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Volume I

Ernest Orlando Lawrence
Berkeley National Laboratory

Site Environmental Report for 2006
Volume I

Environment, Health, and Safety Division

September 2007

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Preface

Each year, Ernest Orlando Lawrence Berkeley National Laboratory prepares an integrated report on its environmental programs to satisfy the requirements of United States Department of Energy Order 231.1A, *Environment, Safety, and Health Reporting*.[1] The *Site Environmental Report for 2006* summarizes Berkeley Lab's environmental management performance, presents environmental monitoring results, and describes significant programs for calendar year 2006. (Throughout this report, Ernest Orlando Lawrence Berkeley National Laboratory is referred to as "Berkeley Lab," "the Laboratory," "Lawrence Berkeley National Laboratory," and "LBNL.")

The report is separated into two volumes. Volume I is organized into an executive summary followed by six chapters that contain an overview of the Laboratory, a discussion of the Laboratory's environmental management system, the status of environmental programs, and summarized results from surveillance and monitoring activities. Volume II contains individual data results from surveillance and monitoring activities.

The *Site Environmental Report* is distributed by releasing it on the Web from the Berkeley Lab Environmental Services Group (ESG) home page, which is located at http://www.lbl.gov/ehs/esg/. Many of the documents cited in this report also are accessible from the ESG Web page. CD and printed copies of this *Site Environmental Report* are available upon request.

The report follows the Laboratory's policy of using the International System of Units (SI), also known as the metric system of measurements. Whenever possible, results are also reported using the more conventional (non-SI) system of measurements, because the non-SI system is referenced by several current regulatory standards and is more familiar to some readers. Two tables are provided at the end of the Glossary to help readers: the first defines the prefixes used with SI units of measurement, and the second provides conversions to non-SI units. Years mentioned in this report refer to calendar years unless specified as fiscal year(s).

Readers are encouraged to comment on this report by completing the survey form in the Web version of the report. This report was prepared under the direction of Michael Ruggieri of ESG, and address any questions regarding this report to him (by telephone at 510-486-5440; or by e-mail at mrruggieri@lbl.gov). The primary authors are David Baskin, Robert Fox, John Jelinski, Ron Pauer, Michael Ruggieri, Patrick Thorson, and Linnea Wahl. Other key contributors include Steve Wyrick (Volume II), Alice Ramirez (word processing), Flavio Robles (illustration support), and Netty Kahan (technical editing).

Executive Summary

Building 50 Complex

Ernest Orlando Lawrence Berkeley National Laboratory (Berkeley Lab) is a multiprogram scientific facility operated by the University of California for the United States Department of Energy (DOE). The Laboratory's research is directed toward the physical, biological, environmental, and computational sciences—in order to deliver the scientific knowledge and discoveries pertinent to DOE's missions.

This annual *Site Environmental Report* covers activities conducted in calendar year (CY) 2006. The format and content of this report satisfy the requirements of DOE Order 231.1A, *Environment, Safety, and Health Reporting*,[1] and the operating contract between the University of California Office of the President (UCOP) and DOE.[2]

INTEGRATED SAFETY MANAGEMENT AND ENVIRONMENTAL MANAGEMENT SYSTEM

Berkeley Lab employs Integrated Safety Management (ISM), which is a DOE management system that applies the following core Environment, Health, and Safety functions to all Laboratory work:

1. Work planning
2. Hazard and risk analysis
3. Establishment of controls
4. Work performance in accordance with the controls
5. Feedback and improvement

Laboratory activities are planned and conducted with full regard to protecting the public and the environment and complying with appropriate environmental laws and regulations.

In 2006, Berkeley Lab continued to implement a performance-based Environmental Management System (EMS), which is integrated with the Laboratory's ISM System. When practical, the existing processes used for ISM were used to support and implement environmental performance improvement and compliance management. New processes were developed to support the EMS where needed. For more information, see Chapter 2.

OPERATING PERMITS, INSPECTIONS, AND INCIDENTS IN 2006

- At the end of the year, Berkeley Lab held 47 environmental operating permits from various regulatory agencies for air and water quality protection and hazardous waste handling.
- Twenty-five inspections of Berkeley Lab's environmental programs occurred during the year. Two violations were received and both were reported under the DOE occurrence-reporting program,[3] which is used to track incidents across the DOE complex. In March 2006, the final report from the California Department of Toxic Substances Control (DTSC) 2005 inspection of the Hazardous Waste Handling Facility (HWHF) was received and cited two Class II violations.
  1. The first violation cited Berkeley Lab for failing to provide Hazardous Waste Operations and Emergency Response Supervisor training for a Technician Specialist. This training was completed shortly after the original inspection in 2005.
  2. The second violation cited the Laboratory for failing to notify DTSC when two new job titles were created (Radioactive/Mixed Technical Lead and Hazardous Waste Technical Lead). The Laboratory submitted a permit modification shortly after the 2005 inspection.
- Another DOE occurrence report was issued in March 2006, when a drum of asbestos wastes described as "mastic" and "mastic remover solid" was transported on-site to the HWHF. The contents subsequently were discovered as being liquid rather than solid. The waste was removed from the pending shipment and was shipped as a liquid.

Berkeley Lab was fined $28,000 in March 2007 by DTSC for hazardous waste violations that resulted from inspections between 2003 and 2005. These violations were discussed in previous Site Environmental Reports. Specifically, the Laboratory was fined for accepting hazardous waste from off-site, in this case from Building 903, and transporting hazardous materials to the 903 warehouse, which is not authorized to accept hazardous waste. The Laboratory also was fined for holding hazardous waste in a Satellite Accumulation Area for more than one year, which is a California Health and Safety Code violation. Berkeley Lab corrected the violations at the time they were issued and continues to work to prevent additional instances. DTSC has acknowledged that all terms and conditions of the Consent Order were met.

For additional information on operating permits, inspections, and incidents, see Chapter 3.

PERFORMANCE EVALUATION

Each year, UCOP and DOE perform an assessment of Berkeley Lab's environmental program, using measures developed jointly by Berkeley Lab, UCOP, and DOE. For fiscal year (FY) 2006 (October 1, 2005–September 30, 2006), there were three environmental measures and Berkeley Lab received A ratings for each of them by accomplishing the following.[4]

- The number of environmental Notices of Violations issued to the Laboratory did not exceed two.
- All five of the EMS goals were achieved.
- More than two waste minimization, emission reduction and/or resource conservation projects were implemented.

For more information on environmental performance measures, go to Berkeley Lab's Office of Institutional Assurance home page at http://www.lbl.gov/DIR/OIA/OCA/contract-performance/index.html.

ENVIRONMENTAL MONITORING AND DOSE ASSESSMENT

Berkeley Lab's environmental monitoring program serves several purposes:

- To demonstrate that Laboratory activities operate within regulatory and DOE requirements
- To provide a historical record of any Laboratory impacts on the environment
- To support environmental management decisions
- To provide information on the effectiveness of emission control programs

Environmental radiological measurements are performed to assess the maximum potential dose to members of the public. In addition, both radiological and nonradiological constituents are monitored and compared to regulatory and DOE limits.

To assess potential doses to the public resulting from Laboratory operations, three types of environmental radiation are measured:

1. Penetrating radiation (gamma and neutron) from sources such as accelerators
2. Emissions of dispersible radionuclides to stack air and sanitary sewer water from Laboratory activities
3. Concentrations of radionuclides in the ambient environment (air, surface water, vegetation, soil, sediment, and groundwater)

In 2006, the maximum dose to a member of the public from penetrating radiation was below detection limits and indistinguishable from the average United States background level, 3.6 millisieverts (mSv) (360 millirem [mrem]).[5] The estimated maximum potential dose from all airborne radionuclides released from the Laboratory in 2006 was 1.3×10^{-4} mSv (0.013 mrem). This is approximately 0.1% of the United States Environmental Protection Agency dose limit for dispersible radionuclide emissions (0.10 mSv [10 mrem]).[6]

Berkeley Lab also estimates the cumulative dose impact (population dose) from its dispersible radionuclide emissions to the entire population found within an 80-kilometer (km) (50-mile) radius of Berkeley Lab. This measure is the sum of all individual doses to the population residing or working within this radius. The population dose for 2006 from dispersible radionuclide emissions was estimated at 1.3×10^{-3} person-sievert (person-Sv) (0.13 person-rem). From natural background radionuclides alone, this same population receives an estimated dose of 13,000 person-Sv (1,300,000 person-rem). No regulatory standard exists for this measure.

During the year, ambient air, creek water, rainwater, sediment, soil, stormwater, and wastewater were monitored for radiological and nonradiological constituents to comply with operational permits and DOE requirements. Results were below or near analytical detection limits, or within urban background levels and below regulatory limits.

Investigations and monitoring conducted since the early 1990s have characterized nine principal groundwater contamination plumes, all of which are on-site and do not involve groundwater used as a source of public drinking water. Berkeley Lab received approval from the DTSC on March 29, 2006, for the *RCRA* (Resource Conservation and Recovery Act) *Corrective Measures Implementation (CMI) Workplan*,[7] and on September 1, 2006, for a *Soil Management Plan*[8] and a *Groundwater Monitoring and Management Plan*.[9] These plans describe the nature and extent of the contamination, the remedial measures to clean up the contaminants, and the institutional controls required to reduce potential risk from exposure to the contaminants. In addition, the *Groundwater Monitoring and Management Plan* provides the requirements for ongoing groundwater and surface water monitoring.

For more details on environmental monitoring conducted in 2006, see Chapter 4.

1 Introduction

Lawrence Berkeley National Laboratory (outlined) is located east of the University of California Berkeley campus

1.1 HISTORY

Lawrence Berkeley National Laboratory was founded by Ernest O. Lawrence in 1931. Lawrence received the 1939 Nobel Prize in physics for his invention of the cyclotron (particle accelerator); and he is generally credited with the modern concept of interdisciplinary science, in which scientists, engineers, and technicians from different fields work together on complex scientific projects addressing national needs and programs. Lawrence's pioneering work established a great tradition of scientific inquiry and discovery at the Laboratory. Eleven Nobelists have been associated with the Laboratory; the eleventh received the honor in 2006. Eighty-one of its current researchers are members of the National Academies,[1] which forms committees to advise the federal government and public.

The Laboratory supports work in such diverse fields as genomics, physical biosciences, nanoscience, life sciences, fundamental physics, accelerator physics and engineering, energy conservation technology, and materials science. Through its fundamental research in these fields, Berkeley Lab has achieved international recognition for its leadership and has made numerous contributions to national programs. Berkeley Lab's research embraces the following concepts to align with the United States Department of Energy (DOE) mission:

- Explore the complexity of energy and matter
- Advance the science needed to attain abundant clean energy
- Understand energy impacts on our living planet
- Provide extraordinary tools for multidisciplinary research

Since its beginning, Berkeley Lab has been managed by the University of California (UC) Office of the President. Numerous Berkeley Lab scientists are faculty members on the campuses of either UC Berkeley or UC San Francisco. They and other Berkeley Lab researchers guide the work of graduate students pursuing advanced degrees through research at the Laboratory. High school students and teachers, as well as college and graduate students, participate in many Berkeley Lab programs designed to enhance science education, which is part of the Laboratory mission.

1.2 LABORATORY SITE DESCRIPTION AND ENVIRONMENTAL SETTING

Sections 1.2.1 through 1.2.3 describe the physical location, population, space distribution, and water supply at Berkeley Lab. Sections 1.2.4 through 1.2.7 describe the Laboratory site's meteorology, vegetation, wildlife, geology, and hydrogeology.

1.2.1 Location

Berkeley Lab is located about 5 kilometers (km) (3 miles [mi]) east of San Francisco Bay (see Figure 1-1) on land owned by the University of California. The Laboratory's main site is situated on approximately 82

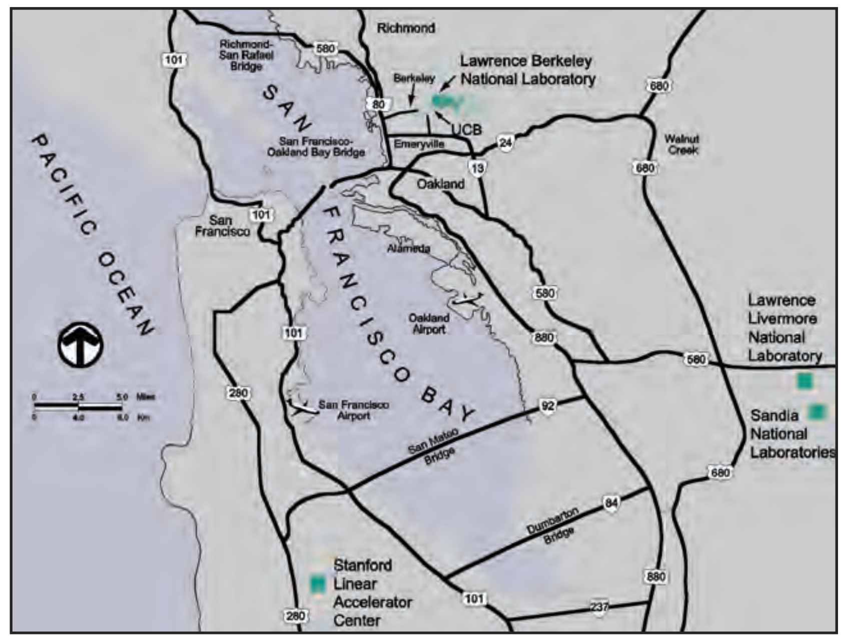


Figure 1-1 San Francisco Bay Area Map

hectares (202 acres) of this land. University of California provides long-term land leases to the DOE for the buildings at the Laboratory.

The main site lies in the hills above the UC Berkeley campus, on the ridges and draws of Blackberry Canyon (which forms the western part of the site) and adjacent Strawberry Canyon (which forms the eastern part of the site). Elevations across the site range from 135 to 350 meters (m) (450 to 1,150 feet [ft]) above sea level. The western portion of the site is in Berkeley, with the eastern portion in Oakland. The population of Berkeley is estimated at 102,743, and that of Oakland at 370,736.[2]

Adjacent land use consists of residential, institutional, and recreational areas (see Figure 1-2). The area to the south and east of the Laboratory, which is University land, is maintained largely in a natural state but includes UC Berkeley's Strawberry Canyon Recreational Area and Botanical Garden. Northeast of the Laboratory are the University's Lawrence Hall of Science, Space Sciences Laboratory, and Mathematical Sciences Research Institute. Berkeley Lab is bordered on the north by single-family homes and on the west by the UC Berkeley campus, as well as by multiunit dwellings, student residence halls, and private homes. The area to the west of Berkeley Lab is highly urbanized.

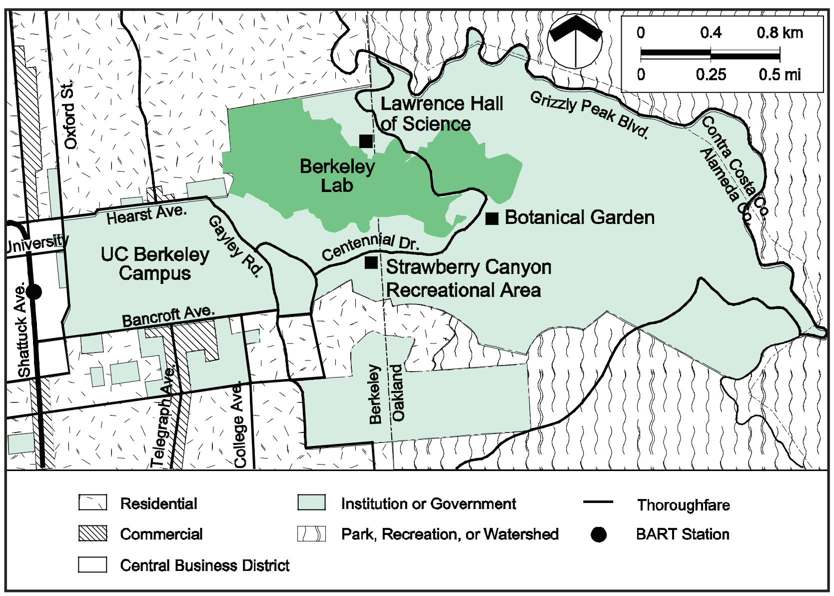


Figure 1-2 Adjacent Land Use

1.2.2 Population and Space Distribution

Approximately 3,000 scientists and support personnel and 1,400 students work at Berkeley Lab. In addition, the Laboratory hosts 4,200 participating guests each year, who use its unique scientific facilities for varying lengths of time. Berkeley Lab also supports 300 scientists and staff at off-site locations, including Walnut Creek, Oakland, Berkeley, and Washington, D.C. Approximately 300 of the Laboratory's scientists serve as faculty members at UC Berkeley and UC San Francisco.[3]

Berkeley Lab research and support activities are conducted in structures having a total area of 213,000 gross square meters (gsm) (2.29 million gross square feet [gsf]). About 79% of the total space is at the main site, about 5% is on the UC Berkeley campus (i.e., Donner and Calvin Laboratories), and the remaining approximate 16% is located in the various other off-site leased buildings. Figure 1-3 shows the Berkeley Lab space distribution.[3]

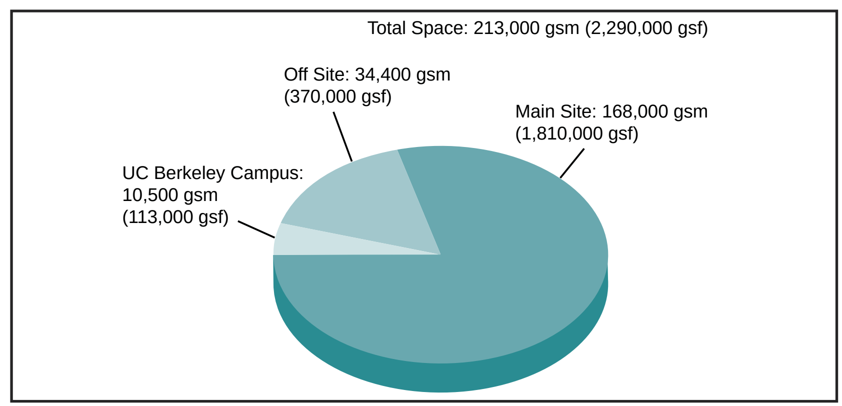


Figure 1-3 Space Distribution

1.2.3 Water Supply

All domestic water for the Laboratory's main site is supplied by the East Bay Municipal Utility District (EBMUD). The site has no drinking-water wells.

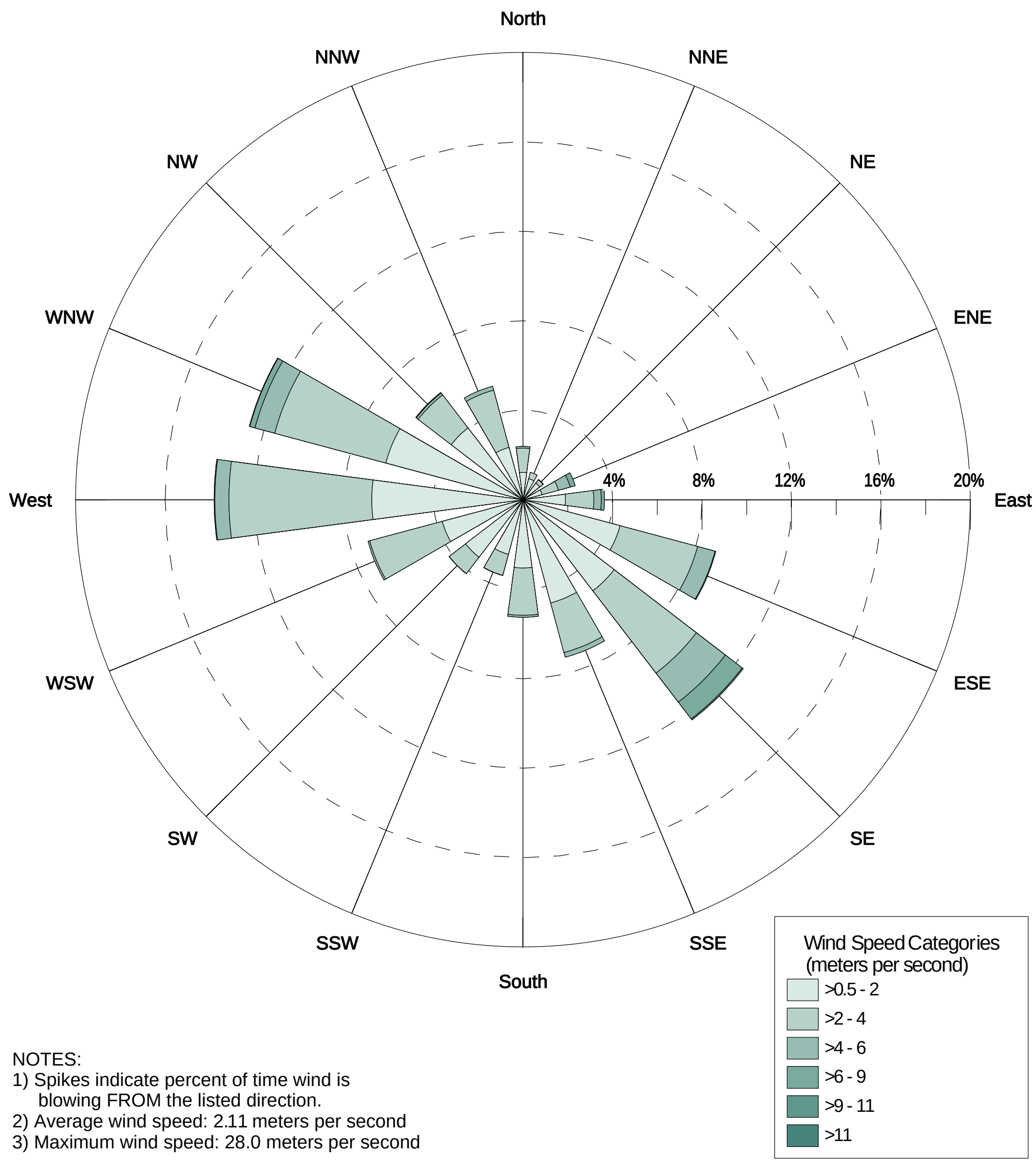
The domestic water originates in Sierra Nevada watershed lands and is transported to the Bay Area and ultimately to Berkeley Lab through a system of lakes, aqueducts, treatment plants, and pumping stations. EBMUD tests for contaminants and meets disinfection standards required by the Safe Drinking Water Act.[4]

1.2.4 Meteorology

The climate of the site is temperate, influenced by the moderating effects of nearby San Francisco Bay and the Pacific Ocean to the west, and on the east by the East Bay hills paralleling the eastern shore of this same bay. These physical barriers contribute significantly to the relatively warm, wet winters and cool, dry summers of the site. The average annual temperature at the site is about 13° Celsius (C) (55° Fahrenheit [F]). More than 90% of the time the temperature is in the range of 5° to 20°C (41° to 68°F). Seldom does the maximum temperature exceed 32°C (90°F) or the minimum temperature drop below 0°C (32°F).

The average annual precipitation stated in more than 30 years of Berkeley Lab records is greater than 78 centimeters (cm) (nearly 31 inches [in]) of rain for the season (October 1 to September 30). Measurable snow does not fall at Berkeley Lab. About 95% of the annual rainfall occurs between October and April; typically the wettest of these months are December through February.

On-site wind patterns change little from one year to the next. The most prevalent wind pattern occurs during fair weather, with daytime westerly winds blowing off the bay, followed by lighter nighttime southeasterly winds originating in the East Bay hills. The other predominant wind pattern is associated with storm systems passing through the region, which usually occur during the winter months. South-to-southeast winds in advance of each storm are followed by a shift to west or northwest winds after passage of the system. Figure 1-4, a graphical summary of the annual wind patterns (called a "wind rose"), illustrates the frequency of the two predominant wind patterns.



NOTES:
1) Spikes indicate percent of time wind is blowing FROM the listed direction.
2) Average wind speed: 2.11 meters per second
3) Maximum wind speed: 28.0 meters per second

Figure 1-4 Annual Wind Patterns

1.2.5 Vegetation

Vegetation on the Berkeley Lab site is a mixture of native plants, naturalized exotics, and ornamental species. The site was intensively grazed and farmed for approximately 150 years before the development of the Laboratory at this site in the 1930s. At the main site, the Laboratory manages on-site vegetation so that it is coordinated with the local natural succession of native plant communities. Berkeley Lab also works to maintain a wooded and savanna character in the areas surrounding buildings and roads. Ornamental species are generally restricted to public spaces and courtyards and to areas adjacent to buildings. The site has no rare, threatened, or endangered species of plants present. Figure 1-5 shows the vegetation types and locations on-site.

The Lab's main site is managed to minimize wildland fire damage to structures. The vegetation management program is designed to reduce the potential flame heights of groundcover vegetation to no more than 0.9 m (3 ft).

