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BERKELEY LAB

Lawrence Berkeley
National Laboratory

Site Environmental Report for 2016

Environment/Health/Safety Division

September 2017

DISCLAIMER

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

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DISTRIBUTION

Subject: 2016 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 2016. 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 2016 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,

Paul Golan
Site Office Manager

Site Environmental Report for 2016

September 2017

Cover photo: Outdoor LBNL residents follow safety rules when crossing the road. Photograph by Zachary Harvey.

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

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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 2016. The format and content of this report satisfy the requirements of both DOE Order 231.1B Admin Chg 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 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 operating contract's performance evaluation process. For fiscal year (FY) 2016, which began October 1, 2015, and ended September 30, 2016, the EMS was given a performance rating of A minus 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 2016 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. To support this rating, Berkeley Lab prepared a list of projects completed during the performance period that achieved reduced environmental impacts.

The EMS was also graded through the federal Office of Management and Budget's EMS Annual Report Data, in which elements of the International Organization for Standardization (ISO) 14001 standard are rated and the degree of integration between the EMS and Berkeley Lab's sustainable practices is measured. Overall scores fall into one of three categories: green (highest), yellow (middle), or red (lowest). For FY 2016, 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 2016. Six minor violations issued during these inspections are discussed, one of which was rescinded in 2017.

This report also includes information on environmental monitoring performed in 2016 (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. While most stormwater discharges measured throughout the LBNL site fall within acceptable levels established by the state's stormwater permit, iron and aluminum exceeded permitted levels. Berkeley Lab is aggressively implementing controls to reduce iron and aluminum discharge levels.

The controls include construction of asphaltic berms to restrain and filter runoff to storm drains, and installation of filtration units in storm drain basins to absorb metal contaminants.

The radiological dose assessments (Chapter 5) performed in 2016 concluded that the maximum dose to a hypothetical resident from Berkeley Lab's airborne radionuclide releases was approximately 0.12% of the DOE and U.S. Environmental Protection Agency annual limit of 10 millirem per year (mrem/year); the dose from all radiation sources at Berkeley Lab was approximately 0.1% of the average natural background radiation dose of 310 mrem/yr in the United States, and about 0.4% 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 assessments results, and quality assurance measures conducted in 2016. 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, Lisa Ehlers, Robert Fox, Zachary Harvey, John Jelinski, Maram Kassis, Ken Kievit, Brendan Mulholland, Jeff Philliber, Nancy Sutherland, Patrick Thorson, and Suying Xu. 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 available on ESG's Publications webpage at http://www2.lbl.gov/ehs/esg/Reports/tableforreports.shtml.

The Site Environmental Report can be viewed or downloaded from the ESG website, where many of the documents cited in this report can also be found: http://www2.lbl.gov/ehs/esg/. 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 nearly 3,800 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 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 UC-owned land immediately east of the UC Berkeley campus, straddling the border of the cities of Berkeley and Oakland in Alameda County.

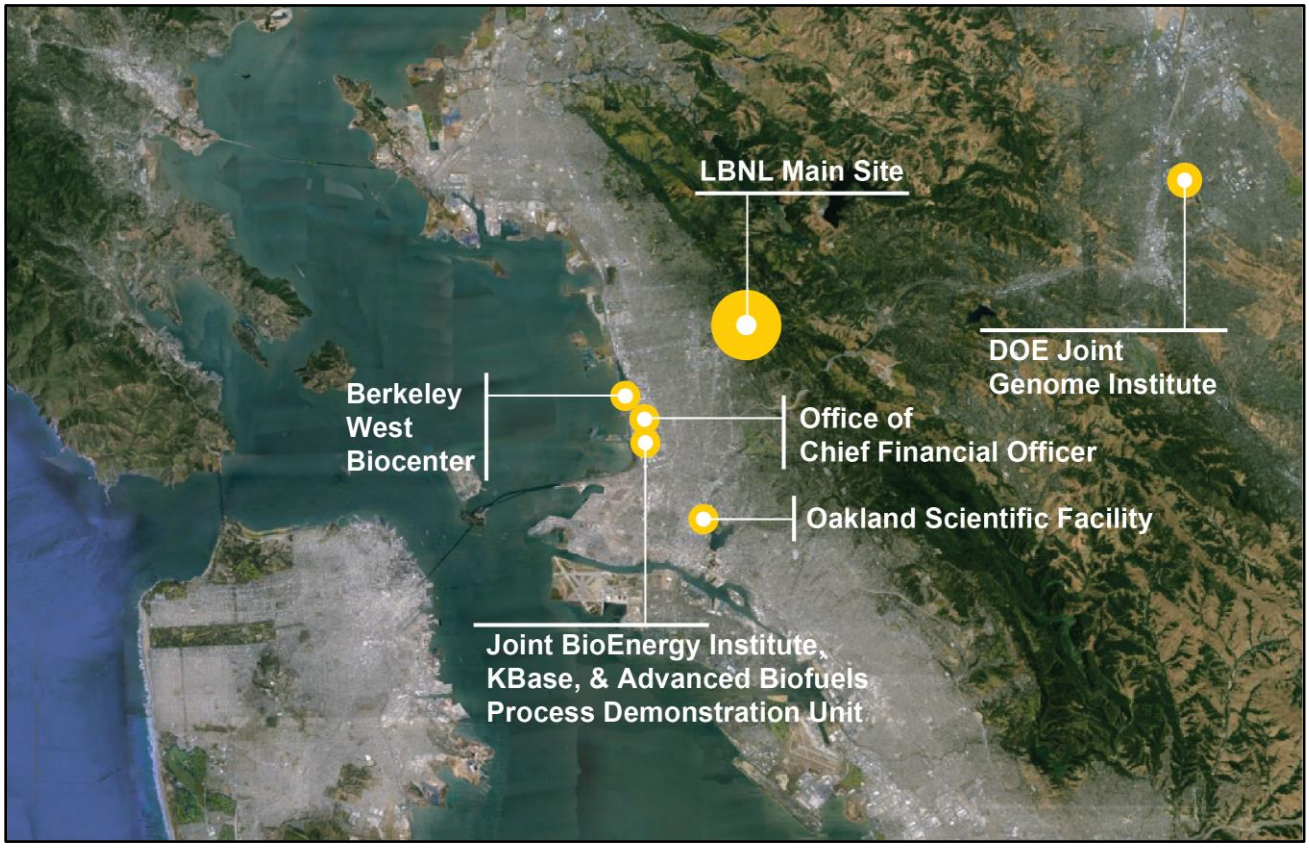

Figure 1-1 LBNL Main Site and Satellite Facility Locations in the East Bay

LBNL satellite facilities in Berkeley, Emeryville, Oakland, and Walnut Creek consist of leased buildings in developed urban areas. The Oakland Scientific Facility housed the National Energy Research Scientific Computing Center until

the center relocated at the beginning of 2016 to the newly constructed Shyh Wang Hall (Building 59) on the main site. Berkeley Lab maintains a small presence at the Oakland Scientific Facility to meet business needs.

Berkeley Lab is mostly bounded by a large area of land 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 recreation areas. Nearby points of interest include UC Berkeley's Strawberry Canyon Recreational Area, Botanical Garden, and Lawrence Hall of Science. To the north of Berkeley Lab is a residential neighborhood of low-density 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.

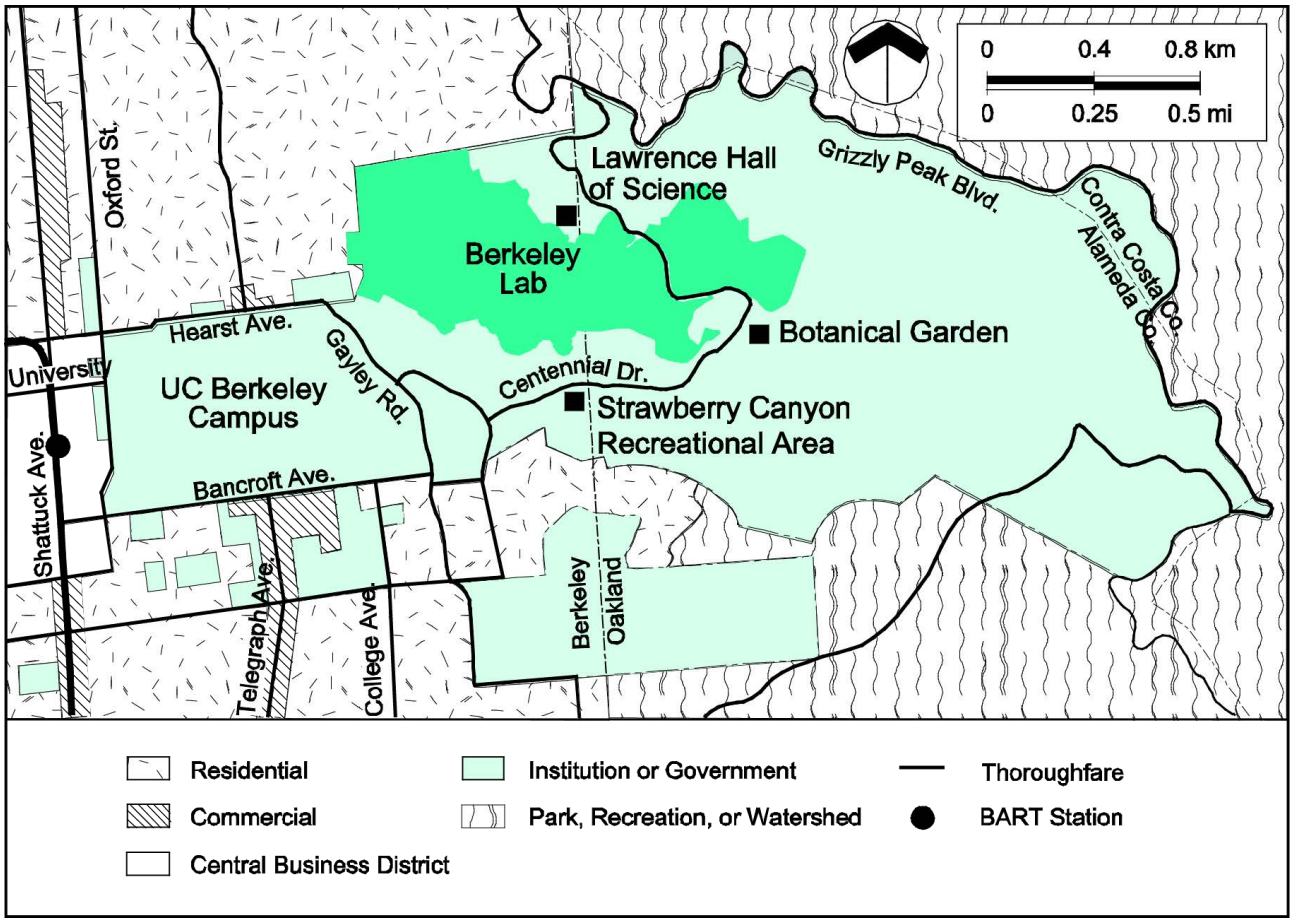

Figure 1-2 LBNL Main Site and Adjacent Land Use

1.2 ENERGY SUPPLY

Nearly all electric power for the LBNL site is provided by the Western Area Power Administration. About 8% of the total power is purchased from hydropower sources, 5% from renewable energy credits, and 1% from a solar power array located at the Lawrence Livermore National Laboratory site. 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.

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 2016 were 95°F and 35°F, respectively.

Based on more than 40 years of on-site measurements, the precipitation total for a "water year" averages 29.7 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 2015/2016 water year – at 27.4 inches – was more than for any of the previous four seasons, but still below average for the fifth consecutive season, continuing the driest period since California became a state in 1850.

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 2016, 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.

