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Lawrence Livermore National Laboratory is a premier applied science laboratory that is part of the National Nuclear Security Administration (NNSA) within the U.S. Department of Energy (DOE). LLNL has been managed since its inception in 1952 by the University of California for the U.S. government. In May 2007, DOE selected Lawrence Livermore National Security, LLC (LLNS), to manage the Laboratory. The seven-year management contract term, which begins on October 1, 2007, may be extended for up to an additional 13 years for successful performance.

As a national security laboratory, LLNL is responsible for ensuring that the nation's nuclear weapons remain safe, secure, and reliable. The Laboratory also meets other pressing national security needs, including countering the proliferation of weapons of mass destruction and strengthening homeland security, and conducts major research in atmospheric, earth,

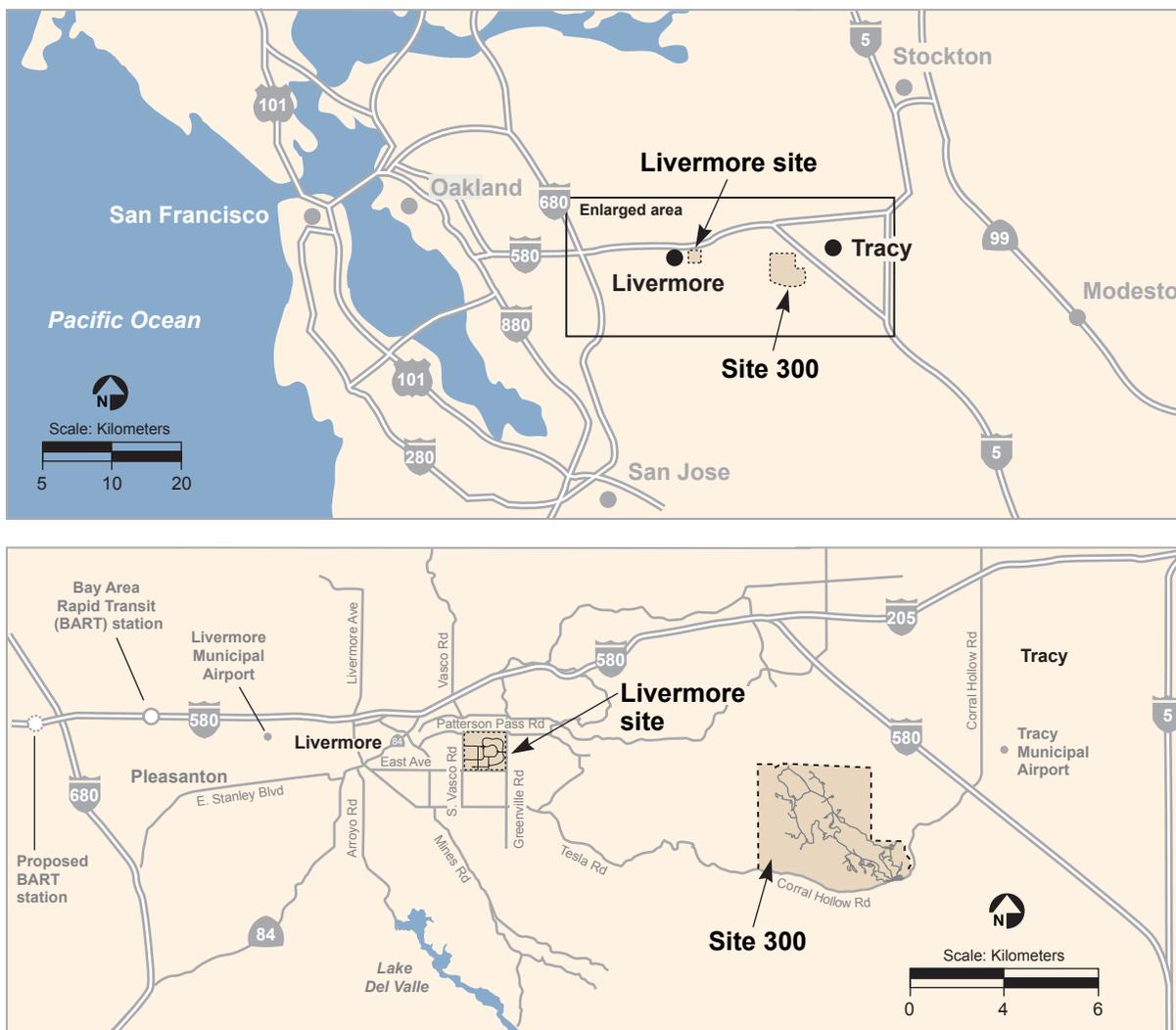


Figure 1-1. Location of the two LLNL sites—the Livermore site and Site 300.

environmental, and energy sciences; bioscience and biotechnology; and engineering, basic science, and advanced technology. The Laboratory serves as a scientific resource to the U.S. government and a partner to industry and academia. The Laboratory has a staff of more than 8000.

