3.9 Geology/Soils/Seismic/Topography

3.9.1 Regulatory Setting

For geologic and topographic features, the key federal law is the Historic Sites Act of 1935, which establishes a national registry of natural landmarks and protects "outstanding examples of major geological features." Topographic and geologic features are also protected under the California Environmental Quality Act (CEQA).

This section also discusses geology, soils, and seismic concerns as they relate to public safety and project design. Earthquakes are prime considerations in the design and retrofit of structures. The Department's Office of Earthquake Engineering is responsible for assessing the seismic hazard for Department projects. Structures are designed using the Department's Seismic Design Criteria (SDC). The SDC provides the minimum seismic requirements for highway bridges designed in California. A bridge's category and classification will determine its seismic performance level and which methods are used for estimating the seismic demands and structural capabilities. For more information, please see the Department's Division of Engineering Services, Office of Earthquake Engineering, Seismic Design Criteria.

3.9.2 Affected Environment

This section describes the geologic setting, topography, surface and groundwater, rock/soils, and geologic hazards including seismic hazards (strong ground shaking, liquefaction, fault-induced ground rupture, tsunami, seiche, seismically induced landslides and rock falls, and settlement), non-seismically induced earth movement, and economic resources/mineral hazards, as applicable. Information in this section is based on the reports listed below prepared for the SR-241/SR-91 Express Lanes Connector project.

- *District Preliminary Geotechnical Report* (February 2016)
- *Phase I Initial Site Assessment SR-241/91 Express Lanes Connector Project* (October 2015)

There are 11 geomorphic provinces in California, as defined by the California Geological Survey. Geomorphic provinces are geologic regions with distinct landforms and geology. The Project Area is within the Peninsular Ranges Geomorphic Province. The total width of the province is approximately 225 miles (mi), with a maximum land bound width of 65 mi. The province region is characterized by a series of northwest trending mountain ranges, valleys and faults, such as the Whittier-Elsinore and the San Andreas Faults.

3.9.2.1 Topography

The Project Area exhibits highly variable topography, ranging from flat areas along the freeway mainlines and in Santa Ana Canyon to steep natural slopes within the Santa Ana Mountains. The Project Area extends from the northwestern foothills along the Santa Ana Mountains into Santa Ana Canyon.

