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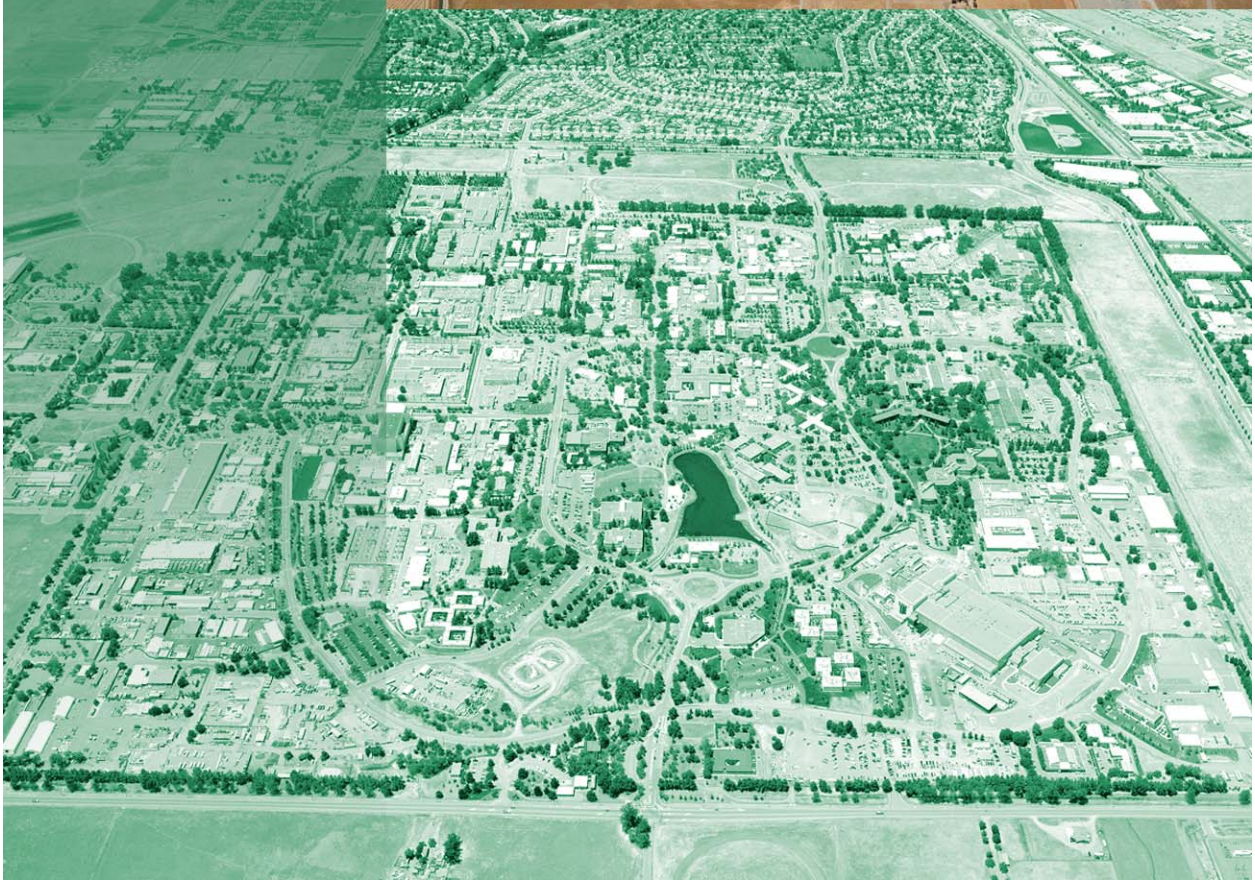
Introduction



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 serves as a resource to the U.S. government and is a partner with industry and academia.

LLNL is a full-service research laboratory with the infrastructure—engineering, maintenance, and waste management activities, as well as environmental protection, security, fire, health and safety, and medical departments—necessary to support its operations and more than 8000 personnel.

