4.3 GEOLOGY AND SOILS

This section describes the geology, soils, and seismicity of the Specific Plan area. The information presented below has been developed based on several sources of data. These sources include *Geotechnical Investigation for the Niven Nursery Site* (Harza Engineering Company 1998a) (Appendix C-1); *Review of Geologic Conditions for the Central Larkspur Area Specific Plan, Larkspur, California* (World Environmental Science & Technology 1999) (Appendix C-2); personal communication with Miller Pacific Engineering Group (Appendix C-3); and review of published literature, maps, and Internet sites on geology, soils, and seismicity of the area.

4.3.1 EXISTING SETTING

REGIONAL SETTING

The Specific Plan area lies in the central portion of the Coast Ranges Geomorphic Province in the seismically active San Francisco Bay Area. The northwest to southeast trending ridges and valleys of the Coast Ranges have formed in response to the active tectonism of the region. Tectonics of the region are controlled by the San Andreas Fault System. The northwest to southeast striking San Andreas fault represents the boundary between the Pacific Plate, primarily offshore to the east-southeast, and the North American Plate, primarily onshore to the west-northwest. In response to the relative northwest movement of the Pacific Plate with respect to the North American Plate, other faults have formed. These include fault structures such as the Hayward fault, the Rogers Creek fault, and the Calaveras fault, all located within 25 miles of the site. Large-magnitude earthquakes could be generated on any of these regional active faults.

The regional geology of the area is characterized as part of the Franciscan Complex of Jurassic to Cretaceous age. The Franciscan Complex is a tectonostratigraphic group of rocks that form the basement complex of the region between the San Andreas fault and the Hayward and Rogers Creek faults. The rock types within this complex include chert, shale, graywacke sandstone, siltstone, limestone, greenstone, greenschist, and blueschist. Rocks are metamorphosed to various degrees from very low grade to low grade metamorphism. Tectonic deformation of the rocks is very common, with weaker shale units often sheared and fractured around more massive graywacke sandstone and greenstone units. Near San Francisco Bay, this basement complex is overlain by alluvial deposits of sand, silt, and clay and a clayey silt/silty clay formed in the estuarine and deeper portions of the bay (Bay Mud). Bay Mud is a low density, high water content, compressible material and is present underlying portions of the Central Larkspur area. Bay Mud is often interbedded with alluvial sand deposits, especially at the margins of the bay.

LOCAL SETTING

Geologic and Soils Conditions

The Specific Plan area is located on the northwest margin of San Francisco Bay. It is on a natural upland peninsula that extended into the historical wetland margins of San Francisco

Bay. Larkspur Creek is located along the southern and eastern boundaries of the Specific Plan area. This area is generally composed of fine-grained colluvium derived from the erosion of nearby hills and alluvial deposits of marsh sediments and Bay Mud. Soils in the Specific Plan area have been mapped as xerothents-urban complex, indicating significant artificially deposited fill materials that can exhibit variable drainage and engineering strength characteristics (USDA SCS 1979). The artificial fill materials range in thickness from approximately 2 feet to 9 feet below ground surface. This material appears to be composed of fine-grained sand with clay and gravel, and fine-grained sand mixed with organics and shell fragments (West 1999).

Geologic maps of the Specific Plan area published by the California Geological Survey (CGS) (formerly the California Division of Mines and Geology) show the Specific Plan area as being underlain by artificial fill (Qaf) and Bay Mud (Qm). The nearest bedrock to the Specific Plan area consists of Franciscan Complex graywacke sandstone with outcrops located within 0.2 mile to the west (Rice et al. 1976).

The western portion of the Specific Plan area, primarily consisting of Subareas 1 and 2, appears to be underlain primarily by Pleistocene alluvium. The alluvium is underlain by the Franciscan Complex, which formed during the Jurassic and Cretaceous periods between 65 and 180 million years ago (California Division of Mines and Geology 1969, Rice et al. 1976). Investigations at nearby properties at 532 and 600 Magnolia Avenue did not appear to encounter Bay Mud. An excavation of underground storage tanks performed approximately 300 feet west of Subarea 3 at 600 Magnolia Avenue encountered fill and alluvium overlying sandstone and shale bedrock at a depth of approximately 10 feet below ground surface (Environmental Resolutions, Inc. 1999). The extent of Bay Mud underlying the western and topographically higher portion of the Specific Plan area, primarily Subareas 1 and 2, appears to be limited.

Native geologic materials underlying the eastern portion of the Specific Plan area, including most of Subarea 3, consist of Bay Mud (deposited within the last 11,000 years) overlying older Pleistocene alluvium deposited within the last 1.6 million years. Bay Mud is broken down into two units, Younger Bay Mud and Older Bay Mud. Both Younger Bay Mud and underlying Older Bay Mud were encountered in boreholes above alluvial soils at the Niven property (Harza Engineering Company 1998a) (Appendix C-1). Younger Bay Mud consists of highly compressible silt and clay sediments that overlies alluvium and Older Bay Mud and covers the bay bottom and margins. Younger Bay Mud consists of soft, uniform, gray silty clay to clayey silt containing 45% to 95% clay-size particles, silt, minor fine sand, and fragments of shells (California Division of Mines and Geology 1969). The term "Older Bay Mud" is used to describe a deposit of medium stiff dark greenish-gray silty clay with varying amounts of sand and fine gravel. At the mouths of streams and creeks and in marshland areas, Bay Mud is often interbedded with alluvial deposits.