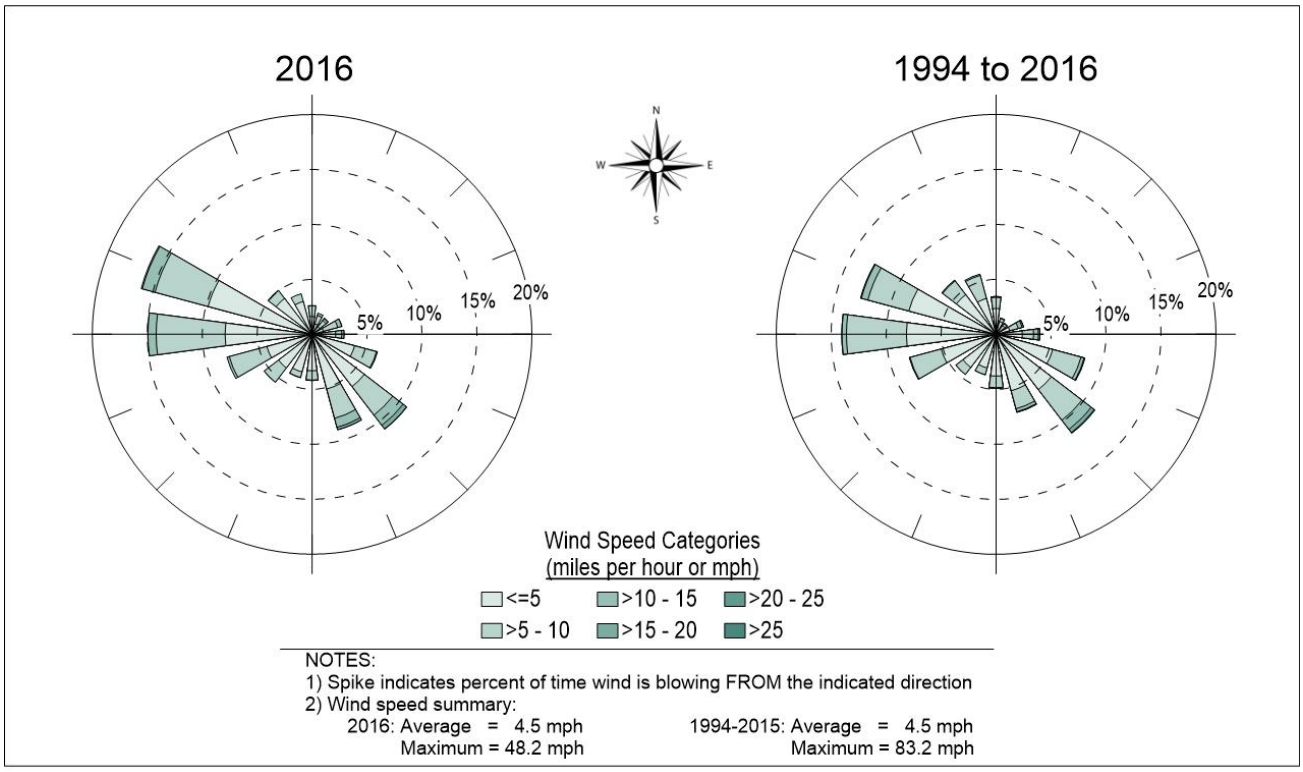

Figure 1-3 Annual Wind Patterns from 1994 to 2016

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

1.6 WILDLIFE

Wildlife is common at Berkeley Lab because the site is adjacent to 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 for species at risk:

A small area of about 1 acre on the south-facing slope of Blackberry Canyon has been identified as a site where the arachnid Lee's micro-blind harvestman (*Microcina leei*) lives. *Microcina leei* is listed as critically imperiled under both federal and state law.

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

The three principal bedrock units – the Great Valley Group, the Orinda Formation, and the Moraga Formation – underlie the site, as described below:

1. The western and southern portions of the site are underlain by marine siltstones and shales of the Great Valley Group. The permeability of these rocks is relatively low, with groundwater flow controlled through open fractures rather than through pore spaces.
2. Non-marine sedimentary rocks of the Orinda Formation overlie the Great Valley Group and constitute the exposed bedrock over most of the site's developed area. The Orinda Formation consists primarily of sandstones, mudstones, and conglomerates deposited in fluvial and alluvial environments. Groundwater typically moves at a lower rate in this formation than in the underlying Great Valley Group or overlying Moraga Formation; therefore, this formation impedes the horizontal and vertical flow of groundwater.
3. The Moraga Formation 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, and although the rock's permeability is low, groundwater flows readily through the numerous open fractures.

In addition to the three main units described above, the Claremont Formation (primarily marine chert and shale) and the San Pablo Group (primarily marine sandstones) underlie the easternmost area of the site.

Surface materials consist primarily of soil, colluvium (soil accumulated at the foot of a slope), 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 and filling 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.

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.

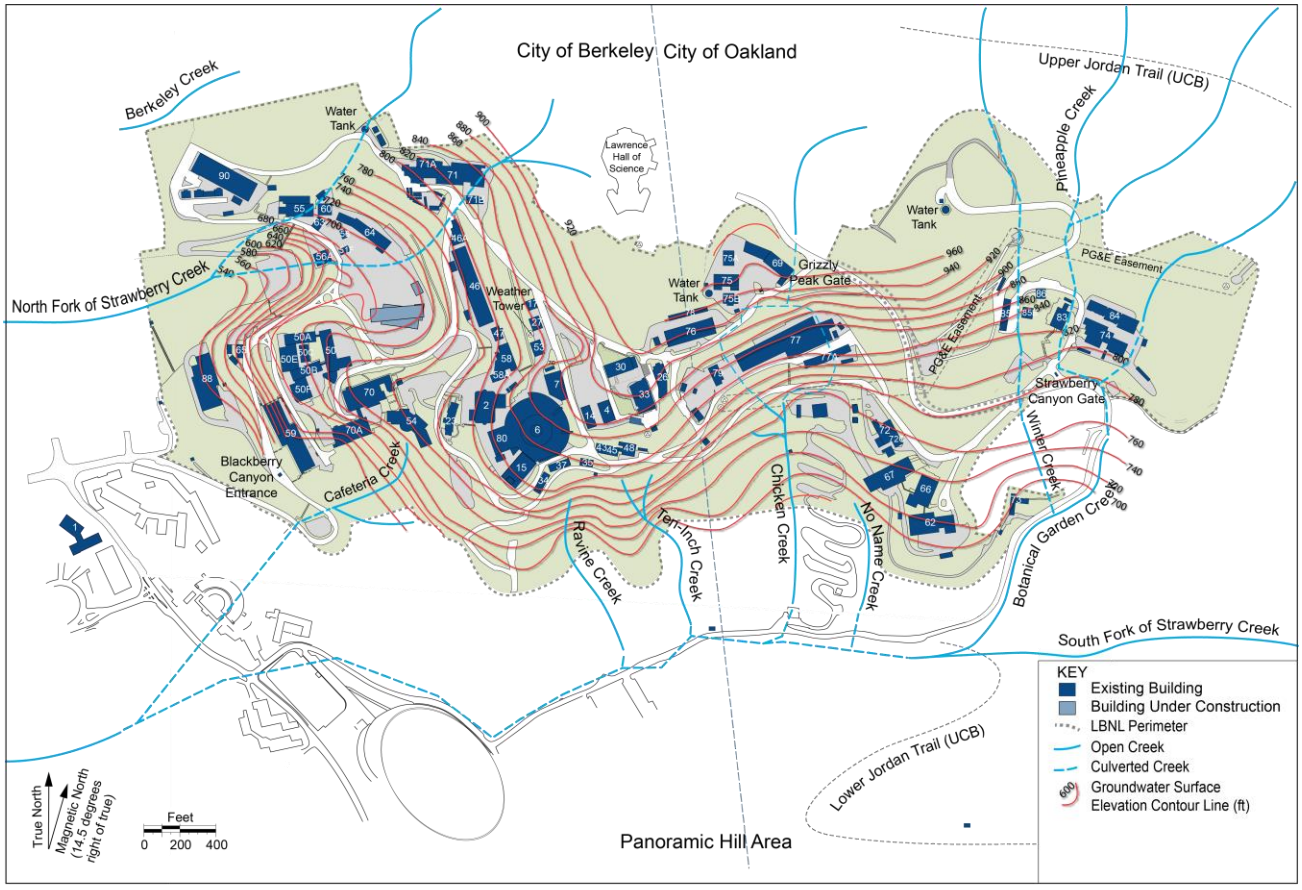

Figure 1-5 Surface Water Locations and Groundwater Elevations at Berkeley Lab

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, 2004). This standard was revised in September 2015. DOE has set October 2018 as the date by when sites will transition to the revised standard.

As required, Berkeley Lab has established an EMS that ensures that environmental activities are well managed and cost-effective while remaining in compliance and reducing environmental impacts. The EMS also strives for continual improvement through the four-step "Plan-Do-Check-Act" framework for management systems.

The EMS 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 presents guidelines for implementing environmental policy in compliance with the ISO 14001 standard. A link to the *Environmental Management System Plan* and related documents is available on the Environmental Services Group (ESG) website at http://www2.lbl.gov/ehs/esg/.

DOE Order 436.1 also requires that a site's sustainability goals be integrated into the EMS. Berkeley Lab's *Annual Site Sustainability Plan* (LBNL, 2016b) 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)
- Electronic stewardship (life-cycle management)
- Climate change resilience

In total, more than 30 sustainability goals are set forth in these areas by federal legislation and formalized by executive order, primarily Executive Order 13693, *Planning for Federal Sustainability in the Next Decade*, issued in 2015. This executive order also creates an "opportunity to reduce agency direct greenhouse gas emission by at least 40 percent over the next decade while at the same time fostering innovation, reducing spending, and

strengthening the communities in which our Federal facilities operate." Berkeley Lab updates its sustainability plan each year and publishes it online at http://sbl.lbl.gov/results/reports.html.

2.2 ENVIRONMENTAL MANAGEMENT SYSTEM IMPLEMENTATION

As noted above, Berkeley Lab addresses elements of the ISO standard in its *Environmental Management System Plan* and by implementing procedures as described in the following subsections.

2.2.1 EMS Core Team

Berkeley Lab's EMS is implemented and maintained by a "Core Team," consisting of representatives from the following organizations that are essential to meeting the site's environmental objectives:

- Environment/Health/Safety (EHS)
- Facilities
- Procurement and Property Management
- Sustainable Berkeley Lab

An EHS representative leads the team, and a DOE Berkeley Site Office representative attends scheduled meetings to observe and stay informed. Formal meetings were held in February and September, although Core Team members interacted throughout the year in order to reach environmental and sustainability performance goals.

The Core Team has the following primary responsibilities:

- Identify environmental aspects and determining their significance.
- Develop objectives and targets for significant aspects.
- Prepare and implement Environmental Management Programs (EMPs).
- Coordinate internal and external audits of the EMS.
- Review performance results.
- Prepare materials for management reviews.

2.2.2 Environmental Aspects

As part of the "plan" step for a management system, the Core Team routinely reviews environmental aspects (i.e., any activity, product, or service that interacts, whether adversely or beneficially, with the environment) associated with LBNL research and operations. The approximately 40 environmental aspects are grouped into the following categories:

- Emissions and discharges
- Waste generation and recycling
- Materials and resources
- Land and building development and use

Although no new aspects were added in 2016, a new methodology for assessing each aspect was introduced after being approved during the May management review (see Section 2.2.6). Before 2016, the assessment approach

used by the Core Team was based on grading each aspect according to the level of risk (low, medium, high) with eight factors:

- Cost
- Duration
- Effect on Berkeley Lab's mission
- Effect on public image
- Potential for improvement
- Potential legal exposure
- Probability of occurrence
- Severity of impacts

The new approach is also risk based, but streamlined to grade solely on two factors – the likelihood of occurrence and the impact of occurrence – which indirectly will consider the other factors when determining a risk value. This approach is consistent with the Risk Severity Guidelines for Issues Management Application, found in the *Lawrence Berkeley National Laboratory Issues Management Program Manual* (LBNL, 2016c), used by Berkeley Lab's Office of Institutional Assurance and Integrity (OIAI) and follows the definitions of low, medium, and high risk for likelihood of occurrence and impact of occurrence used by OIAI. Additionally, both the Core Team and subject matter experts in the Environmental Services Group were invited to grade the list of environmental aspects after LBNL senior management approved the new approach at the May EMS management review meeting. This streamlined approach garnered input from a broader base of participants who spent less time than before on the important task of grading environmental aspects.

