TECHNICAL BACKGROUND REPORT to the SAFETY ELEMENT of the GENERAL PLAN for the CITY OF COACHELLA

In RIVERSIDE COUNTY, CALIFORNIA

SEISMIC HAZARDS
GEOLOGIC HAZARDS
FLOODING HAZARDS
FIRE HAZARDS
HAZARDOUS MATERIALS MANAGEMENT
SEVERE WEATHER HAZARDS
DISASTER PREPAREDNESS

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CHAPTER 1: SEISMIC HAZARDS

Earthquake-triggered geologic effects include ground shaking, surface fault rupture, landslides, liquefaction, subsidence, tsunamis and seiches. Some of these hazards can occur in the city of Coachella, as discussed in detail below. Earthquakes can also lead to reservoir failures, urban fires, and toxic chemical releases.

In seismically active southern California, an earthquake has the potential to cause far-reaching loss of life or property, and economic damage. This is because damaging earthquakes are relatively frequent, affect widespread areas, trigger many secondary effects, and can overwhelm the ability of local jurisdictions to respond. Although it is not possible to prevent earthquakes, their destructive effects can be minimized. Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning, public education, emergency exercises, enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can significantly reduce the scope of an earthquake's effects and avoid disaster. The record shows that local government, emergency relief organizations, and residents can and must take action to develop and implement policies and programs to reduce the effects of earthquakes. Thus, this document not only discusses the potential seismic hazards that can impact the city of Coachella, but also provides action items and programs that can help the City become more self-sufficient in the event of an earthquake.

1.1 Seismic Context – Earthquake Basics

The outer 10 to 70 kilometers of the Earth consist of enormous blocks of moving rock called ***tectonic plates***. There are about a dozen major plates, which slowly collide, separate, and grind past each other. In the uppermost brittle portion of the plates, friction locks the plate edges together, while plastic movement continues at depth. Consequently, the near-surface rocks bend and deform near plate boundaries, storing strain energy. Eventually, the frictional forces are overcome and the locked portions of the plates move. The stored strain energy is then released in seismic waves that radiate out in all directions from the rupture surface causing the Earth to vibrate and shake as the waves travel through. This shaking is what we feel in an earthquake. Most earthquakes occur on or near plate boundaries. Southern California has many earthquakes because it straddles the boundary between the North American and Pacific plates, and fault rupture accommodates their motion.

By definition, the break or fracture between moving blocks of rock is called a ***fault***, and such differential movement produces a fault rupture. Few faults are simple, planar breaks in the Earth. They more often consist of smaller strands, with a similar orientation and sense of movement. A strand is mappable as a single, fairly continuous feature. Sometimes geologists group strands into segments, which are believed capable of rupturing together during a single earthquake. The more extensive the fault, the bigger the earthquake it can produce. Therefore, multi-strand fault ruptures produce larger earthquakes.

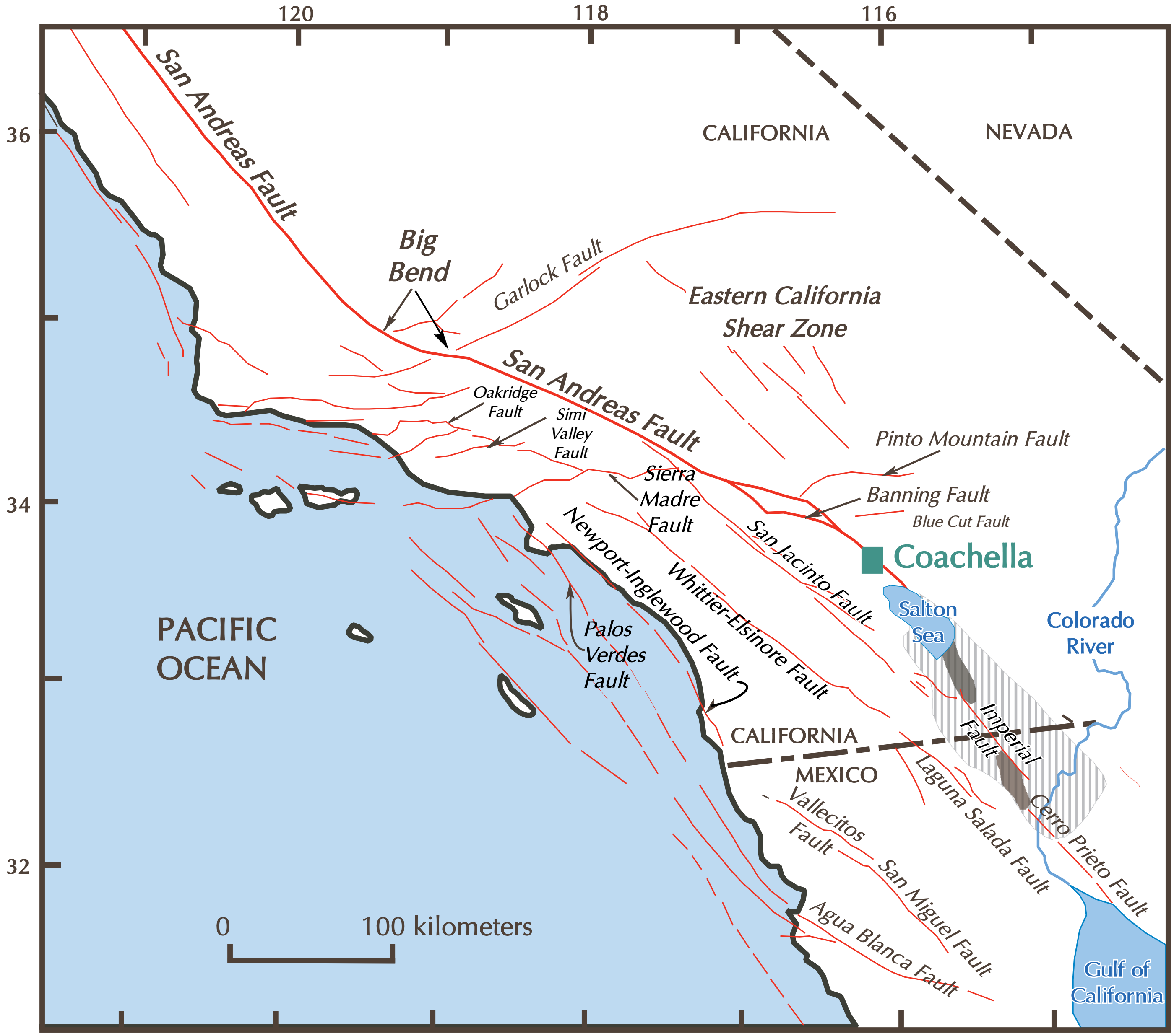
Total ***displacement*** is the length, measured in kilometers (km), of the total movement that has occurred along a fault over as long a time as the geologic record reveals. It is usually estimated by measuring distances between geologic features that have been split apart and separated (offset) by the cumulative movement of the fault over many earthquakes. ***Slip rate*** is a speed, expressed in millimeters per year (mm/yr). Slip rate is estimated by measuring an amount of offset accrued during a known amount of time, obtained by dating the ages of geologic features. Slip rate data also are used to estimate a fault's earthquake recurrence interval. Sometimes referred to as "repeat time" or "return interval," the ***recurrence interval*** represents the average amount of time that elapses between major earthquakes on a fault. The most specific way to derive the recurrence interval for a given fault is to excavate trenches across the fault to obtain ***paleoseismic*** evidence of earthquakes that have occurred during prehistoric time. Paleoseismic studies show that faults with high slip rates generally have shorter recurrence intervals between major earthquakes. This is so because a high slip rate indicates rocks that, at depth, are moving relatively quickly, and the stored energy trapped within the locked, surficial rocks needs to be released in frequent (geologically speaking), large earthquakes.

Most of the city of Coachella, like most of the western part of southern California, is riding on the Pacific Plate, which is moving northwesterly (relative to the North American Plate), at about 50 millimeters per year (mm/yr), or about 165 feet in 1,000 years. This is about the rate at which fingernails grow, and seems unimpressive. However, it is enough to accumulate enormous amounts of strain energy over tens to thousands of years. Despite being locked in place most of the time, in another 15 million years (a short time in the context of the Earth's history), due to plate movements, Los Angeles (which, like the western portion of Coachella is on the Pacific Plate) will be almost next to San Francisco (which is on the North American Plate). The easternmost section of the Coachella General Plan study area is on the North American plate because it is east of the San Andreas fault, the main dividing fault between the Pacific and North American plates. This means that the eastern portion of the study area is slowly moving south relative to the rest of the city of Coachella.

Although the San Andreas fault marks the main separation between the Pacific and North American plates, only about 60 to 70 percent of the plate motion actually occurs on this fault. The rest is distributed along other faults of the San Andreas system, including the San Jacinto, Whittier-Elsinore, Newport-Inglewood, Palos Verdes, and several offshore faults. To the east of the San Andreas fault, slip is distributed among faults of the Eastern California Shear Zone, including those responsible for the 1992 M_W 7.3 Landers and 1999 M_W 7.1 Hector Mine earthquakes. (M_W stands for ***moment magnitude***, a measure of earthquake energy release, discussed further below.) Thus, the zone of plate-boundary earthquakes and ground deformation covers an area that stretches from Nevada to the Pacific Ocean (see Figure 1-1).

Because the Pacific and North American plates are sliding past each other, with relative motions to the northwest and southeast, respectively, all of the faults mentioned above trend northwest-southeast, and are strike-slip faults. On average, ***strike-slip faults*** are nearly vertical breaks in the rock, and when a strike-slip fault ruptures, the rocks on either side of the fault slide horizontally past each other. However, there is a kink in the San Andreas fault commonly referred to as the "Big Bend," located about 186 miles (300 km) northwest of Coachella (Figure 1-1). Near the Big Bend, the two plates do not slide past each other. Instead, they collide, causing localized compression, which results in folding and thrust faulting. ***Thrusts*** are a type of dip-slip fault where rocks on opposite sides of the fault move up or down relative to each other. When a thrust fault ruptures, the top block of rock moves up and over the rock on the opposite side of the fault.

In southern California, ruptures along thrust faults have built the Transverse Ranges geologic province, a region with a unique east-west trend to its landforms and underlying geologic structures that is a direct consequence of the plates colliding at the Big Bend. Many of southern California's most recent damaging earthquakes have occurred on thrust faults that are uplifting the Transverse Ranges, including the 1971 M_W 6.7 San Fernando, 1987 M_W 5.9 Whittier Narrows, 1991 M_W 5.8 Sierra Madre, and 1994 M_W 6.7 Northridge earthquakes. Thrust faults in southern California have been particularly hazardous because many are "***blind***," that is, they do not extend to the surface of the Earth, and have therefore been difficult to detect and study before they rupture. Some earthquakes in southern California, including the 1987 Whittier Narrows earthquake and the 1994 Northridge earthquake, occurred on previously unknown blind thrust faults. As a result, a great amount of research in the last 15 years has gone into learning to recognize subtle features in the landscape that suggest the presence of a buried thrust fault at depth, and developing techniques to confirm and study these structures. Some geologists have started



Source: Modified from Fuis and Mooney, 1990.

MAP EXPLANATION

- Fault
- Onshore Spreading Center
- New Crust (late Cenozoic)

Earth Consultants International

Project Number: 3106
Date: 2011

Regional Fault Map

Figure 1-1

to develop paleoseismic data for these buried thrust faults, including recurrence interval, estimates of the maximum magnitude earthquake these faults are capable of generating, and displacement per event.

A smaller kink in the San Andreas fault occurs in the vicinity of San Gorgonio Pass, to the northwest of Palm Springs. This kink (or "knot" as it is often called) is a result of a slight bend and a step in the main fault's surface trace. As with the Big Bend, complex fault patterns, including thrust faulting, have developed in this area to accommodate these changes. Consequently, the Coachella Valley area, including the city of Coachella, is exposed to risk from multiple types of earthquake-producing faults. The highest risks are due to movement on the San Andreas (strike-slip, right-lateral) fault zone (which includes the San Gorgonio Pass thrust fault), the San Jacinto (strike-slip, right-lateral) fault zone, faults in the Eastern California Shear Zone (including the right-lateral strike-slip Burnt Mountain, Eureka Peak, Pisgah-Bullion Mountain-Mesquite Lake, and Landers faults), and the Pinto Mountain fault (strike slip, left-lateral). These faults or fault zones will be discussed in more detail in Section 1-4 below.

1.2 Regulatory Context

1.2.1 Alquist-Priolo Earthquake Fault Zoning Act

The Alquist-Priolo Special Studies Zones Act was signed into law in 1972 (in 1994 it was renamed the Alquist-Priolo Earthquake Fault Zoning Act). The primary purpose of the Act is to mitigate the hazard of fault rupture by prohibiting the location of structures for human occupancy across the trace of an active fault (Hart and Bryant, 1999; 2007). This State law was passed in direct response to the 1971 San Fernando earthquake, which was associated with extensive surface fault ruptures that damaged numerous homes, commercial buildings and other structures.

The Act requires the State Geologist (i.e., the Chief of the California Geological Survey) to delineate "Earthquake Fault Zones" along faults that are "sufficiently active" and "well defined." These faults show evidence of Holocene (the time period between today and the past about 11,000 years) surface displacement along one or more or their segments (sufficiently active) and are clearly detectable by a trained geologist as a physical feature at or just below the ground surface (well defined). The boundary of an "Earthquake Fault Zone" is generally about 500 feet from major active faults, and 200 to 300 feet from well-defined minor faults. Alquist-Priolo Earthquake Fault Zone maps are distributed to all affected cities and counties for their use in planning and controlling new or renewed construction. The Act dictates that cities and counties withhold development permits for sites within an Earthquake Fault Zone until geologic investigations demonstrate that the sites are not threatened by surface displacements from future faulting (Hart and Bryant, 2007). Projects include all land divisions and most structures for human occupancy. State law exempts single-family wood-frame and steel-frame dwellings that are less than three stories and are not part of a development of four units or more. However, local agencies can be more restrictive. A section of the Alquist-Priolo-zoned San Andreas fault extends through the eastern and northeastern portions of the city of Coachella. The California Geological Survey has also zoned other faults in the northern and southeastern portions of the Coachella General Plan area (see Section 1.5).

1.2.2 Seismic Hazards Mapping Act

The Alquist-Priolo Earthquake Fault Zoning Act only addresses the hazard of surface fault rupture and is not directed toward other earthquake hazards. Recognizing this, in 1990 the State passed the Seismic Hazards Mapping Act (SHMA), which addresses non-surface fault rupture earthquake hazards, including strong ground shaking, liquefaction and seismically induced landslides. The California Geological Survey (CGS) is the principal State agency charged with implementing the Act. Pursuant to the SHMA, the CGS is directed to provide local governments with seismic hazard zone maps that identify areas susceptible to liquefaction, earthquake-induced landslides and other ground failures. The goal is to minimize loss of life and property by identifying and mitigating seismic hazards. The seismic hazard zones delineated by the CGS are referred to as "zones of required investigation." Site-specific geological hazard investigations are required by the SHMA when construction projects fall within these areas.

The CGS, pursuant to the 1990 SHMA, has been releasing seismic hazards maps since 1997, with emphasis on the large metropolitan areas of Los Angeles, Orange and Ventura counties (funding for this program limits the geographic scope of these studies to these three counties in southern California). As a result, at this time, there are no State-issued (and thus official) seismic hazard zone maps for the city of Coachella. Nevertheless, the methodology that the CGS uses to prepare these maps is well documented, and can be duplicated in areas that the CGS has yet to map. To that end, and for the purposes of this study, we have followed a simplified version of the CGS methodology to identify areas in Coachella that are susceptible to liquefaction or earthquake-induced slope instability. These hazards are discussed in more detail in Section 1.6.

1.2.3 California Building Code

The International Conference of Building Officials (ICBO) was formed in 1922 to develop a uniform set of building regulations; this led to the publication of the first Uniform Building Code (UBC) in 1927. In keeping with the intent of providing a safe building environment, building codes were updated on a fairly regular basis, but adoption of these updates at the county- and city-level was not mandatory. As a result, the building codes used from one community to the next were often not the same. In 1980, recognizing that many building code provisions, like building exits, are not affected by local conditions, and that industries working in California should have some uniformity in building code provisions throughout the State, the legislature amended the State's Health and Safety Code to require local jurisdictions to adopt, at a minimum, the latest edition of the Uniform Building Code Insert (UBC). The law states that every local agency, such as individual cities and counties, enforcing building regulations must adopt the provisions of the California Building Code (CBC) within 180 days of its publication, although each jurisdiction can require more stringent regulations, issued as amendments to the CBC. The publication date of the CBC is established by the California Building Standards Commission and the code is known as Title 24 of the California Code of Regulations. Based on the publication cycle of the UBC, the CBC used to be updated and republished every three years.

Then, in 1994, to further the concept of uniformity in building design, the ICBO joined with the two other national building code publishers, the Building Officials and Code Administrators International, Inc. (BOCA) and the Southern Building Code Congress International, Inc. (SBCCI), to form a single organization, the International Code Council, (ICC). In the year 2000, the group published the first International Building Code (IBC) as well as an entire family of codes, (i.e. building, mechanical, plumbing and fire) that were coordinated with each other. As a result, the last (and final) version of the UBC was issued in 1997. However, the California Building Standards Commission, after careful review of the 2000 IBC, chose not to use the IBC, but instead continued to adopt the older 1997 UBC as the basis for the CBC. The 2001 CBC (based on the 1997 UBC) was used throughout the State from 2001 to 2007, often with local, more restrictive amendments based upon local geographic, topographic or climatic conditions.

In 2007 the California Building Standards Commission (BSC) issued the 2007 edition of the CBC based on the 2006 IBC, and more recently, the 2010 edition of the CBC based on the 2009 IBC. Updates of the IBC and CBC have been issued every three years since then. The 2013 CBC became effective on January 1, 2014. [For updates and additional information regarding the CBC, refer to the California Building Standards Commission website at www.bsc.ca.gov/].

The CBC provides requirements for structural design that apply to the construction, alteration, replacement, and demolition of every building or structure and any appurtenances connected or attached to such buildings or structures throughout the state of California. The code is meant to safeguard the public's health, safety and general welfare through structural strength, general stability and means of egress by regulating and controlling the design, construction, quality of materials, use and occupancy, location, and maintenance of all buildings and structures within its jurisdiction. It is important to recognize, however, that building codes provide **minimum** standards. With respect to seismic shaking, for example, the provisions of the building code are designed to prevent the catastrophic collapse of structures during a strong earthquake; however, structural damage to buildings, and potential loss of functionality, are expected. Specific provisions contained in the California Building Code that pertain to seismic and geologic hazards are discussed further in other sections of this document.

1.2.4 Unreinforced Masonry Law

Enacted in 1986, the Unreinforced Masonry Law (Senate Bill 547, codified in Section 8875 et seq. of the California Government Code) required all cities and counties in zones near historically active faults (Seismic Zone 4 per the Building Code at the time of the bill passage) to identify potentially hazardous unreinforced masonry (URM) buildings in their jurisdictions, establish an URM loss-reduction program, and report their progress to the State by 1990. The owners of such buildings were to be notified of the potential earthquake hazard these buildings posed. Some jurisdictions implemented mandatory retrofit programs, while others established voluntary programs. A few cities only notified the building owners, but did not adopt any type of strengthening program. Starting in 1997, California required all jurisdictions to enforce the 1997 Uniform Code for Building Conservation (UCBC) Appendix Chapter 1 as the model building code, although local governments could adopt amendments to that code under certain circumstances (ICBO, 2001; CSSC, 2006). The UCBC standards were meant to significantly reduce but not necessarily eliminate the risk to life from collapse of the structure. Prior to 1997, local governments could adopt other building standards that preceded the UCBC, and in fact, in many jurisdictions, retrofits were conducted in accordance with local ordinances that only partially complied with the latest UCBC. The 2013 California Building Code (CBC) includes building standards for historical buildings (2013 California Historical Building Code, Part 8 of Title 24), and building standards for existing buildings (2013 California Existing Building Code, Part 10 of Title 24) based on the 2012 International Existing Building Code.

According to the 2000, 2003 and 2006 reports by the Seismic Safety Commission on the "*Status of the Unreinforced Masonry Building Law*," the City of Coachella's initial survey indicated that there were 14 unreinforced masonry (URM) buildings in the city. However, a review of these buildings using metal detectors later showed that thirteen of these are reinforced. The one true URM in the city was reported as destroyed in a fire in 1994.

1.2.5 Real Estate Disclosure Requirements

Since June 1, 1998, the Natural Hazards Disclosure Act has required that sellers of real property and their agents provide prospective buyers with a "Natural Hazard Disclosure Statement" when the property being sold lies within one or more State-mapped hazard areas. For example, if a property is located in a Seismic Hazard Zone as shown on a map issued by the State Geologist, the seller or the seller's agent must disclose this fact to potential buyers. The law specifies two ways in which this disclosure can be made: (1) Using the Natural Hazards Disclosure Statement as provided in Section 1102.6c of the California Civil Code, or (2) using the Local Option Real Estate Disclosure Statement as provided in Section 1102.6a of the California Civil Code. The Local Option Real Estate Disclosure Statement (Option 2) can be substituted for the Natural Hazards Disclosure Statement (Option 1) only if the Local Option Statement contains substantially the same information and substantially the same warnings as the Natural Hazards Disclosure Statement.

California State law also states that when a house built before 1960 is sold, the seller must give the buyer a completed earthquake hazards disclosure report and a copy of the booklet entitled "The Homeowner's Guide to Earthquake Safety." This publication was written and adopted by the California Seismic Safety Commission. The most recent edition of this booklet is available from the web at www.seismic.ca.gov/. The booklet includes a sample of a residential earthquake hazards report that buyers are required to fill in, and describes structural weaknesses common in homes that if they fail in an earthquake can result in significant damage to the structure. The booklet then provides detailed information on actions that homeowners can take to strengthen their homes.

Those regions in the study area that have the potential of being impacted by seismically induced surface fault rupture (see Section 1.5) and liquefaction or slope instability (see Section 1.6), as identified in this report, should be disclosed to prospective buyers, following the provisions of the Natural Hazards Disclosure Act.

1.2.6 California Environmental Quality Act

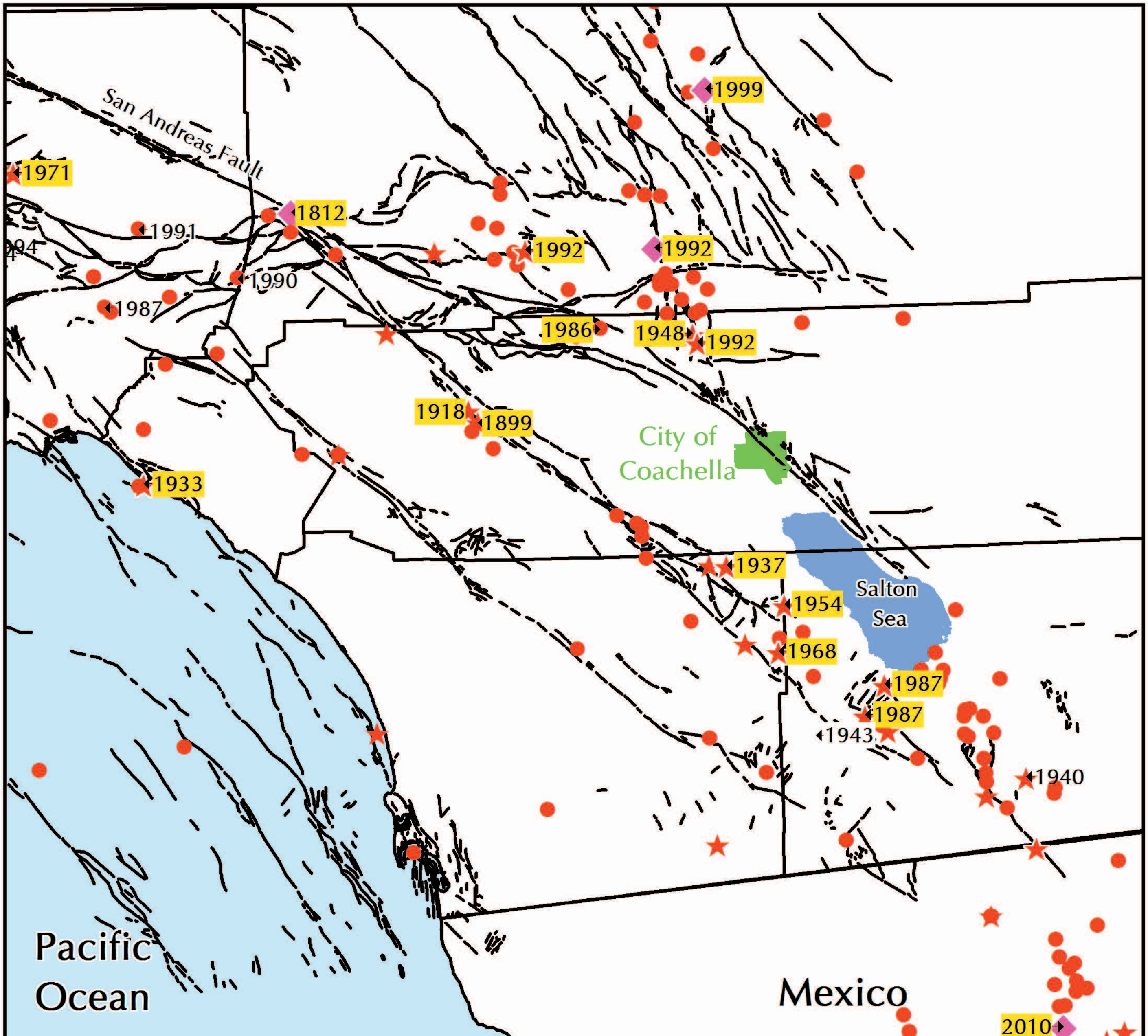
The California Environmental Quality Act (CEQA) was passed in 1970 to insure that local governmental agencies consider and review the environmental impacts of development projects within their jurisdictions. CEQA requires that an Environmental Impact Report (EIR) be prepared for projects that may have significant effects on the environment. EIRs are required to identify geologic and seismic hazards, and to recommend potential mitigation measures, thus giving the local agency the authority to regulate private development projects in the early stages of planning. The law requires that these documents be issued in draft form and made available at local libraries and City Hall for individuals and organizations to review and comment on. The comments are addressed in the final report submitted for approval or refusal by the Planning Commission and/or City Council.

1.3 Notable Past Earthquakes

Figure 1-2 shows the approximate epicenters of some of the historical earthquakes that have resulted in significant ground shaking in the southern California area, including Coachella. The most significant of these events, either because they were felt strongly in the area, or because they led to the passage of important legislation, are described below.

1.3.1 Wrightwood Earthquake of December 12, 1812

This large earthquake occurred on December 8, 1812 and was felt throughout southern California. Based on accounts of damage recorded at missions in the earthquake-affected area, an estimated magnitude of 7.5 has been calculated for the event (Toppozada et al., 1981). Subsurface investigations and tree ring studies show that the earthquake likely ruptured the Mojave Section of the San Andreas fault near Wrightwood, and may have been accompanied by



Source: Jennings, 1994; SCEC earthquake catalog; NEIC earthquake catalog

Explanation

- Magnitude 7+
- Magnitude 6 - 7
- Magnitude 5 - 6
- Quaternary faults
- 1899 Earthquakes discussed further in the text

N, S, E, W

0 20 Miles

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Notable Regional Earthquakes

Figure 1-2

a significant surface rupture between Cajon Pass and Tejon Pass (Jacoby, Sheppard and Sieh, 1988; www.scecdc.scec.org/quakedex.html). The worst damage caused by the earthquake occurred significantly west of the San Andreas fault at San Juan Capistrano Mission, where the roof of the church collapsed, killing 40 people. The earthquake also damaged walls and destroyed statues at San Gabriel Mission, and is thought to have triggered an earthquake thirteen days later that damaged several missions in the Santa Barbara area (Deng and Sykes, 1996). Strong aftershocks that occurred for several days after the main earthquake collapsed many buildings that had been damaged by the main shock.

1.3.2 San Jacinto Earthquake of 1899

This earthquake occurred at 4:25 in the morning on Christmas Day, in 1899. The main shock is estimated to have had a magnitude of 6.5. Several smaller aftershocks followed the main shock, and in the town of San Jacinto, as many as thirty smaller tremors were felt throughout the day. The epicenter of this earthquake is not well located, but damage patterns suggest the location shown on Figure 1-2, near the town of San Jacinto, with the causative fault most likely being the San Jacinto fault. Both the towns of San Jacinto and Hemet reported extensive damage, with nearly all brick buildings either badly damaged or destroyed. Six people were killed in the Soboba Indian Reservation as a result of falling adobe walls. In Riverside, chimneys toppled and walls cracked (Claypole, 1900). The main earthquake was felt over a broad area that included San Diego to the southwest, Needles to the northeast, and Arizona to the east. No surface rupture was reported, but several large "sinks" or subsidence areas were reported about 10 miles to the southeast of San Jacinto.

1.3.3 San Jacinto Earthquake of 1918

This magnitude 6.8 earthquake occurred on April 21, 1918 at 2:32 P.M. Pacific Standard Time (PST), near the town of San Jacinto. The earthquake caused extensive damage to the business districts of San Jacinto and Hemet, where many masonry structures collapsed, but because it occurred on a Sunday, when these businesses were closed, the number of fatalities and injuries was low. Several people were injured, but only one death was reported. Minor damage as a result of this earthquake was reported outside the San Jacinto area, and the earthquake was felt as far away as Taft (west of Bakersfield), Seligman (Arizona), and Baja California.

Strong shaking cracked the ground, concrete roads, and concrete irrigation canals, but none of the cracks are thought to have been caused directly by surface fault rupture. The shaking also triggered several landslides in mountain areas. The road from Hemet to Idyllwild was blocked in several places where huge boulders rolled down slopes. Two men in an automobile were reportedly swept off a road by a landslide, and would have rolled several hundred feet down a hillside had they not been stopped by a large tree. Two miners were trapped in a mine near Winchester, but they were eventually rescued, uninjured. The earthquake apparently caused changes in the flow rates and temperatures of several springs. Sand craters (due most likely to liquefaction) were reported on one farm, and an area near Blackburn Ranch "sunk" approximately three feet (one meter) during the quake (/www.scecdc.scec.org/quakedex.html).

1.3.4 Long Beach Earthquake of 1933

The M_w 6.4 Long Beach earthquake occurred on March 10, at 5:54 P.M. PST, following a strong foreshock the day before. The earthquake killed 115 people and caused $40 to 50 million in property damage (www.scecdc.scec.org/quakedex.html). The earthquake ruptured the Newport-Inglewood fault, and shaking was felt from the San Joaquin Valley to Northern Baja California (Mexico). Although its epicenter was located at the boundary between Huntington Beach and Newport Beach, the tremor was called "the Long Beach earthquake" because the worst damage was focused in the city of Long Beach. Although this earthquake occurred far away from the Coachella area and was probably not felt here, it is discussed in this report because it led to code changes that apply to all of California. Specifically, the regional significance of this earthquake is that damage to school buildings was especially severe, which led to the passage of the Field and Riley Acts by the State legislature. The Field Act regulates school construction and the Riley Act regulates the construction of buildings larger than two-family dwellings.

1.3.5 San Jacinto Fault Earthquake of 1937

This magnitude 6.0 earthquake occurred on March 25, 1937 at 8:49 AM PST, just after the advent of modern seismology, and as a result, it is one of the first earthquakes for which both an epicentral location and numerical magnitude value (using the then newly developed Richter scale) were determined. The event is known as the Terwilliger Valley earthquake, although this is actually a misnomer, since its epicenter is almost 19 miles (30 km) to the east-southeast of Terwilleger Valley. The earthquake caused very little damage given that the epicentral area was (and still is) sparsely populated. Nevertheless, a few chimneys were toppled, plaster cracked, and windows broke in structures located relatively near the epicenter (Wood, 1937). "It was recognized at the time, however, that the quake could have easily caused the kind of damage seen in Santa Barbara in 1925 or in Long Beach in 1933, had it been located in a densely populated area, being nearly the same magnitude as those destructive quakes" (http://www.data.scec.org/chrono_index/sanj37.html).

1.3.6 Desert Hot Springs Earthquake of 1948

This magnitude 6.0 earthquake struck on December 4, 1948 at 3:43 P.M. PST. The fault involved is believed to be the South Branch of the San Andreas (or Banning fault, depending on nomenclature used). The Desert Hot Springs earthquake of 1948 not only was felt over a large area (as far away as central Arizona, parts of Mexico, Santa Catalina Island, and Bakersfield), but also caused notable damage in regions far from the epicenter. In the Los Angeles area, a 5,800-gallon water tank split open, water pipes were broken at UCLA and in Pasadena, and plaster cracked and fell from many buildings. In San Diego, a water main broke. In Escondido and Corona, walls were cracked. The administration building of Elsinore High School was permanently closed due to the damage it sustained, as was a building at the Emory School in Palm City. Closer to the epicenter, landslides and ground cracks were reported, and a road leading to the Morongo Indian Reservation was badly damaged (Louderback, 1949). In Palm Springs, the city hit hardest by the quake, thousands of dollars of merchandise was thrown from shelves and destroyed. Part of a furniture store collapsed. Two people were injured when the shaking induced a crowd to flee a movie theater in panic. Numerous other instances of minor structural damage were reported. Fortunately, despite the damage brought on by this earthquake, no lives were lost.

1.3.7 San Jacinto Fault Earthquake of 1954

This magnitude 6.4 earthquake struck on March 19, 1954 at 1:54 A.M. PST. Magistrale et al. (1989) suggest that the Clark fault of the San Jacinto Fault Zone was involved. The 1954 San Jacinto fault earthquake, sometimes referred to as the Arroyo Salada earthquake, caused minor damage over a wide area of southern California, cracking plaster walls as far away as San Diego, and knocking plaster from the ceiling at the Los Angeles City Hall. In Palm Springs, a water pipe was broken, and the walls of several swimming pools were cracked. Part of San Bernardino experienced a temporary blackout when power lines snapped in the shaking. Indio and Coachella also experienced minor damage. The shock was felt as far away as Ventura County, Baja California, and Las Vegas (Louderback, 1954).