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**).

LLNL was founded at the Livermore site in 1952 at a former U.S. Navy training base. At that time the location was relatively isolated, being approximately 1.6 km (1 mi) from the Livermore city limits. Since then, Livermore has evolved from a small town of fewer than 7000 people to a city of about 80,000. Today the city borders the LLNL site on the west and north. The economy, which had been primarily agricultural, has diversified to include light industry and business parks.

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 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. Sandia/California engages in research and development associated with nuclear weapons systems engineering as well as related national security tasks. Although components of their missions are similar, LLNL and Sandia/California are separate entities, each with its own operating management and environmental management systems.

To the south of the LLNL and Sandia/California sites, there 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. Within the last few years, residential developments, both houses and apartments, have filled the

Figure 1-1. Locations of LLNL Livermore site and Site 300

formerly vacant fields immediately to the west of the Livermore site. A small business park lies to the southwest. A very small amount of 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 30.3 km^2 (11.8 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. The remainder of the surrounding area is in agricultural use, primarily as grazing land for cattle and sheep. The nearest residential area is the town of Tracy, population 76,500, located 10 km[1] (6 mi) to the northeast. About 6.2 million people live within 80 km (50 mi) of Site 300. 95% live more than 32 km (20 mi) from Site 300 in such distant metropolitan areas as Oakland, San Jose, and Stockton.

Meteorology and geography play primary roles in how the environment is affected by human actions. Dispersal of particles in air, for example, is influenced by the wind and rain, which in turn are influenced by geographical characteristics. Similarly, the movement of groundwater is constrained by the particular geology of a site. Thus, knowledge of wind, rainfall, geology, and geographical characteristics is used to understand the effects that operations at LLNL might have on the surrounding environment. An understanding of LLNL's meteorological and geographic setting is needed to better monitor Laboratory operations effectively and efficiently.

METEOROLOGY

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 warm, 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 2004 were 22.0 °C (71.7 °F), 8.1 °C (46.6 °F), and 15.0 °C (59.1 °F), respectively. The mean daily maximum, minimum, and average temperatures for Site 300 in 2004 were 20.8 °C (69.4 °F), 12.1 °C (53.8 °F), and 16.5 °C (61.6 °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 range from –4 °C (25 °F) during the coldest winter mornings to 40 °C (104 °F) during the warmest summer afternoons