Geotechnical investigations, which would not typically be prepared until development proposals are presented to the City, would include site-specific soil testing results and other detailed geologic and soils information that would be needed for site-specific environmental

and engineering analyses. Because no development proposals for sites within the Specific Plan area have been submitted to the City at this time, no geotechnical investigations are required. Due to the availability of geotechnical investigations previously done for Subarea 3, however, detailed geologic and soils information is presented below for Subarea 3.

Subarea 3 Geologic and Soils Conditions

Harza Engineering Company prepared the *Geotechnical Investigation for the Niven Nursery Site* (Specific Plan Subarea 3) in April 1998 (Appendix C-1). This report indicated that, according to historical maps of former shorelines, Subarea 3 is located on the limits of historic San Francisco Bay margins. Subarea 3 was originally a peninsula trending in an east-west direction through the central portion of the property. Fill was placed on the property in the late 1800s.

The alluvium underlying the Subarea 3 is characterized as medium dense silty, clayey sands and gravels and stiff silty clays (Harza Engineering Company 1998a) (Appendix C-1). Bay Mud (Younger and Older) was encountered to a depth of approximately 35 feet below ground surface, and the alluvium was encountered to 46 feet below ground surface, the maximum depth investigated.

Geologic and Seismic Hazards

The Specific Plan area is located in the seismically active San Francisco Bay Region. Several types of faults are mapped by the CGS (formerly the Division of Mines and Geology). These include active faults with surface displacement within the last 11,000 years; potentially active faults with surface displacement between 11,000 and 1.6 million years ago; and inactive faults with no surface displacement within the last 1.6 million years. Active faults of the region (Exhibit 4.3-1) include the San Andreas fault (located approximately 8 miles southwest of central Larkspur), the Hayward fault (located approximately 10 miles northeast), and the Rogers Creek fault (located approximately 12 miles north-northeast). The smaller inactive San Pablo fault is located approximately 5 miles east of the Specific Plan area, and a relatively small, inactive, unnamed fault is located approximately 1 mile north of the Specific Plan area (Wentworth 1997).

Other geologic faults may be present in the area, but none are considered active by the CGS.

Seismic Hazards

Seismic hazards are generally classified as two types, primary and secondary. Primary geologic hazards include surface fault rupture. Secondary geologic hazards include ground shaking, liquefaction, and surface fault rupture, among others. As no active faults are known to cross central Larkspur, the primary geologic hazard of surface fault rupture is not anticipated to affect the Specific Plan area. Seismically induced damages at the Specific Plan area are likely to be caused by secondary effects such as ground shaking and liquefaction.

Exhibit 4.3-1 Regional Earthquake Faults

Ground Shaking

Based on the geologic materials underlying the Specific Plan area, the ground shaking amplification is estimated to be extremely high (ABAG 2003). However, estimates of actual ground shaking intensity according to the Modified Mercalli Intensity Scale of 1931 (Table 4.3-1), which depend on the size and distance from the earthquake, indicate that earthquake shaking intensity would be as follows:

< IX (strong—nonstructural damage) for a 1989 Loma Prieta type earthquake (Richter Magnitude 6.9 on a distant fault);

< X (violent—considerable damage) for a maximum credible Hayward fault earthquake (Richter Magnitude 7.1); and

< XI (very violent—extreme damage) for the maximum credible regional earthquake (Richter Magnitude 7.9) equivalent to the 1906 San Francisco earthquake (ABAG 2002).

Table 4.3-2 presents a comparison of the Modified Mercalli Intensity Scale to the Richter Magnitude scale. The Richter Magnitude scale is generally reported for earthquakes. Ground shaking intensities are also related to the ground accelerations caused during the earthquakes. Peak ground accelerations are generally reported as a percent of gravity. Peak ground accelerations for the Specific Plan area with a 10% probability of being exceeded in the next 50 years are estimated to be 50% to 60% of gravity (0.5g to 0.6g). (California Division of Mines and Geology 1996.) Damage to a single-family dwelling typically begins at 0.2g (Risk Prediction Initiative 1996).

Liquefaction

Liquefaction is a secondary seismic hazard involving saturated cohesionless sand and silty sand sediments located close to the ground surface. Liquefaction occurs when the strength of a soil is decreased and pore pressure increases as a response to strong seismic shaking and cyclic loading. During the loss of strength the soil becomes mobile, similar to a liquid, and can move both horizontally and vertically. The potential for liquefaction is determined by three main factors: depth of groundwater; soil type (sands and silty sands are most vulnerable); and the seismicity of the area. Liquefaction is most common in saturated sandy soils, and can be responsible for widespread structural damage. At the ground surface, large fissures can open and sand boils can form, resulting in damage to structures, utilities, pavements, and other infrastructure.