1.3.8 Borrego Mountain Earthquake of 1968

This magnitude 6.5 earthquake struck on April 8, 1968 at 6:29 P.M. It resulted in about 18 miles of surface rupture along the Coyote Creek fault (a branch of the San Jacinto Fault Zone), and triggered slip was observed on fault systems up to 40 miles away. When the Borrego Mountain earthquake struck, it was the largest and most damaging quake to hit southern California since the Kern County earthquake of 1952. It was felt as far away as Las Vegas, Fresno, and even Yosemite Valley. The quake caused damage across most of southern California – power lines were severed in San Diego County, plaster cracked in Los Angeles, and the Queen Mary, in dry-dock at Long Beach, rocked back and forth on its keel blocks for 5 minutes. A few ceilings collapsed at various places in the Imperial Valley. Close to the epicenter, the quake caused landslides, hurling large boulders downslope, damaging campers' vehicles at Anza-Borrego Desert State Park, and caused minor surface rupture, cracking Highway 78 at Ocotillo Wells (Lander, 1968).

The event apparently caused small displacements along the Superstition Hills fault (2.2 cm), Imperial fault (1.2 cm), and the Banning-Mission Creek fault (0.9 cm), 28, 43.5, and 31 miles (45, 70, and 50 km), respectively, from the epicenter. These fresh breaks and displacements were not noticed immediately after the mainshock, but no other significant events occurred within the interim that could have caused them. These are probably among the first noted instances of triggered slip, and they proved to be some of the most intriguing features of the Borrego Mountain earthquake.

1.3.9 San Fernando (Sylmar) Earthquake of 1971

This magnitude 6.6 earthquake occurred on the San Fernando Fault Zone, the westernmost segment of the Sierra Madre fault, on February 9, 1971, at 6:00 A.M. The surface rupture caused by this earthquake was nearly 12 miles long, and occurred in the Sylmar-San Fernando area. The maximum slip measured at the surface was nearly six feet. The earthquake caused over $500 million in property damage and 65 deaths. Most of the deaths occurred when the Veteran's Administration Hospital collapsed. Several other hospitals, including the Olive View Community Hospital in Sylmar suffered severe damage. Newly constructed freeway overpasses also collapsed, in damage scenes similar to those that occurred 23 years later in the 1994 Northridge earthquake. Loss of life could have been much greater had the earthquake struck at the busier time of the day. As with the Long Beach earthquake, legislation was passed in response to the damage caused by the 1971 earthquake. In this case, the building codes were strengthened and the Alquist-Priolo Special Studies Zones Act (now call the Earthquake Fault Zoning Act, see Section 1.2.1) was passed in 1972.

1.3.10 North Palm Springs Earthquake of 1986

This magnitude 5.6 earthquake occurred on July 8, 1986 at 2:21 A.M. PDT, along either the Banning fault or the Garnet Hill fault. The epicenter was about 6 miles northwest of Palm Springs, and about 31 miles from Coachella. The North Palm Springs earthquake was responsible for at least 29 injuries and the destruction or damage of 51 homes in the Palm Springs-Morongo Valley area. It also triggered landslides in the region. Damage caused by this quake was estimated at over $4 million. Ground cracking was observed along the Banning, Mission Creek, and Garnet Hill faults, but these cracks were due to shaking, not surface rupture (Person, 1986). Most of the ground fractures occurred on the northern side of the fault, between Whitewater Canyon on the west, and Highway 62 on the east. Fractures varied from single, discontinuous breaks less than 1 mm wide, to extensively fractured zones 30 to 40 m (100 to 120 feet) wide (Morton et al., 1989).

1.3.11 Elmore Ranch and Superstition Hills Earthquakes of 1987

The magnitude 6.2 Elmore Ranch earthquake struck on November 23, 1987 at 5:54 P.M. PST. This earthquake resulted in left-lateral strike-slip motion along the Elmore Ranch and associated faults, and appears to have triggered a larger earthquake the next morning on the right-lateral Superstition Hills fault, which is perpendicular to the Elmore Ranch system (Hudnut et al., 1989). A maximum surface offset of 12.5 centimeters was reported, and the faults where surface rupture was observed included the Elmore Ranch (main, west, and east branches), Lone Tree, and Kane Spring (main and east branches). The magnitude 6.6 Superstition Hills earthquake occurred the morning of November 24, at 6:16 A.M. PST, near the Salton Sea. A maximum surface offset of about 50 cm (20 inches) was observed on the Superstition Hills fault within 24 hours of the earthquake. However, during the next several months, the offset was observed to have increased to nearly 1 meter (3 ft), and triggered slip was observed on the Imperial, San Andreas, and Coyote Creek faults (Sharp et al., 1989).

1.3.12 Joshua Tree Earthquake of 1992

This magnitude 6.1 earthquake struck on April 22, 1992 at 9:50 P.M. PST, approximately 21 miles north of Coachella. This event resulted from right-lateral strike-slip faulting and was preceded by a magnitude 4.6 foreshock. The earthquake sequence raised some alarms due to the San Andreas fault's proximity; scientists assigned the San Andreas fault a 5 to 25 percent chance of generating an even larger earthquake within three days. Although an earthquake on the San Andreas fault did not materialize, the Landers earthquake occurred roughly two months and 6,000 aftershocks later, showing that the concern caused by the Joshua Tree earthquake was at least partially warranted (http://www.data.scec.org/chrono_index/joshuatr.html). There was no surface rupture associated with the Joshua Tree event, but aftershocks of the quake suggested that the fault that slipped was a north- to northwest-trending, right-lateral strike-slip fault at least 15 km long (Jones et al., 1995). Based on these data, researchers suggest that the Eureka Peak fault may have been the fault responsible for this earthquake.

Damage caused by the Joshua Tree earthquake was slight to moderate in the communities of Joshua Tree, Yucca Valley, Desert Hot Springs, Palm Springs, and Twentynine Palms. Thirty-two people were treated for minor injuries. Though somewhat forgotten in the wake of the Landers earthquake, the Joshua Tree quake was a significant event on its own, and was felt as far away as San Diego, Santa Barbara, Las Vegas, Nevada, and even Phoenix, Arizona (Person, 1992).

1.3.13 Landers Earthquake of 1992

On the morning of June 28, 1992, most people in southern California were awakened at 4:57 by the largest earthquake to strike California in 40 years. Named "Landers" after the small desert community near its epicenter, the earthquake had a magnitude of 7.3. The power of the earthquake was illustrated by the length of the ground rupture it left behind. More than 50 miles of surface rupture associated with five or more faults occurred as a result of this earthquake. The earthquake ruptured five separate faults: Johnson Valley, Landers, Homestead Valley, Emerson, and Camp Rock faults (Sieh et al., 1993). Other nearby faults also experienced triggered slip and minor surface rupture. The average right-lateral strike-slip displacement was about 10 to 15 feet, but a maximum of up to 18 feet was observed. Centered in the Mojave Desert approximately 120 miles from Los Angeles and 39 miles from Coachella, the earthquake caused relatively little damage for its size (Brewer, 1992). It released about four times as much energy as the very destructive 1989 Loma Prieta earthquake in the San Francisco area, but fortunately, it did not claim as many lives (one child died in Yucca Valley when bricks from the collapsed chimney fell into the room where he was sleeping).

1.3.14 Big Bear Earthquake of 1992

This magnitude 6.4 earthquake struck a little more than three hours after the Landers earthquake on June 28, 1992, at 8:05:30 A.M. PDT. This earthquake is technically considered an aftershock of the Landers earthquake (indeed, the largest aftershock), although the Big Bear earthquake occurred over 20 miles west of the Landers rupture, on a fault with a different orientation and sense of slip than those involved in the main shock. From its aftershocks, the causative fault was determined to be a northeast-trending left-lateral fault. This orientation and slip are considered "conjugate" to the faults that slipped in the Landers rupture. The Big Bear earthquake did not break the ground surface, and, in fact, no surface trace of a fault with the proper orientation has been found in the area.

The Big Bear earthquake caused a substantial amount of damage in the Big Bear area, but fortunately, it claimed no lives. However, landslides triggered by the quake blocked roads in that mountainous area, aggravating the clean-up and rebuilding process (www.scecdc.scec.org/ quakedex.html).

1.3.15 Hector Mine Earthquake of 1999

Southern California's most recent large earthquake was a widely felt magnitude 7.1. It occurred on October 18, 1999, in a remote region of the Mojave Desert, 47 miles east-southeast of Barstow, and more than 60 miles from Coachella. Modified Mercalli Intensities of VI (Table 1-1) were reported by two individuals in the Coachella area (http://earthquake.usgs.gov/ earthquakes/dyfi/events/ci/hectormi/us/index.html). The Hector Mine earthquake is not considered an aftershock of the M 7.3 Landers earthquake of 1992, although Hector Mine occurred on similar, north-northwest trending strike-slip faults within the Eastern Mojave Shear Zone. Geologists documented a 25-mile (40-km) long surface rupture and a maximum right-lateral strike-slip offset of about 16 feet on the Lavic Lake fault.

1.3.16 Baja California Earthquake of 2010

A magnitude 7.2 earthquake that occurred just south of the U.S. / Mexico border on Easter Sunday, April 4, 2010, at 3:40:42 PM PDT, was felt throughout Mexico, southern California, Arizona, and Nevada. Researchers who reviewed the seismograph data found that here were two sub-events: first a magnitude 6 earthquake that ruptured an 18-km section of the Pescadores fault, followed, about 15 seconds later, by a larger event on the Borrego fault. Both of these faults are part of the Laguna Salada fault system, which is the southern extension of the Elsinore fault. The total length of the zone of surface rupture is approximately 120 km (75 miles), extending across several faults, some unknown prior to the earthquake. Maximum surface fault rupture of about 4.3 m (14 feet) of predominantly right-lateral displacement was measured on the Pescadores fault; both right-lateral strike-slip and down-to-the-east vertical displacements were observed along the zone of fault rupture.

Surface rupture continued northward to just past the border into California. The main earthquake caused triggered slip of up to a few centimeters on several faults in the Salton Sea area, and as far north as the Mecca Hills, about 8 miles to the southeast of Coachella (Weldon, 2010; Wei et al., 2011). Secondary effects, including liquefaction, rockfalls and shattering were reported along a wide area in the El Centro and Brawley region, and westward toward San Diego. A peak instrumental ground acceleration of 1.1g was recorded at the Salton Sea. Similar or stronger shaking may have occurred closer to the epicenter, but given the lack of instrumentation in that area, went unrecorded. Based on observations reported by at least 30 residents, shaking in Coachella as a result of this earthquake was moderate, in the Modified Mercalli intensity V range (http://earthquake.usgs.gov/earthquakes/dyfi/events/ci/14607652/

us/index.html). By November 2010, more than 10,000 aftershocks had been recorded (Hauksson et al., 2010). Many of the aftershocks occurred along the Elsinore, San Jacinto, and the southern extension of the San Andreas fault through the Brawley area. The largest aftershock was a magnitude 5.7 on June 14, 2010 that occurred just north of the International Border, about 5 miles from Ocotillo.

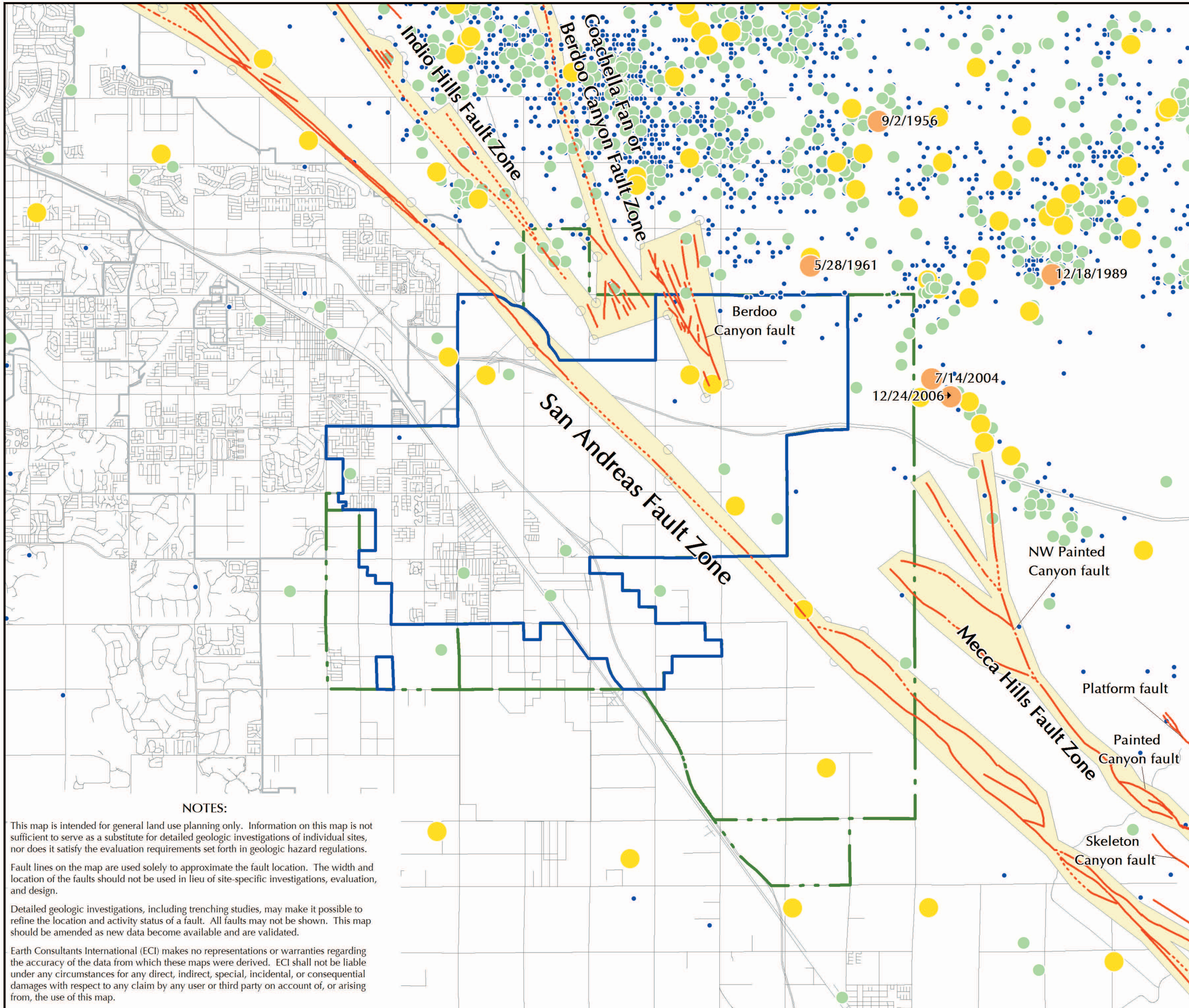
In addition to the earthquakes described above, hundreds of small earthquakes have occurred and will continue to occur in the immediate vicinity of Coachella. Plate 1-1 shows the epicentral locations of earthquakes in and around the city that were instrumentally detected between 1932 and April 2014, and those estimated to have occurred in the area between about 1800 and 1932. Earthquakes that occurred prior to 1932 are only approximately located because prior to that year there were no instruments available to measure the location and magnitude of an earthquake. The map shows that only a few magnitude 4 and smaller earthquakes have occurred in the Coachella General Plan area proper. Significant seismicity occurs to the east and northeast, along the San Andreas Fault Zone, and farther east, in the Mojave or Eastern California Shear Zone. The largest of these, in the magnitude 4 to 5 range, have all occurred to the east and northeast of the Coachella General Plan study area (see Plate 1-1), and although most likely associated with the San Andreas fault, are not directly linked with known mapped traces of the fault. The historical earthquake distribution shown on Plate 1-1 illustrates the concept that the southern San Andreas fault is locked, and presumed to be accumulating strain that will eventually be unleashed in a large-magnitude surfacing-rupturing earthquake.

1.4 Seismic Ground Shaking

Strong ground shaking causes the vast majority of earthquake damage. As mentioned previously, when a fault breaks in the subsurface, the seismic energy released by the earthquake radiates away from the hypocenter (the focus or section of the fault plane that first ruptures) in waves that are felt at the surface as shaking. In general, the bigger and closer the earthquake, the more damage it may cause. However, other effects discussed below are also important. Earthquakes are typically classified by the amount of damage reported, or by how strong and how far the shaking was felt. An early measure of earthquake size still used today is the seismic intensity scale, which is a qualitative assessment of an earthquake's effects at a given location. The most commonly used measure of seismic intensity is called the ***Modified Mercalli Intensity*** (MMI) scale, which has 12 damage levels (see Table 1-1). Although it has limited scientific application, intensity is intuitively clear and quick to determine. Keep in mind, however, that earthquake damage depends on the characteristics of human-made structures, and the complex interaction between the ground motions and the built environment. Governing factors include a building's height, construction, and stiffness, which determine the structure's resonant period; the underlying soil's strength and resonant period; and the periods of the incoming seismic waves. Other factors include architectural design, condition, and age of the structures.

Scientists used to measure the amplitude of ground motion, as recorded by an instrument a given distance from the epicenter, to report the size of an earthquake (such as the now outdated Richter magnitude). Seismologists have determined that the most meaningful factor in determining the size of an earthquake is the amount of energy released when a fault ruptures. This measure is called the ***seismic moment*** (abbreviated M_w), and most moderate to large earthquakes today are reported using moment magnitude. Both traditional magnitude scales and seismic moment scales are logarithmic. Thus, each one-point increase in magnitude represents a ten-fold increase in amplitude of the waves as measured at a specific location, and a 32-fold increase in energy. That is, a magnitude 7 earthquake produces 100 times (10 x 10) the ground motion amplitude of a magnitude 5 earthquake. Similarly, a moment magnitude 7 earthquake releases approximately 1,000 times more energy (32 x 32) than a moment magnitude 5 earthquake.

Faults and Historical (1800-2014) Seismicity Map
Coachella, California



NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.

Detailed geologic investigations, including trenching studies, may make it possible to refine the location and activity status of a fault. All faults may not be shown. This map should be amended as new data become available and are validated.

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Explanation

Earthquake Magnitude

- 4 to 5
- 2 to 3
- 3 to 4
- <2

Quaternary Fault; solid where well located, dashed where approximately located, dotted where concealed or inferred.

1974 Alquist-Priolo Earthquake Fault Zone; boundaries delineated as straight-line segments that connect encircled turning points. (The CGS is in the process of revising these zones.)

Coachella City Boundary

Coachella Planning Area Boundary

N W E S

8000 0 8000 Feet

2000 0 2000 Meters

Scale: 1:96,000

Base Map: From City of Coachella.
Sources: Southern California Earthquake Center (January 1932 to April 2014); National Earthquake Information Center (1800 to 1931); Alquist-Priolo Earthquake Fault Zones [Reproduced with permission CGS CD-ROM 2001-05 (2002)]; US Geological Survey (2011); Philibosian et al. (2011); location of main San Andreas fault from Petra (2006, 2007).

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Date: 2014

Plate 1-1

An important point to remember is that any given earthquake will have one moment and, in principle, one magnitude, although there are several methods of calculating magnitude, which give slightly different results. However, one earthquake will produce many levels of intensity because intensity effects vary with the location and the perceptions of the observer.

Another measure of the size and felt effects of an earthquake at a given location is ground acceleration. Acceleration is a measure of the forces released by the earthquake that result in the shaking of the ground we associate with earth tremors. Acceleration is scaled using as a reference the **acceleration due to gravity**, **g**, defined as the acceleration at which an object falls if released at rest in a vacuum. Horizontal ground acceleration is frequently responsible for widespread damage to structures, so structural engineers use estimates of horizontal ground acceleration that a building may be expected to experience during its lifetime to design the building. To make these estimates, it is important to know a fault's style of movement (i.e., is it dip-slip or strike-slip), total displacement, slip rate, and the age of its most recent activity. These values allow an estimation of how often a fault produces damaging earthquakes, and how big an earthquake should be expected the next time the fault ruptures. Full characterization of shaking potential also requires estimates of peak (maximum) ground displacement and velocity, the duration of strong shaking, and the periods (lengths) of waves that will control each of these factors at a given location.

In general, the degree of shaking can depend upon:

- **Source effects**. These include earthquake size, location, and distance. In addition, the exact way that rocks move along the fault can influence shaking. For example, the 1995, M_W 6.9 Kobe, Japan earthquake was not much bigger than the 1994, M_W 6.7 Northridge, California earthquake, but the city of Kobe suffered much worse damage. This is in part because during the Kobe earthquake, the fault's orientation and movement directed seismic waves into the city, whereas during the Northridge earthquake, the fault's motion directed waves away from populous areas.

- **Path effects**. Seismic waves change direction as they travel through the Earth's contrasting layers, just as light bounces (reflects) and bends (refracts) as it moves from air to water. Sometimes seismic energy gets focused in one location and causes damage in unexpected areas. Focusing of the seismic waves during the 1989 M_W 7.1 Loma Prieta earthquake caused damage in San Francisco's Marina district, some 62 miles (100 km) distant from the rupturing fault.

- **Site effects**. Seismic waves slow down in the loose sediments and weathered rock at the Earth's surface. As they slow, their energy converts from speed to amplitude, which heightens shaking. This is similar to the behavior of ocean waves – as the waves slow down near shore, their crests grow higher. The Marina District of San Francisco also serves as an example of site effects. Earthquake motions were greatly amplified in the deep, sediment-filled basin underlying the District compared to the surrounding bedrock areas. Seismic waves can get trapped at the surface and reverberate (resonate). Whether resonance will occur depends on the period (the length) of the incoming waves. Waves, soils and buildings all have resonant periods. When these coincide, tremendous damage can occur.

[Waves repeat their motions with varying frequencies. Slow-to-repeat waves are called long-period waves. Quick-to-repeat waves are called short-period waves. Long-period seismic waves, which are created by large earthquakes, are most likely to reverberate and cause damage in long-period structures, like bridges and high-rise buildings that respond to long-period waves. Shorter-period seismic waves, which tend to die out quickly, will most often cause damage in areas relatively close to the rupturing fault, and they will cause most damage to shorter-period structures such as one- to three-story buildings. Very short-period waves are most likely to cause near-fault, interior damage, such as to equipment.]

Table 1-1: Abridged Modified Mercalli Intensity Scale

<table>
<tr><th colspan="2">Intensity Value and Description</th><th>Average Peak Velocity (cm/sec)</th><th>Average Peak Acceleration (g = gravity)</th></tr>
<tr><td>I.</td><td>Not felt except by very few under especially favorable circumstances (I Rossi-Forel scale). Damage potential: None.</td><td><0.1</td><td><0.0017</td></tr>
<tr><td>II.</td><td>Felt only by a few persons at rest, especially on upper floors of high-rise buildings. Delicately suspended objects may swing.
(I to II Rossi-Forel scale). Damage potential: None.</td><td rowspan="2">0.1 – 1.1</td><td rowspan="2">0.0017 – 0.014</td></tr>
<tr><td>III.</td><td>Felt quite noticeably indoors, especially on upper floors of buildings, but many people did not recognize it as an earthquake. Standing automobiles may have rocked slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale). Damage potential: None.</td></tr>
<tr><td>IV.</td><td>During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made creaking sound. Sensation like a heavy truck striking building. Standing automobiles rocked noticeably. (IV to V Rossi-Forel scale). Damage potential: None. Perceived shaking: Light.</td><td>1.1 – 3.4</td><td>0.014 - 0.039</td></tr>
<tr><td>V.</td><td>Felt by nearly everyone; many awakened. Some dishes, windows, and so on broken; plaster cracked in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may have stopped. (V to VI Rossi-Forel scale).
Damage potential: Very light. Perceived shaking: Moderate.</td><td>3.4 – 8.1</td><td>0.039-0.092</td></tr>
<tr><td>VI.</td><td>Felt by all; many frightened and ran outdoors. Some heavy furniture moved, few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale). Damage potential: Light. Perceived shaking: Strong.</td><td>8.1 - 16</td><td>0.092 -0.18</td></tr>
<tr><td>VII.</td><td>Everybody ran 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. (VIII Rossi-Forel scale).
Damage potential: Moderate. Perceived shaking: Very strong.</td><td>16 - 31</td><td>0.18 - 0.34</td></tr>
<tr><td>VIII.</td><td>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. (VIII+ to IX Rossi-Forel scale). Damage potential: Moderate to heavy. Perceived shaking: Severe.</td><td>31 - 60</td><td>0.34 - 0.65</td></tr>
<tr><td>IX.</td><td>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. (IX+ Rossi-Forel scale). Damage potential: Heavy. Perceived shaking: Violent.</td><td>60 - 116</td><td>0.65 – 1.24</td></tr>
<tr><td>X.</td><td>Some well-built wooden structures destroyed; most masonry and frame structures destroyed; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (X Rossi-Forel scale).
Damage potential: Very heavy. Perceived shaking: Extreme.</td><td>> 116</td><td>> 1.24</td></tr>
<tr><td>XI.</td><td>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.</td><td></td><td></td></tr>
<tr><td>XII.</td><td>Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.</td><td></td><td></td></tr>
</table>

Modified from Bolt (1999); Wald et al. (1999).

Seismic shaking has the potential to impact the Coachella area, given that the city is bisected by the most significant seismic source (fault) in southern California, the San Andreas, and not too distant from several other faults. In order to provide a better understanding of the shaking hazard posed by those faults near the General Plan area, we conducted a deterministic seismic hazard analysis for a central point in the city (City Hall) and several other randomly selected points in the General Plan area using the software program EQFAULT by Blake (2000). This analysis estimates the Peak Horizontal Ground Accelerations (PHGA) that could be expected at these locations due to earthquakes occurring on any of the known active or potentially active faults within about 62 miles (100 km). The fault database (including fault locations and earthquake magnitudes of the maximum magnitude earthquakes for each fault) used to conduct these seismic shaking analyses is that used by the California Geological Survey (CGS) and the U.S. Geological Survey (USGS) for the National Seismic Hazard Maps (Petersen et al., 1996; Cao et al., 2003). However, as described further in the text, recent paleoseismic studies suggest that some of these faults may actually generate even larger earthquakes than those used in the analysis. Where appropriate, this is discussed further below.

PHGA depends on the size of the earthquake (which is dependent on the rupturing fault's dimensions), the proximity of the rupturing fault to the study site, and local soil conditions. Effects of soil conditions are estimated by use of an attenuation relationship derived empirically from an analysis of recordings of earthquake shaking in similar soils during earthquakes of various sizes and distances. Given that most of the developed portions of Coachella are underlain by alluvial sediments, we used alluvium for most of the deterministic analyses conducted for this study, and the attenuation relationships of Campbell and Bozorgnia (2000, 2003, revised, alluvium), and Boore et al. (1997; with NEHRP soil type D). The ground motions presented here are the ranges of the acceleration values calculated using these two attenuation equations.

Based on the ground shaking analyses described above, those faults that can cause peak horizontal ground accelerations of about 0.1g or greater (Modified Mercalli Intensities greater than VII) in the Coachella area are listed in Table 1-2. For maps showing most of these faults, refer to Figure 1-1 and Plate 1-2. Those faults included in Table 1-2 that could have the greatest impact on the Coachella area, or that are thought to have a higher probability of causing an earthquake, are described in more detail in the following pages. The deterministic analyses indicate that the San Andreas fault has the potential to generate very strong to moderate ground shaking in Coachella, with PGHA (median) of between about 0.5g and 1.05g (between 0.73g and 1.76g at the median plus 1 sigma standard deviation level). Shaking at these levels can cause significant damage to older structures, and moderate to significant damage to newer buildings constructed in accordance with the latest building code provisions. Other faults that may generate moderate to strong shaking in the study area include the San Jacinto, Burnt Mountain and Eureka Peak faults.

Table 1-2 shows:

- The approximate distance, in miles and kilometers, between the fault and various points in the Coachella area, given as a range. Since these measurements are based on specific, but randomly selected points in the study area; other points in the city could be closer or farther away from the faults than the distances provided herein;
- The maximum magnitude earthquake (M_{max}) each fault is estimated capable of generating;
- The range in peak ground horizontal accelerations (PGHA), provided both for the median (50^{th} percentile) and median plus 1 sigma standard deviation (84^{th} percentile), or intensity of ground motion, expressed as a fraction of the acceleration of gravity (g), that could be experienced in different areas of Coachella if the M_{max} occurs on the faults listed; and

- The range in Modified Mercalli seismic Intensity (MMI) values estimated for the Coachella area.

Table 1-2: Estimated Horizontal Peak Ground Accelerations and Seismic Intensities in the Coachella General Plan Area

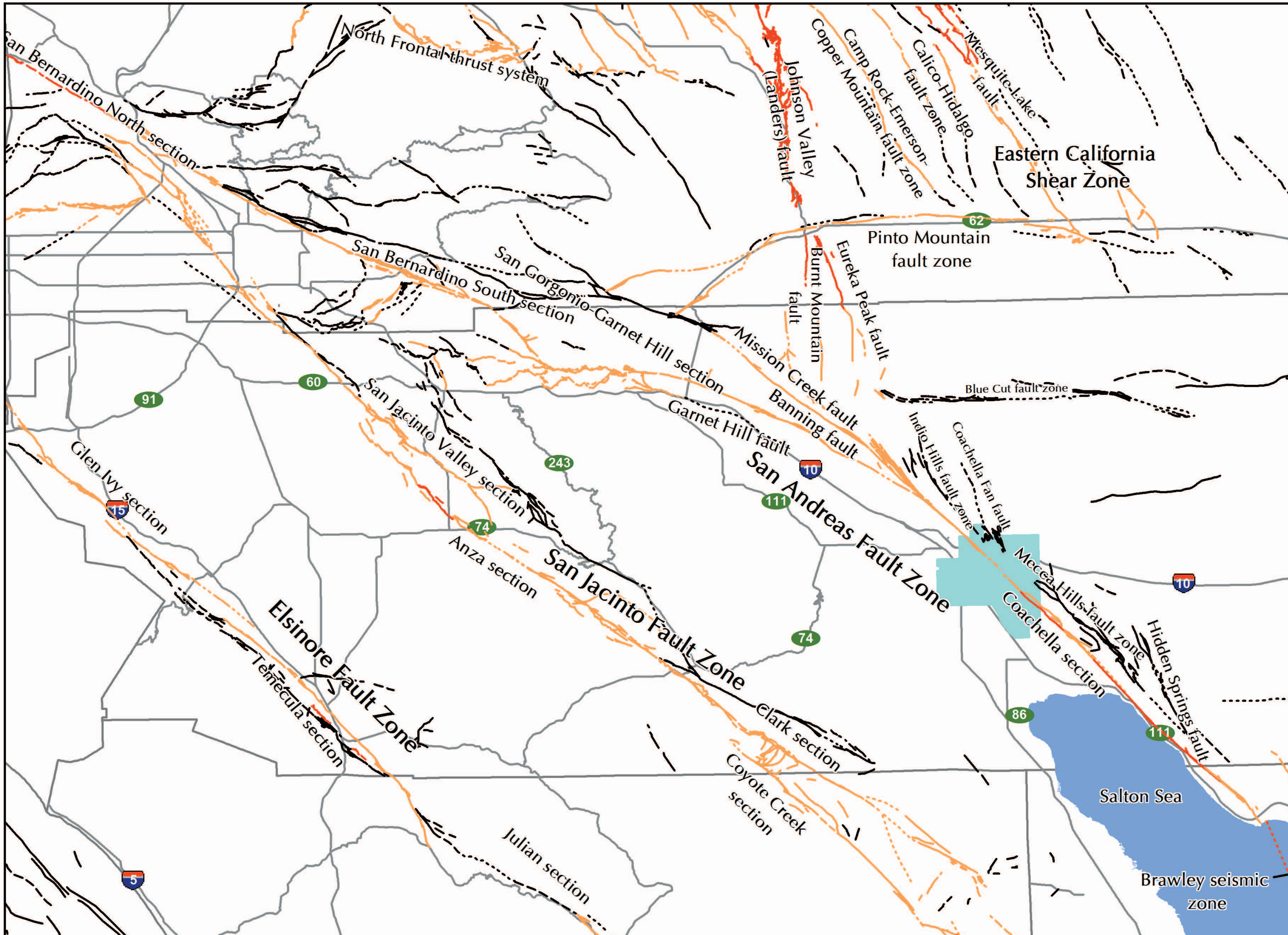
Fault or Fault Segment	Approx. Distance to Coachella (mi)	Approx. Distance to Coachella (km)	Magnitude of M_{max}	PGHA (g) from M_{max} (median, median + 1 sigma)	MMI from M_{max}
San Andreas fault (entire Southern)	0 – 6	0 – 10	8.0	1.05 – 0.5, 1.76 – 0.73	XII - X
San Andreas (Coachella segment)	0 – 6	0 – 10	7.2	0.69 – 0.42 1.15 – 0.63	XII - X
San Andreas (Coachella + San Bernardino)	0 – 6	0 – 10	7.7	0.89 – 0.47, 1.50 – 0.70	XII - X
San Andreas (San Bernardino)	21 – 29	34 – 46	7.5	0.20 –0.10, 0.31 –0.13	IX - VII
San Jacinto (Anza)	19 – 26	30 – 42	7.2	0.18 – 0.10, 0.27 – 0.15	IX – VII
Pisgah – Bullion Mtn. – Mesquite Lake	30 – 37	48 – 60	7.3	0.14 – 0.07, 0.23 – 0.12	IX - VI
Pinto Mountain	28 – 35	45 – 57	7.2	0.11 – 0.06, 0.22 – 0.11	IX – VI
Landers (Landers-like earthquake)	32 – 40	51 – 65	7.3	0.12 – 0.05, 0.21 – 0.09	VIII - VI
Burnt Mountain	18 – 26	29 – 42	6.5	0.12 – 0.05, 0.20 – 0.09	VIII - VI
Eureka Peak	18 – 26	29 – 42	6.4	0.12 – 0.05, 0.20 – 0.08	VIII - VI
San Jacinto (Clark)	21 – 28	33 – 45	6.6	0.10 – 0.05, 0.17 – 0.09	VIII – VI
Calico – Hidalgo	43 – 51	70 – 81	7.3	0.10 – 0.04, 0.17 – 0.07	VIII - V
Lenwood – Lockhart – Old Woman Springs	50 - 58	81 – 93	7.5	0.10 – 0.04, 0.17 – 0.06	VIII - V
North Frontal Fault (East)	39 – 47	63 – 75	6.7	0.10 – 0.03, 0.16 – 0.04	VIII - V
North Frontal Fault (West)	53 – 60	85 – 96	7.2	0.10 – 0.02, 0.17 – 0.04	VIII - IV

Abbreviations used in Table 1-2:
mi – miles; **km** – kilometer; $\mathbf{M_{max}}$ – maximum magnitude earthquake; **PGHA** – peak ground horizontal acceleration as a percentage of **g**, the acceleration of gravity; **MMI** – Modified Mercalli Intensity.