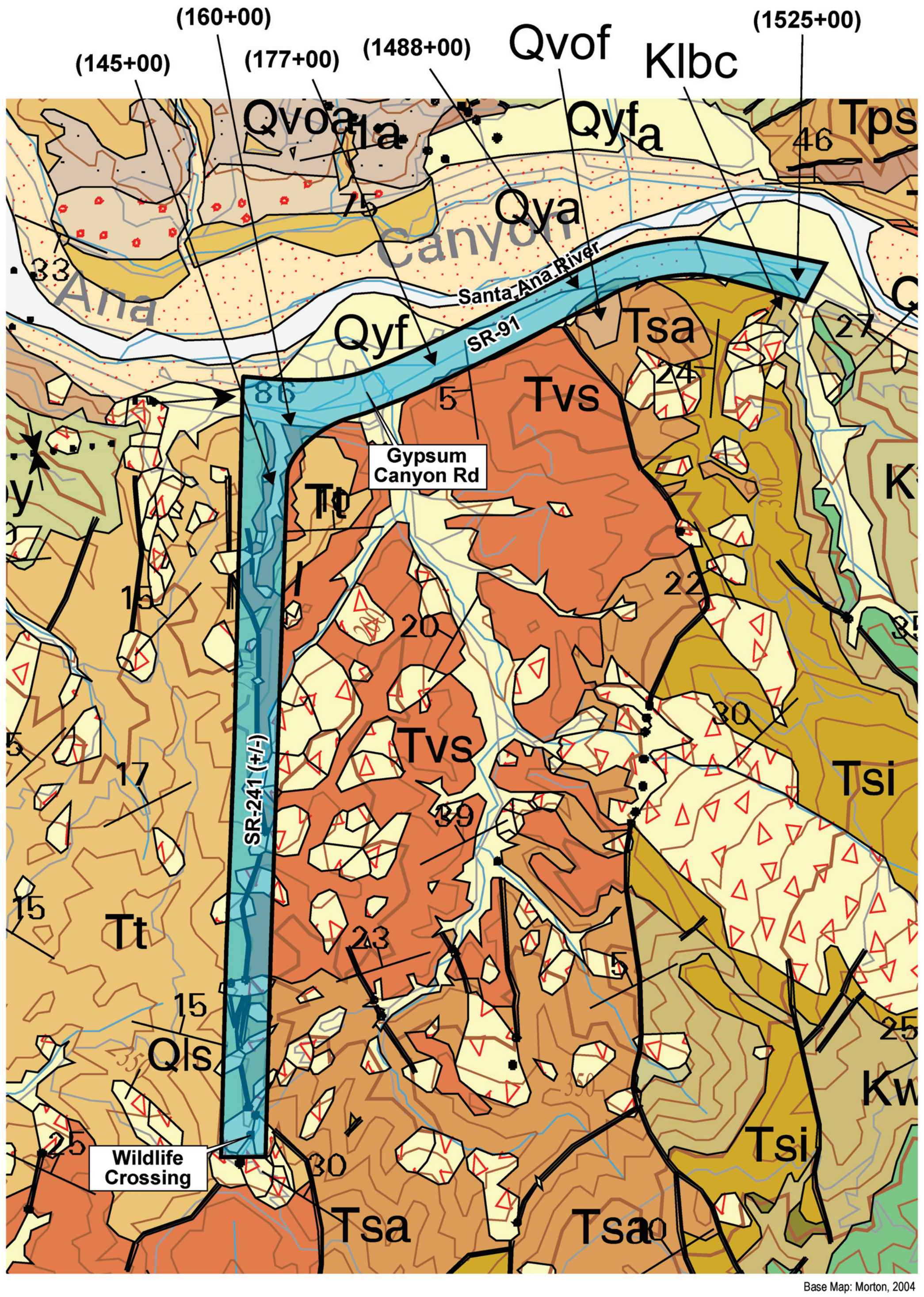
3.9.2.2 Stratigraphy/Soils/Geologic Landforms

Within the alignment of SR-241 and SR-91, the subsurface has been highly modified through cuts and fills to accommodate the freeways, and there are no unique surficial geologic landforms in the Project Area. In this area, there are several subsurface geologic formations, or units. These formations and units include artificial fill, young alluvial deposits, terrace deposits, sedimentary bedrock units that include the Topanga Formation, undifferentiated, the Vaqueros-Sespe Formation, and the Santiago Formation. The existing cut slope on the south side of SR-91 is underlain by terrace deposits and bedrock of the Santiago Formation. Regional geology is shown in Figure 3.9.1.

Please refer to Section 3.10, Paleontology, Table 3.10.1, Geologic Time Periods and Geologic Units in the Area of Project Disturbance, for a description of the geologic units within the Project Area.

3.9.2.3 Surface Water

The major drainage within the Project Area is the Santa Ana River that originates in the San Bernardino Mountains, and drains to the Pacific Ocean near Newport Beach, and which is adjacent to SR-91 in the Project Area. Runoff from the Project Area drains to the Santa Ana River. Nine surface drainage features were identified in the Project Area, including Gypsum Canyon Creek. Five of these drainages are concrete-, riprap-, or asphalt-lined and are designed to convey runoff from SR-241 or SR-91. Numerous subdrains have been constructed below the existing SR-241/SR-91 Mainline and Connectors.