The following vegetation management is conducted annually:

- Cutting off tree limbs below a minimum of 1.8 to 2.4 m (6 to 8 ft) from the ground (depending on species)
- Cutting grasses to a maximum of 7.6 cm (3 in)
- Removing brush, except ornamental bushes, throughout the vegetation management area

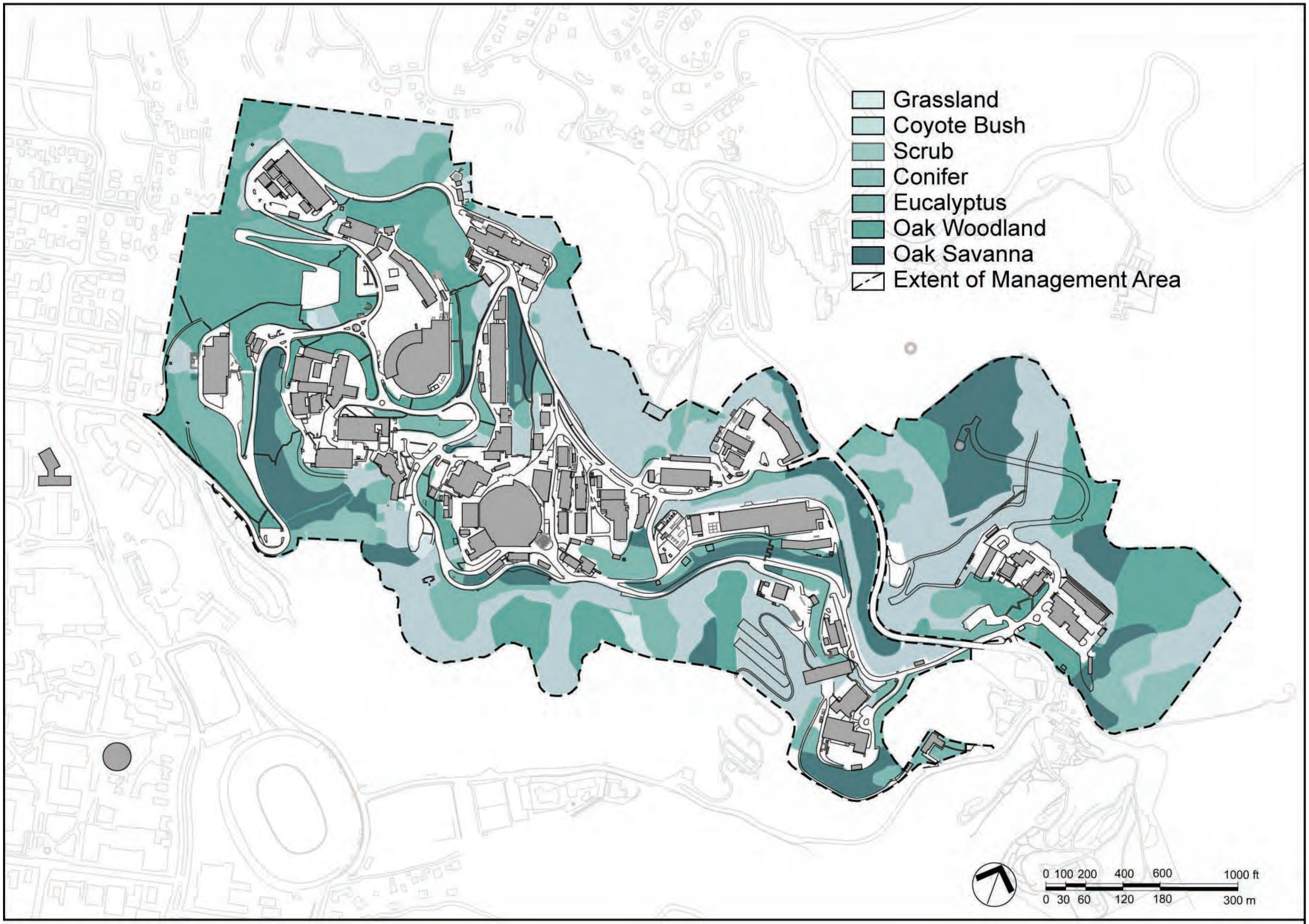


Figure 1-5 Vegetation Types (Map Revised 1999)

The purpose of these vegetation management (fuel reduction) efforts is to substantially reduce the intensity of any future fire storm. As a result, Laboratory buildings would more likely survive such a fire, and the lower-intensity fire conditions at the Laboratory would allow regional fire fighters to suppress the flame front so that it would not proceed to the west of the Laboratory.

Berkeley Lab also works with the Hills Emergency Forum (comprised of representatives from the neighboring cities of Berkeley and Oakland, the East Bay Regional Park District, EBMUD, and UC Berkeley) to improve vegetation management of the urban-wildland interface in the areas adjacent to the Laboratory.

1.2.6 Wildlife

Wildlife is abundant in the area surrounding Berkeley Lab because the site is adjacent to open spaces managed by the East Bay Regional Park District and the University of California. Wildlife that frequents the Laboratory site is typical of wildlife in disturbed (e.g., previously grazed) areas that have a Mediterranean climate and are located in midlatitude California. More than 120 species of birds, mammals, and reptiles/amphibians are thought to exist on the site. The most abundant large mammal is the Columbian black-tailed deer.

1.2.6.1 Protected Habitats

Lee's Micro-Blind Harvestman *(Microcina Leei)* is listed as threatened under both federal and state law. This arachnid was first identified on the main site in the 1960s and again in the 1980s. An area of the Laboratory on the south-facing slope of Blackberry Canyon has been identified as the type of locality where the species occurs. This area consists of a dense canopy of oak-bay woodland with undisturbed sandstone rocks that are embedded in the soil and have moist conditions underneath.[3]

The Alameda Whipsnake *(Masticophis lateralis euryxanthus)* is listed as threatened under both federal and state law and is found in open-canopied shrub communities, including coastal scrub and chaparral, and adjacent habitats including oak woodland, savanna, and grassland areas. The eastern portion of the site is an area of potential Whipsnake habitat.[3]

A number of drainages exist on the main site; some are ephemeral or intermittent, and others—such as the North Fork of Strawberry Creek, Chicken Creek, and their tributaries—are considered "jurisdictional" under the Clean Water Act and thus warrant special attention. According to the California Department of Fish and Game, these jurisdictional drainages, along with four freshwater seeps, support riparian habitat.[3]

1.2.7 Geology and Hydrogeology

Three geologic formations underlie the majority of the site. These formations and their properties are described below:

1. The western and southern parts of Berkeley Lab are underlain by marine siltstones and shales of the Great Valley Group. It consists primarily of low-permeability rock with moderately spaced open fractures that allow for groundwater movement. The hydraulic conductivity (measure of the rate at which water can move through a permeable medium) ranges between approximately 10^{-5} and 10^{-8} meters per second (m/s) (3.3×10^{-5} and 3.3×10^{-8} feet per second [ft/s]).
2. River-deposited sediments of the Orinda Formation overlie the Great Valley Group and underlie most of the developed area of the site. The Orinda Formation consists primarily of low-permeability rock with closed fractures that inhibit groundwater movement. The hydraulic conductivity generally ranges between approximately 10^{-7} and 10^{-12} m/s (3.3×10^{-7} and 3.3×10^{-12} ft/s), although the hydraulic conductivity may be greater where coarser materials are present. The

Orinda Formation typically has lower values of hydraulic conductivity than the underlying Great Valley Group or overlying Moraga Formation, and therefore it impedes the horizontal and vertical flow of groundwater.

3. Ancient landslide deposits from the Moraga Formation underlie most of the higher elevations of Berkeley Lab, as well as much of the central developed area ("Old Town"). These deposits constitute the main water-bearing unit at Berkeley Lab. The hydraulic conductivity of the Moraga Formation is relatively high, generally ranging between 10^{-4} and 10^{-6} m/s (3.3×10^{-4} and 3.3×10^{-6} ft/s). Although the permeability of the rock matrix is low, groundwater flows readily through the numerous open fractures. The presence of low-permeability interbeds of fine-grained sediments, as well as zones with little fracturing, creates perched water conditions at many locations.

The Claremont Formation and San Pablo Group underlie the easternmost area of the site. The Claremont Formation consists of chert and shale. The San Pablo Group consists of marine sandstones.

The surficial geology consists primarily of colluvium and fill. Weathered detritus from the bedrock units has accumulated as soil deposits, generally from one to several meters thick. Because of the hilly terrain, up to tens of meters of cuts and fills have been necessary to provide suitable building sites.

The active Hayward Fault, a branch of the San Andreas Fault System, trends northwest to southeast along the base of the hills at Berkeley Lab's western edge. The inactive Wildcat Fault traverses the site north to south along the canyon at the Laboratory's eastern edge. In addition to the faulting, landsliding and tilting of the rock units underlying the site have helped to develop a complex geological structure.

Groundwater is a concern at the Laboratory because of its potential effect on slope stability and on the underground movement of contaminants (see Section 4.4). The water table depths vary from approximately 0 to 30 m (100 ft) below the surface across the site. During the past 20 years, the Laboratory has carried out a successful program of slope stabilization to reduce the risk of property damage caused by soil movement. This program includes construction of subsurface drain lines (hydraugers), vegetation cover, and soil retention structures.

2 Performance-Based Environmental Management System

Berkeley Lab's Molecular Foundry Building designed to meet the Leadership in Energy and Environmental Design silver standard

2.1 SUMMARY

To continually improve environmental stewardship, Berkeley Lab has established a performance-based Environmental Management System (EMS)—a systematic approach to ensuring that environmental activities are well managed and provide business value. This approach includes those components of the ISO 14001 EMS[1] standard that provide the most value—which allows the Laboratory to focus resources on those activities that have important environmental benefits, while maintaining and building on the strengths of the current environmental compliance programs. The goals of the Laboratory's EMS are the following:

- Compliance with applicable environmental and public health laws and regulations
- Prevention of pollution and conservation of natural resources
- Continual improvement of the Laboratory's environmental performance

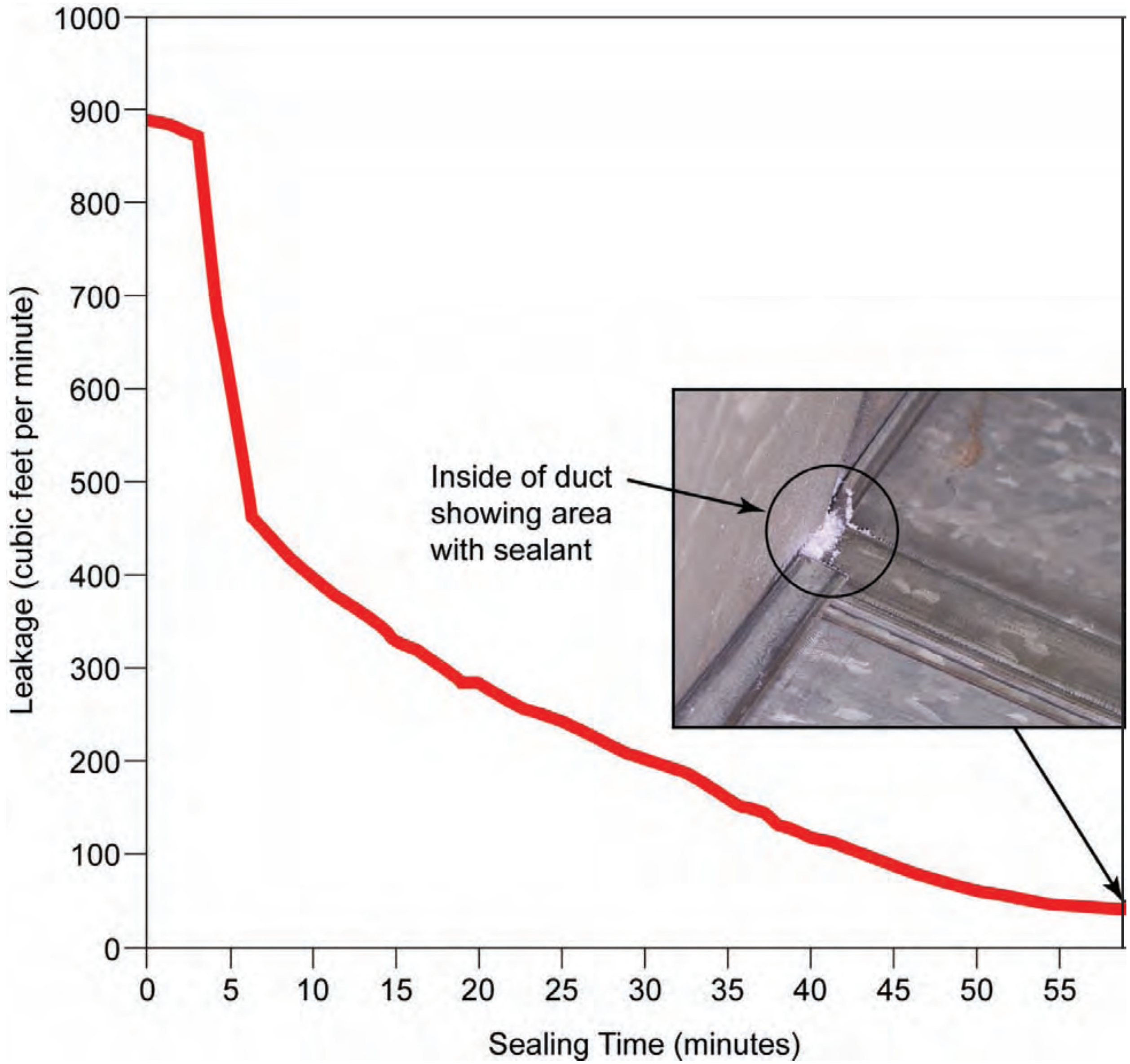
United States Executive Order 13148, *Greening the Government through Leadership in Environmental Management*,[2] required all federal agencies to implement an EMS by December 31, 2005. DOE Order 450.1, *Environmental Protection Program*,[3] established the EMS requirement for all DOE facilities and mandated that the EMS be integrated with existing Integrated Safety Management (ISM) systems. In a letter dated December 28, 2005, the DOE Berkeley site manager notified the director of the Office of Science that the Berkeley Lab EMS conforms to DOE Order 450.1.

In 2006, an EMS Core Team—composed of representatives from Berkeley Lab's Environment, Health, and Safety (EH&S), Facilities, and Procurement organizations—continued the annual cycle of implementing the following tasks:

- **Identification of aspects and impacts**. Environmental aspects (activities or services that may produce a change to the environment) resulting from Laboratory operations were reviewed. The environmental impacts associated with each aspect also were reviewed, and a determination was made regarding its environmental significance.
- **Development of objectives and targets**. Nine activities were determined to be significant, and objectives and targets were developed for reducing their environmental impacts:
    1. Chemical use at Building 37 cooling tower
    2. Commute traffic to and from Laboratory
    3. Diesel particulate matter (DPM) emissions
    4. Electrical and gas use at Building 6

Reductions in fleet petroleum were largely due to the use of E85 fuel (15% unleaded and 85% ethanol) by the majority of LBNL's vehicle fleet

A nonchemical (Dolphin) water treatment system was installed at the Building 37 cooling tower, which eliminated use of chemicals to control biological fouling, scale, and corrosion



A process developed by LBNL's Environmental Energy Technologies Division was used to seal the HVAC ducts at Buildings 50A and 70 to reduce electrical and natural gas use. Graph shows reductions in duct leaks after application of sealant.

5. Heating, ventilation, and air-conditioning (HVAC) at Buildings 50A and 70
6. Procurement of environmentally preferable goods and services
7. Sitewide electricity use
8. Sitewide natural gas use
9. Vehicle fleet petroleum use

- **Preparation of Environmental Management Programs (EMPs)**. Nine EMPs were prepared that summarize how the objectives and targets will be achieved, including actions, target deadlines, and personnel responsible for implementing the appropriate actions.
- **Assessments**. The EMS program was reviewed by Berkeley Lab's Office of Contract Assurance (OCA). The assessment determined that the EMPs were successful at reducing environmental impacts and that most activities were performed to the satisfaction of the EMS Plan and the corresponding procedures. Two oversights were found regarding EMS Core Team participation in the annual aspects and impacts review and training of a Core Team staff member.

2.2 BACKGROUND

Neither Executive Order 13148 nor DOE Order 450.1 required that the organization's EMS meet a recognized standard, such as the ISO 14001 standard for EMSs. So, in 2002, before Berkeley Lab had developed its EMS approach, an analysis was performed to identify whether gaps existed between then-current programs and systems and each element required by an ISO 14001 EMS. Relevant Berkeley Lab documents were reviewed, and appropriate program managers were interviewed. The results from the analysis indicated where deficiencies existed for each element. Potential actions required to address each gap were identified, and each element was evaluated for its significance in assuring environmental compliance and improving environmental performance.

As a result, Berkeley Lab developed and implemented a performance-based EMS—a systematic approach to ensuring that environmental stewardship activities are not only well managed but also provide business value. Accordingly, the EMS was based on the work, the environment in which the work is performed, and the hazards or risks associated with the work at the Laboratory. The performance-based approach includes those components of ISO 14001 that provide the most value—rather than simply all the components of an ISO 14001–type of EMS, regardless of value. This approach allows Berkeley Lab to focus resources on those activities that have a greater environmental benefit and to maintain the current strengths of the environmental compliance programs.

A system was established that incorporated an annual cycle of planning, implementing, evaluating, and improving processes and actions to achieve the EMS goals (see Figure 2-1).

Berkeley Lab's EMS program was documented in the *Performance-Based Environmental Management System Plan*.[4] This document, as well as other EMS-related documentation, is available at the following Web site: http://www.lbl.gov/ehs/esg/emsplan/emsplan.htm.

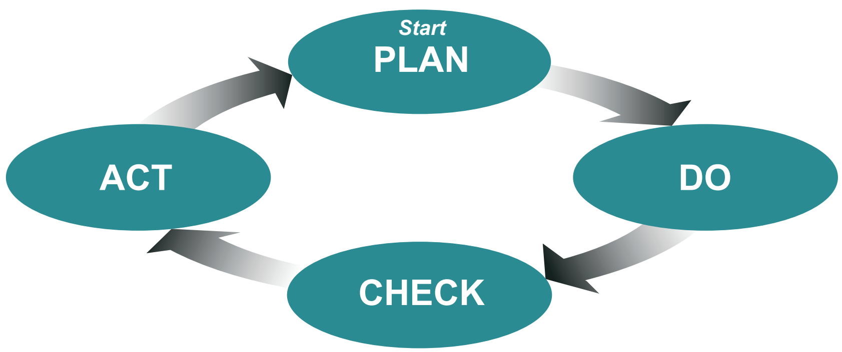


Figure 2-1 Cycle of Activities That Are Performed to Achieve EMS Goals

2.3 INTEGRATION OF EMS INTO ISM

The EMS has been integrated with the Laboratory's ISM system. To the extent that it has been practical, ISM processes have been used to support environmental performance improvement and compliance management. Where it has been impractical, new processes were developed to support the EMS and were integrated with the ISM.

Both the EMS and ISM strive for continual improvement, through a plan-do-check-act cycle. This cycle calls for defining the scope and purpose of the system, followed by a planning *(plan)* step to develop programs and procedures that must then be implemented *(do)*. Once implemented, programs must be assessed *(check)* and any problems corrected *(act)* to improve the effectiveness of the management system and to achieve improved environment, safety, and health performance.

2.4 IMPLEMENTATION

The following six areas are key to the implementation of the Laboratory's performance-based EMS program:

1. EMS Core Team
2. Environmental aspects
3. EMPs
4. Training
5. Appraisals
6. Management review

Each of these fundamental areas is described below.

2.4.1 EMS Core Team

The Core Team has been established to design, implement, and maintain an EMS to manage environmental compliance matters and to reduce environmental impacts over time. It consists of key representatives from the EH&S, Facilities, and Procurement organizations that are most knowledgeable of environmental management concerns; and the team is led by a representative of the EH&S organization. As issues arise, other organizations are consulted or brought into the team; similarly, input from other groups (e.g., the Laboratory's Safety Review Committee or Division Safety Coordinators) is solicited through designated Core Team representatives. A representative from the DOE Berkeley Site Office also attends the meetings, to maintain an operational awareness of the EMS Core Team activities. The following are some of the primary functions of the Core Team:

- Identification of environmental aspects
- Determination of significant impacts
- Development of objectives and targets for the significant aspects
- Preparation and implementation of the EMPs
- Evaluation of all EMPs annually
- Coordination of internal assessments of the EMS
- Review of performance results
- Preparation of recommendations to management on improvements to the EMS
- Coordination of the annual management review of the EMS
- Coordination of internal communications about the EMS

2.4.2 Environmental Aspects

Each year the Core Team identifies environmental aspects: activities or services that may produce a change to the environment—whether adverse or beneficial—resulting from Berkeley Lab operations. In addition, the Core Team determines the significance of each aspect's potential impact, using the following factors to shape its decisions:

- Severity of impact
- Duration of impact

- Probability of occurrence
- Cost of addressing impact
- Effect on public image
- Effect on Laboratory mission
- Potential legal exposure
- Potential for improvement

Each impact is given a numeric rating based on a three-tiered scoring system: high (3), medium (2), and low (1). Average scores and overall ratings for each impact are determined and used to provide a starting point for the significance determination. Before this list is finalized, the Core Team and other related employees perform further evaluations of these identified aspects and impacts before a determination of significance is finalized.

2.4.3 Environmental Management Programs

Each significant aspect selected by the Core Team has objectives and targets assigned to reduce or improve the associated environmental impacts. These are formally documented in an EMP. An EMP establishes goals and strategies, actions to achieve goals, and resource needs; develops procedures, metrics, or techniques; and sets up schedules. An EMP leader is selected from the Core Team members to monitor the performance of each EMP.

2.4.4 Training

In Berkeley Lab's EMS approach, training is targeted and graded, commensurate with the EMS activity. There are four types of training:

1. General EMS awareness
2. Comprehensive EMS awareness
3. EMS implementation
4. EMS auditor

2.4.5 Appraisals

The internal assessments of the EMS program and activities are performed annually. The review will determine whether the EMS activities conform to the requirements of the Laboratory's EMS program plan and whether it has been properly implemented and maintained. Suggestions will be made for corrective action and opportunities for improvement. Additionally, the assessor may review the performance of the EMPs. The results of the internal assessment will be presented to a Berkeley Lab senior management team during the annual management review meeting. In addition, on a three-year cycle, a third-party auditor will be retained to determine whether the Laboratory's EMS activities conform to the requirements of the EMS Plan and whether it has been properly implemented and maintained. Representatives from DOE will be invited to participate as observers on the audit. The results of the validation audit also will be presented to a Berkeley Lab management team at the next normally scheduled management review session. A special management review may be convened if the validation audit determines that there are any significant weaknesses in the program. All significant findings will be tracked using the Laboratory's Corrective Action Tracking System.

2.4.6 Management Review

The status of the EMS is reviewed annually by a Berkeley Lab senior management team as appropriate for the activities involved. The review includes progress in achieving EMS objectives and targets, as well as the results of EMS internal and external reviews. Based on this review, the Laboratory's management may determine changes needed in the EMS program: factors such as improved assessment methodologies or major changes to the facility's mission, products, and processes are considered in determining the need for changes.

2.5 2006 ENVIRONMENTAL MANAGEMENT PROGRAMS

Based on the EMS Core Team's review of environmental aspects and impacts, nine areas were identified for potential improvement. In each case, objectives and targets were developed and an EMP established to improve the Laboratory's environmental performance in the specific area. Table 2-2 summarizes the projects that were undertaken in 2006.

2.6 ENVIRONMENTAL MANAGEMENT PROGRAMS FOR 2007

Consistent with the goal of continual progress, Berkeley Lab performs an annual review of its environmental aspects and impacts. Areas for environmental improvement are also reassessed annually based on this review. As a result, the set of EMPs will likely change as existing ones are completed, discontinued, or modified, and as new ones are added. For 2007, three areas have been targeted for further improvements, and four additional areas are currently under consideration for improvement:

Existing EMPs

1. DPM Emissions Reduction
2. Fleet Petroleum Use Reduction
3. Increase of Procurement of Environmentally Preferable Goods and Services

Potential EMPs

1. Energy Use Reduction Measures
2. Sanitary Waste Generation Reduction
3. Traffic Congestion Reduction
4. Water Use Conservation Measures

Table 2-2 Environmental Management System Projects Undertaken in 2006

Project	Objective	Accomplishment(s)
Fleet Petroleum Use	Maintain vehicle fleet petroleum use below 20% of fiscal year (FY) 1999 levels	Tracked fuel usage and implemented reduction strategies including replacing light trucks with sedans, replacing high-mileage vehicles with alternative fuel vehicles (AFV), and acquiring AFV or fuel-efficient vehicles. 2006 petroleum fuel use was 35% less than the 1999 baseline year.
Diesel Particulate Matter (DPM)	Reduce DPM emissions 5% per year	Calculated DPM emissions from mobile and stationary sources using calendar year 2005 as a baseline year. DPM emissions were reduced by streamlining operations and maintenance to ~53% for stationary and ~25% for mobile sources.
Electricity Use	Reduce electricity use site-wide	Implemented measures to conserve electricity, including an awareness program and adjustment of lighting, HVAC units, and chillers. Reduced electricity use ~1.7%.
Natural Gas Use	Reduce natural gas use site-wide	Implemented measures to conserve natural gas by reducing hot water temperatures, lowering indoor heating temperatures, optimizing thermostat controls and boiler combustion efficiencies. Reduced natural gas use ~15.6%.
Seal HVAC Ducts	Reduce electrical and natural gas use at Buildings 50A and 70	Used a process developed by one of LBNL's research divisions to seal HVAC ducts at Buildings 50A and 70.
Environmentally Preferable Purchasing	Increase procurement of Energy Star Products and Recycled Content Products (RCP)	Developed green purchasing policies and procedures to increase purchases of RCP. RCP procurements improved from ~25% in FY 2005 to ~52% in FY 2006.
Cooling Tower Water Treatment System	Reduce water and chemical use in cooling tower at Building 37	Installed a nonchemical (Dolphin) water treatment system at the Building 37 cooling tower. Reduced chemical use by ~$7,000 per year.
Building Energy-Use Study	Conduct a study to reduce electrical and natural gas use at Building 6	Conducted a retro-commissioning study to identify projects for reducing electrical and natural gas use at Building 6.
Commute Traffic Study	Conduct a study to reduce Laboratory commute traffic	Conducted a ridership survey to identify potential areas of improvement in the Laboratory bus system and use of mass transit.

