APPENDIX D

Geotechnical Background Report

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APPENDIX D

Geotechnical Background Report For the Coachella Valley Multiple Species Habitat Conservation Plan and Natural Community Conservation Plan

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Table of Contents

Tables

GEOTECHNICAL BACKGROUND REPORT
FOR THE
COACHELLA VALLEY MSHCP/NCCP EIR/EIS

I. Purpose and Introduction

The Coachella Valley Multiple Species Habitat Conservation Plan/Natural Communities Conservation Plan (HCP) was prepared by the Coachella Valley Mountains Conservancy under contract to and with the assistance of the Coachella Valley Association of Governments (CVAG) and its member jurisdictions, in conjunction with various federal and state regulatory agencies, to serve two primary goals: 1) to balance environmental protection and economic development objectives in the HCP planning area, and 2) to simplify compliance with endangered species related laws.[1] The HCP planning area encompasses more than 1.2 million acres of developed and undeveloped land in the Coachella Valley, which is located in central Riverside County, California.

The purpose of this report is to describe the existing seismic and geologic conditions of the HCP planning area and to provide a general description of the geotechnical and developmental constraints facing the region. The assessment is largely based upon data and information gathered during a 2001 literature review of numerous geotechnical analysis, including several assessments prepared for the Safety Elements of local jurisdictions' General Plans.

II. Seismicity

I. Regional Tectonic Setting

The Coachella Valley is located in the northwestern portion of a broad, tectonic depression known as the Salton Trough, which extends from the Gulf of California to the San Gorgonio Pass, a narrow divide between drainage to the Pacific Ocean and the Salton Trough. The Salton Trough is approximately 130 miles long and 70 miles wide, and is roughly divided into two parts by the Salton Sea: the Coachella Valley to the north and the Imperial Valley to the south. The HCP planning area occurs entirely within the Coachella Valley portion.

The Salton Trough is actually the northern portion of the Gulf of California, a rift basin formed by oblique strike-slip motion between the North American and Pacific plates.[2] As the basin spreads, it forces the Pacific tectonic plate northwest into the North American Plate. These plates are sliding past one another at a rate of about 50 millimeters per year, and their movement is

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[1] "Administrative Review Draft, Coachella Valley Multiple Species Habitat Conservation Plan/Natural Communities Conservation Plan," Coachella Valley Mountains Conservancy, August 2000.

[2] "Emerging Perspectives of the Salton Trough Region with an Emphasis on Extensional Faulting and Its Implications for Later San Andreas Deformation," Eric G. Frost, Steve C. Suitt, and Mitra Fattahipour.

responsible for generating the earthquakes that occur in southern California.[3] About 70% of the movement between the Pacific and North American Plates is accommodated by the San Andreas fault, which passes through the northeastern Coachella Valley.[4] The remaining motion is distributed between the Eastern Mojave Shear Zone and several other northwest trending faults west of the San Andreas fault zone, including the San Jacinto, Whittier-Elsinore, Newport-Inglewood, Palos Verdes, and several offshore faults.

J. Measuring Seismic Activity

The intensity of seismic at a given location is a complex interaction of many factors, but of primary importance are the magnitude of the earthquake, distance from the epicenter, type of bedrock or soil materials between the epicenter and subject location, and site-specific topographic features.[5] The amount of damage sustained typically decreases with increasing distance from the epicenter.

Vibrations generated by earthquakes are recorded and measured by seismographs, instruments which amplify ground motions and can be used to determine the time, epicenter, and local depth of an earthquake. The severity of an earthquake is generally classified according to its magnitude or intensity. Magnitude is a measure of the amount of energy released when a fault ruptures. Although several magnitude scales have been developed, the original and most widely known is the Richter Scale. Earthquake magnitude is expressed on the Richter Scale in whole numbers and decimals and varies logarithmically with the wave amplitude recorded on a seismograph. Therefore, each whole number step in magnitude represents a ten-fold increase in the amplitude of the waves on a seismogram, and about a 31-fold increase in the amount of energy released.

Seismic intensity is a qualitative estimate of the damage caused by an earthquake at a given location. Intensity is measured on the Modified Mercalli Intensity (MMI) Scale, which includes twelve levels of intensity, ranging from I (tremor not felt) to XII (total damage). The scale is based upon observed structural and physical damage and human reactions to the quake. A single earthquake can have many intensities, which are measured at various distances from the epicenter. Table 1 describes the various intensity levels of the MMI scale and corresponding peak acceleration values, where applicable.

Seismologists, engineers, urban planners, and others involved in emergency response planning describe a fault's potential or anticipated level of activity using the terms "maximum probable earthquake" and "maximum credible earthquake." A maximum probable earthquake (MPE) is the largest earthquake a fault is predicted to be capable of generating within a specific time period, such as 50 or 100 years. The MPE is typically used to address the anticipated seismic risk of a local area over the lifespan of new or existing development. The maximum credible earthquake (MCE) represents the largest earthquake a fault is capable of generating, without regard to a specified time period. It represents a worst-case scenario and if often considered in emergency planning and the design of critical facilities, such as fire stations, hospitals, and dams.

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[3] "Technical Background Report to the Safety Element of the General Plan for Cathedral City," Earth Consultants International, Inc., June 1999.

[4] Ibid.

[5] "Technical Background Report to the Safety Element of the General Plan for Desert Hot Springs," Earth Consultants International, Inc., May 28, 1997.

Table 1
Modified Mercalli Intensity Scale (abridged)

Seismic Intensity Value	Seismic Intensity Description	Average Peak Velocity (cm/sec)	Average Peak Acceleration
I	Not felt except by very few under favorable circumstances.		
II	Felt only by a few persons on upper floors of high-rise 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 automobiles may rock slightly. Vibration like passing of a truck. Duration estimated.		
IV	During the day felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like a heavy truck striking building. Standing automobiles rocked noticeably.	1-2	0.015g-0.02g
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc. broken. Cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.	2-5	0.03g-0.04g
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved. A few instances of fallen plaster and damaged chimneys. Damage slight.	5-8	0.06g-0.07g
VII	Everybody runs outdoors. Damage negligible in buildings 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 cars.	8-12	0.10g-0.15g
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, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.	20-30	0.25g-0.30g
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.	45-55	0.50g-0.55g
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.	more than 60	more than 0.60g
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 bent greatly.		
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.		

Source: Table 1.1, “Technical Background Report to the Safety Element of the General Plan for Desert Hot Springs,” Earth Consultants International, Inc., May 28, 1997.

K. Seismic Activity in the Planning Area

Due to its proximity to numerous active faults, the Coachella Valley has a long history of seismic activity. The following table identifies the faults and magnitudes of earthquakes that have resulted in significant in the Coachella Valley over the past century.

Table 2
Historical Earthquakes Impacting the Coachella Valley

Date/Time	Magnitude	Epicenter Location
Dec. 25, 1899/4:25 a.m.	6.5	San Jacinto
April 21, 1918/2:32 p.m.	6.8	San Jacinto
March 25, 1937/8:49 a.m.	6.0	Terwilliger Valley
October 21, 1942/9:30 a.m.	6.6	Fish Creek Mountains
December 4, 1948/3:43 p.m.	6.0	Desert Hot Springs
March 19, 1954/1:54 p.m.	6.4	San Jacinto
April 8, 1968/6:29 p.m.	6.5	Borrego Mountains
July 8, 1986/2:21 a.m.	5.9	North Palm Springs
November 23, 1987/5:54 p.m.	6.2	Elmore Ranch
November 24, 1987/6:16 a.m.	6.6	Superstition Hills
April 22, 1992/9:50 a.m.	6.1	Joshua Tree
June 28, 1992/4:57 a.m.	7.3	Landers
June 28, 1992/8:05 a.m.	6.4	Big Bear
October 16, 1999/2:46 a.m.	7.1	Hector Mine

Source: “Technical Background Report to the Safety Element for the General Plan of Palm Desert,” Earth Consultants International, Inc., April 5, 2001.

1. Faults Within the Planning Area

Several faults cross directly through the HCP planning area, including the following. These faults are described in detail below.

