10 GEOLOGY

This chapter provides an overview of geologic conditions in Novato. The chapter begins with a discussion of State and local regulations relating to geologic hazards followed by an overview of local geologic conditions and seismic activity. The chapter concludes with a discussion of the primary seismic and geological hazards in Novato.

A. Regulatory Framework

1. State Regulations

a. California Building Code

The California Building Code (CBC) is included in Title 24 of the California Code of Regulations and is a portion of the California Building Standards Code. Under State law, all building standards must be centralized in Title 24, otherwise they are not enforceable. The CBC incorporates the Uniform Building Code, a widely adopted model building code in the United States. Through the CBC, the State provides a minimum standard for building design and construction. The CBC contains specific requirements for seismic safety, excavation, foundations, retaining walls and site demolition. It also regulates grading activities, including drainage and erosion control.

b. Alquist-Priolo Earthquake Fault Zoning Act

The Alquist-Priolo Earthquake Fault Zoning Act (Alquist-Priolo Act) was passed in 1972 to mitigate the hazard of surface faulting to structures for human occupancy. This act prohibits the location of structures designed for human occupancy across active faults and regulates construction within fault zones. However, the Alquist-Priolo Act only addresses hazards associated with surface fault rupture, and does not address other hazards associated with earthquakes (the Seismic Hazards Mapping Act addresses these other hazards). There are no Alquist-Priolo zones within the Novato area.

c. The Seismic Hazards Mapping Act

The Seismic Hazards Mapping Act was passed in 1990 to addresses seismic hazards such as strong ground shaking, soil liquefaction, and earthquake-related landslides. This act requires the State of California to identify and map areas that are at risk for these hazards. Cities and counties are also required to regulate development in the mapped seismic hazard zones. In Novato, the primary method of regulating development projects in these areas is through the permit process. A permit cannot be issued until a geological investigation is completed. However, geotechnical investigations are not required for single-family homes.

d. Assembly Bill 6

In 1998 the State Legislature adopted Assembly Bill 6, which expanded Civil Code Section 1102.6 regarding the disclosure of earthquake hazards. Since June 1998, the sellers of residential property must give prospective buyers a "Natural Hazard Disclosure Statement" if the residential property lies within an earthquake fault zone or a seismic hazard zone. The new law is intended to warn prospective real estate buyers that local earthquake or seismic hazards may limit their ability to develop the property or obtain insurance and may affect their ability to obtain assistance after a disaster.

2. Local Regulations and Plans

a. Novato General Plan

Geology-related hazards are addressed in the Safety and Noise chapter of the existing General Plan. The Safety and Noise chapter contains SF Objective 1, which calls for the City to "reduce seismic hazards." Policies and programs implementing this objective call for the City to mitigate seismic hazards associated with new development and discourage high density development in high-risk areas. SF Objective 2 calls for the City to "minimize the risk of personal injury and property damage resulting from slope and soil instability." Policies and programs implementing this objective call for the City to mitigate slope- and soil-related hazards associated with new development and to require financial protection for public agencies and individuals as a condition of approval for projects in high-risk areas.

b. Hillside Ordinance

Novato Zoning Code Section 19.26, Hillside and Ridgeline Protection, establishes development standards for hillside areas to reduce the potential for slope failure and exposure to other soil-related hazards. The ordinance requires reduced development intensity in areas with steep slopes and establishes design requirements for buildings proposed in hillside areas.

B. Regional Geology

Novato is located in the Coast Range Physiographic province of California. The features of this province were formed by tectonic forces resulting in extensive uplifting, folding and faulting of the area. Northwest trending elongated ridges and intervening valleys characterize the province.

The northern and western portion of Novato is underlain by bedrock of the Franciscan Formation of Late Jurassic to Cretaceous age. The Franciscan Formation consists of a mixture of metamorphosed sandstone, shale, volcanics, serpentine and chert. The eastern area of Novato is underlain by the Late Jurassic to Late Cretaceous of the Great Valley Sequence, consisting of the Novato Conglomerate believed to have been tectonically thrust over the Franciscan Formation rocks.

C. Local Geology

Surficial soils in Novato vary considerably. Soils are comprised primarily of deposits from streams, flood basins and mountain runoff known as alluvium. The low-lying alluvium deposits consist of sand, gravel, silt and small amounts of clay.