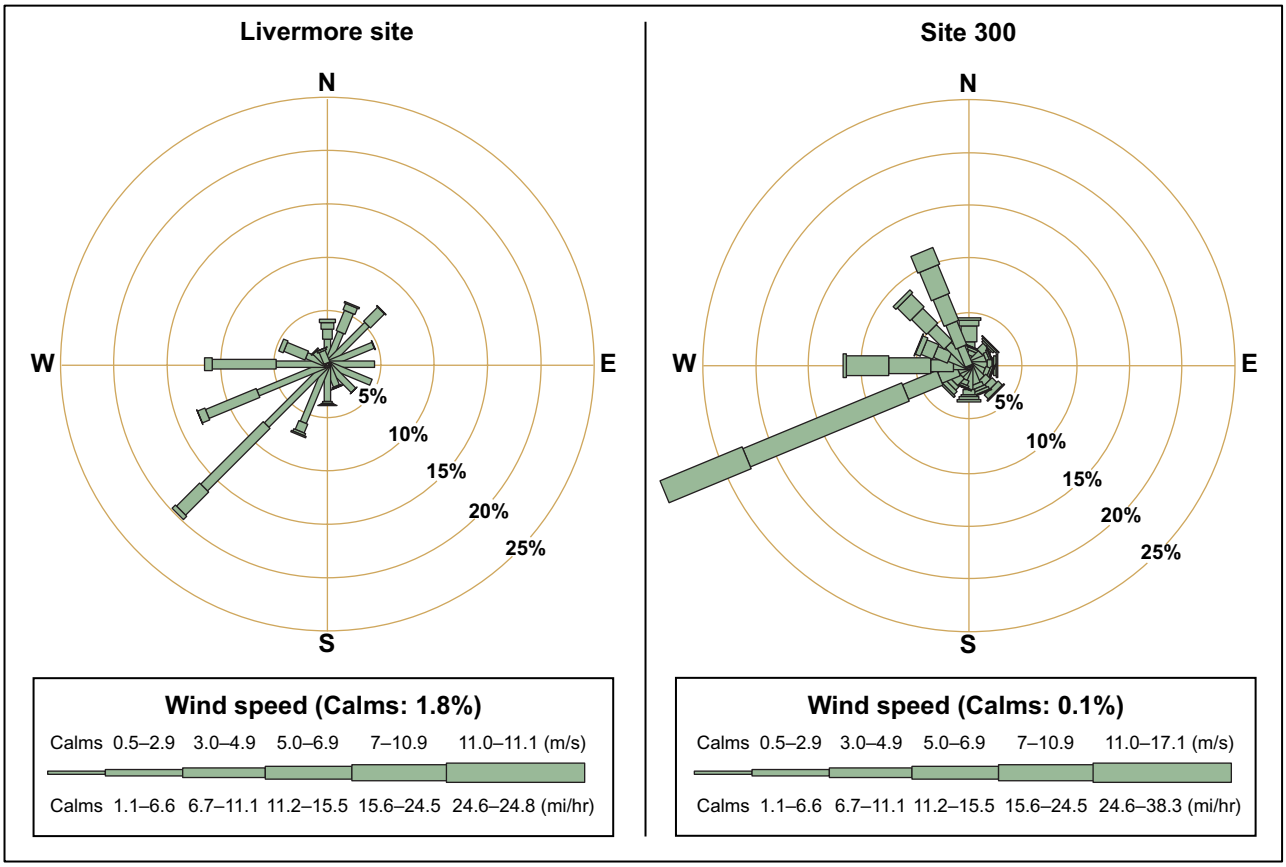
1. This distance is from the northeast border of Site 300 to Sutter Tracy Community Hospital.

at the Livermore site. While the mean annual temperature was near-normal during 2004, several individual months experienced large departures from normal. A persistent warm high pressure system and offshore winds caused March to be the warmest at the Livermore site since at least 1989 and also caused record heat in April. High temperatures reached 29 °C (84 °F) on March 18, the highest ever recorded for so early in the season. The high temperature reached 31.0 °C (88 °F) on April 25 and 33.5 °C (92 °F) on the following two days, a record for April and for so early in the year. The arrival of Arctic air caused record cold in late November and early December. Freezing temperatures occurred on three mornings in late November, including –1.8 °C (29 °F) and –3.9 °C (25 °F) on November 29 and 30, respectively. Morning low temperatures continued to dip below freezing during the first five days of December, including –5 °C (23 °F) on December 4, the lowest temperature recorded in 2004. The lowest temperature at Site 300 was –0.4 °C (31 °F) on the morning of December 20. The warmest day of the year was August 11 when the temperature reached 40 °C (104 °F) at the Livermore site and 36.8 °C (98 °F) at Site 300.

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 about 52% of the wind comes from the south-southwest through west directions. This prevailing pattern occurs primarily during the summer. During the winter, winds from the northeast are more common. The peak wind gust at the Livermore site of 25 m/s (56 mph) from the south occurred on February 25 in advance of a storm. Based on a 47-year record, the highest and lowest annual rainfalls were 85.2 and 16.7 cm (33.57 and 6.57 in.), and the normal annual rainfall is 34.6 cm (13.62 in.). In 2004, the Livermore site received 27.8 cm (10.96 in.) of rain, or only 80% of normal. The spring (March–May) total rainfall of 1.5 cm (0.58 in.) was the third driest ever recorded at the Livermore site since 1958. An early storm dropped 1.3 cm (0.52 in.) of rain on September 19. The maximum daily rainfall of 3.1 cm (1.21 in.) fell on December 30.

