11. Geology and Soils

Like many jurisdictions in the State of California, the City of Livermore is located in a geographic area which is susceptible to significant seismic events and related hazards which occur due to the presence of earthquake faults and soil composition in the region. This chapter uses the term "Livermore" to cover the City of Livermore together with the immediately surrounding area within the Urban Growth Boundary (UGB) and Sphere of Influence (SOI). See the Introduction for more information on these boundaries. This chapter describes the existing geology and soil, seismic, and paleontological characteristics in Livermore.

11.1 REGULATORY FRAMEWORK

This section summarizes regulations for geology and soils at the federal, State, regional, and City level.

11.1.1 FEDERAL REGULATIONS

11.1.1.1 PALEONTOLOGICAL RESOURCES PRESERVATION ACT

The federal Paleontological Resources Preservation Act of 2002 limits the collection of vertebrate fossils and other rare and scientifically significant fossils to qualified researchers who have obtained a permit from the appropriate state or federal agency. Additionally, it specifies these researchers must agree to donate any materials recovered to recognized public institutions, where they will remain accessible to the public and to other researchers. This act incorporates key findings of a report, *Fossils on Federal Land and Indian Lands*, issued by the Secretary of the Interior in 2000, that establishes that most vertebrate fossils and some invertebrate and plant fossils are considered rare resources.[1]

11.1.2 STATE REGULATIONS

11.1.2.1 ALQUIST-PRIOLO EARTHQUAKE FAULT ZONING ACT

The Alquist-Priolo Earthquake Fault Zoning Act was passed in 1972 to mitigate the hazard of surface fault rupture to structures used for human occupancy.[2] The main purpose of the act is to prevent the construction of buildings used for human occupancy on top of active faults. This act only addresses the hazard of surface fault rupture—not other earthquake hazards such as earthquake-induced liquefaction or

[1] U.S. Department of the Interior, May 2000, *Fossils on Federal & Indian Lands, Report of the Secretary of the Interior*, May 2000.
https://www.blm.gov/sites/blm.gov/files/programs_paleontology_quick%20links_Assessment%20of%20Fossil%20Management%20on%20Federal%20%26%20Indian%20Lands%2C%20May%202000.pdf, accessed on September 15, 2021.

[2] California Geological Survey, Alquist-Priolo Earthquake Fault Zoning Act, https://www.conservation.ca.gov/index/Documents/CGS-SR-1%20Web%20Copy.pdf, accessed on September 15, 2021.

landslides.[3] The act requires the State Geologist to establish regulatory zones (known as Earthquake Fault Zones or Alquist-Priolo Zones) around surface traces of active faults and to issue appropriate maps.[4] The maps, which are developed using existing United States Geological Survey's (USGS) 7.5-minute quadrangle map bases, are then distributed to all affected cities, counties, and State agencies for their use in planning and controlling new or renewed construction. Generally, construction within 50 feet of an active fault zone is prohibited.

11.1.2.2 CALIFORNIA BUILDING CODE

The State of California provides a minimum standard for building design through Title 24, Part 2, of the California Code of Regulations (CCR), commonly referred to as the "California Building Code" (CBC). The CBC is updated every three years. It is generally adopted on a jurisdiction-by-jurisdiction basis, subject to further modification based on local conditions. The City of Livermore regularly adopts each new CBC update under the Livermore Municipal Code (LMC) Chapter 15.02. These codes provide minimum standards to protect property and public safety by regulating the design and construction of excavations, foundations, building frames, retaining walls, and other building elements to mitigate the effects of seismic shaking and adverse soil conditions. They also regulate grading activities, including drainage and erosion control.

11.1.2.3 CALIFORNIA ENVIRONMENTAL QUALITY ACT

Paleontological resources are afforded protection under the California Environmental Quality Act (CEQA). The Society of Vertebrate Paleontology has set significance criteria for paleontological resources.[5] Most practicing professional vertebrate paleontologists adhere closely to the Society of Vertebrate Paleontology's assessment, mitigation, and monitoring requirements as specifically provided in its standard guidelines. Most State regulatory agencies with paleontological laws, ordinances, regulations, and standards accept and use the professional standards set forth by the Society of Vertebrate Paleontology.

11.1.2.4 CALIFORNIA PUBLIC RESOURCES CODE SECTION 5097

California Public Resources Code (PRC) Section 5097.5 prohibits the destruction or removal of any paleontological site or feature from public lands without the permission of the jurisdictional agency.

11.1.2.5 CALIFORNIA PENAL CODE SECTION 622.5

The California Penal Code Section 622.5 details the penalties for damage or removal of paleontological resources, whether from private or public lands.

[3] California Geological Survey, Alquist-Priolo Earthquake Fault Zoning Act, https://www.conservation.ca.gov/index/Documents/CGS-SR-1%20Web%20Copy.pdf accessed on September 15, 2021.

[4] California Geological Survey, Alquist-Priolo Earthquake Fault Zoning Act, https://www.conservation.ca.gov/index/Documents/CGS-SR-1%20Web%20Copy.pdf, accessed on September 15, 2021.

[5] Society of Vertebrate Paleontology, 2010, Standard Procedures for the Assessment and Mitigation of Adverse Impacts to Paleontological Resources. Society of Vertebrate Paleontology. Impact Mitigation Guidelines Revision Committee.

11.1.3 REGIONAL REGULATIONS

11.1.3.1 2012 ALAMEDA COUNTY EMERGENCY OPERATIONS PLAN

The Alameda County Emergency Operations Plan (EOP), adopted December 2012, formalizes the County's emergency management approach to reduce vulnerabilities to both natural and human-made disasters. The EOP provides basic guidance for earthquakes, flooding, fire, landslides, severe weather, pandemics and epidemics, as well as hazardous material emergencies. The EOP further includes mitigation programs, which are split into three categories: emergency prevention and protection; response concept of operations; and recovery concept of operations.