Project Area

(160+00) = Approximate Station Number (for reference only)

EXPLANATION

Contact—Accuracy of location ranges from well-located to approximately located

Fault—Solid where accurately located; dashed where approximately located or inferred; dotted where concealed; queried where location or existence uncertain. Includes strike-slip, normal and reverse dip-slip, oblique-slip, and thrust faults. Arrow and number indicate measured dip of fault plane

Fault scarp—Solid where accurately located; dashed where approximately located. Hachures on upthrown block

Landslide scarp—Solid where accurately located. Hachures on upper part of headscarp

Subsidence scarp—Solid where accurately located. Hachures on upper surface

Anticline—Solid where accurately located; dotted where concealed. Arrowhead on axis shows direction of plunge

Syncline—Solid where accurately located; dotted where concealed. Arrowhead on axis shows direction of plunge

Overturned anticline—Solid where accurately located. Arrowhead on axis shows direction of plunge

Overturned syncline—Solid where accurately located. Arrowhead on axis shows direction of plunge

Suture—Location approximate

Ground fissures—San Jacinto Valley area

Strike and dip of beds

- Inclined
- Vertical
- Overturned
- Horizontal

Strike and dip of metamorphic foliation

- Inclined
- Vertical

Strike and dip of primary igneous foliation

- Inclined
- Vertical

Bearing and plunge of linear features

- Inclined

UNITS

Qyf — **Young alluvial fan deposits (Holocene and late Pleistocene)**—Gravel, sand, and silt, mixtures, some contain boulders; unconsolidated.

Qya — **Young axial channel deposits (Holocene and late Pleistocene)**—Gravel, sand, and silty alluvium; gray, unconsolidated.

Qvof — **Very old alluvial fan deposits (middle to early Pleistocene)**—Sandy alluvium; reddish-brown, well-indurated, fan surfaces well-dissected.(Terrace Deposits)

Qls — **Landslide deposits (late Holocene)**—Active or recently active landslides; unconsolidated to consolidated. Includes many early Holocene landslides that in part have been reactivated during late Holocene

Tt — **Topanga Formation (middle Miocene)**—Marine sandstone, siltstone, and locally conglomerate. Includes:

Tvs — **Vaqueros and Sespe Formations, undifferentiated (early Miocene, Oligocene, and late Eocene)**—Interbedded sandstone and conglomerate; marine and nonmarine

Tsa — **Santiago Formation (middle Eocene)**—Sandstone and conglomerate, marine and nonmarine

Tsis, Tsicg, Tsi — **Silverado Formation (Paleocene)**—Sandstone, siltstone, and conglomerate; nonmarine and marine. Much of unit is thoroughly weathered. Basal conglomerate (Tsicg) and Serrano clay (Tsis) are subdivided locally

Ladd Formation (Late Cretaceous)

Klbc — **Baker Canyon Conglomerate Member**—Conglomerate, conglomeratic sandstone and pebble conglomerate; marine and locally nonmarine(?)

FIGURE 3.9-1

N

0 0.25 0.5
MILES (APPROXIMATE)

SOURCE: CH2MHILL

SR-241/SR-91 Express Lanes Connector

Geologic Map

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3.9.2.4 Groundwater

In the Project Area, groundwater levels in Santa Ana Canyon generally correspond to the elevation of the Santa Ana River bed (approximate elevation 384 feet [ft], across from the SR-91 Station 1480+00). Groundwater levels could fluctuate due to a number of factors, including seasonal variation, irrigation, and construction. The bedrock units present above Santa Ana Canyon along the alignment are generally considered non-water bearing. However, local seepages do exist within the formation along fracture/fault zones, and local perched water bodies may be present where there are permeability contrasts within the unit.

3.9.2.5 Naturally Occurring Oil and Gas

Based on information from a search of the California Department of Oil, Gas, and Geothermal Resources Wildcat Maps, oil and gas wells have historically been located within the immediate vicinity of the Project Area. However, no existing or previous oil or gas wells are known to be located within the Project Area. Idle or plugged oil/gas wells are located more than 0.6 mi from the Project Area.