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 significantly 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 2004. The peak wind speed at Site 300 reached 29 m/s (65 mph) on January 1 and December 29 from the south and south-southeast, respectively. 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 (north) of more significant terrain (i.e., winds are typically southerly during storms) than at the Livermore site, rainfall amounts are typically 20 to 25% lower. Based on a 45-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 26.8 cm



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 2004 at the Livermore site was 2.5 m/s (5.6 mph); at Site 300 it was 6.1 m/s (13.7 mph).

Figure 1-2. Wind rose showing wind direction and speed frequency at the Livermore site and Site 300 during 2004

(10.55 in.). In 2004, Site 300 received 20.2 cm (7.96 in.) of rain, or only 75% of normal. The spring (March–May) total rainfall of 0.8 cm (0.30 in.) was the least ever recorded since at least 1960. An early storm dropped 0.9 cm (0.34 in.) of rain on September 19. The maximum daily rainfall of 2.1 cm (0.81 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 swamp deposits, consisting of gravels, sands, silts, and clays, at an average thickness of about 100 m (325 ft). The valley is approximately 25-km (16-mi) long and averages 11-km (6.8-mi) in width. 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 4-8**.

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 approximately 538 m (1765 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 is a summary of 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. Artificial recharge, if needed to maintain groundwater levels, is accomplished by releasing water from Lake Del Valle or from the South Bay Aqueduct into arroyo channels in the east. 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 water table varies in depth from the surface from about 10 to 40 m (30 to 130 ft). **Figure 1-3** shows a groundwater elevation contour map of the Livermore site area's shallowest, laterally extensive water-bearing unit (hydrostratigraphic unit or HSU), HSU-2. 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.