2.2.3 Environmental Management Programs

As part of the "do" step for a management system, the Core Team's grading described above determines which of Berkeley Lab's environmental aspects are significant. Aspects deemed significant require development and maintenance of an EMP document to define the objective, target, strategy, and actions for reducing impacts to the environment. The 2016 annual review identified no change from the previous year to the list of significant aspects. The current set of EMPs remains as follows:

- Energy use
- Greenhouse gas (GHG) emissions
- Petroleum use
- Solid waste diversion
- Sustainable acquisition
- Traffic congestion
- Water use

These EMPs are part of more than 30 sustainability goals mentioned in Section 2.1. The objective, target, and status of each EMP are summarized in Table 2-1. Berkeley Lab's *Annual Site Sustainability Plan* (LBNL, 2016b) contains more details on changes, strategy, and actions for all sustainability goals.

Table 2-1 Environmental Management Programs

Aspect/Activity	Objective(s)	Target(s)	Status at End of FY 2016
Energy Use	Implement sustainable practices to achieve energy efficiency.	Reduce energy use intensity 25% by end of FY 2025, achieving 2.5% reduction annually (baseline: FY 2015).	Consumption was 1% 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 11% below baseline. Scope 3 emissions were 38% below baseline.
Petroleum Use	Reduce vehicle fleet petroleum consumption.	Reduce fleet's annual petroleum consumption by 2% annually (baseline: FY 2005 fleet fuel consumption).	Consumption was 52% 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, by end of FY 2015. Divert at least 50% of construction and demolition debris by end of FY 2015.	70% diversion for nonhazardous solid waste. 96% diversion for construction and demolition debris.
Sustainable Acquisition	Increase procurement opportunities for environmentally sustainable products.	Increase the percentage of priority sustainable products purchased (baseline: FY 2012).	82% of new applicable subcontract actions were reviewed to ensure they included appropriate sustainable acquisition provisions and clauses.
Traffic Congestion	Reduce commute traffic through transportation demand management; report Scope 3 GHG emissions.	Optimize parking. Facilitate/promote non-single-occupant vehicle commuting. Enhance shuttle bus operations. Plan for off-site construction truck trips within the limits of the LBNL Long-Range Development Plan (LBNL, 2007).	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 34% 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.

2.2.4 Training

Training is targeted and graded, commensurate with EMS roles and responsibilities. Training is provided at three levels of increasing rigor, as follows:

- **General EMS awareness.** Content is integrated into course LBNL0010, Safety, Emergency Preparedness, and Trafficking Persons, a training that is required for all personnel new to Berkeley Lab.
- **Comprehensive EMS awareness.** Intended for EMS Core Team members, training covers the basics of the ISO 14001 standard and applicability to Berkeley Lab.
- **EMS implementation and EMS auditor.** Intended for EMS professionals, training includes multi-day courses taught by specialized organizations.

2.2.5 Audit

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 14001:2015 standard by October 2018, a date formally established by DOE.

In preparation for this transition to the newer version of the ISO standard, a gap analysis of the EMS was completed in the summer of 2016 with assistance from EHS quality assurance staff. Many changes had occurred in global business practices, environmental requirements, and sustainability awareness since the last revision to the standard, so the changes to the ISO standard were substantial. For example, the structure and terminology of the standard were reworked to make it easier for an organization to integrate multiple ISO standards. Other changes to the standard include the following:

- Providing greater involvement for senior managers.
- Incorporating risk-based thinking.
- Focusing on improving environmental performance.
- Adopting a process approach.
- Providing flexibility in documented information.

The gap analysis identified areas of the EMS that need improvement under the new standard. Of the nearly 200 conditions (i.e., "shall" statements) in the standard, fewer than 20% of them in the EMS were identified as needing some level of improvement, and none of the conditions were found to be entirely missing. Conditions needing improvement were identified in six of the standard's seven clause areas: leadership, planning, support, operation, performance evaluation, and improvement. An example of a condition needing improvement is assessing Berkeley Lab's environmental aspects to include considering how potential emergency situations can have an environmental impact. Previously, only aspects from routine operations were considered. Working documents for the EMS, such as the program plan and implementing procedures, are being updated to address needed improvements.

2.2.6 Management Review

As part of the "act" step for a management system, senior management of organizations involved in implementing the EMS must meet periodically with the EMS Program Manager to review program status. A representative from both the research and operations areas of Berkeley Lab also attends to observe and then share information with other organizations.

At a minimum, the following topics cited in the ISO 14001 standard are covered in the reviews:

- 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

Management reviews were performed in May and September. They focused on the status of the corrective actions that were initiated as a result of the external audit of the EMS conducted in May. In addition, the reviews included a discussion on options for hosting future management review meetings that will foster greater involvement from the entire LBNL community. Before the meeting, a detailed document was distributed that described the status of each topical area, allowing the meeting to focus on critical issues.

2.3 ENVIRONMENTAL MANAGEMENT PERFORMANCE AND HIGHLIGHTS

At the end of each fiscal year (FY), which begins October 1 of one year and ends September 30 of 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, 2016) 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 A minus – 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 FY 2016 (DOE Berkeley Site Office, 2016) for providing an effective and efficient EMS. This evaluation is based on objectives in DOE's *FY 2017 Performance Evaluation and Measurement Plan* (Section J, Appendix B in DOE, 2016); both the plan and report are required by the operating contract between DOE and UC. The following activities contributed to earning a high performance score:

- Successfully managed several capital projects to address environmental remediation issues. No releases of hazardous materials to the environment occurred from these projects. These remediation efforts also retire, or reduce, environmental risk from Berkeley Lab's overall liabilities.

- Established a new waste hauling contract for the main site that included specific clauses that will improve compliance with stormwater regulations.
- Implemented an expanded, elevated, and more effective management review of the EMS.
- Identified and managed several stormwater infrastructure improvement projects designed to increase compliance with the Industrial General Permit (e.g., asphaltic berms to contain sediments, filter boxes in or near storm drains to absorb metals in runoff).
- Underwent seven inspections involving four different regulatory agencies and received only four minor violations that were corrected either on the spot or by the end of the day.
- Conducted an update commute survey of LBNL community. The results will be used for several purposes, including the annual reporting on Scope 3 greenhouse gas emissions from employee commuting.
- Completed a gap analysis of ISO 14001:2015. Began transition to the new ISO standard, which must be completed by October 2018.

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

For FY 2016, Berkeley Lab's EMS program earned the highest score of "green," based on collective ratings in the above categories. 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 four A's and one B for the reporting period.

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 2016 for 61 activities or equipment are summarized in Table 3-1 by area of environmental program.

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)	Joint BioEnergy Institute & Advanced Biofuels Process Demonstration Unit
	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. Six minor violation notices resulted from nine inspections in 2016. Information about these inspections is summarized in Table 3-2 and discussed in Section 3.4.3.1. 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
COB[a]	Hazardous Materials Business Plan, fixed treatment units, and hazardous waste generator areas at the main site	June 6	2
	Underground storage tanks	Oct. 27	2*
U.S. EPA	NESHAP[b] program	June 2	0
	Inspection of the Hazardous Waste Handling Facility, the Building 77 treatment unit, and waste accumulation areas and satellite accumulation areas in and around Building 77	June 15	2
LBNL	Self-monitoring inspections required by EBMUD for groundwater treatment units	Feb. 17 July 29	0 0
	Self-monitoring inspections required by EBMUD for the Building 77 fixed treatment unit	Sept. 22	0
	Self-monitoring inspections required by EBMUD for the Hearst and Strawberry sanitary sewer outfalls	March 2 Sept. 22	0 0

* One violation rescinded in 2017 (see Section 3.4.3.3).

[a] City of Berkeley (under California's Certified Unified Program Agency)

[b] National Emission Standards for Hazardous Air Pollutants

3.3 DOE-REPORTABLE ENVIRONMENTAL INCIDENTS

The DOE Occurrence Reporting Program tracks environmental incidents across the DOE complex. One environmentally related occurrence report (#SC-BSO-OPERATIONS-2016-0004) was submitted on March 11. A worker unintentionally cut into a line containing Freon R-22 refrigerant while preparing to relocate piping in the Cave 5 area of Building 88. Several pipes ran vertically into the ceiling, none of which were labeled, so it was difficult to identify their types. Before the line was cut, it was thought to be a condensation pipe from an air conditioning unit. After it was cut, technicians responded and promptly secured the leak. A conservative estimate of released Freon was 1 pound, a quantity too small to trigger external reporting.

Another environmentally related occurrence report (#SC-BSO-LBL-EHS-2016-0001) documented the discharge of foam to the storm drain system from the Building 85 (Hazardous Waste Handling Facility) fire suppression system. On October 14 the building's fire suppression system unexpectedly activated and released foam outside one of the storage areas. An estimated 100 gallons of material was released, with approximately 50 gallons reaching the nearest storm drain aided by rainfall that day. EHS notified the California Office of Emergency Services and completed the necessary reporting forms.

Because the fire suppression system had been activated accidentally three times since August 2014, LBNL management determined that the system was susceptible and another occurrence report should be submitted. On October 24, Occurrence Report #SC-BSO-LBL-EHS-2016-0002 was submitted and categorized as a management concern within the DOE program. For the corrective action to this management concern, Berkeley Lab established a cross-functional team from EHS, Facilities, and Protective Services to develop an inventory list of critical fire suppression systems and equipment at the Hazardous Waste Handling Facility, and define the associated preventive maintenance actions that must be entered into the Facilities work order system. It is anticipated that corrective actions for this management concern will be completed in 2017.

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, 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 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:

- Hazardous air pollutants (e.g., radionuclides, air toxics)
- Criteria air pollutants (e.g., carbon monoxide, nitrogen oxides, particulate matter)
- 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, *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 2016 was approximately 0.12% of this limit.

Berkeley Lab documents its NESHAP review and compliance annually; the *Radionuclide Air Emission Report for 2016* (LBNL, 2017b) is the most recent report submitted to the U.S. EPA. The report is available on ESG's Publications webpage at http://www2.lbl.gov/ehs/esg/Reports/tableforreports.shtml.

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 2016, Berkeley Lab held 35 operating permits issued by the Air District (BAAQMD, 2014); 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, seven industrial boilers with a combustion rating of at least 2 million BTUs per hour are registered with the Air District. All permits issued by the Air District are listed in Table 3-3.

Table 3-3 BAAQMD-Permitted Air Emission Sources

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 systems (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.

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 2016, and reported zero emissions for this equipment for the year.

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 50 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, 2016b).

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, Chapter 6.95, Section 25500–25547.8).

As a federal facility, Berkeley Lab is subject to EPCRA Toxic Release Inventory reporting requirements. If usage exceeds threshold quantities, a U.S. EPA Form R must be submitted. Berkeley Lab determined in 2016, as in previous years, 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	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Chlorofluorocarbons	1140	209	172	150	319	202	70	193	322	397
Methanol	139	152	180	147	88	103	172	127	87	129
Nitric acid	198	667	614	592	634	631	633	556	78	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
- Joint BioEnergy Institute and the Advance Biofuels Process Demonstration Unit
- Joint Genome Institute

The HMBPs are also available on ESG's Publications webpage at http://www2.lbl.gov/ehs/esg/Reports/tableforreports.shtml.

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 these 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	—

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, Berkeley Lab submitted an application to DTSC to renew the permit. DTSC determined in July that the application was administratively complete, and is presently performing a thorough review of the application. During the review period, Berkeley Lab will submit an environmental analysis document to DTSC to support the renewal application. In the meantime, the existing permit remains effective and enforceable until the new permit is issued. DTSC review of the permit application will also include a public comment period.

Administration and enforcement for the three lowest 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 at the site, and recycles most of that by diverting it to a nearby cooling tower to replace the water consumed by the cooling process. Approximately 475,000 gallons of water was recycled in this manner in 2016. By the end of 2016, the cumulative volume of water recycled since the system's installation in 2011 had reached nearly 2.7 million gallons.

Table 3-6 Summary of Fixed Treatment Unit Operations

FTU	Building No.	Treatment Types	Approximate Gallons of Wastewater Treated in 2016
004	70A/70F	Acid neutralization	599,500 (475,000 estimated recycled)
005	2	Acid neutralization	77,650
006	77	Metals precipitation and acid neutralization	13,100
007	67	Acid and alkaline neutralization	28,775

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 Mixed Waste Site Treatment Plan (DOE, 1995).