3.9.2.6 Faulting

The Southern California region is seismically active due to the influence of several earthquake fault systems resulting from interaction between the Pacific and North American crustal plates. An active fault is defined by the State of California as a sufficiently active and well-defined fault that has exhibited surface displacement within the last 11,000 years. A potentially active fault is defined by the State as a fault with a history of movement between 11,000 and 1.6 million years ago. There are two primary hazards associated with active faults: fault-induced ground rupture and ground shaking. The Project Area is not located within an Earthquake Fault Zone according to the Alquist-Priolo Earthquake Fault Zoning Act of 1972. However, a number of inactive faults are within the Project Area according to regional studies as shown on Figure 3.9.1 and Figure 3.9.2. No active faults transverse the Project Area.

3.9.2.7 Geologic Hazards

An earthquake along the Whittier-Elsinore Fault Zone and other regionally active faults could result in ground shaking within the Project Area. In addition, although the Peralta Hills Fault (located approximately 2.5 mi west-southwest of the proposed SR-241 Wildlife Undercrossing) is not considered active, it is thought to have experienced movement in the Late Quaternary period. Therefore, Caltrans includes this fault in its seismic design criteria. During an earthquake, seismic waves are produced that extend in all directions from the fault rupture.

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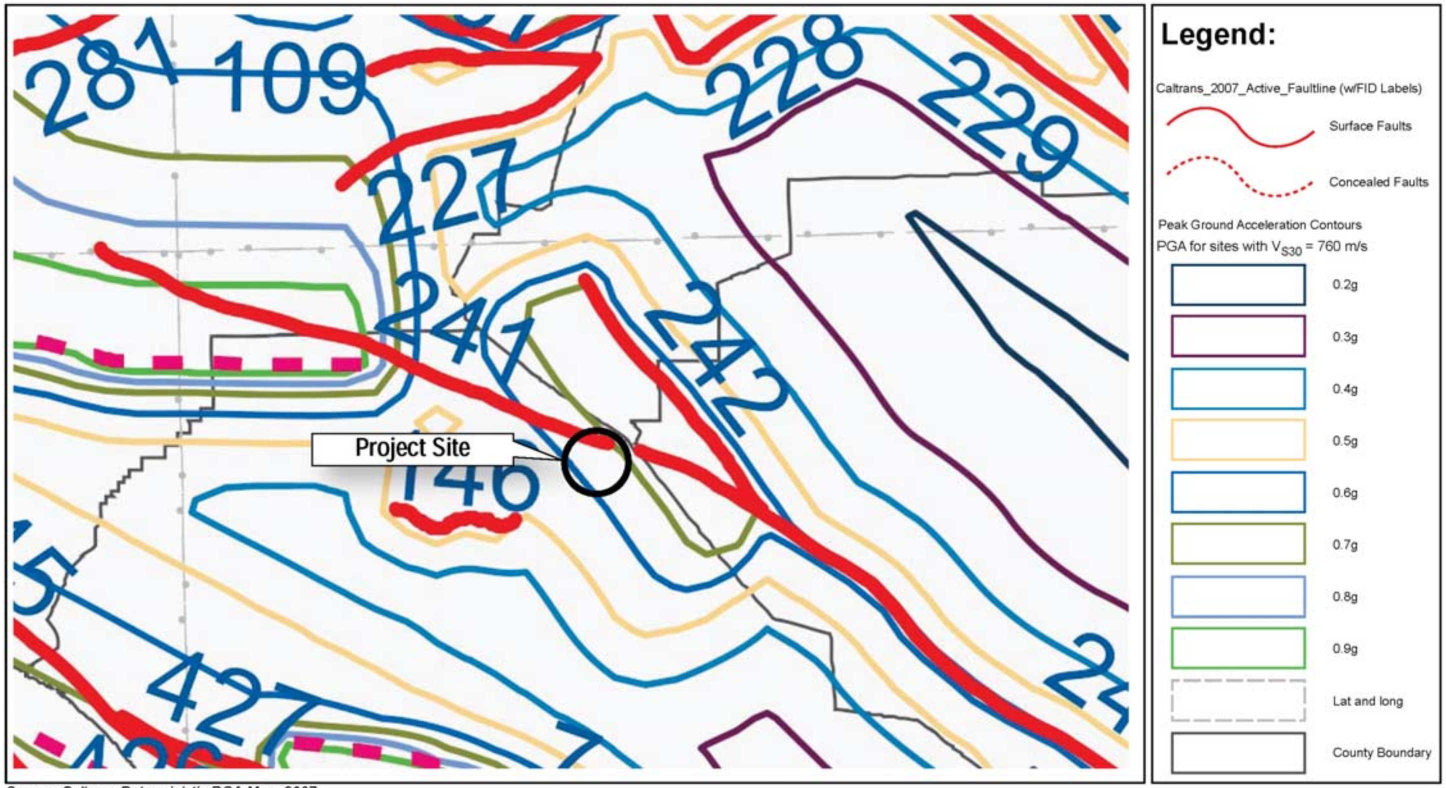