Holocene estuarine, tidal, lagoonal deposits of fine sands, silts, clays and sporadic outcroppings of peat (generally referred to as Young Bay Mud) are exposed along the San Francisco Bay margin, along the Petaluma River, and in the Bahia area in the northern part of Novato. Areas of engineered fill placed over bay mud are found in the central to southeastern area between Hamilton Air Force Base and Bel Marin Keys, between the Northwest Pacific Railroad and Highway 101 in the vicinity of Novato Creek, and southward to Novato Boulevard and south of Highway 37. Engineered levee fill is found in low lying areas along Novato Creek, near the Petaluma River and along roads associated with

Hamilton Air Force Base. Engineered fill is also used in scattered areas of low elevation, primarily below Highway 101 and the railroad.

D. Seismicity, Faults, and Fault Zones

Novato is located in the seismically active San Francisco Bay region, an area with a long and complex history of tectonic movements. The region is situated on a plate boundary marked by the San Andreas fault system, which consists of several northwest trending active and potentially active faults. In the Bay Area, movement along this plate boundary is distributed across a complex system of strike-slip, right-lateral, parallel and sub-parallel faults. In the Novato area, these include the San Andreas, Burdell Mountain, Tolay, Rodgers Creek, and Hayward fault zones, as shown on Figure 10-1. The nearest potentially active fault is the Burdell Mountain fault, which is located within Novato's Sphere of Influence (SOI).

1. Earthquake Probability

The United States Geological Survey (USGS) Working Group on California Earthquake Probabilities has evaluated the probability of one or more earthquakes of Richter magnitude 6.7 or higher occurring in the San Francisco Bay Area within the next 30 years. The result of the evaluation indicated a 70 percent likelihood that such an earthquake event will occur in the Bay Area between 2000 and 2030.[1]

An active fault is defined by the California Division of Mines and Geology (CDMG) as one which has had active surface displacement within Holocene time (i.e. over the past 11,000 years). Some faults are characterized as active based on surface displacements within historic time (over the last 200 years), while others are characterized as active based on surface displacements in rocks or sediments within the last 11,000 years. The Hayward and San Andreas faults are active faults based on both recorded historical activity and geologic displacement. The Rodgers Creek fault is active based on the geologic record. This definition of "active fault" does not mean that all faults for which there is no evidence of surface displacement during the Holocene period are inactive. Some faults may have been active during this time period, but they did not result in changes to the surfaces that are easily identifiable. Meanwhile, other faults may still be active although they have not been active during the Holocene period. Occasionally, earthquakes occur on blind thrust faults that are buried and show no evidence of past surface rupture, as was the case with the Northridge earthquake in 1994.

2. Active and Potentially Active Faults

The CDMG has defined potentially active faults as those for which there is evidence of surface displacement within the Quaternary period; that is approximately within the last 1.6 million years. Faults classified as potentially active show no evidence of surface displacements within the past 11,000 years, but this period of time is short in geologic terms. The Tolay and Burdell Mountain faults are considered potentially active.

Novato could be subject to damage from movement on any one of the active or potentially active Bay Area earthquake faults. Table 10-1 lists the nearest active and potentially active faults to Novato, maximum expected earthquake and magnitude. The sections below describe each of these faults.

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[1] U.S. Geological Survey (USGS), 1999. *Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030 – A Summary of Findings.* Open File Report 99-517.