- San Andreas Fault Zone (Coachella Valley and San Bernardino Mountains Segments; aka Banning Fault and Mission Creek Fault)
- Garnet Hill Fault
- Devers Hill Fault
- White House Canyon Fault
- Blind Canyon Fault
- Long Canyon Fault
- Unnamed faults in Desert Hot Springs
- Blue Cut Fault
- Faults in the Mecca Hills

San Andreas Fault Zone

The San Andreas fault zone is the principal boundary between the Pacific and North American tectonic plates. It is a complex strike-slip fault system that represents a continuous zone of faulting from the San Francisco area to the Salton Sea. Motion accommodated by the fault zone is distributed along a complex system of interrelated faults.[6] In southern California, the San Andreas fault consists of three segments: 1) Mojave Desert segment, 2) San Bernardino Mountains segment, and 3) Coachella Valley segment. Only the San Bernardino Mountains and Coachella Valley segments occur within the MSHCP planning area.

The San Bernardino Mountains segment extends from the Cajon Pass area, east-southeast to its terminus in the vicinity of Thousand Palms Canyon, in the middle of the HCP planning area. Within the Plan area this fault has been historically referred to as the Mission Creek Fault. The segment is believed to have a slip rate of 24mm/year ± 5 mm/year, and the most recent surface-rupturing earthquake on this segment is thought to have occurred in 1812.[7] In 1995, the Working Group on California Earthquake Probabilities (WGCEP) estimated that it has a 28 percent probability of a major rupture between 1994 and 2024.[8]

The Coachella Valley segment of the San Andreas Fault Zone crosses through the northeasterly portion of the HCP planning area and is characterized by the multi-branched faulting of the combined Mission Creek and Banning Faults east of Thousand Palms Canyon. Paleoseismic studies indicate that this segment last ruptured around A.D. 1680, and prior to 1680, earthquakes on this segment occurred at an average recurrence interval of 220 years.[9] The segment is creeping at a rate of about 2 to 4 mm/year, and has a long-term slip rate of about 25 mm/year ± 5 mm/year.[10] The WGCEP estimates that the Coachella Valley segment has more than a 22 percent probability of rupturing before the year 2024.[11]

The Coachella Valley segment consists of two strands: 1) the Mission Creek fault, also known as the North Branch or San Andreas Fault strand, and 2) the Banning Fault strand, also known as the South Branch fault. These strands run roughly parallel to one another in the western HCP planning area, but converge into a single strand in the southeastern Indio Hills and continue southeast to the Durmid Hills, on the northeast side of the Salton Sea. The relatively straight course of these strands through the Mecca, Durmid, and Indio Hills indicate that they are probably vertical or nearly vertical, and that they must extend deep into the earth's crust.[12] The San Andreas fault is not recognizable on the surface or subsurface beyond the Durmid Hills fault segment (in Imperial County), and the severe crumpling of lacustrine sediments in this vicinity indicates that the presently active San Andreas fault may end there.[13] However, it has been

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[6] "Emerging Perspectives of the Salton Trough Region with an Emphasis on Extensional Faulting and Its Implications for Later San Andreas Deformation," Eric G. Frost, Steve C. Suitt, and Mitra Fattahipour. South Coast Geological Society, 1997.

[7] "Technical Background Report to the Safety Element for the General Plan of Cathedral City," Earth Consultants International, Inc., June 1999.

[8] Ibid.

[9] Ibid.

[10] Ibid.

[11] Ibid.

[12] "Geology of the Southeastern San Andreas Fault Zone in the Coachella Valley Area, Southern California," Thomas W. Dibblee, Jr..

[13] Ibid.

suggested that the fault continues southward to join the presently active Brawley and Imperial seismic zones.[14]

The Mission Creek and Banning Faults are believed to be capable of generating magnitude 7.1 earthquake and magnitude 7.4 earthquakes, respectively.[15] These segments also have the potential to rupture simultaneously.

The Mission Creek Fault strand enters the Coachella Valley near the convergence of the San Bernardino and Little San Bernardino Mountains, near the northwestern city limits of Desert Hot Springs. It extends roughly along the easterly edge of the valley floor, bisecting the most populated portion of Desert Hot Springs and the Thousand Palms Oasis in the Indio Hills. The fault forms a ground water barrier north of Cathedral City, with ground water on the north site typically closer to the ground surface than water on the south side of the fault.[16] Geotechnical trenching studies conducted along the fault in the Desert Hot Springs area have documented several breaks that can be traced upward in the alluvium to within one foot of the ground surface.[17]

The Banning Fault forms the southern margin of the San Bernardino Mountains and enters the Coachella Valley from the west through the San Gorgonio Pass. It crosses through southern Desert Hot Springs and the Seven Palms Valley area, and continues east along the southern portion of the Indio Hills. In the vicinity of Edom Hill, this fault consists of one primary fault and at least three secondary splays.[18] Where it underlies the Edom Hill landfill, the fault forms a broad linear valley, with offset drainages, closed depressions, and truncated spurs.

The Banning Fault is believed to have been the source of the 1986 North Palm Springs earthquake (magnitude 5.9), which resulted in extensive ground fracturing between Whitewater Canyon and State Highway 62. Some fractures were reported to be between 100 and 120 feet wide.[19] Although the earthquake did not result in a ground surface rupture, ground fractures and landsliding were reported.

The southernmost segment of the San Andreas fault, the Indio segment, extends from the junction of the Mission Creek and Banning faults in the Indio Hills, southward to the end of the San Andreas Fault Zone at the Salton Sea. This segment has not ruptured with a major earthquake during historic times, but has shown evidence of sympathetic slip with magnitude 6 and greater earthquakes on the Imperial fault and the southern section of the San Jacinto fault.[20]

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[14] Ibid.

[15] "Technical Background Report to the Safety Element for the General Plan of Cathedral City," Earth Consultants International, Inc., June 1999.

[16] Ibid.

[17] Ibid.

[18] Ibid.

[19] Ibid.

[20] "Seismicity, 1980-86," David P. Hill, Jerry P. Eaton, and Lucile M. Jones, from the U.S. Geological Survey Professional Paper 1515, 1990.

Garnet Hill Fault

The Garnet Hill Fault extends roughly from Whitewater Canyon to the vicinity of Edom Hill, although it is mapped as an inferred and concealed fault as it approaches Edom Hill. It northwesterly orientation and proximity to the San Andreas fault zone suggest that the Garnet Hill Fault may be associated with, and perhaps even an ancestral branch of, the San Andreas Fault.[21] The Garnet Hill Fault is not considered an "active" fault by the California Department of Conservation, Division of Mines and Geology, and may not be capable of generating an earthquake. However, ground fractures associated with the 1986 North Palm Springs earthquake were reported along this fault, and it has the potential to move coseismically during an earthquake on another nearby fault. For this reason, local jurisdictions may wish to treat it as an "active" fault and subject it to the development review process described in the California Alquist-Priolo Earthquake Fault Zoning Act.

Devers Hill Fault[22]

The Devers Hill Fault, located east of State Highway 62 in Desert Hot Springs, extends for a relatively short distance in a northeast-southwest trending direction. Given its orientation, the fault appears to be a secondary fault that ruptures in response to earthquakes on the San Andreas fault. Its scarp ranges from 3 to 12 feet in height and is moderately dissected.

White House Canyon Fault[23]

The White House Canyon Fault lies approximately 300 feet north of, and nearly parallel with the Mission Creek (San Andreas) fault in northern Desert Hot Springs. It extends into alluvium and crosses canyons and saddles between mountain ridges in the Little San Bernardino Mountains. Where mapped, it coincides closely with the Alquist-Priolo Earthquake Fault Zone for the Mission Creek fault.

Blind Canyon Fault[24]

The Blind Canyon Fault generally extends in a north-south direction in northeastern Desert Hot Springs. Its northern terminus occurs within the Little San Bernardino Mountains, just north of the incorporated limits of Desert Hot Springs. From there, it extends south-southeast and may merge with the Mission Creek fault. Several studies of the Blind Canyon Fault have been conducted over since the 1970s but have not been conclusive about the fault's level of activity or inactivity, and it is unclear whether it should be considered an "active" fault. Nonetheless, the fault may be related to the San Andreas fault and could move in sympathy with movement on the San Andreas fault. For this reason, building setbacks have been recommended along the trace of the fault, and until a consensus is reached regarding the recency of its activity, site-specific fault investigations should be required where development is proposed in the vicinity of the fault.

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[21] "Technical Background Report to the Safety Element of the General Plan of Desert Hot Springs," Earth Consultants International, Inc., May 28, 1997.

[22] Ibid.

[23] Ibid.

[24] Ibid.