The liquefaction susceptibility of fill materials can range from very low to very high, depending on the density of the soil, the unit thickness, water content, and grain-size distribution (Knudsen et al. 1997). Liquefaction commonly occurs in sands and silty sands of relatively uniform grain size distribution, but can also occur to a lesser extent in clayey sands.

Table 4.3-1 Modified Mercalli Intensity Scale of 1931	
I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in building of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bend greatly.
XII	Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air.
Source: California Geological Survey 2002	

The liquefaction susceptibility of water-saturated Bay Mud is high due to common sand and silty sand lenses, especially at the margins of the bay. The silty clay and clayey silt portions of the Bay Mud formation are not liquefiable, but would be affected by liquefaction of interbedded sand lenses. The liquefaction susceptibility for Pleistocene alluvium is characterized as low to moderate (Knudsen et al. 1997). Because the Franciscan Complex is

composed of consolidated bedrock units such as shale, greenstone and graywacke sandstone, it is not liquefiable.

Table 4.3-2
Comparison of Richter Magnitude and Modified Mercalli Intensity

Richter Magnitude	Expected Modified Mercalli Intensity at Epicenter	General Description
2	I - II	Usually detected only by instruments
3	III	Felt indoors
4	IV - V	Felt by most people; slight damage
5	VI - VII	Felt by all; many frightened and run outdoors; damage minor to moderate
6	VII - VIII	Everybody runs outdoors; damage moderate to major
7	IX - X	Major damage
8+	X - XII	Total and major damage

Source: California Geological Survey 2002

The presence of fill materials and Bay Mud underlying the Specific Plan area make those portions of the area potentially susceptible to liquefaction. However, results of the geotechnical investigation in Subarea 3 indicate that the liquefaction susceptibility of the soil is low based on the density, moisture content and grain size distribution of the soils penetrated (Harza Engineering Company 1998a) (Appendix C-1). Bay Mud underlying the Specific Plan area is dominated by silty clay and clayey silt. A single small area was encountered during the subsurface investigation that was characterized as loose silty sand from the ground surface to 7 feet below ground surface. Because of the high concentration of fines (silt plus clay) of 49%, this material is considered unlikely to undergo liquefaction.

Compressible Soils

The settlement of clay and silt soils is a common problem in development, especially on deposits of Bay Mud, and to a lesser extent alluvial soil, colluvium, and fill. Settlement generally occurs in two phases, known as primary consolidation settlement and secondary consolidation settlement. Primary consolidation settlement is the result of a volume change in saturated cohesive soils because of the expulsion of the water which occupies void spaces. Secondary consolidation settlement is observed in saturated cohesive soils, such as Bay Mud, and is the result of long-term plastic adjustment of soil fabrics. Primary consolidation settlement can amount to very considerable settlement and extreme distress to normal structures. Secondary consolidation settlement is generally much smaller than Primary.

Surface soils encountered during the Harza geotechnical investigation (Appendix C-1) generally consist of fill material. This fill material consists of firm to hard sandy, gravelly clays and silts and medium dense to dense silty sands and gravels extending to depths of approximately 4 to 9 feet. This fill material was found to be heterogeneous and potentially compressible, and was underlain by Bay Mud or alluvial soils consisting of stiff to hard silty

clays and sandy silts. The Bay Mud, extending to a depth of approximately 35 feet, was found to be highly compressible and variable in consistency. The Bay Mud and/or fill material was found to be underlain by alluvial soils consisting of medium dense to dense, silty and clayey sands and gravels and stiff silty clays which extended to the maximum depth explored during the geotechnical investigation of 46 feet below ground surface.

Corrosive Soils

Soils underlying the Specific Plan area are moderately to extremely corrosive to steel because of their salt content. Sandier soils are generally less corrosive than highly saline clayey soils, such as Bay Mud.

REGULATORY SETTING

Various state and local regulations apply to geologic hazards in the San Francisco Bay area. The primary applicable regulations are described below.

State of California

Alquist-Priolo Earthquake Fault Zoning Act

The Alquist-Priolo Special Studies Zone Act, now known as the Alquist-Priolo Earthquake Fault Zoning Act (PRC§2621 et seq.), was enacted in 1972. The Alquist-Priolo Act prohibits construction of most types of buildings intended for human occupancy across the traces of active faults and strictly regulates construction along active faults. The act is intended to reduce the hazard to life and property from surface fault ruptures during earthquakes; it is not directed toward other earthquake hazards.

The Alquist-Priolo Act defines criteria for identifying active faults. A fault is considered "sufficiently active" if one or more of its segments or strands show evidence of surface displacement during Holocene time (approximately the last 11,000 years); it is "well-defined" if its trace can be clearly identified by a trained geologist at the ground surface or in the shallow subsurface, using standard professional techniques, criteria, and judgment (Hart and Bryant 1997).