11.1.3.2 2018 TRI-VALLEY LOCAL HAZARD MITIGATION PLAN

The Cities of Livermore, Dublin and Pleasanton, along with the Dublin San Ramon Services District, adopted the Tri-Valley Local Hazard Mitigation Plan (LHMP) in 2018. The LHMP includes hazard mitigation goals, strategies, and priorities, and provides a comprehensive assessment of the area's hazards and vulnerabilities. The priorities of the mitigation programs are to reduce the loss of life, minimize structural damage, reduce disruption of essential services, protect the environment, and promote hazard mitigation as an integrated public policy.

11.1.4 LOCAL REGULATIONS

11.1.4.1 LIVERMORE 2003-2025 GENERAL PLAN

The Livermore 2003-2025 General Plan includes goals, policies, and implementation measures related to geology, soils, and seismicity in the Public Safety Element. Applicable goals, policies, and actions in the 2003-2025 General Plan serve to protect community health and safety from human-made and natural disasters and prepare for emergency situations in Livermore. As part of the General Plan Update, some existing General Plan goals, policies, and implementation measures could be amended, substantially changed, or new policies could be added. A list of policies applicable to geology and soils is provided in Table 11-1.

TABLE 11-1	2003-2025 LIVERMORE GENERAL PLAN RELEVANT GOALS, POLICIES, AND ACTIONS
Goal PS-1	Reduce risk to the community from earthquakes and other geologic hazards.
Policy PS-1.1-P1	Urban development within earthquake fault zones and areas of high landslide susceptibility, shown in Figure 10-3 (of the GP), shall be conditioned upon the preparation of site-specific geotechnical investigations.
Policy PS-1.1-P2	The City shall rely on the most current and comprehensive geologic hazard mapping available to assist in the evaluation of potential seismic hazards associated with proposed new development. Projects proposed in areas identified as being subject to moderate or high geologic hazard shall be required to conduct site-specific geotechnical investigation.
Policy PS-1.1-P3	No structure proposed for human occupancy shall be placed across the trace of any active or potentially active fault within the Planning Area. The Greenville Fault and Las Positas Fault shall be assumed active, and the Livermore Fault shall be assumed potentially active, unless and until proven otherwise.
Policy PS-1.1-P4	Geologic and engineering studies shall be required for all proposed building projects, per State law, and all critical facilities (schools, hospitals, fire and police stations) within the City so that these facilities can be constructed in a manner that mitigates site-specific geotechnical challenges and will minimize the risk to the public from seismic hazards.
Policy PS-1.1-P5	Construction shall be prohibited in areas with severe erosion (slopes over 10 percent), as mapped by the USDA's Natural Resources Conservation Service, unless it can be clearly demonstrated through geotechnical engineering analysis that the project will not contribute to increased erosion, sedimentation or runoff.
Policy PS-1.1-P6	Development shall be prohibited in areas susceptible to slope failure (defined as landslide susceptibility areas 3 and 4 on Figure 10-3 (of the General Plan) or current hazard mapping), per State law, unless site-specific geotechnical investigation indicates that landslide hazards can be effectively mitigated.
Policy PS-1.1-P7	Prohibit development on expansive soils which are subject to a high probability of sliding; developments proposed below areas of expansive soils in foothill areas shall be conditioned to avoid damage from potential slide areas.
Policy PS-1.1-P8	No building site or greenhouse, in whole or in part, may be located on a pre-development slope of more than 20 percent. No building may be located on a site that requires an access road over a natural slope of more than 25 percent. Cultivated agriculture may not be conducted on a slope, prior to topographical alteration, of more than 20 percent.
Action PS-1.1-A1	Retain a geologist registered in the State of California to evaluate the geologic reports required under policies PS-1.1-P2 and PS-1.1-P3 (above) and advise the City regarding them.
Action PS-1.1-A2	Adopt appropriate setbacks for development or perform detailed fault shear zone studies to define building setback requirements within earthquake fault zones. The ultimate setback required will be determined as geologic studies are made as a condition of processing development proposals.
Policy PS-1.2-P1	Major utility lines shall be carefully planned where they cross a fault. They shall cross at right angles, or nearly so, be accessible for rapid repair, and be provided with safety measures such as automatic shutoff valves, switches and expansion joints. Other equipment shall be provided to ensure minimal adverse impact on adjacent and surrounding areas and to facilitate restoration of service in the event of fault displacement.
Policy PS-1.2-P2	Areas of high shrink-swell potential soils shall incorporate suitable mitigation measures. If development is allowed in areas of high shrink-swell potential, special measures must be undertaken in site grading, foundation design and construction to alleviate potential movements.
Policy PS-1.2-P3	The City shall control site preparation procedures and construction phasing to reduce erosion and exposure of soils to the maximum extent possible.
Action PS-1.2-A1	Promote programs that identify unreinforced masonry buildings and other buildings that would be at risk during seismic events and continue to promote strengthening of these buildings.
Action PS-1.2-A2	Promote programs that encourage residents to make their homes more seismically resistant and resilient.

11.1.4.2 LIVERMORE MUNICIPAL CODE AND DEVELOPMENT CODE

In addition to the General Plan, the Livermore Municipal Code and the Livermore Development Code (LDC) regulate geology, soil, and seismic related issues in the city. The LMC includes requirements to preserve the integrity of the city's geologic and soil resources and to reduce impacts from seismic events, landslides, erosion, and subsidence. The LMC is organized by Title, Chapter, and Section. Most provisions related to geology, soils, and seismic events are in Title 15, Buildings and Constructions. Other provisions related to geology, soils and seismic events are in Part 10, Subdivisions of the LDC.

11.1.4.3 LIVERMORE EMERGENCY OPERATIONS PLAN

The Livermore Emergency Operations Plan (EOP) is the foundation for disaster response and recovery operations for the City of Livermore and outlines how the City complies with and implements the requirements of the California Emergency Services Act to protect the lives and property within Livermore. The Livermore EOP establishes the emergency organization, specifies policies and general procedures, and provides for coordination of the responsibilities of the City of Livermore as a member of the Alameda Operational Area with other member organizations, in all phases of an emergency or disaster. The Livermore EOP provides an overview of the Emergency Operations Center and outlines the various modes of activation of the EOP. Most provisions related to geology, soils, and seismic events are in Section 2.3 of the EOP. Existing Conditions

This section describes the existing geology and soils characteristics, natural hazards which pose a health and safety risk, and the presence of paleontological resources in Livermore.