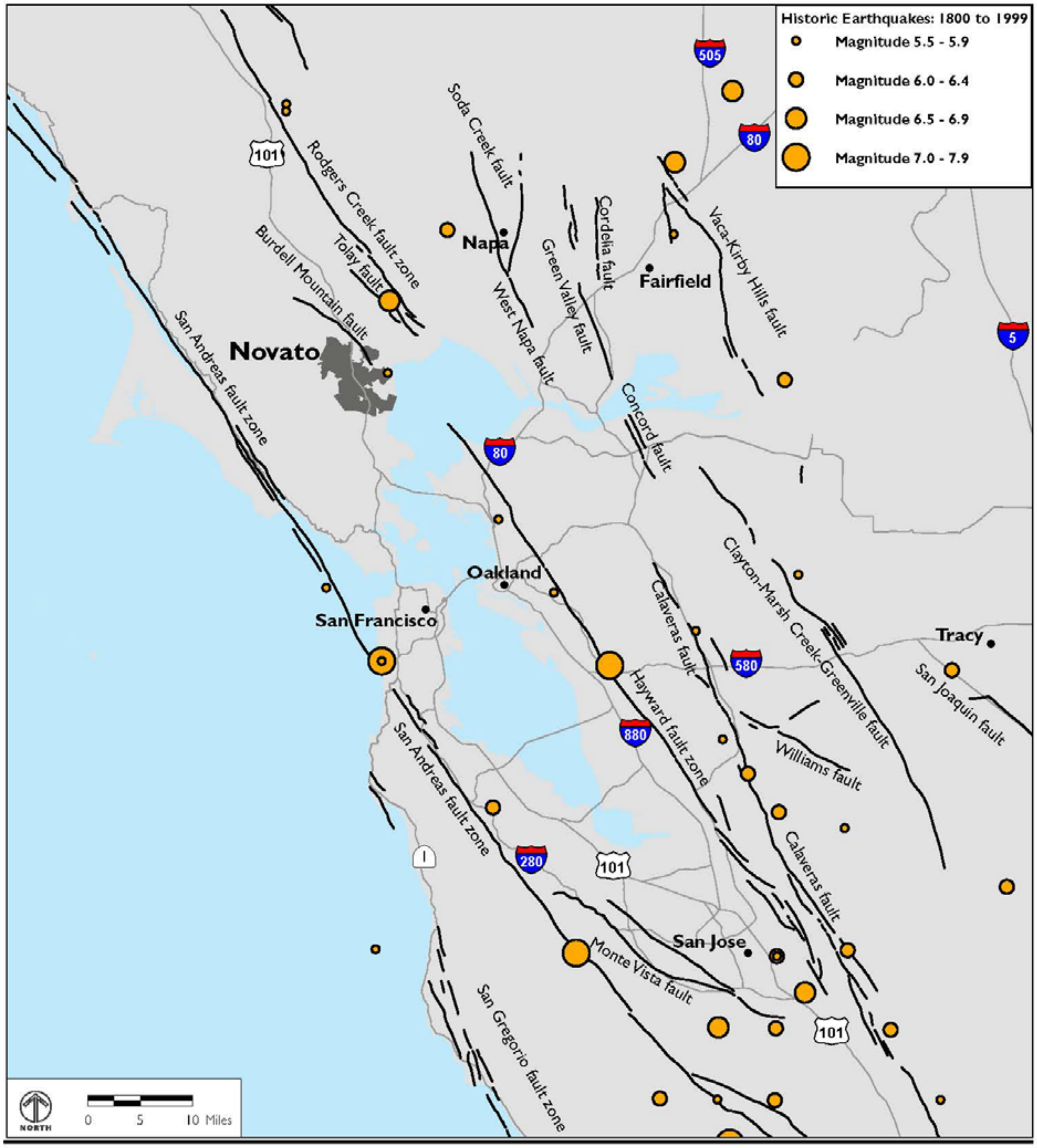


FIGURE 10-1

REGIONAL FAULTS AND HISTORIC EARTHQUAKES

TABLE 10-1 ACTIVE AND POTENTIALLY ACTIVE EARTHQUAKE FAULTS

Fault	Type[a]	Maximum Potential (Moment) Magnitude Earthquake[b] (Mw)	Distance from Novato	
			(Miles)	(km)
Hayward	A	7.10	13.7	8.0
Rodgers Creek	A	7.00	4.8	19.3
Tolay	B	NA[c]	0.0	0.0
San Andreas	A	7.90	13.7	8.0
Burdell Mountain	B	NA	4.8	19.3

[a] Type A = active fault; Type B = potentially active fault.
[b] Moment magnitude is related to the physical size of a fault rupture and movement across a fault. Moment magnitude provides a physically meaningful measure of the size of a faulting event. The maximum moment magnitude earthquake data are from *Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030* (USGS, 1999).
[c] NA = Not Available. There is no data on the maximum magnitude of potentially active faults, since there is no lithologic evidence that forms the basis for the calculations of the other numbers.

a. San Andreas Fault

The San Andreas fault is active and represents the principal seismic hazard in northern California. The San Andreas fault is an active fault based on both recorded historical activity and geologic displacement. The main trace of the San Andreas fault trends northwest-southeast and extends over 700 miles from the Gulf of California through the Coast Ranges to Point Arena, where the fault extends offshore. Surface rupture during historic earthquakes, fault creep and historic seismicity confirm that the San Andreas fault and its branches (the Hayward, Calaveras and San Gregorio faults) are all active today. The San Andreas fault is approximately 9.5 miles west of the Novato City limit.