LLNL operations release a variety of contaminants into the environment via atmospheric, surface water, and groundwater pathways. Some of the contaminants, such as particles from diesel engines, are common at many types of facilities while others, such as radionuclides, are unique to facilities like LLNL. All releases are carefully monitored and regulated. Local meteorology, topography, and hydrogeology affect the dispersion of the contaminants. Health impacts of the dispersed contaminants, if any, are dependent on where people and biota are situated with respect to LLNL.

1.1 Location

LLNL consists of two sites—an urban site in Livermore, California, referred to as the “Livermore site”; and a rural experimental test site, referred to as “Site 300,” near Tracy, California. See **Figure 1-1**.

1.1.1 Livermore Site

The Livermore site is just east of Livermore, a city of about 80,000 in Alameda County. The site occupies 3.3 square kilometers (km²) (1.3 square miles [mi²]), including the land that serves as a buffer zone around most of the site. The areas surrounding the Livermore site are:

- south—Sandia National Laboratories/California (Sandia/California), operated by Lockheed-Martin for DOE, adjacent to the Livermore site; south of Sandia/California—mostly low-density residential areas and agricultural land devoted to grazing, orchards, and vineyards; farther south—open space and ranchettes with some agricultural use
- southwest—small business park
- west—residential developments, including houses and apartments
- north—extensive business park
- northeast—200-hectare (ha) (500-acre [ac]) parcel of open space, rezoned for light industry
- east—small amount of very low-density residential development; agricultural land extending to the Altamont Hills, which define the eastern margin of the Livermore Valley

Within an 80-km (50-mi) radius of the Livermore site are communities such as Tracy and Pleasanton and the more distant (and more densely populated) cities of Oakland, San Jose, and San Francisco. Of the 7.1 million people within 80 km (50-mi) of the Laboratory, only about 10% are within 32 km (20 mi).

1.1.2 Site 300

Site 300, LLNL’s Experimental Test Site, was established in 1955. It is located in the Altamont Hills of the Diablo Range and straddles the San Joaquin and Alameda county line. The site is 20 km (12 mi) east of the Livermore site and occupies 28.3 km² (10.9 mi²). The areas surrounding Site 300 are:

- south—agricultural land; a testing site operated by SRI International, approximately 1 km (0.62 mi) south
- southwest—Carnegie State Vehicular Recreation Area for off-road vehicles, open to the public
- northwest—agricultural land; wind turbine generators on the hills

- east—property owned by Fireworks America, which uses it storing fireworks components; property leased by Teledyne/RISI from Fireworks America, where detonation initiators are manufactured
- northeast—land proposed for residential development
- southeast—Corral Hollow Ecological Reserve, 40 ha (99 ac) of riparian woodland and annual grassland, and a protected refuge area for wildlife; formerly southeastern corner of Site 300, transferred to the California Department of Fish and Game in 1974 because of its unique assemblage of rare amphibian and reptile species

The remainder of the surrounding area is in agricultural use, primarily as grazing land for cattle and sheep.

The city of Tracy, with a population of over 80,000, is approximately 10 km (6 mi) to the northeast (measured from the northeastern border of Site 300 to Sutter Tracy Community Hospital). Of the 6.2 million people who live within 80 km (50 mi) of Site 300, 95% are more than 32 km (20 mi) away in distant metropolitan areas such as Oakland, San Jose, and Stockton.

1.2 Meteorology

Meteorological data including wind speed, wind direction, rainfall, humidity, solar radiation, and air temperature are gathered continuously at both the Livermore site and Site 300. Mild, rainy winters and warm-to-hot, dry summers characterize the climate at both sites. For a detailed review of the climatology for LLNL, see Gouveia and Chapman (1989).

A new 52-meter (m) (170-foot [ft]) meteorological tower, identical to the tower at the Livermore site, was installed at Site 300 in September 2006, and instrumentation of the tower began in late December. The new tower, which will eventually replace an 8-m (26-ft) tower in use since 1979, has three measurement levels as compared to the older tower's one level. The multiple levels allow redundant measurements, improved data quality control, and better characterization of wind direction and speed, turbulence, and temperature through a deeper layer above the ground. The instruments can be lowered and raised by an electric elevator, which allows for safer and faster maintenance. Current plans are for both towers to provide simultaneous measurements through 2007, after which the older tower will be taken down. Measurements from the two towers will be compared for differences.

Temperature, rainfall, and wind speed data for the Livermore site and Site 300 during 2006 are summarized in **Table 1-1**. More detailed information is provided below.