11.1.5 GEOLOGY

The Planning Area is located in the Livermore Valley within the Coast Ranges Geomorphic Province. The Coast Ranges Geomorphic Province is a long region of moderate relief containing many elongate ridges and narrow valleys that are approximately parallel to the coast. In the San Francisco Bay Area, the Coast Ranges Geomorphic Province is characterized by a series of northwest-to-southeast-trending ridges and valleys associated with faulting and folding.[6] The Livermore Valley is an east-west trending valley, unique to the East Bay, and is a deep alluvial depression containing sediments deposited as part of the Livermore Gravel Formation. The Greenville fault forms the eastern border of the valley, separating it from the Altamont Hills. The valley ranges in elevation from 400 to 500 feet above mean sea level.

The Livermore Valley is structurally controlled by faulting from the Greenville and Las Positas Faults.[7] Both of these faults are located in Livermore and both have been designated as Alquist-Priolo Earthquake Fault Zones. Drainage in the Livermore Valley includes various waterways and creeks including three major arroyos: Arroyo del Valle, Arroyo Las Positas, and Arroyo Mocho. These arroyos generally flow westward

[6] Schoenherr, Allan A. 2017. *A Natural History of California, 2nd Edition*. University of California Press, Oakland, California.

[7] D. W. Carpenter, J. J. Sweeney, P. W. Kasameyer, N. R. Burkhard, K. G. Knauss, and R. J. Shlemon, 1984, Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas, dated August 1984. Available online: https://www.osti.gov/servlets/purl/6050765. Accessed: September 16, 2021.

across the Livermore Valley to join Arroyo de la Laguna in Pleasanton, which drains in a southerly direction approximately 18 miles to the San Francisco Bay via Niles Canyon and Alameda Creek which occur outside Livermore. Refer to the Biological Resources Report for more details on hydrologic features within Livermore.

The predominant geologic units within the Livermore are Qa, Qg, Qoa and QTlg, which are discussed in more detail below.[8],[9] Figure 11-1 is a Geologic Map that shows the surface expression of the major geologic units within Livermore.

Qa (Holocene Alluvium): This unit consists of sediments that have been transported and deposited by streams. Alluvium can be vulnerable to seismically induced instability.

Qg (Holocene Stream Gravel): This unit consists of coarser grained sediments that have been transported and deposited by streams. Stream gravel deposits may be vulnerable to erosion on slopes.

Qls (Holocene Landslide Deposits): The landslide unit contains deposits of unconsolidated solid material and weathered rock fragments that have been transported downslope as a landslide. These deposits may be susceptible to continued flow failures.

Qoa (Pleistocene Alluvium): This unit consists of older sediments that have been transported and deposited by streams. This unit is partially consolidated and is less vulnerable to seismically induced instability, but may contain paleontological resources.

QTlg (Pliocene to Pleistocene Livermore Gravel): This unit is comprised of light reddish-gray cobble-pebble gravel containing debris from Franciscan rocks and minor to major amounts of gray claystone. This unit is weakly cemented and is vulnerable to seismically induced landslides, and may contain paleontological resources.

Tps (Pliocene nonmarine sedimentary rocks): This unit consists of weakly indurated pebble conglomerate, sandstone and greenish gray claystone. Within Livermore, this unit is limited to the hills south of Interstate 580 and east of Greenville Road. This unit is not vulnerable to seismically induced instability, but may contain paleontological resources.

Tbr (Miocene Cierbo Sandstone): This unit consists of tan arkosic marine sandstone that is pebbly and locally fossiliferous. Within Livermore, this unit is limited to hills near the Greenville Fault. This unit is not vulnerable to seismically induced instability, but is likely to contain paleontological resources.

Kp/Kps (Upper Cretaceous Panoche Formation): The Kp unit contains micaceous clay shale with a few thin sandstone beds. The Kps unit contains tan arkosic sandstone with large concretions and some micaceous shale. Within Livermore, these units are limited to the hills east of the Greenville Fault. These units are not vulnerable to seismically induced instability, but may contain paleontological resources.

Unique geologic features are those that are unique to the field of geology. Each rock unit tells a story of the natural processes operating at the time it was formed. The rocks and geologic formations exposed at