Several other faults have the potential to generate moderate seismic shaking in Coachella, with peak ground accelerations in the 0.02 to 0.07 range (median) and 0.03 to 0.14 range (median plus 1 sigma), with Modified Mercalli intensities in the III to VIII range. Faults that would generate these levels of shaking include: Elsinore (Julian segment), San Jacinto (San Jacinto Valley and Borrego segments), Helendale-South Lockhart, Brawley Seismic Zone, Elmore Ranch and Earthquake Valley.

Active and Potentially Active Faults

Within about 50 miles of Coachella, California



NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites,nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.

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Explanation

Fault; solid where location known, dashed where approximate, dotted where concealed. Color indicates age of movement on fault.

Age of last fault displacement.

Fault Showing Evidence of Historic Rupture (Active).

Fault Showing Evidence of Holocene Rupture (Active).

Fault Showing Evidence of Quaternary and Late Quaternary Rupture (Potentially Active).

Coachella General Plan Area

N S W E

50000 0 50000
Feet

15000 0 15000
Meters

Scale: 1:600,000

Base Map: From the City of Coachella.
Sources: U.S. Geological Survey and California Geological Survey, 2010, Quaternary fault and fold database for the United States, accessed June 2011, from USGS web site: http//earthquakes.usgs.gov/regional/qfaults/.

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Plate 1-2

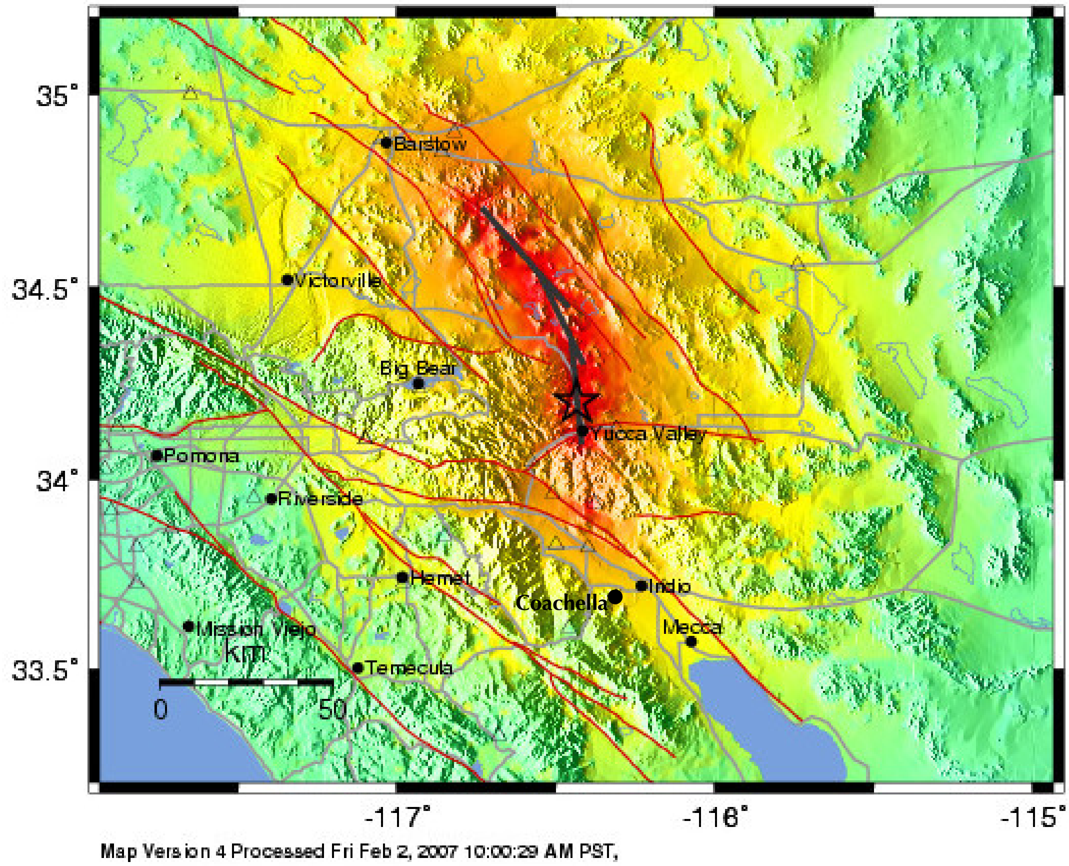
The peak ground horizontal accelerations and intensities summarized in Table 1-2 are shown from largest to lowest for each fault; these should be considered as general values, since different regions of the Coachella General Plan area are expected to feel and respond to each earthquake differently in response to site-specific conditions. As mentioned before, peak ground accelerations and seismic intensity values decrease with increasing distance away from the causative fault. However, local site conditions, such as reflection off the hard rock forming the mountains in the region, can amplify the seismic waves generated by an earthquake, resulting in localized higher accelerations than those listed here. The PHGA analyses conducted for this study provide a general indication of relative earthquake risk throughout the Coachella General Plan area. For individual projects however, site-specific analyses that consider the precise distance from a given site to the various faults in the region, as well as the local near-surface soil types, should be conducted. The faults listed in Table 1-2 are discussed further in the following sections.

The ground motions presented in Table 1-2 are based on the largest earthquake that each fault, or fault segment, is believed capable of generating, referred to as the ***maximum magnitude earthquake*** (M_{max} – as assigned by the California Geological Survey, although some researchers believe some of these faults can generate even larger events). This deterministic approach is useful to study the effects of a particular earthquake on a building or community. However, since many potential earthquake sources can shake the region, it is also important to consider the overall likelihood of damage from a plausible suite of earthquakes. This approach is called probabilistic seismic hazard analysis (PSHA), and typically considers the likelihood of exceeding a certain level of damaging ground motion that could be produced by any or all faults within a given radius of the project site, or in this case, the city, during a given timeframe. Most seismic hazard analyses consider a distance of 100 km (62 miles), but this is arbitrary. PSHA has been utilized by the U.S. Geological Survey to produce national seismic hazard maps such as those used by the Uniform Building Code (ICBO, 1997), the International Building Code (ICC, 2012) and the California Building Code (CBSC, 2013).

We ran the interactive ground motion module from the California Geological Survey (http://www.consrv.ca.gov/CGS/rghm/pshamap/pshamap.asp) and that by the U.S. Geological Survey (http://earthquake.usgs.gov/research/hazmaps/design/) to estimate the ground motions that have a 10 percent and 2 percent probability, respectively, of being exceeded in 50 years in the vicinity of City Hall. [Seismic design parameters in the 2013 California Building Code are based on the maximum considered earthquake, with a ground motion that has a 2 percent probability of being exceeded in 50 years and a recurrence interval of about 2,500 years.] For Coachella, the estimated level of ground motion that has a 10 percent probability of being exceeded in 50 years near City Hall is about 0.67g. The level of ground motion with a 2 percent probability of being exceeded in 50 years is about 1.13g. The ground motions at a site near the northeast corner of the city with a 10 percent and 2 percent probability of being exceeded in 50 years are 0.74g and 1.24g, respectively. This is the area of the city closest to the San Andreas fault, the principal source responsible for these levels of shaking, and a fault that has a high probability of rupturing in the next 30 years. These levels of shaking are in the high to very high range even for southern California, and can be expected to cause moderate to heavy damage, particularly to older and poorly constructed buildings.

Regardless of which fault causes a damaging earthquake, there will always be ***aftershocks***. By definition, these are smaller earthquakes that occur close in time and space to the ***mainshock*** (the biggest earthquake of the sequence). These smaller earthquakes occur as the Earth adjusts to the regional stress changes created by the mainshock. As the size of the mainshock increases, there typically is a corresponding increase in the number of aftershocks, the size of the aftershocks, and the size of the area in which they might occur. On average, the largest aftershock will be 1.2 magnitude units less than the mainshock. Thus, a M_W 6.9 earthquake will tend to produce aftershocks up to M_W 5.7 in size. This is an average, and there are many cases where the biggest aftershock is larger than the average predicts. The key point is this: any major earthquake will produce aftershocks large enough to cause additional damage, especially to already weakened structures. Consequently, post-disaster response planning must take damaging aftershocks into account.

Figure 1-3: Modified Mercalli Intensity ShakeMap for the June 28, 1992 Landers Earthquake



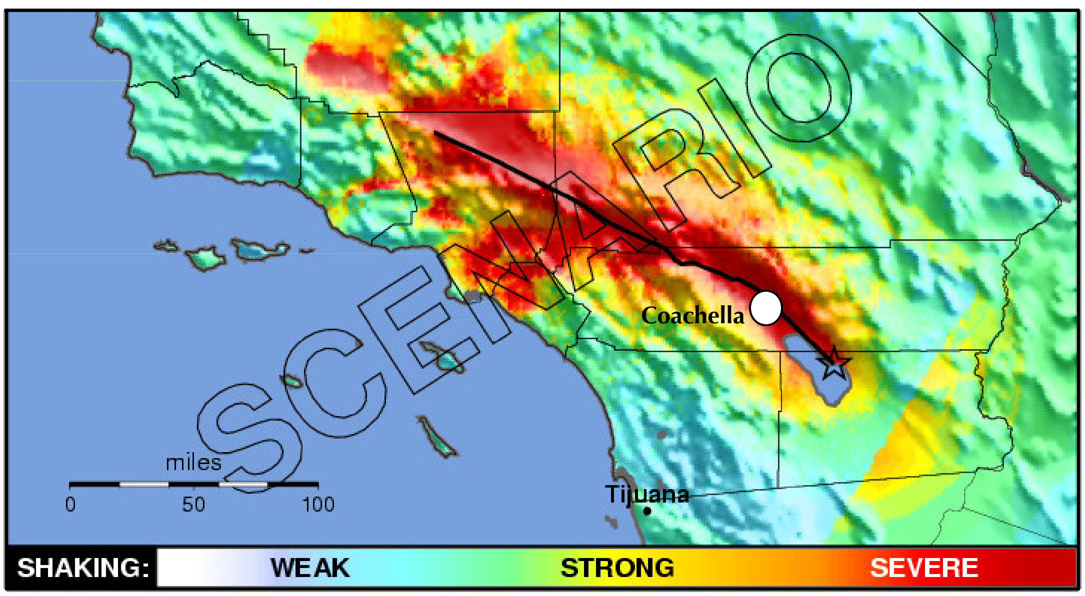
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: http://earthquake.usgs.gov/earthquakes/shakemap/sc/shake/Landers/

Another way to communicate the seismic shaking hazard is with the use of ShakeMaps. A ShakeMap is a representation of the various levels of ground shaking throughout the region where an earthquake occurs. ShakeMaps are compiled from the California Integrated Seismic Network (CISN) – a network of seismic recording instruments placed throughout the state – and are automatically generated following moderate to large earthquakes. Preliminary real-time maps are posted on the Internet, often minutes after the earthquake occurred (http://earthquake.usgs.gov/eqcenter/shakemap/), giving disaster response personnel an immediate picture of where most damage likely occurred. Although several shaking parameters can be illustrated on ShakeMaps, such as peak acceleration or velocity, most people can relate more easily to maps illustrating the *intensity* of ground shaking. Scientists have compared actual instrumental ground motion recordings to observed Modified Mercalli Intensities from recent California earthquakes to estimate shaking intensities; this allows them to estimate and develop shaking intensity distribution maps immediately following an earthquake. Figure 1-3 shows the ShakeMap generated by the U.S. Geological Survey for the 1992 Landers earthquake. Notice the strong level of shaking reported for the Coachella Valley area, including the city of Coachella.

ShakeMaps can also be used for planning and emergency preparedness by creating hypothetical earthquake scenarios. These scenarios are not predictions – knowing when or how large an earthquake will be in advance is still not possible. However, using realistic assumptions about the size and location of a future earthquake, we can make predictions of its effects, and use this information for loss estimations and emergency response planning. Figure 1-4 is an Intensity ShakeMap for the hypothetical magnitude 7.8 "ShakeOut" earthquake scenario that involves rupture of the entire southern San Andreas fault, from the Salton Sea northward to Lake Hughes, in northern Los Angeles County. The San Andreas fault would rupture through the city of Coachella, resulting in severe shaking and surface fault rupture in the region. We used the ShakeOut scenario in the loss estimation analyses presented in Section 1.9 of this report.

Figure 1-4: ShakeMap for a Magnitude 7.8 Earthquake Scenario (the ShakeOut Scenario) on the Southern San Andreas Fault



Source: http://earthquake.usgs.gov/eqcenter/shakemap/sc/shake/ShakeOut2_full_se/#Decorated

1.4.1 San Andreas Fault Zone

The San Andreas fault is the principal boundary between the Pacific and North American plates. The fault extends nearly 1,300 km (800 miles), from near Cape Mendocino in northern California to the Salton Sea region in southern California. This fault is considered the "Master Fault" in southern California because it has relatively frequent, large earthquakes and controls the seismic hazards of the area. Many refer to an earthquake on the San Andreas fault as "The Big One," and for many parts of southern California, including Coachella, this designation is indeed true. Other areas are actually at greater risk from other faults. Nevertheless, the San Andreas fault should be considered in all seismic hazard assessment studies in southern California given its high probability of causing an earthquake in the near future. In 2007-2008, a group of scientists referred to as the 2007 Working Group on California Earthquake Probabilities (WGCEP, 2008) calculated that the southern San Andreas fault had a 59 percent probability of causing an earthquake of at least magnitude 6.7 in the next 30 years. That probability increases with each passing year without an earthquake.

Large faults, such as the San Andreas, are often divided into segments and sections. The sections are typically based on physical characteristics along the fault, particularly changes in dip and/or strike, and style of faulting. Each fault section is assumed to have a characteristic slip rate (rate of movement averaged over time), recurrence interval (time between moderate to large earthquakes), and displacement (amount of offset during an earthquake). Historical records and studies of prehistoric earthquakes show it is possible for more than one section to rupture during a large quake or for ruptures to overlap into adjacent sections. For example, the last major earthquake on the southern portion of the San Andreas fault (and the largest earthquake reported in California) was the 1857 Fort Tejon (magnitude 8) event. The 1857 earthquake ruptured the Cholame, Carrizo, Big Bend, and Mojave North and Mojave South sections of the fault, resulting in displacements of as much as 27 feet (9 meters) along the rupture zone. There are data that suggest that these sections and portions of sections, which are combined into a fault segment, tend to rupture together time and time again in what is referred to as a "characteristic earthquake."

The definition and naming of the various sections, segments, fault strands and fault splays have varied over time, the result of many investigators working on different aspects and parts of the fault zone, and the recent efforts to compile these data into a unified model. In this report, the fault nomenclature used follows that defined by the 2007 Working Group on California Earthquake Probabilities (WGCEP, 2008). The southern and central San Andreas fault is now divided into ten sections named, from north to south, Parkfield, Cholame, Carrizo, Big Bend, Mojave North, Mojave South, San Bernardino North, San Bernardino South, San Gorgonio-Garnet Hill, and Coachella (WGCEP, 2008). The southernmost sections are discussed further below, starting with the Coachella section, as this is the section that extends through the Coachella General Plan area.

The **Coachella section** comprises the relatively straight, predominantly right-lateral strike slip fault that extends from Bombay Beach in the Salton Sea northward to the Biskra Palms area north of Indio, a distance of about 42 miles. The Coachella section is the only section of the southern San Andreas that has not produced a major earthquake in historic times (Sieh and Williams, 1990; Fumal et al., 2002; Philibosian et al., 2011). Paleoseismic studies indicate that the last surface-rupturing earthquake on this segment occurred more than 320 years ago, around A.D 1680 (Sieh and Williams, 1990) or A.D. 1690 (Philibosian et al., 2011).

At least five detailed studies have been conducted along the Coachella section of the fault from Indio southward, in addition to dozens of site-specific fault investigations conducted in response to zoning of the fault under the Alquist-Priolo Earthquake Fault Zoning Act (see Section 1.5). The detailed studies include the Indio site investigated by Sieh (1986), the Coachella site by Philibosian et al. (2011), the Stone Ring Gullies site of Shifflett et al. (2002), the Ferrum site (Sieh and Williams, 1990), and the Salt Creek site (Sieh and Williams, 1990; Williams, 2009). The two studies of most relevance to the Coachella General Plan area are those by Sieh and Williams (1990), and Philibosian et al. (2011).

At the Indio site just north of the city of Coachella, the stratigraphy and fault relations exposed in the trenches allowed Sieh (1986) and Sieh and Williams (1990) to interpret at least four surface-rupturing earthquakes on this section of the fault between A.D. 1000 and A.D. 1700. The most recent earthquake was dated, based on radiocarbon dating of stream and lake deposits exposed in the trenches, at between A.D. 1640 and A.D. 1720, with a preferred date of A.D. 1680. Three previous earthquakes occurred at about A.D. 1450 (±150 years), A.D. 1300 (±90 years), and A.D. 1020 (±20 years). Using these data, the Working Group on California Earthquake Probabilities (1995) calculated an average recurrence interval of 220 ±13 years for this section of the San Andreas fault. More recently, the 2007 Working Group (WGCEP, 2008) calculated an average recurrence interval of 246 years that includes the open interval since the most recent earthquake in about A.D. 1680 (that is, the time period between 1680 and 2006, when the calculation was made). With each passing year without an earthquake on this section of the fault, the average recurrence interval increases a bit.

At the Coachella site, located to the southwest of the intersection of Dillon Road and Avenue 44 in the city of Coachella, Philibosian et al. (2011) exposed evidence for five, and possibly as many as seven or eight, surface-rupturing earthquakes between A.D. 800 and the present. The most recent event (MRE) is dated at between A.D. 1657 and A.D. 1713, with a preferred date of A.D. 1690 (to the nearest decade). Preferred dates (also to the nearest decade) for previous earthquakes include A.D. 1630, A.D. 1420, A.D. 1300, A.D. 1140, A.D. 990, and A.D. 930. Using only the closed earthquake intervals, that is, the time bracketed in between two known earthquakes, the average recurrence interval for this section of the San Andreas fault based on the data collected at the Coachella site is between about 116 and 202 years. If the current open interval of about 320 years, since the last known earthquake, is included in the calculations, the average recurrence interval increases to between 150 and 221 years.

Although this fault section has not had a historical earthquake, portions of it are shown as having historical slip on Plate 1-2 because creep at rates of between about 1 and 4 mm/yr has been measured on it. This creep is the result of both continuous slip and slip triggered by earthquakes (Louie et al., 1985; Sieh and Williams, 1990; Lyons and Sandwell, 2003). Earthquakes that are known to have resulted in triggered slip on the southern San Andreas fault include the 1968 Borrego Mountain and 1979 Imperial Valley earthquakes (Clark, 1984, referencing Allen et al., 1972 and Sieh, 1982; Williams et al., 1986), the 1987 Elmore Ranch-Superstition Hills sequence (Sharp et al., 1989), the 1992 Joshua Tree-Landers-Big Bear sequence (Bodin et al., 1994; Lyons and Sandwell, 2003), and the 2010 El Mayor-Cucapah earthquake (Weldon, 2010; Wei et al., 2011; http://cires.colorado.edu/~bilham/LagunaSalada4April2010/Baja4April.html). This is only a small amount of the overall late Quaternary slip rate that has been calculated for the Coachella section of the fault, estimated at about 30 mm/yr at the Indio site (Sieh, 1986). More recently, the 2007 Working Group on California Earthquake Probabilities assigned the Coachella section a slip rate of 20 ±3 mm/yr, (although in some alternate models they use a slip rate as low as 16 ±3 mm/yr and as high as 24 ±3 mm/yr). The small amount of aseismic creep is not sufficient to release all of the strain that has accumulated on this fault section since its last surface-rupturing earthquake at about A.D. 1680. It is for this reason that this section of the fault is considered to have a high probability of rupturing in the next 30 years.

The **San Gorgonio-Garnet Hill section** is about 41 miles long, and extends westerly from just north of Indio, through the San Gorgonio Pass, to just south of Burro Flats. From south to north, this section is comprised of two main branches (the Banning fault on the south, and the Mission Creek fault on the north), in addition to several other faults including the Garnet Hill fault. At its western end, the Garnet Hill fault merges with the San Gorgonio Pass fault. Unlike the Coachella section to the south, this section is very complex, being mostly oblique strike-slip, with a major thrust component of movement (Yule and Sieh, 2003).

The *Banning fault* is an older, right-lateral strike-slip structure dating back to latest Miocene time (about 4 or 5 to 7.5 million years ago), when it served as an ancestral strand of the San Andreas fault (Matti and Morton, 1993). Based on geologic and geomorphologic characteristics, as well as the fault's tectonic history during the last two million years, Matti et al. (1992) have divided the Banning fault into three segments. Its western segment, extending from the San Jacinto fault southeastward to the Calimesa area, is considered not active because it does not break Quaternary alluvium and has no surface expression (the location of the fault has been inferred from gravity data and other indirect geologic evidence). The central segment, which extends from Calimesa to Cottonwood Canyon, for the most part also does not affect Quaternary deposits, and has been overprinted by reverse and thrust faults that are probably related to development of the San Gorgonio Pass Fault Zone. There is, however, a 2-mile long section of the central Banning fault, with thrust-type motion, that offsets young alluvium in Millard Canyon. Therefore, the fault is active in that area (Yule and Sieh, 2003). The easternmost portion of the ancestral Banning fault, from Cottonwood Canyon to its junction with the Coachella section of the fault near the Indio Hills, has been reactivated during Quaternary time, and has many geomorphic characteristics of youthful strike-slip activity.

The *Mission Creek fault* has right-lateral strike-slip motion along most of its trace, but gradually evolves into thrust-type motion at its western end. Some researchers have suggested this fault is either an older strand of the San Andreas, that is less active than other strands, or is no longer active (Matti et al., 1992; Yule and Sieh, 2003). This is most likely true for the northern end of the fault, but trenching near its southern end, at Thousand Palms Oasis, has shown that at this site, the fault has experienced four and probably five surface-rupturing earthquakes in the past about 1,200 years (Fumal et al., 2002). The most recent earthquake on this strand is most likely the same A.D. 1680 event reported by Sieh (1986) and Sieh and Williams (1990) at the Indio site. Comparison of data obtained at this site with data from the Indio site to the south, and the Wrightwood site about 75 miles (120 km) to the northwest, suggests that the southernmost 125 miles (200 km) of the San Andreas fault rupture together in large earthquakes (Fumal et al. 2002; Fumal, Rymer and Seitz, 2002).

The *Garnet Hill fault* parallels the trend of the Banning fault, extending from a few miles west of Whitewater south to Thousand Palms, where the fault trace dies out. The fault is primarily a right-lateral strike-slip fault along most of its trace, but splays into a series of oblique reverse faults at its western end. Based on seismological data, Yule and Sieh (2003) conclude that the Garnet Hill fault and the Banning fault merge at a depth of about 5 km, and that the single fault plane below this depth was the source of the 1986 North Palm Springs earthquake. They further suggest that the Garnet Hill fault merges with the San Gorgonio Pass Fault Zone to carry slip between the disconnected segments of the San Andreas fault, thus making the Banning-Garnet Hill-San Gorgonio Pass system a significant seismic source in the region.

The *San Gorgonio Pass Fault Zone* consists of a series of north-dipping reverse and thrust faults linked by strike-slip tear faults, giving its surface trace an irregular, saw-tooth appearance (Yule and Sieh, 2003). This zone begins near Cottonwood Canyon and extends westward to the Calimesa area. Faults within this east-west trending zone have thrust ancient crystalline rock southward over younger sedimentary rock and alluvial sediments. These faults formed during the Pleistocene in response to compression created by the bend and the step-over in the trace of the San Andreas fault; activity of some of these faults has continued into the Holocene, as indicated by many youthful scarps that are present in young alluvium (Matti et al., 1992; Yule and Sieh, 2003).

The San Gorgonio-Garnet Hill section is thought to have last ruptured in 1812, although additional studies need to be conducted to confirm this (Yule et al., 2006; Dawson et al., 2008). Paleoseismic data also suggest that the Coachella, San Gorgonio-Garnet Hill, and San Bernardino sections ruptured simultaneously in earthquakes that occurred around A.D. 1500, and possibly A.D. 1680 (Dawson et al., 2008, summarizing data by Fumal et al., 2002, Yule et al., 2006, and McGill et al., 2002). Investigators suggest that some of the strain is also being transferred northward onto the faults in the Indio Hills and probably the Eastern California Shear Zone. The 2007 WGCEP (2008) assigned a slip rate of 10±6 mm/yr to the San Gorgonio-Garnet Hill section.

Rupture of the Coachella and San Gorgonio-Garnet Hill fault segments in a magnitude 7.2 earthquake is estimated capable of generating peak ground accelerations in Coachella of about 0.4g to 1.2g. If the Coachella, San Gorgonio-Garnet Hill and San Bernardino (South and North) sections rupture together in a magnitude 7.7 earthquake, Coachella would experience peak ground accelerations of between 0.5g and 1.5g. These are strong to very strong ground motions.

The **San Bernardino (South and North) segments** combined are about 43 miles (70 km) long and extend from the Burro Flats area northward to approximately Cajon Pass. These faults, like the Coachella section, appear to be nearly vertical, with a predominant strike-slip in motion. Slip rate on the San Andreas fault in this area decreases southward. At the north end of the San Bernardino North segment, in the area of Cajon Pass and Pittman Canyon, the fault has a slip rate of 22±6 mm/yr. To the south, some of the slip is being transferred to the San Jacinto fault through the Crafton Hills fault and related structures, so that slip on the San Bernardino South segment is estimated at 16±6 mm/yr (WGCEP, 2008). Both segments appear to have last ruptured in 1812. If both sections rupture together in the future, the resultant magnitude 7.5 earthquake could cause peak ground accelerations in Coachella of between 0.10g and 0.31g. If, as discussed above, the San Bernardino sections rupture in conjunction with the Mojave, San Gorgonio Pass-Garnet Hill and/or Coachella sections, higher ground motions would be expected in the region.

1.4.2 San Jacinto Fault Zone

The San Jacinto Fault Zone consists of a series of closely spaced faults that form the western margin of the San Jacinto Mountains. The zone is about 280 km (175 miles) in length and extends from its junction with the San Andreas fault in San Bernardino, southeasterly toward the Brawley area, where it continues south of the international border as the Imperial fault. The San Jacinto fault has historically produced more large earthquakes than any other fault in southern California, although none of these earthquakes has been as large as the 1857 and 1906 earthquakes on the San Andreas fault. The two most-recent surface-rupturing earthquakes on the San Jacinto fault were the April 9, 1968, M_w 6.5 on the Coyote Creek section (Jennings, 1994), and the 1987 event on the Superstition Hills section. Offset across the fault traces is predominantly right-lateral strike-slip, similar to the San Andreas fault, although Brown (1990) has suggested that vertical motion contributes up to 10 percent of the net slip.

The San Jacinto Fault Zone has been divided into eight sections. From north to south these include the San Bernardino Valley, San Jacinto Valley, Anza, Coyote Creek, Clark, Borrego, Superstition Mountain, and Superstition Hills sections. Fault slip rates on the various sections of the San Jacinto fault are less well constrained than for the San Andreas fault, but the data available suggest right-lateral slip rates of 6 to 18 (±4 to 6) mm/yr for the northern and central sections of the fault and slip rates of 4 to 5 (±2 to 6) mm/yr for the Coyote Creek and other sections to the south (WGCEP, 2008). This amounts to between about 8 and 36 percent of the total slip on the San Andreas fault system. The Working Group on California Earthquake Probabilities (1995) gave the San Bernardino and San Jacinto Valley segments a 37 percent and 43 percent probability, respectively, of rupturing sometime between 1994 and 2024. These probabilities were reduced somewhat by the WGCEP (2008), to an average of 31 percent for all segments of the San Jacinto fault. The segments of the San Jacinto fault closest to Coachella include the Anza, Clark, and Coyote Creek. These sections are discussed further below.

The **Anza section** of the fault has been studied extensively at Hog Lake, where at least 16 past earthquakes have been resolved from the faulted stratigraphy (WGCEP, 2008 based on data provided by T. Rockwell). The data indicate an average recurrence interval of 238 years for this section, with the most recent earthquake having occurred between about A.D. 1775 and A.D. 1805. This fault section has a slip rate of about 18 (±6) mm/yr. A M_w 7.2 earthquake on this segment would generate peak ground accelerations in the Coachella area of between about 0.10g and 0.27g.

The next sections to the south, the **Clark** and **Coyote Creek**, are sub-parallel to each other, with the Clark section on the east, closer to Coachella. Each section is about 15 miles (24 km) long. There are no paleoseismic data for these sections, so fault parameters, such as slip rate and recurrence interval, are not well defined. Using geodetic data, and assuming that the slip rate from the Anza section to the north is being transferred southward and is being distributed (partitioned) between the two sections, the WGCEP (2008) assigned a slip rate of 14 (±6) mm/yr to the Clark section, and a rate of 4 (±6) mm/yr to the Coyote Creek section. A M_w 6.6 earthquake on either of these sections of the San Jacinto fault would generate peak ground accelerations in Coachella of between about 0.05g and 0.17g.

1.4.3 Pisgah – Bullion Mountain – Mesquite Lake Fault Zone

The Pisgah fault is a 34-km- (21-mile-) long, right-lateral strike-slip fault that experienced triggered slip in 1992 as a result of shaking from the Landers earthquake. The fault is thought to have moved in the past about 11,000 years (during the Holocene, which makes it an active fault), but the interval between surface-rupturing earthquakes on this fault is unknown. The zone is thought to slip at a rate of about 0.8 mm/yr, but geologic studies need to be conducted to confirm these estimates. If only the Pisgah fault ruptured in an earthquake, the resulting event would have a magnitude M_w between 6.0 and 7.0. However, the Pisgah fault may also rupture together with the 55-km- (34-mile-) long Bullion fault to the south, and the 40-km- (22-mile-) long Mesquite Lake fault farther south. The Bullion fault last ruptured on October 16, 1999 during the M_w 7.1 Hector Mine earthquake. Prior to that, both the Bullion and Mesquite Lake faults appear to have ruptured during a large earthquake in the mid to late Holocene (Madden et al., 2006).

Recent studies of the Mesquite Lake fault have shown that this fault has had three large surface-rupturing earthquakes in the past about 10,200 years, each creating an apparent vertical offset of between 1.0 and 1.2 meters, suggesting similar-sized earthquakes. The trenching data indicate this fault has a horizontal slip rate of between 0.7 and 0.9 mm/yr, consistent with the slip rates estimated for several other faults in the Mojave Desert. The paleoseismic data also seem to suggest that earthquakes on this fault occur in clusters, separated by seismically quiet periods that last several thousands of years, and that seismic activity in the shear zone alternates between the eastern and western faults in the region (Madden et al., 2006).

A magnitude 7.3 earthquake is estimated if all three fault segments – the Pisgah, Bullion Mountain and Mesquite Lake – ruptured together. An earthquake of that size on these faults would generate peak horizontal ground accelerations in the Coachella area of about 0.07g to 0.23g, with Modified Mercalli intensities of VI to IX.

1.4.4 Pinto Mountain Fault

The Pinto Mountain fault is a prominent left-lateral strike-slip fault that bounds the north side of the Little San Bernardino Mountains, about 28 miles north-northwest of the city of Coachella at its closest approach. The fault is at least 45 miles (73 km) long, and possibly as much as 56 miles (90 km). Relatively recent studies show that this fault has ruptured repeatedly in the past 14,000 years, with at least four events within the past about 9,400 years (Cadena et al., 2004). The fault is therefore active under the provisions of the Alquist-Priolo Act. Current estimates on its rate of slip suggest a rate of between 1.1 and 2.3 mm/yr. Additional studies should refine those estimates further. A magnitude 7.2 earthquake on this fault could generate peak horizontal ground acceleration in Coachella of about 0.06g to 0.22g. Such an earthquake would cause damage in Coachella typical of Modified Mercalli intensities between VI and IX. An even larger, magnitude 7.5, earthquake on the Pinto Mountain fault would generate stronger ground shaking in the Coachella area.

1.4.5 Landers (or Kickapoo) Fault

The Landers fault was the name given to the group of faults that ruptured during the 1992 Landers earthquake, including the Homestead Valley, Kickapoo, and Johnson Valley faults, and segments of the Burnt Mountain and Eureka Peak faults. Now, the name Landers is used to refer to the Kickapoo fault. The interval between major ruptures on these faults is uncertain, but is probably in the thousands of years, which is why these faults were unknown or poorly known prior to 1992. In 1992, however, some of these faults experienced significant lateral displacements – the Kickapoo fault moved laterally nearly 9.5 feet (3 meters) (Sieh et al., 1993). Individually, these faults could rupture in smaller earthquakes, but their combined lengths allowed for the magnitude 7.3 earthquake that shook southern California on the morning of June 28, 1992. Ground shaking in the Coachella area due to a Landers-type earthquake on these faults would cause horizontal ground accelerations of between 0.05g and 0.21g, with Modified Mercalli intensities in the VI to VIII range.

1.4.6 Burnt Mountain Fault

Like several other Mojave (or Eastern California) Shear Zone faults, the Burnt Mountain fault was unknown prior to late June 1992, when a 3.1-mile- (5 km) length of this fault ruptured at the ground surface, probably during a large aftershock of the Landers earthquake, experiencing about 2.4 inches (6 cm) of right-lateral offset. Geologists later mapped the area and determined that the Burnt Mountain fault has a total length of about 13 miles (21 km). Given its overall length (Wesnousky, 1986), this fault is thought capable of producing a magnitude 6.0 to 6.5 earthquake. The Burnt Mountain fault is at its closest approach about 18 miles to the north of Coachella. An estimated M_w 6.5 earthquake on this fault could generate horizontal ground accelerations in the Coachella area of between about 0.05g and 0.20g, with the higher accelerations occurring in the northern portions of the city, closest to the fault. The level of damage anticipated would be consistent with Modified Mercalli intensities of between VI and VIII.

1.4.7 Eureka Peak Fault

The Eureka Peak fault is a right-lateral strike-slip fault about 12.5 to 15 miles (20 to 25 km) in length that last ruptured, together with other faults, during the 1992 Landers earthquake. Only about 6 miles (10 km) of the fault ruptured at that time, but this allowed geologists to discover the fault and map its full length. Maximum offset on this fault in 1992 was 8-1/4 inches (21 cm); geologists think that this slip occurred in two separate but closely spaced events, plus some afterslip. The first rupture is thought to have occurred about 30 seconds after the Landers mainshock, whereas the second rupture episode was probably as a result of a magnitude 5.6 aftershock that occurred less than three minutes after the mainshock. Researchers have also suggested that the Joshua Tree earthquake of April 22, 1992 was caused by this fault (Jones et al., 1995). The Southern California Earthquake Center estimates that the Eureka Peak fault is capable of generating earthquakes of moment magnitude between 5.5 and 6.8. An average M_w 6.4 earthquake on this fault is estimated capable of generating horizontal peak ground accelerations in Coachella of between 0.05g and 0.20g.