1.2.1 Temperature

Daily temperature measurements have been analyzed at the Livermore site since 1990 and at Site 300 since 1992. The mean daily maximum, minimum, and average temperatures for the two sites during 2006 are listed in **Table 1-1**.

Nighttime temperatures at Site 300 are typically higher (and the diurnal temperature range smaller) than at the Livermore site; stronger winds at Site 300's higher elevation prevent formation of strong nighttime inversions near the ground. At the Livermore site, temperatures typically range from -4 degrees centigrade ($^{\circ}\text{C}$) (25 degrees Fahrenheit [$^{\circ}\text{F}$]) during the coldest winter mornings to 40 $^{\circ}\text{C}$ (104 $^{\circ}\text{F}$) during the warmest summer afternoons. At Site 300, the typical temperature range is somewhat smaller, ranging from -1 $^{\circ}\text{C}$ (30 $^{\circ}\text{F}$) during the coldest winter mornings to 39 $^{\circ}\text{C}$ (102 $^{\circ}\text{F}$) during the warmest afternoons.

While the mean annual temperature was near normal during 2006, several individual months experienced large departures from normal. The combination of frequent rain and several very cold nights caused March to be the coldest at the Livermore site since at least 1989 and at Site 300 since at least 1991. Overnight lows dipped to freezing or below on three mornings at the Livermore site during March.

A strong high-pressure system developed over the western U.S. in mid-June and persisted through August, causing record heat through much of the period. During the second half of June, the high temperature reached at least 32.2 $^{\circ}\text{C}$ (90 $^{\circ}\text{F}$) on 11 days at the Livermore site and on 12 days at Site 300. The high temperatures reached 39.6 and 39.8 $^{\circ}\text{C}$ (103 and 104 $^{\circ}\text{F}$) at the Livermore site on June 22 and 23, respectively. The high temperature of 38.7 $^{\circ}\text{C}$ (102 $^{\circ}\text{F}$) on June 23 was the highest ever recorded at Site 300 during June since at least 1990. The

average temperature of 33.8 $^{\circ}\text{C}$ (93 $^{\circ}\text{F}$) on this date was also the highest daily average ever recorded at Site 300.

The upper high pressure ridge in the western U.S. intensified further and at times extended to the East Coast, causing widespread record heat. The heat wave became extreme from July 21 through July 25 as a layer of hot and moist air originating in the southwestern U.S. deserts warmed further as it dried out while moving over the California Sierra. The high temperature reached at least 42.2 $^{\circ}\text{C}$ (108 $^{\circ}\text{F}$) at the Livermore site and 40 $^{\circ}\text{C}$ (104 $^{\circ}\text{F}$) at Site 300 on each of these five days, with the highest temperature reaching 44.2 $^{\circ}\text{C}$ (112 $^{\circ}\text{F}$) at the Livermore site on July 23

Table 1-1. Summary of temperature, rainfall, and wind speed data at the Livermore site and Site 300 during 2006.

Temperature	Livermore Site		Site 300	
	$^{\circ}\text{C}$	$^{\circ}\text{F}$	$^{\circ}\text{C}$	$^{\circ}\text{F}$
Mean daily maximum	22.1	71.8	21.2	70.2
Mean daily minimum	7.5	45.6	12.5	54.6
Average	14.8	58.7	16.9	62.4
High	44.2 ^(a)	112 ^(a)	42.6 ^(a)	109 ^(a)
Low	-4.0	25	-0.2	32
Rainfall	cm	in.	cm	in.
Total for 2006	38.7	15.24	32.2	12.68
Normal ^(b)	34.6	13.62	27.0	10.64
Wind	m/s	mph	m/s	mph
Average speed	2.3	5.1	5.4	12.1

(a) Record high.

(b) Based on the mean, 1971–2000, at both sites.

and 42.6 °C (109 °F) at Site 300 on July 25. All of the high temperatures on these five days were the highest ever recorded at Site 300 in any month since record keeping began in 1992. The previous record highs for Site 300 were 40.0 °C (104 °F) on August 4, 1998, and July 17, 2005. The previous record high temperature at the Livermore site for July was 41.0 °C (106 °F) on July 2, 1991, and the previous record high for any month was 41.7 °C (107 °F) on August 4, 1998. Both sites also set new records for the highest daily average temperature (average of high and low daily temperature): 34.8 °C (95 °F) on July 23 at the Livermore site (previous record: 32.1 °C [90 °F] on July 12, 1999), and 36.7 °C (98 °F) on four consecutive days ending on July 25 at Site 300 (previous record: 35.9 °C [97 °F] on August 4, 1998). Finally, it was the warmest July and the warmest month on record for the Livermore site since at least 1989 and Site 300 since at least 1991.