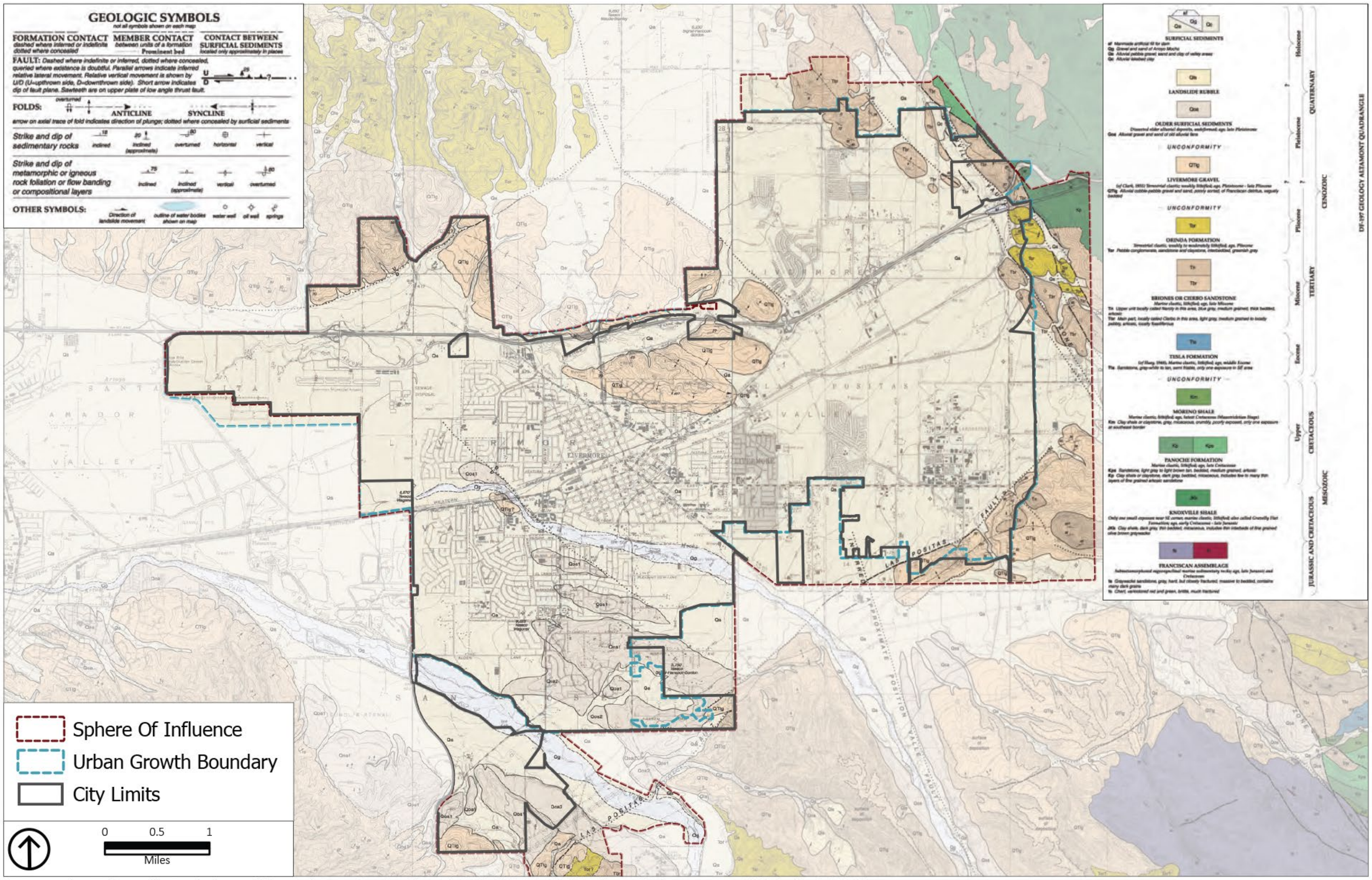
[8] T. W. Dibblee, Jr., 1980, Preliminary Geologic Map of the Livermore Quadrangle, Alameda and Contra Costa Counties, California, U.S. Geological Survey Open-File Report 80-533B, scale 1:24,000. Available online: https://pubs.usgs.gov/of/1980/0533b/plate-1.pdf. Accessed: September 16, 2021.

[9] T. W. Dibblee, Jr., 1980, Preliminary Geologic Map of the Altamont Quadrangle, Alameda County, California, U.S. Geological Survey Open-File Report 80-538, scale 1:24,000. Available online: https://pubs.usgs.gov/of/1980/0538/plate-1.pdf. Accessed: September 16, 2021.

the earth's surface or revealed by drilling and excavation are our only record of that geologic history. What makes a geologic unit or feature unique can vary considerably. For example, a geologic feature may be considered unique if it is the best example of its kind and has distinctive characteristics of a geologic principle that is exclusive locally or regionally, is a key piece of geologic information important to geologic history, contains a mineral that is not known to occur elsewhere in the area, or is used as a teaching tool. Unique geological features are not common in Livermore. The geologic processes are generally the same as those in other parts of the state, country, and even the world. The geology and soils in the Livermore are common throughout the city and region and are not considered to be unique.

GEOLOGY AND SOILS

Figure 11-1 Geologic Map



Source: American Association of Petroleum Geologists, 2006; USGS 2017; City of Livermore, 2021; Esri, 2021.

11.1.6 SOILS

The Livermore Valley floodplain supports very gravelly soils assigned with the Yolo-Pleasanton association, interspersed with loams and clays of the Rincon-San Ysidro association.[10] Soils in Livermore primarily consist of alluvial soils. Alluvial soils are characterized by complex layering of gravel, silty sands, sand, and clayey soils. These soils in Livermore have been deposited into the Livermore Valley over thousands of years by Arroyo del Valle, Arroyo Las Positas, and Arroyo Mocho waterways. Northeast of Livermore is the Springtown Alkali Sink, a large expanse of alkali soils that support unique wetland and grassland habitat.[11]

11.1.7 REGIONAL SEISMICITY

The Earth's crust includes tectonic plates that locally collide with or slide past one another along plate boundaries. California is particularly susceptible to such plate movements, notably the largely horizontal or "strike-slip" movements of the Pacific Plate, as it impinges on the North American Plate. In general, earthquakes occur when the accumulated stress along a plate boundary or fault is suddenly released, resulting in seismic slippage. This slippage can vary widely in magnitude, ranging in scale from a few millimeters or centimeters, to tens of feet. The performance of man-made structures during a major seismic event varies widely due to a number of factors, including:

- Location, with respect to active fault traces or areas prone to liquefaction or seismically-induced landslides;
- Type of building construction (i.e., wood frame, unreinforced masonry, non-ductile concrete frame);
- Proximity, magnitude, depth, and intensity of the seismic event itself as well as many other factors.

In general, evidence from past earthquakes shows that wood frame structures tend to perform well during a seismic event, especially when their foundations are properly designed and anchored. Conversely, older, unreinforced masonry structures and non-ductile reinforced concrete buildings (especially those built in the 1960s and early 1970s), do not perform as well, especially if they have not undergone appropriate seismic retrofitting. Applicable building code requirements, such as those found in the CBC, include seismic requirements that are designed to ensure the satisfactory performance of building materials under prescribed seismic conditions.

