Introduction

CHAPTER 1

Founded in 1952, Lawrence Livermore National Laboratory (LLNL) is a premier research and development institution for science and technology applied to national security. The Laboratory is managed and operated by the University of California for the U.S. Department of Energy. LLNL's primary mission is to ensure that the nation's nuclear weapons remain safe, secure, and reliable. The Laboratory's special capabilities are also applied to the prevention of the spread and use of weapons of mass destruction and to strengthen homeland security. With broadly based capabilities and leadership in mission-focused areas of science and technology, the Laboratory meets other national needs with major advances in research programs in energy and environment, bioscience and biotechnology, and basic science and applied technology. The Laboratory and its more than 8000 employees serve as a resource to the U.S. government and partner with industry and academia.

LLNL operations release a variety of contaminants to the environment via atmospheric and surface water or groundwater pathways. Some of these contaminants are common at many facilities (e.g., particles from diesel engines), while others are unique to facilities like LLNL (e.g., radionuclides). All releases are carefully monitored and regulated. The dispersion of the contaminants is highly dependent upon local meteorology, topography and hydrogeology; any health impact of these dispersed contaminants will depend on where people and biota are situated with respect to LLNL.

Location

LLNL consists of two sites—the urban Livermore site located in Livermore, California in Alameda County, and the rural Experimental Test Site (Site 300) located near Tracy, California, in San Joaquin and Alameda counties (**Figure 1-1**).

The Livermore site lies just east of Livermore, a city with a population of about 80,000. The Livermore site occupies an area of 3.3 km^2 (1.3 mi^2), including the land that serves as a buffer zone around most of the site. Adjoining the site border to the south is Sandia National Laboratories/ California (Sandia/California), operated by Lockheed-Martin under U.S. Department of Energy (DOE) contract.

To the south of the LLNL and Sandia/California sites are mostly low-density residential areas and agricultural areas devoted to grazing, orchards, and vineyards. Farther south, property is primarily open space and ranchettes with some agricultural use. Residential developments, including houses and apartments, abut the property immediately to the west of the Livermore site. A small business park lies to the southwest. A small amount of very low-density residential development lies to the east of the Livermore site, and agricultural land extends to the foothills that define the eastern margin of the Livermore Valley. An extensive business park is located to the north, and a 200 hectare (500 acre) parcel of open space to the northeast has been rezoned to allow development of light industry. Within an 80-km (50-mi) radius of the Livermore site lie nearby communities, such as Tracy and Pleasanton, and the distant population centers of Oakland, San Jose, and San Francisco. Although over seven million people reside within 80 km of the Laboratory, just 10% of them live within 32 km (20 miles).

Site 300, LLNL's Experimental Test Site, which dates from 1955, is located 20 km (12 mi) east of the Livermore site in San Joaquin and Alameda counties in the Altamont Hills of the Diablo Range; it occupies an area of 28.3 km^2 (10.9 mi^2). SRI International operates a testing site located approximately 1 km (0.62 mi) south of Site 300. Property immediately to the east of Site 300 is owned by Fireworks America, which uses it for packaging and storing fireworks displays. The Carnegie State Vehicular Recreation Area is located south of the western portion of Site 300, and wind turbine generators line the hills to the northwest. Forty hectares (99 acres) of riparian woodland and annual grassland, formerly the southeastern corner of Site 300 transferred in 1974 to the California Department of Fish and Game because of its unique assemblage of rare amphibian and reptile species, comprise a protected refuge area for wildlife called the "Corral Hollow Ecological Reserve". The remainder of the surrounding area is in agricultural use, primarily as grazing land for cattle and sheep. The city of Tracy, with a

Meteorology

A new 52-m meteorological tower was installed at the Livermore site in late September 2005 to replace the 35-m tower that was installed in 1979. The new tower is located within 20 meters of the old tower, in the northwestern buffer zone. The new tower has an electrical instrument elevator that will allow safer and quicker maintenance than the older tower that had a hand-crank elevator. The new tower also has three measurement levels, one more than the previous tower. A fast-response hygrometer has been installed at the tower in order to estimate evaporation from the ground.