Typical sea breezes returned in August and provided welcome relief from the intense heat. Even with near-normal temperatures in August, the record heat in June and July made the summer (June through August) the warmest at the Livermore site since at least 1989. While Site 300 had many above-normal temperatures during the summer, it did not set a record although the average daily maximum temperature at Site 300 became the highest recorded since at least 1991, exceeding the previous high set in the previous summer (2005).

September had typical mild weather although the low temperature dipped to a chilly 5.8 °C (43 °F) at the Livermore site on the morning of September 16. This was the lowest recorded temperature in the month of September at the Livermore site since at least 1989. Several early-season polar air masses caused October to be much colder than normal. The low temperatures reached 4.1 °C (39 °F) on four of the last five mornings of the month. The last two months of the year had near-normal average temperatures although several days in December had record warmth or cold. The high temperature reached 20.5 °C (69 °F) at both the Livermore site and Site 300 on December 8. It was the highest temperature recorded at the Livermore site in December since at least 1989. A blast of polar air during the third week of December prevented daily high temperatures to exceed 10 °C (50 °F) at the Livermore site on three days. Overnight temperatures at the Livermore site dipped to below freezing on five consecutive days, including -4 °C (25 °F) on December 19.

The highest temperature recorded at the Livermore site during 2006 was 44.2 °C (112 °F) on July 23; the peak temperature at Site 300 of 42.6 °C (109 °F) occurred on July 25. The lowest temperatures during the year were -4.0 °C (25 °F) at the Livermore site on February 16 and December 19 and -0.2 °C (32 °F) at Site 300 on March 11.

1.2.2 Wind and Rainfall

Both wind and rainfall exhibit strong seasonal patterns. Wind patterns at both sites tend to be dominated by the thermal draw of the warm San Joaquin Valley that results in wind blowing from the cool ocean toward the warm valley during the warm season, increasing in intensity as the valley heats up. During the winter, the wind blows from the northeast more frequently as cold, dense air spills out of the San Joaquin Valley. Approximately 55% of the seasonal