Areas along faults considered sufficiently active and well-defined are zoned differently than other areas, and construction in these areas is regulated more stringently. The Alquist-Priolo Act requires the State Geologist to establish regulatory zones known as "earthquake fault zones" around the surface traces of active faults and to issue appropriate maps. The maps are distributed to all affected cities, counties, and state agencies for their use in planning efforts. According to the California Geologic Survey, the City of Larkspur is not an affected city (CGS, 2003a). Local agencies must regulate most development projects within the zones. Projects include all land divisions and most structures for human occupancy.

Before a project can be permitted in the vicinity of an earthquake fault zone, cities and counties must require a geologic investigation to demonstrate that proposed buildings will not

be constructed across active faults. An evaluation and written report of a specific site must be prepared by a licensed geologist. If an active fault is found, a structure for human occupancy cannot be placed over the trace of the fault and must be set back from the fault (generally 50 feet).

Seismic Hazards Mapping Act

The Seismic Hazards Mapping Act of 1990 (PRC §§2690–2699.6) addresses nonsurface fault rupture earthquake hazards, including liquefaction, strong ground shaking, and seismically induced landslides. Intended to reduce damage resulting from earthquakes, the Seismic Hazards Mapping Act contains provisions conceptually similar to those of the Alquist-Priolo Act. The state is responsible for identifying and mapping areas at risk of strong ground shaking, liquefaction, landslides, and other earthquake and geologic hazards, and affected cities and counties must regulate development in mapped seismic hazard zones. According to the California Geologic Survey, seismic hazard maps have been planned but are not completed for Marin County, thus no seismic hazard map is currently available for the City of Larkspur (CGS 2003b). As such, the City of Larkspur is currently not considered an affected city.

Under the Seismic Hazards Mapping Act, cities and counties may not issue development permits for sites in seismic hazard zones until appropriate site-specific geologic and geotechnical investigations have been completed and measures to reduce potential damage have been incorporated into the development plans. Information on the seismic hazard maps is not sufficient to serve as a substitute for the required site-specific geologic and geotechnical investigations.

City of Larkspur

Larkspur Municipal Code

The State of California provides minimum standards for building design through the California Uniform Building Code (California UBC) (CCR Title 24). The California UBC is based on the Uniform Building Code (UBC), which is used widely throughout the United States and has been modified for conditions within California. Under Larkspur Municipal Code §15.08.010, the City has adopted the California UBC, with minor amendments, as its building code. Seismic Hazard programs under the Larkspur General Plan require that all unreinforced masonry buildings be seismically upgraded; Chapter 15.07 of the Larkspur Municipal Code addresses earthquake hazard reduction in such buildings, establishing minimum standards for structural seismic resistance (retrofitting) to reduce the risk of loss of life or injury.

Site-Specific Geotechnical Investigations

Under the Larkspur General Plan (1990), geotechnical engineering investigations are required for buildings proposed to be constructed in high seismic hazard areas potentially subject to severe ground shaking and ground failure (Bay Mud, stream and landslide deposits) and critical structures or structures made of materials other than wood frame. The investigations

should include a site-specific characterization of anticipated strong ground motion, which would include the estimated peak horizontal ground acceleration, the duration of strong shaking, and the site period. A structural engineer should then review the seismic data to determine whether the minimum California UBC criteria will be adequate. General Plan Action Program [26] also requires geotechnical investigations for areas subject to settlement and subsidence. A review of geologic data and geotechnical investigations previously conducted within the Specific Plan area has been performed, and, in particular, a geotechnical investigation has been conducted for Subarea 3. Additional geotechnical investigations would be required for subsequent development projects pursuant to the Specific Plan.

4.3.2 ENVIRONMENTAL IMPACTS

THRESHOLDS OF SIGNIFICANCE

Implementation of the Specific Plan would have a significant impact on geology and soils if it were to result in:

- the exposure of people or structures to potential substantial adverse effects, including the risk of loss, injury or death involving rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault;
- the exposure of people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving strong seismic ground shaking;
- the exposure of people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving seismic-related ground failure, including liquefaction;
- the exposure of people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving landslides;
- substantial soil erosion or the loss of topsoil;
- development located on a geologic unit or soil that is unstable or that would become unstable as a result of the project and which could potentially result in on- or offsite landslide, lateral spreading, subsidence, liquefaction, or collapse;
- development located on expansive soil, creating substantial risks to life and property; or
- development in areas where soils are incapable of adequately supporting the use of septic tanks or alternative wastewater disposal systems where sewers are not available for the disposal of wastewater.

While development of the Specific Plan area would expose occupants to some risk from seismic and geologic hazards, the policies and programs of the Larkspur General Plan are intended to

minimize the hazards to new development by requiring the assessment of the conditions that might adversely affect them, and adjusting the design and extent of development projects to minimize risk.

