearst and Strawberry Sewer Outfalls

In 2017, Berkeley Lab discharged approximately 25.0 million gallons through the Hearst branch of the sewer system and 51.2 million gallons through the Strawberry branch, as measured by total volumetric flow. Sampling and monitoring are conducted at these sewer outfalls as described briefly below; additional details are given in Sections 4.3.2.1 and 4.3.2.2.

- Radiological monitoring is required by DOE Order 458.1 (DOE, 2013) and corresponding guidance (DOE, 2015). Monitoring verifies compliance with radiological limits established by the Nuclear Regulatory Commission to regulate the use of radioactive materials.
- Non-radiological samples collected at the Hearst and Strawberry outfalls are analyzed for pH, total identifiable chlorinated hydrocarbons, chemical oxygen demand, PCBs, total suspended solids, and specific metals.

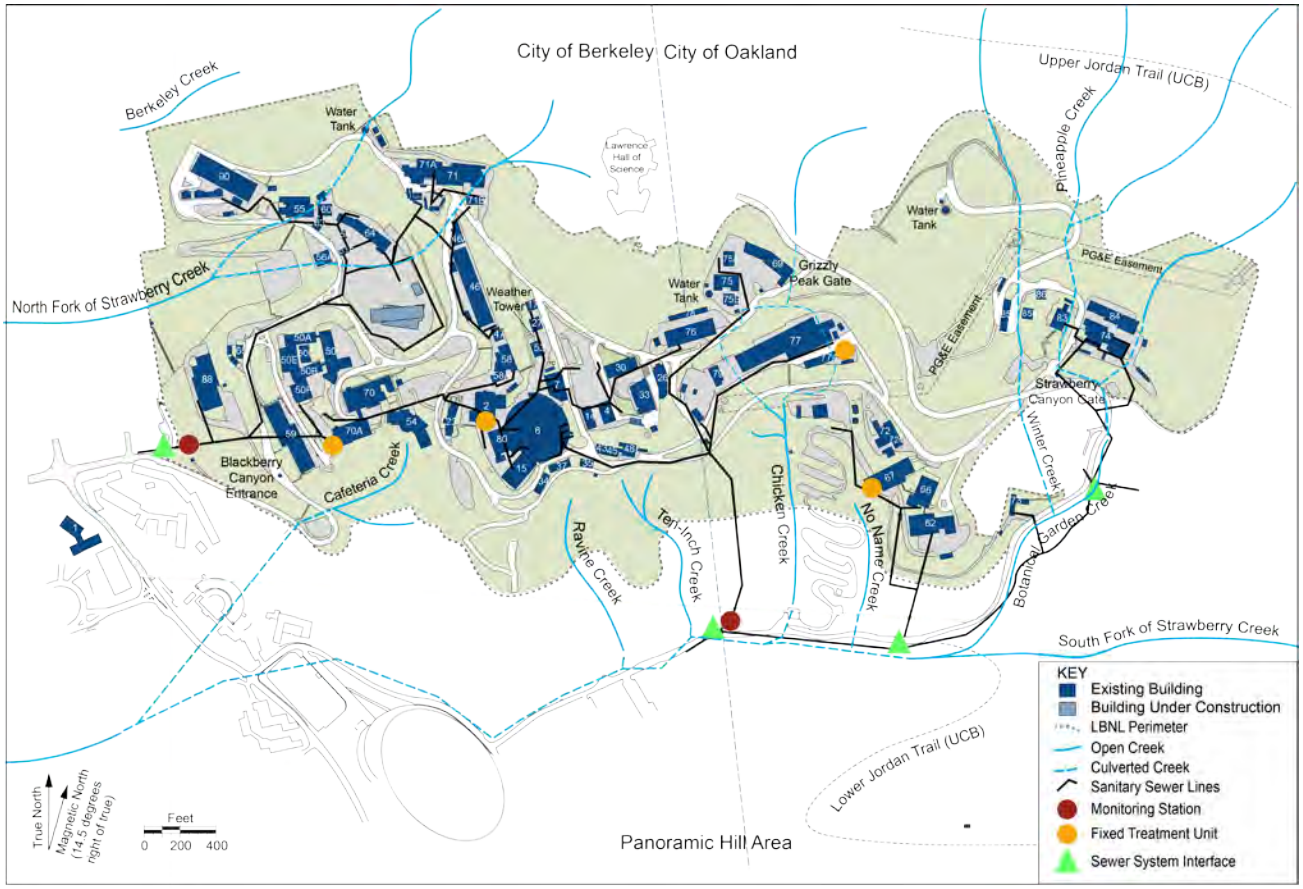

Figure 4-3 Sanitary Sewer System (Main Lines)

4.3.2.1 Radiological Monitoring

For radiological monitoring, time-interval (every hour) composite samples are collected every month at the Hearst and Strawberry outfalls and analyzed by a state-certified laboratory for gross alpha, gross beta, iodine-125, tritium, and carbon-14. All samples taken at the Hearst or Strawberry sanitary sewer outfalls in 2017 were below the minimum detectable activity levels for carbon-14, iodine-125, gross alpha, and tritium. Positive results for gross beta were consistently detected throughout the year at the Hearst and Strawberry sewer outfalls, and are likely due to naturally occurring radioactive material such as potassium-40. The highest monthly gross beta concentration was 25 pCi/L, which is below the federal and state MCL for drinking water of 50 pCi/L.

In accordance with DOE guidance (DOE, 1991), annual discharges are estimated by multiplying the sample result's activity by the volume discharged during the monitoring period, even when the activity level is below the minimum detection limits. Since carbon-14, iodine-125, gross alpha, and tritium were below minimum detectable activity levels, they are considered estimated values. The federal and state regulatory limits for radioisotopes in wastewater are based on total amounts discharged per year. The annual discharge estimated from tritium values totaled 2.91×10^{-2} Ci, or 5.8% of the tritium discharge limit of 5 Ci. The annual discharge estimated from carbon-14 values totaled 2.05×10^{-2} Ci, or 2.1% of the carbon-14 discharge limit of 1 Ci. Both estimates use the maximum concentration for each sample result, even if this value is below the minimum detection limit. For example, all sample results for carbon-14 were below the detection limit, yet the discharge estimate is still a positive number. The estimated annual discharge for all other radioisotopes (i.e., gross alpha, gross beta, and iodine-125) was 6.27×10^{-3} Ci, or 0.63% of the combined discharge limit of 1 Ci.

DOE Order 458.1 requires facilities to control discharges into sanitary sewers if average monthly activity at the point of discharge is greater than five times Derived Concentration Standard (DCS) values for ingested water specified in DOE-STD-1196-2011, *Derived Concentration Technical Standard* (DOE, 2011b). Compliance is demonstrated when the fraction of each DCS value is calculated, based on consecutive 12-month average concentrations, and totaled. Applying conservative assumptions to the radionuclides responsible for the gross alpha (thorium-232) and gross beta (strontium-90) activity, the calculated discharges were 0.0057 (0.57%) and 0.02 (2.0%) of the allowable fractional DCS values in the Strawberry and Hearst sanitary sewer systems, respectively.

4.3.2.2 Non-radiological Monitoring

Berkeley Lab collected two non-radiological samples from both the Hearst and Strawberry outfalls in March and September, in accordance with the self-monitoring sample collection schedule specified by the EBMUD permit. All metals and total identifiable chlorinated hydrocarbon results were either below EBMUD permit limits or not detected. Samples were also analyzed for 176 different PCB congeners as required by the permit, although EBMUD has not designated a discharge limit for PCBs in wastewater. Nearly 60% of these analyses were below detection levels. All pH results were well above 5.5, as required by the permit. Total suspended solids and chemical oxygen demand also do not have discharge limits and are measured to determine wastewater strength, which forms the basis for EBMUD's wastewater treatment charges.

EBMUD visited both outfalls in late May and early June to collect grab samples and 24-hour composite samples. All results were within EBMUD permit discharge limits.

4.3.3 Treated Hydrauger and Extraction Well Discharge

Berkeley Lab currently has eight treatment systems permitted by EBMUD to discharge treated groundwater to the sanitary sewer. Sources of this treated groundwater are certain hydraugers (subsurface drains), groundwater extraction wells, and well sampling and development activities. The treatment process consists of first filtering the groundwater to remove sediment and then passing the contaminated groundwater through a carbon adsorption (i.e., GAC) system to remove hydrocarbons. Samples of the treated water are collected and analyzed for VOCs using U.S. EPA–approved methods. Sampling results have never exceeded the EBMUD permissible discharge limits.

4.3.4 Building 77 Ultra-High Vacuum Cleaning Facility Wastewater

Cleaning processes at the Ultra-High Vacuum Cleaning Facility at Building 77 include passivating (making a metal surface less chemically reactive), acid and alkaline cleaning, and ultrasonic cleaning of metal parts used in research and support activities. Acid and alkaline rinse waters that contain metals from this facility's operations are routed to FTU 006, which can treat approximately 60 gallons of wastewater per minute. As required by the EBMUD permit, Berkeley Lab sampled effluent from the treatment unit in September. Sampling results showed that pH and metals were within the permit limits.

The permit also requires that Berkeley Lab submit an annual report certifying that Building 77 is not discharging chlorinated hydrocarbons or other toxic organic compounds to the FTU or the sanitary sewer. The Total Toxic Organics Compliance Report was submitted to EBMUD in November.

4.3.5 Sewer System Management Plan

Berkeley Lab's *Sewer System Management Plan* (LBNL, 2015) addresses the State Water Board's requirements for maintaining Berkeley Lab's sanitary sewer systems and preventing and reporting overflows. SWRCB regulations require that any public agency owning or operating a wastewater collection system with piping longer than 1 mile prepare a written sewer system management plan to address the proper operation, maintenance, and funding for maintenance and capital improvements of the system. This plan must be reviewed every five years to ensure that information is current and available. The most recent review and update was completed in April 2015. In addition, the plan must be audited by an independent party every two years. The next audit is scheduled for 2018, with the results reported in next year's Site Environmental Report.