Source: Caltrans Deterministic PGA Map, 2007

Fault ID	Fault Name	Mmax
242	Elsinore fault zone (Chino section)	7.6
241	Elsinore fault zone (Whittier section)	7.6
109	Indian Hill fault	6.4
145	Newport Inglewood-Rose Canyon fault zone (S. Los Angeles Basin section-northern)	7.5
427	Newport Inglewood-Rose Canyon fault zone (S. Los Angeles Basin section-southern)	7.5
146	Peralta Hills fault	6.2
240	Puente Hills Blind Thrust	7.3
281	Raymond fault	6.6
228	Red Hill-Etiwanda Avenue fault	6.4
229	San Jacinto fault zone (San Bernardino section)	7.5
227	San Jose fault (Southern California)	6.4
239	Upper Elysian Park Blind Thrust	6.4

FIGURE 3.9-2

N

0 5 10
MILES

SOURCE: CH2M Hill (Caltrans Deterministic PGA Map, 2007)

SR 241/SR 91 Express Lanes Connector

Seismic Hazards Map

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Seismic waves can produce strong ground shaking that is typically strongest near the fault and attenuates as waves move away from the source. The severity of ground shaking is a function of the magnitude of the fault rupture; the distance from the fault to the affected area; and the type, thickness, and condition of the underlying geologic materials in an area.

Areas underlain by unconsolidated recent alluvium or fill may amplify the strength and duration of strong ground motion. The geologic hazards associated with seismic ground shaking are discussed in the following sections. There are several other types of non-seismic geologic hazards that could occur in the Project Area that are also described in the following sections.

Liquefaction

Soil liquefaction occurs when saturated, loose soils lose their strength due to excess pore water pressure caused by earthquake ground shaking. The space between the soil particles is completely filled with water, which exerts pressure on the soil particles, thereby influencing how tightly the soil particles are pressed together. The shaking caused by an earthquake can increase the pore water pressure to a point in which the soil loses strength and ground deformation can occur. The primary factors impacting the possibility of liquefaction in a soil deposit are the intensity and duration of the earthquake shaking, the soil type, the relative density of that soil, the pressures of material above that soil, and the depth to groundwater. The types of soils most susceptible to liquefaction are clean, loose, uniformly graded, fine-grained sands; non-plastic silts that are saturated; and silty sands. When liquefaction occurs, the strength of the soil decreases and the ability of the soil to support structures is reduced. The potential impacts of liquefaction may include settlement of the ground surface, additional forces pushing down on foundation piles as a result of soil settlement above the liquefied layers, and reduction of the shear strength of the liquefied soil, resulting in reduced load-carrying capacity. Areas in the vicinity of the SR-241/SR-91 interchange and Santa Ana Canyon along SR-91 have been mapped as a liquefaction *Zone of Required Investigation* by the California Division of Mines and Geology (CDMG; 2001). Based on soils investigations conducted previously for the original construction of SR-241 and SR-91, local, potentially liquefiable layers are present within Santa Ana Canyon. Therefore, the liquefaction potential in the Project Area is considered low to medium.