Long Canyon Fault[25]

The Long Canyon Fault is a north-south trending fault that occurs along the northeasterly edge of Desert Hot Springs in the Little San Bernardino Mountains. It offsets crystalline basement rock and affects older alluvial surfaces in some locations. However, no evidence has been found to indicate that it is active or requires Alquist-Priolo earthquake fault zoning.

Unnamed Faults in Desert Hot Springs[26]

Several other unnamed faults in the MSHCP planning area have been identified and mapped by geologists. One of these, which occurs in the northwesterly portion of Desert Hot Springs at the base of the San Bernardino Mountains, places an older alluvial fan surface against a younger (possibly Holocene or latest Pleistocene) surface. The juxtaposition of these surfaces indicates that the fault could be active. Another unnamed fault occurs approximately 2 miles further south, just north of the Banning Fault. Given its location in the Painted Hills Formation, it is most likely inactive. Where development is proposed in the vicinity of these faults, site-specific geotechnical studies should be required to evaluate when the faults last ruptured and to what extent building setbacks and other developmental precautions would be necessary.

Blue Cut Fault[27]

According to the WGCEP, the Blue Cut Fault is one of the most active surface faults in southern California. It is located at the northeastern extreme of the MSHCP planning area, along the northern flank of the Eagle Mountains, and consists of three east-west trending segments. Although recent seismic studies suggest that the local branch of the Blue Cut Fault is not active, additional studies are necessary to determine whether and to what extent it poses a seismic threat within the Coachella Valley.

Faults in the Mecca Hills

The Mecca Hills, located northeast of the Salton Sea and along the northeast side of the San Andreas Fault, have been significantly uplifted, faulted and folded by seismic activity along the San Andreas and other local faults. Major faults in the Mecca Hills include the northwest-trending central Painted Canyon Fault and three north-trending faults: the northern Painted Canyon, Eagle Canyon, and Grotto/Hidden Spring faults. The Painted Canyon Fault is at least 20 kilometers long and defined by a zone of crushed rock and fault gouge.[28] The only documented historic fault movement in the Mecca Hills was associated with the Borrego Mountain earthquake of 1968 (magnitude 6.4), when minor creep was triggered on the San Andreas Fault adjacent to the Mecca Hills.[29]

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[25] Ibid.

[26] Ibid.

[27] Ibid.

[28] "Tectonic Transpression and Basement-Controlled Deformation in San Andreas Fault Zone, Salton Trough, California," Arthur G. Sylvester and Robert R. Smith, The American Association of Petroleum Geologists Bulletin, Volume 60, Number 12, December 1976.

[29] I bid.

2. Faults in the Vicinity of the Planning Area

Other faults located outside the HCP planning area are also capable of generating strong and other seismic hazards within the planning area. These include the following:

- San Jacinto Fault Zone
- Elsinore Fault Zone
- Pinto Mountain Fault
- Mojave Shear Zone

San Jacinto Fault Zone

The San Jacinto Fault Zone is a complex array of related faults, which lies along the western margin of the San Jacinto Mountains, approximately 10 to 15 miles southwest of the Coachella Valley. It extends southeast from its junction with the San Andreas fault northwest of Cajon Canyon, to the Brawley area, and continues south into Mexico as the Imperial Fault. A high level of seismic activity has occurred along the San Jacinto fault, and at least ten moderate earthquakes, ranging from magnitude 6 to magnitude 7, occurred on this fault between 1890 and 1986.[30] Slip rates are estimated at 12 mm/year ± 6 mm/year for the northern fault segments, and about 4 mm/year ± 2 mm/year for the southern segments, and investigators have suggested that the fault has a recurrence interval of 150 to 300 years for large ground-rupturing earthquakes.[31] According to the WGCEP, the San Bernardino and San Jacinto Valley segments have a 37% and 43% probability, respectively, of rupturing between 1994 and 2024.[32]

Elsinore Fault Zone

The Elsinore Fault Zone is located approximately 30 miles southwest of the Coachella Valley and extends in a northwest-southeasterly trending direction. Although it is one of southern California's largest fault zones (over 140 miles in length) and is capable of generating magnitude 6.5 to 7.5 earthquakes, it has historically been one of the region's quietest fault zones. The fault last ruptured in 1910, when it produced a magnitude 6.0 earthquake near Temescal Valley.[33] Its slip rate is estimated at about 5 mm/year, and it ruptures approximately every 400 years.[34]

Pinto Mountain Fault[35]

The Pinto Mountain Fault is located northeast of the Coachella Valley and is traceable for approximately 47 miles. It extends from its junction with the Mission Creek branch of the San Andreas Fault in the San Bernardino Mountains, eastward to just east of the City of Twentynine Palms. It consists of several east trending strike-slip faults and is estimated capable of generating a maximum credible earthquake of magnitude 7.0. Holocene movement along the Pinto Mountain Fault was documented in 1986, and in 1993, sympathetic ground ruptures associated

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[30] "Technical Background Report to the Safety Element of the General Plan for Cathedral City," Earth Consultants International, Inc., June 1999.

[31] Ibid.

[32] Ibid.

[33] "Technical Background Report to the Safety Element for the General Plan of Palm Desert (draft)," Earth Consultants International, Inc., April 5, 2001.

[34] Ibid.

[35] "Technical Background Report to the Safety Element of the General Plan for Cathedral City," Earth Consultants International, Inc., June 1999.

with the Landers earthquake were reported. For this reason, the fault is considered active; however, it has historically produced a cluster of epicenters at depth, rather than a well-defined zone of seismic activity.

Mojave Shear Zone[36]

The Mojave Shear Zone (also known as the Eastern California Shear Zone) is located north of the planning area in the southern Mojave Desert. It consists of several northwest-southeast trending faults that collectively appear to be accommodating between 9 and 23 percent of the motion between the North American and Pacific tectonic plates. Among these are the Johnson Valley, Homestead Valley, Helendale, Lenwood, and Old Woman Springs faults. Trenching studies indicate that these faults have ruptured during the Holocene, and therefore, they are considered to be active. The epicenter of the 1992 Landers earthquake occurred on the Johnson Valley fault, and several others ruptured coseismically during this event.

D. Seismic Hazards

Given its proximity to active and potentially active faults, as described above, the Coachella Valley is highly susceptible to seismically-induced geotechnical hazards. Among the most significant seismic hazards affecting the region are: 1) , 2) surface fault rupture, 3) liquefaction, 4) slope instability (landslide and rockfall), 5) seismically induced settlement. Each of these phenomena is discussed in more detail below. Secondary physical damage, which could be triggered by these events, may include fire, disruption of essential utilities and public facilities, release of hazardous materials, and flood inundation from dam or water tank failure. Direct and indirect economic and social losses, such as displaced households and the interruption of business operations, can be equally, if not more disruptive and are more difficult to quantify.

1. Groundshaking

The most significant seismic hazard facing the MSHCP planning area is strong groundshaking. Generally, peak ground accelerations decrease with increasing distance from the causative fault. However, the presence of certain topographic features, such as ridge tops and soft soils, can result in higher localized ground accelerations.[37]

Sophisticated seismic models have been developed to estimate potential ground motions generated by earthquakes of various magnitudes. The U.S. Geological Survey's (USGS) National Seismic Hazard Mapping system generates maps that describe probabilistic groundshaking zones within the Coachella Valley. The results indicate that, given the location and orientation of faults within the valley, the region is separated into several northwest-southeast trending groundshaking zones. The easterly portion of the valley, generally extending from Desert Hot Springs to the northeast Salton Sea, is likely to experience "extremely high" peak horizontal accelerations of greater than 40% the force of gravity, with a 10% probability of being exceeded in 50 years. The two zones adjacent to this, one to the east and one to the west, are likely to experience "very high" peak horizontal ground accelerations between 30% and 40% the force of gravity, with a 10% probability of being exceeded in 50 years. The potential ground motions likely to occur in these zones are among the highest in southern California.

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[36] Ibid.

[37] Ibid.

Strong groundshaking in the Coachella Valley could result in extensive property damage and associated injuries and/or loss of life. Larger earthquakes and those resulting in a longer duration of groundshaking can be expected to result in more structural damage. Structural damage may include impairment or failure of a building's walls, frames, and columns, as well as broken windows, fallen ceilings, and collapsed or rotated chimneys.