Seismic activity in the Coast Ranges is generally associated with active faults of the San Andreas system, which includes major active faults within and surrounding Livermore. Over the width of the San Francisco Bay region, approximately 1.5 inches per year of relative horizontal movement occurs between the North American and Pacific Plates. This movement is partially accommodated by earthquakes and creep along several active faults. Locations of these active faults relative to Livermore are shown on Figure 11-2, Regional Fault Map.

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[10] UC Davis California Soil Resource Laboratory, SoilWeb website. https://casoilresource.lawr.ucdavis.edu/gmap/. Accessed: September 16, 2021.

[11] ICF. 2010. East Alameda County Conservation Strategy, Final Draft. Available online: http://www.eastalco-conservation.org/documents.html. Accessed: August 2021.

GEOLOGY AND SOILS

The City of Livermore is in a seismically active region as shown in Figure 11-2. There are five major fault zones in Livermore: the Greenville, the Las Positas, the Pleasanton, the Calaveras, and the Hayward Faults. The Greenville Fault runs in a northwest-southeast orientation through the northeastern portion of Livermore and is capable of generating an earthquake of up to maximum magnitude (M) 6.9. The Las Positas Fault runs in a northeast-southwest orientation through the southeastern portion of Livermore. The Livermore Earthquake sequence of 1980, of which the two notable earthquakes were M 5.6 and M 5.4, have been attributed to the Greenville and Las Positas Faults. Only the Greenville Fault exhibited fault rupture in the 1980 earthquakes.[12] The Pleasanton Fault, a minor off-shoot of the Calaveras Fault runs in an approximately north-south orientation on the western part of the Livermore Valley, about six miles west of Livermore and has been inferred through aerial photography and the presence of a groundwater barrier. The Calaveras Fault system marks the eastern margin of the East Bay Hills on a north-south axis and has the capacity to generate an earthquake of up to approximately M 7. Lastly, the Hayward Fault is a northwest-southeast trending fault located approximately 17 miles southwest of Livermore and is capable of a maximum earthquake of M 7.4.

When earthquake faults within the San Francisco Bay Area's nine-county area were considered, the USGS estimated that the probability of a M 6.7 or greater earthquake prior to year 2032 is 62 percent, or roughly a two-thirds probability. The forecast probability for each individual fault to produce a M 6.7 or greater seismic event by the year 2032 is 27 percent for the Hayward Fault, 21 percent for the San Andreas Fault, 11 percent for the Calaveras Fault, and 10 percent for the San Gregorio Fault.[13] Earthquakes of this magnitude can create ground accelerations severe enough to cause major damage to structures and foundations not designed to resist earthquakes. Underground utility lines are also susceptible where they lack sufficient flexibility to accommodate the seismic ground motion.[14] In the event of a M 7.8 earthquake on the San Andreas Fault, the seismic forecasts on the Association of Bay Area Governments' interactive GIS website (developed by a cooperative working group that included the USGS and the CGS) suggest that Livermore is expected to experience "severe" shaking.[15]

Due to the active fault lines within and surrounding it, Livermore is historically susceptible to all earthquake-related hazards which include ground rupture, ground shaking, and liquefaction.

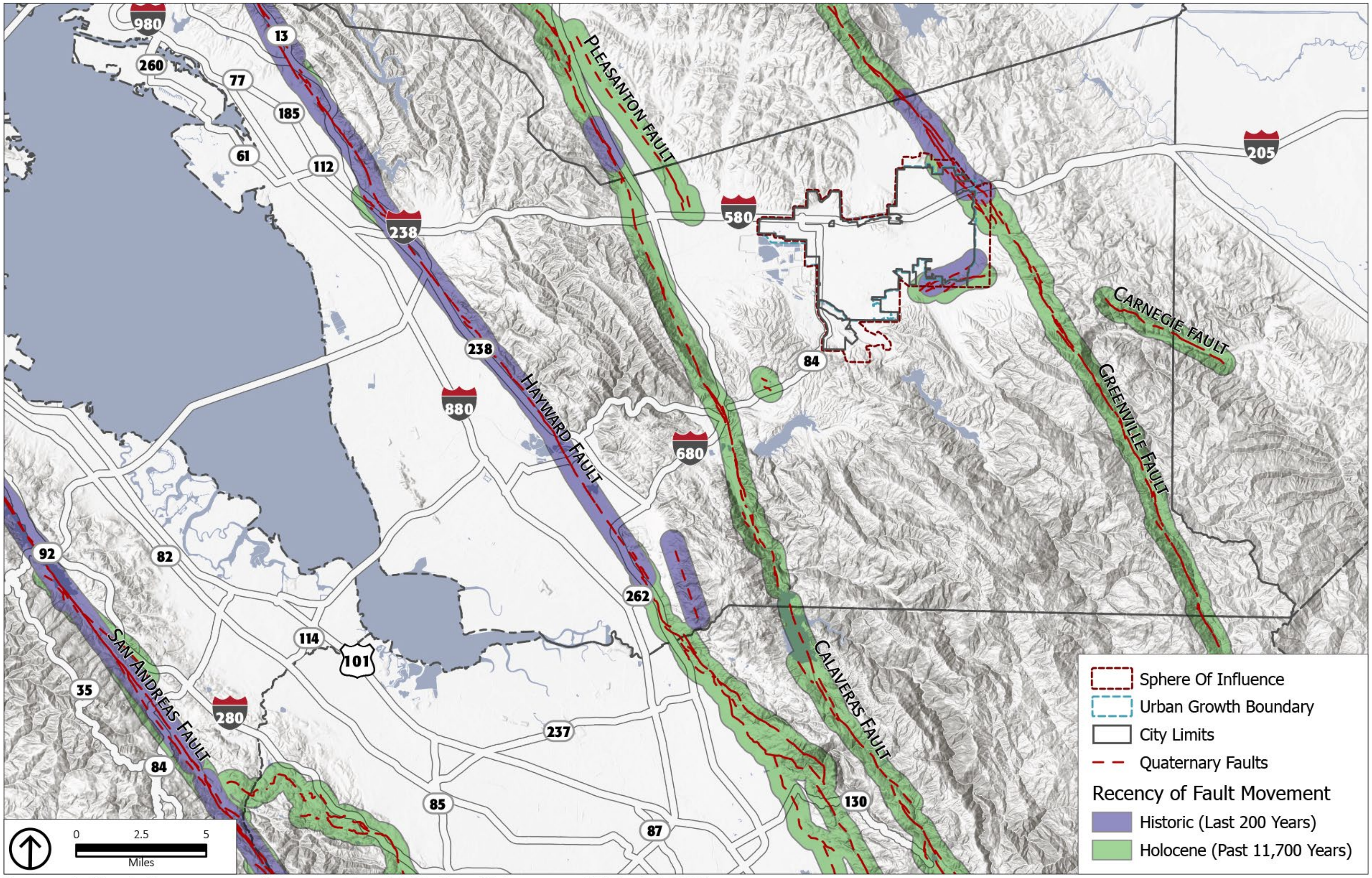
[12] B. A. Bolt, T. V. McEvilly, and R. A. Uhrhammer, 1981, The Livermore Valley, California, Sequence of January 1980, Bulletin of the Seismological Society of America, Vol. 71, No. 2, pp 451-463, April 1981.