3 Environmental Program Summary

Lawn area between Buildings 4 and 25

3.1 INTRODUCTION

This chapter provides an overview of Lawrence Berkeley National Laboratory's environmental protection program, reviews the status of various compliance programs and activities, and presents measures of the Laboratory's environmental performance in key areas for 2006.

3.2 OVERVIEW OF ENVIRONMENTAL RESPONSIBILITIES

To provide the highest degree of protection for the public and the environment, Berkeley Lab applies the principles of ISM to Laboratory activities. This involves the performance of five core functions (http://www.lbl.gov/ehs/pub811/principles.html):[1]

- Work Planning. Clear definition of the tasks that are to be accomplished as part of any given activity.
- Hazard and Risk Analysis. Analysis and determination of the hazards and risks associated with any activity; in particular, risks to employees, the public, and the environment.
- Establishment of Controls. Controls that are sufficient to reduce the risks associated with any activity to acceptable levels. Acceptable levels are determined by responsible line management, but are always in conformance with all applicable laws and Work Smart Standards.
- Work Performance. Conduct of the tasks to accomplish the activity in accordance with the established controls.
- Feedback and Improvement. Implementation of a continuous improvement cycle for the activity, including incorporation of employee suggestions, lessons learned, and employee and community outreach, as appropriate.

The EH&S Division at Berkeley Lab is responsible for administering environmental protection and compliance programs at the Laboratory. The organizational structure of EH&S as of the end of 2006 is shown in Figure 3-1.

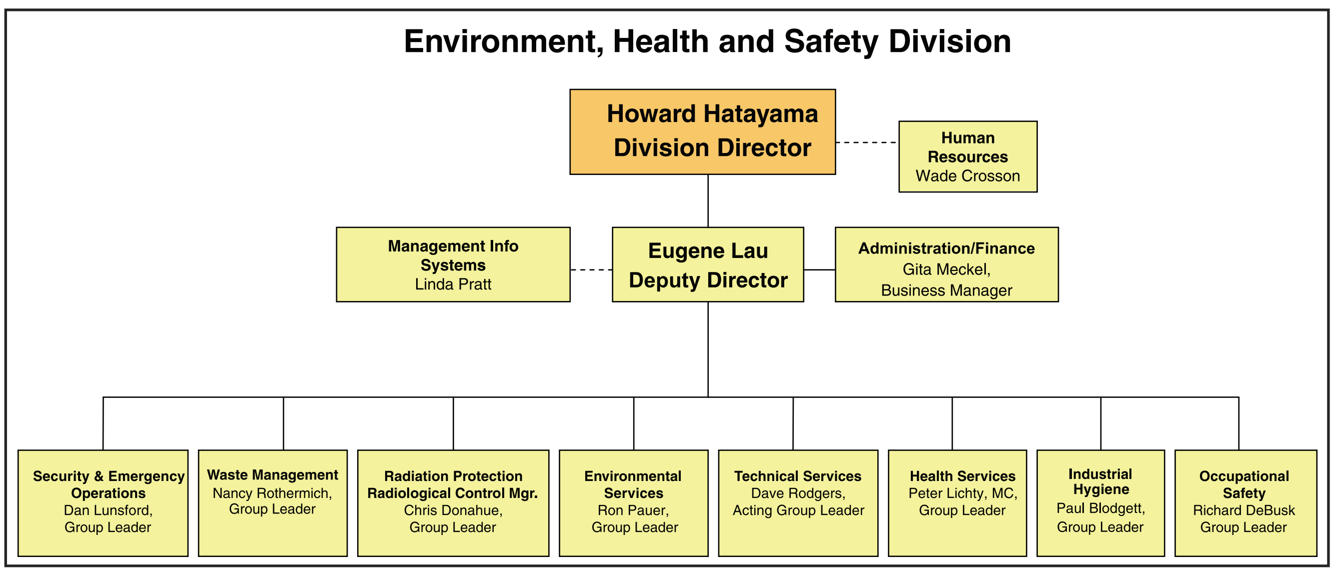


Figure 3-1 Berkeley Lab Environment, Health, and Safety Division Organization in 2006

Environmental protection programs are largely administered by two EH&S organizations:

1. The Environmental Services Group (ESG) oversees sitewide air and water quality compliance activities, provides technical assistance to Laboratory staff, and manages environmental characterization and cleanup. These programs include environmental monitoring activities that provide information critical to demonstrating compliance and making programmatic decisions. (For monitoring result summaries, see Chapter 4.)
2. The Waste Management Group manages hazardous, medical, radioactive, mixed (hazardous and radioactive), and universal waste generated at the Laboratory.

3.2.1 Environmental Management System

To continually improve environmental performance, Executive Order 13148[2] required all federal agencies to implement an EMS by December 31, 2005. An EMS is a systematic approach to achieving environmental goals. DOE Order 450.1[3] established the EMS requirement for all DOE facilities and, in addition, mandated that the EMS be integrated with existing ISM systems.

Berkeley Lab has established a performance-based EMS—a systematic approach to ensuring that environmental stewardship activities are well managed and provide business value. For details on the performance-based EMS, see Chapter 2.

3.3 PROGRAM SUMMARY

The following sections discuss environmental permits, audits, inspections, and DOE-reportable environmental incidents at Berkeley Lab for CY 2006.

3.3.1 Summary of Environmental Permits

Some Berkeley Lab activities require operating permits from environmental regulatory agencies. Table 3-1 summarizes, by area of environmental activity, the 47 active permits held by the Laboratory at the end of the year.

Table 3-1 Environmental Permits Held by Berkeley Lab at the End of 2006

Type of permit	Issuing agency	Description	Number of permits	Section for more information
Air quality	BAAQMD[a]	Various activities with emissions to air	34	3.4.1.2
Hazardous waste	DTSC[b]	Hazardous Waste Handling Facility operations	1	3.4.6.1
	City of Berkeley	Fixed treatment units (5)	1	3.4.6.1
Stormwater	SWRCB[c]	Sitewide stormwater discharges	1	3.4.10.2
Underground storage tanks	City of Berkeley	Underground storage tanks containing petroleum products	6	3.4.10.4
Wastewater	EBMUD[d]	Sitewide and operation-specific wastewater discharges to sanitary sewer	3	3.4.10.1
	CCCSD[e]	Wastewater discharges to sanitary sewer at Joint Genome Institute in Walnut Creek	1	3.4.10.1

[a] Bay Area Air Quality Management District
[b] Department of Toxic Substances Control
[c] State Water Resources Control Board
[d] East Bay Municipal Utility District
[e] Central Contra Costa Sanitary District

3.3.2 Summary of Audits and Inspections

The agencies that regulate the environmental programs at Berkeley Lab periodically inspect the Laboratory. Table 3-2 lists the inspections by these agencies that occurred at Berkeley Lab during the year. The two violations issued by the Department of Toxic Substances Control (DTSC) were received in 2006 as a result of an inspection conducted in 2005. Table 3-2 includes self-monitoring inspections conducted by Berkeley Lab that are required by EBMUD wastewater discharge permits because these activities expose the Laboratory to potential regulatory violations.

3.3.3 Summary of DOE-Reportable Environmental Incidents

Two environmental incidents were reportable under the DOE occurrence-reporting program,[4] which is used to track incidents across the DOE complex:

1. In March 2006, the final report from the June 2005 DTSC inspection of the Hazardous Waste Handling Facility (HWHF) was received and cited two Class II violations. The first violation cited LBNL for failing to provide Hazardous Waste Operations and Emergency Response Supervisor training for a Technician Specialist. This training was completed shortly after the inspection in 2005. The second violation cited LBNL for failing to notify DTSC when two new job titles were created (Radioactive/Mixed Technical Lead and Hazardous Waste Technical Lead). The Laboratory submitted a permit modification shortly after the DTSC inspection.
2. In March 2006, a drum of asbestos wastes described as "mastic" and "mastic remover solid" was transported on-site to the HWHF. The contents subsequently were discovered as being liquid rather than solid. The waste was removed from the pending shipment and was shipped as a liquid.

Table 3-2 Environmental Audits, Inspections, and Appraisals in Calendar Year 2006

Organization	Inspection title	Start date	Length[a] (days)	Violations
City of Berkeley	Underground storage tanks	October 30	1	0
DTSC	Inspection of Hazardous Waste Handling Facility	May 23	2	2[b]
EBMUD	Wastewater monitoring inspection at Hearst and Strawberry outfalls	June 28 December 7	1 1	0 0
	Wastewater monitoring inspection at B25 treatment unit	February 8 April 5 November 14	1 1 1	0 0 0
	Wastewater monitoring inspection at B77 treatment unit	January 25 March 22 November 8	1 1 1	0 0 0
	Wastewater monitoring inspection at groundwater treatment units	February 15 July 20	1 1	0 0
LBNL	EBMUD self-monitoring inspections at Hearst and Strawberry outfalls	June 13 November 14	1 1	0 0
	EBMUD self-monitoring inspections at B77 treatment unit	April 24 June 19 November 14	1 1 1	0 0 0
	EBMUD self-monitoring inspections at B25 treatment unit	May 10 June 20	1 1	0 0
	EBMUD self-monitoring inspections at groundwater treatment units	February 3 April 6 June 2 August 3 October 2 December 12	1 1 1 1 1 1	0 0 0 0 0 0

[a] A portion of a day is tabulated as one day.

[b] Two violations were received in 2006 as a result of a DTSC inspection in 2005.

Berkeley Lab was issued a Consent Order and fine of $28,000 in March 2007 by DTSC for hazardous waste violations that resulted from inspections between 2003 and 2005. These violations were discussed in previous Site Environmental Reports. Specifically, the Laboratory was fined for accepting hazardous waste from off-site, in this case from Building 903, and transporting hazardous materials to the 903 warehouse, which is not authorized to accept hazardous waste. The Laboratory also was fined for holding hazardous waste in a Satellite Accumulation Area for more than one year, which is a California Health and Safety Code violation. Berkeley Lab corrected the violations at the time they were issued and continues to work to prevent additional noncompliance issues. DTSC has acknowledged that all terms and conditions of the Consent Order were met.

3.4 COMPLIANCE PROGRAMS

The following sections provide individual summaries of the environmental compliance programs at Berkeley Lab.

3.4.1 Clean Air Act

The Clean Air Act[5] is the key statutory reference for federal, state, and local air pollution control programs. It classifies air pollutants into these main categories:

- Criteria air pollutants (e.g., carbon monoxide, nitrogen oxides, particulate matter)
- Hazardous air pollutants (e.g., radionuclides, air toxics)
- Ozone-depleting substances (e.g., chlorofluorocarbons or Freons)

The State of California's air pollution control program[6] gives it additional powers to regulate sources of air emissions.

Berkeley Lab divides its air quality protection and compliance activities into two categories: radiological (see Section 3.4.1.1) and nonradiological (see Section 3.4.1.2).

3.4.1.1 Radiological

Radionuclides released to the atmosphere from Laboratory research activities must adhere to NESHAP regulations (40 CFR 61, Subpart H *[National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities*[7]*]*), as well as sections of DOE Order 5400.5, *Radiation Protection of the Public and the Environment*.[8] The United States Environmental Protection Agency (US/EPA) administers the NESHAP regulations, which limit the dose to the public from the Laboratory's airborne radionuclide emissions to 0.10 millisievert per year (mSv/yr) (10 millirem per year [10 mrem/yr]). The Laboratory documents its NESHAP review and compliance at http://www.lbl.gov/ehs/esg/tableforreports/tableforreports.htm.

3.4.1.2 Nonradiological

The Bay Area Air Quality Management District (BAAQMD) implements federal and state air quality requirements for most air emission activities that are not addressed by NESHAP regulations.

At the end of 2006, Berkeley Lab held operating permits issued by BAAQMD for 34 activities,[9] which is one less permit than the preceding year. Two of these operating permits cover activities located at the Production Genomics Facility in Walnut Creek, California. This facility is part of the Joint Genome Institute (JGI), a collaboration involving Berkeley Lab, Lawrence Livermore National Laboratory, and Los Alamos National Laboratory research groups. One permit, for the soil-vapor extraction system near Building 7, was no longer required and was canceled. For a list of active operating permits, see Table 3-3.

Operating permits are renewed annually, at which time BAAQMD also requests information required by the state's Air Toxics "Hot Spots" Information and Assessment Act of 1987.[10] Activities covered by permits are subject to periodic inspection. BAAQMD did not conduct any such inspections during this reporting period.

Table 3-3 Air Emission Sources Permitted by BAAQMD[a] at the End of 2006

BAAQMD category	Description	Building	Abatement type
Combustion equipment	Standby emergency generators	64, 70	Catalytic converter
	Standby emergency generators	67	Diesel particulate filter
	Standby emergency generators	Various [b]	None
	Standby emergency generators	JGI [c]	None
Gasoline dispensing	Unleaded and E85 fueling stations	76	Vapor recovery
Surface coating and painting	Paint spray booth	76, 77	Dry filter
	Epoxy-mixing hood	53	None
Surface preparation and cleaning	Sandblast booth	77	Baghouse
	Vapor degreaser	25	Chiller
	Wipe-cleaning	Sitewide	None
Miscellaneous	Soil-vapor extraction systems	7E, 58	Activated carbon

[a] Bay Area Air Quality Management District

[b] Individual generators located at Buildings 2, 37, 48, 50A, 50B, 55, 62, 64, 66, 70A, 72, 74, 75, 77, 84B, and 85, plus four mobile locations

[c] Two generators located at the Joint Genome Institute in Walnut Creek, California

Berkeley Lab continued operating its E85-fuel dispensing facility at the Building 76 Motor Pool under a research-and-development test-site authorization and permit from the California Air Resources Board (CARB) and BAAQMD, respectively. E85 fuel is a mixture of 85% ethanol and 15% unleaded gasoline. Federal mandates require that Berkeley Lab both increase the percentage of vehicles using alternative fuels and decrease the amount of petroleum used according to a given time schedule. Both BAAQMD and CARB have placed an operating condition upon this fueling station that the Laboratory perform quarterly testing of the system's vapor recovery components. Such aggressive testing is needed to provide data that will speed up the availability of CARB-certified E85-fuel dispensing equipment to the entire California marketplace. Berkeley Lab remains one of only five sites in all of California authorized to dispense this alternative fuel.

3.4.2 Environmental Restoration (Comprehensive Environmental Response, Compensation, and Liability Act of 1980; Resource Conservation and Recovery Act Corrective Action Program)

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)[11] authorizes the US/EPA to manage the cleanup of abandoned or uncontrolled hazardous waste sites. In 2006 no releases occurred that were reportable under CERCLA, and Berkeley Lab conducted no remedial activities related to CERCLA. Berkeley Lab continued, however, to investigate and remediate areas of soil and groundwater contamination at the site under the requirements of the Corrective Action Program (CAP) of the Resource Conservation and Recovery Act of 1976 (RCRA).[12] Because these actions relate primarily to the protection of groundwater, they are described in Section 4.4.

3.4.3 Emergency Planning and Community Right-to-Know Act

The Emergency Planning and Community Right-to-Know Act (EPCRA) was passed in 1986 as Title III of the Superfund Amendments and Reauthorization Act (SARA).[13] The Act 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.[14] Berkeley Lab activities addressing these requirements are summarized in Sections 3.4.3.1 through 3.4.3.3.

3.4.3.1 Toxic Release Inventory

Under Executive Order 13148,[2] DOE is required to evaluate its facilities against the Toxic Release Inventory (TRI) reporting requirements of EPCRA without regard to SIC code. TRI reporting consists of two steps: Berkeley Lab determines chemical usage; and if threshold quantities are exceeded, DOE submits US/EPA Form R.

Berkeley Lab determined that no chemical usage in 2006 exceeded the TRI criterion of 4,536 kilograms (kg) (10,000 pounds [lb]) for a listed substance and that DOE was not required to submit a Form R on behalf of the Laboratory. Table 3-4 shows the highest usage levels of the chemicals from the Laboratory's assessments over the past several years.

Table 3-4 Trends in Highest Quantities of EPCRA[a] Toxic Release Inventory Reporting (in Kilograms[b])

Substance	2002	2003	2004	2005	2006
Chlorofluorocarbons	164	61	72	126	123
Methanol	322	228	206	129	165
Nitric acid	778	582	511	466	403
1,1,1-trichloroethane	<1	7	<1	0	<1

[a] Emergency Planning and Community Right-to-Know Act
[b] 1 kg = 2.2 lb

In 2002, US/EPA lowered reporting thresholds for 18 chemicals and chemical categories that meet the EPCRA Section 313 criteria for persistence, bioaccumulation, and toxicity (PBT). The thresholds were lowered to 45.5 kg (100 lb) for PBT chemicals and 4.5 kg (10 lb) for highly PBT chemicals. In June 2006, Berkeley Lab performed a sitewide survey on all 18 PBT chemicals and chemical categories for which reporting thresholds had been lowered. It was found that the PBT chemicals either were not present at Berkeley Lab or they were used in research experiments; hence the use of the PBT chemicals was exempt from reporting. It should be noted that although the research exemption applies, for most of the PBT chemicals the inventory of the PBT chemical is less than 1% of the EPA reporting threshold for usage.

3.4.3.2 Hazardous Materials Business Plan

The City of Berkeley is the local administering agency for certain hazardous materials regulations falling under state law. Berkeley Lab voluntarily submits an annual *Hazardous Materials Business Plan* (HMBP)[15] to the City of Berkeley, although the Laboratory as a federal facility is exempt from such regulations.

The 2006 HMBP included a list of all hazardous materials present in amounts exceeding the state's aggregate threshold quantities (i.e., 208 liters [L] [55 gallons (gal)] for liquids, 227 kg [500 lb] for solids, and 5.7 cubic meters [m^3] [200 cubic feet] for compressed gases) per building. The plan included a site map as well as summaries of emergency plans, procedures, and training. In addition, the HMBP included permit renewals for the underground storage tanks (USTs) and fixed treatment units (FTUs). Furthermore, in 2006 an additional HMBP was submitted to the City of Berkeley for the Berkeley West Biocenter (leased facility at 717 Potter Street); the plan contained the same components, where applicable, as the HMBP for the main Berkeley Lab site.

3.4.3.3 Risk Management and Prevention Plan

The City of Berkeley requires a Risk Management and Prevention Plan (RMPP)[16] for operations using acutely hazardous materials above certain thresholds established in 40 CFR Part 355. Berkeley Lab does not have any operations that contain acutely hazardous materials above the threshold quantities, and therefore no RMPP is required for the site.

3.4.4 Federal Insecticide, Fungicide, and Rodenticide Act

Passed by Congress in 1972, the Federal Insecticide, Fungicide, and Rodenticide Act[17] restricts the registration, sale, use, and disposal of pesticides. Pesticides, including insecticides and herbicides, are applied at the Berkeley Lab site by licensed contractors only. The Laboratory operates a composting program to minimize the use of herbicides and to reduce solid waste. The mulch generated from composting is used on-site for weed screening and landscaping where herbicides previously were applied. The end products from the chipper and mulcher program also are used to control erosion.

3.4.5 Toxic Substances Control Act

The objective of the TSCA[18] is to minimize the exposure of humans and the environment to chemicals found in manufacturing, processing, commercial distribution, and disposal activities. TSCA establishes a protocol for evaluating chemicals before they are introduced into the marketplace and controlling their use once they are approved for manufacturing. TSCA regulations are administered by the US/EPA.

Polychlorinated biphenyls (PCBs) are one of the principal substances at Berkeley Lab currently affected by the TSCA regulations. Since the TSCA program began, the Laboratory has removed all TSCA-regulated PCB transformers (PCB concentrations greater than 500 parts per million). The remaining equipment containing TSCA-regulated PCBs are four large low-voltage capacitors. These capacitors remain in use, containing an estimated 170 kg (375 lb) of regulated PCB dielectric fluid. Because the small amount of PCBs is below reporting thresholds, the Laboratory is not required to prepare an annual PCB report for the US/EPA.

3.4.6 Resource Conservation and Recovery Act

The primary goal of the RCRA[19] is to ensure that hazardous waste management practices are conducted in a manner that protects human health and the environment. RCRA affects waste treatment, storage, and disposal activities at Berkeley Lab in two areas: hazardous waste (including the hazardous portion of mixed waste) and USTs.

3.4.6.1 Hazardous Waste

In California, DTSC administers the RCRA hazardous waste program. The California program incorporates the provisions of both the federal and state hazardous waste laws.[20] The state program includes both permitting and enforcement elements. The state's permitting program for hazardous waste treatment and storage facilities consists of five tiers, shown in the following list in decreasing order of regulatory complexity:

- Full permit
- Standardized permit
- Permit-by-rule
- Conditional authorization
- Conditional exemption

The state continues to oversee the "full permit" and the "standardized permit" tiers; the other three tiers have been delegated to the City of Berkeley for oversight under California's Certified Unified Program Agency program.

Berkeley Lab's HWHF operates under the "full permit" tier of the program. A full permit is also known as an RCRA Part B permit. The current permit for the HWHF[21] was approved by DTSC on May 4, 1993, and authorizes storage and treatment of certain hazardous and mixed wastes at the HWHF. Berkeley Lab submitted a timely permit-renewal application for operation of its HWHF, and in December 2006 DTSC issued their final permit decision authorizing a new permit. An appeal to that decision was filed, and the new permit remains in pending status. The HWHF continues to operate under the existing permit and is authorized to conduct various treatments, including neutralization, consolidation, solidification, filtration, precipitation, phase separation, ultraviolet (UV) ozone and UV peroxide oxidation, reduction of Class 1–3 oxidizers, air or steam stripping, absorption, adsorption, ion exchange, metallic exchange, evaporation, distillation electrowinning, rinsing of empty containers, mixing of multicomponent resins, and desensitization. Of these, only neutralization of mixed waste was performed in 2006.

Berkeley Lab's waste management program sends off-site for disposal the hazardous, universal, mixed, medical, and radioactive waste generated at the Laboratory. Disposal of medical waste is managed in accordance with the state's Medical Waste Management Act[22] (see Section 3.4.6.2). Low-level radioactive waste is managed in accordance with DOE orders. Mixed waste is managed in accordance with the *Site Treatment Plan* compliance order.[23]

Berkeley Lab has an additional hazardous waste permit[24] to operate five FTUs. The type and location of each unit are listed in Table 3-5. These treatment units operate independently of the HWHF. Three of these FTUs are authorized to operate under the "conditional authorization" tier, while the remaining two are authorized to operate under the "permit-by-rule" tier. The type of treatment determines which tier applies. The City of Berkeley requests renewal of this permit each year. The FTU permit was renewed in March 2006.

Waste management permits and regulations require Berkeley Lab to prepare several reports for the year:

- The *Annual Hazardous Waste Report*,[25] prepared for DTSC, contains facility treatment and disposal information for all hazardous waste activities (including the hazardous waste portion of mixed waste) at the HWHF during the reporting year.
- Quarterly reports on the inventory of mixed waste more than one year old were submitted to meet a DTSC operating-permit requirement.

Table 3-5 Fixed Treatment Units Subject to State's Tiered Permitting

FTU	Building	Description of treatment	Permit tier	Volume of Wastewater treated (gallons)
002	25	Metals precipitation and acid neutralization	Permit-by-rule	8,819
003	76	Oil/water separation	Conditional authorization	15,878
004	70A/70F	Acid neutralization	Conditional authorization	824,069
005	2	Acid neutralization	Conditional authorization	45,240
006	77	Metals precipitation and acid neutralization	Permit-by-rule	39,909

In October 1995, DTSC approved the Laboratory's *Mixed Waste Site Treatment Plan*,[26] which documents the procedures and conditions used by Berkeley Lab to manage its mixed-waste streams. The Laboratory prepares an annual report that quantifies the amount of mixed waste in storage at the end of the reporting period. This update is prepared in October for the previous fiscal year (FY) (October 1 to September 30).