Meteorological data (including wind speed, wind direction, rainfall, humidity, solar radiation, and air temperature) are continuously gathered at both the Livermore site and Site 300. Mild, rainy winters and mild-to-hot, dry summers characterize the climate. A detailed review of the climatology for LLNL can be found in *Climatology of Lawrence Livermore National Laboratory* (Gouveia and Chapman 1989). The mean daily maximum, minimum, and average temperatures for the Livermore site in 2005 were 22.0 °C (71.6 °F), 8.0 °C (46.3 °F), and 15.0 °C (59.0 °F), respectively. The mean daily maximum, minimum, and average temperatures for Site 300 in 2005 were 21.1 °C (70.0 °F), 12.6 °C (54.7 °F), and 16.9 °C (62.4 °F), respectively. Nighttime temperatures are typically higher (and diurnal temperature range smaller) at Site 300 compared to the Livermore site; stronger winds at the higher elevation prevent formation of strong nighttime inversions near the ground. Temperatures typically range from –4 °C (25 °F) during the coldest winter mornings to 40 °C (104 °F) during the warmest summer afternoons at the Livermore site. The typical temperature range at Site 300 is somewhat smaller, ranging from –1 °C (30 °F) during the coldest winter mornings to 38 °C (100 °F) during the warmest afternoons.

While the mean annual temperature was near normal during 2005, several individual months experienced large departures from normal. Rainfall in the first part of January followed by persistent fog caused this month to be the coldest January since 1992. The lowest daytime high temperature reached only 5.6 °C (42 °F) on January 13. A strong high-pressure system persisted over the western U.S. during July and August causing offshore winds with widespread dry conditions and record heat. It was the warmest July for both the Livermore site and Site 300 since at least 1989 and 1991, respectively.[1] High temperatures reached or exceeded 37.8 °C (100 °F) at the Livermore site on six days in the month including four consecutive days in the middle of the month. The high temperature of 40.0 °C (104 °F) at Site 300 on July 17 matched the record of August 4, 1998. Slightly cooler but still hot weather,

[1] Daily temperature statistics have been analyzed since 1990 and 1992 for the Livermore site and Site 300, respectively.

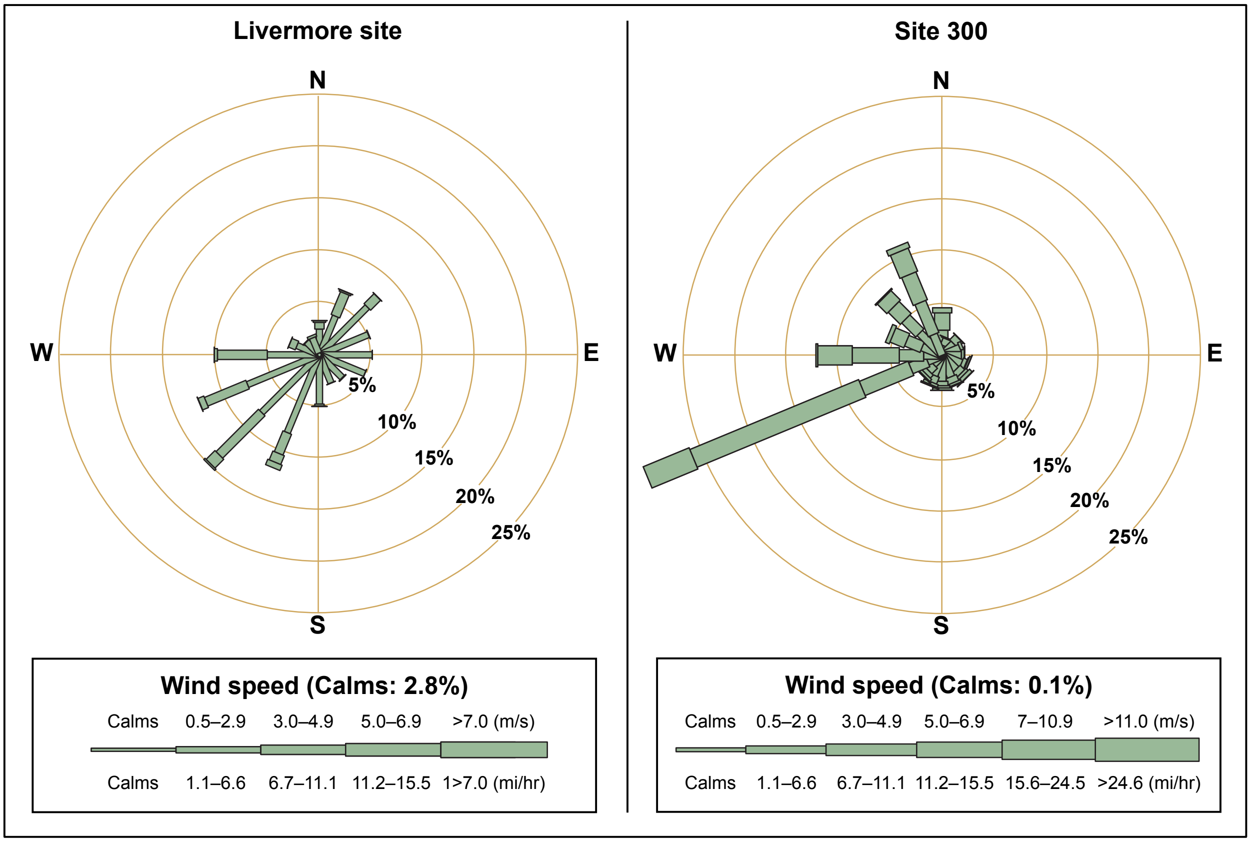
strong west-southwesterly winds with average wind speeds of 22–30 mph, and an extremely dry atmosphere mixing down to the surface contributed to a 6200 acre fire that burned primarily west of Site 300 in the late afternoon and evening of July 19. The relative humidity hovered near 10% during the fire. After some welcome clouds, and a few sprinkles, but no measurable rain on July 21 from remnants of a Gulf of Mexico hurricane, the heat quickly returned, with temperatures reaching 39.6 °C (103 °F) and 37.7 °C (100 °F) at the Livermore site on the 23rd and 24th. Temperatures on the final seven days of the month reached or exceeded 90 °F. While the dry atmosphere allowed the Livermore site to cool off at night, temperatures stayed high during the night at Site 300 for much of the month. The temperature remained above 26.7 °C (80 °F) at Site 300 for nearly nine consecutive days, from 7 a.m. on July 12 until 4 a.m. on the 21st. The heat persisted into August with Site 300 having its warmest August since at least 1991 and the Livermore site just missed having its warmest August on record.