Seismically Induced Landslides and Slope Stability

Seismically induced landslides are rock, earth, or debris flows on slopes that can occur as a result of seismic shaking. Landslides constitute a major geologic hazard because they can be widespread and can cause substantial damage to life and property. Although landslides commonly occur in connection with other major natural disasters (e.g., earthquakes, volcanoes, wildfires, and floods), they can occur on any terrain given the right conditions of rock or soil, moisture content, and angle or slope. Steep bare slopes, bedded (layered) rock, deposits/erosion of stream or river sediment, and heavy rains can also contribute to landslides. Steep slopes in the vicinity of the Project Area as well as slopes located along the south side of the SR-91 mainline have been mapped as an earthquake-induced landslide *Zone of Required Investigation* by CDMG (2001). One cut slope on the south side of SR-91 would be modified by the Proposed Project improvements. The slope appears to be stable and does not exhibit signs of weakness; however, the slope continues to experience considerable erosion. Therefore, there is a low-to medium-potential for landslides along the hillside areas of the alignment.

Seismic Settlement

Seismic settlement is a phenomenon in which loose, unsaturated sands tend to settle or become denser during strong seismic shaking. Sediments that are sufficiently loose can experience seismic settlement, which can cause ground settlement and damage to structures. Hazards associated with seismically induced settlement in the Project Area are considered low.

Lateral Spreading

Lateral spreading occurs due to pore water pressure or liquefaction in shallow deposits during an earthquake, resulting in lateral displacement of gently sloping ground. Similar to the potential for liquefaction, within the Project Area, the potential for hazards associated with lateral spreading is considered low to medium.

Seismically Induced Inundation

Seismically induced inundation occurs when an earthquake causes catastrophic failure of a water-retaining structure, such as a reservoir, dam, or levee, and subsequent flooding occurs due to the release of water from the structure. The portion of SR-91 within the Project Area is in a potential dam inundation area for Prado Dam.

Tsunami and Seiche

The Project Area is above elevations that could experience flooding associated with tsunamis. As a result, a tsunami is not considered a potential geologic hazard for the Proposed Project, and therefore, is not discussed further in this analysis. Surface water could overtop Prado Dam as result of strong seismic shaking, presenting a seiche hazard.

Compressible and Expansive Soils

Near the surface, ground settlement can occur when new loads are added to soil, or when a change in water levels results in a decrease in pore water pressures within compressible soils. Collapsible soils consist predominantly of sand-and-silt-size particles arranged in a loose “honeycomb” structure. This loose structure is held together by small amounts of water-softening cementing agents, such as clay or calcium carbonate. When the soil becomes wet, these cementing agents soften and the honeycomb structure collapses and generates ground settlement. Expansive soils are characterized by their ability to undergo significant volume changes (shrink or swell) as a result of variations in moisture content even without an increase in external loads. Changes in soil moisture content can result from precipitation, landscape irrigation, utility leakage, roof drainage, perched groundwater, drought, or other factors and may result in unacceptable settlement or heave of structures or concrete slabs supported on grade. The soils within the Project Area can be somewhat expansive and compressible; however, hazards associated with compressible and expansive soils are considered low.

Erosion

Erosion occurs when rock and/or soil surfaces are exposed to weathering caused by wind and/or water. The United States Geological Survey has delineated Soil Erodibility Factors (K Factors) that indicate how susceptible surface soils are to erosion. Soils within the Project Area have been mapped with a K Factor ranging from 0.05 to 0.37; therefore, the Project Area is considered to have a moderate erosion potential.

Subsidence

Regional subsidence results from the withdrawal of groundwater and/or hydrocarbons from subsurface areas. As groundwater or hydrocarbons are pumped out of the ground, the resultant voids or pores are compressed under the pressures of the materials above. Accumulation of the compression results in subsidence of the ground surface. The Project Area is not located in an area of significant groundwater or hydrocarbon withdrawal; therefore, the potential for subsidence is low.