3.4.6.2 Medical Waste

Medical waste includes biohazardous waste (e.g., blood and blood-contaminated materials) and "sharps" waste (e.g., needles) produced in the following activities:

- Research relevant to the diagnosis, treatment, or immunization of human beings or animals
- Diagnosis, treatment or immunization of humans or animals
- Production of biological products used in medicine

In California, the state's Medical Waste Management Act[22] contains requirements designed to ensure the proper storage, treatment, and disposal of medical waste. The state program is administered by the Department of Health Services (DHS).

The Laboratory generates medical waste at about 150 different locations distributed over 15 buildings, including 3 off-site buildings. Berkeley Lab does not treat any medical waste: it is treated at off-site vendor facilities, using either incineration or steam sterilization.

Berkeley Lab produced 15,955 kg (35,144 lb) of medical waste in 2006. Under the state's program, the Laboratory is considered a large-quantity generator because it generates more than 91 kg (200 lb) of medical waste each month. All large-quantity generators must register with the DHS and are subject to periodic inspections. DHS did not inspect the medical waste program at Berkeley Lab during the year.

3.4.6.3 Corrective Action Program

Berkeley Lab is currently in the final phase of the RCRA Corrective Action Program (CAP), corrective Measures Implementation (CMI). The purpose of the CMI phase is to design, construct, operate, maintain, and monitor the corrective measures (cleanup activities) recommended by the Laboratory in the *Corrective Measures Study (CMS) Report*[27] and approved by the DTSC.[28] These approved measures will 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 initial step of the CMI phase was preparation of the *RCRA Corrective Measures Implementation (CMI) Workplan*.[29] The CMI workplan, which was approved by the DTSC on March 28, 2006, provides detailed descriptions of the design and the status of the approved corrective measures. Also as part of the CMI phase, the Laboratory submitted a *Soil Management Plan*[30] and a *Groundwater Monitoring and Management Plan*[31] to the DTSC on March 15, 2006. These management plans describe the nature and extent of the contamination and the institutional controls required to reduce potential risk from exposure to the contaminants. The *Groundwater Monitoring and Management Plan* also provides the requirements for ongoing groundwater and surface water monitoring. Both plans were approved by DTSC on September 1, 2006. These documents, as well as other RCRA CAP documents prepared by Berkeley Lab, are available for public review at the City of Berkeley main public library and at http://www.lbl.gov/ehs/erp/html/documents.shtml.

The Laboratory maintains a proactive interactive approach with stakeholders in the RCRA CAP, including the DTSC, the Regional Water Quality Control Board (RWQCB), and the City of Berkeley. The Environmental Restoration Program holds regularly scheduled meetings with these agencies, at which planned and completed activities are discussed.

3.4.7 Executive Order 13101 *(Greening the Government through Waste Prevention, Recycling, and Federal Acquisition)*

United States Executive Order 13101[32] replaced Executive Order 12873 *(Federal Acquisition, Recycling, and Waste Prevention)*. Like its predecessor, Executive Order 13101 seeks to integrate recycled materials into the procurement and acquisition process. Identified categories of products include the following:

- Paper and paper products
- Vehicular products
- Construction products
- Transportation products
- Park and recreation products
- Landscaping products
- Miscellaneous products
- Nonpaper office products

All federal agencies must procure only US/EPA-listed items with specified contents of recycled materials, unless a product is not available competitively within a reasonable time frame, does not meet appropriate performance standards, or is only available at an unreasonable price.

Berkeley Lab has had an affirmative procurement program ongoing since 1992. The Laboratory's Procurement staff searches for products made from recycled materials and works with other federal facilities to enhance their power to purchase environmentally sound products. The Laboratory has implemented a "stepped" program to ensure that only US/EPA-listed products manufactured from recycled materials will be purchased, as long as these materials are available at a reasonable cost and are compatible with the Laboratory's operating needs.

3.4.8 Hazardous Waste Source Reduction and Management Review Act

The California State Legislature passed the Hazardous Waste Source Reduction and Management Review Act[33] in 1989. With an emphasis on minimizing waste and preventing pollution, the Act has the following goals:

- Reduce hazardous waste at its source
- Encourage recycling wherever source reduction is infeasible or impractical
- Manage hazardous waste in an environmentally safe manner and minimize present and future threats to health and the environment if it is infeasible to reduce or recycle
- Document hazardous waste management information and make that information available to state and local governments

Every four years, Berkeley Lab prepares a two-part report in compliance with this Act: the *Source Reduction Evaluation Review Plan and Plan Summary*[34] and the *Hazardous Waste Management Report Summary*.[35] The last report was compiled in 2003 and submitted to DOE Oakland Operations Office as part of the DOE-wide report. In 2006 the Laboratory was not required to update this report.

3.4.9 Pollution Prevention Act of 1990

The Pollution Prevention Act of 1990[36] declares that source reduction is a national policy, and the Act directs US/EPA to study and encourage source reduction policies. Berkeley Lab's levels of pollution are below the de minimis thresholds identified in the Act, and therefore the Laboratory is not subject to its reporting requirements.

3.4.10 Clean Water Act

The CWA[37] regulates the discharge of pollutants from both point and nonpoint sources to the waters of the United States, using various means;

these include development of pollutant discharge standards and limitations and also a permit and licensing system to enforce the standards. California is authorized by US/EPA to administer the principal components of the federal water quality management program.

Additionally, the California Porter-Cologne Water Quality Control Act[38] established a comprehensive statewide system for regulating water use. This 1969 act provides for a three-tiered system of regulatory oversight and enforcement: the State Water Resources Control Board (SWRCB), the nine RWQCBs, and local governments.

For the Berkeley Lab main site, the regional regulatory agency is the San Francisco Bay RWQCB. The local agencies are (1) the cities of Berkeley and Oakland for stormwater and (2) EBMUD for drinking-water supply and wastewater discharges. Central Contra Costa Sanitary District (CCCSD) is responsible for both wastewater and stormwater discharges from the JGI, which is in Walnut Creek.

3.4.10.1 Wastewater

The Laboratory has three wastewater discharge permits[39] issued by EBMUD for the following activities:

1. General sitewide wastewater discharge
2. Treatment unit discharge of rinse water from the metal finishing operations in Buildings 25 and 77
3. Treatment unit discharge of groundwater from hydraugers and groundwater monitoring wells

The permits incorporate standard terms and conditions, individual discharge limits, and provisions, as well as monitoring and reporting requirements. Under each permit, Berkeley Lab submits periodic self-monitoring reports. The number of reports and their timing depend on the individual permit. No wastewater discharge limits were exceeded in 2006. (For more information regarding the results of the Laboratory's annual wastewater self-monitoring program, see Chapter 4.)

In 2003, EBMUD renewed the permits and increased the renewal term from one to four years, so that the current permits do not expire until 2007. EBMUD also elected to combine the permits from Buildings 25 and 77 into one permit.

EBMUD inspects the Laboratory's sanitary sewer discharge activities without prior notice; the inspections include the collection and analysis of wastewater samples. The agency conducted inspections on ten separate occasions throughout the year. Table 3-2 lists these inspections, which were routine sample collections. No violations resulted from these inspections.

The wastewater discharge permit for Buildings 25 and 77 requires that each facility maintain a *Toxic Organics Management Plan* (TOMP).[40] Each TOMP outlines facility management practices designed to minimize the release of toxic organics to the sanitary sewers or external environment.

The terms of the wastewater discharge permits also require an *Accidental Spill Prevention and Containment Plan* (ASPCP).[41] Specifically, Berkeley Lab must maintain this plan for areas where spills are most likely to occur. Berkeley Lab has prepared operation-specific plans for the following activities: sitewide photoprocessing, Buildings 25 and 77 metal finishing, Building 76 vehicle services, and Buildings 2 and 70A rinse water treatment. EBMUD requires that plan documents be maintained on file in the relevant areas and that essential emergency information be posted. These plans are not required to be submitted to the agency. The TOMP and ASPCP for Building 77 have been combined.[42]

The Laboratory now holds a Class III Industrial User Permit[43] issued by CCCSD for general wastewater discharged at the JGI. It was issued on December 3, 2004, and it contains requirements for inspecting and reporting on operations, but no monitoring requirements.

3.4.10.2 Stormwater

Berkeley Lab's stormwater releases are permitted under the California-wide *Industrial Activities Storm Water General Permit* (or General Permit).[44] The General Permit is issued by the SWRCB but administered and enforced by the RWQCB and the City of Berkeley. Under this permit, the Laboratory has implemented a *Storm Water Pollution Prevention Plan* (SWPPP)[45] and a *Storm Water Monitoring Program* (SWMP).[46] The purpose of the SWPPP is to identify sources of pollution that could affect the quality of stormwater discharges, and to describe and ensure the implementation of practices to reduce pollutants in these discharges. The SWMP describes the rationale for sampling, sampling locations, and analytical parameters (radiological and nonradiological). Together, these documents represent the Laboratory's plan and procedures for identifying, monitoring, and reducing pollutants in its stormwater discharges.

The General Permit requires submission of an annual report on stormwater activities by July 1. Berkeley Lab transmitted its annual report to the RWQCB and the City of Berkeley in June.[47] No regulatory concerns were raised by either agency regarding the annual report. (For a summary of the stormwater monitoring results, see Chapter 4.) No inspections of this program took place during the year.

Construction of the Laboratory's Molecular Foundry Building required authorization under the State of California's *General Permit for Stormwaters Discharge Associated with Construction Activity*[48] because the site for the project exceeded 0.4 hectares (one acre) in size. When the project ended in the first half of 2006, a Notice of Termination for coverage under this construction-based general permit was submitted to the RWQCB. The Regional Board approved this request in August. The Molecular Foundry site is now covered under the Sitewide Industrial Activities General Permit.

3.4.10.3 Aboveground Storage Tanks

Aboveground storage tanks (ASTs) also fall under the authority of the CWA.[37] The CWA and the state's Aboveground Petroleum Storage Act[49] outline the regulatory requirements for ASTs. Under the authority of the CWA, a *Spill Prevention, Control, and Countermeasures (SPCC) Plan*[50] is required for petroleum-containing tanks—aboveground and underground tanks. Berkeley Lab maintains an SPCC Plan with the goal of preventing and, if needed, mitigating spills or leaks from petroleum-containing tanks. ASTs are provided with secondary containment or spill kits to capture any potential leaks. The locations of the 30 ASTs are shown in Figure 3-2. A new 5,700 L (1,500 gal) diesel, double-walled, aboveground tank was installed at the Molecular Foundry (Building 67) in 2006 and became operational in May 2006. In addition, a 15,100 L (4,000 gal) AST is installed offsite at the JGI to support an engine generator; the JGI maintains an SPCC Plan for this AST.

Nonpetroleum (i.e., chemical or hazardous) ASTs consist of FTU tanks, storage drums at Waste Accumulation Areas (WAAs), and storage drums at product distribution areas. FTU operators inspect FTU tanks each operating day. EH&S staff inspect WAAs weekly. Product distribution areas containing petroleum and nonpetroleum drums are inspected by the Fire Department during routine inspections.

The E85-fuel dispensing-station tank (located at Building 76) provides a fuel mixture of 85% ethanol and 15% gasoline. The station supports approximately 60 alternative-fuel vehicles. The use of 85%-ethanol fuel is one of the Laboratory's strategies for reducing petroleum usage by its fleet of vehicles. In FY 2006, Berkeley Lab was able to reduce its petroleum usage for fleet vehicles by 35% as compared to the 1999 baseline year. The National Ethanol Vehicle Coalition has commended the Laboratory for installing the E85-fuel dispensing station and for supporting the use of a clean, domestic, renewable fuel.

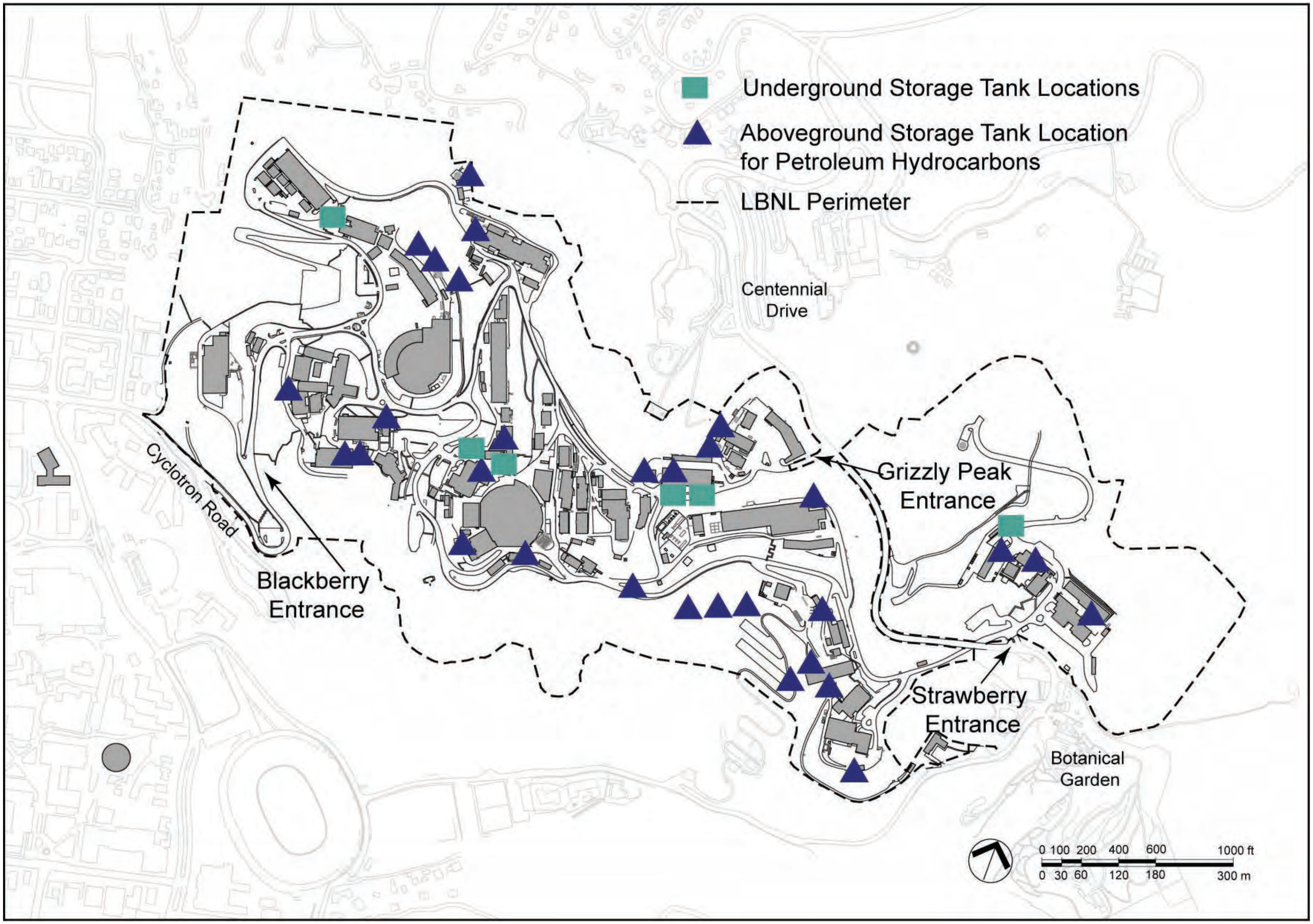


Figure 3-2 Aboveground and Underground Storage Tank Locations at the End of Calendar Year 2006

3.4.10.4 Underground Storage Tanks

In the early 1980s, California addressed the problem of groundwater contamination from leaking USTs through a rigorous regulatory and remediation program.[51] The state program for USTs that contain hazardous materials addresses permitting, construction design, monitoring, record keeping, inspection, accidental releases, financial responsibility, and tank closure.

The state's program satisfies the provisions of the federal RCRA requirements.[52] The City of Berkeley is the local administering agency for UST regulations that apply to Berkeley Lab.

Two Berkeley Lab employees have passed the State of California exam to become UST Designated Operators. The two UST Designated Operators are responsible for conducting monthly inspections of the UST systems; these inspections supplement the daily inspections conducted by other facility employees. The UST Designated Operator provides annual training to the employees that conduct the daily UST inspections.

At the end of 2006, six permitted USTs were in operation at the Laboratory (see Table 3-6 and Figure 3-2). The tanks contain either diesel fuel or unleaded gasoline. The Laboratory has removed nine USTs since 1993 and properly closed each site.

On October 30, leak-detection monitors were tested and recertified for all UST systems. During the recertification, the City of Berkeley inspected all six USTs and found no violations. On October 30, all product piping (pressure and suction) was pressure-tested for the UST systems. All piping passed the pressure tests. Also in October, every spill bucket at the fill port of each UST was tested for leaks. All spill buckets were found free of leaks.

Table 3-6 Underground Storage Tank Operating Permits from the City of Berkeley

Registration tank ID number	Building	Stored material	Capacity in liters (gallons)	Construction	Year installed
Fiberglass tanks, double-walled					
2-1	2	Diesel	15,200 (4,000)	Fiberglass	1988
2-2	2	Diesel	3,800 (1,000)	Fiberglass	1988
85-1	85	Diesel	9,500 (2,500)	Fiberglass	1995
Steel tanks, double-walled, with fiberglass plastic corrosion protection					
55-1	55	Diesel	3,800 (1,000)	Glasteel	1986
76-1	76	Unleaded gasoline	38,000 (10,000)	Glasteel	1990
76-2	76	Diesel	38,000 (10,000)	Glasteel	1990

3.4.11 Safe Drinking Water Act

The Safe Drinking Water Act[53] and amendments established requirements to protect underground sources of drinking water and set primary drinking-water standards for public water systems. Berkeley Lab has no drinking-water wells on-site. The drinking water provided to the site comes from the EBMUD supply and distribution system. EBMUD water is tested for compliance with state and federal drinking-water standards. Berkeley Lab has taken measures to protect its distribution system for its drinking-water supply by installing backflow-prevention devices on main supply lines throughout the site.

EBMUD now uses chloramine for disinfection of the drinking-water supply. Although chloramine improves the water supply for human consumption, it is toxic to fish and other aquatic organisms. To prevent toxic effects to organisms involved in laboratory research, researchers have instituted measures to neutralize the chloramine to provide water in which these organisms can safely exist.

Additionally, to prevent toxic effects to organisms living in neighboring creeks, Berkeley Lab has programs to prevent drinking water from being discharged to the Laboratory's storm drains. When responding to waterline breaks and when testing and flushing fire hydrants, the Facilities Division and Fire Department neutralize the chloramine before the water reaches nearby storm drains.

3.4.12 National Environmental Policy Act and California Environmental Quality Act

The National Environmental Policy Act of 1969 (NEPA)[54] established national policy for assessing federal actions that have the potential to impact the environment. The NEPA process is intended to help officials of the federal government make decisions that are based on an understanding of environmental consequences and take actions that protect, restore, and enhance the environment. The California Environmental Quality Act of 1970 (CEQA)[55] is similar to NEPA. The California legislature established CEQA with the following intentions:

- To inform both state and local government decision makers and the public of potential significant environmental effects of proposed activities
- To identify ways to avoid or reduce environmental impacts
- To disclose to the public the reasons why a project is approved if significant environmental effects are involved

As a federal facility located on land leased from the Regents of the University of California, Berkeley Lab complies with the provisions of both NEPA and CEQA. The exception to this is for projects occurring on unleased portions of Berkeley Lab and where federal funding or permits are not involved. Such projects may be subject only to CEQA requirements. Since the DOE and the UC Regents have the ultimate decision making authority on Berkeley Lab activities under NEPA and CEQA, respectively, Laboratory staff provides information to enable both entities to determine whether Berkeley Lab's proposed actions will have a significant effect on the environment.

In 2006, approximately 550 proposed federal actions were reviewed pursuant to NEPA and CEQA. Of these, the majority were research proposals and small facilities projects. The more significant reviews included:

- Categorical Exclusions and Exemptions (NEPA and CEQA, respectively) that were prepared for several projects, including the proposed Richmond Warehouse lease and operation, the proposed demolition and removal of various trailers and small structures, and proposed seismic rehabilitation of various structures.
- An Environmental Assessment prepared pursuant to NEPA for the proposed User Support Building, and a Finding of No Significant Impact resulted; a Mitigated Negative Declaration was prepared under CEQA.

- An Environmental Assessment (NEPA) prepared for the proposed demolition of Building 51 and the Bevatron; this paired with an Environmental Impact Report circulated in 2005 for the same project.
- Substantial preparatory work conducted on NEPA and CEQA documents that were not publicly circulated in 2006; these include the User Guest House (Negative Declaration) and the 2006 Long Range Development Plan EIR. Both were circulated for public review in 2007.

3.4.13 Federal Endangered Species Act

The Federal Endangered Species Act (FESA)[56] requires that activities taking place at Berkeley Lab on federally controlled property, or using federal permission or funding, undergo a screening process or the NEPA process to determine whether federally listed or proposed species may be present or affected by the action. No compliance activities were required in 2006.

3.4.14 California Endangered Species Act

The California Endangered Species Act (CESA)[57] requires that activities taking place at Berkeley Lab on UC Regents land, or using UC Regents or state permission or funding, undergo a screening process or the CEQA process to determine whether state-listed or proposed species may be present or affected by the action. No compliance activities were required in 2006.

3.4.15 National Historic Preservation Act

The National Historic Preservation Act[58] provides for a National Register of Historic Places, which lists buildings, structures, sites, objects, and districts that possess historic, architectural, engineering, archaeological, or cultural significance. Berkeley Lab currently is undergoing a sitewide inventory with a qualified historian in consultation with the State Historic Preservation Officer to determine which assets at Berkeley Lab are eligible for listing on the National Register and to comply with the Act.

3.4.16 Migratory Bird Treaty Act

The Migratory Bird Treaty Act[59] legislates that actions and projects undertaken at Berkeley Lab must undergo appropriate NEPA and CEQA review, which includes assessment of biological impacts, to determine whether species subject to the provisions of the Migratory Bird Treaty Act would be affected. No compliance activities were required in 2006.

3.5 PERFORMANCE MEASURES

Since 1994, Berkeley Lab, DOE, and DOE's managing contractor, the University of California Office of the President (UCOP), have used a system to annually measure the effectiveness of the Laboratory's performance, including the performance of its environmental programs. These performance measures have been integrated directly into the operating contract for Berkeley Lab. Possible ratings include letter grades ranging from A+ to F. Berkeley Lab has consistently received top marks from both DOE and UCOP since the inception of environmental performance measures ten years ago.

For FY 2006 (October 1–September 30), there were three environmental measures. Berkeley Lab achieved an A rating for the environmental protection measure. To achieve that score, the number of Notices of Violation (NOV) issued to the Laboratory could not exceed two; the Laboratory received two during the fiscal year. Both NOVs were issued as a result of an HWHF inspection by the DTSC in June 2005. On March 15, 2006, LBNL received the final inspection report, citing two Class II violations of the Part B Permit training program (see Section 3.3.3). Berkeley Lab also achieved an A rating for the second measure, the meeting of all EMS goals. The Laboratory accomplished the five EMS goals established for FY 2006:

1. Complete the external triennial audit
2. Receive external audit validation of effective implementation of EMS

3. Analyze environmental aspects and impacts
4. Implement EMPs to improve environmental performance
5. Complete internal annual assessment

The Laboratory also achieved an A rating for implementing more than two waste minimization, emission reduction, and/or resource conservation projects. The implemented projects included installation of digital imagers at two Berkeley Lab locations, sealing ventilation ducts at two buildings, installing a non-chemical-based water treatment system, and reducing energy use throughout the Laboratory.

For more information on environmental performance measures, go to Berkeley Lab's Office of Institutional Assurance home page at http://www.lbl.gov/DIR/OIA/OCA/contract-performance/index.html.

4 Environmental Monitoring

Aerial view of Berkeley Lab and surrounding environment

4.1 INTRODUCTION

The Berkeley Lab environmental monitoring program assesses whether the Laboratory's emissions are impacting the health of the public or the environment. The program is important for environmental stewardship and for demonstrating compliance with requirements imposed by federal, state, and local agencies. The program also confirms adherence to DOE environmental protection policies and supports environmental management decisions.

This chapter presents summaries of the 2006 monitoring results for the following categories:

- Stack and ambient air
- Surface water and wastewater
- Groundwater
- Soil and sediment
- Vegetation and foodstuffs
- Penetrating radiation

A comprehensive *Environmental Monitoring Plan*[1] prepared by Berkeley Lab provides the basis and current scope for each of these monitoring programs. This plan is updated regularly; the most recent revision was completed in February 2006.

All of the individual sample results except for groundwater are presented in Volume II of this *Site Environmental Report*. Additional details on groundwater investigations and results are included in Environmental Restoration Program reports, which are available at the City of Berkeley main public library and at http://www.lbl.gov/ehs/erp/html/documents.shtml.