The size, shape, age, and engineering properties of affected structures play an important role in determining the amount of structural damage sustained as a result of an earthquake. Generally, long-period seismic waves, which are characteristic of earthquakes that occur about 10 miles and farther from the area of concern, damage preferentially long-period structures, such as bridges and high-rise buildings.[38] Short-period seismic waves are more typical of earthquakes that occur less than 10 miles from the area of concern, and have the potential to damage preferentially short-period structures, including one and two-story buildings. Mobile homes and older, soft-story, pre-cast concrete, wood frame, tilt-up, and unreinforced masonry buildings are particularly susceptible to seismic damage and/or collapse. Reinforced concrete frame and multi-story steel frame buildings are generally less likely to collapse, although interior and exterior damage may still occur.

Given the proximity of the San Andreas fault to the Coachella Valley, the most recent version of the Uniform Building Code (UBC) requires the incorporation of near-source construction factors into the design of new buildings in the region. The retrofitting and/or rehabilitation of older and structurally weak structures to current building and fire codes is critical to reducing seismic damage and preventing injuries and deaths. A more comprehensive discussion of hazard mitigation programs is provided later in this report.

2. <u>Surface Fault Rupture</u>

Surface fault rupture refers to the fracturing or displacement of the earth's surface along the trace of a fault. This occurrence can pose significant hazards to structures built along the trace of the fault, and increases the threat of injury and/or loss of life to humans occupying such structures. A major ground-rupturing earthquake can also trigger smaller, secondary surface displacements on nearby faults and other locations elsewhere in the region.

According to the California Division of Mines and Geology, 22 earthquakes or earthquake sequences resulted in surface faulting in California between 1974 and 1994, resulting in an average of 1.1 fault-rupture events per year during this period.[39] Although most of these surface ruptures were relatively minor, displacements of one foot or more occurred during six of the earthquake events. The 1986 North Palm Springs earthquake resulted in a maximum displacement of approximately 7 centimeters, and triggered minor slip along the Garnet Hill and more distant faults.[40] The 1992 Landers earthquake resulted in approximately 460 to 600 centimeters of surface rupture displacement, which connected several separate faults and triggered slip on at least 10 other faults.[41]

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[38] "Technical Background Report to the Safety Element of the City of Rancho Mirage General Plan Update," Leighton and Associates, Inc., December 20, 1995.

[39] "Fault Hazard Zones in California: Alquist-Priolo Earthquake Fault Zoning Act with Index to Earthquake Fault Zones Map," Earl W. Hart, California Dept. of Conservation, Division of Mines and Geology, revised 1994.

[40] Ibid, Table 5.

[41] Ibid, Table 5.

Implementation of the Alquist-Priolo Earthquake Fault Zoning Act, signed into law in California in 1972, is the single most important method of mitigating the direct hazards of surface fault rupture. The purpose of the Act is to prohibit the location of most structures for human occupancy across the trace of active faults. Under the Act, the State Geologist (Chief of the Division of Mines and Geology) is required to delineate wide "earthquake fault zones" along known potentially and recently active faults, as defined below.

- Active Fault – one which has shown evidence of surface displacement within Holocene time (about the last 11,000 years)
- Potentially Active Fault – one which shows evidence of surface displacement during Quaternary time (last 1.6 million years). This has been modified to 750,000 years by the U.S. Geological Survey.[42]

The above definitions eventually proved to be too broad, as they applied to a vast and unmanageable number of potentially active faults within the state boundaries. In 1975, the terms "sufficiently active" and "well-defined" were added to the Act to help the State Geologist determine if a fault should be zoned.[43] A "sufficiently active" fault shows evidence of Holocene surface displacement (observable or inferred) along one or more of its segments or branches. "Well-defined" means that the trace of the fault is clearly detectable by a trained geologist as a physical feature at or just below the ground surface. Although these definitions are somewhat subjective, they provide a meaningful framework within which the Act can be implemented.

The boundaries of Alquist-Priolo Fault Zones are straight-line segments, which extend about 500 feet from major active faults, and 200 to 300 feet from well-defined minor faults.[44] Cities and counties affected by the zones must withhold development permits for sites within the zones until geologic investigations demonstrate that the sites are not threatened by surface displacement from future faulting. Under the Act, jurisdictions are also required to submit to the State Geologist geologic reports for "project" sites in Earthquake Fault Zones. The Act also provides guidelines to assist in the preparation of fault investigations and the evaluation of potential surface fault rupture hazards.

3. Liquefaction

Liquefaction is the substantial or total loss of shear strength of loose, sandy, saturated sediments in the presence of ground accelerations greater than 0.2g. When liquefaction occurs, foundation soils behave like a liquid or fluid-like substance and settle, resulting in structural distress or failure, lateral spreading, the buoyant rise of buried structures, and/or ground oscillation.

Liquefaction is not a random phenomenon, but occurs only when three geologic and hydrologic conditions are present simultaneously.[45] First, the site must be subjected to strong groundshaking of relatively long duration. Second, on-site soils must consist of loose or recently deposited,

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[42] "Technical Background Report to the Safety Element of the General Plan for Cathedral City," Earth Consultants International, Inc., June 1999.

[43] "Fault Hazard Zones in California: Alquist-Priolo Earthquake Fault Zoning Act with Index to Earthquake Fault Zones Map," Earl W. Hart, California Dept. of Conservation, Division of Mines and Geology, revised 1994.

[44] Ibid.

[45] "Technical Background Report to the Safety Element of the General Plan for Cathedral City," Earth Consultants International, Inc., June 1999.

unconsolidated sediments which are composed primarily of sand or silty sand. Third, ground water must occur within about 50 of the ground surface to adequately saturate loose surface soils.

The potential for liquefaction to occur within the Coachella Valley ranges from none to high, depending upon location and site-specific characteristics. Given its proximity to several active faults, the entire valley is susceptible to strong groundshaking of relatively long duration. This satisfies the first condition for liquefaction. The second condition – the presence of recently deposited or unconsolidated, sandy sediments – is satisfied only on the low-lying desert floor and areas underlain by late Pleistocene or Holocene (recently deposited) alluvium, such as active drainage channels. The surrounding mountains are generally comprised or granite bedrock and metamorphic rock, and alluvial sediments at the base of the mountains typically consist of coarse-grained sand, gravel, cobble, and boulders. Neither of these formations is susceptible to liquefaction.

The third condition – shallow depth to ground water – is present only in limited locations throughout the valley. In the western valley, depth to ground water on the low-lying valley floor is generally greater than 50 feet and even reaches several hundred feet in some locations. Where this is the case, the potential for liquefaction to occur is low to none. Should ground water tables rise significantly in the future, this hazard will need to be reassessed.

The exception to this is land immediately adjacent to and north of the Mission Creek and Banning Faults, where the faults act as barriers to ground water. In these locations, the water table is at or nearly at the surface on the north side of the fault. Springs and flowing wells have been reported in the vicinity of Willow Hole, and near-surface water sources support native fan palm oases in various locations along the north side of the fault zones, including the Thousand Palms Oasis and Pushwalla Canyon. In contrast, water tables on the south side of the faults are generally much deeper. At the base of the Indio Hills, just east of Madison Street (extended), for example, the water table on the south side of the Mission Creek Fault is greater than 100 feet deep, even though it is shallow enough to support native fan palm trees on the north side of the fault.[46] Given that these areas are generally characterized by loose, sandy sediments, the potential for liquefaction to occur on the north sides of the faults is moderate to high.

On the low-lying desert floor in the eastern valley, generally east of La Quinta, ground water typically occurs less than 30 feet below the ground surface, and the potential for liquefaction is moderate to high.[47] Liquefaction could also occur within or adjacent to major drainages if near-surface sediments become sufficiently saturated from precipitation. However, given the rapid percolation rate of these soils, it is unlikely that the three conditions required for liquefaction would occur simultaneously.[48]

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[46] "Road Log, Field Trip Along the San Andreas Fault Zone from Whitewater to Bombay Beach, Salton Trough, California," Joan Baldwin, Marshall Payne, and Lavon Lewis, as published in "Southern San Andreas Fault – Whitewater to Bombay Beach, Salton Trough, California," South Coast Geological Society, November 1997.

[47] "Technical Background Report to the Safety Element for the General Plan for the City of La Quinta," Earth Consultants International, Inc., November 10, 1999.

[48] "Technical Background Report to the Safety Element for the General Plan of Desert Hot Springs," Earth Consultants International, Inc., May 28, 1997.