The State Water Board's Sanitary Sewer Order, "Amending Monitoring and Reporting Program for Statewide General Waste Discharge Requirements for Sanitary Sewer Systems," requires that all spills be reported. Also, monthly reporting is required regardless of whether any sanitary sewer overflow has occurred (SWRCB, 2013). Sanitary sewer overflow reporting is accomplished through the online California Integrated Water Quality System (http://www.waterboards.ca.gov/ciwqs/), which is used by the State Water Board and the Regional Water Quality Control Boards to track water quality–related information. No sanitary sewer overflows occurred during the year.

4.4 GROUNDWATER

This section describes Berkeley Lab's groundwater monitoring program and provides a brief summary of the site's groundwater contaminant plumes and the corrective measures applied to each. More detailed information on RCRA Corrective Action Program activities is provided in the Environmental Restoration Program's progress

reports, which contain the site groundwater monitoring data, maps showing monitoring well locations and contaminant concentrations, and graphs showing variations in contaminant concentrations over time. These reports, which are currently produced annually, are available at the main branch of the Berkeley Public Library and on the program's website at https://ehs.lbl.gov/resource/environmental-restoration-program/.

4.4.1 Groundwater Monitoring Overview

The groundwater monitoring network consists of more than 175 wells, including 17 that are used to monitor for potential migration of VOC-contaminated groundwater beyond the developed areas of the site (see Figure 4-4). The objectives of groundwater monitoring are as follows:

- Evaluate the continued effectiveness of the corrective measures that have been implemented for cleanup of contaminated groundwater.
- Document that groundwater plumes continue to be stable or attenuating and are not migrating off site.
- Monitor progress toward attaining the required groundwater cleanup levels.
- Monitor progress toward attaining the long-term goal of restoring all groundwater at the site to drinking water standards, if practicable. (Groundwater at Berkeley Lab is not used for domestic, irrigation, or industrial purposes.)

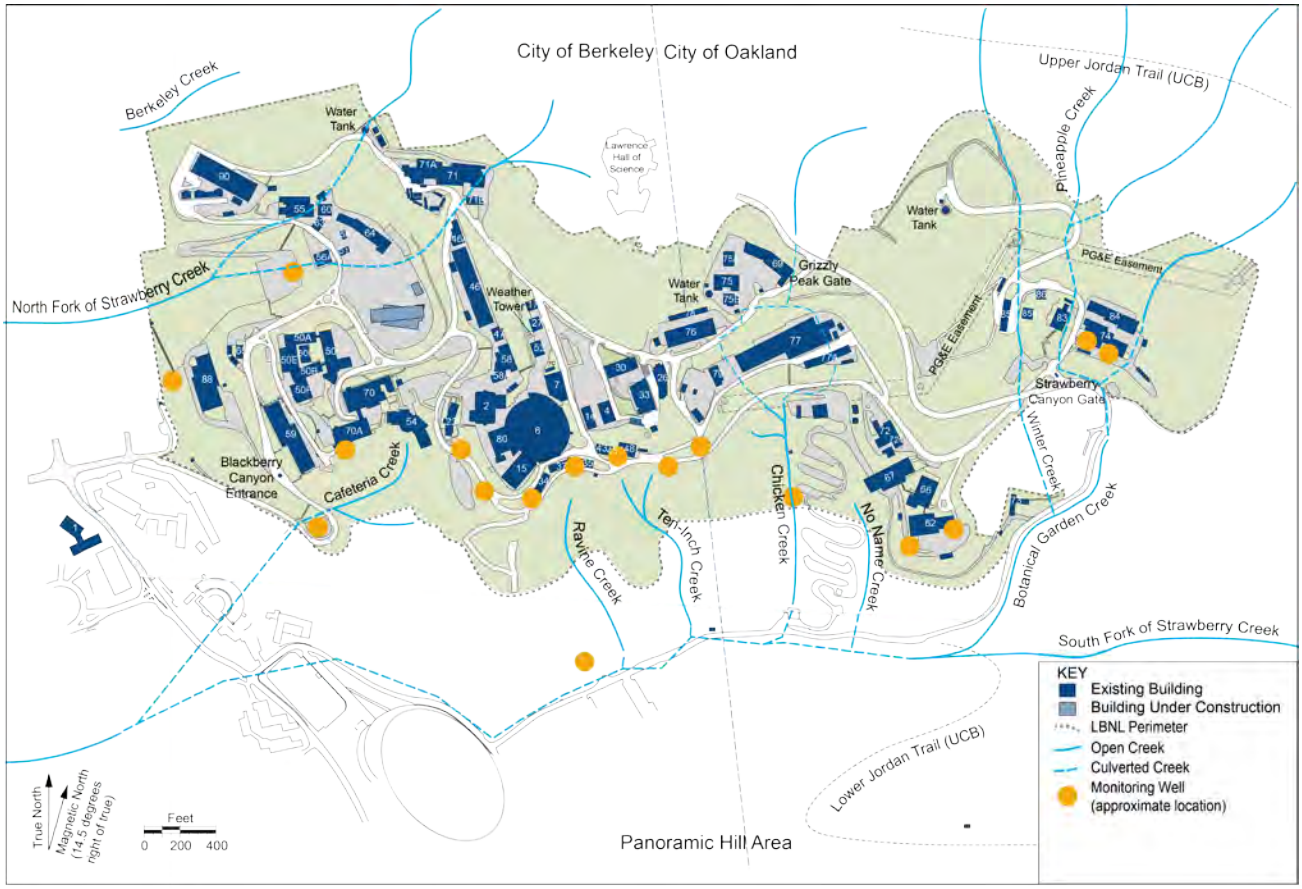

Figure 4-4 Groundwater Monitoring Wells Closest to the Site Boundary

The groundwater monitoring data continue to indicate that the corrective measures have been effective in reducing VOC concentrations in the groundwater, and that groundwater contaminant plumes are stable or diminishing and contaminants are not migrating off site.

VOCs: Berkeley Lab has identified four principal plumes of VOC-contaminated groundwater at the site: Old Town, Building 51/64, Building 51L, and Building 71B. The geometry and distribution of chemicals in the Old Town Plume indicate that the plume consists of three lobes (i.e., Building 7, Building 25A, and Building 52 lobes) that were originally separate plumes but subsequently merged. In addition to the four principal plumes, VOC-contaminated groundwater is present in the following six localized areas: former Building 51A, former Building 51 Vacuum Pump Room, Building 69A, Building 75/75A, Building 76, and Building 77. The locations of the plumes and other areas of groundwater contamination are shown on Figure 4-5.

The primary VOCs detected in the groundwater are chlorinated VOCs (e.g., tetrachloroethylene, trichloroethylene, 1,1,1-trichloroethane, carbon tetrachloride) and their associated degradation products (e.g., 1,1-dichloroethylene, cis-1,2-dichloroethylene, 1,1-dichloroethane, and vinyl chloride). Concentrations of VOCs in most areas have declined significantly, primarily from the implemented corrective measures. However, VOC concentrations remain above MCLs in a number of areas. The areas where VOC concentrations in the groundwater exceed MCLs are shown on Figure 4-5.