Historical earthquakes along the San Andreas fault and its branches have caused significant seismic shaking in the East Bay region. The most recent large historical earthquake on the San Andreas fault to affect the area was the magnitude 6.9 Loma Prieta earthquake in 1989. The Loma Prieta earthquake caused intense seismic activity throughout the Bay Area, with most damage focused in lowland infill areas.

b. Hayward Fault

The Hayward Fault is an active fault, as determined by both recorded historical activity and geologic displacement. The Hayward fault zone is the southern extension of a fracture zone that includes the Rodgers Creek fault (discussed below), the Tolay fault (discussed below), the Healdsburg fault (located in Sonoma County) and the Maacama fault (located in Mendocino County). The Hayward fault trends to the northwest within the East Bay, extending 60 miles south from San Pablo Bay in Richmond to San Jose, where it converges with the Calaveras fault, a similar type of fault that extends north to Suisun Bay. Historically, the Hayward fault generated two sizable earthquakes, both in the 1800s. The USGS Working Group on California Earthquake Probabilities includes the Hayward–Rodgers Creek fault systems in the list of those faults that have the highest probability of generating earthquakes of magnitude 6.7 and greater.

c. Rodgers Creek Fault

The Rodgers Creek fault is active based on the geologic record. The Rodgers Creek fault is believed to be entirely locked (i.e. no recognized creep, less than 2 mm/yr).[2] No major earthquake has historically occurred along the Rodgers Creek fault.

d. Tolay Fault

The Tolay Fault is considered potentially active. The Tolay fault, a northern extension of the Hayward fault, is a northwest-trending structure that has shown little if any strike-slip displacement. The fault is an approximately 600 meter zone characterized as a schuppen structure with slivers of Franciscan rock, sheared siltstone and gravel of the Miocene Petaluma Formation.

e. Burdell Mountain Fault

The Burdell Mountain Fault is considered potentially active. The Burdell Mountain Fault is similar in nature to the Hayward fault, but with lesser magnitude, slip and recurrence interval potential. Mapped geologic relationships suggest that the Burdell Mountain fault is an important component of the regional fault zone. Geologic evidence shows that movement has occurred on the Burdell Mountain fault zone within the past 11,000 years, suggesting that it might be active.[3] However, at this time, the Burdell Mountain fault zone is classified as potentially active.[4] This fault occurs within Novato's SOI.

E. Seismic and Geological Hazards

This section describes Novato's vulnerability to the seismic hazards related to earthquakes.

1. Ground Rupture

Ground rupture is a hazard only in areas immediately adjoining a fault. The only fault trace that traverses the city is the Burdell Mountain fault, which is potentially active. The geologic record indicates that it is a quaternary fault with an age of last movement in the 1.6-million-year timeframe. The Burdell Mountain fault therefore has minimal potential for causing ground rupture. All other faults in the region are outside the Novato plan area limits.

2. Ground Shaking

Based on the known active faults and on the large number of potentially active faults, all parts of Novato are potentially subject to strong ground shaking. The intensity of ground shaking at any specific location within the city depends on the characteristics of the earthquake, the distance from the earthquake and on the local geologic and soil conditions. Con-

[2] U.S. Geological Survey (USGS), 1999. *Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030 – A Summary of Findings*. Open File Report 99-517.

[3] County of Marin, 2007. *Marin Countywide Plan.*

[4] Jennings, C.W., 1994. Fault Activity Map of California and Adjacent Areas with Locations and Ages of Recent Volcanic Eruptions, CDMG Geologic Data Map No. 6, 1:750,000.

servatively, ground motions as strong as 6.9 to 7.9 on the Richter Magnitude scale could occur. Currently, there are no critical facilities in Novato, such as high-occupancy buildings, located in areas that have a high risk of ground shaking. The Uniform Building Code requires a higher safety factor for construction in Seismic Zone 4, which includes Novato and the Bay Area. Seismic Zones, developed by the USGS, are based on the strength of ground shaking an area is likely to experience. Although Sesimic Zones numbered 0 through 4 are being phased out by the USGS in favor of more nuanced maps, the current General Plan's Safety and Noise chapter refers to Seismic Zone 4.