The pattern changed dramatically the next month as persistent sea breezes caused it to be the coldest September on record at both the Livermore site and Site 300. Overnight temperatures were especially cool at the Livermore site, with low temperatures dipping below 10.0 °C (50 °F) on 10 mornings, including 6.7 °C (44 °F) on September 11. Record warmth returned in December as a series of storms brought rains and tropical air to the area in the second half of the month. High temperatures at the Livermore site reached 15.6 °C (60 °F) or higher on 11 of the final 14 days of the month including a peak of 19.4 °C (67 °F) on the 20th and 21st. The Site 300 temperature reached 21.3 °C (70 °F) for a few minutes on the 20th as warmer air aloft was apparently transported downward locally. It was the highest temperature recorded since 1991 at Site 300 during December. Both the Livermore site and Site 300 recorded their highest average daily maximum temperatures for December on record.

The highest temperature recorded at the Livermore site during 2005 was 39.5 °C (103 °F) on July 16 and 23; the peak temperature at Site 300 of 40.0 °C (104 °F) occurred on July 17. The lowest temperatures during the year were –2.4 °C (28 °F) at the Livermore site on November 27 and –1.6 °C (29 °F) at Site 300 on December 16.

Both rainfall and wind exhibit strong seasonal patterns. These wind patterns 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. Most precipitation occurs between October and April, with very little rainfall during the warmer months.

Annual wind data for the Livermore site are included in **Figure 1-2**. These data show that winds blow from the south-southwest through west about 49% of the time. This prevailing pattern occurs primarily during the summer.



Note: 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 2005 at the Livermore site was 2.3 m/s (5.2 mph); at Site 300 it was 5.5 m/s (12.3 mph).

Figure 1-2. Wind roses showing wind direction and speed frequency at the Livermore site and Site 300 during 2005

During the winter, winds from the northeast are more common. The peak wind gust at the Livermore site of 20 m/s (44 mph) from the southwest occurred on April 8 as a cold front swept through the area. Based on a 48-year record, the highest and lowest annual rainfalls were 85.2 and 16.7 cm (33.57 and 6.57 in.), and the normal (mean for 1971–2000) annual rainfall is 34.6 cm (13.62 in.). In 2005, the Livermore site received 45.5 cm (17.91 in.) of rain, or 131% of normal. The 2005 rainfall was the most since 1998 when 52.3 cm (20.58 in.) fell. Thunderstorms with intense and frequent lightning dropped 1.3 cm (0.52 in.) of rain on September 19. December was the rainiest month of the year with 11.2 cm (5.02 in.) falling or about 275% of normal. The maximum daily rainfall of 3.6 cm (1.42 in.) fell on December 31.