3.9.2.8 National Natural Landmarks

Nearly 40,000 acres of open space on the Irvine Ranch have been designated a National Natural Landmark (NNL) by both the State of California and the United States Department of the Interior.[1] A small part of the NNL abuts SR-91 east of the SR-241/SR-91 interchange and is within the Project Area.

In the portion of the Project Area that is within the NNL there are four geologic units: the Santiago Formation, Very Old Alluvial Fan Deposits, Young Alluvial Fan Deposits, and Landslide Deposits. None of these geologic units are unique unto themselves at the location within the NNL, as these same units are present in other areas of the NNL. In addition, there are no unique geologic features at this location such as caves, steep and rugged cliff faces, or unusual mineral deposits.

3.9.3 Environmental Consequences

3.9.3.1 Temporary Impacts

Build Alternative (Two-Lane Express Lanes Connector) (Preferred Alternative)

Strong ground shaking could occur during construction of Build Alternative improvements due to regional faults and active faults in the vicinity of the Project Area. As a result, construction activities associated with the Build Alternative could be impacted by ground motion from seismic activities, liquefaction, and landslides if an earthquake were to occur during construction.

The structures proposed as part of the Build Alternative are within an area with slopes mapped as a *Zone of Required Investigation* for stability. The majority of slopes in this area would not be affected by proposed improvements as part of the Build Alternative. However, the existing 1.5:1 (horizontal to vertical (h:v)) cut slope on the south side of SR-91 would be modified to a 2:1 (h:v) slope with benches and drains. In the existing condition, this slope appears to be performing well from a global stability standpoint. No clay seams or significant planes of weakness were mapped on the slope when initially cut as part of the ETC. The proposed 2:1 (h:v) slope with benches is planned for the same height as the existing 1.5:1 (h:v) cut slope and is expected to be stable. However, further evaluation would be required during final

[1] Irvine Ranch Conservancy. Website: http://letsgooutside.org/; Orange County Parks. Website: http://ocparks.com/parks/irvineranch/ (accessed March 31, 2015).

design to identify potential hillside remediation required to stabilize the slope and minimize direct impacts or indirect slope stability impacts over time. There is also a potential for unmapped landslides to occur along or adjacent to the Build Alternative. A Final Geotechnical Report specified in Measure GEO-1 will be prepared during final design that will identify any special hillside remediation that needs to be done prior to construction of the Proposed Project. Any hillside areas to be modified will be geologically mapped during construction to verify the findings evaluated during the final design and revised remediation will be implemented, if warranted.

During construction of the Build Alternative, excavated soil would be exposed, and there would be an increased potential for soil erosion compared to existing conditions. In addition, during a storm event, soil erosion could occur at an accelerated rate. The Proposed Project would be required to adhere to the requirements of the General Construction Permit and implement erosion and sediment control best management practices (BMPs) specifically identified in a project Storm Water Pollution Prevention Plan to keep sediment from moving off site into receiving waters. Refer to Section 3.8, Water Quality and Storm Water Runoff, for additional information regarding construction-related water quality issues.

No Build Alternative

The No Build Alternative does not include the construction of any of the improvements for the SR-241/SR-91 Express Lanes Connector project. As a result, the No Build Alternative would not result in any temporary adverse effects related to geology and seismicity within the Project Area.

3.9.3.2 Permanent Impacts

Build Alternative (Two-Lane Express Lanes Connector) (Preferred Alternative)

Build Alternative improvements would occur mostly within existing pavement or disturbed areas, with the exception of the slope south of SR-91. Retaining walls would be constructed in this area in order to control slope stability. In addition, in this area, the Proposed Project would encroach approximately 100 to 300 ft into the NNL parcel. However, due to the limited encroachment, the project would not impact any designated unique geologic feature.

Moderate to severe seismic shaking is likely to occur in the Project Area during the life of the improvements under the Build Alternative; however, this does not represent a substantially greater hazard than any other area because Southern

California is a seismically active region, and the SR-241/SR-91 Express Lanes Connector project is not located within an active fault zone. In general, the project improvements can be designed to accommodate the expected ground accelerations through compliance with applicable building and seismic codes. As a result, the potential for structural damage can be substantially reduced or avoided through seismic engineering design.