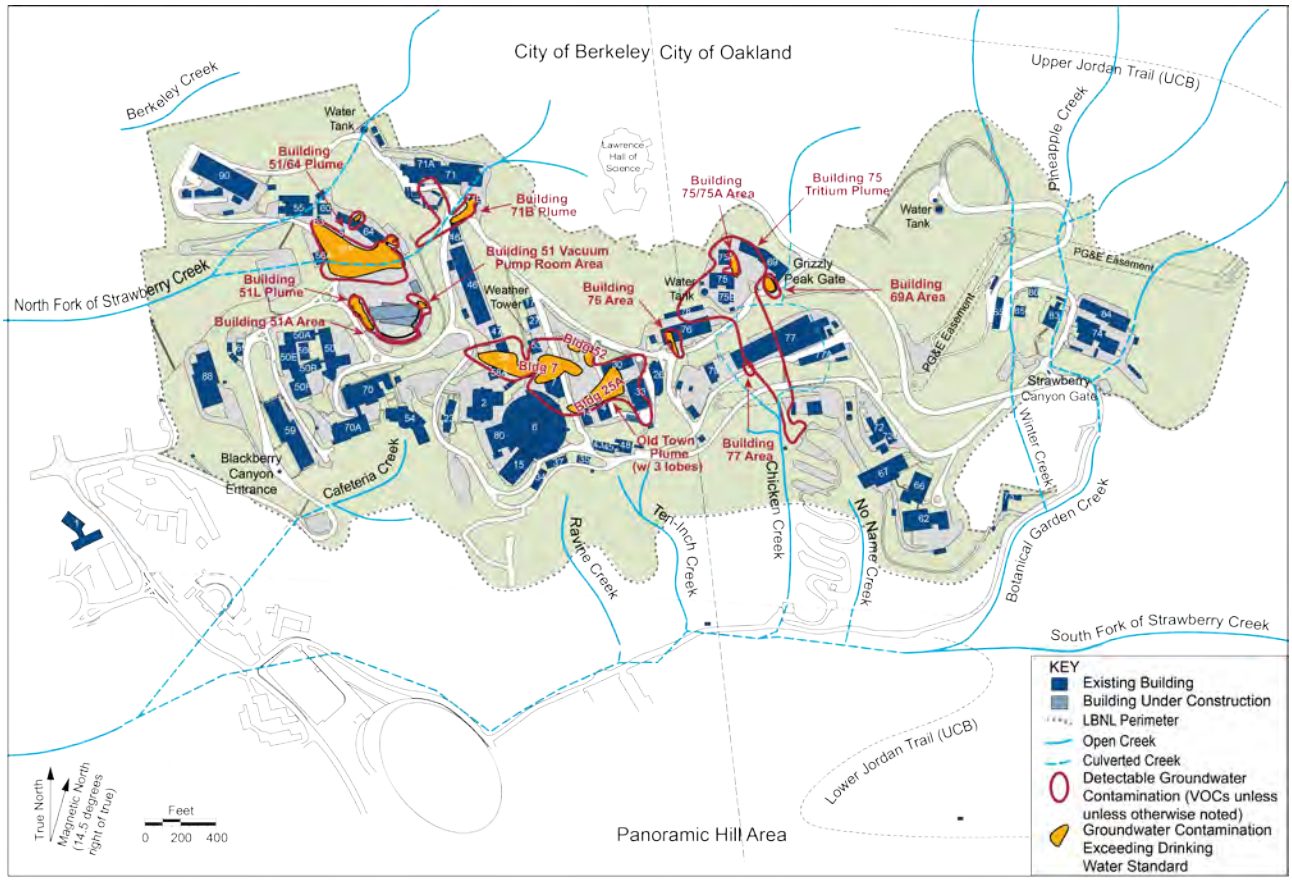

Figure 4-5 Locations of Groundwater Contamination

Metals: Twelve groundwater monitoring wells at the site were previously monitored annually for a specific metal (i.e., arsenic, mercury, molybdenum, or selenium) that historically had exceeded the upper estimate of LBNL background (LBNL, 2002) and any established MCL. In May 2017, DTSC approved Berkeley Lab's request to eliminate the requirement to sample those wells for metals. The request was based primarily on evidence indicating that the exceedances of statistically estimated background levels and MCLs were likely the result of naturally occurring metal concentrations.

Tritium: A plume of tritium-contaminated groundwater extends southward from the Building 75 area. The source of the plume was the former National Tritium Labelling Facility (NTLF), which ceased operation in December 2001. Since closure of the NTLF, concentrations of tritium detected in the groundwater have declined steadily, with concentrations below the drinking water standard of 20,000 pCi/L (U.S. EPA, 1976; RWQCB, 2016) since February 2005. The maximum concentration of tritium detected in 2017 was approximately 40% of the MCL. The location of this tritium plume is shown on Figure 4-5. Concentrations of tritium that were well below the drinking water standard were also previously detected in groundwater samples collected in the Building 71B area and beneath the central area of the former Bevatron site during demolition activities of this structure in 2010.

4.4.2 Treatment Systems

Berkeley Lab is extracting contaminated groundwater from collection trenches, extraction wells, and subdrains to control the migration of groundwater plumes and to clean up contaminated groundwater. Ten GAC treatment systems were in operation in 2017 to treat extracted groundwater, which totaled approximately 9.6 million gallons for the year. The cumulative volume of groundwater treated from 1991 through the end of 2017 exceeds 192 million gallons. The treated water is either injected into the subsurface, if needed for soil flushing, or discharged to the sanitary sewer system in accordance with the EBMUD permit for this type of discharge (EBMUD, 2016).

4.5 SOIL AND SEDIMENT

This section summarizes monitoring results for soil and sediment samples collected in the fall of 2017 and required by DOE Order 458.1 and guidance (DOE, 2015). Locations for soil and sediment sampling are shown on Figure 4-6.

4.5.1 Soil Sampling

Soil samples obtained from the top 2 inches of surface soil were collected from three locations within the LBNL site (near Buildings 75, 80, and 85) and from one off-site environmental monitoring station. The sample from the Building 85 location was split for quality control purposes. Samples were analyzed for gross alpha, gross beta, gamma emitters, tritium, moisture content, pH, and 15 metals.

The radiological results for gross alpha, gross beta, and gamma emitters at each of the sampling locations were similar to background levels that would be attributable to naturally occurring radioactive elements commonly found in soils (Eisenbud, 1973; NCRP, 1987). Tritium measurements at each sampling location were below detection limits.

Moisture content and pH levels at each of the sampling locations were within the historical range for soils at Berkeley Lab. With the exception of mercury, metals results were within both the established LBNL background levels (LBNL, 2009a) and levels commonly found in soils in the United States (Shacklette and Boerngen, 1984).

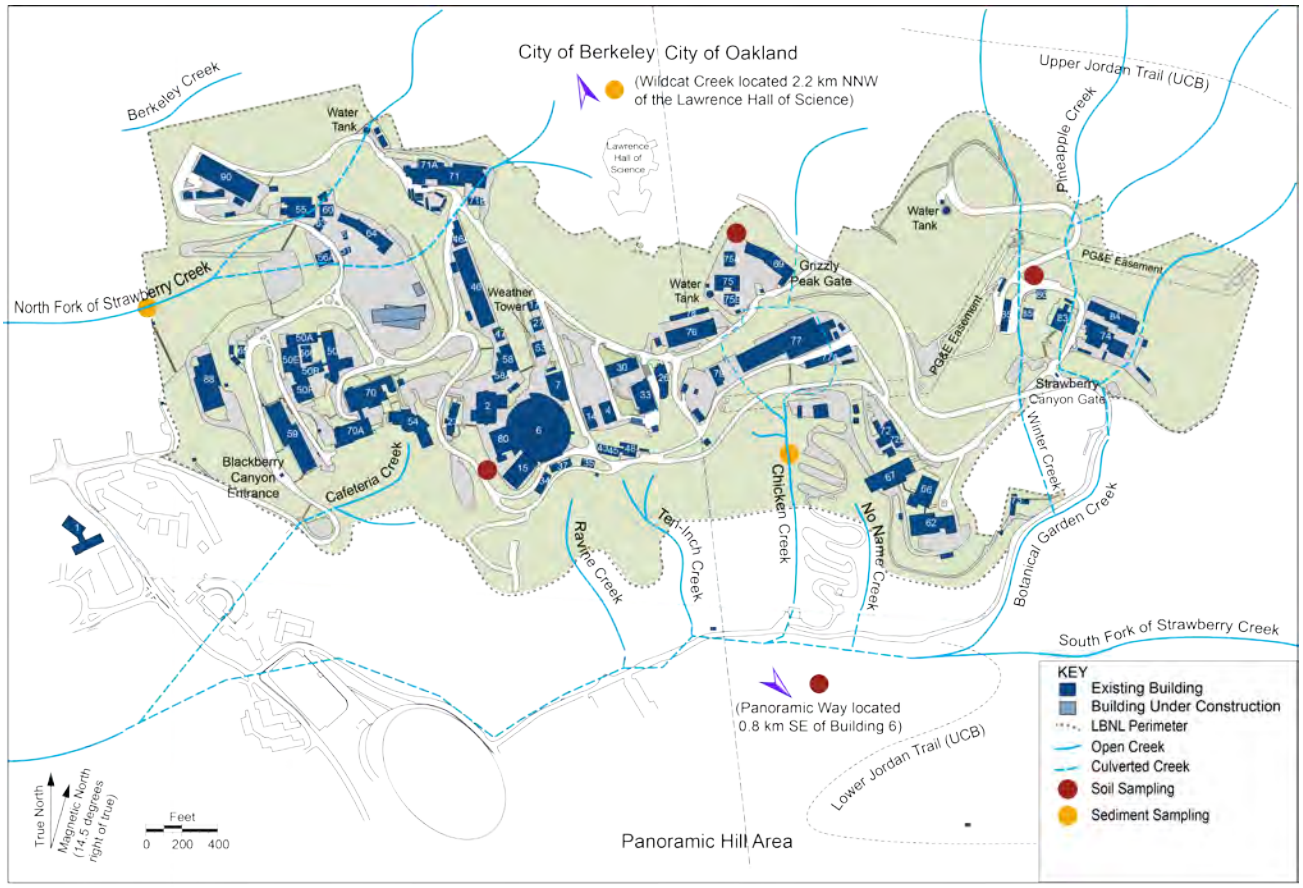

Figure 4-6 Soil and Sediment Sampling Sites

At the Building 80 and Building 85 sampling locations, mercury was detected at concentrations of 0.95 milligrams per kilogram (mg/kg) and 0.68 mg/kg, respectively. The split sample collected at Building 85 contained 0.40 mg/kg of mercury. Both Building 80 and Building 85 results are above the established LBNL soil background concentration for mercury (0.42 mg/kg). However, they are well below the RWQCB's commercial/industrial environmental screening level of 57 mg/kg (RWQCB, 2016) and DTSC's modified commercial/industrial screening level of 4.5 mg/kg (DTSC, 2017a).

4.5.2 Sediment Sampling

Sediment samples were collected at Chicken Creek and the North Fork of Strawberry Creek within the LBNL main site and at Wildcat Creek in Tilden Regional Park. Due to limited sediment availability, several grab samples from the general sampling area of each location were composited and analyzed for gross alpha, gross beta, gamma emitters, tritium, 15 metals, moisture content, pH, petroleum hydrocarbons (diesel and oil/grease), and PCBs. The sample from Chicken Creek was split for quality control purposes.

The radiological results for gross alpha, gross beta, and gamma emitters at each of the sampling locations were similar to background levels of naturally occurring radioactive elements commonly found in soils (Eisenbud, 1973; NCRP, 1987). Tritium measurements at each sampling location were below detection limits.

The results of non-radiological analysis for pH, moisture content, and petroleum hydrocarbons (diesel and oil/grease) measurements at each of the sampling locations were within the historical range for sediments at Berkeley Lab. Metals results were within both the established LBNL soil background levels and levels commonly found in soils in the United States (Shacklette and Boerngen, 1984). With the exception of Chicken Creek, all PCB results were below detection limits.