3. Ground Liquefaction

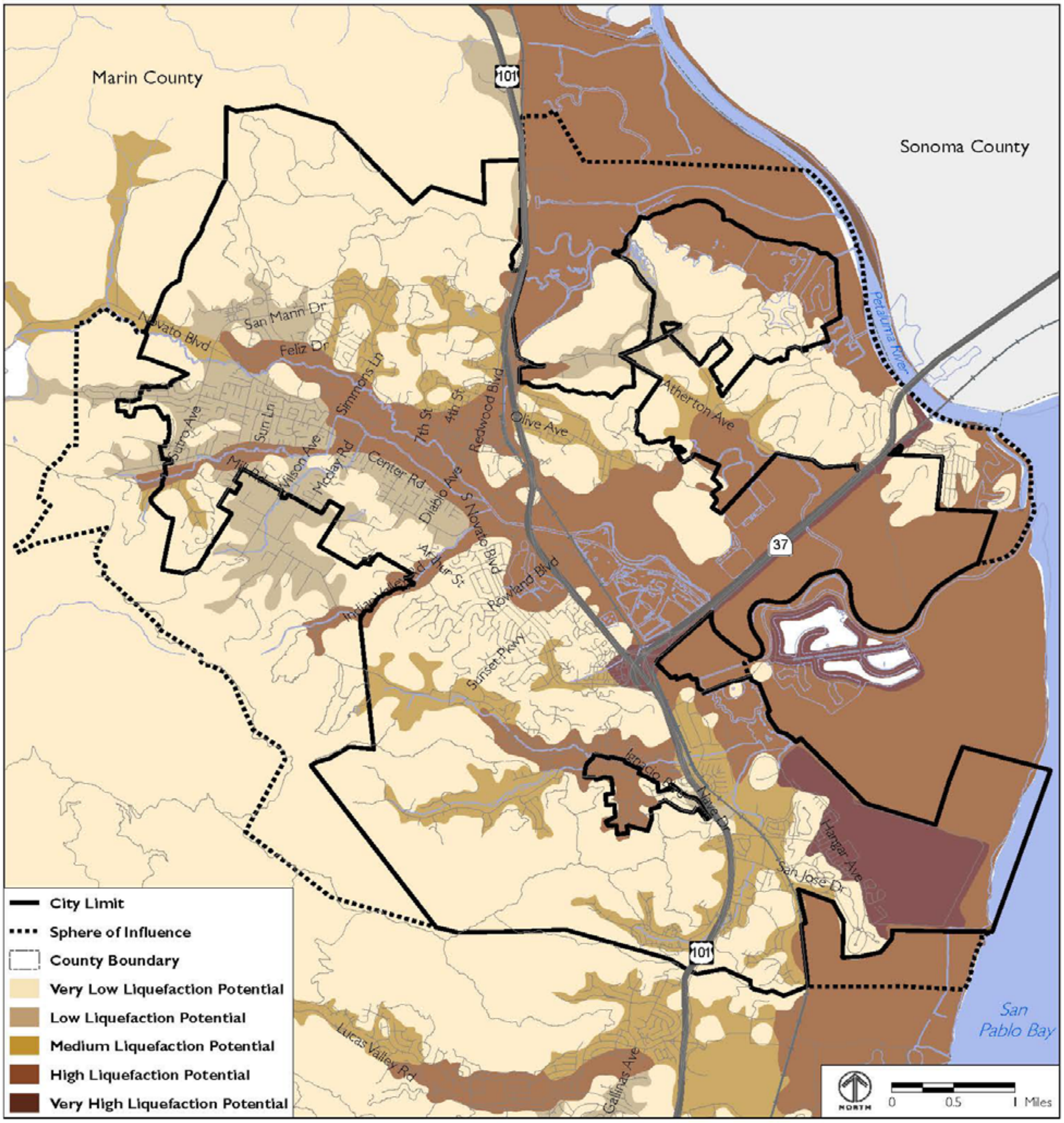
Liquefaction generally occurs as a result of strong ground shaking in areas where granular sediment or fill material either contains, or is located immediately above, high moisture content. The ground shaking transforms the material from a solid state to a temporarily liquid state. Liquefaction is a serious hazard because buildings in areas that experience liquefaction may sink or suffer major structural damage. Liquefaction is most often triggered by seismic shaking, but can also be due to improper grading, landslides or other factors.

Areas in Novato with soils susceptible to liquefaction are primarily located in low-lying area of fill fronting San Pablo Bay, as shown in Figure 10-2. The Early to Late Pleistocene deposits and Holocene estuarine deposits (Bay Mud) are considered to have a medium liquefaction potential. Generally the low-lying areas within the mapped 100- or 500-year floodplain (see Figure 12-3, Chapter 12) will be more prone to liquefaction, especially where underlain by fill. Upland areas within the city have a low to very low potential for liquefaction.

4. Structural Damage or Collapse

The ability for structures to withstand earthquakes varies considerably due to a number of factors. These include location relative to active faults or poor ground areas, building construction, magnitude and intensity of the earthquake, duration of strong ground shaking and distance from the causative faults.