[13] United States Geological Survey (USGS), San Francisco Region Earthquake Probability, http://earthquake.usgs.gov/regional/nca/wg02/images/percmap-lrg.html, accessed on September 28, 2021.

[14] Association of Bay Area Governments (ABAG), 1995, *The San Francisco Bay Area On Shaky Ground*, Publication Number P95001EQK, 13 maps, scale 1:1,000,000.

[15] Association of Bay Area Governments (ABAG), 2013, Interactive Hazards Map, Earthquake Shaking Scenarios, http://gis.abag.ca.gov/website/Hazards/?hlyr=northSanAndreas, accessed on September 28, 2021.

Figure 11-2 Regional Fault Map



Source: California Department of Conservation, 2010; City of Livermore, 2021; Esri, 2021.

11.1.7.1 GROUND SHAKING AND RUPTURE

The most common hazard from a seismic event is ground shaking. While ground shaking due to an earthquake may be experienced many miles from the source of an earthquake, ground rupture is localized in the immediate vicinity of any fault line which experiences a significant seismic event. Because the Greenville and Las Positas Faults lie beneath Livermore, these areas have the potential to experience ground rupture in the event of a strong seismic event.

11.1.7.2 LIQUEFACTION

Liquefaction is a hazard which occurs during prolonged periods of ground shaking in areas with alluvial or granular soils, which are less cohesive than soil types such as clay. Liquefaction is a result of prolonged ground shaking from a seismic event, which causes a sudden rise of an underground water table. When a water table rises in areas with alluvial and granular soils, the water infiltrates the soil bed and compromises the strength and stability of the soil, which can therefore compromise structures in such areas. Although, liquefaction is most often triggered by seismic shaking, it can also be caused by improper grading, landslides, or other factors. In dry soils, seismic shaking may cause soil to consolidate rather than flow, a process known as densification. As discussed in Section 11.2.2, Soils, Livermore is largely located atop alluvial soils. These alluvial soils, in addition to a perched water table, mean that there is a high risk of liquefaction in the low-lying parts of Livermore as shown in Figure 11-3.

11.1.8 LANDSLIDES

Landslides are gravity-driven movements of earth materials that can include rock, soil, unconsolidated sediment, or combinations of such materials. The rate of landslide movement can vary considerably; some move rapidly, as in a soil or rock avalanche, and others “creep,” or move slowly for long periods of time. The susceptibility of a given area to landslides depends on many variables, although the general characteristics that influence landslide hazards are widely acknowledged. Some of the more important contributing factors are:

- **Slope Material.** Loose, unconsolidated soils and soft, weak rocks are more hazardous than are firm, consolidated soils or hard bedrock.
- **Slope Steepness.** Most landslides occur on moderate to steep slopes.
- **Structure and Physical Properties of Materials.** This includes the orientation of layering and zones of weakness relative to slope direction.
- **Water Content.** Increased water content increases landslide hazard by decreasing friction and adding weight to the materials on a slope.
- **Vegetation Coverage.** Abundant vegetation with deep roots promotes slope stability.
- **Proximity to Areas of Erosion or Human-Made Cuts.** Undercutting slopes can greatly increase landslide potential.
- **Earthquake Ground Motions.** Strong seismic ground motion can trigger landslides in marginally stable slopes or loosen slope materials, which increases the risk of future landslides.

Due to the flat terrain over most of Livermore, landslides are only an environmental concern in localized portions of Livermore. Livermore does not have massive gravel extraction operations like to the south and west that would be particularly vulnerable to earthquake-induced landslides. In the event of a severe earthquake, landslides could possibly be triggered in the hills at the periphery of the northern, southern, and eastern areas of Livermore as shown on Figure 11-3. Some of these areas are in close proximity to existing residential neighborhoods. Due to the differences in the physical characteristics of slope materials, which markedly influence landslide potential, some superficially similar areas may differ widely in terms of landslide hazards. For this reason, site-specific geotechnical investigations are essential to the accurate assessment of potential landslide hazards at any given site.

11.1.9 EROSION

Erosion occurs when the upper layers of soil are displaced by erosive agents such as water, ice, snow, air, plants, animals, or human causes. Sandy soils on moderate slopes, or clayey soils on steep slopes are susceptible to erosion when exposed to these forces. Erosion can become more frequent when established vegetation is disturbed or removed due to grading, wildfires, or other factors. As described in Section 11.2.4, Landslides, Livermore is largely flat, and significant erosion is not a common occurrence. Erosion can occur around agricultural lands. However, soils associated with Prime Farmland are classified as having only a slight or moderate erosion potential.[16] The areas most subject to erosion within Livermore are hillsides and exposed areas adjacent to waterways.