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 are presented in **Figure 1-2**. The data show that winds are stronger and show less directional distribution than at the Livermore site. Winds from the west-southwest through west occurred 43% of the time during 2005. The peak wind gust at Site 300 reached 27 m/s (60 mph) from the west-southwest on January 7 and October 8. As is the case for the Livermore site, precipitation at Site 300 is seasonal, with most rainfall occurring between October and April. Because Site 300 is situated downwind of more extensive elevated terrain located to the south and southwest (i.e., upper winds are typically southerly and southwesterly during storms) than at the Livermore site, rainfall amounts are typically 20 to 25% lower. Based on a 46-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 2005, Site 300 received 32.5 cm (12.81 in.) of rain, or 120% of normal. As was the case for the Livermore site, the 2005 rainfall at Site 300 was the most since 1998 when 47.5 cm (18.69 in.) fell. An early storm dropped 0.9 cm (0.34 in.) of rain on September 19. The rainiest month at Site 300 was also December with accumulation of 7.8 cm (3.09 in.) or about 218% of normal. The maximum daily rainfall of 2.8 cm (1.12 in.) fell on December 30.

Topography

The Livermore site is located in the southeastern portion of the Livermore Valley, a topographic and structural depression oriented east-west within the Diablo Range. The Livermore Valley, the most prominent valley in the Diablo Range, is bounded on the west by Pleasanton Ridge and on the east by the Altamont Hills. The valley floor is covered by alluvial, lake, and wetland deposits, consisting of gravels, sands, silts, and clays, at an average thickness of about 100 m (325 ft). The valley is approximately 22.6 km (14 mi) long and generally varies in width between 4 and 11.3 km (2.5 and 7 miles). The valley floor is at its highest elevation of 220 m (720 ft) above sea level along the eastern margin and gradually dips to 92 m (300 ft) at the southwest corner. The major streams passing through the Livermore Valley are the Arroyo del Valle and the Arroyo Mocho, which drain the southern highlands and flow intermittently. Surface waterways in the vicinity of the Livermore site are the Arroyo Seco (along the southwest corner of the site), the Arroyo Las Positas (along the northern perimeter of the site), and the Arroyo Mocho (southwest of the site). These arroyos are shown in **Figure 5-8**. Lake Del Valle, located about 10 km (6 mi) south of LLNL, is the closest large body of water.

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 southeast portion.

Hydrogeology

Livermore Site

The hydrogeology and movement of groundwater in the vicinity of the Livermore site have been the subjects 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 the reports of these investigations and the data supplied by Alameda County Flood Control and Water Conservation District Zone 7, the agency responsible for groundwater management in the Livermore Valley basin (SFBRWQCB 1982a,b).

The Livermore Formation (and overlying alluvial deposits) contains the aquifers of the Livermore Valley groundwater basin and is considered an important water-bearing formation. Natural recharge occurs primarily along the fringes of the basin and through the arroyos during periods of winter flow. Groundwater flow in the valley generally moves 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 in fringe areas, under localized sources of recharge, and in the vicinity of heavily used extraction (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** shows 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 further described in Chapter 8 and illustrated in a cross section (**Figure 8-1**). Although groundwater elevations vary due to seasonal and year-to-year differences in both recharge and groundwater withdrawal from the basin, the qualitative patterns shown in **Figure 1-3** are generally maintained. 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, the contours flatten to a gradient of approximately 0.003.