PCBs were detected in the split sample collected from Chicken Creek at a concentration of 0.015 mg/kg for Aroclor 1260 and 0.02 mg/kg for total PCBs; however, PCBs were not detected for any of the nine Aroclors or total PCBs analyzed in the primary sample at this location. These results are slightly above the method detection limits and well below the RWQCB's environmental commercial/industrial screening level of 1.0 mg/kg (RWQCB, 2016) and the U.S. EPA's regional commercial/industrial screening level of 0.99 mg/kg for Aroclor 1260 (U.S. EPA, 2016b).

4.6 VEGETATION AND FOODSTUFFS

Sampling and analysis of vegetation and foodstuffs can provide information regarding the presence, transport, and distribution of radioactive emissions in the environment. This information can be used to detect and evaluate changes in environmental radioactivity resulting from LBNL activities, and to calculate the potential human dose that would occur from consuming vegetation and foodstuffs.

As a result of past air emissions from the former NTLF located at Building 75, vegetation near that site contains measurable concentrations of tritium. Berkeley Lab analyzes vegetation for both chemical forms in which tritium occurs, namely, organically bound tritium and tissue-free water tritium. Since the closure of the NTLF in December 2001, tritium emissions from LBNL activities have decreased sharply, as noted in Section 4.4.1. Tritium concentrations in vegetation have decreased also, albeit more slowly.

To document changes in the concentrations of tritium in the local vegetation, Berkeley Lab has sampled vegetation every five years since the NTLF was closed. The most recent sampling, in the fall of 2015, confirmed that although vegetation in the vicinity of the former NTLF hillside stack contains measurable tritium concentrations, the concentration continues to decrease. Concentrations in much of the area around this former stack are projected to decrease to below the detection limit by the next scheduled vegetation sampling event, which is in 2020.

4.7 PENETRATING RADIATION MONITORING

Radiation-producing machines (e.g., accelerators, x-ray machines, and irradiators) and various radionuclides are used at Berkeley Lab for high-energy particle studies and biomedical research. Accelerator operations are the primary contributors of penetrating radiation, and when operating, accelerators may produce gamma and neutron radiation. The accelerators include the Advanced Light Source (Building 6), the Biomedical Isotope Facility (Building 56), the 88-Inch Cyclotron (Building 88), and the Laser Accelerator Center (Building 71). The system in Building 71 is an experimental laser-driven accelerator that does not emit measurable gamma or neutron radiation into the environment. Smaller radiation-producing machines (x-ray machines and irradiators) at Berkeley Lab do not measurably increase the dose to the public.

Berkeley Lab uses two methods to determine the environmental radiological impact from accelerator operations, as follows:

- Real-time monitors that continuously detect and record gamma radiation and neutron dose.
- Passive detectors known as optically stimulated luminescence dosimeters, which provide an integrated dose over time from gamma radiation.

The real-time monitors are used to satisfy criteria in DOE Order 458.1. Passive detectors supplement the real-time monitors and confirm that the dose from LBNL operations is negligible and comparable to the measured background location. The locations of real-time monitors and dosimeters are shown on Figure 4-7. The results of both measurement methods are given in terms of dose (see Section 5.2).

4.8 RADIOLOGICAL CLEARANCE OF PROPERTY

Radiological clearance is the process by which property with the potential to contain residual radioactive material is evaluated and then transferred or disposed of. Requirements for this process are set by DOE Order 458.1, which specifies that property can be cleared only if it has been demonstrated that levels of radioactivity are indistinguishable from background. In addition, Berkeley Lab's safety principle of "as low as reasonably achievable" requires that property not be cleared for unrestricted release from radiological control under DOE Order 458.1 and 10 CFR 835 if it contains residual radioactivity that is distinguishable from background.

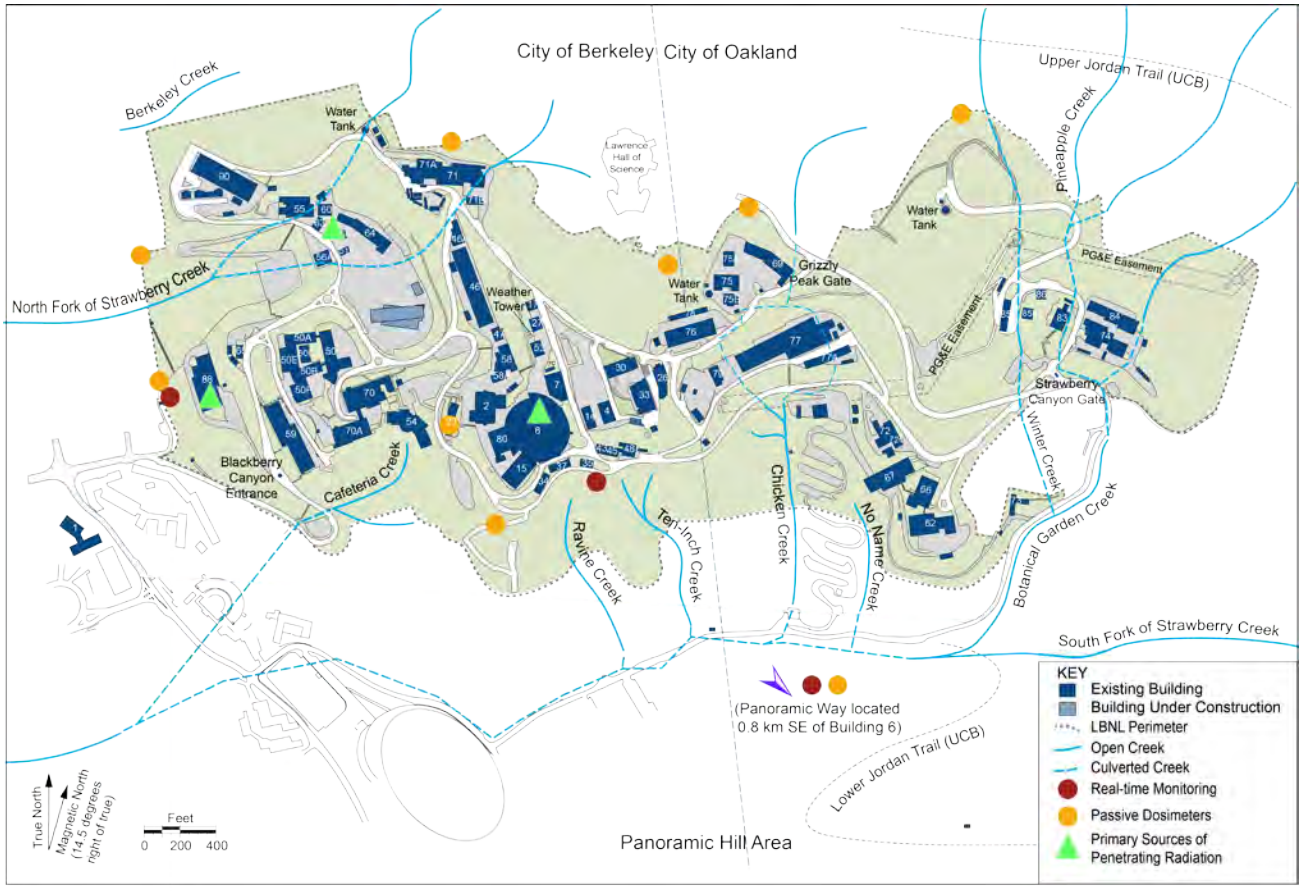

Figure 4-7 Environmental Penetrating Radiation Primary Sources and Monitoring Stations

Berkeley Lab applies the required release and clearance criteria to all property under consideration, and property is released only when it can be demonstrated that it does not contain residual radioactive material, or that residual radioactivity has been characterized sufficiently to demonstrate through process knowledge or radiological survey that it contains only levels of radioactive material indistinguishable from background. Any property that does not meet release criteria is transferred either to another DOE radiological facility for reuse or to a licensed radioactive waste facility for disposal.

In 2017, 165 release and clearance surveys were performed by Berkeley Lab's Radiation Protection Group and 107 unrestricted release surveys were performed by subcontractors performing work at Berkeley Lab; the equipment may be subsequently reused on site or released to the public. Additionally, Berkeley Lab's radiological soil assessment program supported 19 soil excavation projects during this time.

5 Radiological Dose Assessment

5.1 BACKGROUND

Radiological dose is the energy deposited in tissue mass through external irradiation, inhalation, or ingestion due to exposure to radioactive material. The annual dose to the public and the environment from Berkeley Lab's radiological operations is very low. The health effects from such a low dose are either too small to be observed or nonexistent (Health Physics Society, 2010).

This chapter presents maximum potential estimated dose results from Berkeley Lab's penetrating radiation and airborne radionuclide monitoring programs. The results include the annual dose to nearby individual members of the public and the dose to the general population in the region extending 50 miles from the site. Within this region, the daytime population is approximately 7,253,000 (LandScan, 2014). The potential dose to humans projected from each monitoring program is presented in Sections 5.2 and 5.3, and the results are then discussed in Section 5.4 in terms of the overall impact of Berkeley Lab's radiological activities on members of the public in the form of total dose. The radiological impact of Berkeley Lab's operations on local animals and plants is discussed in Section 5.5.

To ensure that radiological impacts to the public and the environment remain very low, Berkeley Lab manages work activity so that radioactive emissions and external exposures are as low as reasonably achievable. Berkeley Lab's environmental program ensures that a screening (qualitative) review is performed on activities that could result in a dose to the public or the environment (LBNL, 2013a). Potential dose from activities that may generate airborne radionuclides is estimated through the required *National Emission Standards for Hazardous Air Pollutants* (NESHAP) regulatory process (U.S. EPA, 1989), as discussed in Section 4.1. An in-depth quantitative review is required if the potential for a public dose is greater than 1 mrem to an individual or 10 person-rem to a population. No quantitative reviews were required or performed in 2017.