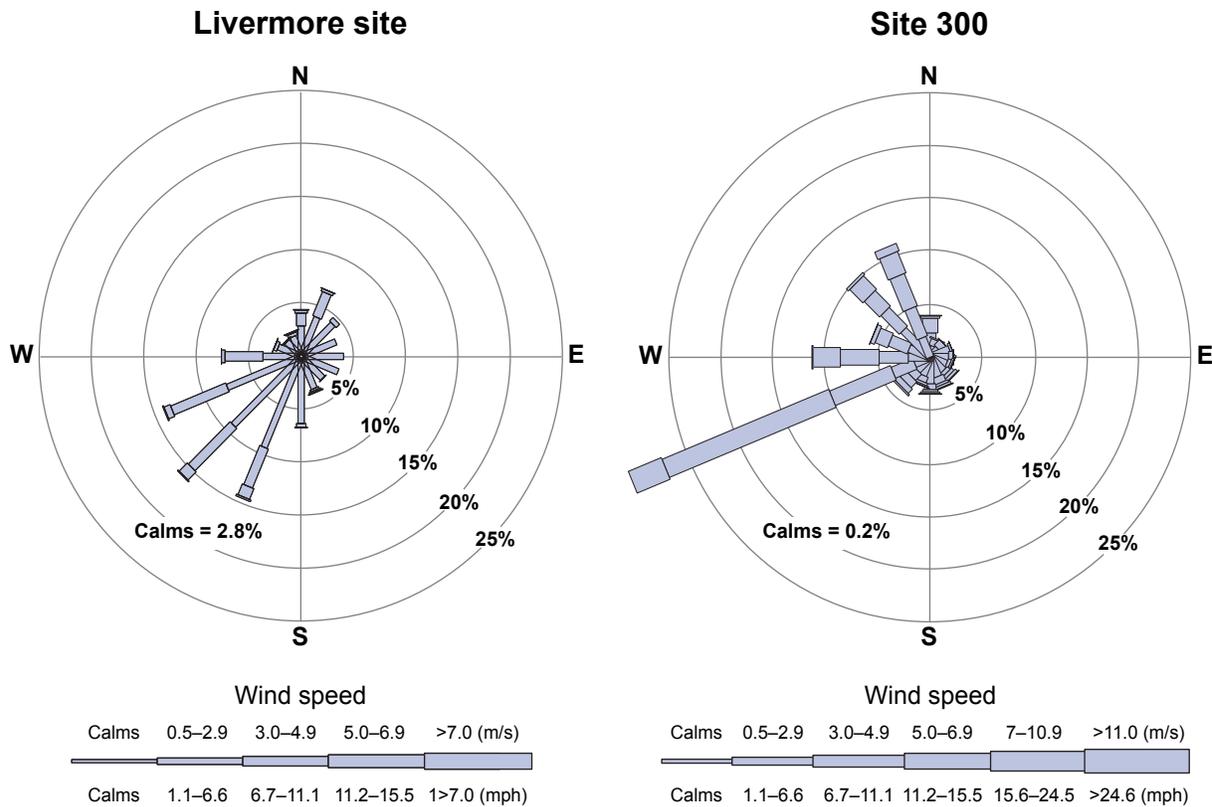


Figure 1-2. Wind roses showing wind direction and speed frequency at the Livermore site and Site 300 during 2006. The length of each spoke is proportional to the frequency at which the wind blows from the indicated direction. Different line widths of each spoke represent wind speed classes. The average wind speed in 2006 at the Livermore site was 2.3 m/s (5.1 mph); at Site 300 it was 5.4 m/s (12.1 mph).

rain at both sites falls in January, February, and March and approximately 80% falls in the five months from November through March, with very little rain falling during the warmer months.

Annual wind data for the Livermore site are shown in **Figure 1-2**. These data show that winds blow from the south–southwest through west–southwest about 45% of the time and more frequently during the summer. During the winter, winds from the northeast are more common. The peak wind gusts at the Livermore site of 19.6 meters per second (m/s) (44 miles per hour [mph]) occurred on January 1 (from the south) and on February 27 (from the south–southwest) and were associated with storms.

Based on a 49-year record, the highest and lowest annual rainfalls were 85.2 and 16.7 centimeters (cm) (33.57 and 6.57 inches [in.]). Normal annual rainfall, which is based on the mean for 1971–2000, is 34.6 cm (13.62 in.). In 2006, the Livermore site received 38.7 cm (15.24 in.) of rain, or 112% of normal. A long series of storms caused heavy and frequent rain in March and April, with monthly rainfall equaling approximately 185% and 370% of their respective normals. Measurable rainfall occurred on 23 and 13 days in March and April,

respectively. March was the rainiest month of the year with 10.9 cm (4.31 in.) of rainfall. The maximum daily rainfall of 2.4 cm (0.96 in.) fell on December 12.

The meteorological conditions at Site 300, while generally similar to those at the Livermore site, are modified by higher elevation and more pronounced topological relief. The complex topography of the site strongly influences local wind and temperature patterns. Annual wind data for Site 300 are presented in **Figure 1-2**. The data show that winds are stronger and have less directional variation than at the Livermore site. Winds from the west–southwest through west occurred 42% of the time during 2006. The peak wind gust at Site 300 reached 31.5 m/s (71 mph) from the south–southeast on January 1.

As at the Livermore site, precipitation at Site 300 is seasonal, with most rainfall occurring between October and April. Because Site 300 is downwind of more extensive elevated terrain to the south and southwest (i.e., upper winds are typically southerly and southwesterly during storms) than at the Livermore site, rainfall amounts at Site 300 are typically 20 to 25% lower. Based on a 47-year record, the highest and lowest annual rainfalls were 59.9 and 14.2 cm (23.58 and 5.61 in.), and the normal annual rainfall is 27.0 cm (10.64 in.). In 2006, Site 300 received 32.2 cm (12.68 in.) of rain, or 119% of normal. The April rainfall of 6.8 cm (2.67 in.) was more than four times the normal and the most recorded in April since record keeping began in 1960. Measurable rainfall occurred on 19 and 13 days in March and April, respectively. The rainiest month at Site 300 was also March, with accumulation of 7.0 cm (2.76 in.) or about 157% of normal. The maximum daily rainfall of 3.3 cm (1.28 in.) fell on January 2.

1.3 Topography

1.3.1 Livermore Site

The Livermore site is located in the southeastern portion of the Livermore Valley, a prominent topographic and structural depression oriented east–west within the Diablo Range. The most prominent valley in the Diablo Range, the Livermore Valley is bounded on the west by Pleasanton Ridge and on the east by the Altamont Hills. The valley is approximately 22.6 km (14 mi) long and varies in width generally between 4 and 11.3 km (2.5 and 7 mi). The valley floor is at its highest elevation of 220 m (720 ft) above sea level along the eastern margin near the Altamont Hills and dips gradually to 92 m (300 ft) at the southwestern corner. The valley floor is covered primarily by alluvial and floodplain deposits consisting of gravels, sands, silts, and clays with an average thickness of about 100 m (325 ft).

The major streams passing through the Livermore Valley are the Arroyo del Valle and the Arroyo Mocho, which drain the southern highlands. Ephemeral waterways flowing through the Livermore site include Arroyo Seco along the southwestern corner and Arroyo Las Positas along the eastern and northern perimeters. Lake Del Valle, about 10 km (6 mi) south of the Livermore site, is the closest large body of surface water.