1.4.8 Calico – West Calico - Hidalgo Fault Zone

The Calico fault is a 55-km (34 mile) long, right-lateral strike-slip structure that exhibited triggered slip during the 1992 Landers earthquake and was the source of a M_L 5.3 earthquake that shook the eastern California area on March 18, 1997. The 1997 earthquake is considered the last large aftershock of the 1992 Landers earthquake, and its epicenter was on the northern section of the fault, about 12 miles east-northeast of Barstow, near the Calico Mountains.

The Calico fault is the longest and fastest-slipping of the faults in the Eastern California Shear Zone, with slip rate estimated at between 1.0 and 2.6 mm/yr. The recurrence interval between earthquakes on this fault is estimated at about 1,500 years (http://www.scecdc.scec.org/fault_index/), although researchers have suggested that in this portion of the southern California fault system, earthquakes recur in clusters, with long periods of inactivity in between (Rockwell et al., 2000). Geologists are currently conducting paleoseismic studies of the Calico fault in an effort to better understand its past earthquake history and test the strength of the earthquake clustering hypothesis (Oskin et al., 2007).

Based on its length, the Calico fault is thought capable of generating an M_w 6.5 to 7.1 earthquake; however, the Calico fault is essentially continuous with the West Calico and Hidalgo faults to the south, and all three of these faults could rupture at the same time, potentially producing a larger magnitude earthquake. The 40-km (25 miles) long Hidalgo fault is thought to have a slower slip rate of only about 0.5 mm/yr, and its earthquake history is unknown. Alone, the Hidalgo fault is thought capable of generating an M_w 6.4 to 7.1 earthquake. For the purposes of this study, and in conformance with the California Geological Survey's fault parameters table (Cao et al., 2003), these faults are assumed to break concurrently in an M_w 7.3 earthquake. Such an event would produce peak horizontal ground accelerations in the Coachella area of between about 0.04g and 0.17g, with Modified Mercalli intensities in the V to VIII range.

1.4.9 Lenwood – Lockhart – Old Woman Springs Faults

Another of the Eastern California Shear Zone faults, the Lenwood fault is a right-lateral strike slip fault approximately 47 miles (75 km) long with a slip rate of about 0.8 mm/year. Trenching studies have shown that the fault has ruptured at least three times in the Holocene, roughly 200-400, 5,000-6,000, and 8,300 years ago, for a recurrence between major surface ruptures of 4,000 to 5,000 years. Prior to the 1992 Landers earthquake, when the fault experienced triggered slip near its southeast end, aseismic creep on this fault had been recorded but not verified (http://www.scecdc.scec.org/fault_index/).

The Lockhart fault, located north of the Lenwood fault, is a right-lateral strike-slip fault approximately 44 miles (70 km) long. The North Lockhart fault – a segment that shows no evidence of Holocene activity – adds 6 miles (10 km) to the length above. The interval between major surface-rupturing earthquakes on the Lockhart fault is estimated at between 3,000 and 5,000 years (Jennings, 1994), with the central portion of the fault having ruptured during the Holocene, and segments both to the north and south believed to have last ruptured in the Quaternary (http://www.data.scec.org/fault_index/lockhart.html).

The Old Woman Springs segment is the main trace of a complex system of faulting at the junction between the Eastern segment of the North Frontal Fault Zone and the Lenwood fault. The Old Woman Springs trace is about 6 miles (10 km) long and exhibits right-lateral strike-slip movement with some vertical slip. The fault is thought to have last moved in the Holocene (http://www.scecdc.scec.org/fault_index/), and is therefore considered active.

Although the Lenwood and Lockhart faults form an essentially continuous, 150-km- (90-mile-) long system, there is no evidence that both of these faults have ruptured together in the past. Nevertheless, such an event might be possible, as evidenced by rupture of five separate fault segments during the Landers earthquake. For the purposes of this study, these faults, together with the Old Woman Springs fault, are assumed to rupture together in a magnitude 7.5 maximum magnitude earthquake. Such an event would generate peak ground accelerations in Coachella of between about 0.04g and 0.17g, with Modified Mercalli Intensities in the V to VIII range. If only one of these faults ruptures in an earthquake, the smaller magnitude event would cause lesser ground motions in Coachella than those reported above.

1.4.10 North Frontal Fault

This south-dipping, partially blind reverse fault zone along the eastern flank of the San Bernardino Mountains consists of several fault splays that have a combined total length of approximately 65 km (40 miles). Several of the fault splays interact with other nearby faults; the most significant of these is the Helendale fault, which seems to right-laterally offset the North Frontal Fault Zone, dividing it into two main segments (referred to as the East and West segments; Meisling, 1984; Bryant, 1986).

The North Frontal fault is thought to have moved in the past 10,000 years, making it an active fault. However, the fault has not been studied in detail, and its recurrence interval, slip rate and other fault parameters are not well understood, although a slip rate of about 0.5 mm/yr is attributed to it. Furthermore, movement on this fault is thought to be responsible for an average uplift rate of about 1 mm/yr of the San Bernardino Mountains. Based on its length, the East segment of the North Frontal Fault Zone is thought capable of generating a maximum magnitude 6.7 earthquake. An earthquake of that size on this fault would be felt in Coachella with peak ground accelerations of between about 0.03g and 0.16g, resulting in Modified Mercalli intensities as high as VIII. If the more distant West segment of the North Frontal Fault Zone ruptured in a 7.2 earthquake, the Coachella area would experience ground shaking of about 0.02g to 0.17g, with Modified Mercalli intensities in the IV to VIII range.

1.4.11 Elsinore Fault Zone

The Elsinore fault is a major right-lateral strike-slip fault that extends from northern Baja California to the Los Angeles Basin, a distance of approximately 306 km (190 miles) (Treiman, 1998). As part of the San Andreas fault system in southern California, the Elsinore fault accommodates about 10 percent of the motion between the Pacific and North American plates (WGCEP, 1995), with a slip of about 5 mm/yr (Bergmann et al., 1993; Millman and Rockwell, 1986; Vaughan and Rockwell, 1986). The 2007 Working Group on California Earthquake Probabilities (WGCEP, 2008) assigned the Elsinore fault an 11 percent probability of rupturing in a M>6.7 earthquake in the next 30 years.

The fault is divided, from south to north into the Laguna Salada, Coyote Mountain, Julian, Temecula, Glen Ivy, and Whittier sections (WGCEP, 2008). The section closest to Coachella is the **Julian segment**, which at its nearest approach is about 42 miles to the west. The 42-mile (68-km) long Julian segment is the longest section of the Elsinore Fault Zone. Its north end is defined by a restraining bend, whereas at its south end, it steps across a 4- to 5-km wide area to the Coyote Mountain section. The most recent surface-rupturing earthquake on this section appears to have occurred about 1,500 years ago, and the penultimate event about 3,000 years ago. There are too few earthquakes resolved on this segment to calculate a recurrence interval. If the Julian segment of the Elsinore fault ruptured in a M 7.1 earthquake, peak ground motions of about 0.03g to 0.14g are anticipated in the Coachella area.

1.4.12 Blue Cut Fault

Although this fault is not included in the State's database of active faults thought capable of generating an earthquake (Cao et al., 2003), and is not identified by either the State or the U.S. Geological Survey as a recently active fault (see Plate 1-2), the Blue Cut fault does have geomorphic expression and thus, may be active. The fault has been the subject of only very limited studies (Hope, 1969a; Crippen and Spencer, 1984; Schell and Schell, 1994, Blythe et al., 2011) that have relied primarily on geomorphic interpretation of maps and aerial photographs, field mapping, and evaluation of fault scarp morphology. Exploratory trenches across the mapped trace of the fault have not, to our knowledge, ever been conducted, most likely because the fault is located in its entirety in the Joshua Tree National Park. The fault is reportedly about 80 km (50 miles) long (Schell and Schell, 1994) extending eastward from the San Bernardino Mountains to the Pinto Basin. The Blue Cut fault is similar in orientation and style to several other east- to northeast-trending, left-lateral faults, including the Pinto Mountain and Garlock faults to the north, that have accommodated (and are accommodating) significant clockwise rotation in the Mojave Desert (Blythe et al., 2011). The fault may be the source of large (M7 to M7.25) but infrequent earthquakes, with a recurrence interval in the tens of thousands of years (Schell and Schell, 1994).

Ground motions in Coachella as a result of an earthquake on the Blue Cut fault were not estimated. However, given that the fault is less than 20 km (12 miles) from Coachella, if the fault ruptures generating a moderate (>M6.5) to large (>M7) earthquake, shaking in Coachella will be strong to very strong, with Modified Mercalli intensities in the VIII to XI range.

1.5 Surface Fault Rupture

1.5.1 Definitions

Primary fault rupture refers to fissuring and displacement of the ground surface along a fault that breaks in an earthquake. Primary fault rupture is rarely confined to a simple line along the fault trace. As the rupture reaches the ground surface, it commonly spreads out into complex fault patterns of secondary faulting and ground deformation. In the 1992 Landers earthquake, the zone of deformation around the main trace was locally hundreds of feet wide (Lazarte et al., 1994). Surface displacement and distortion associated with secondary faulting and deformation can be relatively minor or can be large enough to cause significant damage to structures.

Primary ground rupture due to fault movement typically results in a relatively small percentage of the total damage in an earthquake, yet being too close to a rupturing fault can result in extensive damage. It is difficult and generally costly to safely reduce the effects of this hazard through building and foundation design. Therefore, the preferred, and traditional mitigation measure for this hazard is to avoid active faults by setting structures back from the fault zone. In California, application of this measure is subject to requirements of the Alquist-Priolo Earthquake Fault Zoning Act and guidelines prepared by the California Geological Survey – previously known as the California Division of Mines and Geology (CGS Note 42 by Hart and Bryant, 2007). The final approval of a fault setback lies with the local reviewing agency.

Secondary fault rupture refers to ground surface displacements along faults other than the main traces of active regional faults. Secondary ground deformation includes fracturing, shattering, warping, tilting, uplift and/or subsidence. Unlike the regional faults, most subsidiary faults are not deeply rooted in the Earth's crust and are not capable of producing damaging earthquakes on their own. Movement along these faults generally occurs in response to movement on a nearby regional fault. Yet, the zone of secondary faulting can be quite large, even in a moderate-sized earthquake. For instance, in the 1971 San Fernando earthquake, movement along subsidiary faults occurred as much as 2 km from the main trace (Ziony and Yerkes, 1985). Triggered slip as a result of a regionally large earthquake can also occur in faults many kilometers away from the causative fault. For example, as a result of the 1992 Landers earthquake, triggered surface slips were documented in the Coachella Valley area (Rymer, 2000). Similarly, following the 1999 Hector Mine earthquake, triggered surface slips were recorded in the Salton Trough (Rymer et al., 2002; Meltzner et al., 2006). More recently, as a result of the April 4, 2010 Sierra El Mayor-Cucapah earthquake in Baja California, triggered slip was reported on the San Andreas, Superstition Hills, Imperial and Brawley fault zones (Weldon, 2010, http://response.scec.org/node/273; Wei et al., 2011).

Faults have formed over millions of years, usually in response to regional stresses. Shifts in these stress regimes do occur over millennia. As a result, some faults change in character. For example, a thrust fault in a compressional environment may become a strike-slip fault in a transpressive (oblique compressional) environment. Other faults may be abandoned altogether, and previously not active faults may be reactivated. Consequently, the State of California, under the guidelines of the Alquist-Priolo Earthquake Fault Zoning Act of 1972 (Hart and Bryant, 1999, 2007), classifies faults according to the following criteria:

- ***Active***: faults showing proven displacement of the ground surface within about the past about 11,000 years (within the Holocene Epoch), that are thought capable of producing earthquakes;

- ***Potentially Active***: faults showing evidence of movement within the past 1.6 million years, but that have not been shown conclusively whether or not they have moved in the past 11,000 years; and

- ***Not active***: faults that have conclusively NOT moved in the past about 11,000 years.

The Alquist-Priolo classification is used primarily for residential subdivisions. Different definitions of activity are used by other agencies or organizations depending on the type of facility being planned or developed. For example, longer periods of inactivity are generally required for dams or nuclear power plants. Faults that have ruptured historically form an important subset of active faults. In California, that generally means faults that have ruptured since 1769, when the Spanish first arrived and settled in the area. However, since many parts of the State were not settled until well into the middle of the 1800s, some historical earthquakes most likely went un-noticed and therefore unreported.

The underlying assumption in this classification system is that if a fault has not ruptured in the past about 11,000 years, it is not likely to be the source of a damaging earthquake in the future. In reality, however, most potentially active faults have been insufficiently studied to determine their hazard level. For example, some of the faults that ruptured in the 1992 Landers and 1999 Hector Mine earthquakes were previously thought to be not active, as they appeared to have not moved in at least 11,000 years. Also, although simple in theory, the evidence necessary to determine whether a fault has or has not moved during the past 11,000 years can be difficult to obtain.

In most cases, it is impractical to reduce the damage potential of surface fault rupture by engineering design, and most regulatory agencies, following the position of the California Geological Survey, currently do not allow engineering design for habitable structures (although this is being reconsidered for "minor" faults at this time). Therefore, the most often-used mitigation measure is to simply avoid placing structures on or near active fault traces. The Alquist-Priolo Earthquake Fault Zoning Act requires that geologic investigations, which generally include fault trenching or some other method of subsurface analysis, be performed if conventional structures designed for human occupancy are proposed within a fault zone. These studies must evaluate whether or not an active segment of a fault extends across the area of proposed development following the guidelines for evaluating the hazard of fault rupture presented in Note 49, a publication by the CGS that is available on the worldwide web at http://www.consrv.ca.gov/CGS/rghm/ap/index.htm.

Based on the results of these geologic studies, appropriate structural setbacks are recommended to prevent the siting of the proposed structures directly on top or within a certain distance from the fault. A common misperception regarding setbacks is that they are always 50 feet from the active fault trace. In actuality, as part of a geologic investigation, the project geologist is required to characterize the ground deformation associated with an active fault. Based on these studies, specific setbacks are recommended. If a fault trace is narrow, with little or no associated ground deformation, a setback distance less than 50 feet could be recommended. Conversely, if the fault zone is wide, with multiple splays, or is poorly defined, a setback distance greater than 50 feet may be warranted.

1.5.2 Faults in the Coachella Area

The main fault zoned by the State of California under the criteria of the Alquist-Priolo Act in the Coachella General Plan area is the San Andreas fault. The fault zone extends in a southeasterly direction across the east-central portion of Coachella and the planning area to the southeast of the city (see Plate 1-1). Three other fault zones, referred to from north to south, as the Indio Hills, Berdoo Canyon (also called Coachella Fan), and Mecca Hills fault zones have also been zoned in the area, with portions of those fault zones extending into the City of Coachella General Plan area (Plate 1-1). These fault zones are discussed further below.

The official Alquist-Priolo Earthquake Fault Zone maps that cover the Coachella General Plan area, namely the Indio and Thermal Canyon quadrangles, both date from July 1, 1974, and as such, are part of the first group of maps released by the State. These first maps were based almost exclusively on mapping conducted by previous investigators, with little independent analysis and interpretation conducted by staff from the Fault Evaluation and Zoning Program

(Hart and Bryant, 1999; 2007). As indicated in the bottom-right corner of the Alquist-Priolo maps, the fault data were compiled from mapping conducted by Ware (1958), Popenoe (1959) and Hope (1969b).

These first maps also zoned both active and potentially active faults, with potentially active faults being those that show evidence of displacement in the past 1.6 million years (during the Quaternary). Maps issued after 1977 zoned only those faults that met the criteria of "sufficiently active" and "well-defined" discussed in Section 1.2.1. Between 1976 and 2007, 161 revised maps were issued, with the revisions generally based on the findings of field studies conducted in response to the first official maps. No revised maps have been issued for the Coachella area; however, as of the writing of this report, the maps that cover the Coachella General Plan area are being updated by the California Geological Survey (William Bryant, personal communication, July 2011; Jerome Treiman, personal communication, 2014), to reflect the findings of several trenching studies that have been conducted in the area in the past about 15 years. The preliminary revised maps have not yet been released for review and comment, but are expected to be released before the end of 2014 (Jerome Treiman, personal communication, March 2014). As a result, the boundaries of the Alquist-Priolo Fault Zones shown on Plate 1-1 are those in the original, and still official maps of 1974, and this figure will have to be replaced once the final new Alquist-Priolo maps are issued. The location of the San Andreas fault shown on Plate 1-1, however, has been modified from that shown on the official 1974 maps, as described further in the section below.

1.5.2.1 San Andreas Fault

The San Andreas fault, as the master fault in California, was one of the first structures mapped and zoned by the State Geologist after the Alquist-Priolo Earthquake Fault Zoning Act was signed into law on December 22 1972, with an effective date of March 7, 1973. As mentioned above, the fault was zoned based on mapping done in the 1950s and 1960s, with no independent review by the staff from the California Division of Mines and Geology (now the California Geological Survey). Studies to determine the location of a fault typically involve review of aerial photographs, field mapping, and fault trenching. A significant portion of the San Andreas Fault Zone in the Coachella area underlies the Coachella Canal and/or East Side Dike. Construction of these projects, which were completed in the late 1940s, before the geologic maps of the San Andreas fault used by the State to zone the fault were prepared, obscured many of the landscape features that would help to better define the location of the fault through this area. Tilling, road construction and other practices associated with farming in some areas south of the canal have also destroyed landforms typically associated with faults. As a result, most geological researchers have used pre-1940s aerial photographs of the region to estimate the fault's location, and while these efforts yielded reasonably correct results, the actual fault location, geometry, width of the zone, and recency of activity of the various fault strands are best determined from fault trenching studies. Furthermore, although regional maps of the San Andreas Fault Zone (see Plate 1-2) suggest that the section of the fault that extends through the Coachella General Plan area is simple, consisting of one or two relatively straight traces, the fault zone is locally complex, both at the regional and site-specific scales.

Site-specific complexities have become apparent in those areas where fault trenching studies have been conducted. In the area of Indio where Sieh (1986) and Sieh and Williams (1990) did their studies, the San Andreas fault consists of four strands in a zone at least 164 feet (50 m) wide, with the northeastern fault strand accounting for about 90 percent of the total displacement that has occurred along this portion of the fault zone in the past about 1,000 years. At the site studied by Philibosian et al. (2011), south of Avenue 44 and west of Dillon Road, the main fault zone is approximately 245 feet (75 meters) wide, but the entire width of the deformation zone may be in the thousands of feet. The researchers indicate that additional secondary faults to the northeast, under Avenue 44 and the Coachella Canal, are possible although unlikely, whereas other secondary faults and fractures have been mapped more than 400 feet to the southwest of the main fault at this property and in the parcel immediately to the southeast by other investigators (Medall, Aragon, Worswick and Associates, 1981). Unlike the Indio locality, at this site the southern fault trace investigated by Philibosian et al. (2011) appears to be the main fault based on its lateral continuity across the property, although the trenches excavated at this site were not optimal to address this issue. Locally, in the central portion of the Coachella site, the faults form a zone of depression or basin where a thick section of sediment has accumulated.

In addition to the studies mentioned above, several site-specific fault investigations that included trenching to locate the active traces of the fault have been conducted as part of the requirements to develop properties within an Alquist-Priolo Earthquake Fault Zone. These studies have also shown that the fault is a zone generally hundreds of feet wide, with the main faults oriented about 40 to 50 degrees to the west of north, consistent with the overall regional trend of the San Andreas fault, whereas the secondary faults tend to trend more northerly. These secondary faults, which tend to be a few hundred feet in length occur both to the south and north of the main fault traces. Most of these studies have shown that along a large portion of the fault zone in the Coachella area, the main traces of the San Andreas fault are not located where shown on the 1974 State maps: In the northern portion of the city, where Philibosian et al. (2011) conducted their study, the main fault is about 175 to 300 feet north of where previously mapped, whereas in the central and southern portions of the city, between about Avenues 46 and 50, the fault is about 500 to 650 feet to the southwest of where shown on the 1974 State maps. A revised location for the main fault zone in the Coachella General Plan area, based mostly on work by Petra Geotechnical Inc. (2006, 2007b, 2007c) is shown on Plate 1-1. This plate will have to be updated once the California Geological Survey releases the official revised maps for this area.

In the southern portion of the Coachella General Plan area, the San Andreas fault leaves the alluviated valley and extends through the southwestern portion of the Mecca Hills. In this area the fault zone is 65 to 165 feet (20 to 50 meters) wide, and is "clearly marked on the surface by a nearly straight . . . zone of red brown gouge and crushed rock (Sylvester and Damte, 1999). This section of the fault, from the south side of Thermal Canyon southward, has experienced slip triggered by distant earthquakes, including the 1968 Borrego Springs and 1979 Imperial Valley (Clark, 1984; Williams et al., 1988), 1986 Palm Springs (Williams et al., 1988), 1992 Landers (Rymer, 2000), and 2010 El Mayor-Cucapah (Weldon, 2010, http://response.scec.org/node/273; Wei et al., 2011).

As mentioned previously, the section of the San Andreas fault that extends through the Coachella General Plan area has not ruptured in an earthquake during historic times. At a rate of about 25 mm/yr, the fault has accumulated over the last approximately 320 years sufficient strain to slip more than 26 feet (8 meters) the next time it ruptures. In the ShakeOut scenario (Jones et al., 2008), fault slip in the Coachella area as a result of an earthquake on this segment of the fault is estimated at between 22 and 26 feet (6.7 and 8 meters). This will have significant impacts on the lifelines and infrastructure of the region, including extensive damage to the Coachella Canal, which locally sits on top of the fault zone.

1.5.2.2 Indio Hills Fault Zones, Including Berdoo Canyon (Coachella Fan) Fault

Starting in 1976, the California Division of Mines and Geology (now the California Geological Survey) issued Fault Evaluation Reports (FERs) that describe the faults under study and the rationale for zoning or not zoning a specific trace or splay of a fault. Interestingly, FERs describing the faults zoned in the Alquist-Priolo maps for the Indio and Thermal Canyon quadrangles are not available, which suggests that there are no specific data that explain why sections of the faults in the Indio and Mecca Hills were included in the 1974 Official Alquist-Priolo Earthquake Fault Zone maps. However, given that these early maps included all Quaternary faults, this may be the reason why these faults were zoned at that time. In the U.S. Geological Survey database of "Quaternary faults and folds in the United States" (http://geohazards.usgs.gov/qfaults/map.php), these faults are shown as having moved in the past 130,000 years, but not in the Holocene.

Clark (1984) mapped dozens of relatively short (½- to ¼-mile long), northwest- to north-northwest-trending normal faults in the Indio Hills and Mecca Hills areas that reportedly offset Quaternary and younger alluvium. According to Clark, most of these faults appear to be directly related to movement on the San Andreas fault, and form elongated ridges and/or low hills that are parallel to the main San Andreas fault. In the Indio Hills especially, uplift is highest to the south, and decreases northward. Uplift seems to be the result of recurrent movement on these faults, as indicated by steeper, less weathered scarps near the base of the ridges, and older units being offset more than younger units. Extensive work has been done over the years in the Indio Hills to study the various strands of the San Andreas fault (Keller et al., 1982; Sieh, 1986; Sieh and Williams, 1990; van der Woerd et al., 2006; Behr et al., 2010; Fletcher et al., 2010), but no research projects have been conducted, to our knowledge, of these secondary faults east and north of the San Andreas fault. Recent studies conducted for feasibility and planning purposes, first steps in a development project, have included extensive trenching across many of these features, to evaluate whether or not they are related to faulting (Petra, 2007a). Several of these features have been determined to be faults, although whether they are the result of primary or secondary faulting, regional lateral spreading or earthquake-induced shallow landsliding, or some other process, is still being debated. Preliminary results have been submitted to the California Geological Survey (CGS) as part of the requirement that all investigations of a fault zoned under the Alquist-Priolo Act need to be filed with the CGS. The State Geologist is in the process of reviewing these findings as part of the State's efforts to review and update the current, official Alquist-Priolo Earthquake Fault Zone maps for this area.

1.5.2.3 Mecca Hills Fault Zones

The Mecca Hills, like the Indio Hills to the north and the Durmid Hill to the south, are transpressional features along the San Andreas fault that formed due to a slight deviation in the orientation of the San Andreas fault at these locations. Specifically, along most of its length in the Coachella Valley, the San Andreas fault is parallel to the vector of plate motion, but at these locations, the strike of the fault is about 5 to 7 degrees farther west (Bilham and Williams, 1985). This results in northwest-southeast compression, causing the sediments in these areas, over hundreds of thousands of years, to pop up. Some of the movement associated with this uplift is manifested in the extensive folding and tilting of the sedimentary rocks that form the hills, whereas in other areas, it is accommodated along faults.

In addition to the San Andreas fault, the Mecca Hills are cut by three other fault zones. From west to east, these are the Skeleton Canyon, Painted Canyon and Eagle Canyon faults. These faults form prominent narrow valleys that extend northerly across the hills, locally forcing right steps along some of the drainage courses. Farther east, forming the southeastern margin of the hills is the Hidden Springs fault. Only the northern, horse-tail-shaped end of the Painted Canyon fault, referred to as the NW Painted Canyon Fault Zone, extends into the Coachella General Plan area (see Plate 1-1), with the northern ends of these fault strands appearing to extend even farther north than shown on the Alquist-Priolo Earthquake Fault Zone map. The eastern-most of these faults appears to continue at least 1.45 miles north of the I-10, as indicated by a strong tonal lineament on aerial photographs of the area, in addition to a line of seismicity that includes two of the largest earthquakes recorded in the area (the 12/24/2006 and 7/14/2004 events identified in Plate 1-1). Trenching across these tonal lineaments has been conducted locally as part of the geotechnical feasibility studies for the Lomas del Sol (now La Entrada) project (Petra, 2007a); these studies have shown that both active and potentially active faults extend through these areas, with additional studies required to further define the lateral continuity, width, and activity of the faults. The California Geological Survey is reviewing these studies as part of the process to update the Alquist-Priolo Earthquake Fault Zone map for this area (William Bryant, personal communication, July 2011).

1.6 Ground Failure due to Earthquake Shaking

Various types of ground failure that are the result of earthquake shaking can cause substantial damage to the built environment. The most destructive of these failures include liquefaction and slope failure, but other tectonically induced forms of ground failure are also possible. These are described further below.

1.6.1 Liquefaction

Liquefaction is a geologic process that causes various types of ground failure. It typically occurs within the upper 50 feet of the surface, in saturated, loose, fine- to medium-grained sandy to silty soils in the presence of ground accelerations over 0.2g (Borchardt and Kennedy, 1979; Tinsley and Fumal, 1985). Earthquake shaking suddenly increases pressure in the water that fills the pores between soil grains, causing the soil to have a total or substantial loss of shear strength, and behave like a liquid or semi-viscous substance. This process can be observed at the beach by standing on the wet sand near the surf zone. Standing still, the sand will support our weight. However, if we tap the sand with our feet, water comes to the surface, the sand liquefies, and our feet sink.

Liquefaction can cause structural distress or failure due to ground settlement, a loss of bearing capacity in the foundation soils, and the buoyant rise of buried structures. That is, when soils liquefy, the structures built on them can sink, tilt, and suffer significant structural damage. In addition to loss of bearing strength, liquefaction-related effects include ground oscillations, lateral spreading and flow failures or slumping. The excess water pressure is relieved by the ejection of material upward through fissures and cracks; water or water-soil slurries may bubble onto the ground surface, resulting in features called "sand boils," "sand blows," "sand volcanoes," or "mud spouts." Seepage of water through cracks may also be observed.

The types of ground failure typically associated with liquefaction are explained below.

Lateral Spreading – Lateral displacement of surficial blocks of soil as the result of liquefaction in a subsurface layer is called lateral spreading. Even a very thin liquefied layer can act as a hazardous slip plane if it is continuous over a large enough area. Once liquefaction transforms the subsurface layer into a fluid-like mass, gravity plus inertial forces caused by the earthquake may move the mass down-slope towards a cut slope or free face (such as a river channel or a canal). Lateral spreading most commonly occurs on gentle slopes that range between 0.3 degrees and 3 degrees, and can displace the ground surface by several feet to tens of feet. Such movement damages pipelines, utilities, bridges, roads, and other structures. During the 1906 San Francisco earthquake, lateral spreads with displacements of only a few feet damaged every major pipeline in the area. Thus, liquefaction compromised San Francisco's ability to fight the fires that caused about 85 percent of the damage (Tinsley et al., 1985). Lateral spreading was also reported in and around the Port of Los Angeles during both the 1933 and 1994 earthquakes (Barrows, 1974; Stewart et al., 1994; Greenwood, 1998).

Flow Failure – The most catastrophic mode of ground failure caused by liquefaction is flow failure. Flow failure usually occurs on slopes greater than 3 degrees. Flows are principally liquefied soil or blocks of intact material riding on a liquefied subsurface. Displacements are often in the tens to hundreds of feet, but under favorable circumstances, soils can be displaced for tens of miles, at velocities of tens of miles per hour. For example, the extensive damage to Seward and Valdez, Alaska, during the 1964 Great Alaskan earthquake was caused by submarine flow failures (Tinsley et al., 1985).

Ground Oscillation – When liquefaction occurs at depth but the slope is too gentle to permit lateral displacement, the soil blocks that are not liquefied may separate from one another and oscillate on the liquefied zone. The resulting ground oscillation may be accompanied by the opening and closing of fissures (cracks) and sand boils, potentially damaging structures and underground utilities (Tinsley et al., 1985).

Loss of Bearing Strength – When a soil liquefies, loss of bearing strength may occur beneath a structure, possibly causing the building to settle and tip. If the structure is buoyant, it may float upward. During the 1964 Niigata, Japan earthquake, buried septic tanks rose as much as 3 feet, and structures in the Kwangishicho apartment complex tilted as much as 60 degrees (Tinsley et al., 1985).

Ground Lurching – Soft, saturated soils have been observed to move in a wave-like manner in response to intense seismic ground shaking, forming ridges or cracks on the ground surface. At present, the potential for ground lurching to occur at a given site can be predicted only generally. Areas underlain by thick accumulation of colluvium and alluvium appear to be the most susceptible to ground lurching. Under strong ground motion conditions, lurching can be expected in loose, cohesionless soils, or in clay-rich soils with high moisture content. In some cases, the deformation remains after the shaking stops (Barrows et al., 1994).

As indicated above, there are three general conditions that need to be met for liquefaction to occur. The first of these – ground shaking of relatively long duration – can be expected to occur in the Coachella area as a result of an earthquake on the San Andreas, San Jacinto, Mesquite Lake, Pinto Mountain, and some of the other active faults in the region. The second condition – geologically young, loose, unconsolidated sediments – occurs throughout the valley portions of the Coachella area, and in the canyons east of the San Andreas fault. Note the distribution of Quaternary river channel deposits (Qg), alluvial fan and stream deposits (Qa), and interbedded lake and distal fan deposits (Ql/Qa) in Plate 2-1a. All of these sediments are cohesionless and loose in the upper sections, and thus susceptible to liquefaction if the other two necessary conditions are present. The third condition – historically shallow groundwater within about 50 feet of the surface – has been reported throughout the western half of the General Plan area, in the valley portion of Coachella.

This shallow groundwater, which in a large portion of the region occurred at or within about 10 feet of the ground surface during the 1960s (California Department of Water Resources - DWR, 1964), is water semi-perched on top of a thick sequence of fine-grained silts and clays deposited when this area was covered by ancient Lake Cahuilla. Intense pumping for groundwater in response to the increase in population and agricultural development of the region has significantly reduced the groundwater levels in the deep aquifer, but the shallow, non-potable aquifer levels have remained relatively constant, at least into the 1990s or early 2000s. A review of several fault investigations (such as Sladden Engineering, 2006; Petra, 2006, 2007c), and groundwater monitoring studies conducted for properties where leaks of petroleum fuels from underground storage tanks have been reported (GeoTracker database – see Chapter 5; EAR, 2010; Frey Environmental, 2008, 2009, 2010; RM Environmental, 2001, 2011) show that in general, groundwater levels in the upper aquifer have dropped approximately 10 feet from the levels reported by the DWR in 1964, but are still within the 30- to 50-foot depths considered in liquefaction susceptibility analyses. Furthermore, increased urbanization, with the resultant typical increase in landscaping irrigation, especially if the tile drains now common in the agricultural areas have been removed during development, has the potential to raise the water levels in the shallow aquifer. A shallower regional groundwater table could also develop again in the future if water levels rise in response to decreased pumping of groundwater (due to increased use of imported water) and/or the groundwater recharge programs ongoing in the lower Whitewater River, and proposed in the city of Indio (MWH, 2011).

The areas of Coachella where young unconsolidated sediments and historically shallow groundwater conditions co-exist are shown on Plate 1-3 as susceptible to liquefaction. Areas where groundwater has been reported within 30 feet of the ground surface are shown as having a high susceptibility, whereas areas where groundwater has been reported at depths of between 30 and 50 feet are shown as having a moderate susceptibility. Geotechnical studies to evaluate the potential for liquefaction-induced differential settlement are recommended in these areas prior to development. Given that the groundwater levels in this area may fluctuate seasonally, the geotechnical analyses should use the shallowest groundwater levels reported in the area to calculate the anticipated settlement due to liquefaction. Areas immediately adjacent to the San Andreas fault, especially on the northeast side of the fault, may also be susceptible to liquefaction because the fault locally serves as a groundwater barrier, forcing water upward. Deformation features likely produced by liquefaction during past earthquakes have been observed in many of the trenches excavated to locate the San Andreas fault. These areas are not shown on Plate 1-3 because this condition does not necessarily occur along the entire length of the fault, and the scale of the map (Plate 1-3) does not permit a correct representation of the width of this zone. Nevertheless, geotechnical studies to evaluate the potential for liquefaction-induced differential settlement should be conducted if development is proposed immediately adjacent to the fault zone.

Absent an official map from the California Geological Survey, Plate 1-3 should be used as if it were the official map, and site-specific liquefaction susceptibility studies should be conducted in the mapped areas prior to any proposed development. In accordance with the Seismic Hazards Mapping Act (SHMA), all projects within a State-delineated Seismic Hazard Zone for liquefaction must be evaluated by a Certified Engineering Geologist and/or Registered Geotechnical Engineer (this is typically a civil engineer with training and experience in soil engineering). Most often however, it is appropriate for both the engineer and geologist to be involved in the evaluation, and in the implementation of the mitigation measures. Likewise, project review by the local agency must be performed by geologists and engineers with the same credentials and experience.