In June, the City of Berkeley conducted a three-day CUPA inspection of the main site. The focus was on hazardous waste accumulation areas (WAAs), universal waste, and permit-by-rule systems. The inspection included activities in Buildings 2, 6, 30, 33, 43, 46, 58, 67, 70A, 76, 77, 79, 81, and 88. Two minor violations were found in two rooms in Building 30; both were corrected during the inspection, resulting in no further action needed.

1. A container of hazardous waste was not labeled. A new satellite accumulation area (SAA) was established and the container was properly labeled.
2. A hazardous waste container did not meet the definition of a "closed container," and a sharps container was left open and unattended. An acceptable lid was found to close the first container, and the lid was closed on the sharps container.

Also in June, U.S. EPA personnel, accompanied by representatives of DTSC and the City of Berkeley, conducted an unannounced compliance inspection of various LBNL activities. The inspection visited the Hazardous Waste Handling Facility, the Building 77 treatment unit, and several SAAs and WAAs in and around Building 77. Two violations for minor issues were cited in separate SAAs in Building 77; both issues occurred when the associated coolant system was not in operation. Both issues were corrected, and documents were submitted to the U.S. EPA within one week of the inspection.

1. A 55-gallon drum of waste oil was not fully closed.
2. A 5-gallon container of stored waste oil was not fully closed and its waste label did not contain all the necessary information.

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* (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 March 2006, Berkeley Lab prepared a Soil Management Plan and a Groundwater Monitoring and Management Plan. These plans describe the nature and extent of contamination, the controls used to reduce potential risk from exposure to the contaminants, 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 http://www2.lbl.gov/ehs/erp/html/documents.shtml.

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. Six permitted USTs are located on site containing 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 2016.

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

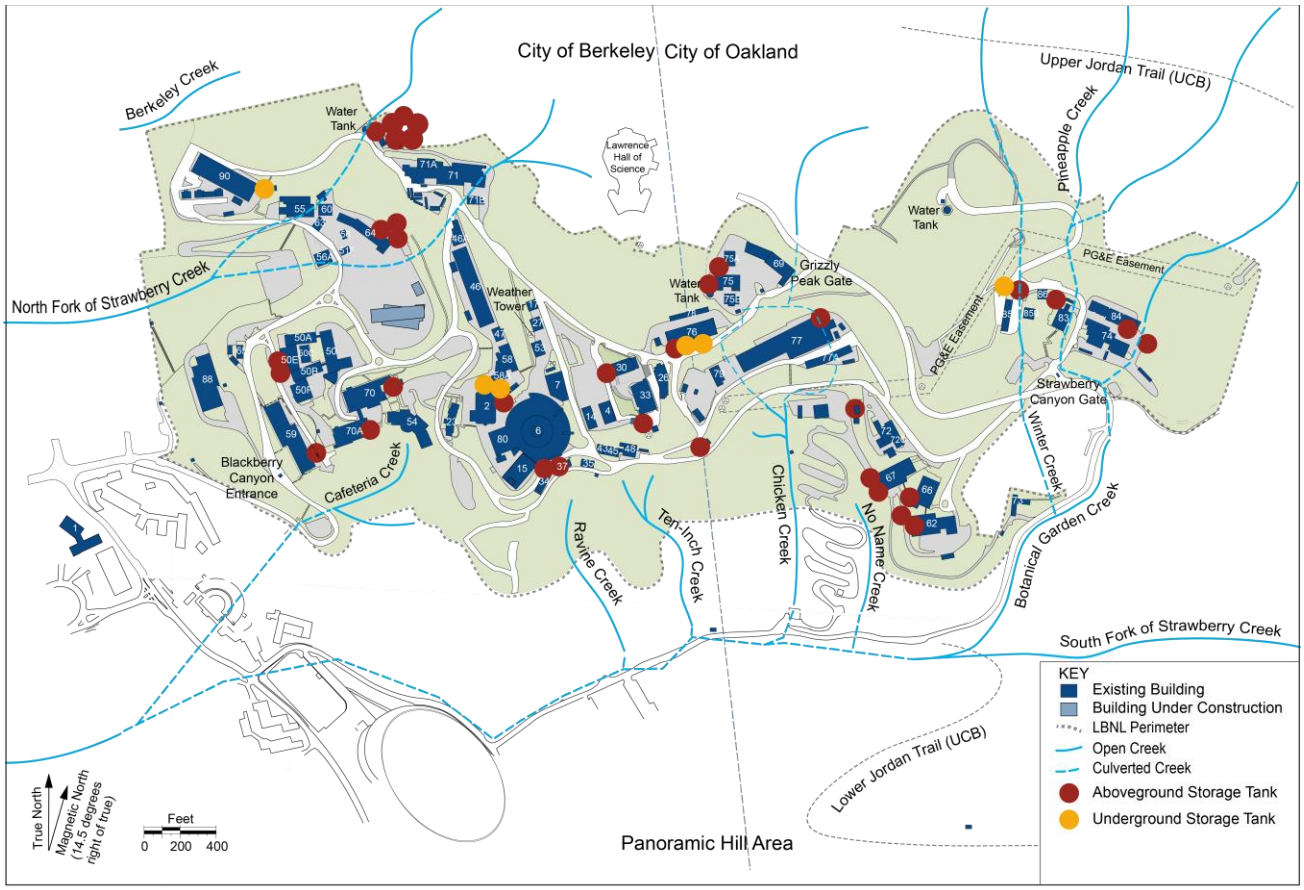

Figure 3-1 Locations of Aboveground and Underground Storage Tanks

In October, the City of Berkeley conducted an inspection of the six permitted USTs at the main site. Two minor violations were issued for historical actions and were resolved in 2017:[1]

1. When each UST was initially permitted to operate, and for each subsequent permit renewal cycle, Berkeley Lab had submitted an incomplete and inaccurate application. The City of Berkeley noted some discrepancies in the description of the tank systems.
2. Berkeley Lab had not submitted as-built drawings for the location and orientation of the tanks and associated piping systems with the latest permit application.

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

[1] In March 2017, Berkeley Lab responded to the violations with a detailed list of components for each tank to address the first violation, and a request to rescind the second violation after learning that the California State Water Resources Control Board considers submission of as-built drawings a one-time event, and not necessary every five years at permit renewal, as the City of Berkeley had cited in the violation notice. The City of Berkeley rescinded the second violation in a letter dated May 17, 2017.

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 1969 California Porter-Cologne Water Quality Control Act 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 WAAs, and storage drums at product distribution areas. The City of Berkeley is responsible for administering and enforcing the regulations that apply to ASTs. Berkeley Lab has 34 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, 2014a). 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).

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, 2013)
- Treated groundwater from hydraugers and groundwater monitoring wells (EBMUD, 2016b)
- Treated rinse water from the metal finishing operations in the Ultra-High Vacuum Cleaning Facility at Building 77 (EBMUD, 2012)
- Treated rainwater from the Old Town Demolition Project (EBMUD, 2016a)

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 2016 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 did not conduct any inspections in 2016.

The sitewide wastewater and groundwater treatment systems permits were approved in 2013. Berkeley Lab will request renewal of the sitewide wastewater permit before it expires in July 2017. The groundwater treatment systems permit, which has no expiration date, applies to eight systems located around the site. Adding the eighth system to the permit was approved by EBMUD in December 2016.

The wastewater discharge permit for the Building 77 Ultra-High Vacuum Cleaning Facility was last approved in 2012. Berkeley Lab will request renewal of this permit before it expires in April 2017. This permit requires that the facility maintain a Toxic Organics Management Plan and a Slug Discharge Plan. 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.

In November 2015, Berkeley Lab applied for 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, and activated charcoal to remove polychlorinated biphenyls (PCBs) that may have accumulated in the rainwater runoff collected at the site. The permit was approved in January 2016 and included conditions regarding compliance with all EBMUD Wastewater Control Ordinance discharge limits and self-monitoring requirements. Berkeley Lab's request to renew the permit for another year was approved 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 permit, which is issued by the Central Contra Costa Sanitary District and is effective through December 2017, 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 it is issued by the State Water Board, the permit is administered and enforced locally by the RWQCB. Under this permit, Berkeley Lab has implemented a Stormwater Pollution Prevention Plan (SWPPP) (LBNL, 2016h), which includes the site's *Stormwater Monitoring Implementation Plan* (LBNL, 2016g).

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 2015/2016 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 2015/2016 season, Berkeley Lab began the year at the "Baseline" compliance level like other sites around the state covered by this permit. However, because elevated levels of aluminum and iron were indicated in sample results from the stormwater season, the State Water Board changed Berkeley Lab's status to compliance "Level 1" for the 2016/2017 season. Berkeley Lab conducted an evaluation to determine whether additional measures could be implemented to lower pollutant levels, and a plan 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 2016, two projects at Berkeley Lab required coverage under the Construction General Permit:

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

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 in 2015 and 2016 under the regulatory authority of U.S. EPA Region 9. Characterization 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 http://www2.lbl.gov/ehs/erp/html/documents.shtml.

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 assist DOE and UC in complying with NEPA and CEQA requirements.

In 2016, DOE determined that three 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 draft Environmental Impact Report was prepared under CEQA and circulated for public and government agency review and comment in the fall of 2016. The report, which examined the Building 59 upgrade and the installation and operation of the NERSC-9 Project, is available at http://www.lbl.gov/community/nersc-9-project/. Two additional activities were determined to be categorically exempt under CEQA.

3.5 SPECIAL PROJECTS

Occasionally, Berkeley Lab has special projects that have higher-than-normal environmental management challenges involving regulatory requirements. In 2016, two such endeavors were 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 section of the site known as Old Town. This project is being conducted in several phases, with Phase 1 activities in 2016 consisting of the following:

- Demolition of Buildings 5, 16, and 16A.
- Removal of the foundation slabs of Buildings 5, 16, and 16A and previously demolished Buildings 40, 41, 52, and 52A.
- Removal of radiologically and PCB-contaminated soil.
- Grading and restoration of the area.

PCBs have been identified in building materials, concrete slabs, storm drains, and soil in and around Buildings 16, 16A, 52, and 52A, and the electrical pad south of Building 52A. PCBs, petroleum hydrocarbons (diesel-range), VOCs, and metal impacts to soil have also been identified in other portions of the Old Town area. These impacted soils will be removed, along with the former building foundations and utilities and some isolated areas of deeper soil. Removal activities will be conducted under the regulatory oversight of the U.S. EPA or DTSC. Radiological impacts have been identified at Building 5, specifically in the slab and subgrade structures, in concrete, asphalt, soil, and below-grade piping, and in the Building 5 yard. The Building 16 superstructure was cleared as non-radiologically impacted before demolition began.

3.5.1.1 Regulatory Oversight

The U.S. EPA requires cleanup and disposal of materials containing and contaminated by PCBs, following 40 CFR 761, *Polychlorinated Biphenyls Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions*. Cleanup activities are being conducted as described in the *Application for Cleanup of Polychlorinated Biphenyls, Old Town Demolition Phase I Project* (DMS, 2016) and an addendum (LBNL, 2016i) submitted to the U.S. EPA Region 9. In its approval of the cleanup application and addendum, the U.S. EPA (2016a) requested that Berkeley Lab also develop a spill response plan for the temporary storage of liquid decontamination wastes and water from excavations that may contain PCBs. Berkeley Lab submitted a Spill Prevention and Response Plan in May (LBNL, 2016f).

Seven meetings with Berkeley Lab, DOE, and the U.S. EPA took place in 2016 to discuss progress on the PCB cleanup project. In addition to meeting, Berkeley Lab led U.S. EPA representatives on a tour of the project site to observe ongoing soil excavation, waste accumulation, and stormwater treatment areas. Berkeley Lab will submit a PCB Cleanup Report to the U.S. EPA upon completion of the PCB remedial work.

DTSC is being kept informed of interactions with the U.S. EPA and the progress of PCB characterization and cleanup activities. When the Old Town Demolition Project is completed, Berkeley Lab will submit a report to DTSC documenting the concentrations of non-radiological contaminants remaining in place.

Earlier assessments of concrete and soil in the Building 5 area of the project site determined they are impacted by radiological constituents. In accordance with the requirements of DOE Order 458.1, *Radiation Protection of the Public and the Environment*, radiological surveys and sampling will be conducted in 2017 to demonstrate compliance with a dose-based standard and to determine proper disposition of materials and equipment. In addition, a final status survey report will be prepared and submitted to DOE in 2017 to document compliance with the DOE order.