1.3.2 Site 300

The topography of Site 300 is much more irregular than that of the Livermore site; a series of steep hills and ridges is oriented along a generally northwest–southeast trend and is separated by intervening ravines. The Altamont Hills, where Site 300 is located, are part of the California Coast Range Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. The elevation of Site 300 ranges from about 530 m (1740 ft) above sea level at the northwestern corner of the site to approximately 150 m (490 ft) in the southeastern portion. Corral Hollow Creek, an ephemeral stream, which drains toward the San Joaquin Basin, runs along the southern and eastern boundaries of Site 300.

1.4 Hydrogeology

1.4.1 Livermore Site

The hydrogeology near the Livermore site has been the subject of several investigations (Stone and Ruggieri 1983; Carpenter et al. 1984; Webster-Scholten and Hall 1988; Thorpe et al. 1990; Blake et al. 1995). This section summarizes these investigations and the data supplied by Alameda County Flood Control and Water Conservation District Zone 7, the agency responsible for the groundwater monitoring network in the Livermore Valley (SFBRWQCB 2006). The Zone 7 Water Agency also manages the groundwater supply in the Livermore Valley and adjacent basins (<http://www.zone7water.com/>).

The Livermore Formation and overlying alluvial deposits contain the primary aquifers of the Livermore Valley groundwater basin. Natural recharge occurs primarily along the basin margins and arroyos during wet winters. In general, groundwater flows toward the central east–west axis of the valley and then westward through the central basin. Groundwater flow in the basin is primarily horizontal, although a significant vertical component probably exists along the basin margins under localized sources of recharge and near heavily used extraction or water production wells.

Beneath the Livermore site, the depth to the water table varies from about 10 to 40 m (30 to 130 ft) below the ground surface. **Figure 1-3** is a groundwater elevation contour map of the Livermore site's shallowest laterally extensive water-bearing unit (hydrostratigraphic unit or HSU), HSU-2. Hydrostratigraphic units are described further in **Chapter 8**. Although groundwater elevations vary from seasonal and year-to-year differences in both recharge and groundwater withdrawal from the basin, the overall pattern shown in **Figure 1-3** persists through time. At the eastern edge of the Livermore site, groundwater gradients (change in vertical elevation per unit of horizontal distance) are relatively steep, but under most of the site and farther to the west, they flatten to a gradient of approximately 0.003.

While groundwater flow beneath the site is generally westward, similar to the regional flow direction, in places it becomes southwesterly, and even easterly, due to extensive groundwater