4.2 AIR QUALITY

Lawrence Berkeley National Laboratory's air monitoring program is designed to measure the impacts from radiological air emissions. The program meets the US/EPA and DOE requirements, which are contained in the following references:

- 40 CFR Part 61, Subpart H (*National Emission Standards for Hazardous Air Pollutants*, or NESHAP)[2]
- DOE Order 5400.5 (*Radiation Protection of the Public and the Environment*)[3]

This program consists of two elements: exhaust-emissions monitoring and ambient-air surveillance. Exhaust-emissions monitoring measures contaminants in building exhaust systems (e.g., stacks). Ambient-air surveillance measures contaminants in the outdoor environment. The number and placement of monitoring stations, as well as the substances collected and their collection frequencies, are routinely reviewed to address changes in Laboratory operations or external requirements.

4.2.1 Exhaust-Emissions Monitoring Results

Berkeley Lab uses various radionuclides in its radiochemical and biomedical research programs. Charged-particle accelerators also generate radioactive materials. These operations result in small amounts of airborne radionuclides, which may be emitted through building exhaust systems.

Berkeley Lab must evaluate the potential for radionuclide emissions from laboratories where radionuclides are used. If the potential emissions exceed the US/EPA-approved threshold, the Laboratory must measure emissions by sampling or monitoring stacks through which emissions are released. *Sampling* means collecting radionuclides on a filter and analyzing the filters at an analytical laboratory; *monitoring* means continuously measuring radionuclides in real time.

The Laboratory measures stack emissions in accordance with an approach approved by US/EPA Region 9 (Table 4-1). Based on this approach, only periodic or quarterly (Category 3) sampling is required because all sources have potential doses that are less than 0.001 mSv/yr (0.1 mrem/yr). However, Berkeley Lab may monitor or sample some stacks more frequently than required by US/EPA. Exercising this option, Berkeley Lab collected monthly samples from four stacks and performed real-time monitoring at four stacks (one of which was also sampled monthly) in addition to collecting samples quarterly from five stacks. Sampling and monitoring locations are shown in Figure 4-1.

Table 4-1 US/EPA-Approved Radionuclide Emissions Measurement Approach

Category	Annual effective dose equivalent[a] (mSv/yr)[b]	Requirements
Noncompliant	AEDE ≥ 0.1	Reduction or relocation of the source and reevaluation before authorization
1	0.1 > AEDE ≥ 0. 01	Continuous sampling with weekly collection and real-time monitoring for short-lived radionuclides
2	0.01 > AEDE ≥ 0.001	Continuous sampling with monthly collection or real-time monitoring for short-lived radionuclides
3	0.001 > AEDE ≥ 0.0001	Periodic sampling 25% of the year
4	0.0001 > AEDE	Potential dose evaluation before project starts and when project changes; no sampling or monitoring required

[a] Abbreviated as AEDE
[b] 1 mSv = 100 mrem

Stack exhaust samples were analyzed for five radiological parameters: gross alpha, gross beta, carbon-14, iodine-125, and tritium. Real-time stack monitoring systems measured alpha emitters and positron emitters. In 2006, the positron emitter fluorine-18 (half-life of 1.8 hours) was the predominant radionuclide emitted and accounted for about 95% of the emitted activity. The Building 56 accelerator was the main source of fluorine-18 emissions (1.23×10^{11} becquerels [Bq] [3.32 curies (Ci)]). Additional details on stack emissions are available in the Laboratory's annual *Radionuclide Air Emission Report*, submitted to US/EPA (at http://www.lbl.gov/ehs/esg, under "Available Documents"). (For information on the projected dose from all radionuclide emissions, see Chapter 5.)

In addition to air emissions from exhaust systems, Berkeley Lab also collects and analyzes tritium levels in rainwater that drains down the inside of stacks associated with the former National Tritium Labeling Facility (NTLF). The average concentration of tritium in drain water collected and analyzed during the year was 5.65×10^4 Bq/L (1.52×10^6 picocuries/L [pCi/L]) and the maximum was 9.19×10^4 Bq/L (2.48×10^6 pCi/L). In accordance with an internal authorization, the stack drain water was sent to the HWHF for disposal as low-level radioactive waste.

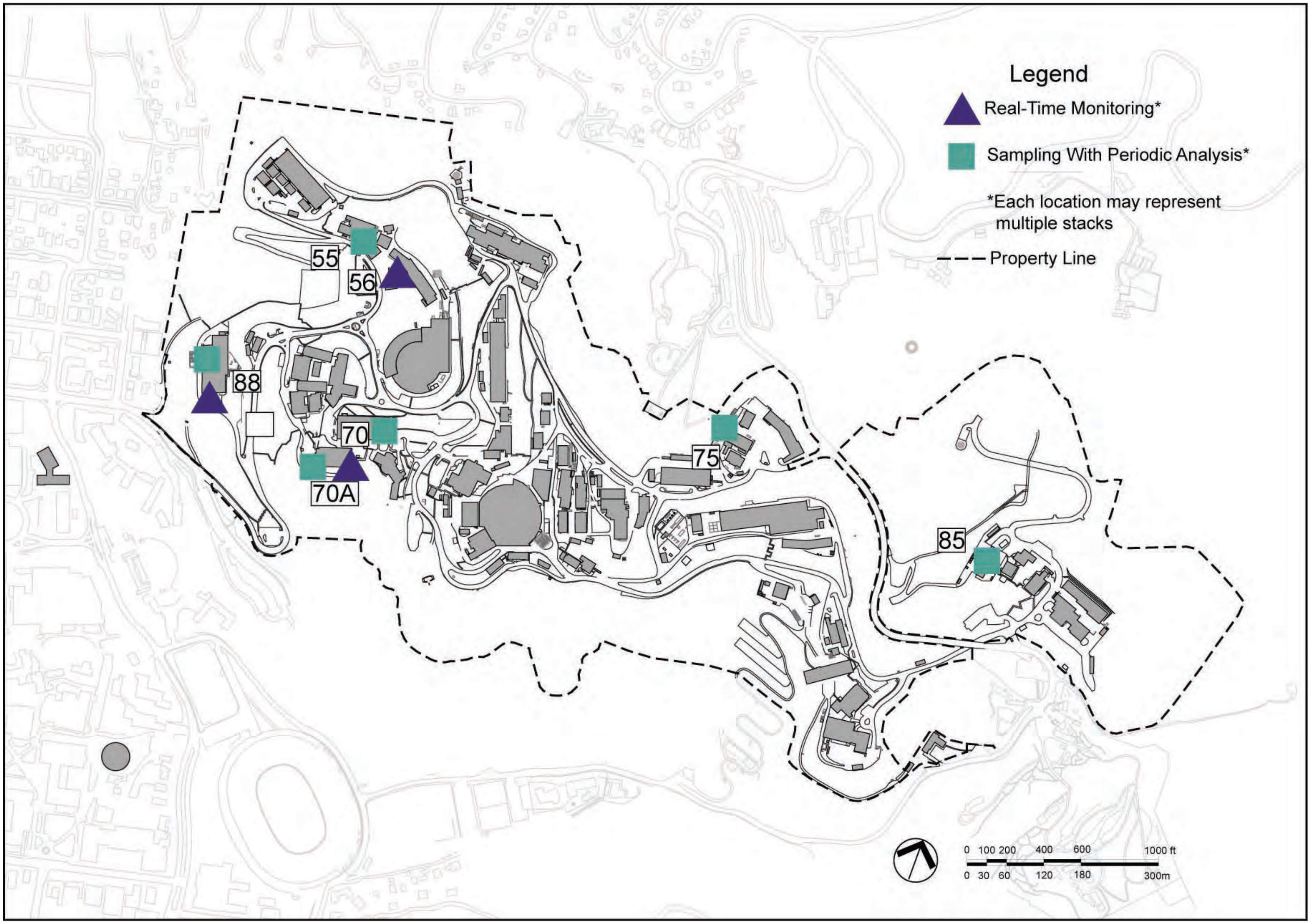


Figure 4-1 Locations of Building Exhaust Sampling and Monitoring

4.2.2 Ambient-Air Monitoring Results

The focus of the ambient-air monitoring program is to determine the levels of two general classes of radionuclides—alpha and beta emitters. Ambient-air monitoring for tritium was eliminated in early 2005, as discussed in the Laboratory's *Site Environmental Report for 2005*.

The network designed to collect air particulate samples for measurement of gross alpha and beta emitters changed considerably at the beginning of 2006. Although the network continued to consist of three sites on the main grounds of the Laboratory and a fourth off-site location, all samplers on the main grounds were relocated. The new locations were chosen based on historical wind patterns and current Laboratory activities. One of the new sites also included a collocated sampler for quality control (QC) purposes. Figure 4-2 shows the old and the new sampling locations.

Table 4-2 summarizes gross alpha and beta sample results from the redesigned sampling network. Although the transition occurred at the first sample changeout of the year, samplers at the previous network design continued to operate for the first month; data for the last month of 2005 and the first month of 2006 from these sites are included in Volume II.

While DOE Order 5400.5 does not provide ambient-air thresholds for either parameter, all results were near or below the analytical detection limits. This observation is consistent with results from prior years across the network.

Table 4-2 Summary of Alpha and Beta Radiation Results for Ambient-Air Samples

Analyte	Station ID	Number of samples	Mean (Bq/m^3)[a]	Median (Bq/m^3)	Maximum (Bq/m^3)
Alpha	ENV-B13A	12	6.4×10^{-5}	6.1×10^{-5}	1.2×10^{-4}
	ENV- B13C[b]	12	4.8×10^{-5}	4.6×10^{-5}	1.2×10^{-4}
	ENV-44	12	5.9×10^{-5}	5.1×10^{-5}	1.2×10^{-4}
	ENV-83	12	6.4×10^{-5}	5.3×10^{-5}	1.3×10^{-4}
Beta	ENV-B13A	12	4.5×10^{-4}	3.3×10^{-4}	8.2×10^{-4}
	ENV-B13C[b]	12	4.5×10^{-4}	3.9×10^{-4}	7.9×10^{-4}
	ENV-44	12	4.6×10^{-4}	4.0×10^{-4}	7.7×10^{-4}
	ENV-83	12	4.6×10^{-4}	3.9×10^{-4}	7.9×10^{-4}

[a] 1 Bq = 27 pCi

[b] Station ENV-B13C provides local background data for alpha and beta radiation in ambient-air particulate.

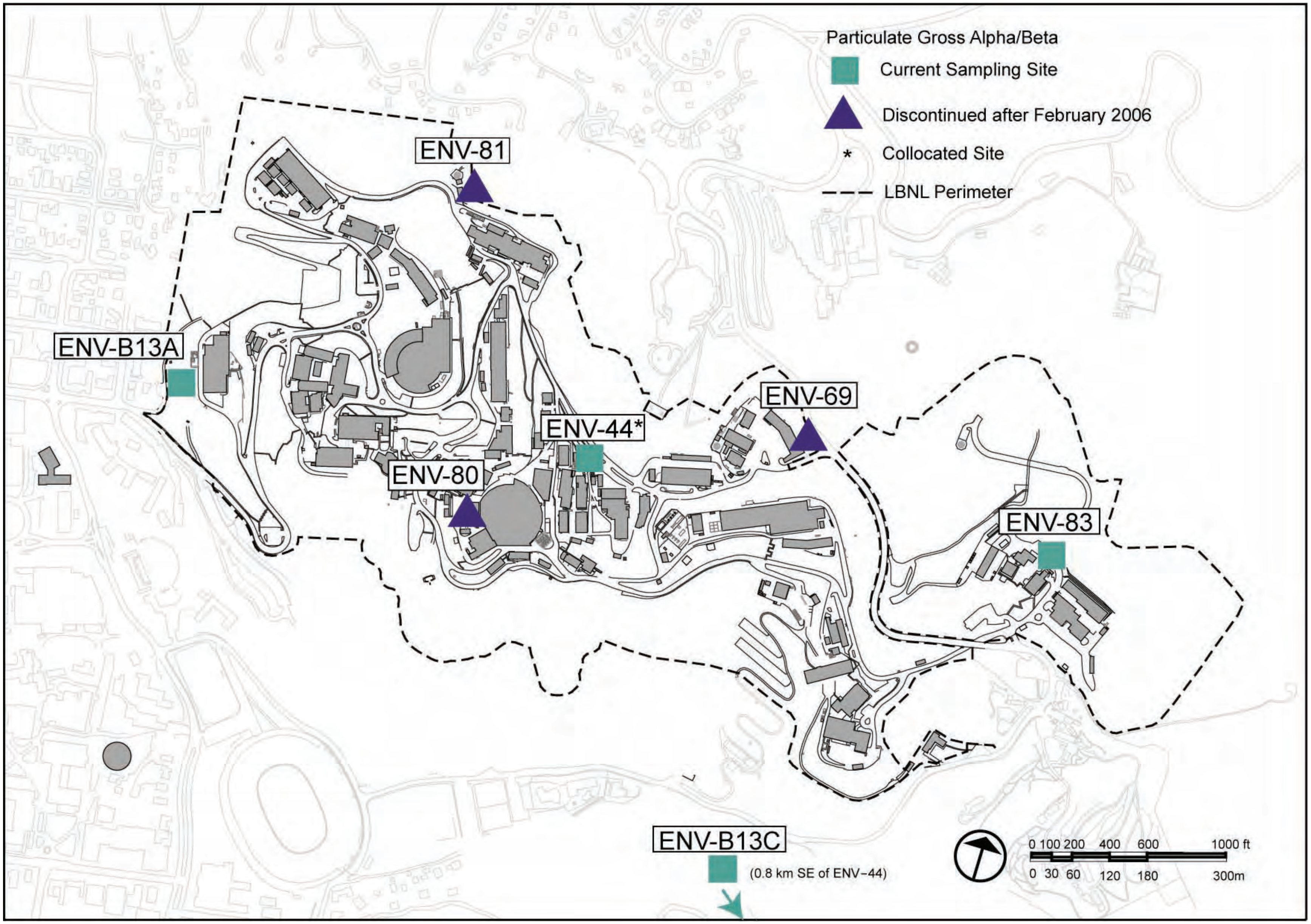


Figure 4-2 Ambient-Air Monitoring Network Sampling Locations

4.3 SURFACE WATER AND WASTEWATER

This section summarizes the monitoring results for surface water (rainwater, creeks, and stormwater) and wastewater.

4.3.1 Surface Water Program

Berkeley Lab lies within the Blackberry Canyon and Strawberry Canyon subwatersheds of the Strawberry Creek watershed. There are two main creeks in these watersheds, the South Fork of Strawberry Creek (in Strawberry Canyon) and the North Fork of Strawberry Creek (in Blackberry Canyon). Both creeks join below the Laboratory on the UC Berkeley campus.

Surface water monitoring for 2006 included rainwater, creeks, and stormwater. Rainwater and creeks are monitored primarily for alpha and beta emitters and tritium, based on DOE Order 5400.5,[3] which prescribes monitoring requirements for radioisotopes. Creek water is also monitored for nonradiological analytes as an ongoing effort to characterize and manage the Laboratory's overall impact on the environment. Stormwater monitoring is a condition of the California-wide *Industrial Activities Storm Water General Permit* (or General Permit)[4] and includes monitoring for metals and other constituents.

Although Laboratory surface waters are not used as a public drinking water supply, Berkeley Lab takes the conservative approach of evaluating surface water results against drinking-water standards. The federal and state maximum contaminant levels for alpha and beta radioactivity in drinking water are 0.6 Bq/L (15 pCi/L) and 1.9 Bq/L (50 pCi/L), respectively.[5,6] The federal and state limit for tritium in drinking water is 740 Bq/L (20,000 pCi/L).[5,6] The Laboratory also uses the water quality objectives stated in the Water Quality Control Plan (Basin Plan) for the San Francisco Bay Basin[7] for comparison purposes.

All surface water samples were analyzed by state-certified laboratories.

4.3.1.1 Rainwater Sampling Results

Measurable rainfall occurred during January through May and October through December. During each of these months, a sample of the composite rainfall for the month was collected near Building 75 at ENV-75 (see Figure 4-3) and analyzed for gross alpha, gross beta, and tritium activity. Sample results were consistent with historical values and were below drinking-water standards. All sample results for alpha and beta were below or near detection limits, with the exception of the October result for beta, 0.57 Bq/L (15 pCi/L), which is well within historical values. No tritium activity was detected in any of the samples.

4.3.1.2 Creeks Sampling Results

The flow in many of the creeks of the Strawberry Creek watershed varies in intensity throughout the year. To track any seasonal variation in water quality, a sample is collected quarterly from each of three creeks: Chicken Creek, the North Fork of Strawberry Creek, and Strawberry Creek (UC). Samples are analyzed for gross alpha, gross beta, and tritium radiological activity, as well as for mercury. The sample scheduled for the first quarter of 2006 at the North Fork of Strawberry Creek could not be collected because the falling of a large tree during a January storm caused extensive damage to the long stairway that leads to the sampling station.

Samples are also collected at a reduced frequency from a second set of creek locations. One set of samples was collected in 2006 at locations in Chicken Creek and the North Fork of Strawberry Creek, plus five other creeks: Botanical Garden Creek, Cafeteria Creek, No Name Creek, Ravine Creek, and Ten-Inch Creek. The samples were analyzed for tritium and numerous metals and volatile organic compounds (VOCs). Figure 4-3 shows all creek sampling locations.

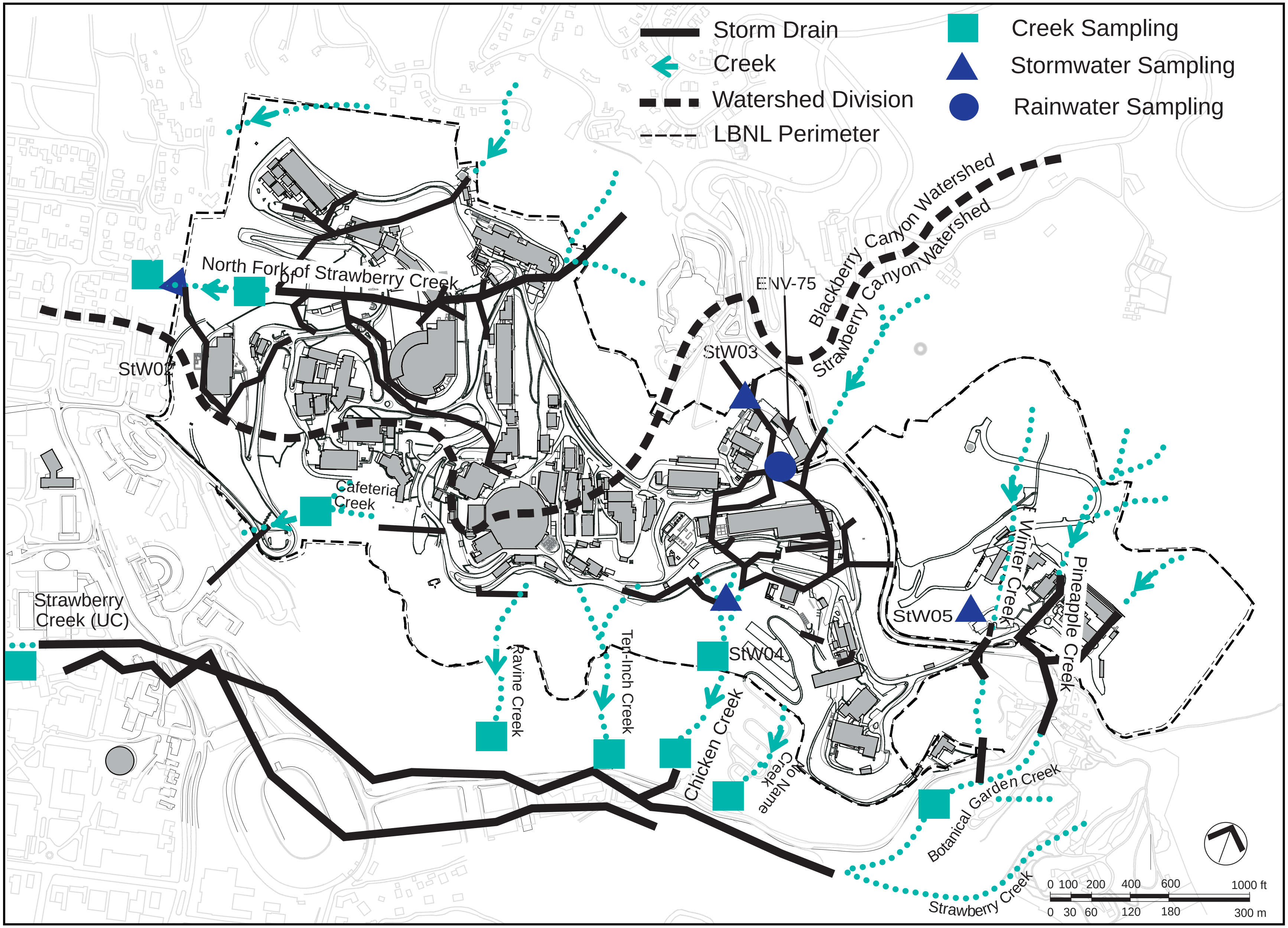


Figure 4-3 Creek, Rainwater, and Stormwater Sampling Locations

No VOCs, mercury, or alpha activity was detected in any samples collected during the year. Similarly, most metals were not detectable in any samples. The metals that were detected were limited to arsenic, barium, copper, selenium, vanadium, and zinc. Their concentrations were (1) within historical levels for the Laboratory, (2) well below the water quality objectives listed in the Basin Plan,[7] and (3) well below the drinking-water standard. The few times (approximately 15% of the time) that gross beta or tritium radioactivity was detected, the activities were only slightly above analytical detection limits and well below the drinking-water standard.

4.3.1.3 Stormwater Sampling Results

Surface runoff from Berkeley Lab can be substantial because of the site's hillside location, the amount of paved or covered surface, the moderate annual rainfall, and the intensity of some rainfall events. All stormwater runoff from the site is routed through its stormwater drainage system to either the South Fork or the North Fork of Strawberry Creek.

Under the terms of California's General Permit, sampling must take place at least twice each stormwater year (i.e., October to September) under specific conditions. Berkeley Lab's SWMP[8] describes the rationale for sampling, sampling locations, and analytical parameters (radiological and nonradiological). See Figure 4-3 for the locations of the four sampling sites. This permit also requires visual observation of one storm each month and visual observation of authorized and unauthorized nonstormwater discharges (e.g., a sewer-line break) once each quarter. Stormwater sampling in 2006, which actually spanned the 2005–2006 and 2006–2007 stormwater years, included the following parameters:

- General indicator parameters: chemical oxygen demand (COD), pH, specific conductance, and total suspended solids (TSS)
- Metals and minerals: aluminum, iron, magnesium, mercury, and zinc
- Nutrients: nitrogen and nitrate
- Petroleum hydrocarbons: oil and grease (in lieu of total organic carbon [TOC]), and total petroleum hydrocarbons (TPH) (as diesel range organics)
- Radioactivity: alpha, beta, and tritium

Only oil and grease, pH, specific conductance, and total suspended solids were explicitly required by the General Permit.

The list of parameters sampled is only a partial listing of potential surface water quality objectives considered by the Basin Plan, yet one that is appropriate for the activities at the Berkeley Lab site. This list assesses the overall state of water quality using a broad range of measures. Effluent limitations in the General Permit refer to 40 CFR Subchapter N standards for industrial source categories, 40 CFR Part 117 and 40 CFR Part 302 regulations for reportable quantities of hazardous substances, and the Basin Plan for the San Francisco Bay Basin.

Sampling results for the year were below detectable concentrations (or activities) for mercury, oil and grease, and tritium across the network. When detectable results for other parameters were observed, the concentrations varied by location and by stormwater sampling event. But in all cases the results were (1) within historical levels for the Laboratory, (2) consistent with urban background levels, (3) within the water quality objectives of the Basin Plan, and (4) well below drinking-water standards.

4.3.2 Wastewater Discharge Program

The Laboratory's sanitary sewer system is based on gravity flow and discharges through one of two monitoring stations, Hearst or Strawberry (see Figure 4-4).

- Hearst Station, located at the head of Hearst Avenue below the western edge of Berkeley Lab, monitors discharges from the western and northern portions of the site. The monitoring site is located at a point immediately before the connection of the Laboratory's sanitary sewer system with the City of Berkeley's sewer main.