Where development is proposed on lands with a moderate to high liquefaction potential, site-specific geotechnical and soils studies should be conducted to evaluate the extent of the hazard. This is especially important if critical or essential facilities (such as hospitals, schools, and fire or police stations) or facilities that will result in the saturation of near-surface soils (such as groundwater recharge basins or storm water detention/retention basins) are proposed. Mitigation of the liquefaction hazard may include avoidance of development altogether, stabilization of ground materials through compaction or replacement of soils, the utilization of construction techniques that attach the structure to ground soils to resist structural damage from liquefaction, and draining water from the uppermost tens of feet of soil.

4. Seismically Induced Slope Instability

Ground accelerations of 0.10g are typically required to trigger landslides and rock falls.[49] Given that various faults in and around the Coachella Valley are capable of generating peak ground accelerations of 0.10g or greater, the region is highly susceptible to seismically induced slope instability.

The 1986 North Palm Springs earthquake was responsible for triggering landslides and rock falls in the Palm Springs area. Landslides were abundant along the sides of steep-walled canyons, while debris and rock falls occurred in fractured basement rock of the San Jacinto, San Bernardino, and Little San Bernardino Mountains.[50]

Similar hazards can be expected to occur if a future earthquake generates moderate to strong groundshaking in the region. Land within and adjacent to hillsides and mountainous terrain is most susceptible to landslides and rock falls. Debris and rock falls are a particular threat in areas where bedrock is intensely jointed or fractured, and where boulders are perched precariously on hillsides and slopes. They can be detrimental to development adjacent to mountain fronts, particularly those at the mouths of steep canyons. Intense ground shattering can be expected on the crests of Painted Hill in Desert Hot Springs, Edom Hill in the Indio Hills, and other steep, narrow ridge tops which focus or amplify seismic energy.[51] After ridge top shattering occurs, the ground surface looks as if it was plowed. Down-slope deformation and/or slumping may occur along the traces of faults which rupture.

Where development is proposed in areas moderately or highly susceptible to slope instability, site-specific geotechnical evaluations should be conducted to determine the extent of the threat and appropriate mitigation measures. Engineered cut or fill slopes, which are incorporated into a project’s design, may also be susceptible to seismically induced deformation, cracking, and/or bulging at the slope face. The design of such slopes and hillside grading techniques should be evaluated to determine whether there is a potential for slope instability. Mitigation may include deeper overexcavation, higher levels of fill compaction, and the use of post-tensioned foundations; however, there are currently no proven engineering standards for mitigating sidehill fill deformation.[52] The impacts of ridge top shattering are best mitigated by avoiding development on steep, narrow ridgelines, although recontouring of ridgetop topography,

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[49] Ibid.

[50] Ibid.

[51] Ibid.

[52] “Technical Background Report to the Safety Element for the General Plan of Palm Desert (draft),” Earth Consultants International, Inc., April 5, 2001.

overexcavation, and the removal and/or compaction of fractured bedrock may reduce this hazard to acceptable levels.[53]

5. Seismically Induced Settlement

Seismically induced settlement refers to the densification or compaction of soils as a result of strong groundshaking. The intensity and duration of groundshaking and the relative density of subsurface soils have a direct bearing on whether and to what extent seismically induced settlement will occur. Loose, recently deposited sediments, such as windblown sand and young alluvium, are most susceptible to settlement, as are artificial fills that have been insufficiently compacted. During strong groundshaking, the pores and voids between the soil grains collapse and result in a reduction in the thickness of the soil column, which can cause fracturing and offset of the ground surface. Local and regional differential settlement can result in significant damage to structures and their foundations, as well as water and sewer pipelines, canals, and other gradient-sensitive infrastructure.

Much of the MSHCP planning area is highly susceptible to seismically induced settlement, although the extent to which settlement could occur in these areas will vary based on differences in grain size and depth of recently-deposited sediments. Susceptible areas include those portions of the low-lying valley floor composed of windblown sands, floodplains, drainages underlain by recently deposited alluvial sediments, and valley margins (the base of natural hills). Among the most commonly employed mitigation measures for seismically induced settlement are overexcavation and recompaction of surface and near-surface soils. Uniform subgrade and fill thickness is preferred, and can be achieved by deeper overexcavation below final grades, especially at cut/fill, fill/natural or alluvium/bedrock contacts.[54] Foundations should be strengthened and designed to a limited degree of differential settlement.

E. Mitigating Seismic Hazards

1. Alquist-Priolo Earthquake Fault Zoning Act

As explained previously, the Alquist-Priolo Earthquake Fault Zoning Act was enacted in 1972 to mitigate the hazards of surface fault rupture. The Act prohibits the location of most structures for human occupancy across the trace of active faults and requires the State Geologist to delineate "earthquake fault zones" along known potentially and recently active faults (faults which are "sufficiently active" and "well-defined"). Cities and counties affected by the zones must withhold development permits for sites within the zones until geologic investigations demonstrate that the sites are not threatened by surface displacement from future faulting.

Surface fault rupture is among the easiest seismic hazards to mitigate, and the Alquist-Priolo Earthquake Fault Zoning Act is intended to serve this purpose. It does not, however, reduce or eliminate the need for site-specific geologic studies within or outside the Earthquake Fault Zones and does not provide sufficient data for the establishment of building setbacks. These measures, in addition to prudent local land use planning, are critical to further mitigating the impacts of surface fault rupture and associated seismic hazards.

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[53] Ibid.

[54] Ibid.

2. Seismic Hazards Mapping Act

The Seismic Hazards Mapping Act (SHMA) was enacted by the State of California in 1990 for the purpose of protecting the health and safety of the public from seismically induced ground failure, including groundshaking, liquefaction, and slope instability. The California Division of Mines and Geology is responsible for implementing the Act and providing local governments with maps that identify areas susceptible to such hazards; hazardous areas are referred to as “zones of required investigation.” When construction is proposed within identified hazard zones, a site-specific geologic hazard investigation must be prepared and appropriate mitigation measures cited. The city or county may only approve a development project after carefully considering the geotechnical findings and their relationship to the policies and criteria established by the SHMA. Mapping of these zones within the MSHCP planning area has not yet been completed (2001).

3. Uniform Building Code

The primary tool used to ensure seismic safety in structures is the Uniform Building Code (UBC). The UBC describes the minimum lateral forces needed to resist seismic shaking, which are based on the area’s seismic zone, type of structural system, building configuration and height, and soil profile of the structure and site in question. The San Andreas and San Jacinto faults are defined as Type A faults by the UBC. The UBC is updated roughly every three years and was last updated in 1997.

Until recently, three different Uniform Building Codes were used throughout the United States, each addressing the prevailing geologic conditions in different geographic sections of the country. Beginning in 1994, the International Code Committee (ICC) began consolidating the three codes into one. The new code is known as the International Building Code (IBC) and is to be used nationwide. The State of California is currently involved in efforts to modify sections of the International Building Code. Until the IBC is adopted by the State, cities and counties in California are precluded from adopting it. It is anticipated that the State will adopt the International Building Code within the next several years, and upon adoption, it will completely replace the UBC.

4. California Building Code

The California Building Code (CBC) is a modified version of the UBC, which is tailored for California geologic and seismic conditions. It is included in Title 24 of the California Administrative Code and includes stringent earthquake provisions for critical structures, including public schools and hospitals. The CBC was last amended in 1998 and adopted by the City in 1999.

5. Seismic Retrofitting

Most injuries and loss of life associated with earthquakes are related to the collapse of buildings and structures. Particularly hazardous buildings include unreinforced masonry (URM) buildings, wood frame structures, pre-cast concrete structures, tilt-up buildings, and mobile homes. Soft-story buildings, which lack adequate strength due to too few shear walls, may also be subject to damage or collapse. Retrofitting programs can significantly reduce the risk of injury and/or death resulting from structural collapse. They typically involve bracing the tops of walls, improving connections between walls, floors, and roofs, and ensuring that wall mortar has acceptable strength.

The California Unreinforced Masonry (URM) Law, enacted in 1986, requires all local governments located in Seismic Zone 4 (as identified by the latest version of the UBC) to do the following: 1) create an inventory of unreinforced masonry buildings in their jurisdictions, 2) establish an earthquake loss reduction program for these buildings, and 3) report all information concerning these efforts to the California Seismic Safety Commission. According to the provisions of the Act, owners of such buildings must be notified of the potential earthquake hazard, and mitigation measures, such as retrofitting or demolition, must be performed.