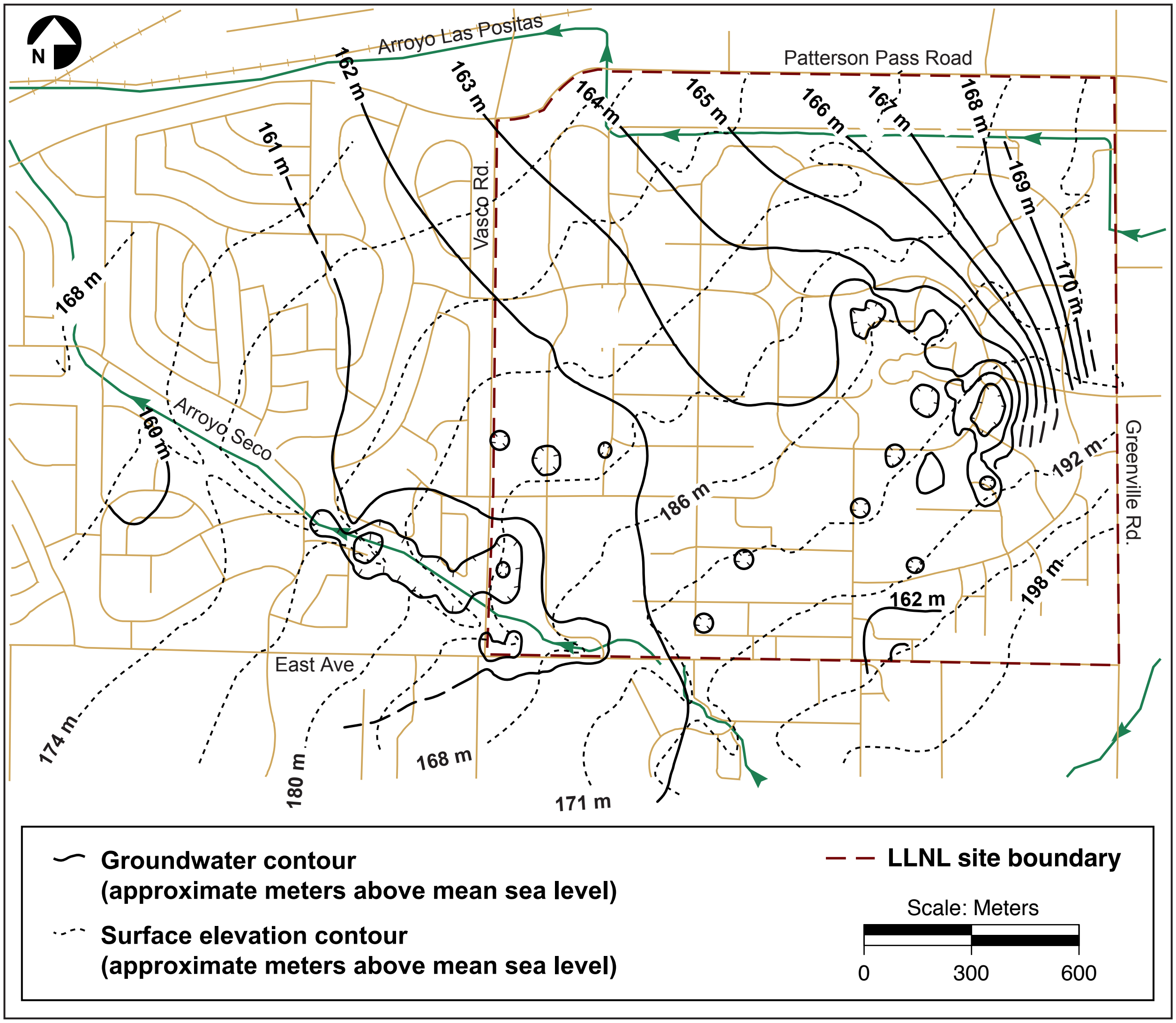


Figure 1-3 Groundwater elevation contours of hydrostratigraphic unit 2 (HSU-2), the shallowest laterally extensive water-bearing unit beneath the Livermore site, October 2005

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 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 in the vicinity of 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). The range in these values reflects the heterogeneity typical of the more permeable alluvial sediments that underlie the area. This range, in combination with the observed water table gradients, yields an estimated average groundwater velocity of about 20 m/y (66 ft/y) (Thorpe et al. 1990).

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 primarily occurs in the Neroly Formation upper and lower blue sandstone units and in the underlying Cierbo Formation. **Figure 8-5** depicts the stratigraphic units that occur beneath Site 300**. Figure 1-4** is a map of the potentiometric surface for the first continuous water-bearing zone at Site 300, which principally occurs 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 generally is 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 thus much of the groundwater flow 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 northwest 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.