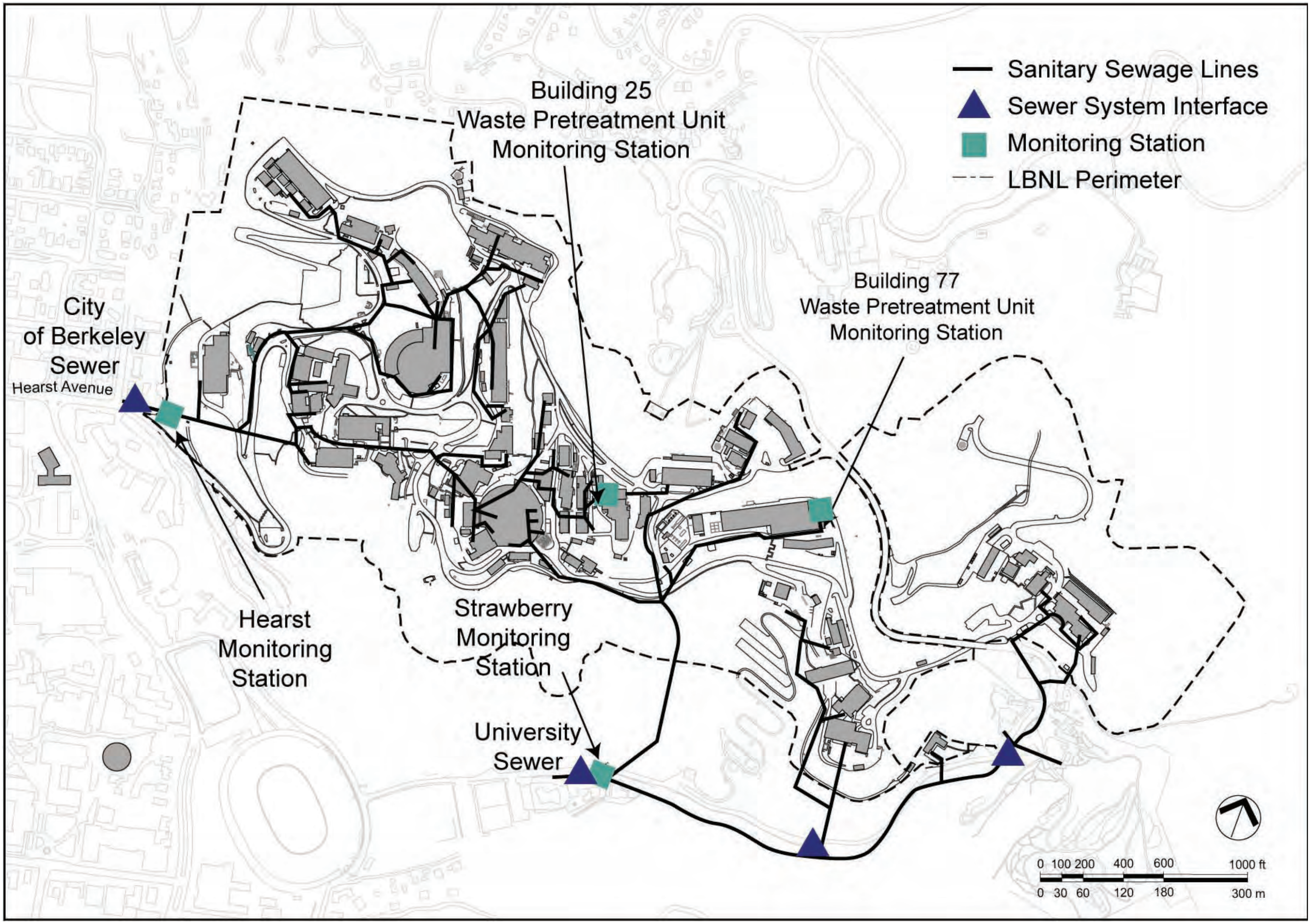


Figure 4-4 Sanitary Sewer System

- Strawberry Station is located next to Centennial Drive in Strawberry Canyon and monitors discharges from the eastern and southern parts of the Laboratory. Downstream from the monitoring station, the discharge system first ties into University-owned piping and then into the City of Berkeley system. Because of the design of the network, the Strawberry Monitoring Station also receives effluent from several UC Berkeley campus facilities that are located above the Laboratory and are separate from the main UC Berkeley campus: Lawrence Hall of Science, Space Sciences Laboratory, Mathematical Sciences Research Institute, Animal Research Facility, and Botanical Garden.

Self-monitoring of wastewater discharges within Berkeley Lab also occurs at wastewater treatment systems located at Buildings 25 and 77 and at groundwater treatment units, according to the terms of their respective EBMUD permits.[9] EBMUD is the local Publicly Owned Treatment Works that regulates all industrial and sanitary discharges to its treatment facilities.

Berkeley Lab has three wastewater discharge permits issued by EBMUD: one for general sitewide discharges, one for the photo fabrication and metal cleaning operations found in Buildings 25 and 77, and one for the discharge of treated groundwater.

The Laboratory's wastewater discharge permits require periodic monitoring for various parameters as specified by EBMUD. In addition, EBMUD performs unannounced monitoring of wastewater discharges. For 2006, no changes in permit requirements occurred, and all sampling results for the three permits were below discharge limits.

4.3.2.1 Hearst and Strawberry Sewer Outfalls

Nonradiological monitoring of sitewide samples includes analyses for pH, total identifiable chlorinated hydrocarbons, TSS, and COD, with additional analyses for metals. Also, total flow is measured and recorded. In 2006, Berkeley Lab discharged approximately 12 million gallons through Hearst Sewer and 25 million gallons through Strawberry Sewer.

Radiological monitoring is required by DOE Order 5400.5[3] and DOE effluent monitoring guidance,[10] but the monitoring also ensures compliance with radiological limits under the California Code of Regulations,[11] cited in the EBMUD wastewater discharge permit. California regulations now incorporate by reference the applicable federal regulations[12] and associated discharge limits.

Analyses are performed by both a state-certified external laboratory and, for certain radiological analyses, an accredited in-house laboratory. Results are compared against the discharge limits for each parameter given in the permits, and self-monitoring reports are submitted to EBMUD in compliance with permit requirements. Annually, Berkeley Lab submits a certification to EBMUD that the Laboratory's discharge is in compliance with the permit's radioactive limits.

4.3.2.1.1 Nonradiological Monitoring Results

Berkeley Lab performed two sampling events at both Hearst & Strawberry outfalls and collected samples as part of self monitoring during 2006. All results were well within discharge limits, as were all measurements made by EBMUD in its two independent sampling events. For the one-time sampling of metals, some metals were below detection limits in both the Hearst and Strawberry outfalls; however, small amounts of copper, mercury, and zinc were measured in both outfalls.

No chlorinated hydrocarbons were detected except chloroform (which is present in EBMUD supply water). According to the permit, the pH level must be equal to or greater than 5.5; all results were well above this value. TSS and COD have no discharge limits and are measured to determine wastewater strength, which forms the basis for the costs charged by EBMUD to the Laboratory for wastewater treatment.

4.3.2.1.2 Radiological Monitoring Results

The Hearst and Strawberry sewer outfalls are continuously sampled at half-hour intervals using automatic equipment. Every four weeks, these composite samples are retrieved and submitted to a state-certified laboratory for analysis of gross alpha radiation, gross beta radiation, carbon-14, iodine-125, phosphorus-32, sulfur-35, and tritium. Periodically, split samples are analyzed for additional QC purposes.

The federal[5] and state[6] regulatory limits for radioisotopes are based on total amounts released per year. For tritium, this limit is 1.9×10^{11} Bq (5 Ci); and for carbon-14 the limit is 3.7×10^{10} Bq (1 Ci). The annual limit for all other radioisotopes is a combined 3.7×10^{10} Bq (1 Ci).

All results for carbon-14, iodine-125, phosphorus-32, and tritium samples collected at the Hearst and Strawberry Monitoring Stations were below minimum detectable activity (MDA).

Extremely low positive results (near detection limits) for gross alpha, gross beta, and sulfur-35 were found. Thirty-two samples were taken for gross alpha, and three of the samples were found positive slightly above the MDA; however, all three results were less than two times the MDA. In one instance, the positive result was not confirmed by the split sample. The highest gross alpha result was 0.074 Bq (2 pCi/L), which is below the federal and state requirements for drinking water. For gross beta results, the highest result was 0.67 Bq (18 pCi/L), which is below the federal and state requirements for drinking water. For sulfur-35 results, three samples were found positive slightly above the MDA. Two of the three positive sulfur-35 results were not confirmed by the results of the split sample because the split sample results were "none detected." All sulfur-35 results were less than two times the MDA. The highest sulfur-35 result was 0.52 Bq (14 pCi/L), which is below the federal and state requirements for drinking water.

Because most of the results were below the MDA, the total annual discharge reported is a conservative upper-limit estimate. The annual discharge of tritium in wastewater and the discharge of carbon-14 were not detected. The estimate of total discharge of other radioisotopes was 8.0×10^{7} Bq (0.0022 Ci). All radioisotopes together were approximately 0.22% of the federal and state limits.

4.3.2.2 Building 25 Photo Fabrication Shop Wastewater

The Photo Fabrication Shop in Building 25 manufactures electronic circuit boards and screen-print nomenclature on panels, and the shop performs chemical milling, to support the needs of Berkeley Lab research and activities. Wastewater containing metals and acids from these operations is routed to an FTU before discharge to the sanitary sewer. The Building 25 FTU treats wastewater in batches rather than continuously.

All sampling performed by Berkeley Lab and EBMUD—two self-monitorings and three sampling events by EBMUD—yielded daily maximum and monthly average results well below EBMUD discharge limits.[9]

4.3.2.3 Building 77 Ultra-High Vacuum Cleaning Facility Wastewater

The Ultra-High Vacuum Cleaning Facility (UHVCF) at Building 77 cleans various types of metal parts used in research and support operations at Berkeley Lab. Cleaning operations include passivating, acid and alkaline cleaning, and ultrasonic cleaning. Anodizing and a small amount of nickel plating are also performed. Acid and alkaline rinse waters that contain metals from UHVCF operations are routed to a nearby 227 L/minute (L/min) (60 gal/min) FTU.

All sampling performed by Berkeley Lab and EBMUD—three self-monitorings and three sampling events by EBMUD—yielded results well within permitted limits.

The Building 77 permit is currently combined with the Building 25 permit. According to the current permit, pH and metals are monitored: at Building 77, Berkeley Lab samples three times per year; at Building 25, the Laboratory samples twice per year. Instead of monitoring for chlorinated hydrocarbons, the Laboratory now submits a *Total Toxic Organics Compliance Report*[13] twice per year; it certifies that Buildings 25 and 77 are implementing the applicable solvent management plan and that no concentrated toxic organics have been dumped into wastewaters.

4.3.2.4 Treated Hydrauger and Extraction Well Discharge

Since 1993, EBMUD has permitted Berkeley Lab to discharge treated groundwater to the sanitary sewer. The treatment process consists of passing the contaminated groundwater through a two-stage carbon-drum adsorption system.

The EBMUD permit[14] allows for discharge of treated groundwater from certain hydrauger (subsurface drain) treatment systems and extraction wells, and also from well sampling and development activities. Samples of the treated water are collected monthly and analyzed for VOCs using US/EPA-approved methodologies. All samples results verified that discharge limits have not been exceeded. All treated groundwater discharged under the permit is routed through the Hearst Sewer. One of the conditions for this discharge is the submission of a semiannual report that provides information on the volumes treated and discharged, as well as analytical results for samples collected from the treated water. (For further discussion of groundwater monitoring and treatment, see Section 4.4.)

4.4 GROUNDWATER

This section reviews the groundwater monitoring program at Berkeley Lab, emphasizing 2006 results. More detailed information on the program is provided in the Environmental Restoration Program Quarterly Progress Reports, which contain all the groundwater monitoring data, site maps that show monitoring well locations and contaminant concentrations, and graphs that show changes in contaminant concentrations over time. These reports are available for public review at the City of Berkeley main public library and at http://www.lbl.gov/ehs/erp/html/documents.shtml.

Berkeley Lab is currently in the final phase of the RCRA CAP Corrective Measures Implementation (CMI). The primary objectives of groundwater monitoring during this phase are (1) to evaluate the continued effectiveness of the corrective measures that have been implemented for cleanup of contaminated groundwater and (2) to ensure that groundwater plumes are not migrating off-site. An additional objective is to monitor progress toward attaining the long-term goal of restoring all groundwater at the Laboratory to drinking-water standards, if practicable.

4.4.1 Hydrogeologic Characterization

Moraga Formation volcanic rocks, Orinda Formation sediments, and Great Valley Group sediments constitute the principal bedrock units underlying the site. The geologic structure and physical characteristics of these three units, as well as the site topography, are the principal factors controlling the movement of groundwater and groundwater contaminants at the Laboratory. (The geology and hydrogeology of these three units are described in more detail in Section 1.2.7.)

Depth to groundwater is measured monthly in site monitoring wells. The depth to groundwater ranges from approximately 0 to 30 m (0 to 100 ft). Figure 4-5 shows groundwater elevations at Berkeley Lab. This map shows that the groundwater surface generally mirrors the surface topography.

In the western part of Berkeley Lab, groundwater generally flows toward the west; over the rest of the Laboratory, groundwater generally flows toward the south. In some areas, due to the subsurface geometry of geologic units, groundwater flow directions vary from the general trends presented on the groundwater elevation map. The velocity of the groundwater varies from

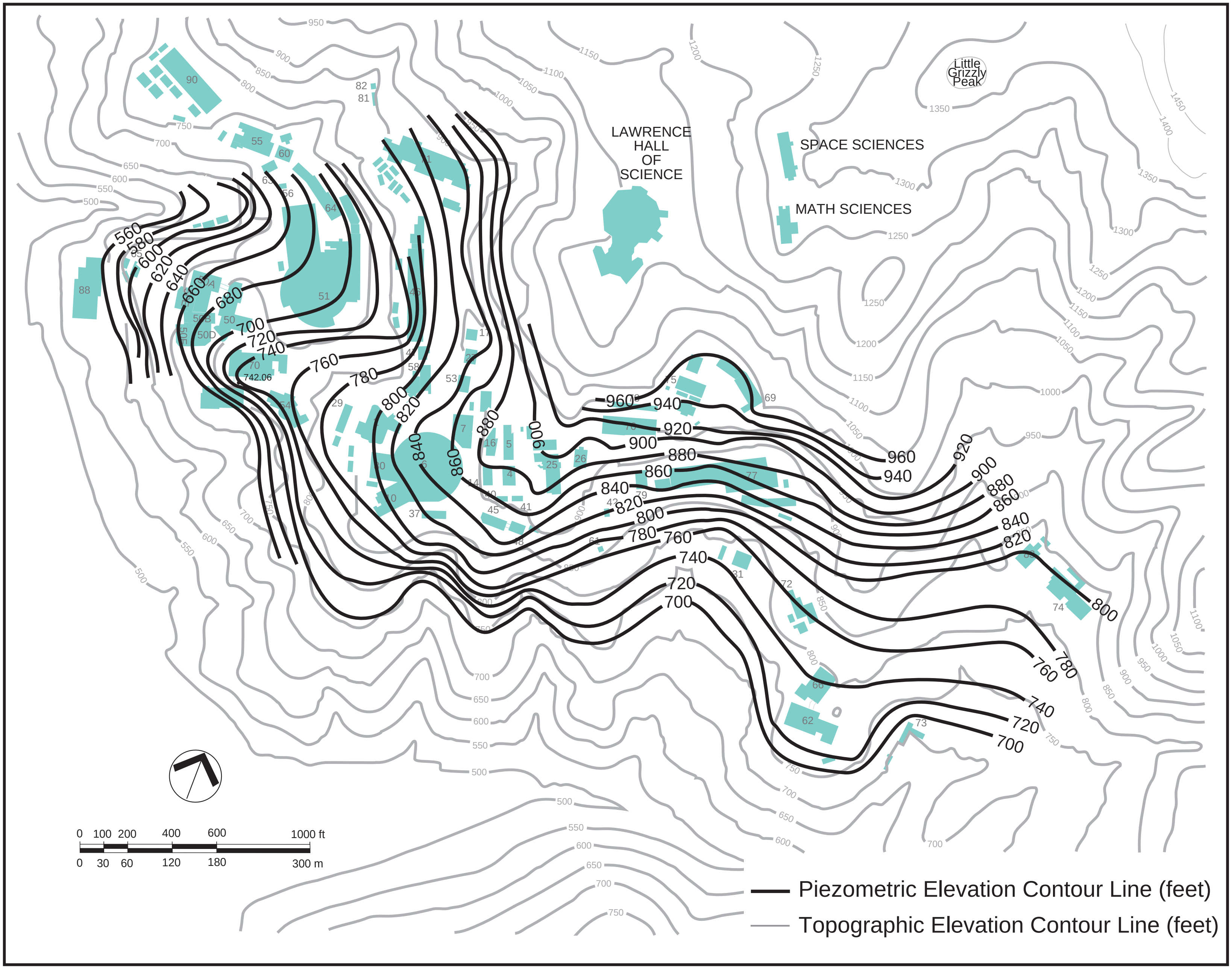


Figure 4-5 Groundwater Piezometric Map

approximately 0.001 meter per year (m/yr) (0.003 foot per year [ft/yr]) to about 300 m/yr (about 1,000 ft/yr).

4.4.2 Groundwater Monitoring Results

The groundwater monitoring network at Berkeley Lab consists of more than 180 wells, with 16 of the wells located nearest the site boundary and 1 well off-site (see figure 4-6). The Laboratory's groundwater monitoring wells are sampled for VOCs, metals, and/or tritium in accordance with a schedule approved by the RWQCB. Selected wells are also monitored for other potential contaminants.

Halogenated VOCs are the primary contaminants that have been detected in the site groundwater. Except for a single well, MWP-7, in which trichloroethylene (TCE) and/or tetrachloroethylene (PCE) were detected at concentrations below the drinking-water standard,[5,6] no VOCs or tritium were detected in any of the 17 perimeter or off-site wells in 2006. Sitewide VOC results are discussed in detail in Section 4.4.3.

The only metals detected in 2006 at concentrations above both the drinking-water standard and Berkeley Lab background levels[15] were arsenic and selenium (in one well each). No plumes are associated with these metals, and the metals are likely to be naturally occurring. Elevated arsenic concentrations, for example, may be attributed to the relatively high concentration of this metal in some sedimentary rocks at the Laboratory. In addition, molybdenum, which has no drinking-water standard, was detected above the background level in four wells.

Concentrations of tritium were below the drinking-water standard in all wells in 2006.

4.4.3 Groundwater Contamination Plumes

Based on groundwater monitoring results, nine principal groundwater contamination plumes have been identified (listed below). One of these plumes, the Old Town plume, has been subdivided into multiple lobes to reflect the commingling of contaminated groundwater from different sources.

- *VOC plumes:* Old Town (Building 7 lobe, Building 25A lobe, and Building 52 lobe), Buildings 51/64, Building 51L, Building 69A, Building 71B, and Building 76
- *Tritium plume:* Building 75
- *Petroleum hydrocarbon (diesel):* Buildings 7 and 74

Additional areas where concentrations of VOCs in the groundwater exceeded the drinking water standard in 2006 are located near Buildings 75/75A and near Building 77; the extent of contamination in these areas is limited. The locations of the plumes and the above drinking water standards in September 2006 are shown on Figure 4-7.

4.4.3.1 Old Town VOC Plume—Building 7 Lobe

The Old Town VOC plume is a broad, multilobed plume that underlies much of the central portion of Berkeley Lab known as "Old Town." The geometry and distribution of chemicals in the plume indicate that it consists of three coalescing lobes that were originally discrete plumes derived from distinct sources. The Building 7 lobe contains significantly higher VOC concentrations than the other two plume lobes, the Building 25A lobe and the Building 52 lobe.

The Building 7 lobe extends northwestward from the northwest corner of Building 7 to the parking area downslope from Building 58. The principal Building 7 lobe constituents are halogenated VOCs that were used as cleaning solvents, including PCE and carbon tetrachloride, and their associated degradation products (e.g. TCE; 1,1-dichloroethene (DCE); cis-1,2-DCE; and vinyl chloride). A number of interim corrective measures were instituted in prior years for the Old Town VOC plume, including excavating contaminated soil from the source area, removing a sump that was the source of the groundwater contamination, and installing several groundwater extraction trenches to control plume migration.

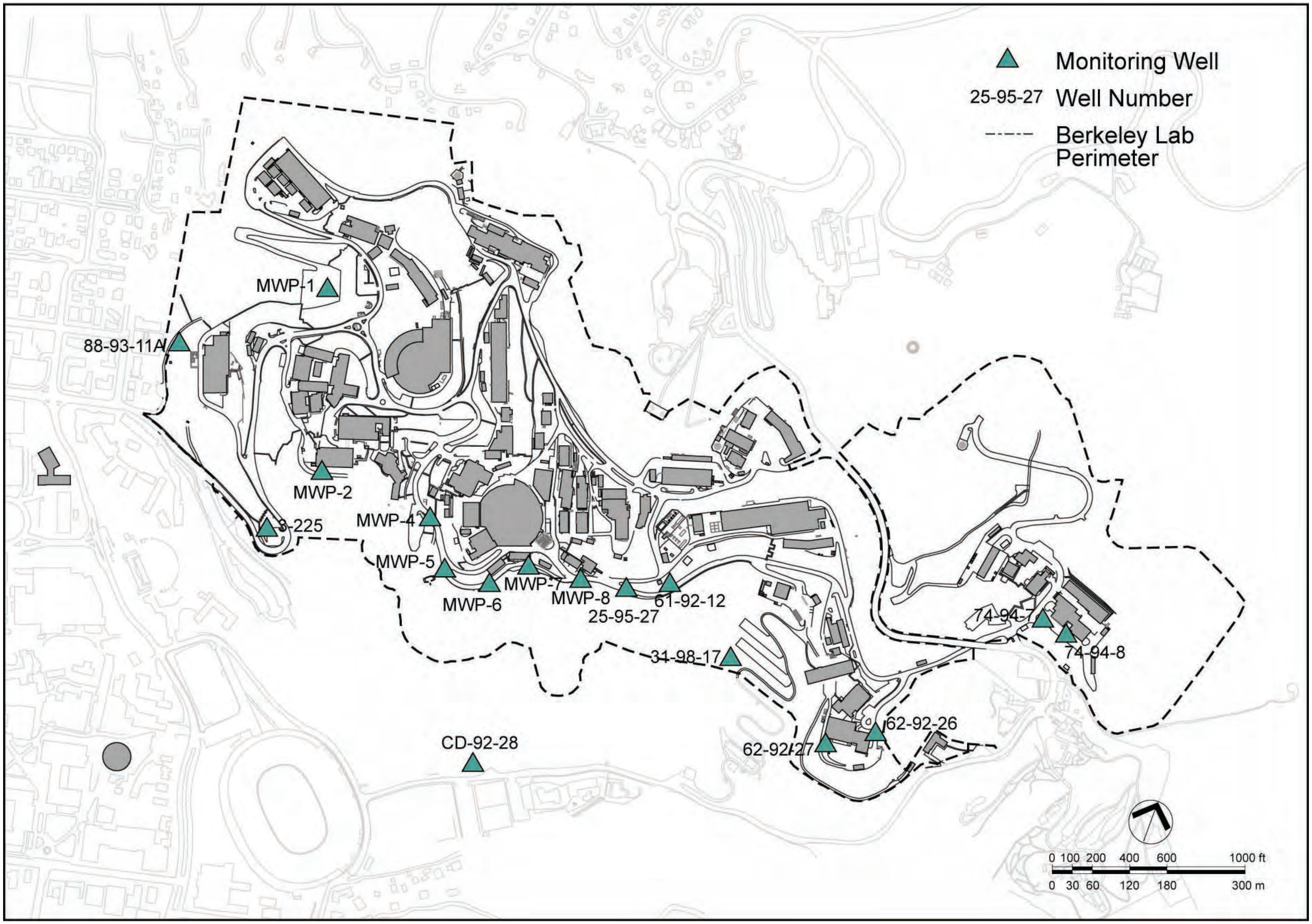


Figure 4-6 Approximate Locations of Monitoring Wells Closest to the Berkeley Lab Property Line

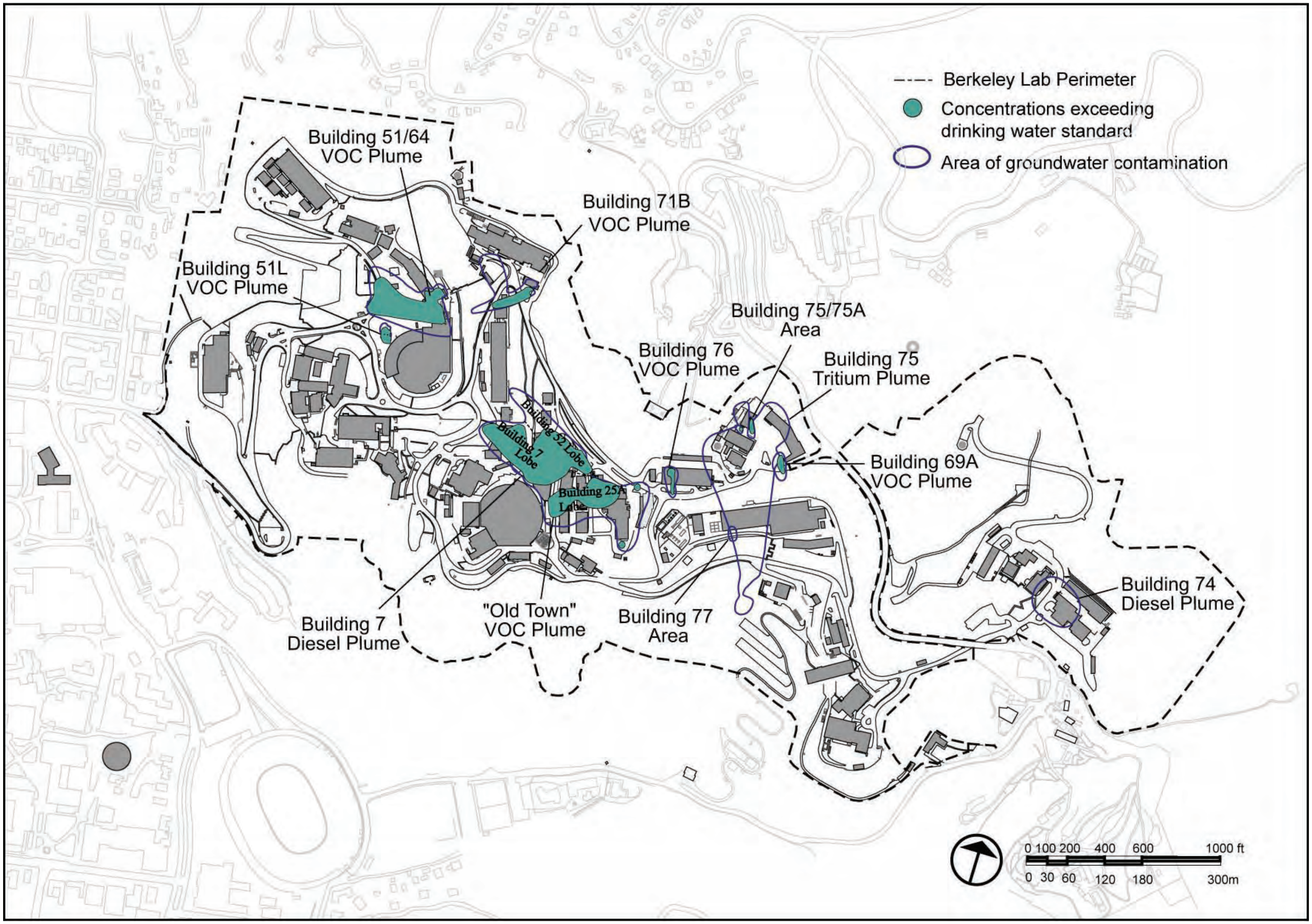


Figure 4-7 Locations of Plumes and Extent of Groundwater Contamination Above Drinking-Water Standards (September 2006)

The corrective measures approved for the Building 7 lobe consist of excavation and off-site disposal of contaminated soil remaining in the source area, continuation of in situ soil flushing, and Monitored Natural Attenuation (MNA). In situ soil flushing consists of the injection of clean water into, and concurrent downgradient extraction of contaminated groundwater out from, the subsurface. The extracted water is cleaned on-site using granular activated carbon (GAC) treatment systems before being reinjected for flushing. MNA refers to the reliance on natural attenuation processes within the context of a carefully controlled and monitored site cleanup approach to achieve site-specific remediation objectives.