6. Real Estate Disclosure

According to the California Natural Hazards Disclosure Act (AB1195), effective June 1, 1998, all sellers of real property and their real estate brokers must disclose to prospective buyers whether a parcel is within one or more State-mapped hazard areas, including geologic, flooding, and fire hazard areas. Disclosure must be made using one of two standardized Natural Hazard Disclosure Statement forms provided in the California Civil Code. If the property is located within a Seismic Hazard Zone or Alquist-Priolo Earthquake Fault Zone, as delineated by the State Geologist, the seller and/or his agent must disclose this fact to potential buyers.

7. California Environmental Quality Act

Enacted in 1970, the California Environmental Quality Act (CEQA) requires local government agencies to consider and disclose to the public the potential environmental impacts of development projects proposed within their jurisdiction. An Environmental Impact Report (EIR) must be prepared for projects that may have a significant impact on the environment and must identify geologic and seismic hazards associated with the project, as well as mitigation measures, where appropriate.

III. Soils and Geology

The Salton Trough is a low-lying rift basin that lies between the North American and Pacific Plates of the earth’s surface. The physiography of the Salton Trough has been progressively influenced and shaped by a combination of interrelated environmental factors, including climate, rainfall, wind, seismic activity, the course of the Colorado River, and the amount of water contained within the basin.

Although the mountain ranges that flank the Salton Trough are largely composed of solid crystalline materials, the valley floor consists of much younger fine and medium-grained sediments that have filled the basin over millions of years. The Salton Trough was once subject to marine sedimentation from the Gulf of California. However, over time, sediment deposited by the Colorado River into the Gulf of California formed a large fan-shaped delta or dam across the valley, effectively separating the Salton Trough from the Gulf of California.[55] The damming off of marine waters allowed the waters of the Salton Trough to evaporate, although periodic inundation from the Colorado River has resulted in the filling of lakes in the Salton Trough, such as the Salton Sea, which was formed in 1905. Since then, infilling of the Salton Trough has been associated with terrestrial sediments originating from the adjacent mountain ranges.

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[55] “Emerging Perspectives of the Salton Trough Region With an Emphasis on Extensional Faulting and its Implications for Later San Andreas Deformation,” Eric G. Frost, Steve C. Suitt, Mitra Fattahipour.

Analysis of regional lithologic units can offer greater insight into the region's natural history and present-day geologic and seismic hazards. Because the HCP planning area is located within the northwestern part of the Salton Trough (known as the Coachella Valley), the following discussion addresses the geology of this particular area, rather than that of the entire Salton Trough.

L. Geologic Units in the Planning Area

The HCP planning area consists of a wide range of earth materials, which were formed or deposited over millions of years. These materials are typically described according to their geologic age, as described in Table 3.

Table 3
Geologic Units in the Coachella Valley

Geologic Period	Age (years)	Formation Name and Description
Quaternary		
Recent	0 to 11,000	• Active Stream Channel Deposits: layered well-sorted sand and gravel • Alluvial Fan Deposits: poorly sorted sand and gravel • Alluvial Plain Deposits: fine-grained sand, silt and clay • Sand Dune Deposits: fine-grained sand, silty sand and sandy silt • Stream Terrace Deposits: layered gravelly sand, sand with cobbles and boulders
Upper Pleistocene	11,000 to 400,000	• Pleistocene Alluvial Fan Deposits, also known as Ocotillo Conglomerate and/or Cabezon Fanglomerate: pebbly to cobbly conglomerate with sandstone
Tertiary		
Lower Pleistocene	400,000 to 1.6 million	• Palm Spring Formation: siltstone and claystone with sandstone layers
Middle & Upper Pliocene	1.6 million to 3.4 million	
Lower Pliocene	3.4 million to 5 million	• Imperial Formation: friable sandstone and poorly indurated shale; marine fossils in the sandstone section
Upper Miocene	5 million to 11 million	• Split Mountain Formation: Conglomeratic sandstone with Andesitic flows 400 to 700 feet thick near base of unit
Cretaceous	80 million to 120 million	• Rocks of Southern California Batholith: granite, quartz diorite, and gabbro
Paleozoic to Precambrian	more than 215 million	• Metamorphic rocks: schists, limestone, gneisses
Precambrian	more than 570 million	• San Gorgonio Complex (also known as Chuckwalla Complex): amphibolite and migmatic paragneisses

Note: ages are approximate, as the ages of many of these units are not well constrained.
Source: "Technical Background Report to the Safety Element of the General Plan for Cathedral City," Earth Consultants International, Inc., June 1999.

Basement Rocks

The various mountain ranges surrounding the Coachella Valley are often described in general terms according to the geologic provinces in which they occur. The Peninsular Range includes the San Jacinto and Santa Rosa Mountains, which border the valley to the southwest. The Peninsular Range extends from Riverside-San Bernardino County to the southern tip of Baja California and is composed of fairly old granitic rock (Mesozoic), which has intruded even older metasedimentary rock of Mesozoic and Paleozoic age.[56] The Santa Rosa Mountains represent a thick, strong, relatively homogeneous basement rock unit that is highly resistant to erosion and seismic deformation.

The Transverse Ranges geologic province is composed of east-west trending mountains, including the San Bernardino, Little San Bernardino, and Orocopia Mountains that form the northeasterly edge of the Coachella Valley. Like the Peninsular Range, the Transverse Range surrounding the valley exposes a pre-Cenozoic crystalline basement complex, which is primarily composed of batholithic granite that has intruded numerous pendants of metamorphic rock.[57] Basement rocks of the Transverse Ranges are a heterogeneous complex of many types, including granite-quartz, quartz-diorite, and gabbro, and range in age from Precambrian to Cretaceous.

Sedimentary Formations[58]

Over millions of years, the Salton Trough has been filled with sedimentary deposits up to 20,000 feet thick. Various sedimentary layers, or formations, are exposed throughout the Coachella Valley, particularly in the low-lying hills along the length of the San Andreas fault.

The oldest sedimentary formation in the planning area, known as Coachella Fanglomerate, is exposed on the east side of Whitewater Canyon and may be up to 4,900 feet thick. It is composed of debris-flow and stream-laid deposits of gneiss, granite, and volcanic rocks and includes a thin basalt flow near the top, which has been dated to about 10 million years ago. The basal unit in the Mecca Hills, which may correlate to the Coachella Fanglomerate, is known as the Mecca Formation. Where it is exposed in Painted Canyon, this formation is about 400 feet thick. It is composed of various sediments at different locations, including granite, gneiss, cobbles, sand, siltstone and clay.

The Imperial Formation is composed of tan sandstone and siltstone, probably of early Pleistocene age. It was deposited when the Gulf of California extended into the northern reaches of the Coachella Valley and contains marine fossils in the sandstone section. It is exposed in Whitewater Canyon and near Cabazon in the San Gorgonio Pass. The upper layer of this formation is exposed near the north end of the Indio Hills and at Thousand Palms Spring.

The Palm Spring Formation is a terrestrial layer, which is extensively exposed in the Indio and Mecca Hills, and to a lesser degree in the vicinity of Whitewater Canyon. Its thickness ranges from about 2,000 feet in the northwestern Indio Hills, to 4,800 feet in the Mecca Hills east of the San Andreas fault. The southernmost exposure of this formation is found in the Durmid Hills.

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[56] Ibid.

[57] "Geology of the Southeastern San Andreas Fault Zone in the Coachella Valley Area, Southern California," Thomas W. Dibblee, Jr.

[58] Ibid.

Ocotillo Formation, of Pleistocene age, is extensively exposed as alluvial fan deposits on both sides of the San Andreas fault zone in the Indio Hills, as well as in the northern and eastern parts of the Mecca Hills. In the northern Indio Hills, it is about 2,000 feet thick. It is largely composed of cobble, gravel, and sand containing granite and metamorphic units.

Alluvial (stream-deposited) and eolian (wind-deposited) sediments, which compose the valley floor, are the most recently laid sediments in the Coachella Valley. Alluvial deposits largely consist of gravel, sand, and clay, which are deposited by mountain streams and runoff within alluvial fans and the lower reaches of canyons at the base of surrounding mountains. In the vicinity of the Salton Sea, alluvial deposits consist of fine clay of probable lacustrine origin.