11.1.10 LAND SUBSIDENCE

Land subsidence is a human-induced hazard in which the over-extraction of groundwater or oil causes the depression and caving in of soil deposits. The over-extraction of groundwater or oil causes these soils to shrink which results in sinkholes that may compromise building foundations, pavement, and infrastructure.[17]

Land subsidence has not been well documented within Alameda County, although valley deposits within the county are at risk of subsidence if groundwater over-extraction occurs. However, no cases of groundwater over-extraction have been documented in Livermore or the greater Alameda County.[18] In addition, the Livermore Valley groundwater basin is currently monitored by Zone 7 Water Agency for subsidence and no significant subsidence has been documented.[19]

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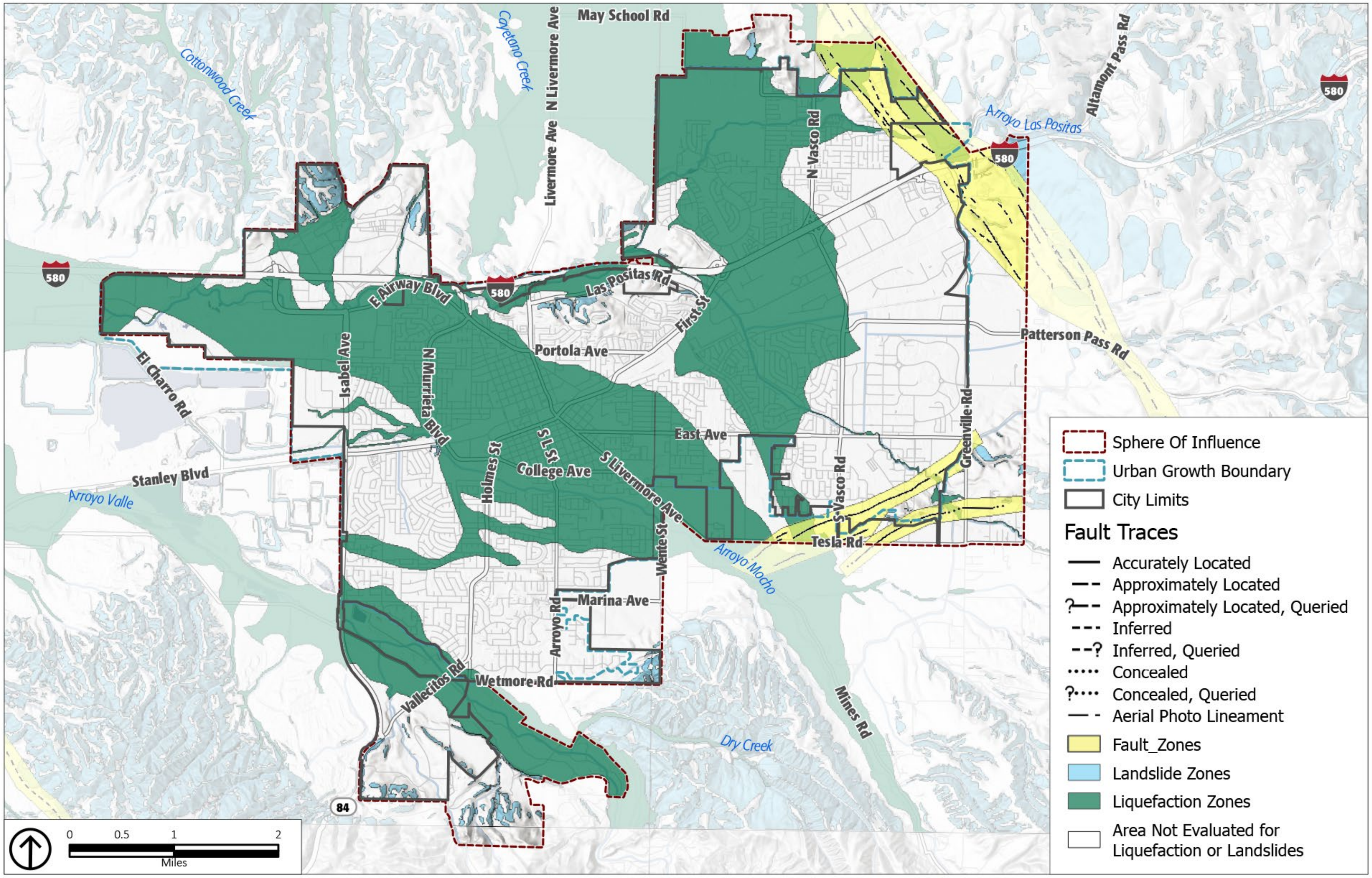
[16] UC Davis California Soil Resource Laboratory, SoilWeb website. https://casoilresource.lawr.ucdavis.edu/gmap/. Accessed: September 16, 2021.

[17] U.S. Geological Survey, Groundwater Decline and Depletion, https://www.usgs.gov/special-topic/water-science-school/science/groundwater-decline-and-depletion?qt-science_center_objects=0#qt-science_center_objects. Accessed on September 16, 2021.

[18] Blackwell, E., M. Shirzaei, C. Ojha and S. Werth, 2020, Tracking California's sinking coast from space: Implications for relative sea-level rise, Science Advances Vol. 6, no. 31. Available online: https://advances.sciencemag.org/content/6/31/eaba4551#:~:text=Su%20rates%20exceeding,mm%2Fyear%20in%20Southern%20California. Accessed September 16, 2021.

[19] Zone 7 Water Agency, 2019, Annual Report for the Sustainable Groundwater Management Program 2018 Water Year (October 2017 – September 2018) Livermore Valley Groundwater Basin, dated March 2019. Available online: https://sgma.water.ca.gov/portal/alternative/print/2. Accessed September 16, 2021.

Figure 11-3 Seismic Hazards Map



Source: California Department of Conservation, 2010; City of Livermore, 2021; Esri, 2021.