PROJECT-LEVEL IMPACTS

Impact **4.3-1**

Increased Exposure to Strong Seismic Ground Shaking. *Given the seismicity of the region, construction of retail, office, hotel, residential units, and other facilities in the Specific Plan area would result in the risk of exposing an increased number of people and structures to strong ground shaking. Given the required geotechnical investigation and compliance with the City's building codes, this impact is considered* ***less than significant****.*

Implementation of the Specific Plan would expose an increased number of people or structures to the risk of substantial adverse effects (e.g. loss, injury, or death) resulting from strong seismic ground shaking. The U.S. Geological Survey (USGS) Working Group on Earthquake Probabilities (U.S. Geological Survey 2003) estimates that there is a 62% probability that a Richter magnitude 7.0 or greater earthquake will occur in the San Francisco Bay Region between 2002 and 2031. An earthquake of this size anywhere within the region would be felt in the Specific Plan area, and could affect the area through strong seismic ground shaking and other secondary earthquake effects. Given the seismicity of the region, construction of new retail, office, hotel, residential units, and other facilities in the Specific Plan area would result in exposing more people and structures to the risks associated with strong ground shaking.

As discussed in Regulatory Setting above, the Larkspur General Plan requires that geotechnical investigations be performed for buildings proposed to be constructed in high seismic hazard areas that are potentially subject to severe ground shaking and ground failure. Because the presence of Bay Mud and alluvial deposits in the Specific Plan area, this requirement is applicable to the Specific Plan area. Further, the City has adopted the California UBC and seismic hazard programs contained in the Municipal Code that address minimum standards for structural seismic resistance for construction. The City's Building Department reviews and enforces compliance with these standards. These protective measures would ensure that development on the Specific Plan site is engineered and designed to withstand the effects of seismic ground shaking and other secondary earthquake effects. With the required incorporation of seismic construction standards in future development projects, the risk of catastrophic effects of seismically induced ground shaking (such as complete structural failure) would be considered less than significant.

Impact **4.3-2**

Potential for Seismic-Related Ground Failure, Including Liquefaction. *Seismic-related ground failure is considered a hazard in the Specific Plan area. Geologic investigations conducted for the Specific Plan area indicate that liquefaction potential in the Specific Plan area varies from high to very low because the underlying geologic structure trends from fill and Bay Mud on the eastern portion of the site to alluvium underlain by sandstone and shale bedrock on the western portion of the site. Given the required geotechnical investigations and compliance with the City's building codes, this impact is considered* ***less than significant****.*

World Environmental Services & Technology (WEST), in *Review of Geologic Conditions for the Central Larkspur Area Specific Plan* (Appendix C-2), reviewed documents describing the geology, hydrogeology, and soil conditions for the Specific Plan area. WEST conducted a reconnaissance level walk-through of the entire Specific Plan area and found that the geology of the area is variable; the eastern portion of the area is underlain by fill and Bay Mud as described below in the Harza investigation, the western portion of the area is underlain primarily by Pleistocene alluvium, which itself is underlain by Franciscan formation sandstone and shale bedrock. WEST noted that geotechnical investigations performed at two sites located further west on Magnolia Avenue did not encounter Bay Mud at all. The liquefaction susceptibility of water-saturated Bay Mud is high, whereas liquefaction susceptibility for Pleistocene alluvium is low to moderate and for bedrock is very low. However, the preparation of site-specific geotechnical investigations, which would include soil sampling, would result in more precise estimation of the liquefaction susceptibility of the Specific Plan area.

Harza Engineering Company's *Geotechnical Investigation for Niven Nursery Site* (Appendix C-1) addressed the hazard of liquefaction on the Niven property (Subarea 3) and concluded that liquefaction potential on that property is low. Liquefaction is associated primarily with saturated cohesionless soil layers located close to the ground surface, but Harza found no saturated loose sand or silty sand cohesionless units in subsurface boreholes. Soils penetrated were predominantly fine-grained and any sand or silty sand units had high percentages of clay and silt, which would preclude liquefaction from occurring. A full geotechnical investigation for the remainder of the Specific Plan area has not yet been performed, but would be required when development projects are proposed.

Lateral spreading and earthquake-induced landsliding involve lateral ground movements caused by earthquake vibrations. These lateral ground movements are often associated with a weakening or failure of an embankment or soil mass overlying a layer of liquefied sands or weak soils. Due to the relative flatness of the Specific Plan area and the generally low potential for liquefaction in Subarea 3, seismically-induced lateral spreading and landsliding are not expected.

WEST reviewed the Harza study and noted that the recommendations in the Harza report are specific to residential development using slab-on-grade construction on fill and Bay Mud. These findings are not transferable to the remainder of the Specific Plan area, which is expected to use other types of construction for commercial and multifamily development, nor should they be applied to other areas of the Specific Plan that, because of the variable nature of the site geology, are likely to exhibit different underlying characteristics. WEST concluded that "Geotechnical [investigations] should not be used when the nature, size, location, configuration, orientation of the proposed structure is changed" (World Environmental Science & Technology 1999). WEST recommends that geotechnical investigations, including geotechnical testing and engineering design, be performed for seismic setting, maximum credible earthquake magnitude and ground shaking potential, flood potential, and compressibility and liquefaction susceptibility for the remainder of the Specific Plan area. Appropriate codes and specifications defined by the City should be used by properly licensed

professional engineers in the evaluation and design of the proposed structures at the time development applications are submitted to the City and the type of construction and location are known.