5.2 DOSE FROM PENETRATING RADIATION

As discussed in Section 4.7, penetrating radiation from LBNL operations is measured by real-time monitors and passive dosimeters. The results of real-time penetrating radiation measurements indicate that the maximum potential annual dose from gamma and neutron radiation to a person outside the western boundary of the site was 1.88×10^{-1} mrem. This potential dose was located at the nearest residence, about 360 feet from the primary contributing source, which was the 88-Inch Cyclotron. This dose is statistically higher than the measured background for Berkeley Lab, but represents a small fraction (0.2%) of the DOE Order 458.1 compliance limit of 100 mrem per year for the dose to any member of the public.

The annual population dose to people in the surrounding region that extends 50 miles from the site was estimated at 1.95×10^{-1} person-rem, based on the most recent population figure and measured dose around the perimeter of the site. A network of passive optically stimulated luminescence dosimeters located around the perimeter of Berkeley Lab validates the real-time penetrating radiation measurements and confirms that the dose from LBNL activities is negligible. The dose from penetrating radiation is not affected by wind patterns.

5.3 DOSE FROM DISPERSIBLE AIRBORNE RADIONUCLIDES

Dose due to dispersible contaminants represents the time-weighted exposure to a concentration of a substance, whether the contaminant is inhaled in air, ingested in drink or food, or absorbed through skin contact with soil or other environmental media.

Very small quantities of dispersible radionuclides originate as emissions from building exhaust points that are generally located on rooftops, as discussed in Section 4.1. Once emitted, these radionuclides may interact with environmental media such as air, water, soil, plants, and animals. Each of these media represents a potential pathway of exposure affecting human dose.

The dose to an individual or the population is calculated by computer programs that estimate dispersion of airborne radionuclide emissions while factoring in wind speed and direction, atmospheric stability, and precipitation. The radiological NESHAP regulation requires DOE facilities that potentially release airborne radionuclides to assess the impact of such releases using a U.S. EPA–approved computer program. Berkeley Lab satisfies this requirement by using both CAP88-PC and COMPLY.

In late 2016, U.S. EPA Region 9 approved Berkeley Lab's request to use a streamlined approach to model dispersion of radiological air emissions through a single virtual stack to comply with NESHAP requirements. This methodology was then used to prepare the annual radionuclide air emission report submitted to the U.S. EPA. Previously, the dose assessment process was performed by collecting information and evaluating radionuclide emissions from approximately 10 grouped stack locations. Use of the single virtual stack method resulted in significant savings in staff resources in performing this assessment and preparing the annual report. Details of dose calculations from dispersible airborne radionuclide emissions are included in the *Radionuclide Air Emission Report for 2017* (LBNL, 2018).

The NESHAP regulation requires that the location of the maximally exposed individual to airborne emissions be determined. For the main LBNL site, this location was identified as the Lawrence Hall of Science, which is located at the northern edge of the site and downwind of the primary contributing source: fluorine-18 emissions from Buildings 55, 56, and 64. The maximum possible dose at this location is a hypothetical and conservative value because the exposure calculation assumes that the person is always present at the location the entire year. For 2017, the calculated annual dose from airborne radionuclides was 9.65×10^{-3} mrem, which is approximately 0.1% of the DOE and U.S. EPA annual limit for airborne radionuclides of 10 mrem/yr (DOE, 2013; U.S. EPA, 1989).

As with penetrating radiation, the collective dose from airborne radionuclides to the population is estimated within a radius of 50 miles of the site. The estimated population dose from all airborne emissions from the LBNL main site for the year was 1.69×10^{-1} person-rem. There is no regulatory standard for the collective dose metric.

5.4 TOTAL DOSE TO THE PUBLIC

The total radiological impact to the public from penetrating radiation and airborne radionuclides is well below applicable standards and less than local background radiation levels by several orders of magnitude. As shown on Figure 5-1, the maximum effective dose equivalent from penetrating radiation and airborne radionuclides from LBNL operations to an individual residing near Berkeley Lab in 2017 was approximately 2.0×10^{-1} mrem/yr. Penetrating radiation (i.e., gamma and neutron radiation) from accelerators at Berkeley Lab and radionuclides

from airborne radionuclide emissions contributed to this total dose, which is a conservatively high estimate since the location of the maximum dose for penetrating and airborne radiation differ slightly, as described in previous sections. Yet, this value is very low at approximately 0.06% of the average natural background radiation dose (310 mrem/yr) in the United States (NCRP, 2009), and approximately 0.2% of the DOE annual limit from all sources (100 mrem/yr) (DOE, 2013).

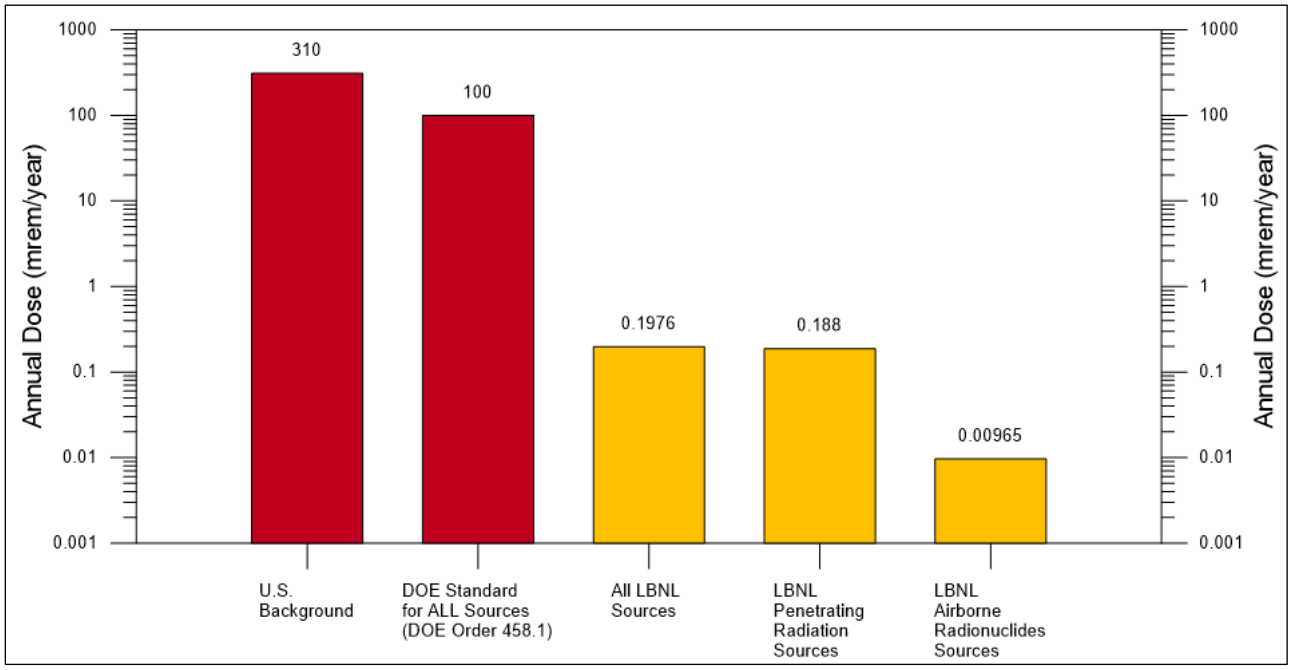

Figure 5-1 Comparative Radiological Doses for 2017

5.5 DOSE TO ANIMALS AND PLANTS

As described in DOE technical standard DOE-STD-1153-2002, *A Graded Approach for Evaluating Radiation Dose to Aquatic and Terrestrial Biota* (DOE, 2002), DOE requires that animals and plants be protected from liquid and airborne emissions by limiting the radiation dose to aquatic animals and terrestrial plants (1 rad/day) and riparian and terrestrial animals (less than 0.1 rad/day).

To estimate the dose to animals and plants, the following sources of exposure were considered:

- Animal ingestion of vegetation, water, and soil
- Animal inhalation of dusty soil
- Plant uptake of water
- External exposure of animals and plants to radionuclides in water, soil, and sediment

Creek water, soil, and sediment samples were collected and analyzed for several radionuclides, including tritium and gamma-emitting radionuclides. Measured levels of these radionuclides were either similar to natural background levels or well below applicable standards. The impact of these sample results was evaluated using the DOE-endorsed computer model RESRAD-BIOTA. This evaluation showed that both terrestrial and aquatic systems

passed the "general screening process" described in the DOE technical standard (DOE, 2002) and confirmed that the calculated dose for terrestrial or aquatic systems is far below DOE dose limit requirements.

6 Quality Assurance

6.1 OVERVIEW

Berkeley Lab's overarching quality assurance (QA) policy is documented in the *Requirements and Policies Manual* (LBNL, 2014a). Details on the operating principles and practices used by organizations to achieve reliable, safe, and quality performance are provided in the *Quality Assurance Program Description* (QAPD) (LBNL, 2013c), which describes the elements necessary to integrate QA, management systems, and process controls into LBNL operations. The QAPD provides the framework for LBNL administrators, managers, supervisors, and staff to plan, manage, perform, and assess their work. EHS's Environment, Waste & Radiation Protection Department implements elements of the QAPD through its *Quality Management Plan* (LBNL, 2016a), which describes a graded approach to quality and programmatic assurance based on the scope of the department's technical programs.