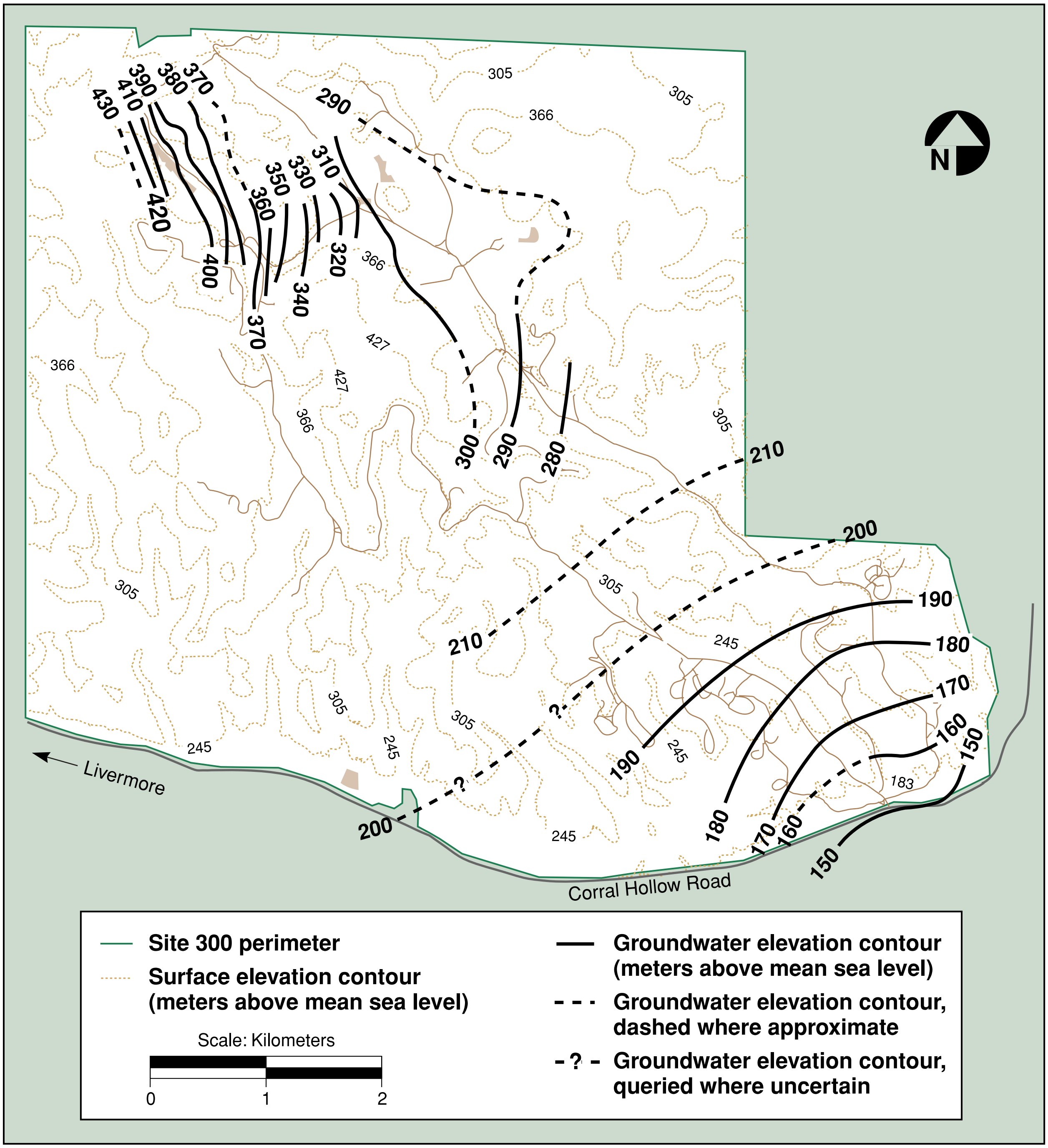


Figure 1-4. Approximate groundwater elevations for the principal continuous water-bearing zone at Site 300

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 General Services Area pump water from this aquifer and are 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.

Summary

Meteorology, topography, and geology affect the dispersal of contaminants 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 also takes into account the unique features of the Livermore site and Site 300 to tailor sampling and analysis programs for each potentially important environmental pathway.

Contributing Authors

We acknowledge the work of Brent Bowen, John Karachewski, Donald MacQueen, Ring Peterson, and Michael Taffet in preparing this chapter.