The Larkspur General Plan requires that geotechnical investigations be performed for buildings proposed to be constructed in high seismic hazard areas that are potentially subject to severe ground shaking and ground failure. Because of the low to high liquefaction potential of Bay Mud and alluvial deposits, this requirement is applicable to the Specific Plan area. Further, the City has adopted the California UBC and seismic hazard programs contained in the Municipal Code that address minimum standards for structural seismic resistance for construction. The City's Building Department reviews the results of geotechnical investigations, including liquefaction susceptibility, and determines which appropriate standards would be applicable to the proposed development; it also enforces compliance with these standards. These protective measures would ensure that development in the Specific Plan area is appropriately engineered and designed such that damage from liquefaction would not occur. As such, this impact is considered less than significant.

Impact **4.3-3**

Soil Erosion During Construction Activities. *Erosion of soils during construction could affect Larkspur Creek, located along the southern and eastern boundaries of the Specific Plan area, and Corte Madera Creek, to which Larkspur Creek is a tributary, by adding to the sediment load of the creeks. This impact is considered* ***potentially significant****.*

The Specific Plan area is located on a flat, relatively level area with cohesive fill and native soils; as such, soil erosion occurs infrequently on most of the Specific Plan area. However, Larkspur Creek runs along the southern and eastern boundaries of the Specific Plan area, and erosion of soils during construction activities could potentially affect the creek in those areas. Soils loosened, exposed, and stored in piles during construction in the vicinity of Larkspur Creek could potentially become mobilized by stormwater during construction activities. Such uncontrolled soil erosion could potentially affect the creek by adding to its sediment load. Because Larkspur Creek is a tributary of Corte Madera Creek, the amount of sediment in Corte Madera Creek could also increase as a result. The City reviews certain types of projects, including those that may be constructed in the Specific Plan area, for compliance with the City's Grading Ordinance and the Subdivision Code (see Section 4.4, Hydrology and Water Quality, for additional information). In compliance with the federal Clean Water Act, (CWA) the City requires the submission of Stormwater Pollution Prevention Plan (SWPPP) for all construction activities involving more than 1 acre of land. The SWPPP, which must be prepared before the issuance of Building Permits and prior to the commencement of construction activities, will include specifications for best management practices (BMPs) that will be implemented during project construction to minimize runoff from the construction areas, including storage and maintenance areas and building materials handling areas. The SWPPP requirement does not apply to construction projects involving less than 1 acre of land; as such, some construction activities in the Specific Plan area, particularly those occurring near Larkspur Creek, may result in an increase in sediment runoff into the creek. For this reason, potentially significant impacts related to soil erosion may result during future construction in the Specific Plan area.

Impact **4.3-4**

Damage to Onsite Foundations and Other Structures Caused by Soil Compressibility and Secondary Consolidation Settlement. *Portions of the Specific Plan area are underlain by Bay Mud, which is susceptible to soil compression and secondary consolidation. Increases in traffic loads on Doherty Drive is not expected to cause noticeable settlement, and implementation of recommendations in site-specific geotechnical investigations, which are required by the General Plan, would reduce the risk of settlement to new buildings in the Specific Plan area. This is a* ***less-than-significant impact****.*

Soil compression may cause a form of subsidence, better known as settlement, that could result in structural damage under certain circumstances. Soils underlying the Specific Plan area are potentially compressible. Existing onsite fill and underlying Bay Mud are present at variable thicknesses and depths. Structures could be susceptible to primary consolidation settlement of up to 17 inches, which could damage foundations, utilities, concrete slabs, pavements, and other site improvements. Differential settlement of buildings placed over variable underlying site conditions can also occur, potentially causing damage. Secondary consolidation settlement of Bay Mud and other Specific Plan area soils after surcharge, which is recommended in the geotechnical investigation for Subarea 3, may result in up to 1.5 inches of settlement to the area (Harza Engineering Company 1998a) (Appendix C-1), potentially resulting in damage to foundation systems, utilities, concrete slabs-on-grade, and other structures.

The Harza geotechnical investigation included recommendations for residential development on the Niven property; however, for the remainder of the site, WEST concluded that "Geotechnical [investigations] should not be used when the nature, size, location, configuration, orientation of the proposed structure is changed." WEST recommended that geotechnical investigations, including geotechnical testing and engineering design, be performed for seismic setting, maximum credible earthquake magnitude and ground shaking potential, flood potential, and compressibility and liquefaction susceptibility for the remainder of the site and appropriate codes and specifications should be used by properly licensed professional engineers in the evaluation and design of the proposed structures at the time development applications are submitted to the City and the type of construction and location are known. As discussed in the regulatory setting section of this chapter, the Larkspur General Plan requires that geotechnical investigations be performed for buildings proposed to be constructed in areas subject to settlement and subsidence. As such, development project's proposed for portions of the Specific Plan area underlain by Bay Mud would be required to include the preparation of geotechnical investigations that would address soil compression. Implementation of site-specific soil treatment and other remediation recommended in the geotechnical investigations would reduce the risk of soil compression and secondary consolidation on buildings in the Specific Plan area to a less-than-significant level.