Seismic Hazard Zones

Coachella, California

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

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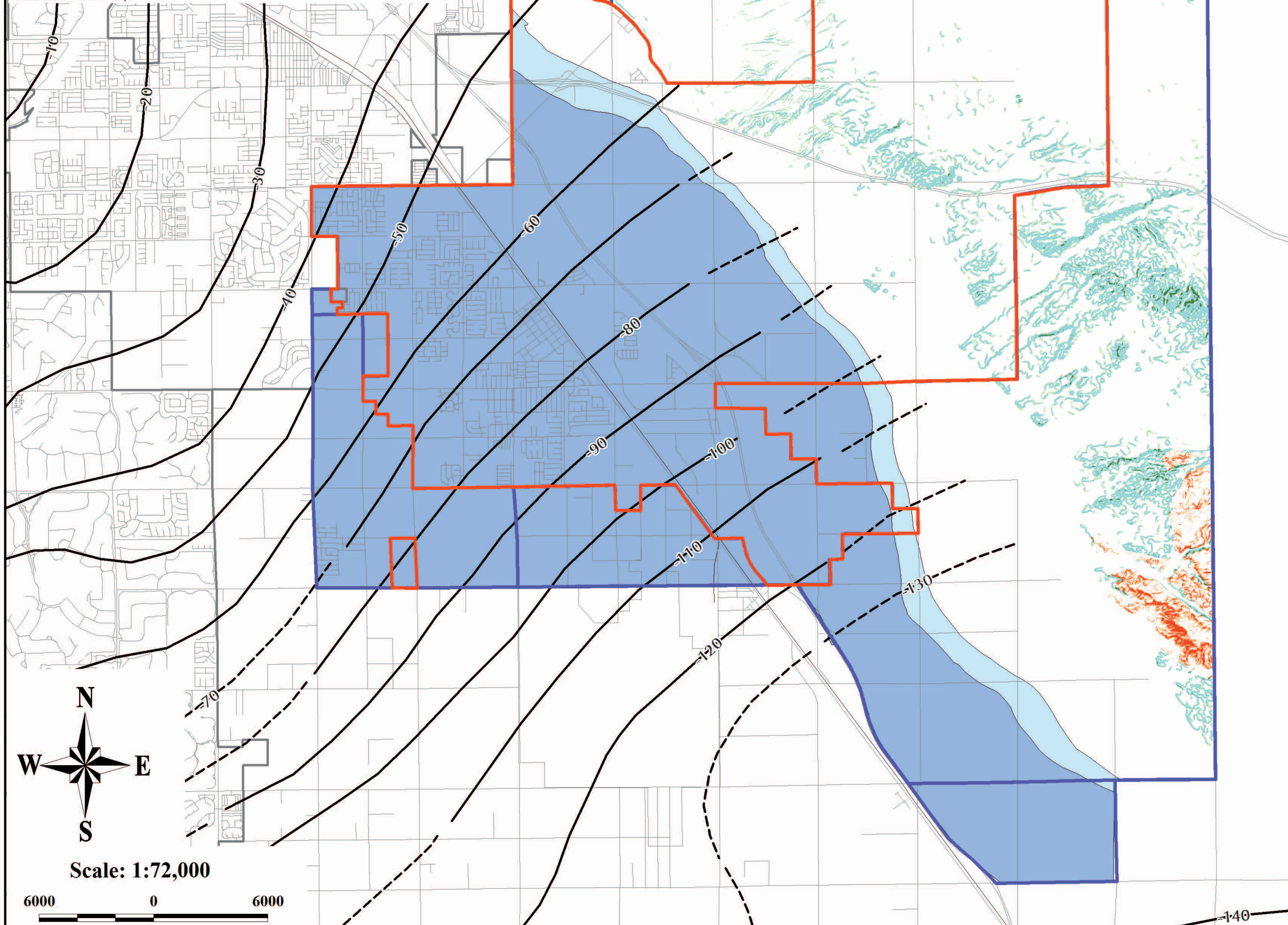

Base Map: From the City of Coachella.

Sources: Groundwater levels from California Department of Water Resources (1964); geological data derived from Dibble (2008) and Rogers (1965) - See Plate 2-1a; California Geological Survey (2004, 2008); Keefer and Wilson (1989); recent groundwater information obtained from various sites in the GeoTracker database (http://geotracker.swrcb.ca.gov/), and from geotechnical and fault evaluation studies in the City of Coachella files. Slope gradients used in the slope instability analysis derived from the USGS 10m Digital Elevation Model.

Explanation

Earthquake-Induced Slope Instability

Rock Falls Rock Slides	Areas underlain by bedrock where the local topographic, geological, and geotechnical conditions indicate a potential for permanent ground displacements, such that mitigation may be required. Refer to text for additional information.
Soil Falls Soil Slides Soil Slumps	Areas underlain by Holocene and Pleistocene sediments where the local topographic, geological, and geotechnical conditions indicate a potential for earthquake-induced soil block slides or soil slumps. Mitigation measures may be required if these areas are developed. Refer to text for additional information.

Liquefaction Susceptibility

High	Areas underlain by youthful, unconsolidated sediments, and where historically shallow groundwater, within 30 feet of the ground surface, has been reported. These conditions indicate a high potential for permanent ground displacements such that mitigation for liquefaction may be required.
Moderate	Areas underlain by youthful, unconsolidated sediments, and where historically shallow groundwater, 30 to 50 feet below the ground surface, has been reported. These conditions indicate a moderate potential for permanent ground displacements such that mitigation for liquefaction may be required.
(black line)	Historical groundwater elevation in feet relative to sea level (DWR, 1964). This shallow groundwater is generally perched above fine-grained sediments, and is for the most part not potable. Review of several geotechnical, geological and groundwater monitoring reports indicate that between 1990 and 2011, groundwater levels have dropped approximately 10 feet from the levels shown here.
(red line)	Coachella City Boundary
(blue line)	Coachella Planning Area Boundary

Note that shallow groundwater, within 30 feet of the ground surface, and unconsolidated sediments susceptible to liquefaction occur locally adjacent to the San Andreas fault, with shallower groundwater levels typically present on the east side of the fault zone. These zones are not shown on this map. Nevertheless, studies to evaluate the potential for liquefaction should be conducted on a site-specific basis in areas proposed for development adjacent to the fault zone.

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CITY OF COACHELLA CALIFORNIA

Plate 1-3

In order to assist project consultants and reviewers in the implementation of the SHMA, the State has published specific guidelines for evaluating and mitigating liquefaction (CDMG, 1997; CGS, 2008). Then, in 1999 a group sponsored by the Southern California Earthquake Center (SCEC, 1999) published recommended procedures for carrying out the California Geological Survey guidelines. In 2003, a consensus report that describes new criteria for the definition and study of the liquefaction resistance of soils was published by the Earthquake Engineering Research Center (Seed et al., 2003), and additional studies can be expected in this field. Consultants should review and apply the most recent, peer-reviewed guidelines for liquefaction study as applicable to the specific site being studied.

In general, a liquefaction study is designed to identify the depth, thickness, and lateral extent of any liquefiable layers that would affect the project site. An analysis is then performed to estimate the type and amount of ground deformation that might occur, given the seismic potential of the area. Mitigation measures generally fall in one of two categories: ground improvement or foundation design. Ground improvement includes such measures as removal and recompaction of low-density soils, removal of excess ground water, in-situ ground densification, and other types of ground improvement (such as grouting or surcharging). Special foundations that may be recommended range from deep piles to reinforcement of shallow foundations (such as post-tensioned slabs). Mitigation for lateral spreading may also include modification of the site geometry or inclusion of retaining structures. The types (or combinations of types) of mitigation depend on the site conditions and on the nature of the proposed project (CDMG, 1997; CGS, 2008). Given the benefits of the groundwater recharge programs that are ongoing and have been proposed in the lower Coachella Valley, mitigation measures to reduce the hazard of liquefaction in the Coachella General Plan area should emphasize the densification of the soils or other ground improvements, and the strengthening of the structural foundations, rather than the pumping of water to reduce the groundwater levels.

1.6.2 Earthquake-Induced Slope Failure

Strong ground motions can worsen existing unstable slope conditions. Seismically induced landslides can overrun structures, harm people or damage property, sever utility lines, and block roads, thereby hindering rescue operations after an earthquake. Over 11,000 landslides were mapped shortly after the 1994 Northridge earthquake, all within a 45-mile radius of the epicenter (Harp and Jibson, 1996). Although numerous types of earthquake-induced landslides have been identified, the most widespread type generally consists of shallow failures involving surficial soils and the uppermost weathered bedrock in moderate to steep hillside terrain (these are also called disrupted soil slides). Rockfalls and rock-slides on very steep slopes are also common. The 1989 Loma Prieta and 1994 Northridge earthquakes showed that reactivation of existing deep-seated landslides can also occur (Spittler et al., 1990; Barrows et al., 1995). One of the most impressive ancient landslides in the southern California region is the Martinez Mountain Landslide located immediately to the southwest of La Quinta. Some geologists have suggested that seismic shaking triggered this rock avalanche (Morton and Sadler, 1989).

A combination of geologic conditions leads to landslide vulnerability. These include high seismic potential; rapid uplift and erosion resulting in steep slopes and deeply incised canyons; highly fractured and folded rock; and rock with inherently weak components, such as silt or clay layers. Slope failures in soils can also occur, with slope angle, moisture content, and intensity of shaking being the most important triggers or components responsible for failure. The orientation of the slope with respect to the direction of the seismic waves (which can affect the shaking intensity) can also control the occurrence of landslides. Groundwater conditions at the time of the earthquake play an important role in the development of seismically induced slope failures. Thus, the 1906 San Francisco earthquake, which occurred in April after a winter of exceptionally heavy rainfall, produced over ten thousand slope failures (Wilson and Keefer, 1985), including some very large landslides and mudflows that killed several people. The 1989 Loma Prieta earthquake however, occurred in October, during the third year of a drought, and slope failures were limited primarily to rockfalls and reactivation of older landslides that were manifested as ground cracking in the scarp areas but with very little movement (Griggs et al., 1991).

Keefer and Wilson (1989) conducted a survey of the slope failures caused by over 40 earthquakes around the world and found that seismic shaking is one of the most important triggers of landslides in arid and semi-arid regions. Even in areas that receive very little precipitation, earthquakes larger than about magnitude 6 have caused hundreds to thousands of slope failures.

One of the most comprehensive and still widely used landslide classification schemes is that by Varnes (1978). His classification emphasizes the type of movement (falls, topples, rotational slides, translational slides, lateral spreads, flows, and combinations of the above), followed by the type of material involved (bedrock and engineering soils, with soils further divided into predominantly coarse-grained and predominantly fine-grained). Keefer (1984) and Wilson and Keefer (1985) used a modification of Varnes' (1978) scheme to classify earthquake-induced landslides. Their primary criteria include material, mechanism of movement and amount of internal disruption; secondary criteria include water content, velocity, depth, and geologic environment. Wilson and Keefer (1985) consider only two types of material – bedrock and soil, with soil comprising all uncemented or slightly cemented aggregate of mineral grains, including young sedimentary deposits, the regolith or weathered deposits that mantle bedrock, and man-made fill slopes. A review of their classification shows that earthquake-induced landslides that occur in rock and sedimentary deposits under dry conditions fall, with one exception, into their Category I landslides. The landslides in this category are all highly or very highly disrupted, having occurred rapidly or extremely rapidly. With the exception of rock avalanches, the materials involved are mostly shallow, generally less than 3 meters (10 feet) deep. The specific types of landslides in this category include rock falls, rock slides, rock avalanches, soil falls, and soil slides. These types of slope failures are described further in Table 1-3. The geologic and slope conditions commonly necessary for these failures to occur were used to evaluate the earthquake-induced slope instability potential in the Coachella General Plan and develop the potential earthquake-induced landslide zones shown on Plate 1-3.

The last type of slope failure included in Table 1-3, soil slumps, falls into Wilson and Keefer's (1985) Category II. This landslide category is characterized by relatively coherent slides that move slower than Category I slides, and are generally deep-seated. Soil slumps may occur in both dry and wet soil conditions. Although not shown on Plate 1-3, in the Coachella General Plan area earthquake-induced soil slumps may occur locally in man-made structures, including the embankment of the East Side dike (especially if retaining runoff water on its east side at the time of the earthquake), and in the walls of unlined or clay-lined reservoirs, ponds, and recharge basins. Soil slumps may also occur in the relatively gently sloped alluvial fans draining the Indio and Mecca Hills.

Table 1-3: Earthquake-Induced Slope Failures in Arid Environments

Landslide Type	Geologic Material. Environment	Minimum Slope (in degrees)	Velocity; Depth; Type of Movement	Potential Location in Coachella
Consolidated Bedrock (Igneous, Metamorphic and Sedimentary)				
Rock Falls	Weakly cemented, intensely fractured or weathered; with conspicuous planes of weakness dipping out of slope; precariously perched boulders. Common near ridge crests and on ledges; artificially cut slopes, and slopes undercut by active erosion.	34	Extremely rapid (>10 ft/sec); shallow (<10 ft deep); bouncing, falling and free-falling.	Locally in the Mecca Hills, where the Palm Spring Formation crops out in steep slopes, and in the northeast corner of the General Plan area, where plutonic rocks crop out.
Rock Slides	Weakly cemented, intensely fractured or weathered; conspicuous planes of weakness dipping out of slope, or boulders surrounded by weak matrix. Common in hillside flutes and channels, artificially cut slopes, and slopes undercut by active erosion.	25	Rapid to extremely rapid (>1 ft/sec); shallow (<10 ft deep); translational (planar or gently undulatory) sliding on basal shear surface, typically a pre-existing discontinuity such as bedding, joint, or fault.	Locally in the Mecca Hills, where beds of the Palm Spring Formation dip out of slope in canyon walls.
Rock Avalanches	Intensely fractured and exhibiting significant weathering, planes of weakness dipping out of slope, weak cementation, and/or evidence of previous landsliding. Generally restricted to slopes with more than 500 feet (150 m) of relief undercut by erosion.	25	Extremely rapid (>10 ft/sec); deep (>10 ft deep); complex, involves sliding and/or flow as a stream of rock fragments. May be accompanied by blast of air that can knock down trees and structures beyond the limits of the debris.	Rock avalanches may occur in the Little San Bernardino Mountains to the north and east of the Coachella General Plan area. The toe of the debris apron could impact the northeastern portion of the study area.
Unconsolidated and Weakly Consolidated Deposits (Older Alluvium, Alluvium, Colluvium, Soil, Artificial Fill)				
Soil Falls	Granular soils that are slightly cemented or contain clay binder. Generally common on bluffs and steep slopes such as stream banks, terrace faces, and artificially cut slopes.	34 – 40 (possible); >40 (more likely)	Extremely rapid to very slow (>1 ft/5 yr to >10 ft/sec); bouncing, falling, free falling.	May occur in steep slopes underlain by the Ocotillo Conglomerate, parallel or nearly parallel to slope faces.
Soil Slides	Holocene and Pleistocene loose, unsaturated sands, coarse-grained sediments, sensitive clays.	15	Moderate to rapid (>1 ft/sec); shallow (<10 ft deep); translational sliding on basal shear surface or zone of weakened sensitive clay.	May occur in the hillsides underlain by the Ocotillo Conglomerate.
Soil Slumps	Loose, dry to wet sand or silt; uncompacted or poorly compacted man-made fill consisting of sand, silt or clay; pre-existing soil slump deposits. Common on embankments built on soft, saturated materials; in hillside cut-and-fill areas; and on river floodplains.	10	Slow to rapid (> 5ft/year to < 1 ft/sec; deep (> 10 ft); sliding on basal shear surface with a component of headward rotation.	May occur along the East Side dike, especially if it is retaining water, and on the walls of partly filled reservoirs, ponds, and recharge basins. Also in the gentle slopes off the Indio and Mecca Hills, and the alluvial fans draining the hills.

Sources: Modified from Varnes (1978), Keefer (1984), Wilson and Keefer (1985) and CGS (2008).

The hills in the eastern section of the Coachella General Plan area have not been mapped within a State-delineated Seismic Hazard Zone for seismically induced landsliding because this mapping program has not yet been funded for Riverside County. Topographically, the eastern one-third to one-half of the Coachella General Plan area consists of gentle to steep hills, locally with steep canyon walls. Although the hills are for the most part currently undeveloped, sections of the I-10 freeway, the East Side dike, the Coachella Canal, and some roads at the foot of these hillsides are susceptible to earthquake-induced slope instability.

Rockfalls may happen suddenly and without warning, but are more likely to occur in response to earthquake-induced ground shaking, during periods of intense rainfall, or as a result of man's activities, such as grading and blasting. Wilson and Keefer (1985) reported that ground acceleration of at least 0.10g in steep terrain is necessary to induce earthquake-related rockfalls. Although exceeding this level of shaking does not guarantee that rockfalls will occur, this is certainly a concern in the Mecca Hills given the high ground accelerations anticipated in the area when the southern San Andreas fault ruptures next. Specifically, portions of the Mecca Hills in the southeasternmost section of the General Plan Area are underlain by bedrock assigned to the Palm Spring Formation. Faults, joints and fractures have formed several wedges of rock that are precariously attached to the slope faces; strong shaking during an earthquake is likely to topple these rocks posing a rockfall hazard to areas adjacent to and below these slopes. That this has happened in the past is evident, as large chunks of rock can be seen scattered around on the canyon floors. The 1992 Landers earthquake triggered several rock falls and rock slides in the Mecca Hills, including a large failure that blocked access to Red Canyon (Rymer, 2000). Given how the epicenter of the Landers earthquake occurred nearly 45 miles (72 km) from Red Canyon, it is clear that a near-source earthquake on the San Andreas fault would be particularly damaging to the rock faces in the Mecca Hills.

Rock falls and other types of bedrock landslides may also occur in the northeastern portion of the Coachella General Plan area, where plutonic rocks crop out. Steep relief to the north of the study area, in the Little San Bernardino Mountains, if combined with intensely jointed and fractured rock can result in rock falls, rock slides and rock avalanches. Rock avalanches are not likely to start within the General Plan area, but the toe of the disrupted material could encroach into the area's northeastern corner.

The hills north and northwest of the Mecca Hills are underlain by softer sediments assigned to the Ocotillo Formation (see Chapter 2 and Plate 2-1). These deposits form rounder slopes than the Palm Springs Formation in the Mecca Hills, but locally, especially along the canyon walls, these deposits form relatively steep to nearly vertical slopes that can fail in response to shaking during an earthquake. Different types of earthquake-induced slope failures can occur in this area, depending in great part on the angle of the slopes, as described in Table 1-3 and shown on Plate 1-3. Loose boulders left behind by erosion and removal of the surrounding matrix can also fail, bouncing, rolling and locally free falling. Areas directly downhill from these hillside regions are most vulnerable to the effects of slope failure. Existing slopes that are to remain adjacent to or within proposed developments should be evaluated for the geologic conditions mentioned above (also refer to Section 2.3.1 in Chapter 2). For suspect slopes, appropriate geotechnical investigation and slope stability analyses should be performed for both static and dynamic (earthquake) conditions. Protection from rockfalls or surficial slides can often be achieved by protective devices such as barriers, retaining structures, catchment areas, or a combination of the above. The runout area of the slide at the base of the slope, and the potential bouncing of rocks must also be considered. If it is not feasible to mitigate the unstable slope conditions, building setbacks should be imposed.

In accordance with the SHMA, all development projects within a State-delineated Seismic Hazard Zone for seismically induced landsliding must be evaluated and reviewed by State-licensed engineering geologists and/or geotechnical engineers (for landslide investigation and analysis, this typically requires both). In order to assist in the implementation of the SHMA, the State has published specific guidelines for evaluating and mitigating seismically induced landslides (CDMG, 1997; CGS, 2008). The Southern California Earthquake Center (SCEC, 2002) sponsored the publication of the "Recommended Procedures for Implementation of DMG Special Publication 117." The steep slope areas identified in Plates 1-3 and 2-2 should be evaluated following these procedures if development near these slopes is proposed.

1.6.3 Seismically Induced Settlement

Under certain conditions, strong ground shaking can cause the densification of soils, resulting in local or regional settlement of the ground surface. During strong shaking, soil grains become more tightly packed due to the collapse of voids and pore spaces, resulting in a reduction of the thickness of the soil column. This type of ground failure typically occurs in loose granular, cohesionless soils, and can occur in either wet or dry conditions. Unconsolidated young alluvial deposits are especially susceptible to this hazard. Artificial fills may also experience seismically induced settlement. Damage to structures typically occurs as a result of local differential settlements. Regional settlement can damage pipelines by changing the flow gradient on water and sewer lines, for example. As shown in Plate 2-1a, the valley portion of Coachella is underlain by young, unconsolidated alluvial and lacustrine sediments, locally mantled with wind deposits (map symbols Qg, and Ql/Qa). These sediments are susceptible to seismically induced settlement.

Mitigation measures for seismically induced settlement are similar to those used for liquefaction. Recommendations are provided by the project's geologist and soil engineer, following a detailed geotechnical investigation of the site. Overexcavation and recompaction is the most commonly used method to densify soft soils susceptible to settlement. Deeper overexcavation below final grades, especially at cut/fill, fill/natural or alluvium/bedrock contacts may be recommended to provide a more uniform subgrade. Overexcavation should also be performed so that large differences in fill thickness are not present across individual lots. In some cases, specially designed deep foundations, strengthened foundations, and/or fill compaction to a minimum standard that is higher than that required by the UBC may be recommended.

1.6.4 Deformation of Sidehill Fills

Sidehill fills are artificial fill wedges typically constructed on natural slopes to create roadways or level building pads. Deformation of sidehill fills was noted in earlier earthquakes, but this phenomenon was particularly widespread during the 1994 Northridge earthquake. Older, poorly engineered road fills were most commonly affected, but in localized areas, building pads of all ages experienced deformation. The deformation was usually manifested as ground cracks at the cut/fill contacts, differential settlement in the fill wedge, and bulging of the slope face. The amount of displacement on the pads was generally about three inches or less, but this resulted in minor to severe property damage (Stewart et al., 1995). This phenomenon was most common in relatively thin fills (about 27 feet or less) placed near the tops or noses of narrow ridges (Barrows et al., 1995).

This hazard could occur locally in the hillsides on the eastern portion of the Coachella General Plan region, such as along portions of the I-10 freeway where fills were placed on the outside of a cut to create a wider cut for the road embankment. With increased development of the hillsides in this area, this hazard may become more common, as building pads built on the sides of a slope are particularly vulnerable to deformation as a result of ground shaking.

Hillside grading designs are typically conducted during site-specific geotechnical investigations to determine if there is a potential for this hazard. There are currently no proven engineering standards for mitigating sidehill fill deformation, consequently current published research on this topic should be reviewed by project consultants at the time of their investigation. It is thought that the effects of this hazard on structures may be reduced by the use of post-tensioned foundations, deeper overexcavation below finish grades, deeper overexcavation on cut/fill transitions, and/or higher fill compaction criteria.

1.6.5 Ridgetop Fissuring and Shattering

Linear, fault-like fissures occurred on ridge crests in a relatively concentrated area of rugged terrain in the Santa Cruz Mountains during the 1989 Loma Prieta earthquake. Shattering of the surface soils on the crests of steep, narrow ridgelines occurred locally in the 1971 San Fernando earthquake, but was widespread in the 1994 Northridge earthquake. Ridgetop shattering (which leaves the surface looking as if it was plowed) by the Northridge earthquake was observed as far as 22 miles away from the epicenter. In the Sherman Oaks area, severe damage occurred locally to structures located at the tops of relatively high (greater than 100 feet), narrow (typically less than 300 feet wide) ridges flanked by slopes steeper than about 2.5:1 (horizontal:vertical). It is generally accepted that ridgetop fissuring and shattering is a result of intense amplification or focusing of seismic energy due to local topographic effects (Barrows et al., 1995).

Ridgetop shattering is likely to occur locally in the Indio and Mecca Hills, and in the Little San Bernardino Mountains within and bordering, respectively, the Coachella General Plan area during a strong earthquake on the San Andreas, Burnt Mountain or Pinto Mountain faults. Given that there is currently no significant development on these ridgelines, damage to structures as a result of this hazard in the Coachella area is at this time low to none. If, and when development starts to encroach onto the hillside areas, the potential for ridgetop shattering will increase, unless mitigation measures to reduce this hazard are implemented in the design and construction of the proposed structures.

Projects located or proposed in steep hillside areas should be evaluated for this hazard by a Certified Engineering Geologist. Given that it is difficult to predict exactly where this hazard may occur, avoidance of development along the tops of steep, narrow ridgelines is probably the best mitigation measure. Recontouring of the topography to reduce the conditions conducive to ridgetop amplification, along with overexcavation below finish grades to remove and recompact weak, fractured bedrock is thought to reduce this hazard to an acceptable level. Post-tensioned slab foundations that can accommodate some minor movements and differential settlement can also help reduce the impacts of this hazard.

1.7 Other Potential Seismic Hazards

1.7.1 Seiches

A seiche is defined as a standing wave oscillation in an enclosed or semi-enclosed, shallow to moderately shallow water body or basin. Seiches continue (in a pendulum fashion) after the cessation of the originating force, which can be tidal action, wind action, or a seismic event. Reservoirs, lakes, ponds, swimming pools and other enclosed bodies of water are subject to these potentially damaging oscillations (sloshing). Whether or not seismically induced seiches develop in a water body is dependent upon specific earthquake parameters (e.g., frequency of the seismic waves, distance and direction from the epicenter), as well as site-specific design of the enclosed bodies of water, and is thus difficult to predict. Whether an earthquake will create seiches depends upon a number of earthquake-specific parameters, including the earthquake location (a distant earthquake is more likely to generate a seiche than a local earthquake), the style of fault rupture (e.g., dip-slip or strike-slip), and on the configuration (length, width and depth) of the water basin.

Amplitudes of seiche waves associated with earthquake ground motion are typically less than 0.5 m (1.6 feet high), although some have exceeded 2 m (6.6 ft). A seiche in Hebgen Reservoir, caused by an earthquake in 1959 near Yellowstone National Park, repeatedly overtopped the dam, causing considerable damage to the dam and its spillway (Stermitz, 1964). The 1964 Alaska earthquake produced seiche waves 0.3 m (1 ft) high in the Grand Coulee Dam reservoir, and seiches of similar magnitude were reported in fourteen bodies of water in the state of Washington (McGarr and Vorhis, 1968). Seiches in pools and ponds as a result of the 2010 Baja California earthquake were reported and often captured on video in southern California and Arizona, and the Chile earthquake of February 27, 2010 reportedly caused a 0.5-foot-high seiche 4,700 miles away, in Lake Pontchartrain, New Orleans.

Given that there are several lakes, ponds, and reservoirs in and around Coachella, seiches as a result of ground shaking can be expected to occur in the study area. The amplitude of the seiche waves that could occur in these water bodies cannot be predicted given that several parameters combine to form these waves, although, given the relatively shallow depth of these bodies of water, the seiches are anticipated to be relatively minor. Nevertheless, property owners down-gradient from ponds, lakes and pools that could seiche during an earthquake should be aware of the potential hazard to their property should any of these bodies of water lose substantial amounts of water during an earthquake. Water in swimming pools is known to slosh during earthquakes, but in most cases, the sloshing does not lead to significant damage.

Damage as a result of sloshing of water inside water reservoirs is discussed further in the Flood Hazards Chapter (Chapter 3). Site-specific design elements, such as baffles, to reduce the potential for seiches are warranted in tanks and in open reservoirs or ponds where overflow or failure of the structure may cause damage to nearby properties. Damage to water tanks iduring earthquakes, such as the 1992 Landers-Big Bear sequence and the 1994 Northridge, resulted from seiching. As a result of those earthquakes, the American Water Works Association (AWWA) developed Standards for Design of Steel Water Tanks (D-100) that provide revised criteria for seismic design (Lund, 1994).

1.7.2 Tsunami

A tsunami is a sea wave caused by any large-scale disturbance of the ocean floor that occurs in a short period of time and causes a sudden displacement of water. The most frequent causes of tsunamis are shallow underwater earthquakes and submarine landslides, but tsunamis can also be caused by underwater volcanic explosions, oceanic meteor impacts, and even underwater nuclear explosions. Tsunamis can travel across an entire ocean basin, or they can be local. Tsunamis are characterized by their length, speed, low period, and low observable amplitude: the waves can be up to 200 km (125 mi) long from one crest to the next, they travel in the deep ocean at speeds of up to 950 km/hr (600 mi/hr), and have periods of between 5 minutes and up to a few hours (with most tsunami periods ranging between 10 and 60 minutes). Their height in the open ocean is very small, a few meters at most, so they pass under ships and boats undetected (Garrison, 2002), but may pile up to heights of 30 m (100 ft) or more on entering shallow water along an exposed coast, where they can cause substantial damage. The highest elevation that the water reaches as it runs up on the land is referred to as wave runup, uprush, or inundation height (McCulloch, 1985; Synolakis et al., 2002). Inundation refers to the horizontal distance that a tsunami wave penetrates inland (Synolakis et al., 2002).

Because of the substantial increase in population in the last century and extensive development along the world's coastlines, a large percentage of the Earth's inhabitants live near the ocean. As a result, the risk of loss of life and property damage due to tsunami has increased substantially. Between 1992 and 2002, tsunamis were responsible for over 4,000 human deaths worldwide (Synolakis et al., 2002). Then, on December 26, 2004, a magnitude 9.3 earthquake off the northwest coast of Sumatra, Indonesia caused tsunamis in the Indian Ocean that resulted in more than 184,000 confirmed fatalities in the region, with another nearly 170,000 missing, and presumed killed, in Indonesia alone. The earthquake and resulting tsunamis also displaced nearly 1.7 million people in ten countries in South Asia and East Africa, making it the most devastating natural event in recorded history, and increasing overnight the worldwide awareness of tsunamis as a potentially devastating natural hazard. Hundreds of tourists that did not know about evacuating to higher ground were killed by the tsunamis. More recent devastating tsunamis include the September 29, 2009 earthquake and tsunami sequence in Samoa that killed 189 people, the February 27, 2010 earthquake and tsunami in Chile, and the March 11, 2011 Tohoku-oki earthquake and tsunami in Sendai, Japan.

Given Coachella's inland location, the tsunami hazard in the city is nil.

1.8 Vulnerability of Structures to Earthquake Damage

Although it is not possible to prevent earthquakes from occurring, their destructive effects can be minimized, especially since most of the loss of life and injuries due to an earthquake are related to the collapse of hazardous buildings and structures. [FEMA (1985) defines a hazardous building as "any inadequately earthquake resistant building, located in a seismically active area, that presents a potential for life loss or serious injury when a damaging earthquake occurs."] Therefore, the vulnerability of a community to earthquake damage can be reduced with a comprehensive hazard mitigation program that includes the identification and mapping of hazards, prudent planning and enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures.

As discussed previously, building codes have generally been made more stringent following damaging earthquakes. To mitigate for seismic shaking in new construction, recent building codes use amplification factors to account for the impacts that soft sediments and proximity to earthquake sources have on ground motion. Three main effects are considered: (1) soft soils, (2) proximity to earthquake sources (referred to as near-source factors), and (3) the seismic characteristics of the nearby earthquake sources (seismic source type). Each of these effects is discussed further below.

Soft-Soil Effects. The soft soil amplification factors were developed from observations made after the 1985 Mexico City, 1989 Loma Prieta and other earthquakes that showed the amplifying impact that underlying soil materials have on ground shaking. The ground-shaking basis for code design includes six soil types based on the average soil properties for the top 100 feet of the soil profile (see Table 1-4).

Youthful, unconsolidated alluvial sediments classified as site class type F soils may underlie those portions of the Coachella General Plan area that are susceptible to liquefaction (refer to Plate 1-3). The lacustrine (lake) deposits (Ql/Qa sediments on Plate 2-1a) may locally contain clay layers thick enough to be described as site class E or F. Site-specific studies need to be conducted in these areas to determine the soil class type that best fits the site conditions. Similarly, areas along the eastern edge of the valley underlain by youthful, unconsolidated sediments, but where groundwater is too deep for liquefaction, may fall under either site class E or D (compare Plates 2-1a and 1-3). The alluvial fan sediments at the base of the hillsides, in the eastern half of the General Plan area, both immediately west of and to the east of the San Andreas fault are best represented by site class D, except in the narrow canyons where these deposits are most likely less than 100 feet thick, and underlain by sediments assigned to the Ocotillo Conglomerate. Site class C may be most appropriate for these areas. Site-specific studies designed to characterize the shear wave velocity and undrained shear strength of the soil column would be necessary if these fans are to be developed. The areas underlain by the Ocotillo Conglomerate are best represented by site class C. The areas underlain by bedrock assigned to the Palm Spring Formation, in the southeastern portion of the General Plan area, most likely fall in site class B, unless deeply weathered.

**Table 1-4: Site Class Definitions (Based on Soil Profile Types)
(from Chapter 20, ASCE Standard 7.10)**

<table>
<tr><th rowspan="2">Site Class</th><th rowspan="2">Soil Profile Name/ Generic Description</th><th colspan="3">Average Soil Properties for the Upper 100 Feet</th></tr>
<tr><th>Shear Wave Velocity (feet/second)</th><th>Standard Penetration Resistance (blows/foot)</th><th>Undrained Shear Strength (psf)</th></tr>
<tr><td>A</td><td>Hard Rock</td><td>>5,000</td><td>N/A</td><td>N/A</td></tr>
<tr><td>B</td><td>Rock</td><td>2,500 to 5,000</td><td>N/A</td><td>N/A</td></tr>
<tr><td>C</td><td>Very dense soil and soft rock</td><td>1,200 to 2,500</td><td>>50</td><td>>2,000</td></tr>
<tr><td>D</td><td>Stiff soil profile</td><td>600 to 1,200</td><td>15 to 50</td><td>1,000 to 2,000</td></tr>
<tr><td rowspan="2">E</td><td>Soft soil profile</td><td><600</td><td><15</td><td><1,000</td></tr>
<tr><td colspan="4">Any profile with more than 10 feet of soil having the following characteristics:
1. Plasticity index PI > 20
2. Moisture Content ≥ 40%, and
3. Undrained shear strength < 500 psf</td></tr>
<tr><td>F</td><td colspan="4">Any profile containing soil having one or more of the following characteristics:
1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils.
2. Peats and/or highly organic clays, where the thickness of this section is more than 10 feet.
3. Very high plasticity clays (more than 25 feet of clay with plasticity index PI > 75).
4. Very thick soft/medium stiff clays (thickness of the soil > 120 feet) and undrained shear strength < 1000 psf.</td></tr>
</table>

From Table 20.3-1 of the American Society of Civil Engineers, Standard 7-10
psf = pounds per square foot

Near- Source Factors – The Coachella area is subject to near-source design factors given that the San Andreas fault extends across the city, and is located within 15 km of all locations in the city (see Table 1-2 and Plates 1-1 and 1-2). These parameters, which first appeared in the 1997 Uniform Building Code (UBC), address the proximity of potential earthquake sources (faults) to the site. These factors were present in earlier versions of the UBC for implementation into the design of seismically isolated structures, but are now included for all structures. The adoption into the 1997 code of all buildings in UBC seismic zone 4 was the result of observations of intense ground shaking at levels higher than expected near the fault ruptures at Northridge in 1994, and again one year later, in Kobe, Japan. The 1997 UBC also included a near-source factor that accounts for directivity of fault rupture. The direction of fault rupture was observed to play a significant role in distribution of ground shaking at Northridge and Kobe. For Northridge, much of the earthquake energy was released into the sparsely populated mountains north of the San Fernando Valley, while at Kobe, the rupture direction was aimed at the city and was a contributing factor in the extensive damage. However, the rupture direction of a given source cannot be predicted, and as a result, the UBC required a general increase in estimating ground shaking of about 20 percent to account for directivity. These factors are now included in the seismic maps provided in the CBC, and do not need to be calculated separately.