Berkeley Lab's *Environmental Monitoring Plan* (LBNL, 2013b) and guidance from DOE (2015b) and the U.S. EPA (1989) are also part of the QA system; indeed, the monitoring and sampling activities and results presented in this report were conducted in accordance with those guidelines. Whenever extra QA and quality control (QC) measures are required, a Quality Assurance Project Plan is developed and implemented. NESHAP stack air monitoring activities (LBNL, 2012b) and the Environmental Restoration Program (LBNL, 2009b) are examples of programs with a Quality Assurance Project Plan.

In 2017, Berkeley Lab had contracts with five commercial analytical laboratories for specific analytical services:

1. ALS (Fort Collins, Colorado)
2. BC Laboratories (Bakersfield, California)
3. Enthalpy Analytical (Berkeley, California)
4. GEL Laboratories (Charleston, South Carolina)
5. Vista Analytical Laboratory (El Dorado Hills, California)

All of these laboratories are certified through California's Environmental Laboratory Accreditation Program (ELAP) by having demonstrated the capability to analyze samples for environmental monitoring using approved testing methods (CDPH, 1994). These laboratories must meet demanding QA and QC specifications and certifications that were established to define, monitor, and document laboratory performance (LBNL, 2012d; DoD/DOE, 2013), and their QA and QC data is incorporated into Berkeley Lab's data quality assessment processes.

Each data set (batch) received from these analytical laboratories is systematically evaluated and compared to established data quality objectives before the results can be authenticated and accepted into the environmental monitoring database. Categories of data quality objectives include accuracy, precision, representativeness, comparability, and completeness. When possible, quantitative criteria are used to define and assess data quality.

In addition to the ELAP certification, analytical laboratories supporting DOE facilities are subject to periodic auditing through the DOE Consolidated Audit Program (DOECAP). A DOECAP audit generally takes three days to complete and is conducted by five or more experienced auditors from across the DOE complex. When one of the laboratories contracted to provide analytical services to Berkeley Lab is audited, at least one LBNL representative is typically on the audit team. A DOECAP audit also entails a review of the analytical laboratory's performance in

proficiency testing, as required by the California ELAP. In 2017, three of the five analytical laboratories – ALS, Enthalpy Analytical, and GEL Laboratories – were audited under the DOECAP. None was found to have a major deficiency during an audit, and any identified minor deficiencies were followed by corrective action plans and tracked to closure.

Complementing the objectives of Berkeley Lab's QAPD, DOE Berkeley Site Office's Oversight and Issues Management Program (DOE, 2014) enables its staff to participate in LBNL operational activities such as field orientations, meetings, audits, workshops, document and information system reviews, and day-to-day communications. This interaction provides an effective and efficient means of meeting contractual requirements between DOE and UC while allowing Berkeley Lab to accomplish its assigned missions. This assurance system includes attributes such as metrics and targets to assess performance, rigorous self-assessment and improvement, identification and correction of negative performance trends before they become significant issues, and timely communication with the DOE Berkeley Site Office on assurance-related information.

6.2 ENVIRONMENTAL MONITORING SAMPLES AND RESULTS PROFILE

Berkeley Lab's environmental monitoring programs, both routine and project-specific, collected 2,795 individual air, sediment, soil, and water samples in 2017, generating 66,837 analytical results. Samples were obtained from over 1,240 locations on or surrounding the main site. Some of these locations are shown on figures in the sections of Chapter 4 that summarize program results; others are in the referenced project or program documents, such as the Environmental Restoration Program documents available on the program's website (https://ehs.lbl.gov/resource/environmental-restoration-program/) or in hardcopy reports at the main branch of the Berkeley Public Library.

The sampling result totals include those from activities associated with Phase 1B and 3 of the Old Town Demolition Project and the IGB/MUP Project that were carried out by the demolition subcontractor and provided to Berkeley Lab. These projects accounted for over 70% of the environmental monitoring programs' sampling locations in 2017, almost 45% of the individual samples collected, and nearly 40% of the analytical results.

6.3 SPLIT AND DUPLICATE SAMPLING FROM ENVIRONMENTAL MONITORING

An essential activity undertaken to measure the quality of environmental monitoring results is the regular collection and analysis of split and duplicate samples. In 2017, a total of 45 split and 156 duplicate samples were collected for either radiological or non-radiological analyses, or both. These samples led to 254 split and 3,503 duplicate results. In addition, 201 blank samples were submitted for QA purposes. The primary purpose of a blank sample is to identify artificially introduced contamination.

Berkeley Lab uses the metrics of relative percent difference and relative error ratio to determine whether paired results, such as split or duplicate samples, are within control limits. *Relative percent difference* is defined as the absolute value of the difference between two results divided by the mean of the two results. *Relative error ratio* is defined as the absolute value of the difference between two results divided by the sum of the analytical error of the two results. Relative percent difference is determined in all cases; relative error ratio is applicable only to radiological analyses for which analytical error is included in the same result.

When the primary sample and the split or duplicate sample results are below analytical detection limits, the results from these tests are not meaningful. When QA pair results exceed control limits, the program leader investigates the cause of the discrepancy.

6.4 ANALYTICAL LABORATORY QUALITY CONTROL TESTING

Analytical laboratories routinely perform QC tests to assess the quality and validity of their sample results. These tests are run with each batch of environmental samples submitted by Berkeley Lab. The same relative percent difference and relative error ratio metrics are used to evaluate these control sample results, with the relative error ratio test applicable only to radiological analyses.

During the year, the six analytical laboratories performed 3,506 radiological and non-radiological QC analyses to validate the environmental samples submitted by Berkeley Lab. These QC analyses include various types of blank, replicate (duplicate), matrix spike, and laboratory control samples. Table 6-1 shows the breadth and diversity of the QC activity.

In addition to the relative percent difference and relative error ratio tests, lower and upper control limits are established for each analyte and for each type of QC test. As with split and duplicate QA, when QC results exceed established criteria, an investigation is performed to determine the cause of the discrepancy.

Table 6-1 Summary of Quality Control Testing Performed by Analytical Laboratories

Program	Number of Sample Batches	Number of QC Analyses	Number of Laboratories Involved	Radiological[a]	Non-radiological[b]
Stack Air	38	114	2	√	–
Stormwater and Creeks	114	351	4	√	√
Wastewater	114	495	5	√	√
Groundwater	110	687	5	√	√
Sediment	18	58	4	√	√
Soil	15	40	4	√	√
IGB/MUP	224	923	3	√	√
Old Town Demolition, Phase 1B	139	481	4	√	√
Old Town Demolition, Phase 3	87	357	4	√	√

[a] A check mark in this column indicates that the program tests for radiological substances.

[b] A check mark in this column indicates that the program tests for non-radiological substances. A dash means no testing occurred.

References

Bay Area Air Quality Management District (BAAQMD), 2017. *Permit to Operate for Lawrence Berkeley National Laboratory (Plant No. 723 and GDF No. 6134)* and *Permit to Operate for Joint Genome Institute (Plant No. 14549)*. July.

California Department of Public Health (CDPH), 1994. Certification and Amendment Process, 22 CCR §64803 (as amended).

California Health and Safety Code §39000 *et seq.*, 1967. Air Resources (as amended).

California Health and Safety Code §25100 *et seq.*, 1972. Hazardous Waste Control Law (as amended).

California Health and Safety Code §25280 *et seq*., 1983. Underground Storage of Hazardous Substances (as amended).

California Health and Safety Code §25500 *et seq*., 1985. Hazardous Materials Release Response Plans and Inventory Law (as amended).

California Health and Safety Code §44300 *et seq.*, 1987. Air Toxics "Hot Spots" Information and Assessment Act (as amended).

California Health and Safety Code, §25270 *et seq.*, 1989. Aboveground Petroleum Storage Act (as amended).

California Health and Safety Code §117600–118360, 1991. Medical Waste Management Act (as amended).

California Water Code §13000 *et seq*., 1969. California Porter-Cologne Water Quality Control Act (as amended).

Central Contra Costa Sanitary District, 2017. *Permit to Operate for Joint Genome Institute*. December.

Department of Toxic Substances Control (DTSC), 2017a. Human and Ecological Risk Office (HERO), Human Health Risk Assessment (HHRA) Note 3, *DTSC-Modified Screening Levels (DTSC-SLs)*, June.

Department of Toxic Substances Control (DTSC), 2017b. Approval of *Revised Soil Characterization Report for the Mercury-Impacted Area North of Former Building 5 at the Lawrence Berkeley National Laboratory*. Letter from Karen Toth (DTSC) to Ron Pauer (Berkeley Lab) dated July 21.

DMS, 2015. *Sampling and Analysis Plan for PCBs – Above-Slab Building Characterization*. June.

DMS, 2016. *Application for Cleanup of Polychlorinated Biphenyls, Old Town Demolition Phase 1 Project.* March.

East Bay Municipal Utility District (EBMUD), 2016. Wastewater Discharge Permit No. 5034789-1 [groundwater treatment systems] for Lawrence Berkeley National Laboratory. December.

EBMUD, 2017a. Wastewater Discharge Permit No. 0660079-1 [sitewide] for Lawrence Berkeley National Laboratory. July.

EBMUD, 2017b. Wastewater Discharge Permit No. 5023891-1 [Building 77 FTU] for Lawrence Berkeley National Laboratory. July.

EBMUD, 2017c. Special Discharge Permit No. 19644654 [Old Town Demolition Project] for Lawrence Berkeley National Laboratory. December.

Eisenbud, M., 1973. *Environmental Radioactivity*, 2nd Edition, Academic Press Inc. September.

Executive Order 13423, 2007. *Strengthening Federal Environmental, Energy, and Transportation Management*.

Executive Order 13693, 2015. *Planning for Federal Sustainability in the Next Decade*.

Health Physics Society, 2010. *Radiation Risk in Perspective*. Position Statement of the Health Physics Society.