Excavation of the source area soil was completed on September 6, 2006. Approximately 420 m^3 (550 yd^3) of contaminated soil were excavated and transported off-site for disposal at a Class 2 landfill. The in situ soil-flushing system consists of three groundwater extraction trenches and numerous groundwater extraction and injection wells. The system is designed to flush contaminants from the subsurface and to control the migration of contaminated groundwater.

The source removal together with in situ soil flushing has significantly reduced VOC concentrations through much of the Building 7 lobe area, with the annual average concentration of total VOCs in source and core area wells declining from approximately 20,000 micrograms per liter (µg/L) to less than 3,000 µg/L in 2006. The maximum concentration of total VOCs detected in 2006 was 64,310 µg/L, which primarily consisted of PCE (37,000 µg/L) and TCE (25,000 µg/L). It should be noted that because this sample was collected from a well that is screened entirely in a low-permeability zone in the core of the plume, it is not representative of the overall Old Town plume contamination.

4.4.3.2 Old Town VOC Plume—Building 25A Lobe

The Building 25A lobe of the Old Town VOC plume encompasses two subplumes of groundwater contamination. The main Building 25A subplume extends from the western portion of Building 25A westward to the eastern edge of Building 6. The Building 25 subplume is located south of Building 25. The principal constituents of the Building 25A subplume are halogenated VOCs that were used as cleaning solvents, including TCE and its degradation products (e.g. 1,1-DCE and cis-1,2-DCE). Carbon tetrachloride is also present at low concentrations.

The corrective measures approved for the Building 25A lobe consist of continuation of in situ soil flushing. Since flushing was started in 2002, the annual average concentration of total VOCs in the Building 25A subplume source and core area wells has declined from approximately 300 µg/L to 70 µg/L in 2006. Significant declines in the concentrations of VOCs have been observed in the Building 25 subplume since the initiation of soil flushing in April 2006, with the concentration of carbon tetrachloride declining to less than the drinking-water standard. Soil flushing was temporarily halted on September 2, 2006, to monitor for possible rebound in contaminant levels. Except for carbon tetrachloride (0.68 µg/L), which slightly exceeded the drinking-water standard of 0.5 µg/L, concentrations of VOCs in groundwater samples collected south of Building 25 remained below the drinking-water standard.

4.4.3.3 Old Town VOC Plume—Building 52 Lobe

The Building 52 lobe of the Old Town VOC plume extends northwest from the area east of Building 52 to the east edge of Building 46, where the contaminated groundwater is captured by a subdrain that was installed in the 1950s as a landslide mitigation measure. The principal lobe constituents are halogenated VOCs that were used as cleaning solvents, including PCE and carbon tetrachloride, and their degradation products (e.g. TCE; 1,1-DCE; cis-1,2-DCE; and chloroform).

The corrective measures approved for the Building 52 lobe consist of continuation of in situ soil flushing and the continued capture of groundwater at the Building 46 subdrain. Since flushing was started in 2003, the annual average concentration of total VOCs in the Building 52 lobe source and core area wells has declined from more than 100 µg/L to less than 10 µg/L in 2006, with concentrations declining to levels below drinking-water standards through much of the lobe area.

4.4.3.4 Building 51/64 VOC Plume

The Building 51/64 VOC Plume extends south and west from the southeast corner of Building 64 beneath the former location of Building 51B. The principal plume constituents are halogenated VOCs that were used as cleaning solvents, including 1,1,1-trichloroethane (TCA); TCE; PCE; and their associated degradation products (e.g. 1,1-DCE; 1,1-dichloroethane (DCA); cis-1,2-DCE; and vinyl chloride).

In 2000, contaminated soil was excavated from the source area of the plume as an interim corrective measure. The corrective measures approved for the Building 51/64 VOC Plume consist of continuation of in situ soil flushing, MNA, and the continued collection and treatment of water from the Building 51 subdrain system. In addition, Hydrogen Release Compound (HRC) is being injected into the subsurface to enhance the natural degradation processes in the downgradient plume area. Since flushing was started in 2003, the annual average concentration of total VOCs in source and core area wells has declined from more than 4,000 µg/L to 300 µg/L in 2006. The maximum concentration of total halogenated VOCs (primarily 1,1-DCA) detected in 2006 was 9,389 µg/L in a groundwater sample from a multiport well in the source area. This well was constructed with short, approximately 1 ft, screened intervals to target specific permeable zones within the bedrock, and therefore it is not representative of the water-bearing unit as a whole. Excluding the multiport well, the maximum total VOC concentration in the source area has declined from more than 700,000 µg/L prior to excavation of the source area in 2000 to less than 1,000 µg/L at the end of 2006.

4.4.3.5 Building 51L VOC Plume

The Building 51L VOC plume is located beneath the area where Building 51L was located. The principal plume constituents are halogenated VOCs that were used as cleaning solvents, including TCE, PCE, and associated degradation products (e.g., cis-1,2-DCE; trans-1,2-DCE; and vinyl chloride). The maximum concentration of total VOCs (primarily cis-1,2-DCE) detected in 2006 was 979 µg/L.

The corrective measure approved for the Building 51L VOC plume was excavation of the contaminated source area soil. At the end of 2006, approximately 1,030 m^3 (1,350 yd^3) of contaminated soil were excavated from the source area of the plume and transported off-site for disposal at a Class 2 landfill. This action should significantly reduce VOC concentrations in the groundwater.

4.4.3.6 Building 69A VOC Plume

The Building 69A VOC plume is located west of Building 69A. The principal plume constituents are degradation products of halogenated VOCs (e.g., cis-1,2-DCE and vinyl chloride) that were used as cleaning solvents.

The corrective measure approved for the Building 69A VOC Plume is MNA. In addition, HRC is being injected into the subsurface to enhance the natural degradation processes. The maximum concentration of total

VOCs (primarily cis-1,2-DCE) detected in 2006 was 113 µg/L. Since HRC injection was started, the concentrations of cis-1,2-DCE and vinyl chloride in wells monitoring the plume have generally declined.

4.4.3.7 Building 71B VOC Plume

The Building 71B VOC plume extends southwest from Building 71B toward the Building 51/64 area. The principal plume constituents are halogenated VOCs that were used as cleaning solvents, including TCE and PCE, and their associated degradation products (e.g. cis-1,2-DCE). Between 2000 and 2004, highly contaminated soil was excavated from the plume source area as interim corrective measures.

The corrective measures approved for the Building 71B VOC plume consist of continuation of in situ soil flushing with the injection of HRC and continued collection and treatment of contaminated effluent from the hydraugers that drain groundwater from the slope west of Building 46A.

Since flushing was started in 2004, the annual average concentration of total VOCs in source area wells has declined from more than 300 µg/L to approximately 30 µg/L in 2006. Concentrations of total VOCs declined from a maximum of more than 6,000 µg/L initially to approximately 20 µg/L at the end of 2006.

4.4.3.8 Building 76 VOC Plume

The Building 76 VOC plume extends approximately 100 feet southward from the motor-pool area on the south side of Building 76. The principal plume constituent is the cleaning solvent TCE and its degradation products (e.g. cis-1,2-DCE). The maximum concentration of total VOCs detected in groundwater samples collected in 2006 was 31 µg/L. No corrective measures are required for the Building 76 plume.

4.4.3.9 Tritium Plume

The Building 75 tritium plume extends southward from Building 75 toward Chicken Creek and covers the areas of Buildings 69, 75, 75A, 75B, and 77. In addition, low concentrations of tritium have been detected in monitoring wells in the Building 71B area, although no tritium was detected in the Building 71B area in 2006. (The detection limit is <11 Bq/L [<300 pCi/L]). The source of the tritium was the former NTLF at Building 75. The maximum concentration of tritium detected in groundwater in 2006 was at monitoring well 75-97-5 and measured 622 Bq/L (16,800 pCi/L), which is below the drinking-water standard of 740 Bq/L (20,000 pCi/L).[5] Monitoring well 75-97-5 historically has been the only monitoring well in which tritium has been detected above the drinking-water standard. Concentrations of tritium in monitoring well 75-97-5 have been decreasing since closure of the NTLF, with the concentration below the drinking-water standard since the beginning of 2005.

4.4.3.10 Petroleum Hydrocarbon Plumes

Petroleum hydrocarbon contaminated groundwater is present in two areas where USTs formerly were located: north of Building 6 and near Building 74. No aromatic VOCs, including BTEX components (i.e., benzene, toluene, ethyl benzene, xylenes), were detected at either of the UST sites in 2006. A dual-phase (groundwater and soil vapor) extraction and treatment system was installed north of Building 6 in 1998 as an interim corrective measure and continues to operate.

4.4.4 Treatment Systems

As described above, Berkeley Lab is using collection trenches and subdrains to control the migrations of groundwater plumes. Eleven GAC systems were operated in 2006 to treat the extracted groundwater. The treated water is used mainly for on-site soil-flushing activities. Excess water is released to the sanitary sewer in accordance with Berkeley Lab's treated groundwater discharge permit from EBMUD.[14]

The total volume of contaminated groundwater treated by these systems during the year was about 51,800 m^3 (13.7 million gal).

4.5 SOIL AND SEDIMENT

This section summarizes the monitoring results for soil and sediment samples.

4.5.1 Soil Sampling Results

Soil samples obtained from the top 2 to 5 cm (1 to 2 in) of surface soils were collected from three locations on the Laboratory site and one off-site environmental monitoring station (see Figure 4-8). Samples were analyzed for gross alpha and gross beta radiation, gamma emitters, tritium, moisture content, pH, and metals.

For radioisotope analysis, the alpha, beta, and gamma emitter results were similar to background levels of naturally occurring radioisotopes commonly found in soils. Tritium measurements at each of the sampling locations were below detection limits.

For non-radioisotope analysis, measurements of pH and moisture content at each of the sampling locations were within the typical range for soils. All metal concentrations measured were at or near the established background values for the Berkeley Lab site. The sample collected at the Building 80 location contained a mercury concentration of 1.20 milligrams per kilogram (mg/kg), which is above the upper-level background value for mercury (0.60 mg/kg) in soil at Berkeley Lab but well below the Preliminary Remediation Goal of 310 mg/kg set up by the US/EPA.[16] This location will be sampled in future years to monitor any changes in mercury concentrations.

4.5.2 Sediment Sampling Results

Sediment samples were collected at the main and tributary creek beds of the North Fork of Strawberry Creek and Chicken Creek (see Figure 4-8). The samples were analyzed for gross alpha, gross beta, and gamma emitters, tritium, metals, pH, moisture content, and petroleum hydrocarbons (diesel fuel and oil/grease).

For radioisotope analysis, the levels of alpha, beta, and gamma emitters were within background levels of naturally occurring radioisotopes commonly founds in sediments. Tritium measurements at each of the sampling locations were below detection limits.

For non-radioisotope analysis, all metals concentrations measured were at or near the established background values for the Berkeley Lab site.[17] Measurements of pH, moisture content, and petroleum hydrocarbons (TPH diesel and oil/grease) at all of the locations were within the historical values typically found at the Berkeley Lab site over the past five years.

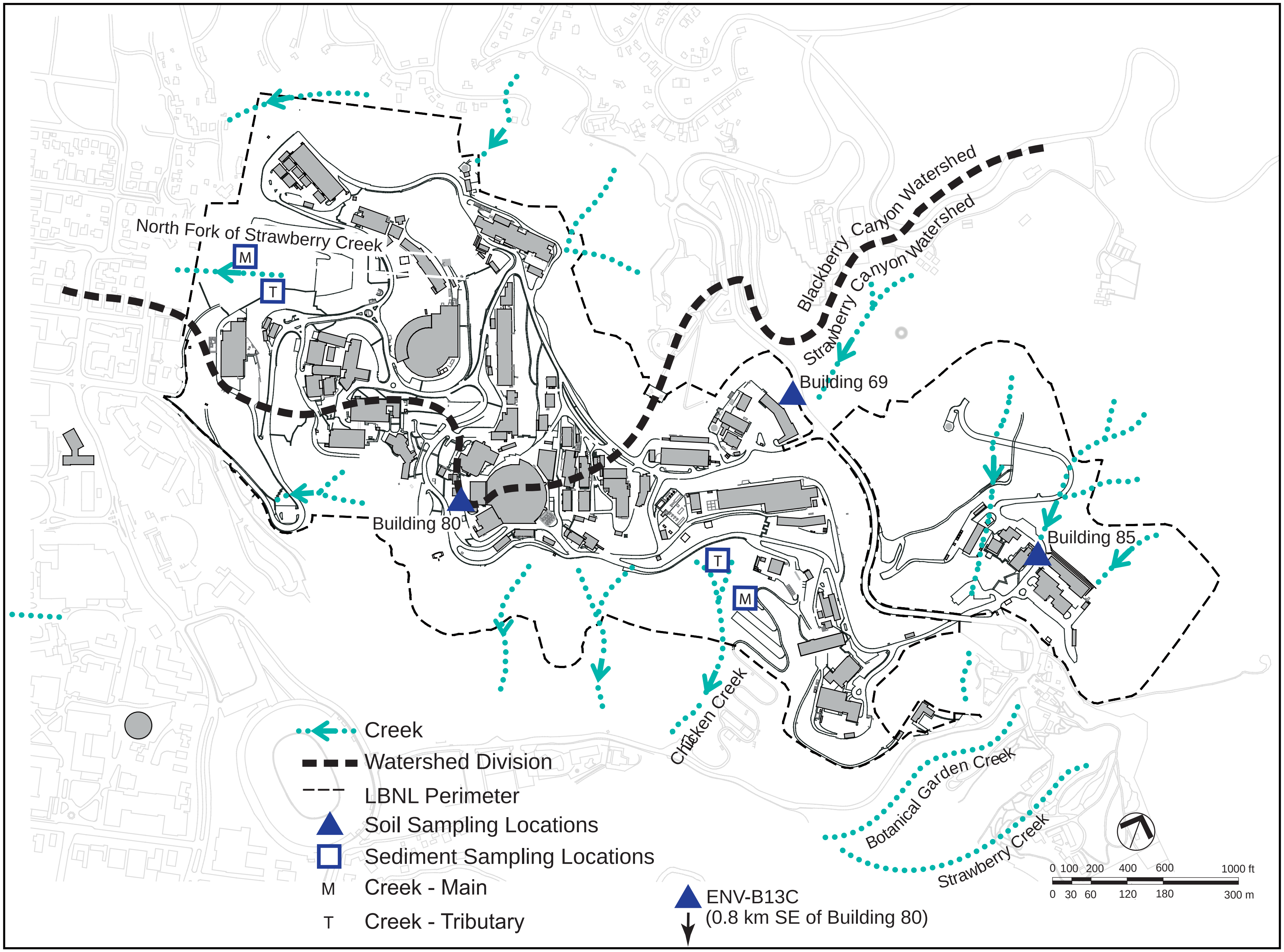


Figure 4-8 Soil and Sediment Sampling Sites

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 Berkeley Lab activities and to calculate potential human doses that would occur from consuming vegetation and foodstuffs.

Due to historical air emissions from the former NTLF Hillside Stack, vegetation near that site contains measurable concentrations of tritium. Tritium in vegetation occurs in two chemical forms—tissue-free water tritium and organically bound tritium—and Berkeley Lab analyzes vegetation for both forms.

Since the closure of the NTLF in 2002, tritium emissions from Berkeley Lab have decreased sharply, and concentrations in vegetation are expected to slowly decrease with time. To document changes in the concentrations of tritium in the local vegetation, Berkeley Lab samples it at least every five years; in 2006, no routine vegetation samples were collected for this purpose.

4.7 PENETRATING RADIATION MONITORING

Radiation-producing machines (e.g., accelerators, x-ray machines, irradiators) and various radionuclides are used at Berkeley Lab for high-energy particle studies and biomedical research. Penetrating radiation is associated primarily with accelerator and irradiator operations at the Laboratory.

When operating, accelerators produce both gamma radiation and neutrons. To detect gamma radiation and neutrons from accelerator operations, Berkeley Lab places radiation-detection equipment at environmental monitoring stations near the site's research accelerators, which include the Advanced Light Source Facility (Building 6), Biomedical Isotope Facility (Building 56), and 88-Inch Cyclotron (Building 88).

The Laboratory uses two methods to determine the environmental radiological impact from accelerator operations:

- Real-time monitors that continuously detect and record gamma radiation and neutron doses
- Passive detectors called "thermoluminescent dosimeters" (TLDs), which by laboratory analysis provide an average dose over time from gamma radiation

The locations of real-time monitors and TLDs are shown in Figure 4-9. Results of both measurement methods are given in terms of "dose" and are provided in Section 5.2.

Irradiators at Berkeley Lab produce only gamma radiation. Used for radiobiological and radiophysics research, a gamma irradiator with a 1.5×10^{13} Bq (400 Ci) cobalt-60 source is housed at Berkeley Lab in Building 74; the irradiator is in a massive interlocked structure that is covered with reinforced concrete. Routine surveys confirmed that the maximum gamma radiation doses at 1 m (3.3 ft) from the outside walls or ceiling of the building were indistinguishable from background levels (0.002 mSv per hour (mSv/hr) [0.2 mrem/hr]).

Berkeley Lab also uses other, smaller, well-shielded gamma irradiators that pose considerably less potential for environmental impact than does the Building 74 irradiator. This class of smaller irradiators does not measurably increase the dose to the public.

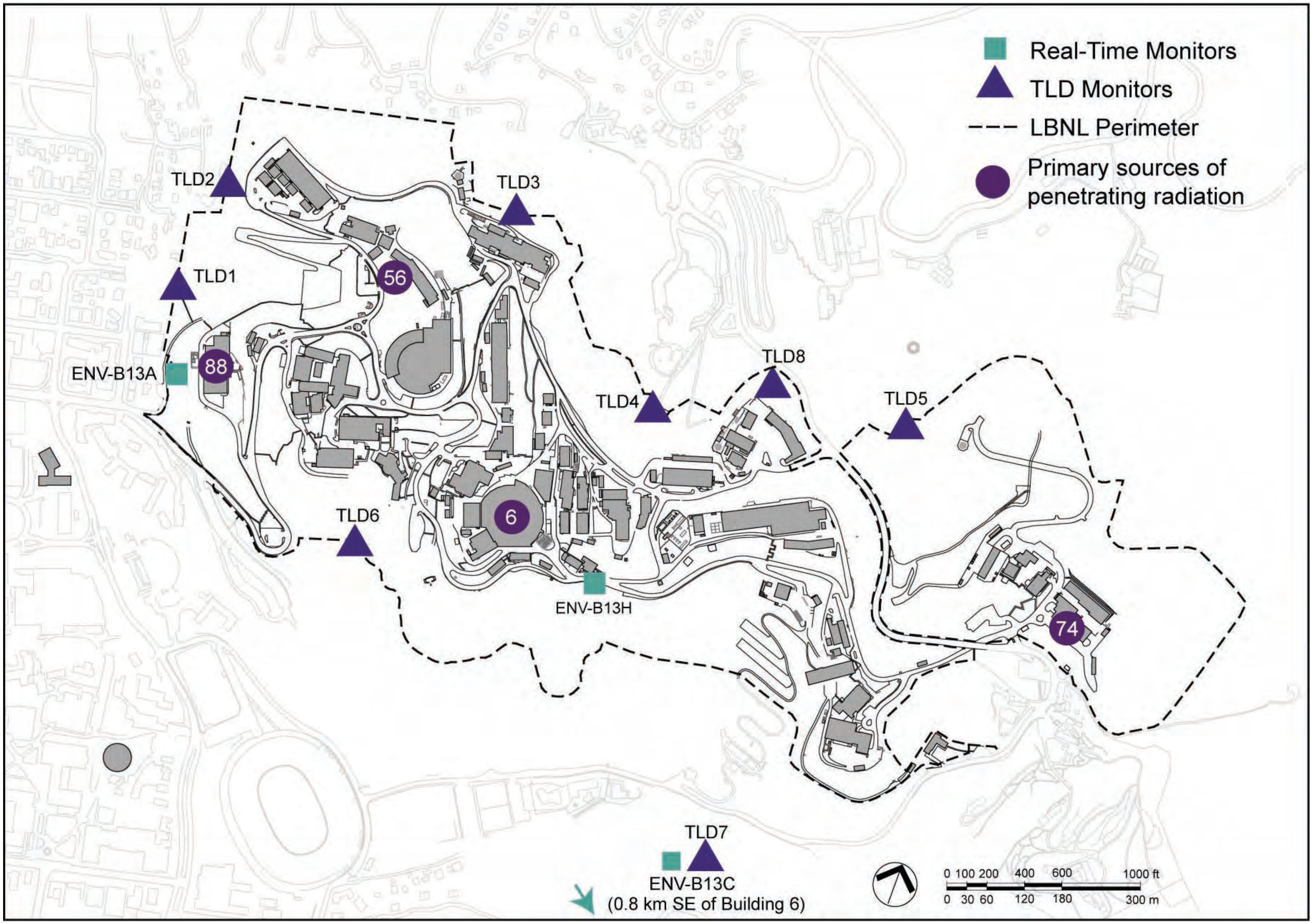


Figure 4-9 Environmental Penetrating Radiation Monitoring Stations

5 Radiological Dose Assessment

North side of the Advanced Light Source Facility

5.1 BACKGROUND

Earlier chapters refer to monitoring and sampling results in terms of concentrations of a substance. An exposure to concentrations of a substance over a period of time is referred to as "dose." Because doses are calculated rather than measured, they represent potential or estimated, instead of actual, doses. This chapter presents the estimated dose results from Lawrence Berkeley National Laboratory's penetrating radiation and airborne radionuclide monitoring programs. These doses include all known radionuclides released in significant quantities from Berkeley Lab. The doses projected from each monitoring program are presented separately before they are cumulatively evaluated to summarize the overall impact of the Laboratory's radiological activities on members of the public. Additionally, the radiological impact of Berkeley Lab's operations on local animals and plants is discussed.

To minimize radiological impacts to the environment and the public, Berkeley Lab manages its programs so that radioactive emissions and external exposures are as low as reasonably achievable (ALARA). The Laboratory's Environmental ALARA Program ensures that a screening (qualitative) review is performed on activities that could result in a dose to the public or the environment. Potential doses from activities that may generate airborne radionuclides are estimated through the NESHAP[1] process. If the potential for a public dose is greater than 0.01 mSv (1 mrem) to an individual or 0.1 person-sievert (person-Sv) (10 person-rem) to a population, an in-depth quantitative review is required. No quantitative reviews were required or performed in 2006.