Settlement is an existing cause of damage to Doherty Drive. Comments received on the previously circulated Draft EIR (Busse, Maltzahn, 2002) and confirmed by the City Planning Department (Pendoley, pers. comm., 2003) noted that Doherty Drive has been subject in the past to settlement and submersion. Based on the thickness of the Bay Mud beneath Doherty Drive and the length of time the fill has been in place, it is estimated that 90 to 95 percent of the settlement has already occurred in the 30 or more years since the fill/roadway was

constructed (Morisoli, pers. comm., 2003). Thus while additional settlement may occur in the future, the extent of the settlement would be more limited than was experienced in previous years.

Settlement is sometimes attributed in part to increased vehicular traffic on roadways. Development in the Specific Plan area would contribute additional vehicular traffic to Doherty Drive. Specifically, the future development in the Specific Plan area would contribute 99 trips during the P.M. peak hour to the segment of Doherty Drive east of Piper Park, whereas the existing volume is 1,000 trips during the P.M. peak hour. During the construction phases of future development, heavy equipment may also be routed to Doherty Drive. It has been speculated that additional traffic on Doherty Drive would increase the potential for inducing settlement. According to geotechnical analysis of Doherty Drive, however, transient loads, such as moving vehicles, regardless of their weight, would have no noticeable effect on settlement of the street surface (Miller Pacific Engineering Group, pers. comm., 2003). These "transient" loads do not induce settlements of the Bay Mud because they are relatively light in relation to soil or asphalt fill and the Bay Mud can withstand short term loads with no noticeable settlement. In contrast, very heavy vehicles, if parked along the roadway for a period of months or years, would theoretically induce some small settlement of the underlying Bay Mud; however, these settlements would likely be so small that they would not be noticeable (Morisoli, pers. comm., 2003). As such, the Specific Plan would not be expected to have a significant impact related to settlement-related damage of Doherty Drive.

Impact **4.3-5**

Damage to Underground Utilities Caused by Corrosive Soils. *Highly corrosive soils underlying the Specific Plan area could cause damage to underground utilities, potentially leading to the disruption of service. This impact is considered* ***potentially significant****.*

The soils underlying the Specific Plan area are moderately to extremely corrosive to steel. The highly corrosive soils could cause damage to underground utilities constructed of steel pipelines. Corrosion of utility pipelines could result in the disruption of utility services and the release of natural gas, water, or wastewater into the environment. The geotechnical investigations currently required by the General Plan do not specifically require testing for corrosive soils and do not require implementation of protective features against corrosive soils. As such, this impact is considered potentially significant.

Impact **4.3-6**

Destabilization of Excavations and Trenches. *Shallow groundwater conditions potentially encountered during grading and utility construction could result in unsafe conditions for construction workers. Given the compliance with existing safety regulations, this impact is considered* ***less than significant****.*

The Specific Plan area is located on a natural upland peninsula that extended into the historical wetland margins of San Francisco Bay. It is located adjacent to tidally influenced surface water within Larkspur and Corte Madera Creeks and may therefore be tidally influenced. Fluctuations in the groundwater level could occur in the Specific Plan area as a result of tidal fluctuations, the change in seasons, variations in rainfall, and other factors. Because the area is a former tidal marsh and is located adjacent to tidal marsh, shallow

groundwater conditions may be encountered during grading operations and utility construction at the Specific Plan area. Shallow groundwater may act to destabilize excavations and trenches during construction, resulting in unsafe conditions for construction workers. However, given required dewatering and trench stabilization in compliance with occupational safety and health guidelines of the California Occupational Safety and Health Administration (Cal/OSHA) and federal OSHA, this impact is considered less than significant.

Impact **4.3-7**

Potential for Surface Fault Rupture. *The nearest mapped active earthquake fault, the San Andreas fault, is located 8 miles from central Larkspur. No known active faults traverse the Specific Plan area. This impact is considered* ***less than significant****.*

Surface fault rupture is not considered a hazard in the Specific Plan area. The nearest active earthquake fault zoned under the Alquist-Priolo Earthquake Fault Zone Act is the San Andreas fault, located approximately 8 miles southwest of central Larkspur, and the Hayward fault, located approximately 10 miles to the northeast. This impact is considered less than significant.

Impact **4.3-8**

Exposure to Landslides. *The Specific Plan area is flat and relatively level; the nearest location with potentially unstable slopes is south of East Ward Street. This impact is considered* ***less than significant.***

The Specific Plan area is flat and relatively level, and is located to the north and east of the nearest hills. The offsite location nearest to the Specific Plan area with potentially unstable slopes is south of East Ward Street, and it is not expected to affect the Specific Plan area because of its distance from the area. Because there are no known landslides that would potentially affect the Specific Plan area, this impact is considered less than significant.

Impact **4.3-9**

Loss of Topsoil. *The Specific Plan area is dominated by fill soils, not topsoil. This impact is considered* ***less than significant****.*

Elements of construction for subsequent development projects, such as installation of underground utility lines and storm drain installation and upgrading, would require excavation of soils. Such work could potentially result in the loss of surface material in the Specific Plan area. However, the soils in the Specific Plan area are dominated by human-placed fill soils that are not properly characterized as topsoil. Since the Specific Plan area was filled, very little topsoil has formed in the area. This impact is considered less than significant.