EBMUD regulates discharges to the sanitary sewer of treated rainwater that may accumulate in excavations and groundwater that may be extracted during the demolition activities. The State Water Board regulates stormwater discharges. Permits for both activities are discussed in Sections 3.4.4.2 and 3.4.4.3, respectively.

3.5.1.2 Demolition Progress

Building material surveys to identify materials that may contain hazardous substances, such as lead, asbestos, and PCBs, were completed before 2016 (DMS, 2015b; Northgate, 2014; Weiss, 2010). When building demolition began in 2016, Berkeley Lab conducted air monitoring and implemented dust suppression measures to ensure that LBNL personnel and the public were not exposed to harmful dust. No concrete or soil generated during the cleanup was reused or recycled. Equipment used at the project site was decontaminated, then wipe-sampled to confirm it was clean before being removed from the work site. The following work was completed during 2016:

- **Building 5 and Former Radiological Waste Yard.** On May 10, the U.S. EPA approved the PCB cleanup application for Building 5 and the radiological waste yard. Berkeley Lab provided a report to the U.S. EPA concluding that no significant releases of PCBs occurred in the waste yard area (LBNL, 2016a). Building 5 was demolished. Radiologically and mercury-contaminated soil was removed from the area. Cleanup verification samples were collected and radiological surveys were completed. Building materials, equipment, and soil were transported to a low-level radiological waste facility in Nevada for disposal.
- **Building 16 and 16A Area.** On May 24, the U.S. EPA approved the amendment to the PCB cleanup application to include Buildings 16 and 16A. Approximately 20% of the building slab was demolished in 2016. Contaminated soil west of Building 16 was removed, and partial cleanup verification sampling west of Building 16 was conducted. The preliminary results for most sample locations are below the U.S. EPA–approved cleanup goal of 0.94 milligrams per kilogram (mg/kg) total PCBs, but some areas may require additional excavation, which is planned for 2017. Also in 2017, the remainder of the building slab will be demolished, which will include removal of sub-slab soil at two locations at the south end of former Building 16, along with cleanup verification soil sampling.

- **Building 40 and 41 Areas.** Two areas did not require a PCB or radiological cleanup. Buildings 40 and 41 were demolished previously, and the foundation slabs are scheduled to be removed in 2017.
- **Buildings 52 and 52A Area and the former Electrical Pad.** The May 10 approval by the U.S. EPA of the PCB cleanup application included Buildings 52 and 52A and the electrical pad. The concrete slabs were demolished and two localized areas were disposed of as hazardous material (PCB > 50 mg/kg); the remainder of the concrete was transported off site for disposal as construction debris (PCB < 50 mg/kg) at permitted landfills. Contaminated soil was removed, and soil having a PCB concentration greater than 0.94 mg/kg was disposed of as PCB remediation waste. This was followed by cleanup verification sampling. In the area west of Building 52, cleanup verification sample results indicated that PCB concentrations in two areas exceeded the cleanup goal. Northeast of Building 52, elevated concentrations of PCBs have been detected in soil beneath a corroded storm drain pipe. Additional soil excavation is planned for these three locations in 2017, and will be followed by a second round of cleanup verification sampling.

3.5.1.3 Waste Status

In 2016, approximately 216 cubic yards of soil and approximately 100 cubic yards of debris from the Building 5 area were characterized as low-level radiological waste and transported to the Nevada National Security Site.

Stormwater was collected in excavation areas at the Old Town Demolition Project. Some of the stormwater was in contact with PCB-impacted soil and, as a result, became contaminated. Approximately 37,700 gallons of stormwater was pumped into holding tanks and treated using GAC before being discharged to the sanitary sewer system under a Special Wastewater Discharge Permit issued by EBMUD.

3.5.2 Integrative Genomics Building and Modular Utility Plant Project

Site access efforts began in May in preparation for future development of the IGB/MUP Project 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 the figures of the site used in this report, such as Figure 3-1. In 2016, these efforts were confined to the area where the MUP will be constructed to support the future IGB. In preparing the site, Berkeley Lab conducted the following demolition, characterization, and off-site disposal activities:

- Concrete retaining wall "bump out" and the soil and concrete features from behind the wall.
- Concrete from, and soil behind, the east retaining wall and hillside to accommodate construction of a new retaining wall.
- Soil from the east elevation turnaround area.
- Soil from additional excavation activities associated with a new fire line in Smoot Road.

Characterization and off-site disposal activities in 2016 were performed in conformance with both the *Sampling and Analysis Plan for Characterization of Soil and Concrete to Support the Modular Utility Plant Construction at the Lawrence Berkeley National Laboratory* (Weiss, 2016) and the *Soil Management Plan, Building 91 Integrative Genomics Building and Building 91U Modular Utility Plant* (LBNL, 2016e).

3.5.2.1 Characterization

Samples of concrete, paint, soil, and waterproofing material 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 *Report of Soil and Concrete Characterization to Support the Modular Utility Plant and Other Construction at the Bayview Area of the Lawrence Berkeley National Laboratory* (Weiss, 2017), 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 both Waste Connections, Inc., and Republic Services. In 2016, approximately 2,100 cubic yards of materials were shipped in covered trucks under nonhazardous waste manifests to Waste Connections' Potrero Hills Landfill in Suisun City, California, and to Republic Services' Keller Canyon Landfill in Pittsburg, 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 2016 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, which consists of emissions sampling and monitoring to measure contaminants in building exhaust systems, is designed to measure the impacts from radiological air emissions. The air monitoring 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 evaluate the potential for 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 and subsequent analysis of the filters 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 2016, 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 2016, sampling was required 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

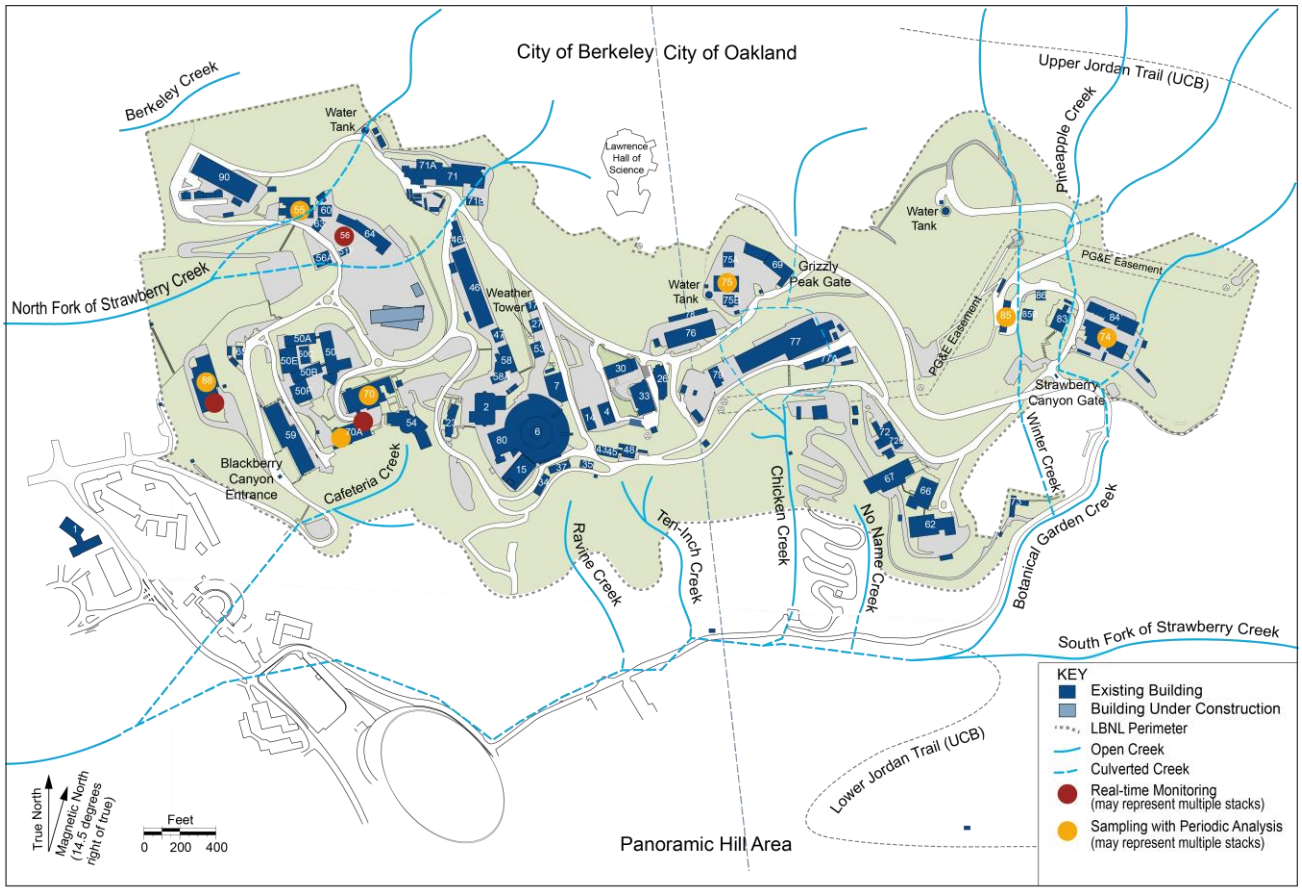

Figure 4-1 Building Exhaust Sampling and Monitoring Locations

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% of the emitted activity. The Building 56 glovebox was the main source of fluorine-18 emissions, at 0.98 curies (Ci). Additional details on stack emissions are available in Berkeley Lab's *Radionuclide Air Emission*

Report for FY 2016 (LBNL, 2017b), which was submitted to the U.S. EPA, and is available on ESG's Publications webpage at http://www2.lbl.gov/ehs/esg/Reports/tableforreports.shtml.

For information on the estimated dose from radionuclide emissions, see Chapter 5.

4.2 SURFACE WATER

Sampling of surface waters at and around Berkeley Lab comprises creek water and stormwater.

4.2.1 Creek Sampling

Surface water quality is checked by sampling creeks within the Strawberry Creek watershed. As shown on Figure 4-2, the sampled creeks flow through – or originate within – the LBNL site. They include the North Fork of Strawberry Creek, Chicken Creek, Upper Botanical Garden Creek, No Name Creek, Ravine Creek, and Winter Creek, which is sampled at two locations (inflow and outflow points to the site). Because seasonal changes can affect the flow volume and water quality, samples are collected semiannually – once during the wet season and once during the dry season. Sampling was conducted in March and August.