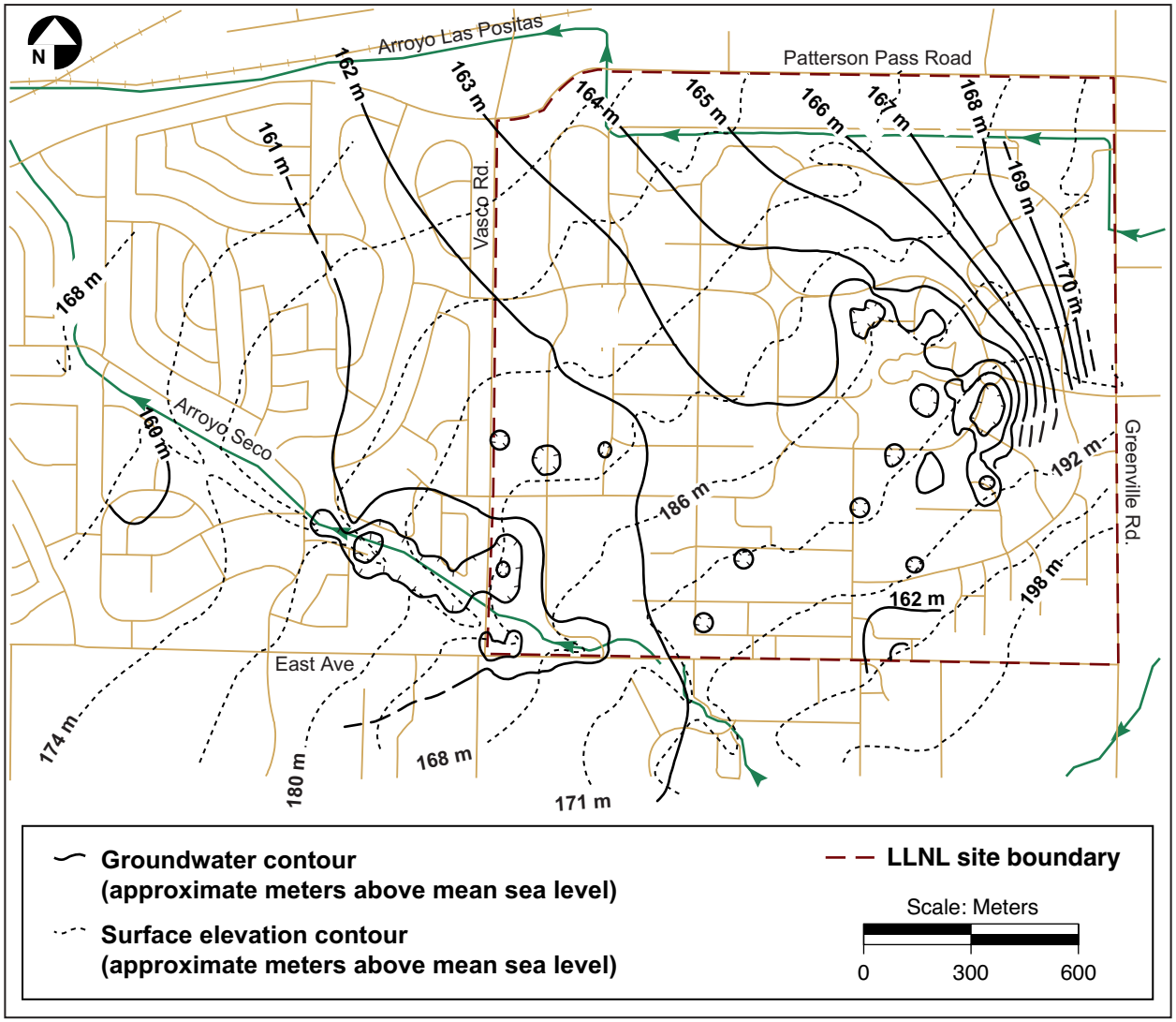


Figure 1-3. Groundwater elevation contours of hydrostratigraphic unit 2 (HSU-2), the shallowest laterally extensive water-bearing unit beneath the Livermore site, November 2004

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. Most groundwater occurs in the Neroly Formation upper and lower blue sandstone aquifers. Significant groundwater is also locally present in permeable Quaternary alluvium valley fill. Much less groundwater is present within perched aquifers in the unnamed Pliocene nonmarine unit. Perched aquifers contain unconfined water separated from an underlying main body of water by impermeable layers; normally they are discontinuous and highly localized. 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 may confine the groundwater and 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.

Groundwater flow in most aquifers follows the attitude 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, groundwater in bedrock flows roughly south-southeast, approximately coincident with the attitude of bedrock strata.

The thick Neroly lower blue sandstone, stratigraphically near the base of the formation, generally contains confined water. Wells located in the western part of the General Services Area pump water from this aquifer and are used to supply drinking and process water.

Figure 1-4 shows the elevation contours for groundwater in the regional aquifer at Site 300. This map of the groundwater elevations is based primarily on water levels in the Neroly lower blue sandstone aquifer.