Liquefaction is a potential geologic hazard for the Build Alternative. Like other secondary seismic hazards, this condition will be investigated as part of the Final Geotechnical Report (Measure GEO-1). The liquefaction hazard would be minimized through implementation of appropriate design measures.

There are no landslides mapped along or adjacent to the Build Alternative; however, there is a potential for unmapped landslides to occur along or adjacent to the Build Alternative. A Final Geotechnical Report specified in Measure GEO-1 will be prepared during final design that will identify any special soil remediation that needs to be done prior to construction of the Proposed Project.

Impacts related to erosion occurring after the completion of construction that may affect the traveling public or the project facilities can be substantially reduced through design and grading techniques. The Build Alternative would result in potential for erosion and a need for sensitive design and grading techniques to reduce erosion. Refer to Section 3.8, Water Quality and Storm Water Runoff, for additional discussion regarding construction-related water quality issues and mitigation, including BMPs.

Although portions of SR-91 within the Project Area could be subject to dam inundation and seiche, this risk is the same with the No Build condition.

No Build Alternative

Under the No Build Alternative, existing earthquake, seismic, and landslide issues would continue to potentially affect the existing facilities along the project segments of SR-241 and SR-91. However, the grading and use of cut-and-fill slopes required for the SR-241/SR-91 Express Lanes Connector project would not occur under the No Build Alternative.

3.9.4 Avoidance, Minimization, and/or Mitigation Measures

The measures listed below are required, and will be incorporated during construction of the Build Alternative to avoid and minimize permanent impacts to geology and soils.

All improvements under the Build Alternative would be designed, constructed, and operated in accordance with all applicable standards, including the following design and safety standards:

- Caltrans design standards (for highway and roadway improvements on Caltrans facilities) in the Highway Design Manual (2012 or more current);
- California Occupational Safety and Health Administration (Cal/OSHA) related to worker safety during construction and operation in Title 8 Chapter 3.2, California Safety and Health Regulations, California Code of Regulations; and
- National Fire Protection Association (NFPA) Safety Codes and Standards.

Compliance with the applicable agency/jurisdiction seismic design standards would reduce the risk associated with geologic hazards related to seismicity, soil erosion, and slope instability during construction and operation of the SR-241/SR-91 Express Lanes Connector to acceptable levels. Measures GEO-1 and GEO-2 documented below would further reduce potential impacts related to liquefaction, seismic shaking, fault-induced ground rupture, slope instability, and erosion.

Measure GEO-1 **Final Geotechnical Report.** During Final Design, a qualified geotechnical engineer will conduct a comprehensive geologic and geotechnical investigation and prepare a design-level geotechnical report. This report will document geology-related constraints and hazards such as fault-induced ground rupture, slope instability, settlement, liquefaction, or related secondary seismic impacts that may be present along the alignment of the Build Alternative. The performance standard for this report will be the California Department of Transportation's (Caltrans) Geotechnical Manual (2012 or most recent version) standards as they apply to the project features and structures. The measures recommended in the design-level geotechnical report will be incorporated into the Final Design and project specifications. The construction contractor will implement the measures recommended in the design-level geotechnical reports as included in the project design and specifications.

Measure GEO-2 **Quality Assurance/Quality Control Plan.** During Final Design, a quality assurance/quality control (QA/QC) plan will be prepared and implemented during construction. The QA/QC plan will include observing, monitoring, and testing by the Project Geotechnical Engineer and/or the Project Geologist prior to and during construction to confirm that the geotechnical/geologic recommendations from the design-level geotechnical report and standard design and construction practices are fulfilled by the contractor, or if different site conditions are encountered, appropriate changes are made to accommodate such issues. Weekly reports will be prepared during all project-related grading, excavation, and construction activities.