Aeolian deposits, also known as sand dune deposits, are silty sand and fine and medium-grained sand fractions that are transported by strong, sustained winds. These winds typically enter the Coachella Valley from the northwest, where they are funneled through the narrow San Gorgonio Pass, and blow in a southeasterly direction, continually moving sand and other fine-grained sediment to the southeast. The coarsest materials are present where the wind velocity is highest, especially at the north end of the valley.[59] The continual transport of sand in a southeastwardly direction along the central axis of the valley has resulted in the formation of the Palm Springs Sand Ridge, a thick accumulation of windblown sand. The sand ridge covers a significant portion of the valley floor south of Interstate-10 and rises as much as 100 to 120 feet above the valley floor.[60]

B. Geologic Characteristics of the Indio Hills and Mecca Hills

Complex folding and faulting along the San Andreas fault has resulted in the formation of the Indio Hills, Mecca Hills, and Durmid Hills (the Durmid Hills are largely located outside the HCP planning area and, therefore, are not addressed in the following discussion). These hills are of particular interest because they represent the most visible evidence of regional deformation that has occurred adjacent to the San Andreas Fault and provide a window into the geology that underlies the Salton Trough.[61] They are primarily composed of relatively "young" interbedded sandstones and shales of Miocene to Quaternary ageoverlying Precambrian crystalline rocks.[62]

The Indio Hills occur along the northeast flank of the Coachella Valley and have been cut and uplifted along the Mission Creek and Banning branches of the San Andreas Fault, which intersect near Biskra Palms. Other major structural features include Thousand Palms Canyon, Pushwalla Canyon, and numerous alluvial fans, ridges, fault scarps, and offset fluvial drainages, which are characteristic of recent tectonic activity. The sediments that crop out in the Indio Hills generally consist of Ocotillo Conglomerate, a light ten conglomerate containing pebble to cobble-sized clasts of locally derived gneisses and granite, with a lesser amount of volcanic rocks, limestone, and pegmatite.[63] This unit is believed to be late Pleistocene in age.

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[59] Ibid.

[60] "Technical Background Report to the Safety Element of the General Plan of the City of Cathedral City," Earth Consultants International, Inc., June 1999.

[61] "Emerging Perspectives of the Salton Trough Region With an Emphasis on Extensional Faulting and its Implications for Later San Andreas Deformation," Eric G. Frost, Steve C. Suitt, Mitra Fattahipour.

[62] Ibid.

[63] "Technical Background Report to the Safety Element of the General Plan of the City of Cathedral City," Earth Consultants International, Inc., June 1999.

The Mecca Hills lie along the northeast margin of the Salton Sea, near the southern terminus of the San Andreas Fault. Major structures within the Mecca Hills include the central Painted Canyon Fault and three more northerly faults: the northern Painted Canyon, Eagle Canyon, and Grotto Faults. It is believed that the Mecca Hills were either squeezed up mostly on the northeast side by the San Andreas fault, or squeezed between the San Andreas and the parallel faults listed above.[64] Generally, sediments within the Mecca Hills are finer and thicker to the west and thinner, coarse-grained, and poorly bedded to the east.[65] The hills are composed of pre-Cenozoic crystalline basement rock, including gneiss, anorthosite, granite, and schist, overlain by a highly deformed and faulted late Cenozoic sequence, which includes Mecca Formation, Palm Spring Formation, and Ocotillo Conglomerate.[66]

C. Geologic Hazards

The lithologic composition of the Coachella Valley, as described above, renders the area susceptible to numerous geologic hazards. Among these are the risk of landslide, rock fall, collapsible and expansive soils, subsidence, and wind erosion. Each of these potential hazards are described below.

1. Slope Instability

The potential for landslides, rock falls, debris falls, and slumps to occur within and/or adjacent to the slopes of the surrounding mountains and hillsides is moderate to high. These events result in the sudden and rapid transport of rock, soil, vegetation and/or other debris down gradient and may be triggered by earthquakes, heavy rain, or poor grading and construction techniques.

Several landslides have occurred in the Coachella Valley, including the large-scale and deep-seated Martinez Mountains Landslide, which occurred near Highway 86 south of Indio in the Santa Rosa Mountains. This landslide occurred in pre-historic times and consisted of a rock avalanche, which transported granitoid debris nearly 6 miles at estimated velocities of more than 75 miles per hour.[67] Other possible landslides documented in the region include a slump on the south flank of Whitewater Hill and a landslide in the White House Canyon area, north of Desert Hot Springs.[68] The 1986 North Palm Springs earthquake triggered several landslides in the Palm Springs area, particularly within steep-walled canyons.

Landslides and rock falls in the Coachella Valley are most commonly initiated by strong groundshaking. The potential for slope instability to occur is particularly high at the base of steep slopes and deep canyons and adjacent to steeply ascending slopes in the Santa Rosa, San Jacinto, San Bernardino and Little San Bernardino Mountains. These slopes are composed of relatively well-cemented rock outcrops, which contain joints, fractures, and intrusive dikes that can function as planes of weakness.

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[64] “Geology of the Southeastern San Andreas Fault Zone in the Coachella Valley Area, Southern California,” Thomas W. Dibblee, Jr.

[65] “Accommodation of Compression in the Mecca Hills, California,” J.M. Sheridan and R.J. Weldon, II, Dept. of Geological Sciences, University of Oregon, 1994.

[66] “Stratigraphy and Paleomagnetism of the Mecca and Indio Hills, Southern California,” J.L. Boley, J.P. Stimac, and R.J. Weldon, Dept. of Geological Sciences, University of Oregon, 1994.

[67] “Technical Background Report to the Safety Element of the General Plan of Cathedral City,” Earth Consultants International, Inc., June 1999.

[68] “Technical Background Report, General Plan Update, City of Desert Hot Springs,” Earth Consultants International, Inc., May 28, 1997.

Designed cut slopes, which are incorporated into urban development projects, may also expose potentially hazardous fractures that could be susceptible to slope instability. Debris flows are most likely to occur within canyon bottoms, stream channels, excavated areas of steep slopes, and areas where runoff is channeled, as these areas can facilitate the high-velocity transport of boulders, cobbles, and sand.

Landslides and rock falls can damage and/or destroy buildings and other improvements, result in human injury and/or death, and hinder rescue and evacuation operations. The most effective mitigation for reducing these hazards is to avoid development within and/or adjacent to steep slopes and hillsides. Development on slopes that exceed 30 degrees in steepness should be avoided.[69] Where development is proposed at the base of steep slopes, site-specific geotechnical analyses should be conducted to evaluate slope height, angle of inclination, composition of the soil materials, anticipated levels of groundshaking, and other relevant factors. Soil sampling and laboratory testing may be required, and engineered slopes specially designed to resist failure.

2. Collapsible Soils

Hydroconsolidation or soil collapse may occur in recently deposited soils that are deposited in an arid or semi-arid environment, such as eolian sands and silts which comprise much of the Coachella Valley floor. Upon saturation, these soils experience a loss of cementation and rearrangement of their grains, and the minute pores and voids between the soil grains collapse. When combined with the weight of a building or other structure, this occurrence can result in the substantial and rapid settlement of structures, cracking of walls and foundations, tilting or sagging or floors, and functional loss for doors and windows. Soil collapse may be initiated by heavy irrigation, a rise in the ground water table, inundation during flash floods, or other situations in which substantial infiltration of water occurs.

Eolian and alluvial sediments in the planning area are prone to collapse. This includes a significant portion of the valley floor, as well as alluvial fans, washes, and unlined drainage channels. The potential for this hazard to occur should be evaluated on a site-specific basis. Collapsible soils may be mitigated using a number of design and construction techniques, including the pre-saturation of collapsible soils prior to development, achieving positive drainage away from structures, and the minimal use of irrigation water near structural foundations.

3. Expansive Soils

Expansive soils are those which have the ability to shrink (give up water) or swell (take on water). When swelling occurs, the soils can exert significant pressure on buildings and other structures constructed on them. Expansive soils typically contain high quantities of clay particles and are found within older alluvial fan deposits that emanate from mountainous slopes throughout the valley, as well as within claystone layers of the Imperial Formation. The clay is usually concentrated in the agrillic soil horizon, which typically occurs within the upper ten feet of the ground surface.[70]

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[69] Chapter 2: Geologic Hazards, “Technical Background Report, General Plan Update for the County of Riverside,” 2000.

[70] “Technical Background Report, General Plan Update, City of Desert Hot Springs,” Earth Consultants International, Inc., May 28, 1997.

Where development is proposed and the risk of expansion is considered moderate to high, site-specific geotechnical studies should be conducted to determine the presence of expansive soils. Potential hazards can be mitigated by removing the upper soil layer, mixing it with coarser-grained sand, and recompacting them.[71] Other techniques include the use of reinforcing steel in foundations and drainage control devices, which direct runoff away from structural foundations.