There are two documented oil extraction sites in Livermore. The Livermore Oil Field is located in the eastern portion of Livermore and oil production historically has not been excessive.[20] The abandoned Hospital Nose Gas Field is located in the southern portion of Livermore and does not have any producing wells.[21],[22] Based on historical evidence, significant subsidence-related effects from these oil extraction activities has a low likelihood of occurring.[23]

11.1.11 EXPANSIVE SOILS

Soils classified as expansive are those which change dramatically in volume depending on moisture content. When wet, these soils expand; conversely, when dry, these soils contract. Sources of moisture that trigger an expansion include rainfall, landscape irrigation, utility leakage, and perched groundwater[24]. Expansive soils are typically very fine-grained with a high to very high percentage of clay. Soil tests are often used to identify expansive soils to test changes in response to reduced moisture content.[25] A change of 3 percent or greater indicates a moderate to high shrink-swell potential. Such soils are known to cause damage to concrete slabs, structure foundations, and pavement. Areas with expansive soils must often implement special building and structure design which can withstand such a fluctuation in soil. There are clay deposits dispersed in alluvial materials throughout Livermore, which are known to swell and contract during moisture events. However, all projects pursuant to the General Plan Update would be required to follow California Building Code procedures for evaluating the presence of expansive soils and employing strategies to minimize the risks of developing on expansive soils.

11.1.12 PALEONTOLOGICAL RESOURCES

Paleontological resources are the fossilized remains of organisms from prehistoric environments found in geologic strata. They are valued for the information they yield about the history of the earth and its past ecological settings. Paleontological resources include vertebrates (i.e., animals with backbones), invertebrates (e.g., starfish, clams, ammonites, and marine coral), microscopic plants and animals (microfossils), and trace fossils (footprints, burrows, etc.). These resources are found in geologic strata conducive to their preservation, typically sedimentary formations. Paleontological sites are areas that show evidence of prehuman activity. Often, they are simply small outcrops visible on the surface or sites encountered during grading. While the sites are important indications, it is the geologic formations that

[20] H. McLean, 1987, Federal Lands Assessment Program: Sonoma and Livermore Basins, California (Province 79), U.S. Geological Survey Open-File Report 87-450J. Available online: https://pubs.usgs.gov/of/1987/0450j/report.pdf. Accessed September 17, 2021.

[21] California Department of Conservation, California Geologic Energy Management Division, 2021, WellFinder website https://maps.conservation.ca.gov/doggr/wellfinder/#openModal/-121.70805/37.67235/13. Accessed September 17, 2021.

[22] California Department of Conservation, California Geologic Energy Management Division, 2020, 2019 Annual Report of the State Oil and Gas Supervisor, October 2020.

[23] Zone 7 Water Agency, 2019, Annual Report for the Sustainable Groundwater Management Program 2018 Water Year (October 2017 – September 2018) Livermore Valley Groundwater Basin, dated March 2019. Available online: https://sgma.water.ca.gov/portal/alternative/print/2. Accessed September 16, 2021.

[24] Perched groundwater is an occurrence of unconfined subterranean water that is not hydraulically connected to the main aquifer.

[25] Army Corps of Engineers Field Manual TM 5-818-7, 1985, https://www.wbdg.org/FFC/ARMYCOE/COETM/ARCHIVES/tm_5_818_7.pdf, accessed on September 16, 2021.

are the most important since they may contain important fossils. The Society of Vertebrate Paleontology defines a significant fossil resource as, "identifiable vertebrate fossils, large or small, uncommon invertebrate, plant, and trace fossils, and other data that provide taphonomic, taxonomic, phylogenetic, paleoecologic, stratigraphic, and/or biochronologic information. Paleontological resources are considered to be older than recorded human history and/or older than middle Holocene (i.e., older than about 5,000 radiocarbon years)."[26]

As discussed in Section 11.2.1, Geology, the Livermore Valley is underlain with a thick layer of alluvial sediments which are drained from other locations in the surrounding region and deposited into low-lying lands. The alluvial deposits in the Livermore Valley have been recorded to contain several megafauna vertebrate fossils, extracted from Pleistocene age alluvium.[27] Discoveries specifically from the Pleistocene alluvium include the remains of camels (Camelops hesternus), mammoths (Mammuthus columbi), ancient bison (Bison antiquus), horses (Equus occidentalis), and ground sloths (Glossotherium harlani) along with various invertebrate fossils such as teeth and large vertebrate bones.[28] In addition, there are other formations within the Livermore Valley in which fossils have been discovered, including the Pliocene to Pleistocene age Livermore Gravel, the late Miocene to Pliocene Lower Livermore Formation, the late Miocene to Pliocene Sycamore Formation, the late Miocene Neroly Formation and Briones Formation, the Great Valley Complex and the Franciscan Complex. It is anticipated that due to the rich geologic past within the Livermore Valley, there may be significant paleontological resources which have not been unearthed.

11.2 IMPLICATIONS FOR THE GENERAL PLAN UPDATE

Based on information contained in this chapter, the General Plan Update should consider the following:

- Consider the necessary setbacks from active faults, including the Greenville and Las Positas Faults. The setbacks, set by the Alquist-Priolo Earthquake Fault Zone Act, prohibit construction from occurring within 50 feet of an active fault when discussing potential land use changes..
- Consider requiring geotechnical reports on all projects located within 50 feet of the Greenville or Las Positas Faults, and sites located in zones of required investigation for liquefaction or landslides.
- Ensuring that future development is not unduly exposed to landslide hazard zones by keeping landslide hazard maps up to date.

[26] Society of Vertebrate Paleontology, 2010, *Standard Procedures for the Assessment and Mitigation of Adverse Impacts to Paleontological Resources,* page 11. Society of Vertebrate Paleontology. Impact Mitigation Guidelines Revision Committee.

[27] E. B. Parkman, 2006. The California Serengetti [sic]: Two Hypotheses Regarding the Pleistocene Paleoecology of the San Francisco Bay Area, dated November 20, 2006. Available online: https://www.parks.ca.gov/pages/22491/files/the_california_serengetti_pleistocene_paleoecology_of_san_francisco_bay.pdf. Accessed September 17, 2021.

[28] LSA Associates, Inc., 2003, Livermore Draft General Plan and Downtown Specific Plan Environmental Impact Report, Volume I: Master Environmental Assessment, dated June 2003.