Impact **4.3-10**

Potential Expansion of Clay Soils. *Because of the density and pre-existing high water content of soils beneath the Specific Plan area, soil expansion is not a substantial concern. This impact is considered* ***less than significant****.*

Clay soils, which may expand when surcharged with water, are present in soils underlying the Specific Plan area, which include fill, Bay Mud, and alluvium. Soil expansion can result in

damage over time to building foundations, underground utilities, and other subsurface facilities if they are not designed and constructed appropriately to resist the changing soil conditions. Volume changes of expansive soils can also result in the consolidation of soft clays, also known as shallow ground subsidence following the lowering of the water table or the placement of fill. Because the soils in the Specific Plan area are of low density and have pre-existing high water content, expansion of the soils is not considered a substantial concern. This impact is less than significant.

CUMULATIVE IMPACTS

Potential geologic and soil impacts are generally site-specific and do not contribute to a cumulative impact; these potential impacts include exposure to seismic ground shaking and surface fault rupture, exposure to seismic-related ground failure, soil erosion and destabilization of excavations and trenches during construction, exposure to structural damage from soil corrosion and settlement, expansion, compressibility and settlement, and exposure to landslides. Additional traffic volume is not expected to induce settlement of Doherty Drive, and settlement-related damage to Doherty Drive would not be attributed to the Specific Plan or cumulative development.

4.3.3 MITIGATION MEASURES

PROJECT-LEVEL MITIGATION MEASURES

No mitigation measures are required for the following less-than-significant impacts.

4.3-1: Increased Exposure to Strong Seismic Ground Shaking

4.3-2: Potential for Seismic-Related Ground Failure, Including Liquefaction

4.3-4: Damage to Onsite Foundation and Other Structures Caused by Soil Compressibility and Secondary Consolidation Settlement.

4.3-6: Destabilization of Excavations and Trenches

4.3-7: Potential for Surface Fault Rupture

4.3-8: Exposure to Landslides

4.3-9: Loss of Topsoil

4.3-10: Potential Expansion of Clay Soils

The following mitigation measures are recommended for potentially significant impacts.

Impact **4.3-3** mitigation

Soil Erosion During Construction Activities.

Prepare and Implement Stormwater Pollution Prevention Plan

The City shall include the following new policy in the Specific Plan.

New Policy: To reduce the potential for impacts on Larkspur and Corte Madera Creeks from soil erosion caused by grading and other construction activities, the developer for either public or private projects shall prepare an Erosion Control Plan for any construction activity, including those that involve less than one acre of disturbance area, to control the potential for stormwater to erode site soils and cause them to enter the creeks. The plan, which shall be in the form of a SWPPP, shall be reviewed and approved by the City and the San Francisco Bay Regional Water Quality Control Board (RWQCB) prior to the issuance of construction permits and shall be implemented during construction activities and for the next rainy season following completion of construction. The Erosion Control Plan shall comply with the City's Grading Ordinance and shall include, but shall not be limited to, the following measures:

- Grading/earthmoving shall not occur during the rainy season (October 15–March 15). Should construction proceed during or shortly after wet-weather conditions at any time of year, the geotechnical engineer in the field at the time of grading/earthmoving shall provide specific wet-weather grading/earthmoving recommendations.

- A vegetated buffer shall be protected during grading/ earthmoving next to Larkspur Creek. This buffer shall be at least 50 feet wide from the top of the bank on the north/south reach of the creek at the eastern edge of the Specific Plan area, and at least 25 feet wide from the top of bank on the east/west reach of the creek at the southern edge of the Specific Plan area. The conditions of all development permits within Subarea 3 and all subsequent grading permits shall both specify that before the start of any grading, orange barrier fencing shall be installed at the outer edge of the protected buffer area. The fencing shall be maintained until all construction activities have ceased. No construction activity, including the storage of construction materials, or vehicles staging or maneuvering, shall be permitted in the buffer area.

- Silt fencing and straw bales shall be used along Larkspur Creek to trap any silt flows from unvegetated ground.

Impact **4.3-5a, b** mitigation

Damage to Underground Utilities Caused by Corrosive Soils.

(a) Implement Mitigation Measure 4.3-4

The City shall implement Mitigation Measure 4.3-4, Submit Geotechnical Testing and Engineering Design Report, to mitigate the potential for damage to underground utilities from corrosive soils.

(b) Backfill with Noncorrosive Soil and Use Corrosion-Resistant Materials

The City shall include the following new policy in the Specific Plan.

New Policy: Utility line excavations shall be backfilled with noncorrosive soil backfill materials or pipelines shall be constructed of corrosion-resistant materials.

CUMULATIVE MITIGATION MEASURES

No cumulative mitigation measures are required because no significant cumulative impacts would result.

4.3.4 LEVEL OF SIGNIFICANCE AFTER MITIGATION

All impacts are considered less than significant with the implementation of mitigation measures.