In general, evidence from past earthquakes shows that wood frame structures properly tied to their foundations perform very well or, if badly damaged, cause few injuries and life loss even if located in areas of poor ground quality. Older wood frame structures that have stone, brick, or cripple wall foundations, or that are not bolted to their foundations, do not perform well. Unreinforced masonry structures, on the other hand, perform poorly under almost all earthquake conditions, especially if located on poor ground areas. Nearby relatively small earthquakes can be very damaging because of the sharp motions they generate. Distant events, while more damaging to taller buildings, can also damage unreinforced masonry buildings because of the stresses caused by long-period motions. The Uniform Building Code seismic requirements are designed to mitigate against the specific performance of building materials in relation to maximum credible earthquake impacts.



Source: Marin County, GIS

FIGURE 10-2

LIQUEFACTION HAZARD AREAS

5. Landslides and Ground Failure

Landslides are downward and outward movements of slope-forming materials including rock, soil, artificial fill, or combinations of such materials. The size of landslides can vary from tiny events containing less than a cubic yard of material to massive slides containing millions of cubic yards. Large landslides may move downslope for hundreds of yards, or even several miles. A landslide may move rapidly, as in a soil or rock avalanche, or it may move slowly for hours or even weeks. A similar but much slower movement is called creep. Landslides may be limited to recent activity or be ancient landslide masses that display relative stability.

Site-specific geotechnical reports are required by the City of Novato for any development in areas prone to landslides. The susceptibility of a given area to landslides depends on many variables. However, the general characteristics that influence landslide hazards are well understood and it is possible to map areas in terms of general susceptibility to landslides. There are a number of important factors that dictate the probable formation and relative risk of landslide or slope instability. These include:

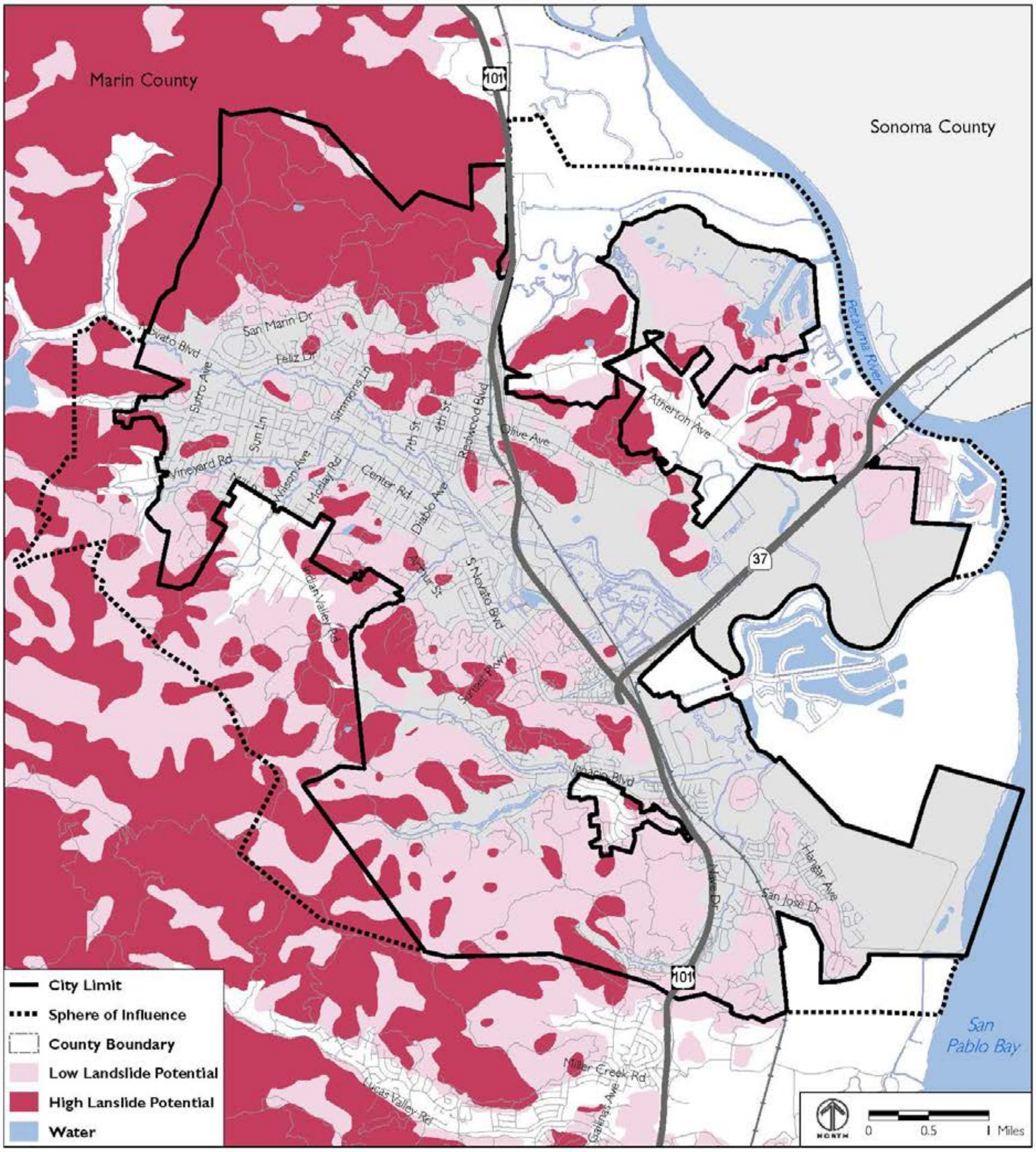
- Slope Material: Loose, unconsolidated soils and soft, weak rocks are more hazardous than are firm, consolidated soils or hard bedrock.
- Slope Steepness: Most landslides occur on moderate to steep slopes.
- Structure and physical properties of materials, including the orientation of layering and zones of weakness relative to slope direction.
- Water Content: Increased water content increases landslide hazard by decreasing resistance to sliding and adding weight to the materials on a slope.
- Vegetation Coverage: Abundant vegetation with deep roots increases slope stability.
- Proximity to Areas of Erosion or Man-Made Cuts: Undercutting slopes may greatly increase landslide potential.
- Earthquake Ground Motions: Strong ground shaking may trigger landslides in marginally stable slopes or loosen slope materials and thus increase the risk of future landslides.