International Organization for Standardization (ISO), 2015. *Environmental Management Systems: Requirements with Guidance for Use*, ISO 14001:2015. September.

LandScan population distribution data, accessed April 14, 2014, http://web.ornl.gov/sci/landscan/.

Lawrence Berkeley National Laboratory (LBNL), 2002. *Analysis of Background Distributions of Inorganic Elements in the Groundwater at Lawrence Berkeley National Laboratory*. July.

LBNL, 2005. *RCRA Corrective Measures Study Report for Lawrence Berkeley National Laboratory*, Environmental Restoration Program. February.

LBNL, 2006. *Groundwater Monitoring and Management Plan*. March.

LBNL, 2009a. *Analysis of Background Distributions of Metals in the Soil at Lawrence Berkeley National Laboratory*. April.

LBNL, 2009b. *Quality Assurance Project Plan for Environmental Restoration Program*. September.

LBNL, 2012a. *Environmental Management System Plan*, LBNL-PUB-3180. May.

LBNL, 2012b. *Quality Assurance Program Plan for NESHAP Compliance*. November.

LBNL, 2012c. *Spill Prevention, Control, and Countermeasure Plan*. December.

LBNL, 2012d. *Statement of Work for Analytical Services*. April.

LBNL, 2013a. *Environmental ALARA Program Plan*, Revision 6. March.

LBNL, 2013b. *Environmental Monitoring Plan*. June.

LBNL, 2013c. *Quality Assurance Program Description*, LBNL/PUB-3111, Revision 11. December.

LBNL, 2014a. *Requirements and Policies Manual,* LBNL/PUB-201. August.

LBNL, 2014b. *Spill Prevention, Control, and Countermeasure Plan for Joint Genome Institute*. February.

LBNL, 2015. *Sewer System Management Plan.* April.

LBNL, 2016a. *Quality Management Plan*. Environment, Waste & Radiation Protection Department. February.

LBNL, 2016b. *Soil Management Plan, Building 91 Integrative Genomics Building and Building 91U Modular Utility Plant*. June.

LBNL, 2016c. *Stormwater Monitoring Implementation Plan.* December.

LBNL, 2016d. *Stormwater Pollution Prevention Plan*. December.

LBNL, 2016e. *Transmittal of Amended Pages for the Application for Cleanup of Polychlorinated Biphenyls, Old Town Demolition Phase I Project*. March.

LBNL, 2017a. *Lawrence Berkeley National Laboratory Annual Site Sustainability Plan*. December.

LBNL 2017b. *Soil Management Plan for Lawrence Berkeley National Laboratory.* December.

LBNL, 2017c. *Spill Prevention, Control, and Countermeasure Plan*. September.

LBNL, 2018. *Lawrence Berkeley National Laboratory Radionuclide Air Emission Report for 2017.* May.

National Council on Radiation Protection and Measurements (NCRP), 1987. *Exposure of the Population of the United States and Canada from Natural Background Radiation*, NCRP Report No. 94.

National Council on Radiation Protection and Measurements (NCRP), 2009. *Ionizing Radiation Exposure of the Population of the United States*, NCRP Report No. 160.

Northgate, 2017a. *Characterization Report for Excavated Soil and Concrete Building 91 Integrative Genomics Building and Building 91U Modular Utility Plant.* September.

Northgate, 2017b. *Sampling and Analysis Plan for Characterization of Soil and Concrete Building 91 Integrative Genomics Building and Building 91U Modular Utility Plant*. January.

Perma-Fix Environmental Services, 2017. *Final Status Survey Report, Old Town Demolition Project, Phase 1 Soil*. November.

San Francisco Bay Regional Water Quality Control Board (RWQCB), 2015. *Water Quality Control Plan for the San Francisco Bay Basin*, Chapter 3.

San Francisco Bay Regional Water Quality Control Board (RWQCB), 2016. *Environmental Screening Levels* (Interim Final). February.

Shacklette, H.T., and J.G. Boerngen, 1984. *Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States*, U.S. Geological Survey Professional Paper 1270.

State Water Resources Control Board (SWRCB), 2011. *Certification, Licensing, and Training Requirements for Underground Storage Tank Owners, Operators, Installers, Service Technicians, and Inspectors*, 23 CCR §2715(f).

SWRCB, 2012. *General Permit for Stormwater Discharges Associated with Construction and Land Disturbance Activities*, Order No. 2009-0009-DWQ as amended, NPDES No. CAS000002. July.

SWRCB, 2013. *Amending Monitoring and Reporting Program for Statewide General Waste Discharge Requirements for Sanitary Sewer Systems*, Order No. WQ 2013-0058-EXEC. August.

SWRCB, 2014. *General Permit for Storm Water Discharges Associated with Industrial Activities*, Order 2014-0057-DWQ, NPDES General Permit No. CAS000001. April.

U.S. Code, Title 42, Chapter 82, Subchapter IX, §6991 (42 USC §6991), 1988. *Resource Conservation and Recovery Act, Regulation of Underground Storage Tanks* (as amended).

U.S. Department of Defense (DoD) and Department of Energy (DOE), 2013. *Quality Systems Manual (QSM) for Environmental Laboratories*, Version 5.0. July.

U.S. Department of Energy (DOE), 1991. *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, DOE/EH0173T. January.

U.S. Department of Energy (DOE), 1995. *Site Treatment Plan for the Lawrence Berkeley National Laboratory, Berkeley, California*. October.

U.S. Department of Energy (DOE), 2002. *A Graded Approach for Evaluating Radiation Dose to Aquatic and Terrestrial Biota*, DOE-STD-1153-2002. July.

U.S. Department of Energy (DOE), 2011a. Order 436.1, *Departmental Sustainability*. May.

U.S. Department of Energy (DOE), 2011b. DOE-STD-1196-2011, *Derived Concentration Technical Standard*.

U.S. Department of Energy (DOE), 2012. Order 231.1B, Administrative Change 1, *Environment, Safety and Health Reporting*. November.

U.S. Department of Energy (DOE), 2013. Order 458.1, Administrative Change 3, *Radiation Protection of the Public and the Environment.* January.

U.S. Department of Energy (DOE) Berkeley Site Office, 2014. *Berkeley Site Office Oversight and Issues Management Program Manual*. May.

U.S. Department of Energy (DOE), 2015. *Environmental Radiological Effluent Monitoring and Environmental Surveillance*, DOE-HDBK-1216-2015. March.

U.S. Department of Energy (DOE), 2017a. *Contract Between the United States of America and the Regents of the University of California*, UC-DOE Prime Contract (No. DE-AC02-05CH11231).

U.S. Department of Energy (DOE) Berkeley Site Office, 2017b. *Performance Evaluation Report of the University of California for Management and Operations of Science and Technology at the Lawrence Berkeley National Laboratory*. December.

U.S. Environmental Protection Agency (U.S. EPA), 1976. National Primary Drinking Water Standards, 40 CFR 141, Subpart B (amended).

U.S. EPA, 1989. National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities, 40 CFR Part 61, Subpart H (amended).

U.S. EPA, 2016a. Approval of *Application for Cleanup of Polychlorinated Biphenyls, Old Town Demolition Phase 1 Project*. May.

U.S. EPA, 2016b. Regional Screening Levels – Generic Tables. May.

Weiss Associates, 2017. *Revised Soil Characterization Report at the Mercury-Impacted Area North of Former Building 5 at the Lawrence Berkeley National Laboratory*. June.

Abbreviations

AEDE	annual effective dose equivalent
AST	aboveground storage tank
BAAQMD	Bay Area Air Quality Management District
Basin Plan	Water Quality Control Plan for the San Francisco Bay Basin
BTU	British thermal unit
CARB	California Air Resources Board
CCCSD	Central Contra Costa Sanitary District
CCHS	Contra Costa Health Services
CCR	California Code of Regulations
CEQA	California Environmental Quality Act
CFR	Code of Federal Regulations
Ci	curie
CUPA	Certified Unified Program Agency (California)
DCS	Derived Concentration Standard
DOE	U.S. Department of Energy
DOECAP	Department of Energy Consolidated Audit Program
DTSC	Department of Toxic Substances Control (California)
E85	85% ethanol / 15% unleaded gasoline fuel blend
EBMUD	East Bay Municipal Utility District
EHS	Environment/Health/Safety Division at Berkeley Lab
ELAP	Environmental Laboratory Accreditation Program
EMS	Environmental Management System
EPCRA	Emergency Planning and Community Right-to-Know Act
ESG	Environmental Services Group
F	Fahrenheit
FTU	fixed treatment unit
FY	fiscal year (October 1 – September 30)
GAC	granular activated carbon
gal	gallon(s)
GHG	greenhouse gas
HMBP	Hazardous Materials Business Plan
IGB	Integrative Genomics Building
ISO	International Organization for Standardization

JGI	Joint Genome Institute
kg	kilogram(s)
L	liter(s)
LBNL	Lawrence Berkeley National Laboratory
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mrem	millirem (one thousandth of a rem, or 1×10^{-3} rem)
mrem/yr	millirem per year
MUP	Modular Utility Plant
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NTLF	National Tritium Labelling Facility
OIAI	Office of Institutional Assurance and Integrity
PCB	polychlorinated biphenyl
pCi/L	picocuries (one trillionth of a curie) per liter
QA	quality assurance
QAPD	Quality Assurance Program Description
QC	quality control
RCRA	Resource Conservation and Recovery Act
rem	roentgen equivalent man
RWQCB	San Francisco Bay Regional Water Quality Control Board
SARA	Superfund Amendments and Reauthorization Act
SF_6	sulfur hexafluoride
SPCC	Spill Prevention, Control, and Countermeasure
SWPPP	Stormwater Pollution Prevention Plan
SWRCB	State Water Resources Control Board
TSCA	Toxic Substances Control Act
UC	University of California
U.S. EPA	United States Environmental Protection Agency
UST	underground storage tank
VOC	volatile organic compound

Glossary

accuracy

The closeness of a measurement to its true value.