4. Subsidence

Ground subsidence is the gradual settling or sinking of the ground surface with little or no horizontal movement. This phenomenon is usually associated with the extraction of oil, gas, or groundwater from below the ground surface, with a resultant loss in volume, but may also occur as a result of an earthquake. In the Coachella Valley, subsidence is typically associated with the extraction of groundwater and the associated lowering of deep subsurface water pressures. Water contained in subsurface clay layers is squeezed out, and the clay is compacted by the weight of overlying sediments. Subsidence can damage buildings and other structures that are sensitive to slight changes in elevation, such as wells, canals, and pipelines. It can also result in changes to surface drainage, reductions in aquifer storage, and the formation of earth fissures. The greatest damage may occur at or near valley margins.

Subsidence as a result of groundwater withdrawal is one of the major environmental concerns facing the Coachella Valley. For several decades, the regional demand for groundwater has exceeded supply, and the groundwater basin serving the region has been in a state of overdraft. Land fissures, which occurred in 1948 just east of the City of La Quinta, occurred just after a significant decline in groundwater over a 30-year period. They are believed to have been the result of subsidence, although their true origin is unknown.[72]

In 1996, the U.S. Geological Survey and the Coachella Valley Water District (CVWD) established a precise elevation network to monitor land subsidence in the lower Coachella Valley (La Quinta and land to the east). Data collected from fourteen of seventeen monument locations indicated cumulative subsidence measurements ranging from 0.2 and 0.5 feet from the 1930s to 1996.[73] When compared to historic water levels, subsidence was found to occur during periods of water level decline, and rebound during periods of water level recovery. Another CVWD study indicates that as much as 7 centimeters of subsidence occurred between 1996 and 1998 in the City of Palm Desert.[74]

Continued overdraft increases the potential for future subsidence in the Coachella Valley, particularly in the lower valley and the southern portion of the upper valley, which are composed of numerous clay layers that separate water-producing zones and could compress when dewatered.[75] The upper Coachella Valley, which consists predominantly of sandy soils with relatively thin clay layers, is less susceptible to subsidence.

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[71] Ibid.

[72] Ibid.

[73] "Coachella Valley Water Management Plan," Coachella Valley Water District, November 2000.

[74] Ibid.

[75] Ibid.

Mitigation of this hazard will require a regional approach to groundwater conservation and recharge. Currently, groundwater recharge in the lower Coachella Valley is limited. CVWD operates a pilot recharge facility south of Lake Cahuilla near Avenue 62 and Madison Street in La Quinta, and has demonstrated that recharge at this location is feasible. The U.S. Geological Survey plans to take precise elevation measurements every 2 to 3 years to determine the extent and magnitude of subsidence in the valley. Continued monitoring of well water levels will also help assess the relationship between groundwater overdraft and regional subsidence.

5. Wind Erosion

Wind erosion occurs on dry, sandy, finely granulated soils and involves the removal of soil from one place and the deposition of it in another. Wind erosion is initiated by wind forces exerted against the ground and can result in the deterioration of the soil structure, as well as nutrient and productivity losses. The presence of sand and dust particles in the air can also contribute to reductions in traffic visibility and constitute a major public health risk, resulting in respiratory distress and/or damage, particularly among children, the elderly, and those with respiratory disease. Dust storms and the abrasive effects of blowing sand can damage buildings, fences, vehicles, and crops and other vegetation. Blowing sand collects on streets, driveways, parking lots, and yards and must be removed at considerable expense.

Much of the land in the western and central Coachella Valley is highly susceptible to wind erosion from strong, sustained winds that emanate from the San Gorgonio Pass. These winds are funneled through the Pass from the west, and cross the central axis of the valley in a southeastwardly direction. Soils in this hazard area are predominantly fine-grained sands and silts, which can be easily picked up and transported by the wind.

Increases in the amount of wind-blown sand are related to episodic flooding of the Whitewater River and other regional drainages, during which large quantities of sand and gravel are deposited on the valley floor. Wind erosion is most severe in areas that are unprotected from strong winds, particularly the central valley floor. The erosion hazard decreases near the mountain front, where mountain spurs and slopes provide protection from strong winds, and soils are composed of heavier cobbles and boulders that cannot be picked up by the wind.

Mitigation of this hazard is difficult because it involves significant monetary expense and considerable environmental changes, such as planting vegetation to buffer the wind and stabilize soils, covering soils with impervious surfaces and/or chemical soil stabilizers, and installing wind fencing. The implementation of erosion control plans during grading and construction of urban development projects is perhaps the most effective method of mitigating this hazard, as the disturbance of surface soils during construction can result in significant wind erosion. Wind erosion during construction can typically be mitigated by limiting the area of exposed soils during grading, installing landscape materials immediately after grading, watering soils before and during construction, and using retaining walls in place of grading fill and cut slopes. Landscape materials used to stabilize soils should be able drought-tolerant and resistant to high salt concentrations in the soil.

Mitigation of the flood potential of the Whitewater River and other major drainages, particularly those located in the western or central valley and those which cross the central axis of the valley, will also reduce the wind erosion hazard. However, such action may require the construction of multi-million dollar upstream dams, concrete channelization, and/or other flood control improvements, which could inhibit the natural percolation of precipitation. Smaller-scale mitigation measures are probably more feasible.

IV. **Conclusions**

The Coachella Valley is highly susceptible to seismically-induced and other geologic hazards due to its proximity to the San Andreas and San Jacinto Fault Zones and other active and potentially active faults, the composition of underlying soils, and the presence of steep, rugged mountains surrounding the region. In some portions of the valley, impacts to urban development typically can be mitigated to acceptable levels through strict adherence to building codes, thoughtful site planning and structural design, and specialized grading and drainage techniques.

However, other areas within the valley are particularly susceptible to significant geotechnical hazards and, therefore, are severely constrained to development. These areas include designated Alquist-Priolo Earthquake Fault Zones, land within and immediately downgradient of steep mountainous slopes, and wind hazard areas along the central axis of the valley. Local jurisdictions have acknowledged the potential hazards that characterize these areas and have largely designated them for open space and/or conservation purposes or uses that are “compatible” with geologic hazards, such as utility rights-of-way and wind energy development.

The proposed MSHCP has a unique opportunity to further preserve these constrained lands for conservation purposes. Not only are these geologically “hazardous” areas constrained to development, but they also provide important habitat opportunities for sensitive biological species. The steep slopes of the Santa Rosa Mountains, for example, provide critical habitat for bighorn sheep, and the wind hazard zones along the central axis of the valley facilitate the natural transport of blowsand and the formation of sand dunes and fields. Some surface fault ruptures allow the seepage of groundwater and the formation of important watering and foraging sites for birds and mammals. The MSHCP should continue to preserve potentially hazardous areas as open space and limit “incompatible” development within them, to the greatest extent practical.

Glossary

Active Fault	fault which shows evidence of surface displacement within the last 11,000 years (Holocene Epoch), as defined by the California Division of Mines and Geology
Alluvial	stream-deposited
Eolian	wind-deposited
Epicenter	point of the earth's surface directly above the point of origin of an earthquake
Fault	fracture or zone of closely associated fractures along which rocks on one side have been displaced with respect to those on the other side; typically the result of repeated displacement that may have taken place suddenly and/or by slow creep
Fault Trace	line formed by the intersection of a fault and the earth's surface
Fault Zone	zone of related faults that are commonly braided and subparallel, but may be branching and divergent
Lacustrine	of or originating from a lake
Lithology	the study of rocks
Magnitude	a measure of the amount of energy released when a fault ruptures
Maximum Credible Earthquake	the largest earthquake a fault is capable of generating
Maximum Probable Earthquake	the largest earthquake a fault is capable of generating over a specific period of time
Paleoseismic Study	excavation across a fault used to gather data about how the fault ruptures and the distance it moves during a single earthquake
Potentially Active Fault	fault which shows evidence of movement within the last 1.6 million years, as defined by the California Division of Mines and Geology (this definition has been modified by the U.S. Geological Survey to read "within the last 750,000 years")

Seismic Intensity	qualitative estimate of the damage caused by an earthquake at a given location
Seismograph	instrument which amplifies ground motions and can be used to determine the time, epicenter, and local depth of an earthquake
Soft-story building	building with a story, generally the first floor, lacking adequate strength or toughness due to too few shear walls
Tilt-up building	buildings constructed of concrete panel walls, often cast on the ground or fabricated off-site, that are tilted upward into their final positions

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