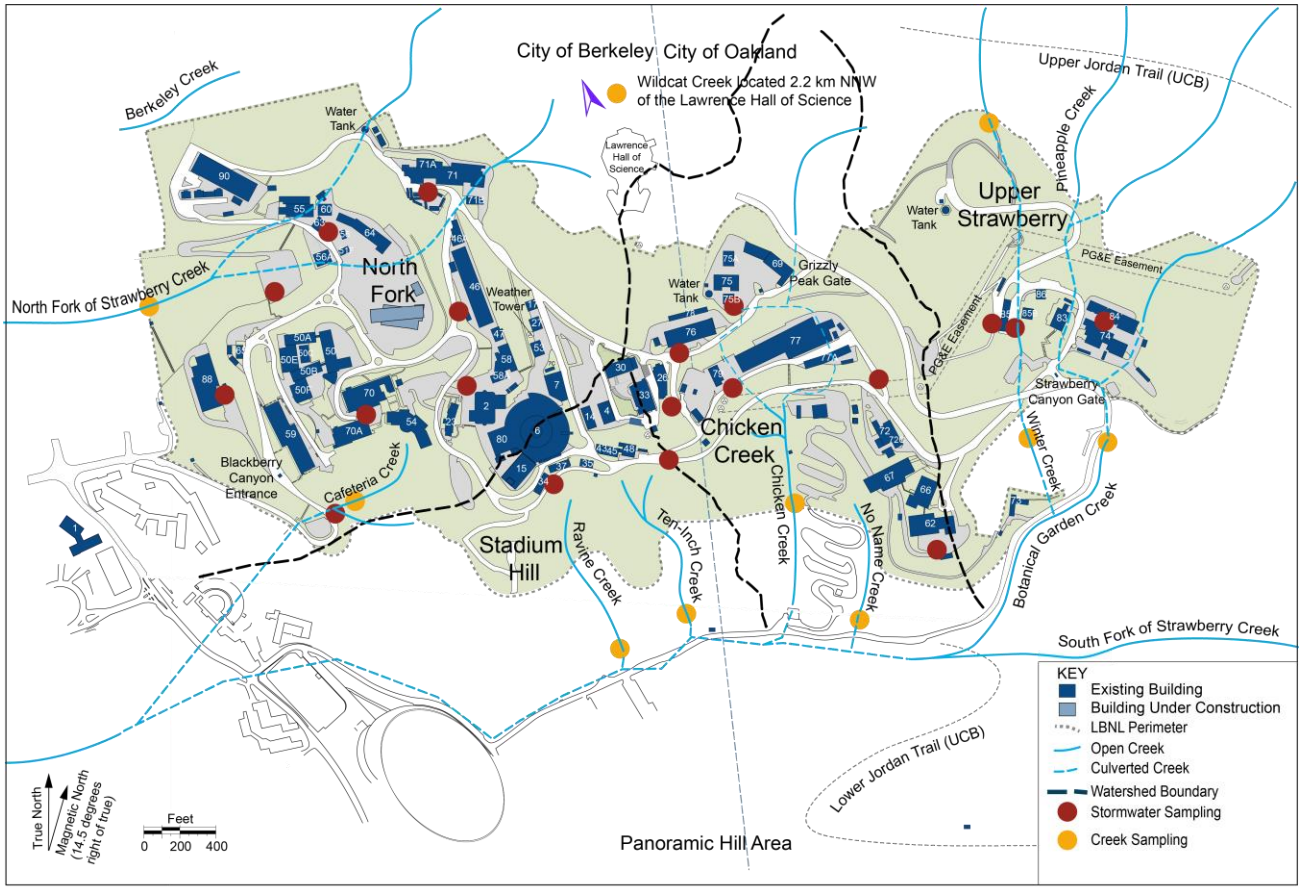

Figure 4-2 Surface Water Sampling Locations

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 from Berkeley Lab. Sampling results confirm that Wildcat Creek is not impacted by LBNL operations.

Samples from the following subset of creeks were analyzed for gross alpha, gross beta, and 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). 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 referred to as the Basin Plan (RWQCB, 2015). The federal and state MCL values for drinking water are as follows (U.S. EPA, 1976; RWQCB, 2015):

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

Laboratory analysis reported 22 of the 27 sample results as non-detectable. As shown in Table 4-2, none of the detectable results from the semiannual samples collected exceeded 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 alpha and beta results.

Table 4-2 Detectable Radiological Results from 2016 Creek Sampling

Activity	MCL[a] (pCi/L)	Creek	Sample (pCi/L)	% of MCL
alpha	15	Winter Creek	2	13.3%
		Chicken Creek	2.33	15.5
		Chicken Creek	2	13.3%
beta	50	Chicken Creek	4.7	9.4%
tritium	20,000	Chicken Creek	230	1.2%

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

Creek samples were also analyzed for VOCs and metals. No VOCs were detected, but the following metals were detected: aluminum, antimony, arsenic, barium, chromium, copper, iron, lead, nickel, selenium, thorium, 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 samples collected in March 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 indicate that concentrations in all samples analyzed for these indicator parameters 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, 2016g). The Industrial General Permit also requires visual observation of the surface water runoff from each qualifying storm event, and dry weather visual observations of non-stormwater discharges once per month.

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 must occur within the first half of each reporting year (July 1–December 31), the other two within the second half of each reporting year (January 1–June 30). For this Site Environmental Report, that translates to reporting sampling results for two stormwater reporting years: the second half of 2015/2016 and the first half of 2016/2017. Given Berkeley Lab's industrial activities, samples must be analyzed for the following nine parameters:

- aluminum
- chemical oxygen demand
- copper
- iron
- pH
- nitrate plus nitrite
- oil and grease
- total suspended solids
- 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 2015/2016 reporting year showed that seven of the nine parameters sampled by Berkeley Lab remained below their numeric action level. However, the averages for the other two parameters (aluminum, at 0.944 mg/L, and iron, at 1.30 mg/L) were above their respective numeric action levels of 0.750 and 1.000 mg/L; therefore, Berkeley Lab's status was changed to compliance "Level 1" for the 2016/2017 reporting year.

This change in compliance level meant that Berkeley Lab needed to identify additional best management practices to implement in order to prevent future exceedances of numeric action levels. It needed to update the SWPPP to document the additional best management practices implemented, then submit an Exceedance Response Actions 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 2016/2017 reporting year, Berkeley Lab was successful in obtaining samples for two qualifying storm events occurring prior to December 31. Similar to the preceding reporting year, levels of aluminum and iron in the samples were above their numeric action levels for both sampling events, while sample results for the other seven parameters remained

below these levels. The results for the entire 2016/2017 reporting year will be reported in the Site Environmental Report for 2017.

In summary, the sampling results from 2016, covering portions of two stormwater reporting years, show that Berkeley Lab's best management practices provide adequate control for stormwater discharges at most locations. At locations where results exceed regional benchmark levels, best management practices were evaluated and improved as warranted, although the results have not improved as expected. Berkeley Lab is considering conducting a background study to determine levels of aluminum and iron flowing onto the site from naturally occurring sources.

4.3 WASTEWATER

Berkeley Lab has an extensive wastewater monitoring program. 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, as will be discussed in the following sections. An overview of monitoring locations and a summary of any sanitary sewer spills are also provided.

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:

- 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.
- 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 2016, Berkeley Lab discharged approximately 19.3 million gallons through the Hearst branch of the sewer system and 19.9 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 under the Nuclear Regulatory Commission or other governmental agency empowered 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, total suspended solids, and specific metals.

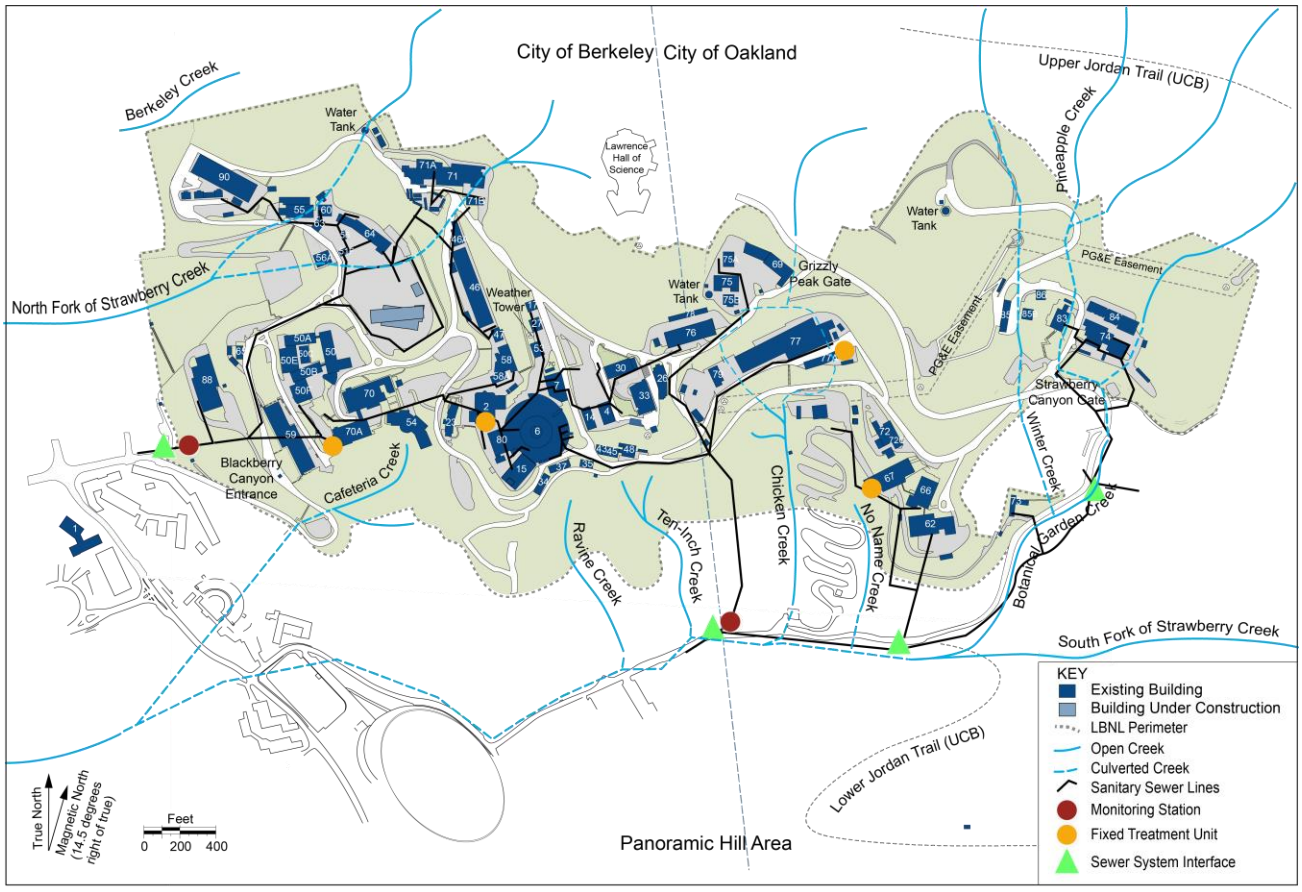

Figure 4-3 Sanitary Sewer System (Main Lines)

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 2016 were below the minimum detectable activity levels for carbon-14, iodine-125, and tritium. Positive results for gross alpha were detected in the February and April samples at the Hearst sewer outfall, and are likely due to naturally occurring radium daughter products. The highest monthly gross alpha concentration was 6.76 pCi/L, which is below the federal and state MCL for drinking water of 15 pCi/L. 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 23.5 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 detectable limits. Since carbon-14, iodine-125, 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 4.49×10^{-3} Ci, or 0.09% of the tritium discharge limit of 5 Ci. The annual discharge estimated from carbon-14 values totaled 1.22×10^{-3} Ci, or 0.12% of the carbon-14 discharge limit of 1 Ci. The estimated annual discharge for all other radioisotopes (gross alpha, gross beta, and iodine-125) was 2.37×10^{-3} Ci, or 0.24% 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 beta (strontium-90) activity, the calculated discharges were 0.01 (1.0%) 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 chlorinated hydrocarbon results were either below EBMUD permit limits or not detected. All pH results were well above 5.5, as required by the permit. Total suspended solids and chemical oxygen demand do not have discharge limits and are measured to determine wastewater strength, which forms the basis for EBMUD's wastewater treatment charges.

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. Samples of the treated water are collected and analyzed for VOCs using U.S. EPA–approved methods to document that EBMUD discharge limits have not been exceeded. Sampling results have never exceeded the 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 late 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.

The State Water Board's Sanitary Sewer Order (WQ 2013-0058-EXEC, *Amending Monitoring and Reporting Program for Statewide General Waste Discharge Requirements for Sanitary Sewer Systems*) requires reporting of all spills, including monthly reporting for each month that no sanitary sewer overflow 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. A total of 12 monthly "No-Spill" certifications were submitted to the online system because 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 semiannual 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 are available at the main branch of the Berkeley Public Library and on the program's website at http://www2.lbl.gov/ehs/erp/html/documents.shtml.

4.4.1 Groundwater Monitoring Overview

The groundwater monitoring network consists of more than 200 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 long-term goal of restoring all groundwater at the site to drinking water standards, if practicable. (Groundwater at Berkeley Lab is not intended for domestic, irrigation, or industrial purposes.)

To meet these objectives, wells are sampled primarily for VOCs, although selected wells are also sampled for metals and tritium where these constituents have previously been considered a potential concern. The groundwater monitoring data continue to indicate that the corrective measures have been effective in reducing groundwater contaminant concentrations. Groundwater plumes are stable or diminishing, and contaminants in the groundwater are not migrating off site.