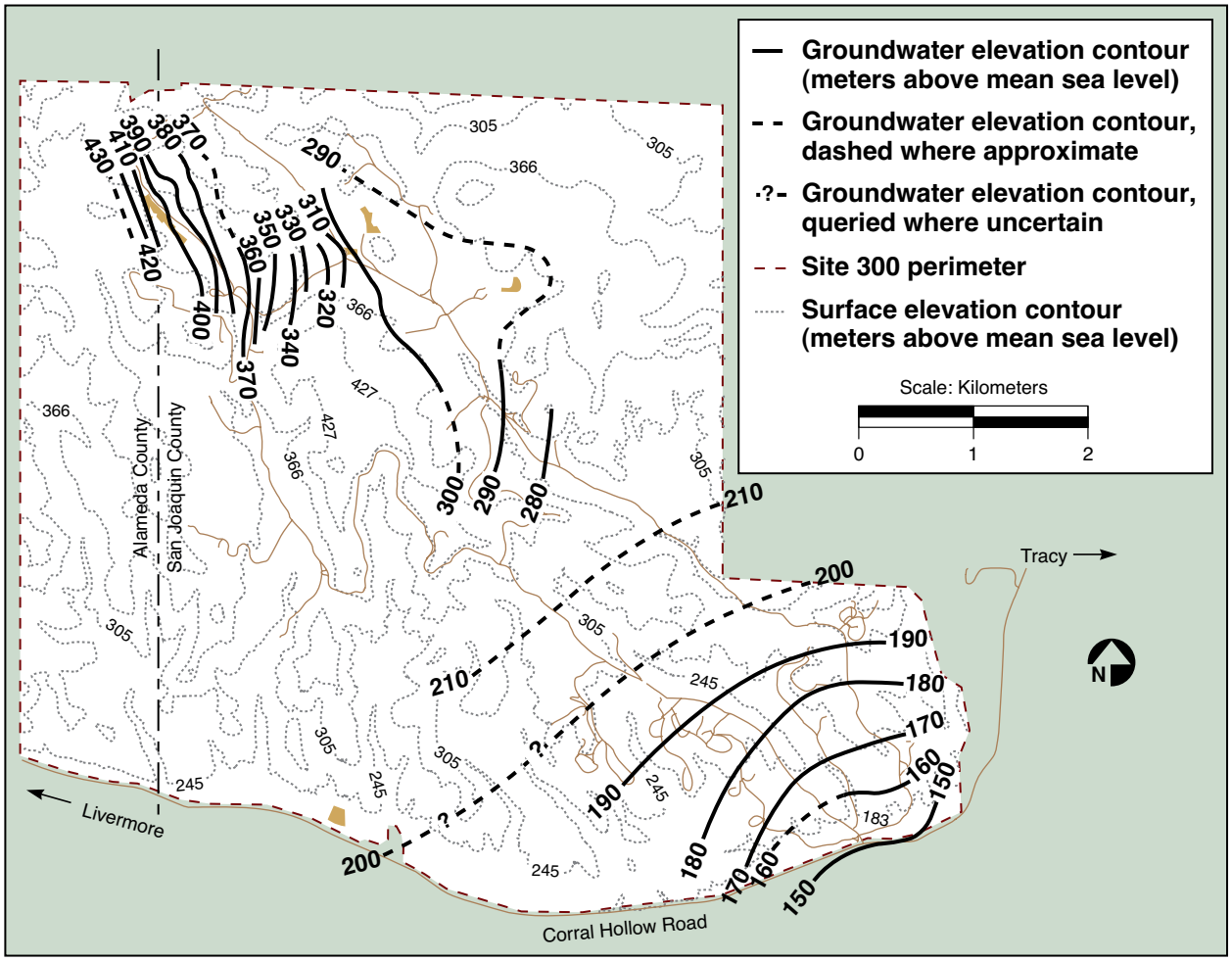


Figure 1-4. Approximate groundwater elevations for the principal continuous water-bearing zone at Site 300

Recharge occurs predominantly in locations where saturated alluvial valley fill is in contact with underlying permeable bedrock or where permeable bedrock strata crop out 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 bedrock aquifers.

Further information on the hydrology of both the Livermore site and Site 300 can be found in the groundwater monitoring and remediation information in Chapter 7.

Summary

LLNL recognizes the importance of geology, hydrogeology, climate, and geographical relationships with its neighbors in assessing potential impacts of operations at the Livermore site and Site 300. Each year LLNL gains additional information to better predict, interpret, and avoid potential impacts. Each environmental medium that is discussed in this document—air, water, terrestrial, and wildlife—may be affected differently. LLNL takes into account the unique locations of the Livermore site and Site 300 to tailor sampling and analysis programs for each method used to monitor the environment.

Contributing Authors

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