Seismic Source Type – Near-source factors considered in the seismic maps provided in the CBC also include a classification of seismic sources based on slip rate and maximum magnitude potential. Essentially, some faults like the San Andreas fault, are highly active and have a high rate of slip. This type of faults is weighted more in the calculations of ground motion for a given area, given that they are more likely to generate a high magnitude earthquake.

Building damage is commonly classified as either structural or non-structural. Structural damage impairs the building's support. This includes any vertical and lateral force-resisting systems, such as frames, walls, and columns. Non-structural damage does not affect the integrity of the structural support system, but includes such things as broken windows, collapsed or rotated chimneys, unbraced parapets that fall into the street, and fallen ceilings.

During an earthquake, buildings get thrown from side to side and up and down. Given the same acceleration, heavier buildings are subjected to higher forces than lightweight buildings. Damage occurs when structural members are overloaded, or when differential movements between different parts of the structure strain the structural components. Larger earthquakes and longer shaking duration tend to damage structures more. The level of damage can be predicted only in general terms, since no two buildings undergo the exact same motions, even in the same earthquake. Past earthquakes have shown, however, that some types of buildings are far more likely to fail than others. This section assesses the general earthquake vulnerability of structures and facilities common in the southern California area, including in Coachella. This analysis is based on past earthquake performance of similar types of buildings in the U.S. The effects of design earthquakes on particular structures within Coachella are beyond the scope of this study.

1.8.1 Unreinforced Masonry Buildings

Unreinforced masonry buildings (URMs) are prone to failure due to inadequate anchorage of the masonry walls to the roof and floor diaphragms, lack of steel reinforcing, the limited strength and ductility of the building materials, and sometimes, poor construction workmanship. Furthermore, as these buildings age, the bricks and mortar tend to deteriorate, making the buildings even weaker. As a result, the State Legislature passed Senate Bill 547, addressing the identification and seismic upgrade of URMs.

In response to the URM Law, all cities and counties in what the Building Code in effect at the time referred as Seismic Zone 4 were to conduct an inventory of their URMs, establish an URM loss-reduction program, and report their progress to the State by 1990. The Seismic Safety Commission has conducted updates to this inventory, more recently in 2003 and 2006.

In 2000, the City of Coachella reported to the Seismic Safety Commission that their original survey showed 14 URMs in the city, but 13 of those had been reinforced (based on a physical review of the buildings using metal detectors). The remaining URM was destroyed in a fire in 1994 (Seismic Safety Commission, 2000). Accordingly, there are no URMs in Coachella. The same information is given in the 2003 and 2006 reports on the "Status of the Unreinforced Masonry Law" by the Seismic Safety Commission.

In 2007, the City retained D.M. Buchanan and Associates Inc. to conduct a City-wide survey of all masonry structures (L. Lopez, Acting Developing Services Director, written communication, 2012). The survey was prepared for the City's Building Official in response to Ordinance 985 entitled *An Ordinance of the City Council of the City of Coachella, California, adding Chapter 15.66 Seismic Hazard Mitigation to Title 15, Buildings and Construction of the Coachella Municipal Code*. This survey, performed on November 1st through 6th of 2007, identified 110 masonry structures in the City, and their ancillary features and associated facilities. Of these, a total of 55 structures were actually studied. The objectives of the study were as follows:

1. Identify whether the surveyed structure has bearing walls sufficiently reinforced with steel to comply with the City's Ordinance which specifies that the walls must have not less than 50 percent of the 1988 Uniform Building Code (UBC) requirement.
2. Identify whether the roof assembly of the structure is securely attached to the bearing walls with a positive "roof to wall" connection.

Per the 1988 UBC code, steel reinforcement for a single-story structure located in Seismic Zone 4 and subjected to 80 miles per hour (mph) winds with a Class "C" exposure generally equates to a requirement of No. 4 bars spaced 24 inches apart, center to center. All structures were considered as separate entities and did not have the benefit of the shielding that could be provided by other structures since these surrounding buildings could be removed at some time and fully expose the structure being studied. The study identified the following twelve commercial structures in the City which are lacking bearing wall steel reinforcement adequate to comply with the City's Ordinance (see Table 1-5). An additional 31 structures were identified as not having a positive roof-to-wall connection.

Table 1-5: Commercial Structures in the City of Coachella Lacking Adequate Bearing Wall Steel Reinforcement

Address	Size of Structure	Approximate Age
52-717 Harrison	43' x 64' = 2,752 SF	44 Years
53-015 Harrison	45' x 26' = 1,170 SF	74 Years
53-175 Harrison	30' x 72.5' = 2,175 SF	84 Years
53-225 Harrison	48' x 47' = 2,256 SF	84 Years
48-487 Grapefruit Blvd	Varies = 200 SF	64 Years
85-963 Grapefruit Blvd	62' x 100' = 6,200 SF	74 Years
1510 and 1530 Sixth Street	50' x 65' = 3,250 SF	84 Years
1586 and 1590 Sixth Street	50' x 70' = 3,500 SF	74 Years
1612 Sixth Street	25' x 40' = 1,000 SF	79 Years
1615 Sixth Street	17' x 31' = 527 SF	74 Years
1632 Sixth Street	70' wide with various length depths = 4,200 SF	79 Years
1694 Sixth Street	50' x 70' = 3,500 x 2 = 7,000 SF	74 Years

Source: Buchanan and Associates, Inc., 2008.

1.8.2 Soft-Story Buildings

Of particular concern are soft-story buildings (buildings with a story, generally the first floor, lacking adequate strength or toughness due to too few shear walls). Residential units above glass-fronted stores, and buildings perched atop parking garages are common examples of soft-story buildings. Many multi-unit residential units built in the 1960s and 1970s are of the "tuck-under parking" type, with open areas at ground level and only thin columns carrying the gravity loads (Graf and Seligson, 2011). Collapse of a soft story and "pancaking" of the remaining stories killed 16 people at the Northridge Meadows apartments during the 1994 Northridge earthquake (EERI, 1995). There are many other cases of soft-story collapses in past earthquakes. In response, the State encourages the identification and mitigation of seismic hazards associated with these types of potentially hazardous buildings, and others such as pre-1971 concrete tilt-ups, mobile homes, and pre-1940 homes. There are several techniques that can be used to seismically strengthen buildings with soft-story construction. Some of these include adding shear walls or steel moment-frames to the entrance openings, and increasing or strengthening the shear walls in the first story. The City of Coachella should consider conducting an inventory of their soft-stories, and encouraging the structural retrofit of these structures so that they not collapse during an earthquake.

1.8.3 Wood-Frame Structures

The loss estimations conducted for this study (see Section 1.9) indicates that about 86 percent of wood-frame structures in Coachella are expected to experience slight to complete damage as a result of ground shaking caused by a M7.8 earthquake on the San Andreas fault, with about 30 percent experiencing moderate to complete damage. A smaller earthquake resulting from rupture of only the Coachella section of the San Andreas fault is anticipated to cause at least slight damage to about 60 percent of the wood-frame structures in the Coachella area.

Structural damage to wood-frame structures often results from an inadequate connection between the superstructure and the foundation. These buildings may slide off their foundations, with consequent damage to plumbing and electrical connections. Unreinforced masonry chimneys may also collapse. These types of damage are generally not life threatening, although they may be costly to repair. Wood frame buildings with stud walls generally perform well during an earthquake, unless they have no foundation or have a weak foundation constructed of unreinforced masonry or poorly reinforced concrete. In these cases, damage is generally limited to cracking of the stucco, which dissipates much of the earthquake's induced energy. The collapse of wood frame structures, if it happens, generally does not generate heavy debris, but rather, the wood and plaster debris can be cut or broken into smaller pieces by hand-held equipment and removed by hand in order to reach victims (FEMA, 1985).

1.8.4 Pre-Cast Concrete Structures

Partial or total collapse of buildings where the floors, walls and roofs fail as large intact units, such as large pre-cast concrete panels, cause the greatest loss of life and difficulty in victim rescue and extrication (FEMA, 1985). These types of buildings are common not only in southern California, but abroad. Casualties as a result of collapse of these structures in past earthquakes, including Mexico (1985), Armenia (1988), Nicaragua (1972), El Salvador (1986 and 2001), the Philippines (1990), Turkey (1999), China (2008) and Haiti (2010) add to hundreds of thousands. In southern California, many of the parking structures that failed during the 1994 Northridge earthquake, such as the Cal-State Northridge and City of Glendale Civic Center parking structures, consisted of pre-cast concrete components (EERI, 1995).

Collapse of this type of structure generates heavy debris, and removal of this debris requires the use of heavy mechanical equipment. Consequently, the location and extrication of victims trapped under the rubble is generally a slow and dangerous process. Extrication of trapped victims within the first 24 hours after the earthquake becomes critical for survival. In most instances, however, post-earthquake planning fails to quickly procure the equipment needed to move heavy debris. The establishment of Heavy Urban Search and Rescue teams, as recommended by FEMA (1985), has improved victim extrication and survivability. Buildings that are more likely to fail and generate heavy debris need to be identified, so that appropriate mitigation and planning procedures are defined prior to an earthquake.

1.8.5 Tilt-up Buildings

Tilt-up buildings have concrete wall panels, often cast on the ground, or fabricated off-site and trucked in, which are then tilted upward into their final position. Connections and anchors have pulled out of walls during earthquakes, causing the floors or roofs to collapse. A high rate of failure was observed for this type of construction in the 1971 San Fernando and 1987 Whittier Narrows earthquakes. Tilt-up buildings can also generate heavy debris.

1.8.6 Reinforced Concrete Frame Buildings

Reinforced concrete structures in southern California typically house offices, hotels, and mixed industrial, commercial, or retail occupancies. Reinforced concrete frame buildings, with or without reinforced infill walls, display low ductility. Earthquakes may cause shear failure (if there are large tie spacings in columns, or insufficient shear strength), column failure (due to inadequate rebar splices, inadequate reinforcing of beam-column joints, or insufficient tie anchorage), hinge deformation (due to lack of continuous beam reinforcement), and non-structural damage (due to the relatively low stiffness of the frame). A common type of failure observed following the Northridge earthquake was confined column collapse (EERI, 1995), where infilling between columns confined the length of the columns that could move laterally in the earthquake.

Older reinforced concrete buildings, dating to before 1980, are reportedly approximately nine times more likely to collapse than more modern, code-conforming reinforced concrete frame buildings and other types of structures built in conformance with the newer seismic-resistant building codes (Liet et al., 2011, as reported in Lynch et al., 2011).

1.8.7 Multi-Story Steel Frame Buildings

Multi-story steel frame buildings generally have concrete floor slabs. However, these buildings are less likely to collapse than concrete structures. Common damage to these types of buildings is generally non-structural, including collapsed exterior curtain wall (cladding), and damage to interior partitions and equipment. Overall, modern steel frame buildings have been expected to perform well in earthquakes, but the 1994 Northridge earthquake broke many welds in these buildings, a previously unanticipated problem.

Older, pre-1945 steel frame structures may have unreinforced masonry such as bricks, clay tiles and terra cotta tiles as cladding or infilling. Cladding in newer buildings may be glass, infill panels or pre-cast panels that may fail and generate a band of debris around the building exterior (with considerable threat to pedestrians in the streets below). Structural damage may occur if the structural members are subject to plastic deformation, which can cause permanent displacements. If some walls fail while others remain intact, torsion or soft-story problems may result.

1.8.8 Mobile (Manufactured) Homes

Mobile homes are prefabricated housing units that are placed on isolated piers, jackstands, or masonry block foundations (usually without any positive anchorage). Floors and roofs of mobile homes are usually plywood, and outside surfaces are covered with sheet metal. Mobile homes typically do not perform well in earthquakes. Severe damage occurs when they fall off their supports, severing utility lines and piercing the floor with jackstands. The results of the loss estimation analyses indicate that 100 percent of the mobile homes in Coachella area are likely to experience moderate to complete damage as a result of an M7.8 earthquake on the San Andreas fault, and nearly 98 percent will experience moderate to complete damage as a result of a M7.1 earthquake on the same fault. This suggests tat inspection and seismic strengthening as needed of the manufactured homes in the area can help to reduce the seismic losses in the city.

1.8.9 Combination Types

Buildings are often a combination of steel, concrete, reinforced masonry and wood, with different structural systems on different floors or different sections of the building. Combination types that are potentially hazardous include: concrete frame buildings without special reinforcing, precast concrete and precast-composite buildings, steel frame or concrete frame buildings with unreinforced masonry walls, reinforced concrete wall buildings with no special detailing or reinforcement, large capacity buildings with long-span roof structures (such as theaters and auditoriums), large un-engineered wood-frame buildings, buildings with inadequately anchored exterior cladding and glazing, and buildings with poorly anchored parapets and appendages (FEMA, 1985). Additional types of potentially hazardous buildings may be recognized after future earthquakes.

In addition to building types, there are other factors associated with the design and construction of the buildings that also have an impact on the structures' vulnerability to strong ground shaking. Some of these conditions are discussed below:

Building Shape – A building's vertical and/or horizontal shape can also be important in determining its seismic vulnerability. Simple, symmetric buildings generally perform better than non-symmetric buildings. During an earthquake, non-symmetric buildings tend to twist, as well as shake. Wings on a building tend to act independently during an earthquake, resulting in differential movements and cracking. The geometry of the lateral load-resisting systems also matters. For example, buildings with one or two walls made mostly of glass, while the remaining walls are made of concrete or brick, are at risk. Asymmetry in the placement of bracing systems that provide a building with earthquake resistance can result in twisting or differential motions.

Pounding – Site-related seismic hazards may include the potential for neighboring buildings to "pound," or for one building to collapse onto a neighbor. Pounding occurs when there is little clearance between adjacent buildings, and the buildings "pound" against each other as they deflect during an earthquake. The effects of pounding can be especially damaging if the floors of the buildings are at different elevations, so that, for example, the floor of one building hits a supporting column of the other. Damage to a supporting column can result in partial or total building collapse.

1.9 Earthquake Scenarios and Loss Estimations

HazUS-MH™ is a standardized methodology for earthquake loss estimation based on a geographic information system (GIS). [HazUS-MH stands for Hazards United States – Multi-hazard.] A project of the National Institute of Building Sciences, funded by the Federal Emergency Management Agency (FEMA), HazUS is considered a powerful advance in mitigation strategies. The HazUS project developed guidelines and procedures to make standardized earthquake loss estimates at a regional scale (also flood and hurricane loss estimates; see Chapter 3, Section 3.3 for the flood losses estimated for Coachella). With standardization, estimates can be compared from region to region. HazUS is designed for use by state, regional and local governments in planning for earthquake loss mitigation, and emergency preparedness, response and recovery. HazUS addresses nearly all aspects of the built environment, and many different types of losses. The methodology has been tested against the experience of several past earthquakes, and against the judgment of experts. Subject to several limitations noted below, HazUS can produce results that are valid for the intended purposes.

Loss estimation is an invaluable tool, but it must be used with discretion. Loss estimation analyzes casualties, damage and economic loss in great detail. It produces seemingly precise numbers that can be easily misinterpreted. Loss estimation results, for example, may cite 454 left homeless by a scenario earthquake. This is best interpreted by its magnitude. That is, an event that leaves 400 people homeless is clearly more manageable than an event that results in 4,000 homeless people; and an event that leaves 40,000 homeless will most likely overwhelm the region's resources. However, another loss estimation analysis that predicts 500, or even 600, people homeless should be considered equivalent to the 454 result. Because HazUS results make use of a great number of parameters and data of varying accuracy and completeness, it is not possible to assign quantitative error bars. Although the numbers should not be taken at face value, they are not rounded or edited because detailed evaluation of individual components of the disaster can help mitigation agencies ensure that they have considered all important variables.

The more community-specific the data that are input to HazUS, the more reliable the loss estimation. HazUS provides defaults for all required information. These are based on best-available scientific, engineering, census and economic knowledge. The loss estimations in this report were tailored to the Coachella General Plan area by including the Riverside County HazUS data obtained as part of a project that developed a detailed inventory of structures and essential facilities for Riverside, San Bernardino and Orange counties (H. Seligson and MMI Engineering, 2008). The revised inventory includes structure-specific information, including structural type, age and thus seismic design level (e.g., high, moderate, low, or pre-code), height, occupancy, and building replacement cost, among other variables, as provided by the owners of the structures (although in a few cases, thee building characteristics were inferred by the authors of the 2008 study). The HazUS analyses presented here also considered the soil types that underlie the study area, including their liquefaction susceptibility, and modifications to the population count, as described further below.

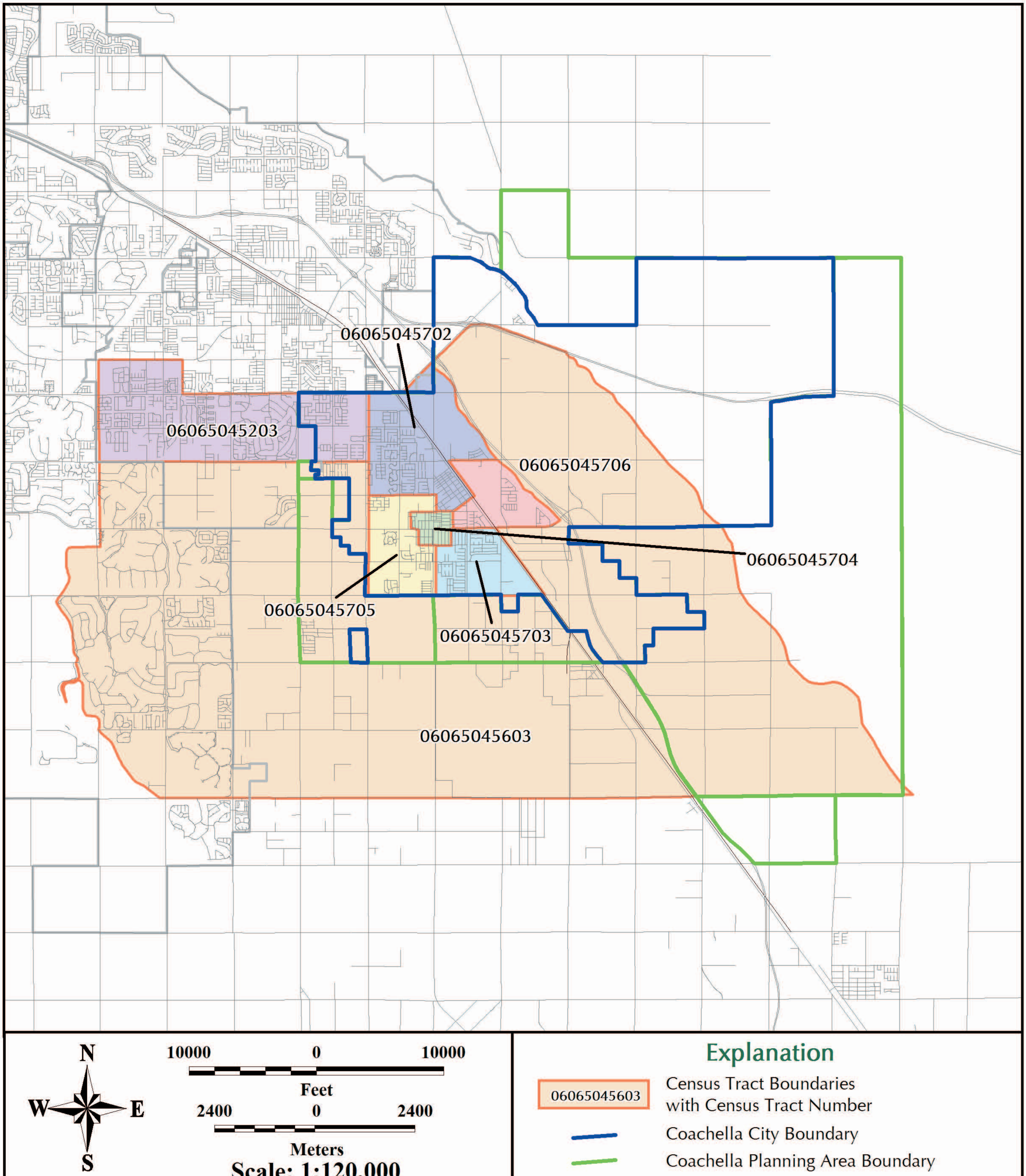
HazUS relies on census data, which are reported by geographical areas or tracts. Unfortunately, census tracts often do not correlate well with city boundaries, especially in areas with low population densities. This is certainly the case for Coachella, where seven census tracts cover most, but not all of the General Plan area, and one of the census tracts considered also includes a large portion of the city of La Quinta to the west. The total area covered by these census tracts is 62.5 square miles (see Figure 1-5). Population counts were modified from those provided in the HazUS database (that date to the census of 2000) to incorporate the 2010 Census Data where available, and thus model the population increase that this area has experienced in the last decade. When the HazUS analyses for this study were conducted in July 2011, the U.S. Census Bureau had released population data for four of the seven census tracts considered (census tracts ending in 703, 704, 705 and 706, see Figure 1-5). These four tracks are entirely within the Coachella General Plan study area, and thus, the 2010 population numbers for these tracts were replaced in the HazUS database. The population counts from 2000 were kept for two of the remaining three census tracts (203 and 603) because a review of historical Google Earth images showed that those portions of the census tracts within Coachella saw very little growth between 2000 and 2010. The population in census tract 702 was increased from the 2000 number to account for new housing developed in 2009. The total population used in the analyses is 43,716 people, a number that correlates closely with the 2010 population counts issued by the U.S. Census Bureau for Coachella (40,704) and the Vista Santa Rosa area (2,926). Thus, although the area considered in the analyses extends beyond Coachella and includes a large portion of La Quinta, the population counts used in the final analyses best represent the population estimates for the Coachella General Plan area only. Other aspects of the database, such as the critical facilities, were also modified to represent only the Coachella General Plan area. This is discussed further where appropriate.

As useful as HazUS can be, the loss estimation methodology has some inherent uncertainties. These arise, in part, from incomplete scientific knowledge concerning earthquakes and their effect upon buildings and facilities, and from the approximations and simplifications necessary for comprehensive analyses. Users should be aware of the following specific limitations:

- HazUS is driven by statistics, and thus is most accurate when applied to a region, or a class of buildings or facilities. It is least accurate when considering a particular site, building or facility.
- Losses estimated for lifelines may be less than losses estimated for the general building stock.
- Losses from smaller (less than M 6) earthquakes may be overestimated.
- Pilot and calibration studies have not yet provided an adequate test concerning the possible extent and effects of landsliding.
- The indirect economic loss module is still experimental. While output from pilot studies has generally been credible, this module requires further testing.
- The databases that HazUS draws from to make its estimates are often incomplete or as mentioned above, either do not match the boundaries of the desired study area, or are no longer representative of current conditions. In the case of Coachella, and as explained above, we made adjustments to the population counts in the HazUS database to approximate the current population numbers.

Essential facilities and lifeline inventory are located by latitude and longitude. However, the HazUS inventory data for lifelines and utilities were developed at a national level and where specific data are lacking, statistical estimations are utilized. Particulars about the site-specific inventory data used in the models are discussed further in the paragraphs below. Other site-specific data used include soil types. The user then defines the earthquake scenario to be modeled, including the magnitude of the earthquake, and the location of the epicenter. Once all these data are input, the software calculates the loss estimates for each scenario (see Figure 1-6).

The loss estimates include physical damage to buildings of different construction and occupancy types, damage to essential facilities and lifelines, number of after-earthquake fires and damage due to fires following the earthquake (included in Chapter 4). The model also estimates the direct economic and social losses, including casualties and fatalities for three different times of the day, the number of people left homeless and number of people that will require shelter, number of hospital beds available, and the economic losses due to damage to the places of businesses, loss of inventory, and (to some degree) loss of jobs. The indirect economic losses component is still experimental; the calculations in the software are checked against actual past earthquakes, such as the 1989 Loma Prieta and 1994 Northridge earthquakes, but indirect losses are hard to measure, and it typically takes years before these monetary losses can be quantified with any degree of accuracy.



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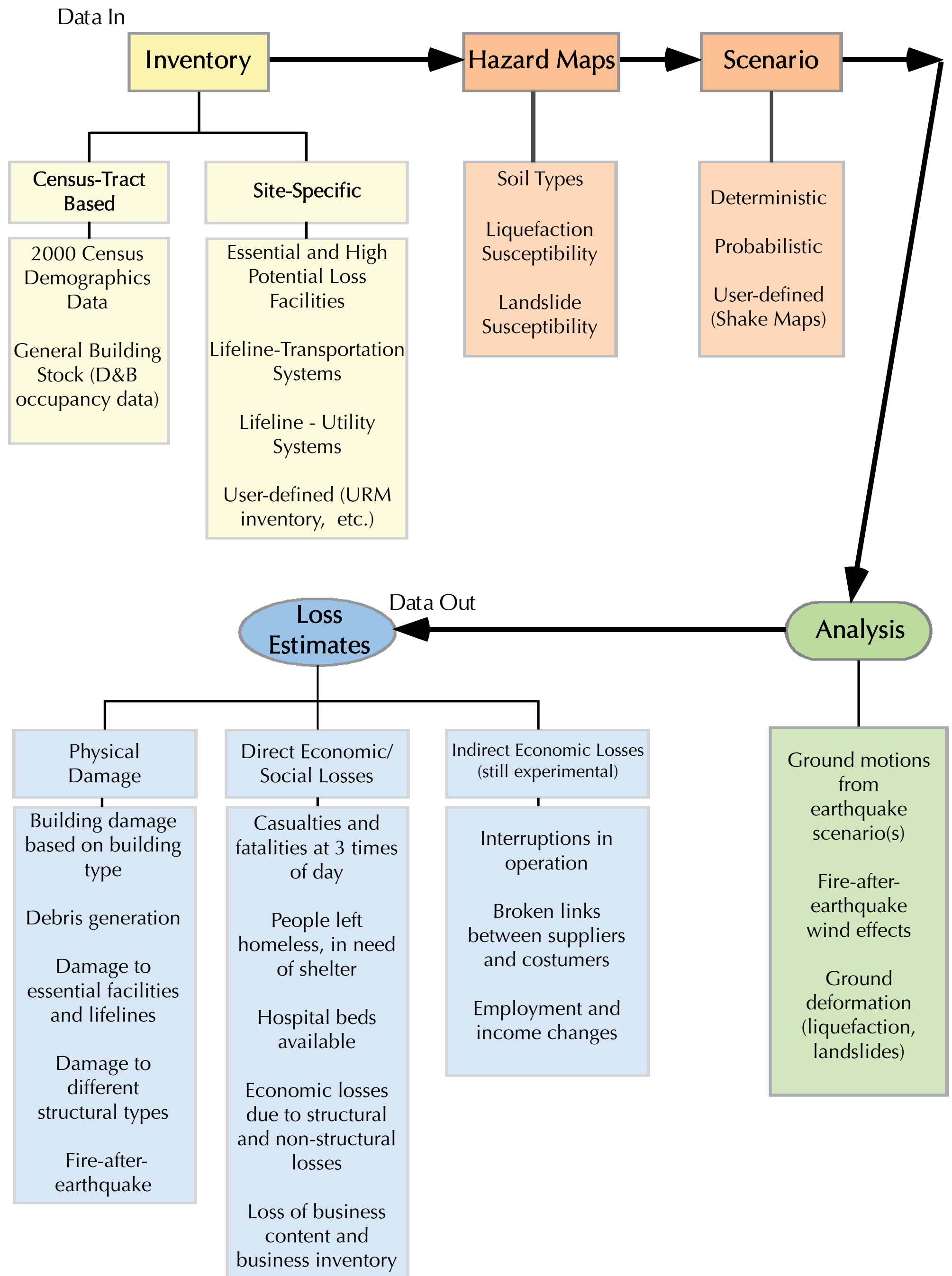
Census Tracts Used in the HazUS Analyses

Figure 1-5



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Generalized Flow Chart Summarizing the HazUS Methodology

Figure 1-6

Two earthquake scenarios were modeled: an earthquake on the southern San Andreas fault rupturing the Mojave South, San Bernardino (North and South), San Gorgonio-Garnet Hill and Coachella sections of the fault (the ShakeOut scenario prepared by the U.S. Geological Survey in the fall of 2008 – see the ShakeMap for this scenario in Figure 1-4), and an earthquake on the Coachella section of the San Andreas fault only, which is the section of the San Andreas fault that extends across the city of Coachella. Specifics about these earthquake-producing fault sections and segments were provided in Section 1.4.1 above, and in Table 1-6 below. The following sections describe the losses anticipated in Coachella due to the two earthquake scenarios modeled.

Table 1-6: HazUS Earthquake Scenarios for the City of Coachella

Fault Source	Magnitude	Description
Southern San Andreas Fault	7.8	A large earthquake that ruptures a 300-km stretch of the southern San Andreas fault, from Bombay Beach to Lake Hugues, using the U.S. Geological Survey's ShakeOut scenario (Jones et al., 2008). This hypothetical earthquake is scientifically realistic; the mean probability of a M7.75 or greater earthquake occurring on the southern San Andreas fault in the next 30 years is 16 percent (Field et al., 2009).
Coachella Valley section of San Andreas Fault	7.1	Lower risk but high probability earthquake event. The Coachella section of the fault has not ruptured since about 1680, and is thus considered to have a high probability of rupturing in the next 30 years. The Coachella section of the fault extends across the city of Coachella and the Coachella General Plan study area.

The results indicate that of the two earthquake scenarios modeled for Coachella, the M_w 7.8 earthquake on the San Andreas fault, given the more intense ground shaking, will cause more damage in the study area. For most of southern California, an earthquake on the San Andreas fault is not the worst-case scenario, as there are often other faults much closer that have the potential to be equally or more damaging. However, the San Andreas fault is the worst-case scenario for Coachella and other communities in the Coachella and Imperial valleys – the fault's location and high probability of rupturing in the next 30 years resolve into a high probability, high risk seismic source for this region. However, the M7.8 ShakeOut scenario is not the worst-case event; the San Andreas fault could rupture in a M8.0 earthquake. The M7.8 ShakeOut scenario is considered realistic and plausible (Perry, Jones and Cox, 2011).

1.9.1 Building Damage

HazUS provides damage data for buildings based on these structural types:

- Concrete
- Manufactured Housing (Trailers and Mobile Homes)
- Precast Concrete
- Reinforced Masonry Bearing Walls
- Steel
- Unreinforced Masonry Bearing Walls
- Wood Frame

and based on these occupancy (usage) classifications:

- Agricultural
- Commercial
- Education
- Government
- Industrial
- Other Residential
- Religion
- Single Family

Loss estimation for the general building stock is averaged for each census tract. Building damage classifications range from slight to complete. As an example, the building damage classification for light, wood frame buildings, the most numerous building type in the city, is provided below.

- Slight Structural Damage: Small cracks in the plaster or gypsum-board at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.
- Moderate Structural Damage: Large cracks in the plaster or gypsum-board at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
- Extensive Structural Damage: Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of "room-over-garage" or other "soft-story" configurations; small foundation cracks.
- Complete Structural Damage: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off their foundations; or develop large foundation cracks.

The HazUS database includes nearly 16,000 buildings in the region, with a total building replacement value (excluding contents) of $3,743 million (2006 dollars). Approximately 90 percent of the buildings considered in the analysis (and 86 percent of the building value) are associated with residential housing. In terms of building construction types found in the region, wood-frame construction makes up approximately 76 percent of the building inventory, and manufactured housing comprises almost another 16 percent. The remaining about 8 percent is distributed between the other general building types.

Estimates of building damage are provided for "High," "Moderate" and "Low" seismic design criteria. Buildings of newer construction (e.g., post-1973) are best designated by "high." Buildings built after 1940, but before 1973, are best represented by "moderate" criteria. If built before about 1940 (i.e., before significant seismic codes were implemented), "low" is most appropriate. The building inventory for the seven census tracts considered indicates that about 1.2 percent of the housing units were built before 1939. About 22 percent of the building units were built between 1940 and 1969, and nearly 64 percent of the units were built after 1980. The remaining units (about 14 percent) were built in the decade between 1970 and 1979.

Therefore, nearly two-thirds of the housing stock in Coachella can be described as in the "high" category for seismic design criteria. However, structural engineers point out that buildings constructed before building codes were upgraded following the 1994 Northridge earthquake have significant deficiencies that could result in higher-than-expected levels of damage. Specifically, in the 1980s, low-rise wood-frame construction relied on stucco and gypsum wallboard for shear resistance, but these materials were observed to perform poorly during the Northridge earthquake. As a result, the newer building codes reduced the shear forces permitted in these materials, and promoted an increase reliance on plywood-sheathed shear panels instead (Graf, 2008; Graf and Seligson, 2011).