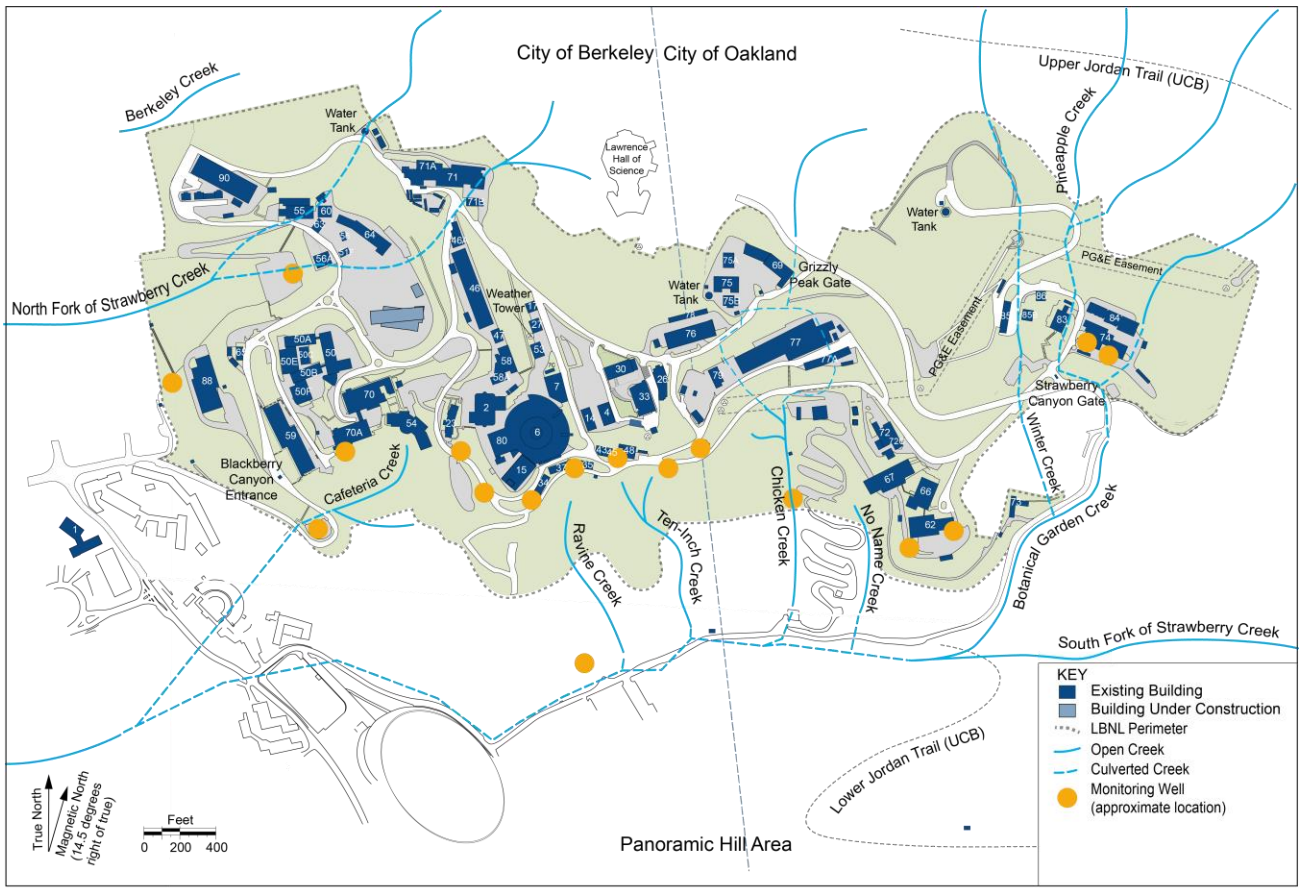

Figure 4-4 Groundwater Monitoring Wells Closest to the Site Boundary

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 it consists of three lobes (i.e., Building 7, Building 25A, and Building 52) that were originally separate plumes but have now merged. In addition, Berkeley Lab monitors VOC-contaminated groundwater 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 where groundwater contamination is monitored are shown on Figure 4-5.

The primary contaminants detected in the groundwater have been chlorinated VOCs, such as tetrachloroethylene, trichloroethylene, 1,1-dichloroethane, and carbon tetrachloride, and their associated degradation products, such as 1,1-dichloroethylene, cis-1,2-dichloroethylene, 1,1,1-trichloroethane, and vinyl chloride. Concentrations of VOCs

in most areas have declined significantly, primarily from the implemented corrective measures. However, VOC concentrations remain above the drinking water standard in a number of areas.

Metals: Twelve groundwater monitoring wells at the site are monitored annually for a specific metal (i.e., arsenic, mercury, molybdenum, or selenium) that historically has exceeded the upper estimate of LBNL background (LBNL, 2002) and any established MCL. The only metal detected at a concentration above both the MCL and the background level in 2016 was arsenic, in two wells. In addition, molybdenum was detected above the background level in four wells. There is no MCL for molybdenum. Concentrations of metals detected were consistent with results from recent years.

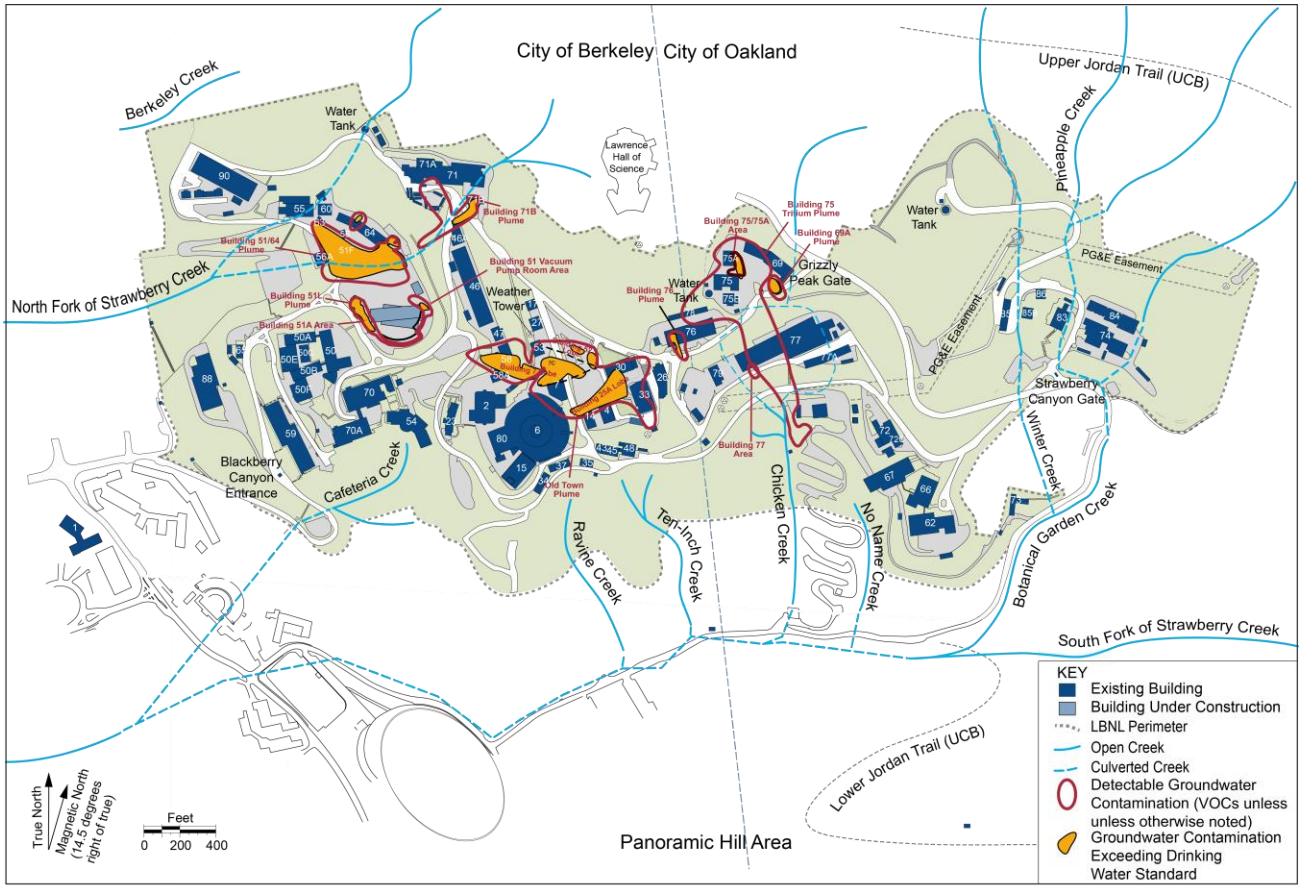

Figure 4-5 Locations of Groundwater Contamination

The exceedances of background are likely statistical artifacts and do not represent contamination. For the few wells where contamination had been suspected, concentrations have decreased and stabilized below levels of concern.

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 consistently below the drinking water standard of 20,000 pCi/L (U.S. EPA, 1976; RWQCB, 2015)

since February 2005. 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 using collection trenches, groundwater 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 2016 to treat extracted groundwater, which totaled approximately 10 million gallons for the year. The cumulative volume of contaminated groundwater treated from 1991 through the end of 2016 exceeds 183 million gallons. Most of the treated water is reinjected into the subsurface for in situ soil flushing. Treated water not needed for soil flushing is discharged to the sanitary sewer 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 2016 and required by DOE Order 458.1 and guidance (DOE, 2015). Locations for soil and sediment sampling are shown on Figure 4-6.

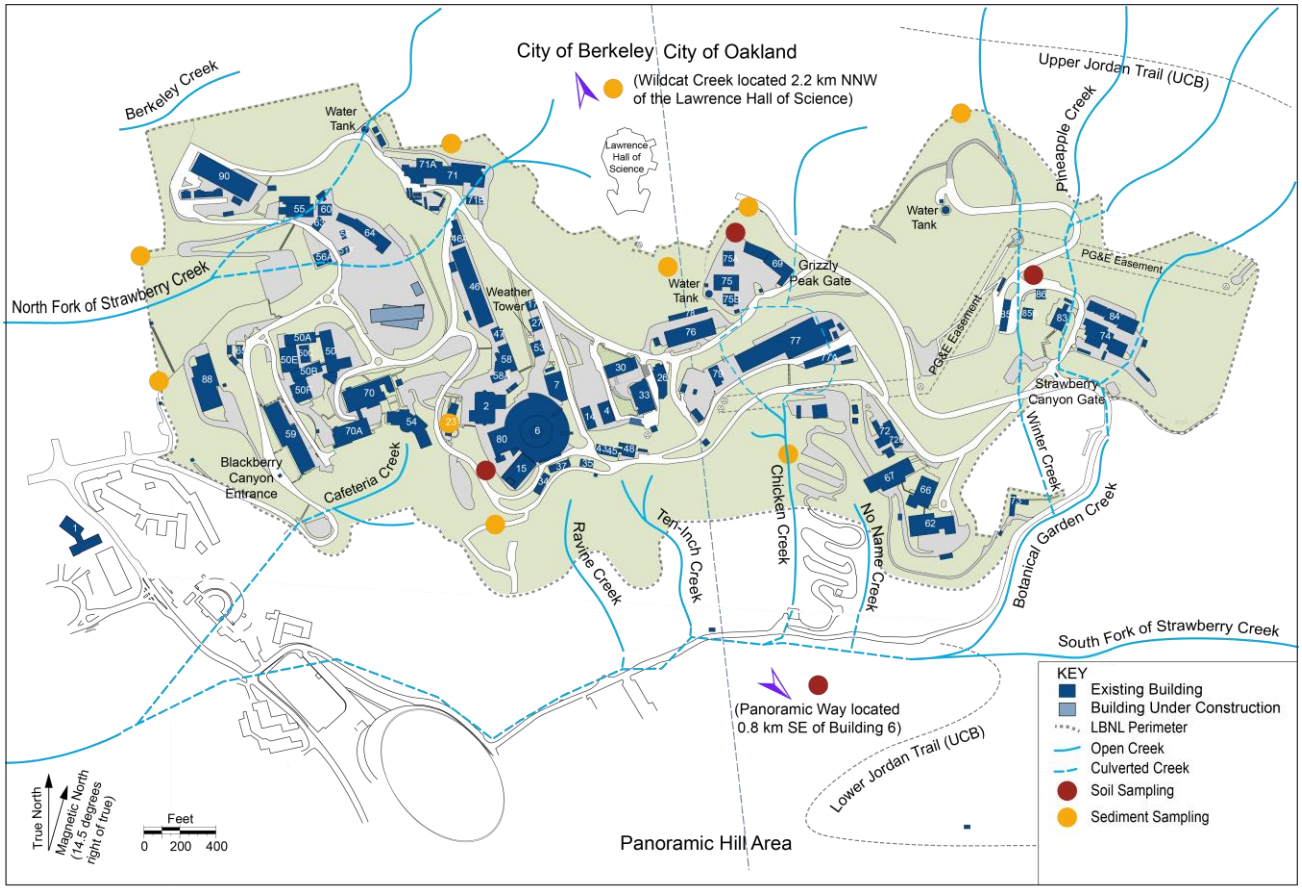

Figure 4-6 Soil and Sediment Sampling Sites

4.5.1 Soil Sampling

Soil samples obtained from the top 2 inches of surface soils were collected from three locations within the LBNL site and one off-site environmental monitoring station. Samples were analyzed for gross alpha, gross beta, gamma emitters, tritium, moisture content, pH, and 15 metals.