5.2 DOSE FROM PENETRATING RADIATION

As discussed in Section 4.7, penetrating radiation from Berkeley Lab operations is measured by real-time monitors and TLDs. Results of penetrating radiation measurements by both methods indicate that the maximum dose to a member of the public (hypothetical person residing near the 88-inch Cyclotron) from penetrating radiation was indistinguishable from natural background levels.

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 concentration is inhaled in air, ingested in drink or food, or absorbed through skin contact with soil or other environmental media. Dispersible radionuclides originate as emissions from building exhaust points generally located on rooftops, as discussed in Section 4.2.1. Once emitted, these radionuclides may affect any of several environmental media: air, water, soil, plants, and animals. Each of these media represents a possible pathway of exposure affecting human dose.

Dose to an individual and the population is determined using computer dispersion models. The NESHAP regulation requires that any facility that releases airborne radionuclides assess the impact of such releases using a computer program approved by the US/EPA.[1] Berkeley Lab satisfies this requirement with the use of the EPA-approved program CAP88-PC.[2] Details of dose calculations from dispersible airborne radionuclides are included in the Laboratory's annual NESHAP report, available at http://www.lbl.gov/ehs/esg/tableforreports/tableforreports.htm.

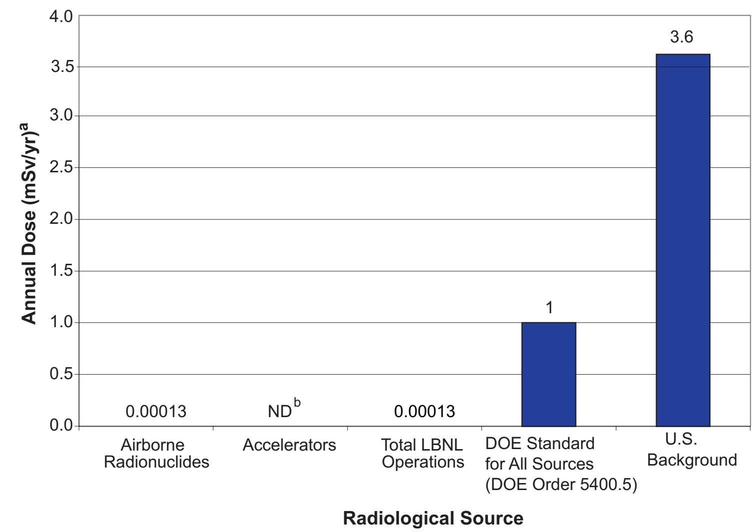
Based on these calculations, the location of the maximally exposed individual (MEI) to airborne emissions was determined to be at the Lawrence Hall of Science (LHS). The maximum possible dose to the MEI (a person residing at the LHS) from airborne radionuclides for 2006 was about 1.3×10^{-4} mSv (0.013 mrem). This value is about 0.1% of the US/EPA annual limit (0.10 mSv/yr [10 mrem/yr]).[1]

The dose from airborne radionuclides to the surrounding population is estimated for a region that extends from the site for 80 km (50 mi). Within this area, the population is about 6,615,000.[3] The estimated population dose from all airborne radionuclides for the year was 1.3×10^{-3} person-Sv (0.13 person-rem).

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 local background radiation levels. Because the greatest possible dose from penetrating radiation was indistinguishable from doses due to background radiation, the 2006 total dose to the MEI from Berkeley Lab activities is due solely to exposure to airborne radionuclides. As presented in Figure 5-1, the maximum effective dose equivalent from Berkeley Lab operations to an individual residing at LHS in 2006 was about 1.3×10^{-4} mSv/yr (0.013 mrem/yr). This dose was primarily from fluorine-18 from the cyclotron at the Biomedical Isotope Facility (Building 56) and from iodine-125 used in biomedical research in Building 55. This value is approximately 0.005% of the average United States background radiation[4] (3.6 mSv/yr [360 mrem/yr]) and about 0.01% of the DOE annual limit (1.0 mSv/yr [100 mrem/yr]).[5]

As noted previously, the estimated dose to the population within 80 km (50 mi) of Berkeley Lab from airborne radionuclides emitted by laboratory operations was 1.3×10^{-3} person-Sv (0.13 person-rem) for the same period. From natural background airborne radionuclides alone, this same population receives an estimated dose of 13,000 person-Sv (1,300,000 person-rem). The dose to the population from Berkeley Lab is less than 0.00001% of the background level.



a 1 mSv/yr = 100 mrem/yr

b Nondetect: Dose from penetrating radiation was indistinguishable from natural background radiation levels.

Figure 5-1 Comparison of Radiological Dose Impacts for 2006

5.5 DOSE TO ANIMALS AND PLANTS

Liquid effluent and airborne emissions may have pathways to animals and plants in addition to their pathways to humans. DOE requires that aquatic organisms be protected by limiting their radiation doses to 1 rad/day (0.01 gray per day [Gy/day]).[5] In addition, international recommendations suggest that doses to terrestrial animals should be limited to less than 0.1 rad/day (0.001 Gy/day), and doses to terrestrial plants should be limited to 1 rad/day (0.01 Gy/day).[6]

Several sources of exposure were considered, including animal ingestion of vegetation, water, and soil; animal inhalation of soil; plant uptake of water; and 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, alpha-emitting radionuclides, and beta-emitting radionuclides. Alpha- and beta-emitting radionuclides in soil and sediment were further characterized by gamma spectroscopy.

These radionuclides, with the exception of tritium, were measured at levels similar to natural background levels. Sample results are provided in Volume II. Alpha- and beta-emitting radionuclides and tritium were evaluated using the DOE-endorsed computer model RESRAD-BIOTA.[7] Both terrestrial and aquatic systems passed the "general screening process" (described in a DOE-approved technical standard[6]), which confirms that Berkeley Lab is in compliance with DOE requirements to limit radiation doses to aquatic organisms to 1 rad/day (0.01 Gy/day). It also shows that the Laboratory is well within international recommendations for limiting dose to other plants and animals.

6 Quality Assurance

View of Berkeley Lab from the hills above

6.1 OVERVIEW

Lawrence Berkeley National Laboratory's quality assurance (QA) policy is documented in the *Operating and Quality Management Plan* (OQMP).[1] The OQMP consists of a set of operating principles used to support internal organizations in achieving consistent, safe, and high-quality performance in their work activities. OQMP principles are applied to individual programs through a graded approach, with consideration given to factors such as environmental, health, and safety consequences.

In addition to the OQMP, the monitoring and sampling activities and results presented in this report were conducted in accordance with Berkeley Lab's *Environmental Monitoring Plan*[2] and applicable DOE[3] and US/EPA[4] guidance. When special QA and quality control (QC) requirements are necessary for environmental monitoring (such as the NESHAP stack monitoring program), a Quality Assurance Project Plan is developed and implemented.

On-site and external analytical laboratories analyze samples for the environmental monitoring program. Both types of laboratories must meet demanding QA and QC specifications and certifications[5] that were established to define, monitor, and document laboratory performance. The QA and QC data provided by these laboratories are incorporated into Berkeley Lab's processes performed to assess data quality. For 2006, seven external analytical laboratories were available for use under contract(s) jointly administered by Berkeley Lab and Lawrence Livermore National Laboratory.

Each set of data (batch) received from the analytical laboratory 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.

The DOE Consolidated Audit Program (DOECAP) annually audits all external analytical laboratories supporting DOE facilities, including those working with Berkeley Lab. In general, DOECAP audits are two to three days in length with five or more auditors participating in the audit. A member of DOE or a DOE contractor representative, trained as a Nuclear Quality Assurance (NQA-1) lead auditor, heads the DOECAP audit team. Other team members come from across the DOE complex and add a wealth of experience. Typically, Berkeley Lab sends one representative to participate in DOECAP audits of Berkeley Lab's external analytical laboratory locations. The team audits each of the following six areas that pertains to the services provided by the particular external analytical laboratory:

1. QA management systems and general laboratory practices
2. Organic analyses
3. Inorganic and wet chemistry analyses
4. Radiochemical analyses
5. Laboratory information management systems and electronic deliverables
6. Hazardous and radioactive material management

The laboratory audits also include a review of the external analytical laboratory's performance in proficiency testing required by the California Environmental Laboratory Accreditation Program. No major deficiencies were found during any of the audits of the seven external laboratories used by Berkeley Lab during the year. Any minor deficiencies identified in the audits are followed by corrective action plans and are tracked to closure.

To verify that environmental monitoring activities are adequate and effective, internal assessments are performed. In 2006, an ESG subject-matter expert performed assessments on the NESHAP Monitoring Program. This assessment found the Monitoring Program to be in compliance with US/EPA and Berkeley Lab requirements.

In addition, external oversight of Berkeley Lab programs is performed through the DOE Operational Awareness Program.[6] Operational awareness activities are ongoing and include field orientation, meetings, audits, workshops, document and information system reviews, and day-to-day communications. DOE criteria for performance evaluation include (1) federal, state, and local regulations with general applicability to DOE facilities and (2) applicable DOE requirements. This program enables DOE to directly oversee Berkeley Lab programs and assess performance.

6.2 PROFILE OF ENVIRONMENTAL MONITORING SAMPLES AND RESULTS

Berkeley Lab's environmental monitoring program collected 847 individual samples (air, sediment, soil, and water) throughout the year; the samples generated more than 2,650 analytical results. In comparison, in 2005 the program collected 1,180 samples, which generated 2,850 analyses. The reduction primarily was due to Berkeley Lab's implementation of a smaller EPA-approved NESHAP stack air monitoring program (see Section 4.2.1 for more information). In all, the samples collected by these programs were obtained from nearly 80 different locations on or surrounding the Berkeley Lab site.

The Environmental Restoration Program also collects and analyzes large numbers of samples throughout the year, which are discussed in reports that can be found at http://www.lbl.gov/ehs/erp/html/documents.shtml and at the Berkeley Public Library. In the next *Site Environmental Report*, we will also summarize the profile of samples and results from the Environmental Restoration Program.

6.3 SPLIT AND DUPLICATE RESULTS 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 collected in the field. In 2006, a total of 88 split and 54 duplicate samples from all programs were collected for either radiological or nonradiological (or both) analyses. The number of split and duplicate samples is well above Berkeley Lab's goal of analyzing one split or duplicate sample for every 10 environmental samples. Additionally, there were 189 blank samples submitted for QA purposes. Blank samples can identify contamination that was obtained outside of the sampling period.

Berkeley Lab uses the metrics of relative percent difference and relative error ratio to determine whether paired results (split-sample; duplicate-sample) 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 where analytical error is determined.

When the primary sample and the split or duplicate sample results are below analytical detection limits, results from these tests are not meaningful. When QA pair results are outside of control limits, an investigation is performed to determine the cause of the discrepancy.

Individual data results for all environmental monitoring programs are presented in Volume II.

6.4 QUALITY CONTROL RESULTS FROM ANALYTICAL LABORATORIES

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.

Six analytical laboratories performed 391 radiological and nonradiological analyses on QC samples in 2006 with an additional 430 similar analyses on QC blank samples. Table 6-1 shows the breadth and diversity of this program.

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. When QC results are outside of established criteria, an investigation is performed to determine the cause of the discrepancy. In 2006, several such investigations were performed, and corrective actions were identified and implemented.

The Environmental Restoration Program also collects and analyzes large numbers of samples throughtout the year, which are discussed in reports that can be found at http://www.lbl.gov/ehs/erp/html/documents.shtml and at the Berkeley Public Library. In the next Site Environmental Report, we will also summarize the profile of samples and results from the Environmental Restoration program.

Table 6-1 Summary of Quality Control Testing Performed by Analytical Laboratories in 2006

Program	Sample batches	QC analyses[a]	Laboratories involved	Radiological	Non-radiological
Ambient air	13	138	2	X[b]	
Rainwater	9	17	3	X	
Sediment	1	53	5	X	X[c]
Soil	1	47	5	X	X
Stack air	21	218	4	X	X
Stormwater and creeks	7	68	4	X	X
Wastewater	21	280	5	X	X

[a] Includes blank, duplicate, and split samples

[b] An "X" in this column denotes that the program tests for radiological substances.

[c] An "X" in this column denotes that the program tests for nonradiological substances.

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Acronyms and Abbreviations

AEDE	annual effective dose equivalent
AFV	alternative fuel vehicle
ALARA	as low as reasonably achievable
ASPCP	Accidental Spill Prevention and Containment Plan
AST	aboveground storage tank
BAAQMD	Bay Area Air Quality Management District
Basin Plan	Water Quality Control Plan for the San Francisco Bay Basin
Berkeley Lab	Ernest Orlando Lawrence Berkeley National Laboratory
Bq	becquerel
BTEX	benzene, toluene, ethyl benzene, and xylene
BTU	British thermal units
C	Celsius
CAP	Corrective Action Program
CARB	California Air Resources Board
CCCSD	Central Contra Costa Sanitary District
CEQA	California Environmental Quality Act of 1970
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CESA	California Endangered Species Act
CFR	Code of Federal Regulations
Ci	curie
cm	centimeter
CMI	Corrective Measures Implementation
CMS	Corrective Measure Study
COD	chemical oxygen demand
CWA	Clean Water Act
CY	calendar year

DCA	dichloroethane
DCE	dichloroethylene
DHS	Department of Health Services
DOE	United States Department of Energy
DOECAP	DOE Consolidated Audit Program
DPM	diesel particulate matter
DTSC	Department of Toxic Substances Control
EBMUD	East Bay Municipal Utility District
EH&S	Environment, Health, and Safety Division at Berkeley Lab
EMP	Environmental Management Program
EMS	environmental management system
EPCRA	Emergency Planning and Community Right-to-Know Act
ESG	Environmental Services Group
F	Fahrenheit
FESA	Federal Endangered Species Act
ft	foot
FTU	fixed treatment unit
FY	fiscal year
GAC	granular activated carbon
gal	gallon
General Permit	*Industrial Activities Storm Water General Permit*
gsf	gross square feet
gsm	gross square meters
Gy	gray (measure of radiation in SI)
HMBP	Hazardous Materials Business Plan
hr	hour
HRC	Hydrogen Release Compound
HVAC	heating, ventilation, and air-conditioning
HWHF	Hazardous Waste Handling Facility
in	inch
ISM	Integrated Safety Management
ISO	International Organization for Standardization
JGI	Joint Genome Institute
kg	kilogram
km	kilometer
L	liter
lb	pound
LBNL	Lawrence Berkeley National Laboratory
LHS	Lawrence Hall of Science
m	meter
m^3	cubic meter
MEI	maximally exposed individual
mg	milligram
mi	mile(s)
mrem	millirem
mSv	millisievert
NEPA	National Environmental Policy Act of 1969
NESHAP	National Emission Standards for Hazardous Air Pollutants
NOV	Notice of Violation
NQA	Nuclear Quality Assurance
NTLF	National Tritium Labeling Facility
OAP	Operating and Assurance Plan
OQMP	Operating and Quality Management Plan
PBT	persistence, bioaccumulation, and toxicity
PCB	polychlorinated biphenyl
PCE	perchloroethylene (tetrachloroethylene)

pCi	picocurie (one trillionth of a curie)
QA	quality assurance
QC	quality control
RCP	Recycled Content Products
RCRA	Resource Conservation and Recovery Act
rem	roentgen equivalent man
RMPP	Risk Management and Prevention Plan
RWQCB	Regional Water Quality Control Board
s	second
SARA	Superfund Amendments and Reauthorization Act
SI	Système Internationale or International System of Units (the metric system)
SPCC	Spill Prevention, Control and Countermeasures
Sv	sievert
SWMP	Storm Water Monitoring Program
SWPPP	Storm Water Pollution Prevention Plan
SWRCB	State Water Resources Control Board
TCA	trichloroethane
TCE	trichloroethylene
TLD	thermoluminescent dosimeter
TOC	total organic carbon
TOMP	Toxic Organics Management Plan
TPH	total petroleum hydrocarbons
TRI	Toxic Release Inventory
TSCA	Toxic Substances Control Act
TSS	total suspended solids
UC	University of California
UCOP	University of California Office of the President
µg	microgram(s)
UHVCF	Ultra-High Vacuum Cleaning Facility
USC	United States Code
US/EPA	United States Environmental Protection Agency
USF&WS	United States Fish and Wildlife Service
UST	underground storage tank
UV	ultraviolet
VOC	volatile organic compound
WAA	Waste Accumulation Area
Web	World Wide Web
yd^3	cubic yard
yr	year

Glossary

Accuracy

The degree of agreement between a measurement and the true value of the quantity measured.

Air particulates

Airborne particles that include dust, dirt, and other pollutants occurring as particles, as well as any pollutants associated with or carried on the dust or dirt.

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.

Ambient air

The surrounding atmosphere, usually the outside air, as it exists around people, plants, and structures. It does not include the air next to emission sources.

Analyte

The subject of a sample analysis.

Aquifer

A subsurface saturated layer of rock or soil that can supply usable quantities of groundwater to wells and springs. Aquifers can provide water for domestic, agricultural, and industrial uses.

Background radiation
Ionizing radiation from sources other than LBNL. Background may include cosmic radiation; external radiation from naturally occurring radioactivity in the earth (terrestrial radiation), air, and water; internal radiation from naturally occurring radioactive elements in the human body; and radiation from medical diagnostic procedures.

Becquerel (Bq)
SI unit of radioactive decay equal to one disintegration per second.

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 0.6 centimeter of aluminum.

Contaminant
Any hazardous or radioactive material present in an environmental medium such as air, water, or vegetation.

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 (conventional units).

De minimis
A level that is considered to be insignificant and does not need to be addressed or controlled.

Detection limit[1]
The lowest concentration of an analyte that can reliably be distinguished from a zero concentration.

Discharge
A release of a liquid into an area not controlled by LBNL.

Dose
The quantity of radiation energy absorbed during a given period of time.

Dose, absorbed
The energy imparted to matter by ionizing radiation per unit mass of irradiated material. The unit of absorbed dose is the gray (SI unit) or rad (conventional unit).

Dose, effective
The hypothetical whole-body dose that would give a risk of cancer mortality and/or serious genetic disorder equal to a given exposure that may be limited to just a few organs. The effective dose equivalent is equal to the sum of individual organ doses, each weighted by degree of risk that the organ dose carries. For example, a 1-millisievert dose to the lung, which has a weighting factor of 0.12, gives an effective dose that is equivalent to 0.12 millisievert (1×0.12).

Dose equivalent
A term used in radiation protection that expresses all types of radiation (alpha, beta, and so on) on a common scale for calculating the effective absorbed dose. It is the product of the absorbed dose and certain modifying factors. The unit of dose equivalent is the sievert (SI unit) or rem (conventional unit).

Dose, maximum boundary
The greatest dose commitment, considering all potential routes of exposure, from a facility's operation to a hypothetical individual who is in an uncontrolled area where the highest dose rate occurs. It assumes that the individual is present 100% of the time (full occupancy), and it does not take into account shielding by obstacles such as buildings or hillsides.

Dose, maximum individual

The greatest dose commitment, considering all potential routes of exposure, from a facility's operation to a hypothetical individual at or outside the LBNL boundary where the highest dose rate occurs. It takes into account shielding and occupancy factors that would apply to a real individual.

Dose, population

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

Dosimeter

A portable detection device for measuring the total accumulated exposure to ionizing radiation. See also Thermoluminescent dosimeter.

Downgradient

Commonly used to describe the flow of groundwater from higher to lower concentration. Analogous to "downstream."

Duplicate sample

A sample that is equivalent to a routine sample and is analyzed to evaluate sampling or analytical precision.

Effective dose equivalent

Abbreviated EDE, it is 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 sievert (SI unit) or rem (conventional unit).

Effluent

A liquid waste discharged to the environment.

Emission

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

Environmental remediation

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

Exposure

A measure of the ionization produced in air by x-ray or gamma radiation. The unit of exposure is the coulomb per kilogram (SI unit) or roentgen (conventional unit).

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, have longer wavelengths (lower energy) and cannot cause ionization.

Groundwater

A subsurface body of water in a zone of saturated soil sediments.

Gray

The gray is the International System (SI) unit for absorbed dose, which is the energy absorbed per unit mass from any kind of ionizing radiation in any kind of matter. One gray is an absorbed radiation dose of one joule per kilogram.

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 on.

Hazardous waste

Waste exhibiting any of the following characteristics: ignitability, corrosivity, reactivity, or EP-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 subhorizontal drain used to extract groundwater for slope stability purposes.

Low-Level Radioactive Waste

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

Millirem

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

Mixed Waste

Any radioactive waste that is also an EPA-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.

Organic compound

A chemical whose primary constituents are carbon and hydrogen.

Part B Permit

The second, narrative section submitted by generators in the RCRA permitting process. It details the procedures followed at a facility to protect human health and the environment.

Perched

Separated from another water-bearing stratum by an impermeable layer.

Person-rem

See Dose, population.

Person-sievert

See 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.

Piezometer

Generally, a small-diameter well primarily used to measure the elevation of the water table.

Plume[1]

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 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.

Positron[2]

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

Practical Quantification Limit (PQL)

The lowest amount of a matrix analyte that can be reliably and consistently measured within specified limits of precision and accuracy.

Precision

The degree of agreement between measurements of the same quantity.

Priority pollutants

A set of organic and inorganic chemicals identified by US/EPA as indicators of environmental contamination.

Rad

A unit of absorbed dose from ionizing radiation (0.877 rad per roentgen).

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.

Radiation

Electromagnetic energy in the form of waves or particles.

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.

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 1 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

See Environmental remediation.

Roentgen

A unit of radiation exposure that expresses exposure in terms of the amount of ionization produced by X or gamma rays in a volume of air. One roentgen is 2.58×10^{4} coulombs per kilogram of air.

Sievert

A unit of radiation dose equivalent. The sievert is the SI unit equivalent to the rem (conventional unit). 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 to produce biological effects. One sievert equals 100 rem.

Source
Any operation or equipment that produces, discharges, and/or emits pollutants (e.g., pipe, ditch, well, or stack).

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

Terrestrial
Pertaining to or deriving from the earth.

Terrestrial radiation
Radiation emitted by naturally occurring radionuclides, such as ^{40}K; the natural decay chains ^{235}U, ^{233}U, or ^{232}Th; or cosmic-ray induced radionuclides in the soil.

Thermoluminescent dosimeter
A type of dosimeter. After being exposed to radiation, the material in the dosimeter (lithium fluoride) luminesces on being heated. The amount of light that the material emits is proportional to the amount of radiation absorbed (dose). See also Dosimeter.

Tritium
A radionuclide of hydrogen with a half-life of 12.3 years. The very low energy of its radioactive decay makes it one of the least hazardous radionuclides.

Universal Waste[3]
Hazardous wastes that are more common and pose a lower risk to people and the environment than other hazardous wastes. Some examples of universal waste are mercury thermostats, batteries, fluorescent lamps, cathode ray tubes, and consumer electronic devices.

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

Notes

[1] Definition from Agency for Toxic Substances and Disease Registry, ATSDR Glossary of Terms (June 21, 2004). http://www.atsdr.cdc.gov/glossary.html.

[2] Definition from Bernard Shlein, Lester A. Slaback, Jr., and Brian Kent Birdy, editors, Handbook of Health Physics and Radiological Health (Lippincott Williams and Wilkins, 1998).

[3] Definition from California Department of Toxic Substances Control, Managing Universal Waste in California, Fact Sheet, (June 2003).

Table G-1 Prefixes Used with SI (Metric) Units

Prefix	Factor	Symbol
exa	1,000,000,000,000,000,000 = 10^{18}	E
peta	1,000,000,000,000,000 = 10^{15}	P
tera	1,000,000,000,000 = 10^{12}	T
giga	1,000,000,000 = 10^{9}	G
mega	1,000,000 = 10^{6}	M
kilo	1,000 = 10^{3}	k
hecto	100 = 10^{2}	h[a]
deka	10 = 10^{1}	da[a]
deci	0.1 = 10^{-1}	d[a]
centi	0.01 = 10^{-2}	c[a]
milli	0.001 = 10^{-3}	m
micro	0.000001 = 10^{-6}	μ
nano	0.000000001 = 10^{-9}	n
pico	0.000000000001 = 10^{-12}	p
femto	0.000000000000001 = 10^{-15}	f
atto	0.000000000000000001 = 10^{-18}	a

[a] Avoid where practical.

Table G-2 Conversion Factors for Selected SI (Metric) Units

To convert SI unit	To U.S. conventional unit	Multiply by
Area		
square centimeters	square inches	0.155
square meters	square feet	10.764
square kilometers	square miles	0.3861
hectares	acres	2.471
Concentration		
micrograms per gram	parts per million	1
milligrams per liter	parts per million	1
Length		
centimeters	inches	0.3937
meters	feet	3.281
kilometers	miles	0.6214
Mass		
grams	ounces	0.03527
kilograms	pounds	2.2046
kilograms	ton	0.00110
Pressure		
pounds per square foot	pascal	0.000145
Radiation		
becquerel	curie	2.7×10^{-11}
becquerel	picocurie	27.0
gray	rad	100
sievert	rem	100
coulomb per kilogram	roentgen	3,876
Temperature		
degrees Celsius	degrees Fahrenheit	1.8, then add 32
Velocity		
meters per second	miles per hour	2.237
Volume		
cubic meters	cubic feet	35.315
liters	gallons	0.2642

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