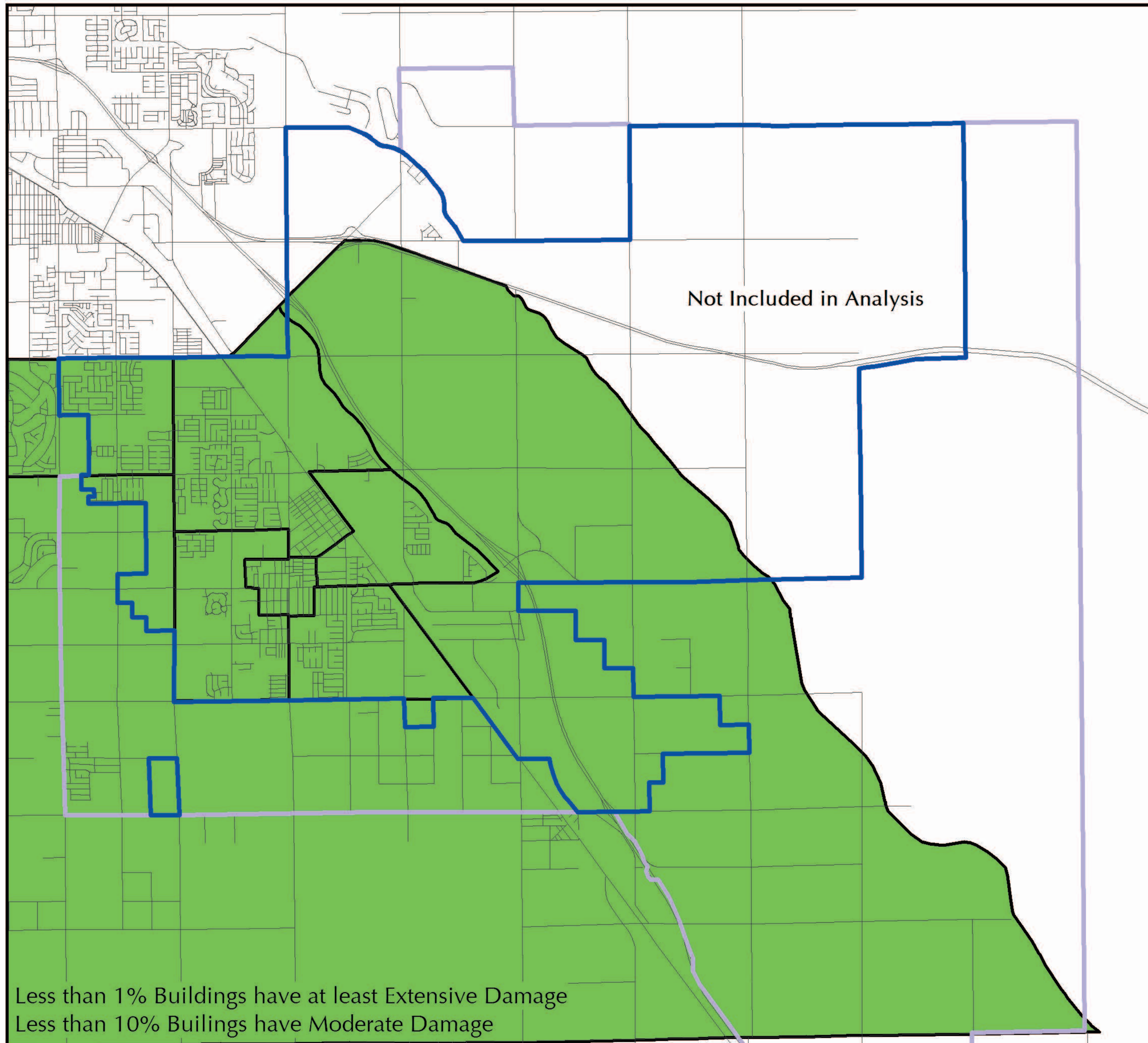
The HazUS models estimate that between 7,259 and 3,891 buildings in the Coachella HazUS study area will be at least moderately damaged by the earthquake scenarios presented herein, with the higher number representative of damage as a result of a M7.8 earthquake on the entire southern San Andreas fault, and the lower number representing damage as a result of a M7.1 earthquake on the Coachella section of the San Andreas fault only. These figures represent about 45 percent and 24 percent, respectively, of the total number of buildings in the region considered in the analysis. Table 1-7 summarizes the expected damage to buildings by general occupancy type, whereas Table 1-8 summarizes the expected damage to buildings in the region, classified by construction type.

Table 1-7: Number of Buildings* Damaged, by Occupancy Type

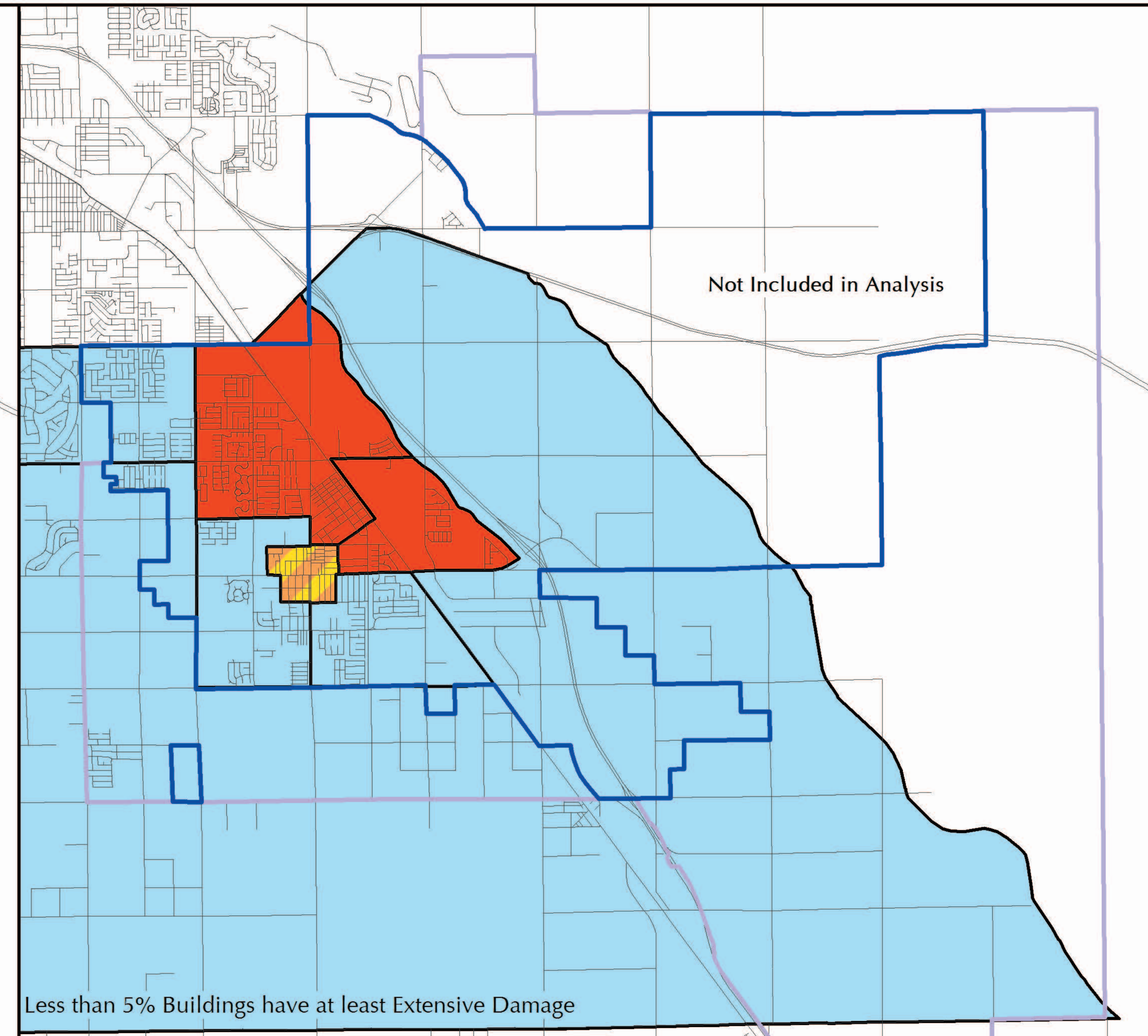
Scenario	Occupancy Type	Slight	Moderate	Extensive	Complete	Total
San Andreas ShakeOut	Agriculture	203	136	67	185	591
	Commercial	49	69	74	195	387
	Education	106	90	40	96	332
	Government	2	1	1	4	8
	Industrial	10	18	18	47	93
	Other Residential	212	81	113	2,486	2,892
	Religion	5	4	3	10	22
	Single Family	6,444	3,303	187	31	9,965
	Total	**7,031**	**3,702**	**503**	**3,054**	**14,290**
San Andreas Coachella	Agriculture	244	155	64	17	480
	Commercial	126	125	56	11	318
	Education	139	74	29	5	247
	Government	3	2	1	0	6
	Industrial	29	32	15	4	80
	Other Residential	265	1,027	1,283	226	2,801
	Religion	8	6	3	1	18
	Single Family	6,111	750	5	0	6,866
	Total	**6,925**	**2,171**	**1,456**	**264**	**10,816**

* Based on a total of 15,998 buildings in the region.

As a percentage of the building damage by occupancy type, the model estimates that more than 90 percent of the residential structures other than single-family homes (i.e., multi-family residential buildings, including duplexes, condominiums and apartments) will suffer at least moderate damage from a M7.8 earthquake on the San Andreas fault. The distribution and severity of the damage to residential structures by census tract as a result of the two



Magnitude 7.1 Earthquake on Coachella Section of San Andreas Fault



Magnitude 7.8 Earthquake on the Southern Sections of the San Andreas Fault (ShakeOut Scenario)

Source: Federal Emergency Management Agency, HAZUS 2.1 v 12.2.0

N W E S

7000 0 7000 14000

Feet

Scale: 1:84,000

EXPLANATION

Building Damage

- 50-70% Buildings have at least Moderate Damage
- 30-50% Buildings have at least Moderate Damage
- 50-70% Buildings have Slight to No Damage
- 70-90% Buildings have Slight to No Damage
- Greater than 90% Buildings have Slight to No Damage
- Coachella City Boundary
- Coachella Planning Area Boundary

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Date: 2014

Residential Building Damage

(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-4

earthquake scenarios is illustrated in Plate 1-4. Note that less than 10 percent of the residential structures in the city are expected to experience more than slight damage as a result of a M7.1 earthquake. A M7.8 event, on the other hand, will significantly impact certain sections of the city, with 50 to 70 percent of the residential structures (including multi-residential and manufactured homes) in some of the central census tracts experiencing at least moderate damage. In other portions of the city where newer residential tracts are located, HazUS estimates that between 10 and 30 percent of the residential buildings will experience at last slight damage.

Nearly 87 percent of the industrial structures, 59 percent of the agricultural, and 84 percent of the commercial structures in the Coachella General Plan area will be at least moderately damaged by a M7.8 earthquake on the San Andreas fault. Similarly, nearly 62 percent of the education buildings, 67 percent of the government buildings, and 74 percent of the religion buildings will suffer at least moderate damage. A smaller M7.1 earthquake on the Coachella Valley segment of the San Andreas fault is expected to cause at least moderate damage to nearly 86 percent of the residential structures other than single-family, and at least moderate damage to about 53, 36 and 48 percent of the industrial, agricultural, and commercial structures, respectively, in the study area. The M7.1 Coachella Valley segment earthquake scenario is also anticipated to cause at least moderate damage to about 30 percent of the educational buildings and nearly 38 percent of the government buildings in the region.

Table 1-8: Number of Buildings* Damaged, by Construction Type

Scenario	Structure Type	Slight	Moderate	Extensive	Complete	Total
San Andreas ShakeOut	Wood	6,868	3,431	168	41	10,508
	Steel	35	66	55	223	379
	Concrete	37	22	30	105	194
	Precast	24	58	46	64	192
	Reinforced Masonry	67	123	106	173	469
	Manufactured Housing	0	2	98	2,448	2,548
	Total	**7,031**	**3,702**	**503**	**3,054**	**14,290**
San Andreas Coachella	Wood	6,476	790	11	1	7,278
	Steel	93	146	70	20	329
	Concrete	75	51	24	7	157
	Precast	67	77	19	4	167
	Reinforced Masonry	152	126	55	8	341
	Manufactured Housing	62	981	1,277	224	2,544
	Total	**6,925**	**2,171**	**1,456**	**264**	**10,816**

* Based on a total of 15,998 buildings in the region.

Although wood-frame buildings comprise the largest number of buildings in the area, and therefore one would expect that most of the buildings damaged would be wood-frame structures, the data show that the building type that will suffer the most damage is manufactured housing. In fact, wood-frame buildings, as a group, are expected to perform relatively well during an earthquake. Case in point, the ShakeOut earthquake on the San Andreas fault is anticipated to cause at least moderate damage to 3,640 wood-frame buildings, comprising about 30 percent of the total number of wood-frame buildings in the region, and to 2,548 manufactured homes, equal to 100 percent of the total number of manufactured homes in the study area. Similarly, a smaller but significant M7.1 earthquake on the Coachella Valley segment of the San Andreas fault is expected to cause at least moderate damage to less than 7 percent of the wood-frame buildings, but to nearly 98 percent of the manufactured homes in the region. The other building types in Coachella, by construction type, that are anticipated to suffer at least moderate damage as a result of a M7.8 earthquake on the San Andreas fault include steel (89 percent will be at least moderately damaged), precast (85 percent), concrete (77 percent), and reinforced masonry (79 percent). An earthquake on only the Coachella Valley segment of the San Andreas fault is anticipated to cause at least moderate damage to 61 percent of the steel buildings in Coachella, 50 percent of the precast buildings, 40 percent of the concrete buildings, and 37 percent of the reinforced masonry buildings.

1.9.2 Casualties

Casualties are estimated based on the observation that there is a strong correlation between building damage (both structural and non-structural) and the number and severity of casualties. In smaller earthquakes, non-structural damage, (such as toppled bookshelves and broken windows) is typically responsible for most of the casualties. In severe earthquakes where there is a large number of collapses and partial collapses, there is a proportionately larger number of fatalities. Data regarding earthquake-related injuries are, however, not of the best quality, nor are they available for all building types. Available data often have insufficient information about the type of structure in which the casualties occurred and the casualty-generating mechanism. HazUS casualty estimates are based on the injury classification scale described in Table 1-9.

Table 1-9: Injury Classification Scale

Injury Severity Level	Injury Description
Severity 1	Injuries requiring basic medical aid without requiring hospitalization.
Severity 2	Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life-threatening status.
Severity 3	Injuries which pose an immediate life-threatening condition if not treated adequately and expeditiously. The majority of these injuries are the result of structural collapse and subsequent entrapment or impairment of the occupants.
Severity 4	Instantaneously killed or mortally injured.

In addition, HazUS produces casualty estimates for three times of day:

- Earthquake striking at 2:00 A.M. (population at home)
- Earthquake striking at 2:00 P.M. (population at work/school)
- Earthquake striking at 5:00 P.M. (commute time).

Table 1-10 provides a summary of the casualties estimated for the earthquake scenarios considered. The analysis indicates that the worst time for a San Andreas fault earthquake to occur in Coachella is during maximum educational, industrial and commercial occupancy loads, such as at 2 o'clock in the afternoon. An M7.8 earthquake on the San Andreas fault sometime during the day is anticipated to cause hundreds of Level 1 and Level 2 injuries, most likely related to people trying to run outside and in the process bumping into overturned furniture, being hit by objects falling off shelves in stores and offices, and by falling debris resulting from the structural damage to primarily commercial and educational buildings.

Table 1-10: Estimated Casualties*

Type and Time of Scenario			Level 1: Medical treatment without hospitalization	Level 2: Hospitalization but not life threatening	Level 3: Hospitalization and life threatening	Level 4: Fatalities due to scenario event
San Andreas Fault ShakeOut Scenario	2A.M. (max. residential occupancy)	Commercial	2	1	0	0
		Commuting	0	0	0	0
		Educational	0	0	0	0
		Hotels	1	0	0	0
		Industrial	1	1	0	0
		Other Res. Residential	189	51	4	8
		Single-Family	53	9	1	2
		Total	**246**	**61**	**6**	**10**
	2 P.M. (max educational, industrial, and commercial)	Commercial	172	56	10	19
		Commuting	1	1	2	0
		Educational	96	32	6	11
		Hotels	0	0	0	0
		Industrial	1	3	1	1
		Other Residential	40	11	1	2
		Single-Family	12	2	0	0
		Total	**332**	**105**	**19**	**33**
	5 P.M. (peak commute time)	Commercial	182	59	10	20
		Commuting	6	7	12	2
		Educational	5	2	0	1
		Hotels	0	0	0	0
		Industrial	7	2	0	1
		Other Residential	68	18	2	3
		Single-Family	20	3	0	1
		Total	**288**	**92**	**25**	**27**
San Jacinto Fault	2A.M. (max. residential occupancy)	Commercial	0	0	0	0
		Commuting	0	0	0	0
		Educational	0	0	0	0
		Hotels	0	0	0	0
		Industrial	0	0	0	0
		Other Residential	38	7	0	1
		Single-Family	14	1	0	0
		Total	**53**	**8**	**1**	**1**
	2 P.M. (max educational, industrial, and commercial)	Commercial	19	4	1	1
		Commuting	0	0	0	0
		Educational	10	2	0	1
		Hotels	0	0	0	0
		Industrial	1	0	0	0
		Other Residential	8	1	0	0
		Single-Family	3	0	0	0
		Total	**42**	**9**	**1**	**2**
	5 P.M. (peak commute) time)	Commercial	20	5	1	1
		Commuting	1	2	3	1
		Educational	1	0	0	0
		Hotels	0	0	0	0
		Industrial	1	0	0	0
		Other Residential	14	3	0	0
		Single-Family	5	0	0	0
		Total	**41**	**9**	**4**	**2**

*Based on a population base of 43,716

Dozens of Level 3 and Level 4 casualties are anticipated as a result of damage to primarily commercial structures, followed by educational structures. Significant damage to steel, concrete, and reinforced masonry structures, construction types typically used in non-residential applications, appears to control the anticipated injury severity levels and counts, as extensive damage to these types of buildings generates heavy debris that can result in significant numbers of trauma cases. Damage to residential structures, typically of wood-frame construction, result in mostly Level 1 and Level 2 injuries. For these same reasons, an earthquake occurring during maximum residential occupancy loads, such as at 2 o'clock in the morning, results in the least number of Level 3 and 4 casualties, with most injuries classified as Level 1 and Level 2.

Many injuries are also anticipated to occur if the San Andreas fault ShakeOut earthquake occurs during maximum commuting hours, such as at 5 o'clock in the evening, with similar numbers expected if the earthquake occurs between about 7 and 9 o'clock in the morning, or between 4 and 6 o'clock in the evening. Most of the casualties at this time are the result of damage to commercial and educational facilities, and damage to residential structures that are occupied at that time by people who have returned home from work or school. A relatively low number of the casualties at this hour are the result of traffic accidents due to drivers losing control of their vehicles, vehicle crashes due to stoplight (electric) failures, and the collapse of bridges and broken roadways (Shoaf, 2008).

A smaller M7.1 earthquake on the Coachella Valley segment of the San Andreas fault through the city of Coachella is anticipated to cause a relatively similar number of casualties in the Coachella area regardless of the time of day when the earthquake occurs. Most injuries will be classified as Level 1 or 2, with damage to commercial, educational and other residential structures controlling the number of casualties anticipated if the earthquake occurs during the day, and damage to residential structures controlling the number and type of injuries that are expected if the earthquake occurs at night.

1.9.3 Damage to Critical and Essential Facilities

HazUS breaks critical facilities into two groups: (1) essential facilities, and (2) high potential loss (HPL) facilities. Essential facilities are those parts of a community's infrastructure that must remain operational after an earthquake. Buildings that house essential services include hospitals, emergency operation centers, fire and police stations, schools, and communication centers. HPL or high-risk facilities are those that if severely damaged, may result in a disaster far beyond the facilities themselves. Examples include power plants, dams and flood control structures, and industrial plants that use or store explosives, extremely hazardous materials or petroleum products in large quantities.

Other critical facilities not considered in the HazUS analysis but that should be considered in both emergency preparedness and emergency response operations given their potential impact on the community include: (1) High-occupancy facilities, such as large assembly facilities, and large multi-family residential complexes because of the potential for a large number of casualties or crowd-control problems; (2) dependent care facilities, such as preschools, schools, rehabilitation centers, prisons, group care homes, nursing homes, and other facilities that house populations with special evacuation considerations; and (3) economic facilities, such as banks, archiving and vital, record-keeping facilities, and large industrial or commercial centers, that should remain operational to avoid severe economic impacts.

There are no hospitals in the Coachella General Plan area. The three closest hospitals to the study area include: 1) JFK Memorial Hospital in Indio, 2) Eisenhower Medical Center in Rancho

Mirage, and 3) Desert Regional Medical Center in Palm Springs. The following table summarizes information about these hospitals, including their expected functionality immediately following the two earthquake scenarios considered for this study.

Table 1-11: Hospitals Near the Coachella General Plan Area

Hospital Name	Address, Distance from Coachella	Bed Capacity	Expected Functionality after Earthquakes
JFK Memorial Hospital	47111 Monroe Street, Indio, CA 92201; approximately 1.1 miles NW of Coachella, 4 miles from downtown Coachella	158 beds	Expected to experience moderate to complete damage as a result of a M7.8 earthquake; expected to be non-functional immediately after and for at least one month after a M7.8 earthquake on the San Andreas fault; only about 30 percent functional after 90 days. Approximately 12 percent functional immediately after and for 3 days following a M7.1 earthquake; about 38 percent functional after day 7; over 80 percent functional after day 30.
Eisenhower Medical Center	39000 Bob Hope Drive, Rancho Mirage, CA 92270; approximately 12 miles to the NW of Coachella; and 15 miles from downtown	313 beds	Several hospital buildings are expected to experience moderate to extensive damage as a result of a M7.8 earthquake on the San Andreas. Only about 17 percent functional on the first 3 days; about 30 percent functional after day 7; only 50 percent functional after day 90. Only 30 percent functional after day 3 following a M7.1 earthquake; nearly 60 percent functional after day 7; nearly 90 percent functional after day 30.
Desert Regional Medical Center	1150 N. Indian Canyon Road, Palm Springs, CA 92262 approximately 22 miles from downtown Coachella	367 beds	Expected to be non-functional immediately after and for at least 2 weeks following a M7.8 earthquake on the San Andreas fault; approximately 36 percent functional after day 30, and about 60 percent functional after day 90. Only about 20 percent functional immediately after a M7.1 earthquake; about 56 percent functional after day 7; about 95 percent functional at day 90.

Hospitals lose functionality as a result of both structural and non-structural damage. Even if the hospital buildings perform well, equipment failures can result in a lack of primary and/or secondary emergency power. Rupture of water lines, and shearing of fire sprinkler heads can result in significant water damage. This is what happened at the Olive View Medical Center in Sylmar as a result of the 1994 Northridge earthquake, requiring the evacuation of 300 patients, and the performance of health care functions in the parking lot for about 30 hours (Pickett, 2008). The M7.8 ShakeOut scenario is expected to cause an immediate interruption of commercial electrical power (Pickett, 2008). As a result, all hospitals in the region should have emergency generators that would kick in automatically upon loss of commercial power, with automatic transfer switches that make the transition from the commercial power to the emergency power sources. All three hospitals near Coachella are expected to be impacted by the extensive damage to the external supply of potable water, which in this region could take months to be repaired. The external waste water system is also expected to be damaged

extensively. The ShakeOut scenario is also expected to result in an immediate interruption of commercial telecommunication systems, which would impact the hospitals directly. Internal communications within the hospitals may also be impaired as a result of structural damage, power losses, and water damage that would cause the circuit breakers to be tripped open.
Given that all three hospitals in the region are anticipated to be non-functional immediately following a M7.8 earthquake on the San Andreas fault (see Tables 1-9 and 1-10), and that hundreds of people in the region are expected to require medical attention (Table 1-10), alternate medical providers both within and outside the community should be identified. Possible sources of care for Level 1 and 2 casualties include urgent care and out-patient medical facilities, and private doctors' offices. Severely hurt patients may have to be airlifted to other hospitals in southern California or Arizona. It is also important to mention that access to hospitals in communities east of the San Andreas fault could be difficult because the fault is anticipated to rupture the roads that cross it, including the I-10 freeway just north of Coachella.

Other critical facilities in the HazUS database for Coachella include 366 school buildings, three fire stations, two police stations, and one emergency operations center. The expected damage to these essential facilities is summarized in Table 1-12, below. High potential loss facilities in the area include three dams, three hazardous materials sites, zero military installations, and zero nuclear power plants. None of the dams are considered "high hazard."

Table 1-12: Expected Damage to Essential Facilities

Scenario	Classification	Total #	# Facilities		
			At Least Moderate Damage >50%	Complete Damage >50%	With Functionality >50% on Day 1
San Andreas Fault - ShakeOut	Hospitals	3	3	1	0
	Schools	364	221	52	0
	EOCs	1	1	0	0
	Fire Stations	3	0	0	1
	Police Stations	2	0	0	0
San Andreas Fault - Coachella	Hospitals	3	1	0	0
	Schools	364	67	0	11
	EOCs	1	0	0	1
	Fire Stations	3	0	0	3
	Police Stations	2	0	0	2

According to the earthquake scenario results, the M7.8 San Andreas fault event will cause at least moderate damage to 221 school buildings, with 52 school buildings displaying complete damage to more than 50 percent of their structure. None of the school buildings are expected to be more than 50 percent functional on the day after the earthquake. By comparison, the smaller M7.1 earthquake scenario is estimated to cause at least moderate damage to 67 of the school buildings in the HazUS study area, but none of the buildings will experience damage to more than 50 percent of the structure. However, only eleven school buildings are expected to be more than 50 percent functional the day after the earthquake. This lack of functionality is most likely the result of non-structural failures, such as toppled unanchored bookshelves, or overturned computer equipment.

The three fire stations considered in the analysis include the station in Coachella proper, the station at the Thermal airport, and the station in PGA West - La Quinta. The station in PGA

West - La Quinta was included to obtain data on its anticipated performance given that the station in Coachella was expected to suffer significant damage, and as a result, other stations in the area would likely be asked to step in and provide emergency response services to both the community they are located in and to Coachella. The analysis results indicate that only one of the three fire stations, and neither of the police stations or the City's EOC is expected to be more 50 percent functional on the day after a M7.8 earthquake on the southern Andreas fault. In comparison, all three fire stations, the two police stations and the City's EOC are expected to be more than 50 percent functional on the day after a M7.1 earthquake on the Coachella Valley segment of the San Andreas fault, except for the limitations imposed by the lack of water and electric power discussed in Section 1.9.6.

1.9.4 Economic Losses

HazUS estimates structural and non-structural repair costs caused by building damage and the associated loss of building contents and business inventory. Building damage can cause additional losses by restricting the building's ability to function properly. Thus, business interruption and rental income losses are estimated. HazUS divides building losses into two categories: (1) direct building losses and (2) business interruption losses. Direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. Business interruption losses are associated with inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the earthquake.

Earthquakes may produce indirect economic losses in sectors that do not sustain direct damage. All businesses are forward-linked (if they rely on regional customers to purchase their output) or backward-linked (if they rely on regional suppliers to provide their inputs) and are thus potentially vulnerable to interruptions in their operation. Note that indirect losses are not confined to immediate customers or suppliers of damaged enterprises. All of the successive rounds of customers of customers, and suppliers of suppliers are affected. In this way, even limited physical earthquake damage causes a chain reaction, or ripple effect, that is transmitted throughout the regional economy.

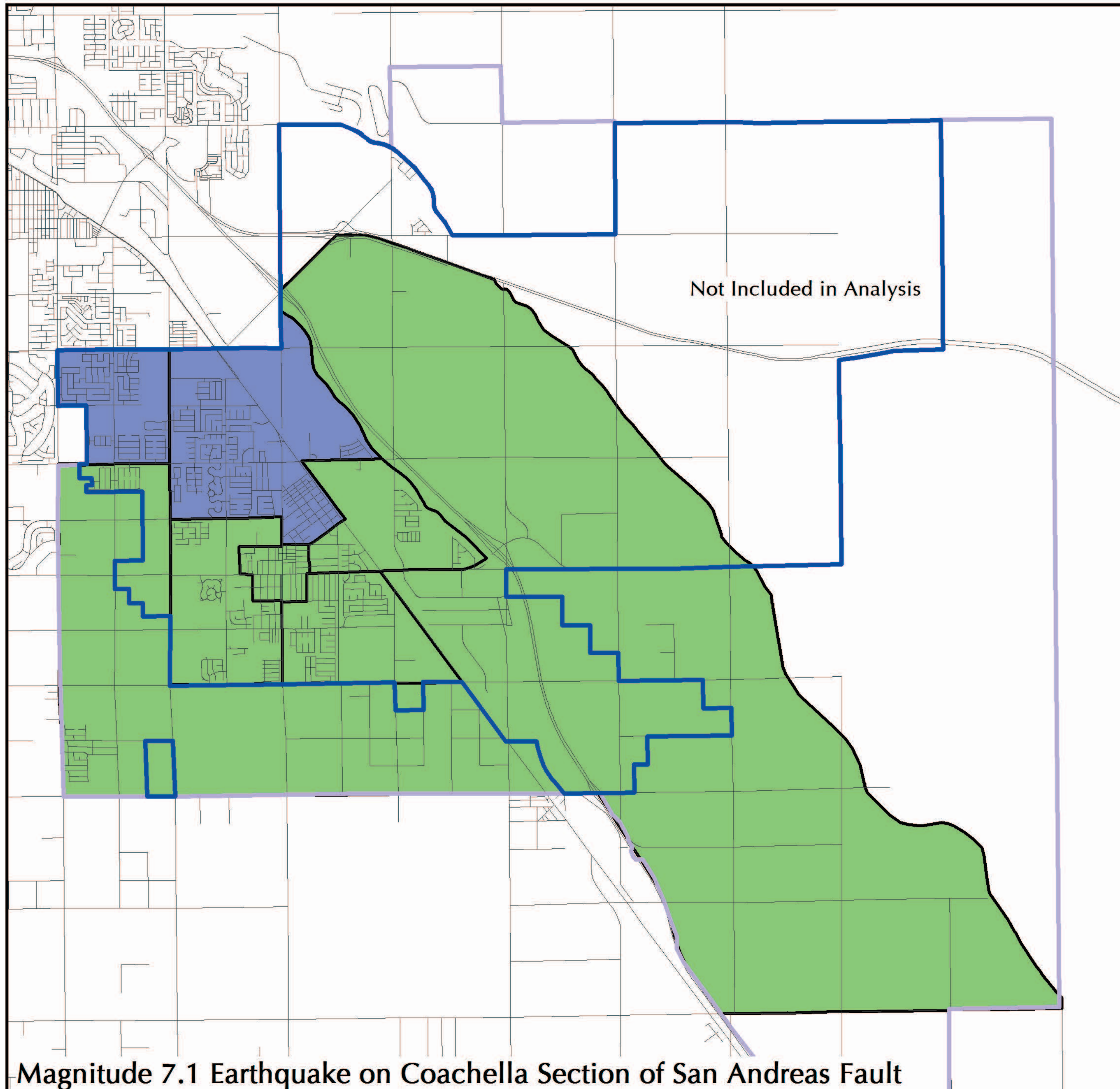
The model estimates that total economic losses in the Coachella area will range from slightly less than $301 million for a M7.1 earthquake on the Coachella Valley segment of the San Andreas fault to slightly more than $1,091 million for a M7.8 earthquake on the San Andreas fault. These figures include building-, transportation-, and lifeline-related losses based on the region's available inventory. Business-related losses include direct building losses (capital stock losses such as structural and non-structural damage, and damage to contents and inventory), and business interruption losses (loss of income from wages, rental properties, relocation expenses, and capital related). Building-related losses estimated for the two earthquake scenarios are summarized in Table 1-13 below. Transportation and utility lifeline losses are summarized in the following sections.

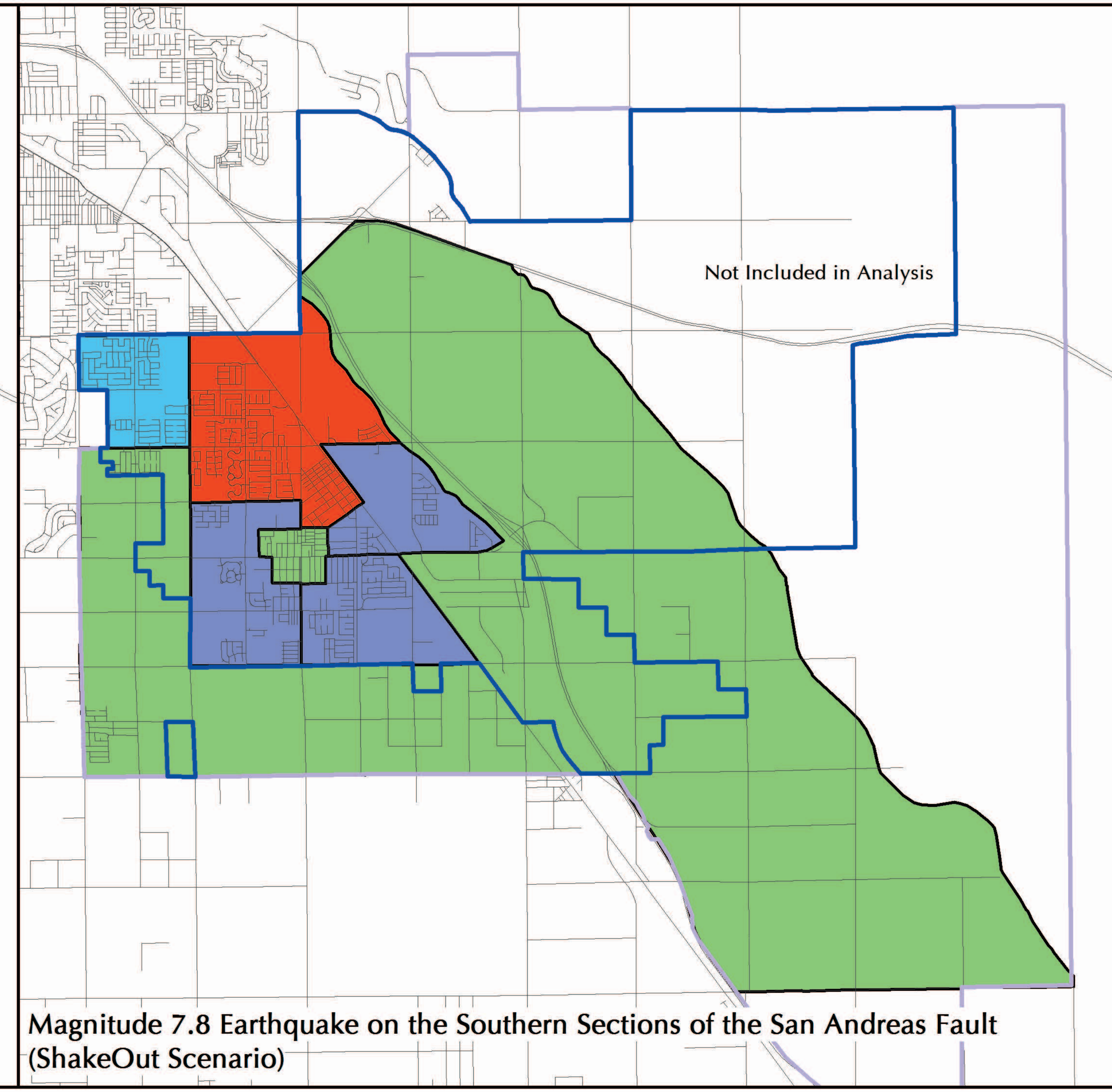
Direct building losses, excluding damage to contents and inventory, are estimated to account for about 65 percent and 66 percent of the building-related economic losses in the city of Coachella as a result of a M7.8 and M7.1 earthquake on the San Andreas fault, respectively. The loss analysis shows that residential occupancies would suffer the most, with a substantial amount of the property damage due to non-structural losses; that is, cosmetic damage to a structure that does not result in the collapse of the structure, and is repairable. This is essentially what building codes are designed to do. Business interruption losses would account for about 16 percent of the losses in the region as a result of either of the two earthquake scenarios.