For radioisotope analysis, gross alpha, gross beta, and gamma emitter results at each of the sampling locations were similar to background levels of naturally occurring radioisotopes commonly found in soils (Eisenbud, 1973; NCRP, 1987). Tritium measurements at each sampling location were below detection limits.

For non-radioisotope analysis, pH and moisture content 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).

At the Building 85 sampling location, mercury was detected at a concentration of 1.20 milligrams per kilogram (mg/kg) in the quality control sample and 0.50 mg/kg in the primary sample. Both results are above the established LBNL soil background concentration for mercury (0.42 mg/kg). However, they are well below the RWQCB's environmental commercial/industrial screening level of 57 mg/kg (RWQCB, 2016) and DTSC's modified commercial/industrial screening level of 4.5 mg/kg (DTSC, 2016).

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.

For radioisotope analysis, gross alpha, gross beta, and gamma emitter results were similar to background levels of naturally occurring radioisotopes commonly found in soils (Eisenbud, 1973; NCRP, 1987). Tritium measurements at each sampling location were below detection limits.

For non-radioisotope analysis, 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 at Chicken Creek at a concentration of 0.015 mg/kg (Aroclor 1260) and 0.011 mg/kg (Aroclor 1268) in the quality control sample; 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 1.00 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. Tritium in vegetation occurs in two chemical forms: organically bound tritium and tissue-free water tritium. Berkeley Lab analyzes vegetation for both forms. 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 as well, 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 detectable 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:

- 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).

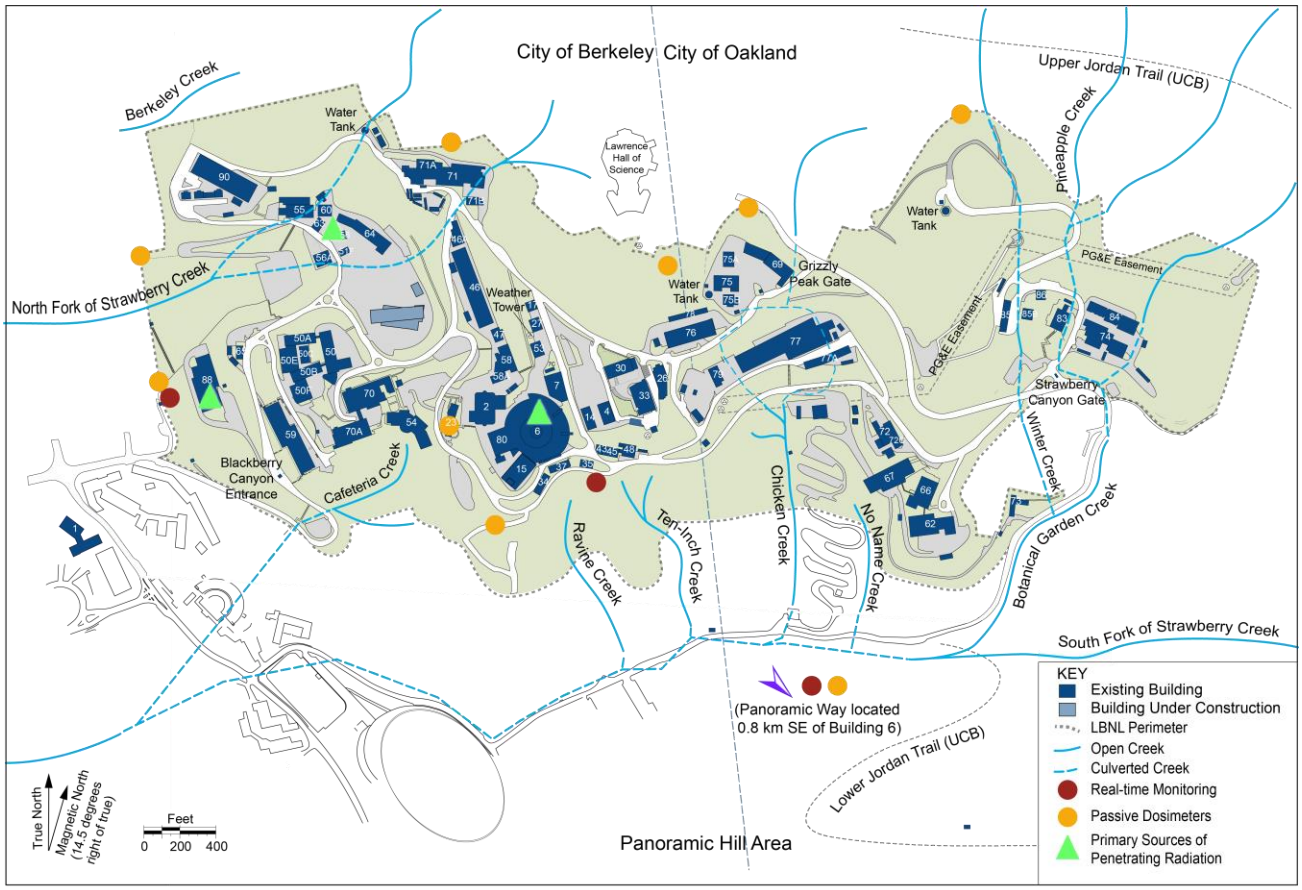

Figure 4-7 Environmental Penetrating Radiation Primary Sources and Monitoring Stations

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.

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. Only high-value released property worth more than $100,000 is included in this Site Environmental Report, and in 2016 Berkeley Lab did not release any high-value property from radiological control.

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 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 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 2016.

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 annual dose from gamma and neutron radiation to a person outside the western boundary of the site was 3.97×10^{-1} mrem. This maximum 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 (0.4%) 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 4.12×10^{-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 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. Details of dose calculations from dispersible airborne radionuclide emissions are included in Berkeley Lab's annual NESHAP report (LBNL, 2017b).

Following NESHAP requirements, the location of the maximally exposed individual to airborne emissions must 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 2016, the calculated annual dose from airborne radionuclides was 1.15×10^{-2} mrem, which is approximately 0.12% 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 2.14×10^{-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 2016 was approximately 4.1×10^{-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 0.1% of the average natural background radiation dose (310 mrem/yr) in the United States (NCRP, 2009), and approximately 0.4% of the DOE annual limit from all sources (100 mrem/yr) (DOE, 2013).

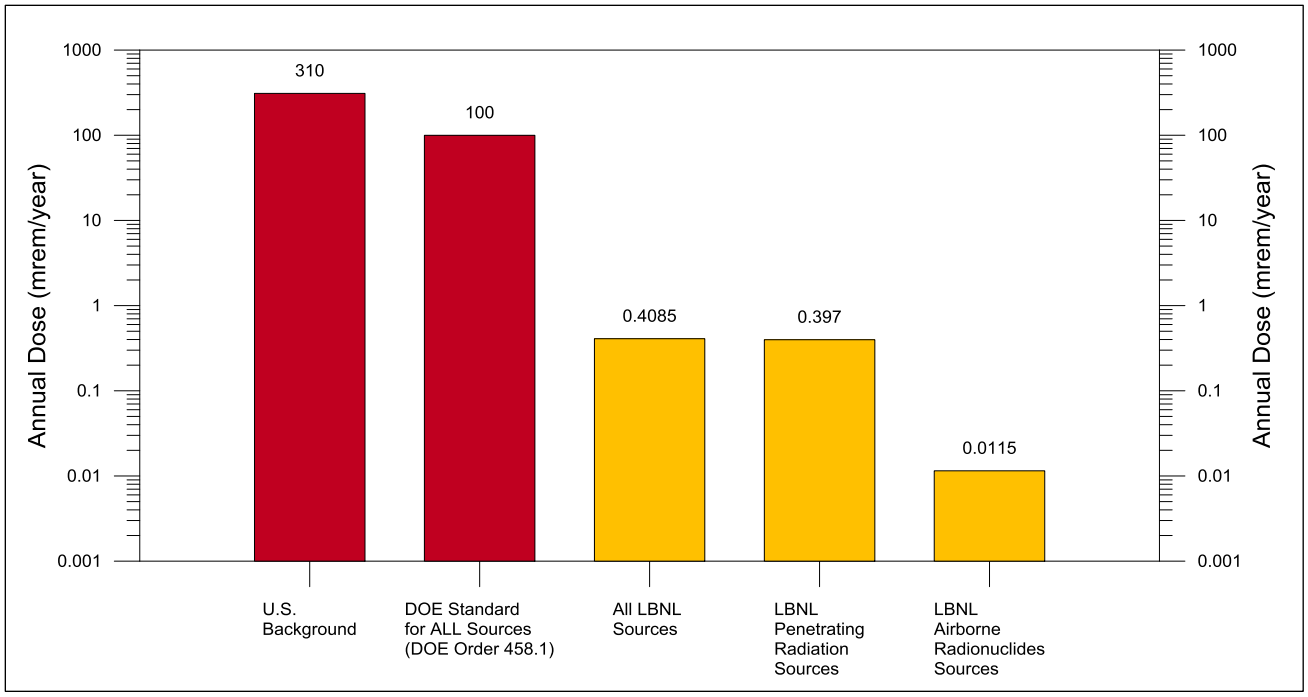

Figure 5-1 Comparative Radiological Doses for 2016

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, 2016d), 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 2016, Berkeley Lab had contracts with five commercial analytical laboratories for specific analytical services:

- ALS (Fort Collins, Colorado)
- BC Laboratories (Bakersfield, California)
- Curtis & Tompkins (Berkeley, California)
- GEL Laboratories (Charleston, South Carolina)
- 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, 1994a). 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 2016, three of the five analytical laboratories – ALS, BC Laboratories, and GEL Laboratories – were audited under the DOECAP. None were 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

A total of 3,062 individual air, sediment, soil, and water samples were collected in 2016 under Berkeley Lab's environmental monitoring programs, generating 91,971 analytical results. Samples were obtained from over 920 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 (http://www2.lbl.gov/ehs/erp/html/documents.shtml) or in hardcopy reports at the main branch of the Berkeley Public Library.

The sampling result totals include those from activities associated with the Old Town Phase 1 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 two-thirds of the environmental monitoring programs' sampling locations in 2016, over 35% 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 2016, a total of 59 split and 159 duplicate samples were collected for either radiological or non-radiological analyses, or both. These samples led to 366 split and 3,985 duplicate results. Additionally, 216 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 five analytical laboratories performed 4,823 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	40	115	2	√	—
Stormwater and Creeks	124	350	4	√	√
Wastewater	114	482	5	√	√
Groundwater	130	845	4	√	√
Soil Investigation	73	255	3	√	√
Sediment	29	96	4	√	√
Soil	13	37	4	√	√
IGB/MUP	154	574	2	√	√
Old Town Demolition, Phase 1B	136	520	3	√	√
DMS Sampling	445	1,549	4	√	√

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

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

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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
EMP	Environmental Management 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
SAA	satellite accumulation area
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
WAA	waste accumulation area

Glossary

accuracy

The closeness of a measurement to its true value.

Advanced Light Source

An accelerator 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 sample 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.

dose, population

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.

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 of 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* dose, population.

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.

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* nuclide and 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.

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