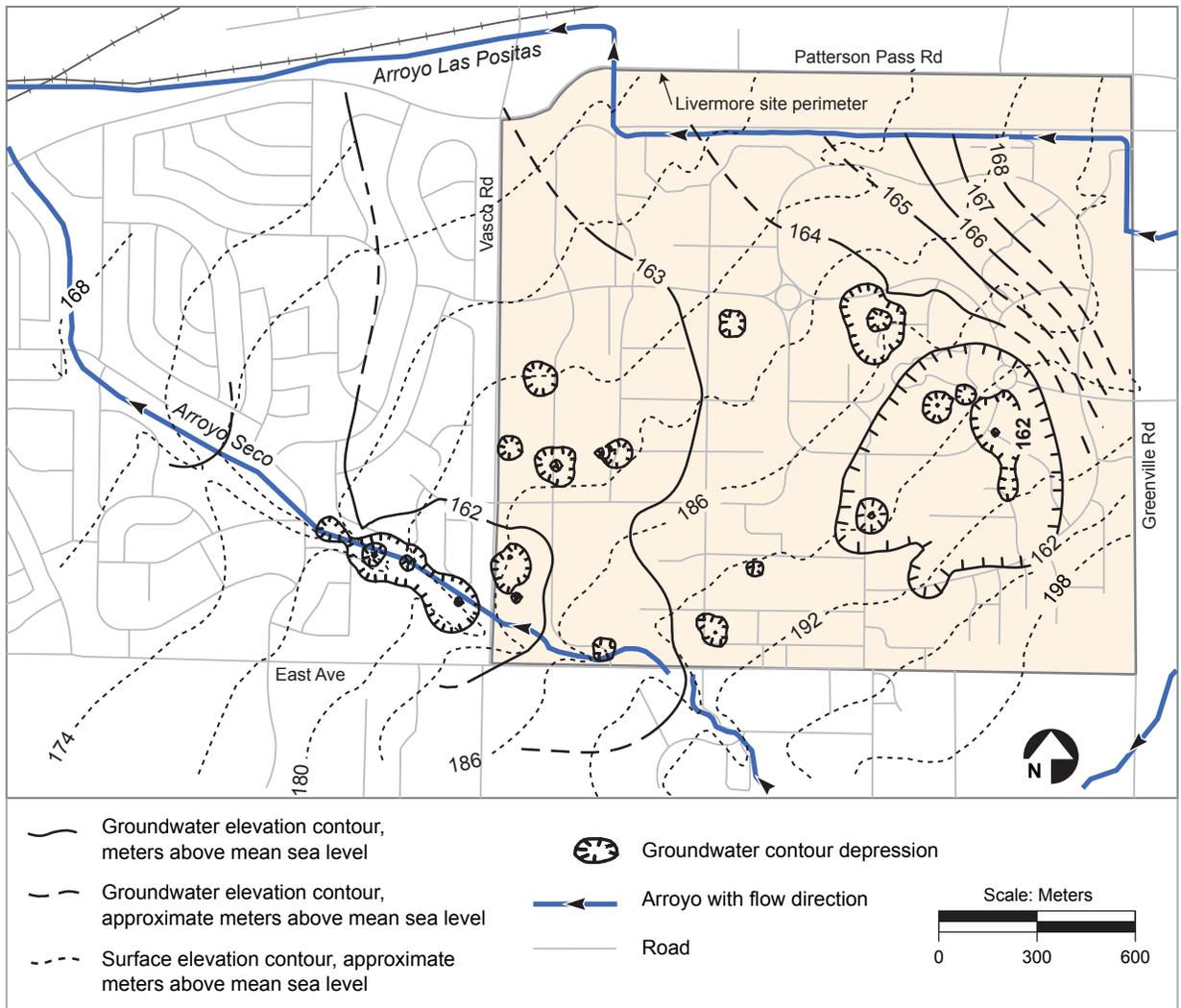


Figure 1-3. Groundwater elevation contours of hydrostratigraphic unit 2 (HSU-2), the shallowest laterally extensive water-bearing unit beneath the Livermore site, October 2006.

extraction associated with the remedial activities at the site. Groundwater recharge and agricultural pumping have also affected the direction of groundwater flow at the site. Aquifer tests on monitoring wells at the Livermore site indicate that the hydraulic conductivity (a measure of the ability of geologic media to transmit water) of the permeable sediments ranges from 1 to about 16 m/day (3.3 to 52 ft/day) (Isherwood et al. 1991). This variability reflects the heterogeneity typical of the more permeable alluvial sediments that underlie the area. The hydraulic conductivities, in combination with the observed groundwater gradients, yields an estimated average groundwater velocity of about 20 meters per year (m/y) (66 feet per year [ft/y]) (Thorpe et al. 1990).