Advanced Light Source

An accelerator at Berkeley Lab that is a third-generation synchrotron light source, one of the world's brightest sources of ultraviolet and soft x-ray beams.

alpha particle

A charged particle comprising two protons and two neutrons, which is emitted during decay of certain radioactive atoms. Alpha particles are stopped by several centimeters of air or a sheet of paper.

analyte

The subject of a chemical analysis.

annual effective dose equivalent (AEDE)

The largest amount of ionizing radiation a person may receive in a given year. It combines the internal and external dose. The AEDE limit is prescribed for various organs, as well as the whole body, and various working conditions. The AEDE limit is 5,000 mrem/year.

background radiation

Ionizing radiation from sources other than Berkeley Lab. Background radiation may include cosmic radiation; radiation from naturally occurring radioactivity in the earth (terrestrial radiation), air, and water; and radiation from naturally occurring radioactive elements in the human body.

beta particle

A charged particle identical to the electron that is emitted during decay of certain radioactive atoms. Most beta particles are stopped by less than 0.2 inches of aluminum.

contaminant

Any hazardous or radioactive material present above background levels in an environmental medium such as air, soil, water, or vegetation. *See also* pollutant.

cosmic radiation

High-energy particulate and electromagnetic radiation that originates outside the earth's atmosphere. Cosmic radiation is part of natural background radiation.

curie

Unit of radioactive decay equal to 2.22×10^{12} disintegrations per minute.

detection limit

The lowest concentration of an analyte that can be measured and reported with 99% confidence that the concentration is greater than zero.

discharge

The release of a liquid or pollutant to the environment or to a system (usually of pipes) for disposal.

dose

The quantity of radiation energy absorbed by a human, animal, or vegetation. Dose to humans is also called effective dose equivalent (measured in units of rem), which takes into account the type of radiation and the parts of the body exposed. Dose to animals and vegetation is also called absorbed dose (measured in units of rad), which is the energy deposited per unit of mass. *See also* effective dose equivalent.

dosimeter

A portable detection device for measuring the total accumulated dose from ionizing radiation. *See also* optically stimulated luminescence dosimeter.

duplicate samples

Two samples taken from and representative of the same population and carried through all steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variance of the total method, including sampling and analysis.

effective dose equivalent (EDE)

The sum of the products of the dose equivalent received by specified tissues of the body and a tissue-specific weighting factor. This sum is a risk-equivalent value and can be used to estimate the health risk of the exposed individual. The tissue-specific weighting factor represents the fraction of the total health risk resulting from uniform whole-body irradiation that would be contributed by that particular tissue. The EDE includes the committed EDE from internal deposition of radionuclides and the EDE due to penetrating radiation from sources external to the body. EDE is expressed in units of rem. *See also* dose.

effluent

A liquid waste discharged to the environment.

effluent monitoring

The collection and analysis of samples or measurements of liquid discharges for the purpose of characterizing and quantifying contaminants, assessing exposures of members of the public, and demonstrating compliance with applicable standards and permit requirements. Effluent is usually monitored at or near the point of discharge.

emission

A release of air to the environment that contains gaseous or particulate matter having one or more contaminants.

environmental monitoring

The collection and analysis of samples or direct measurements of environmental media for possible contaminants. Environmental monitoring consists of two major activities: effluent monitoring and environmental surveillance.

environmental surveillance

The collection and analysis of samples, or direct measurements, of air, water, soil, foodstuff, biota, and other media from LBNL facilities and their environs for possible contaminants with the purpose of determining compliance with applicable standards and permit requirements, assessing radiation exposures of members of the public, and assessing the effects, if any, on the local environment.

fiscal year

The 12-month period for which an organization plans the use of its funds. For the federal government and its contractors, this is the period from October 1 to September 30 the following year.

gamma radiation

Short-wavelength electromagnetic radiation of nuclear origin that has no mass or charge. Because of its short wavelength (high energy), gamma radiation can cause ionization. Other electromagnetic radiation, such as microwaves, visible light, and radio waves, has longer wavelengths (lower energy) and cannot cause ionization.

greenhouse gas

Any of the atmospheric gases (e.g., carbon dioxide, water vapor, and methane) that contribute to the greenhouse effect. The greenhouse effect is the trapping and buildup of heat in the upper atmosphere by gases that absorb infrared radiation. These gases then reradiate some of this heat back toward the earth's surface.

groundwater

Water below the earth's surface in a zone of saturation.

half-life, radioactive

The time required for the activity of a radioactive substance to decrease to half its value by inherent radioactive decay. After two half-lives, one-fourth of the original activity remains (1/2 × 1/2); after three half-lives, one-eighth of the original activity remains (1/2 × 1/2 × 1/2); and so forth.

hazardous waste

Waste exhibiting any of the following characteristics: ignitability, corrosivity, reactivity, or extraction procedure-toxicity (yielding toxic constituents in a leaching test). Because of its concentration, quantity, or physical or chemical characteristics, it may (1) cause or significantly contribute to an increase in mortality rates or cases of serious irreversible illness or (2) pose a substantial present or potential threat to human health or the environment when improperly treated, stored, transported, disposed of, or handled.

hydrauger

A sub-horizontal drain used to extract groundwater for slope stability purposes.

low-level radioactive waste

Waste containing radioactivity that is not classified as high-level waste, transuranic waste, spent nuclear fuel, by-product material (as defined in Section 11(e)(2) of the Atomic Energy Act of 1954, as amended), or naturally occurring radioactive material.

millirem

A common unit for reporting human radiation dose. One millirem is one thousandth (10^{-3}) of a rem. *See also* rem.

mixed waste

Any radioactive waste that is also a RCRA-regulated hazardous waste.

nuclide

A species of atom characterized by what constitutes the nucleus, which is specified by the number of protons, number of neutrons, and energy content; or, alternatively, by the atomic number, mass number, and atomic mass. To be regarded as a distinct nuclide, the atom must be able to exist for a measurable length of time.

optically stimulated luminescence dosimeter

A type of dosimeter in which the material that has been exposed to radiation luminesces after being stimulated by laser light. The amount of light that the material emits is proportional to the amount of radiation absorbed (dose). *See also* dosimeter.

organic compound

A chemical whose primary constituents are carbon and hydrogen.

person-rem

The sum of the radiation doses to individuals of a population. *See also* population dose.

pH

A measure of hydrogen ion concentration in an aqueous solution. Acidic solutions have a pH less than 7, basic solutions have a pH greater than 7, and neutral solutions have a pH of 7.

plume

A volume of a substance that moves from its source to places farther away from the source. Plumes can be described by the volume of air or water they occupy and the direction in which they move. For example, a plume can be a column of smoke from a chimney or a substance moving with groundwater.

pollutant

Any hazardous or radioactive material present in an environmental medium such as air, water, or vegetation. *See also* contaminant.

population dose

The sum of the radiation doses to individuals of a population. It is expressed in units of person-rem. For example, if 1,000 people each received a radiation dose of one rem, their population dose would be 1,000 person-rem.

positron

A particle that is equal in mass to the electron but opposite in charge. A positively charged beta particle.

precision

The degree of agreement between measurements of the same quantity.

rad

The conventional unit of absorbed dose from ionizing radiation, commonly used for dose to animals and vegetation.

radiation

Electromagnetic energy in the form of waves or particles.

radiation protection standard

Limits on radiation exposure regarded as necessary for protection of public health. These standards are based on acceptable levels of risk to individuals.

radioactivity

The property or characteristic of a nucleus of an atom to spontaneously disintegrate, accompanied by the emission of energy in the form of radiation.

radiological

Arising from radiation or radioactive materials.

radionuclide

An unstable nuclide. *See also* nuclide, radioactivity.

relative percent difference

The absolute value of the difference between two results divided by the mean of the two results.

relative percent error

The absolute value of the difference between two results divided by the sum of the analytical error of the two results.

rem

Acronym for "roentgen equivalent man." A unit of ionizing radiation, equal to the amount of radiation needed to produce the same biological effect to humans as one rad of high-voltage x-rays. It is the product of the absorbed dose, quality factor, distribution factor, and other necessary modifying factors. It describes the effectiveness of various types of radiation in producing biological effects.

remediation

The process of improving a contaminated area to an uncontaminated or safe condition.

source

Any operation or equipment (e.g., pipe, ditch, well, or stack), that produces, discharges, and/or emits pollutants, or the location where a pollutant was released to the environment.

split sample

A single well-mixed sample that is divided into parts for analysis and comparison of results.

stack

A pipe, usually vertical, through which air and contaminants are vented to the atmosphere. A stack may be associated with a building or a vehicle (e.g., bus, heavy-duty truck). At Berkeley Lab, stacks are typically constructed of metal; they may discharge air from a local area such as a fume hood, or they may carry air from multiple areas of a building

terrestrial

Pertaining to or deriving from the earth.

terrestrial radiation

Radiation emitted by naturally occurring radionuclides, with the major radionuclides of concern being potassium-40, uranium-235, uranium-238, thorium-232, and their decay products; radiation levels over oceans and other large bodies of water tend to be about one-tenth of the terrestrial background.

tritium

A radionuclide of hydrogen with a half-life of 12.3 years, which decays by emitting a low-energy beta particle.

water year

The term used by hydrologists and climatologists to represent rainfall occurring between October 1 of one year and September 30 of the next year.

wind rose

Meteorological diagram that depicts the distribution of wind direction over a period of time.

This work was supported by the Director, Office of Science, U.S. Department of Energy under Contract Number DE-AC02-05CH11231