Figure 10-3 shows the potential for landslides to occur in the city. Landslides are not common in the lower elevation areas due to relatively flat grades. As shown in the figure, landslides more commonly occur in the upland areas. However, the Novato conglomerate in hilly areas is relatively stable with a low risk of landslide. Many of the hills have shallow soil with Franciscan bedrock very close to the surface, resulting in low to moderate landslide potential.

6. Land Subsidence

Subsidence is the sinking of a large area of ground surface in which the material is displaced vertically downward, with little or no horizontal movement. Subsidence problems are common in the diked baylands because of the highly compressible nature of the existing fill. Areas susceptible to earthquake-induced settlement include those areas underlain by thick layers of colluvial material or un-engineered fill. According to past environmental analyses, fill in the Bahia Marsh area in Novato has settled approximately 6 to 18 inches in the past 40 years.[5] Land subsidence has occurred within the

[5] Herzog and Associates, 1986. *Bahia Marsh Restoration Project EIR.*



Source: Marin County, GIS. Original data from USGS.

FIGURE 10-3

LANDSLIDE HAZARD AREAS

low lying areas, mainly along the Bay margins. The loss of water within the Bay Mud along the Bay margins has led to subsidence, and many areas, such as the former Hamilton Air Force Base, are now below mean sea level and require pumping to drain.

7. Expansive Soils

Expansive soils have a potential to undergo significant changes in volume, in the form of either shrinking or swelling, due to changes in moisture content. Periodic shrinking and swelling of expansive soils can cause extensive damage to buildings, other structures and roads.

Moisture content and the percentage and type of clay minerals present in the soil determine the potential volume change of an expansive soil. Soils composed only of sand and gravel have no potential for volume change due to moisture change. Soils containing clays have variable potential for volume changes. Such soils are generally classified into three expansive soils classes with low, moderate and high potential for volume changes:

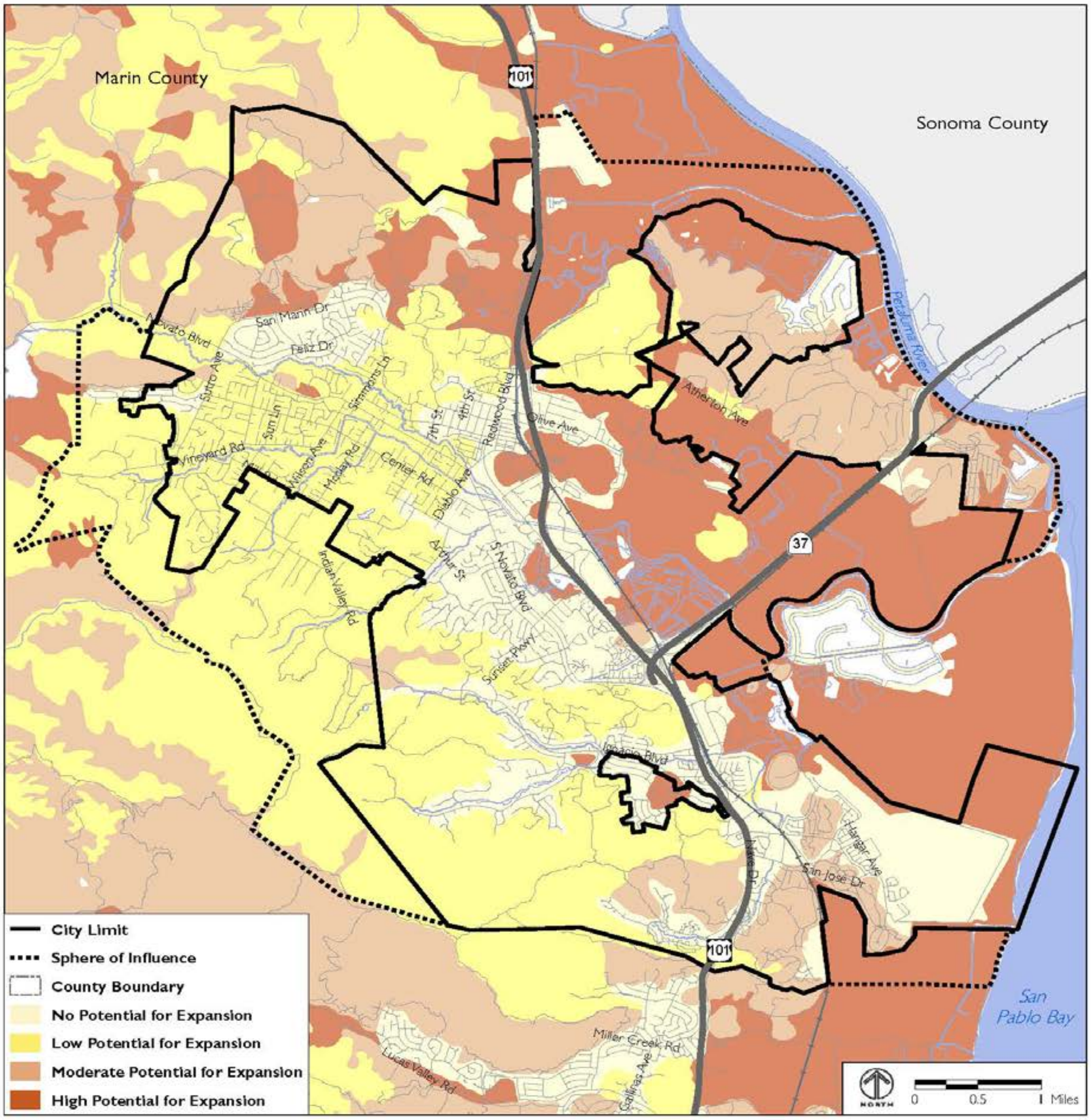
- **Low:** This soil class includes sands and silts with relatively low amounts of clay minerals. Sandy clays may also have low expansion potential, if the clay is kaolinite. Kaolinite is a common clay mineral.
- **Moderate:** This class includes silty clay and clay textured soils if the clay is kaolinitic and also includes heavy silts, light sandy clays and silty clays with mixed clay minerals.
- **High:** This class includes clays and clay with mixed monmorillonite, a clay mineral that expands and contracts more than kaolinite.

Figure 10-4 shows the distribution of expansive soils in Novato.

Soils with no or low expansion potential occur along stream and river valleys and on steep mountain slopes. Soils of high expansion potential in Novato generally occur east of Highway 101.

8. Soil Hazards

Corrosivity testing conducted for local projects in Sonoma and Marin Counties indicate that the potential for corrosive to severely corrosive shallow subsurface soils exists in Young Bay Mud, which occurs in Novato. Young Bay Mud possesses high sulfate and chloride concentrations and maintains a low pH, which would negatively impact metals and concrete used in construction. However, corrosivity is easily mitigated on a site-by-site basis in new development projects by requiring that engineered material be imported to replace corrosive soils.



Source: Marin County, GIS. Original data from USGS.

FIGURE 10-4
EXPANSIVE SOILS