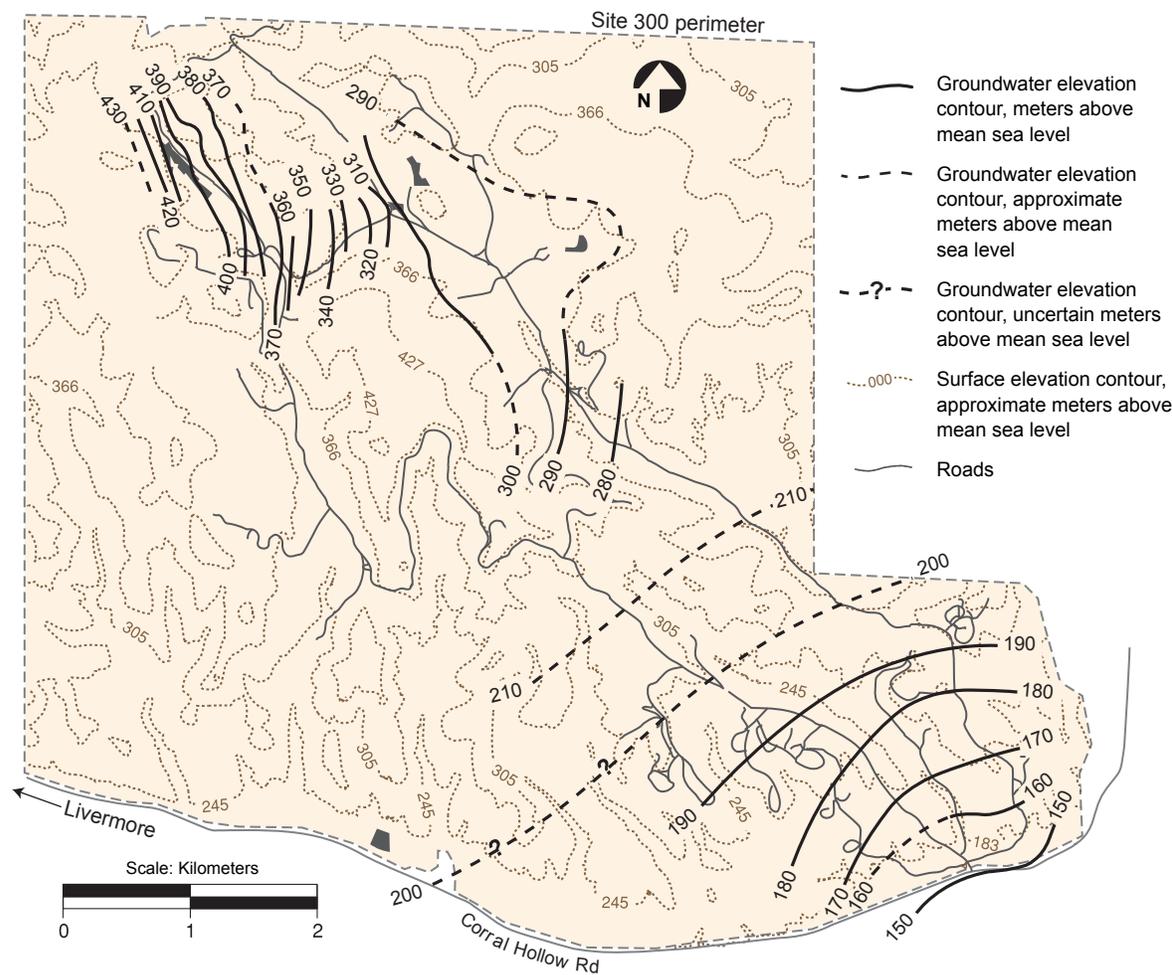


Figure 1-4. Approximate groundwater elevations for the principal continuous water-bearing zone at Site 300.

1.4.2 Site 300

Gently dipping sedimentary bedrock dissected by steep ravines generally underlies Site 300. The bedrock is made up primarily of interbedded sandstone, siltstone, and claystone. Groundwater occurs primarily in the Neroly Formation upper and lower blue sandstone units and in the underlying Cierbo Formation. Stratigraphic units that occur beneath Site 300 are described further in **Chapter 8** (see **Figure 8.5**). **Figure 1-4** is a map of the potentiometric surface for the first continuous water-bearing zone at Site 300, which occurs principally in sandstones within the base of the Neroly Formation. Significant groundwater is also locally present in permeable Quaternary alluvium valley fill and underlying decomposed bedrock, especially during wet winters. Much less groundwater is present within perched aquifers in the unnamed Pliocene nonmarine unit. Perched aquifers contain unconfined groundwater separated from an underlying main body of groundwater by impermeable layers; normally these perched zones are laterally discontinuous. Because water quality is generally poor and

yields are low, these perched water-bearing zones do not meet the State of California criteria for aquifers that are potential water supplies.

Fine-grained siltstone and claystone interbeds in the lower Neroly sandstone unit and the Cierbo Formation may act as aquitards, confining layers, or perching horizons. Groundwater is present under confined conditions in parts of the deeper bedrock aquifers but is generally unconfined elsewhere. Portions of the bedrock section at Site 300 are abundantly fractured, and some groundwater flow therefore occurs in fractures as well as in pores.

The tectonic forces that uplifted the Altamont Hills faulted, gently folded, and tilted the once-horizontal sedimentary strata. A major structure, the east–west trending Patterson anticline, occupies a central location within the site. North of the anticline, bedrock generally dips east–northeast. South of the anticline, bedrock dips south–southeast. Groundwater flow in most water-bearing strata follows the attitude (dip) of the bedrock. In the northwestern part of Site 300, groundwater in bedrock generally flows northeast except where it is locally influenced by the geometry of alluvium-filled ravines. In the southern half of Site 300 and in the central–east portion, groundwater in bedrock flows roughly south–southeast, approximately coincident with the attitude of bedrock strata.

The thick Neroly Formation lower blue sandstone, stratigraphically near the base of the formation, generally contains confined groundwater. Wells located in the western part of the Site 300 General Services Area pump water from this aquifer, which is used for drinking and process supply.

Recharge occurs predominantly in locations where saturated alluvial valley fill is in contact with underlying permeable bedrock or where permeable bedrock strata crop out along the canyon bottom because of structure or topography. Local recharge also occurs on hilltops, creating some perched water-bearing zones. Low rainfall, high evapotranspiration, steep topography, and intervening aquitards generally preclude direct vertical recharge of the deeper bedrock aquifers.

1.5 Conclusion

Meteorology, topography, and geology affect the dispersal of released constituents in the vicinity of the Livermore site and Site 300 and their impact on the public and biota. Each year, LLNL strives to add to what is known about the movement of contaminants in groundwater (see **Chapter 8**) and to improve the quality of meteorological data needed to model dose impacts (see **Chapter 7**). LLNL takes into account the features of the Livermore site and Site 300 discussed in this chapter to tailor the environmental monitoring and assessment programs discussed in the remainder of this report.

Contributing Authors

Brent Bowen, John Karachewski, Donald MacQueen, Sandra Mathews, Michael Taffet