Table 1-13: Building-Related Economic Losses (in millions of $) Estimated as a Result of Two Earthquake Scenarios

Scenario	Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
San Andreas ShakeOut	Income Losses	Wage	0.00	2.32	22.05	0.63	2.14	27.14
		Capital-Related	0.00	1.01	24.48	0.38	1.31	27.17
		Rental	5.35	9.97	9.73	0.14	0.60	25.79
		Relocation	20.86	15.45	13.36	0.62	8.76	59.05
		SubTotal	26.21	28.76	69.61	1.77	12.81	139.15
	Capital Stock Losses	Structural	28.67	28.91	25.31	3.41	33.17	119.46
		Non-Structural	163.86	115.22	93.34	14.59	65.26	452.26
		Content	63.78	27.83	42.24	8.91	24.02	166.79
		Inventory	0.00	0.00	1.01	2.08	3.02	6.11
		SubTotal	256.31	171.96	161.89	29.00	125.46	744.62
	Total		**282.52**	**200.72**	**231.50**	**30.77**	**138.27**	**883.77**
San Andreas Coachella	Income Losses	Wage	0.00	0.61	6.21	0.19	0.62	7.63
		Capital-Related	0.00	0.27	6.81	0.11	0.30	7.49
		Rental	1.44	2.81	2.98	0.05	0.17	7.46
		Relocation	4.72	6.59	4.19	0.27	2.84	18.60
		SubTotal	6.16	10.27	20.18	0.63	3.94	41.17
	Capital Stock Losses	Structural	11.66	7.92	5.62	0.92	9.13	35.26
		Non-Structural	71.82	31.30	16.20	2.64	13.83	135.79
		Content	27.83	5.65	6.53	1.57	5.21	46.78
		Inventory	0.00	0.00	0.17	0.36	0.69	1.22
		SubTotal	111.31	44.87	28.52	5.49	28.86	219.05
	Total		**117.47**	**55.14**	**48.70**	**6.12**	**32.80**	**260.22**

The distribution of economic losses to buildings of different types in the city of Coachella by census tract as a result of the two earthquake scenarios considered are illustrated in Plates 1-5 (Residential), 1-6 (Commercial and Industrial), and 1-7 (Schools). All of these graphics show that a M7.8 earthquake on the entire southern section of the San Andreas fault will be significantly more damaging to Coachella than a M7.1 earthquake on only the Coachella segment of the fault. Furthermore, Plate 1-5 shows that the largest economic losses to residential buildings can be expected in the older, more-densely occupied sections of the city, where there is a higher concentration of pre-1980s structures. Economic losses associated with the damage to commercial and industrial facilities (Plate 1-6) are partly constrained by the age and density of these types of structures in the city (like the residential stock described above), but are also dictated by the location of these facilities relative to the San Andreas fault. Thus, given that there are many industrial facilities along the eastern portion of the city, adjacent to the fault, the census tract where these facilities are located shows significant economic losses, especially as a result of the M7.8 earthquake scenario. Similarly, the losses estimated for school buildings (Plate 1-7) are defined in great part by the age of the structures, and the schools' locations relative to the San Andreas fault. The highest losses anticipated as a result of damage to school buildings are expected in the center of the city, where the oldest schools are located, seconded by the losses in the census tract closest to the San Andreas fault.





Source: Federal Emergency Management Agency, HAZUS 2.1 v.12.2.0

Based on 2000 real estate values, not adjusted for inflation

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Feet

Scale: 1:84,000

EXPLANATION

Economic Loss by Census Tract
(in Millions of Dollars)

- 60 - 70
- 50 - 60
- 40 - 50
- 30 - 40
- 20 - 30
- 10 - 20
- 0 - 10
- Coachella City Boundary
- Coachella Planning Area Boundary

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Project Number: 3106/3218
Date: 2014

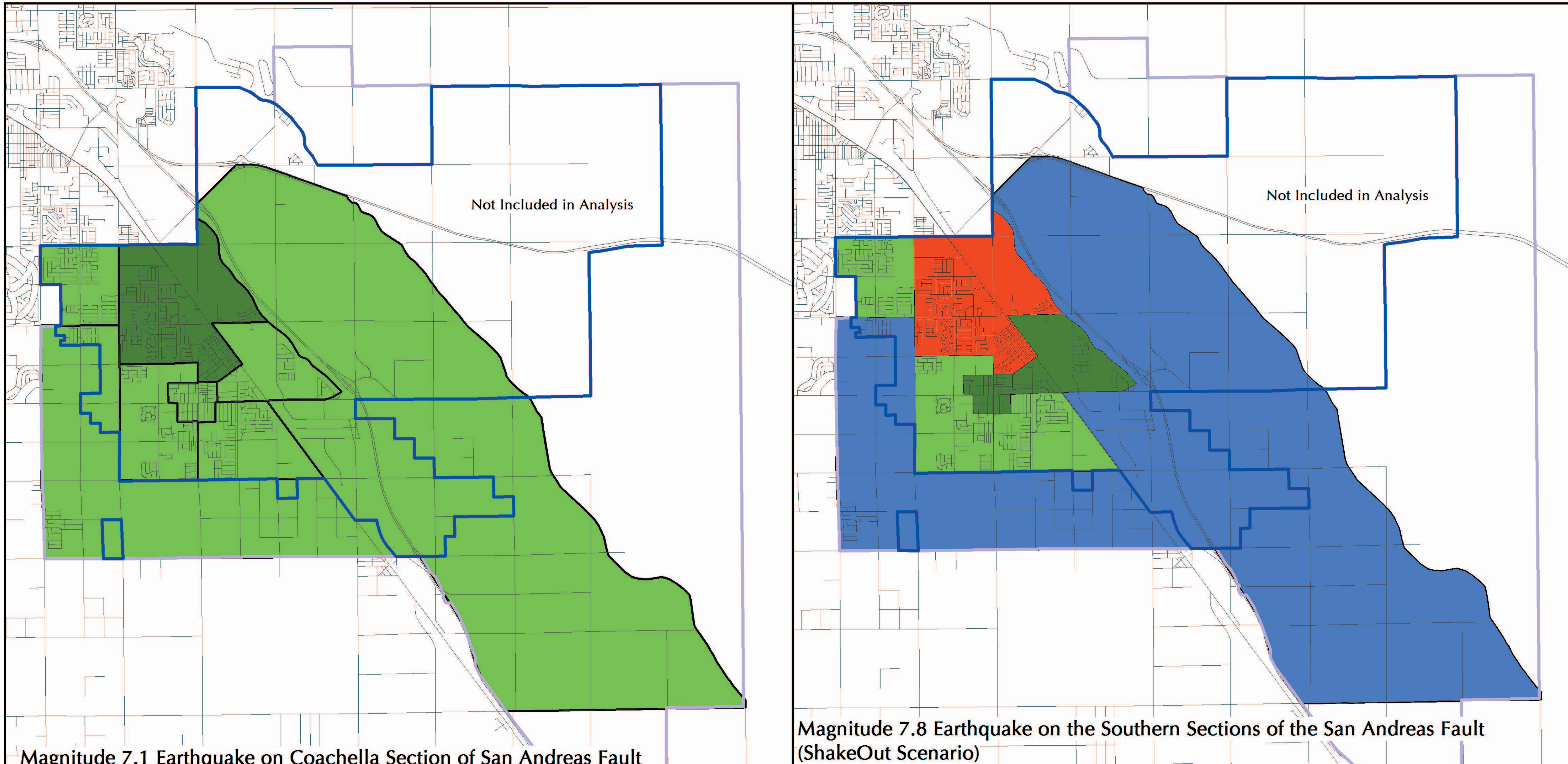
CITY OF COACHELLA
CALIFORNIA

Economic Losses due to Residential Building Damage

(Based on Two Earthquake Scenarios)

Coachella, California

Plate
1-5



Source: Federal Emergency Management Agency, HAZUS 2.1 v 12.2.0

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Scale: 1:84,000

EXPLANATION

Economic Loss by Census Tract
(in Millions of Dollars)

- 80 - 90
- 70 - 80
- 60 - 70
- 50 - 60
- 40 - 50
- 30 - 40
- 20 - 30
- 10 - 20
- 0 - 10
- Coachella City Boundary
- Coachella Planning Area Boundary

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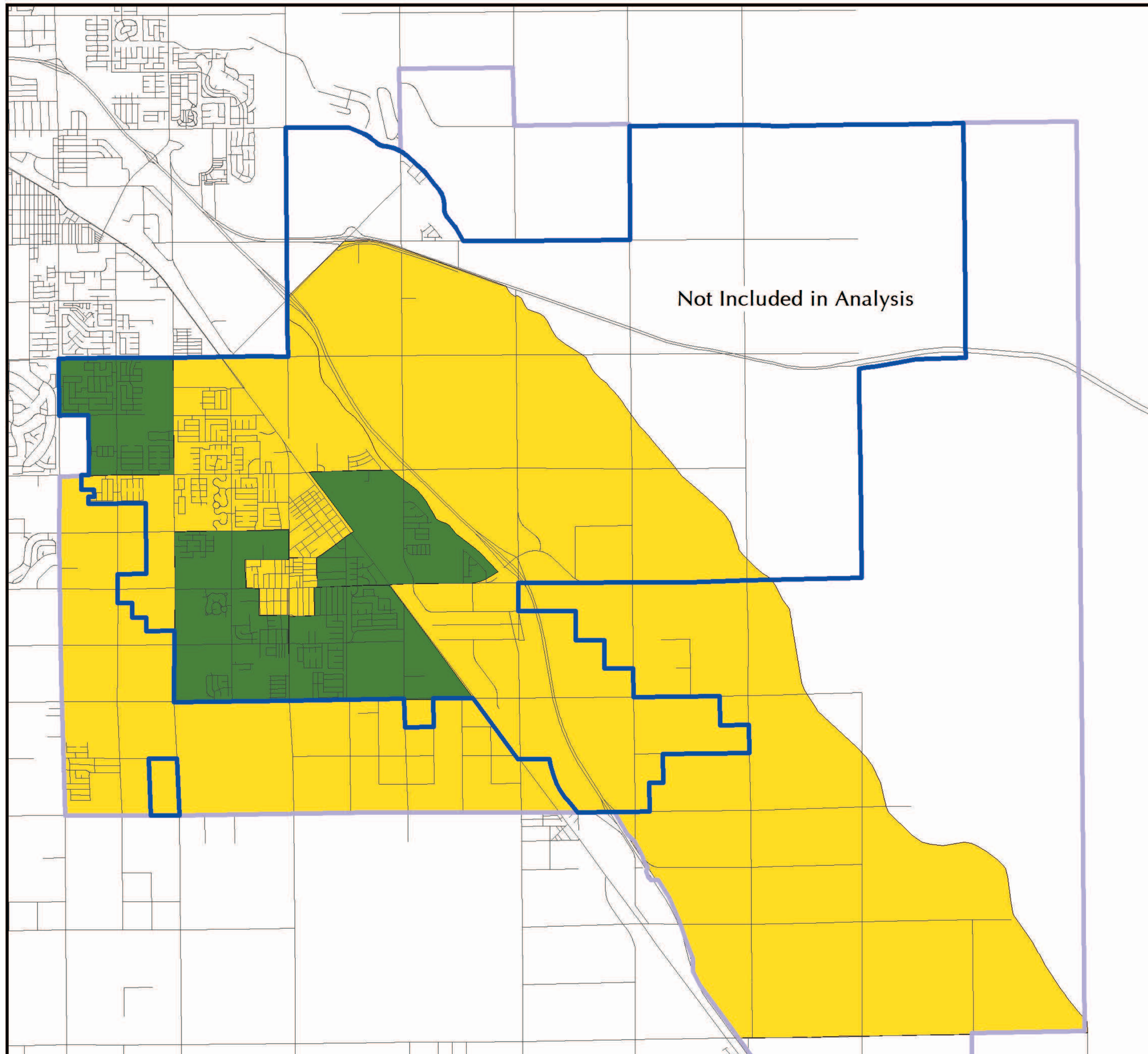
Date: 2014

Commercial and Industrial Loss

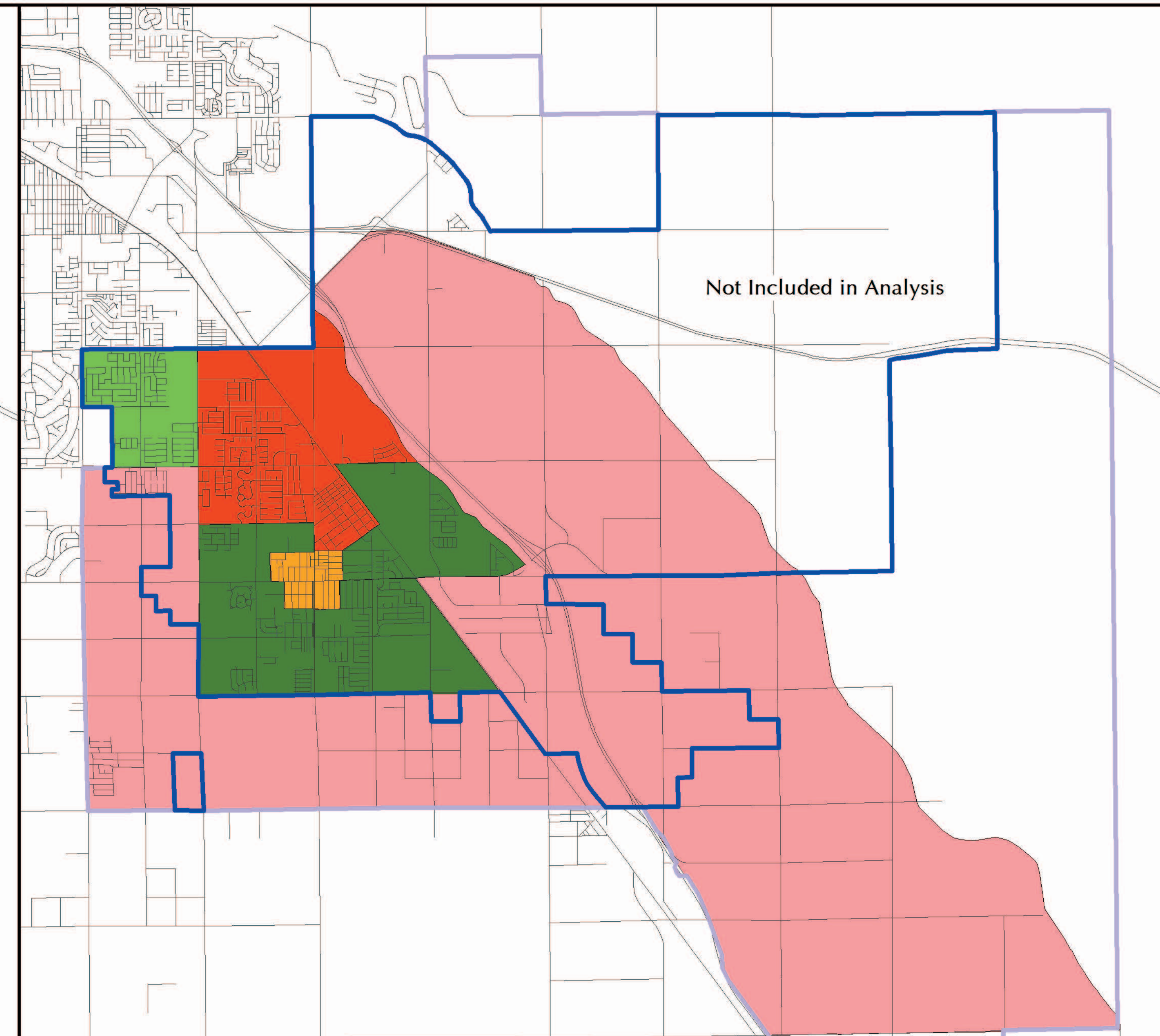
(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-6



Magnitude 7.1 Earthquake on Coachella Section of San Andreas Fault



Magnitude 7.8 Earthquake on the Southern Sections of the San Andreas Fault (ShakeOut Scenario)

Sources: Federal Emergency Management Agency, HAZUS 2.1

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Feet

Scale: 1:84,000

EXPLANATION

Economic Loss by Census Tract
(in Millions of Dollars)

- 15 - 20
- 10 - 15
- 5-10
- 1 - 5
- 0.5 - 1
- 0 - 0.5

- Coachella City Boundary
- Coachella Planning Area Boundary

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Date: 2014

Economic Loss due to School Damage

(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-7

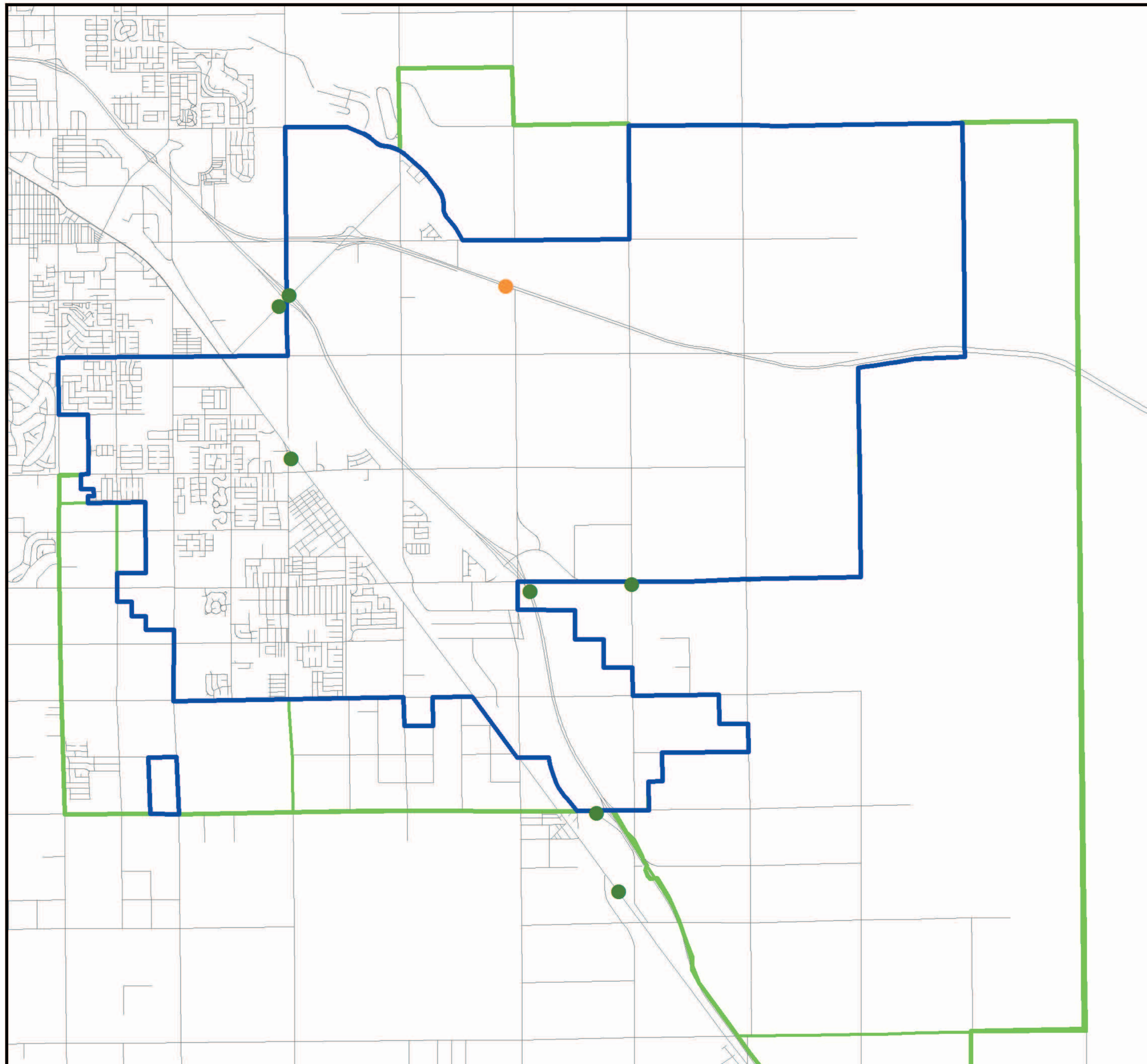
1.9.5 Transportation Damage

Lifelines are those services that are critical to the health, safety and functioning of the community. They are particularly essential for emergency response and recovery after an earthquake. Furthermore, certain critical facilities designed to remain functional during and immediately after an earthquake may be able to provide only limited services if the lifelines they depend on are disrupted. Lifeline systems include transportation and utilities. Transportation systems are discussed in more detail in the following paragraphs, whereas utility lifelines are discussed further in the next section.

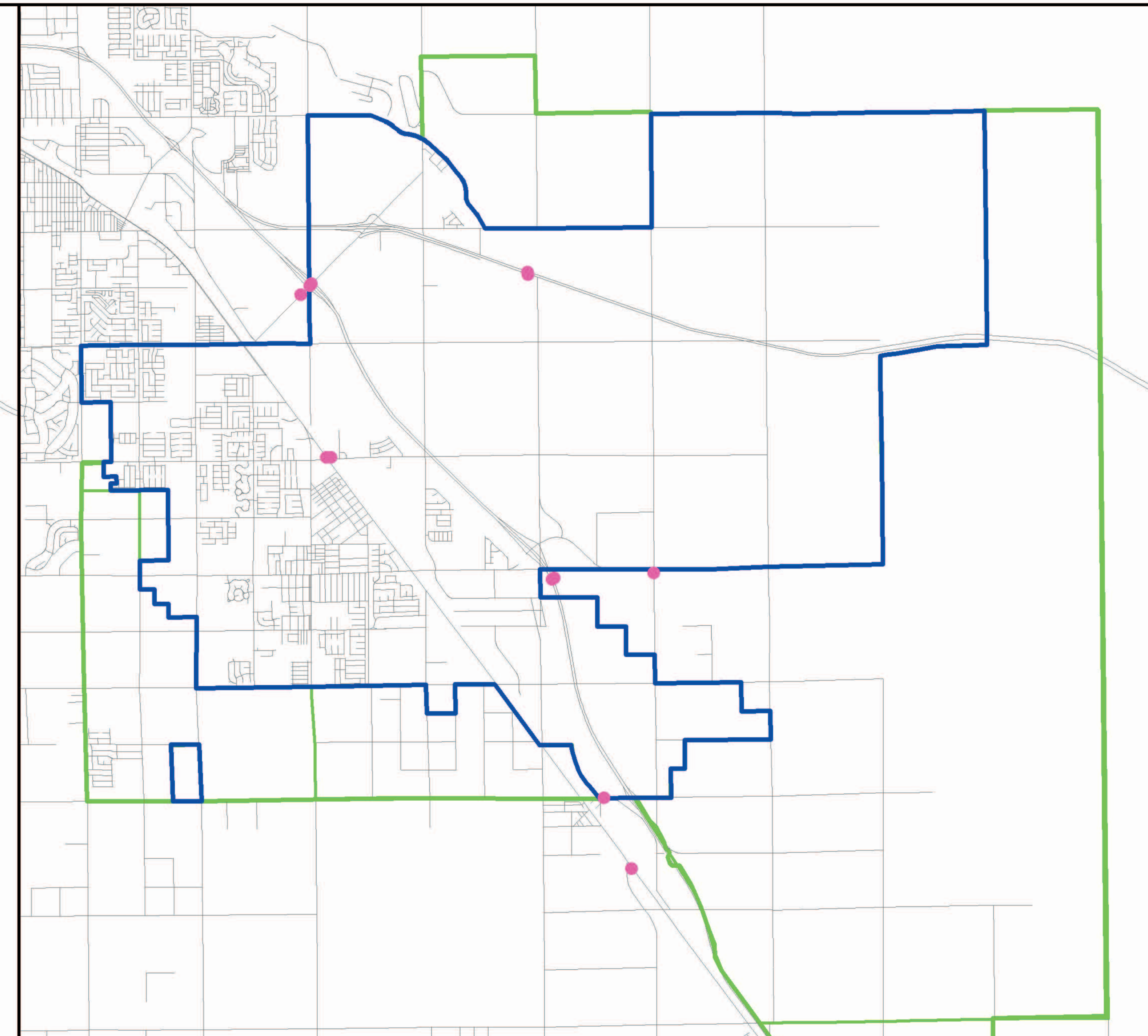
HazUS divides the transportation system into seven components: highways, railways, light rail, bus, ferry, ports, and airports. Only highways, railways, and airports are relevant to the area covered in the analysis for Coachella. The replacement value for the transportation and utility lifeline systems combined in the study area is estimated at over $658 million, with the highway segments ($332.4 million) and airport runways ($73.3 million) accounting for most of this value. The HazUS inventory for the study region includes over 103 kilometers (64 miles) of highways and 21 bridges.

Table 1-14 provides damage and loss estimates for specific components of the transportation system within the study area. The results of this analysis suggest that the transportation system in Coachella will be impacted by a M7.8 earthquake on the San Andreas fault, with more than 80 percent of the bridges in the highway system at least moderately damaged and nearly 50 percent completely damaged. Only one third of the bridges are expected to be more than 50 percent functional one week after the earthquake. A M7.1 earthquake on the Coachella segment of the San Andreas fault is not expected to cause at least moderate damage to any of the bridges in the study area, and 20 of the 21 bridges considered are expected to be more than 50 percent functional on the day after the earthquake. Damage to the bridges in the study region as a result of the two earthquake scenarios considered is illustrated in Plate 1-8.

It is important to mention that given that the study area considered in the HazUS analyses does not include the section of the General Plan area immediately adjacent to and to the east of the San Andreas fault, including where the I-10 freeway extends across the fault zone, the damage to the transportation system is under-represented in the loss estimates presented above. Rupture of the San Andreas fault as a result of either earthquake scenario will involve rupture of the ground surface and ground deformation due to both liquefaction and slope failure, in addition to damage due to shaking. Surface fault rupture will damage most, if not all, of the road segments and bridges that extend across the fault. Treiman et al. (2008) estimate that the ShakeOut scenario will laterally offset the I-10 freeway where it crosses the San Andrea fault in Coachella about 4 meters (13 feet) immediately upon the earthquake occurring, with an additional 2.7 meters (9 feet) possible as afterslip in the weeks to months following the earthquake. The afterslip displacement is anticipated to interfere with recovery efforts. Real et al. (2008) calculated approximately 3 meters (9.8 feet) of lateral spreading at the I-10 / Dillon Road crossing. This amount of lateral spreading has the potential to severely impact the bridge and other infrastructure, such as fiber optic cables, that cross this area. As the I-10 freeway continues east through the hills in the eastern portion of the General Plan area, earthquake-induced soil slides and soil slumps (see Plate 1-3) have the potential to block sections of the freeway, which in turn could impede assistance efforts from communities and states to the east.



Magnitude 7.1 Earthquake on Coachella Section of San Andreas Fault



Magnitude 7.8 Earthquake the Southern Sections of the San Andreas Fault (ShakeOut Scenario)

Source: Federal Emergency Management Agency, HAZUS 2.1 v12.2.0

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Feet

Scale: 1:84,000

EXPLANATION

Bridge Damage

- >50% probability damage exceeds extensive
- >50% probability damage exceeds moderate
- >50% probability damage is slight to none

- Coachella City Boundary
- Coachella Planning Area Boundary

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Project Number: 3106/3218
Date: 2014

Highway Bridge Damage

(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-8

The facilities at the Thermal Airport are also expected to be at least moderately damaged by a M7.8 earthquake on the San Andreas fault. As a result, the airport facility is not expected to be more than 50 percent functional on the day after the earthquake, although it should be by day 7. A smaller but significant M7.1 earthquake is not anticipated to cause at least moderate damage at the airport, and as a result, it should be more than 50 percent functional the day after the earthquake.

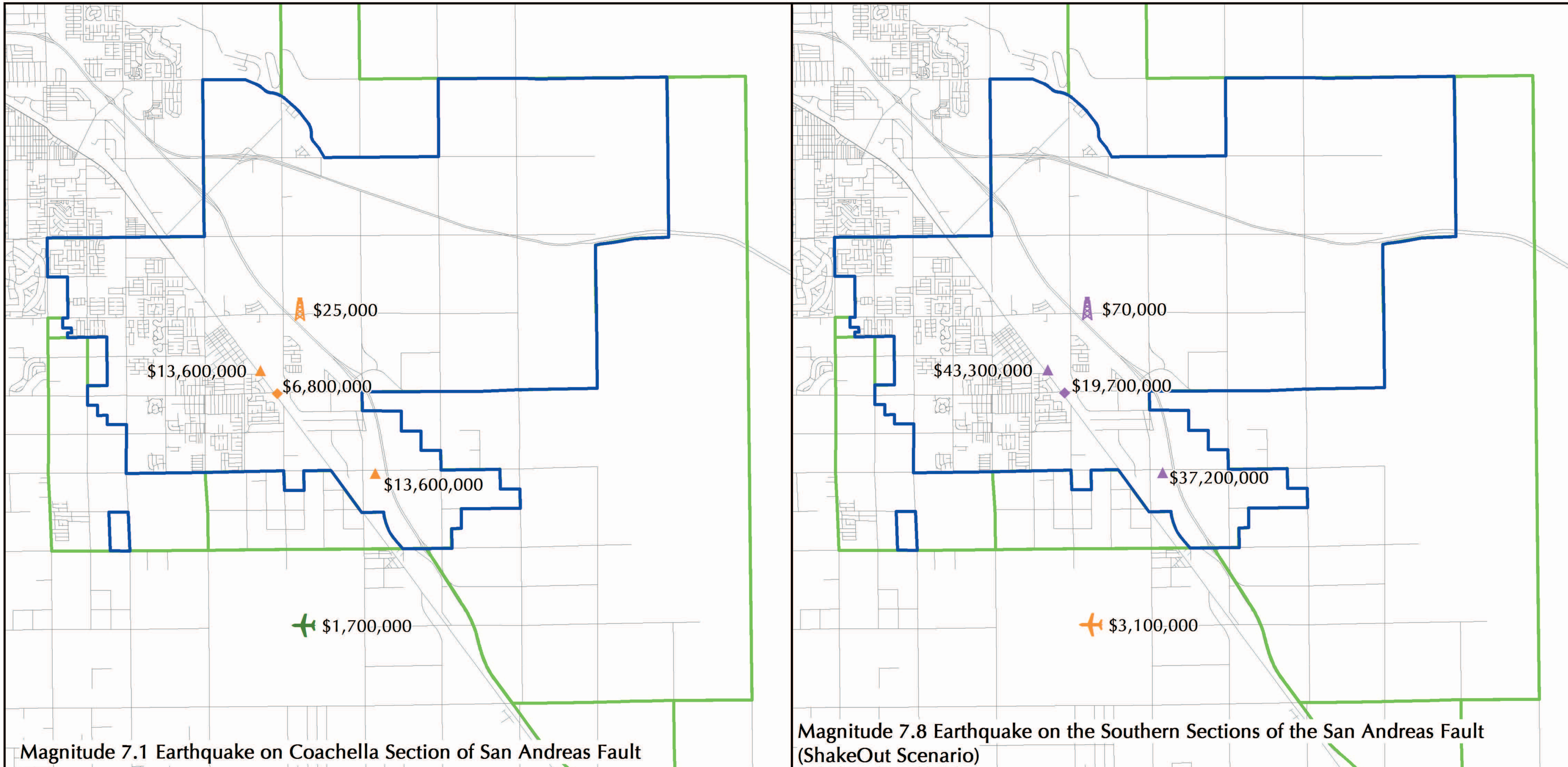
Economic losses to the transportation system as a result of the ShakeOut scenario are estimated at about $13.8 million in the area modeled for the HazUS scenario. Given the extensive damage anticipated just east of the HazUS model area, in the area where the San Andreas fault extends through the Coachella General Plan, total losses to the transportation system are anticipated to be significantly larger. The model estimates losses of about $4.7 million to the transportation system due to a M7.1 earthquake on the Coachella section of the fault (for a quick snapshot of the economic losses to the transportation and utility systems as a result of the earthquake scenarios considered, refer to Plate 1-9). As with the ShakeOut scenario, this estimate is for west Coachella, and does not include damages to the roads and bridges that cross the San Andreas fault, nor damages to the roads and bridges east of the fault, in the hillside areas where earthquake-induced slope instability is a concern.

Additional damage to the transportation system not accounted for by the model may be the result of strong ground shaking. Past earthquakes have shown that ground shaking can cause deformation to the ground surface, with resultant damage to the roadways, but this effect is not modeled effectively.

Table 1-14: Transportation System – Expected Damage and Economic Losses

Scenario	System	Component	Locations/ Segments	With at Least Moderate Damage	With Complete Damage	Functionality >50%		Economic Loss (Millions $)
						After Day 1	*After Day 7*	
San Andreas	Highway	Segments	4	0	0	4	4	0.00
		Bridges	21	17	10	4	7	10.71
	Railways	Segments	6	0	0	6	6	0.00
	Airport	Facilities	1	1	0	0	1	3.10
		Runways	2	0	0	2	2	0.00
San Andreas Coachella	Highway	Segments	4	0	0	4	4	0.00
		Bridges	21	0	0	20	21	3.03
	Railways	Segments	6	0	0	6	6	0.00
	Airport	Facilities	1	0	0	1	1	1.71
		Runways	2	0	0	2	2	0.00

It is also important to remember that the transportation system will be significantly impacted in areas outside of Coachella, such as along the San Gorgonio Pass, due to surface fault rupture, landsliding, liquefaction or other types of seismically induced ground deformation, which could directly and indirectly have an impact on Coachella's residents, both in the short-term and long-term. For example, disrupted roadways are likely to make it very difficult, if not impossible, for commuters outside of the Coachella Valley to return home immediately following the earthquake, as well as hindering evacuation efforts. This will also impact disaster response and recovery, hindering the effective transport of injured individuals to medical facilities outside of



Source: Federal Emergency Management Agency, HAZUS 2.1 v12.2.0

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Feet

Scale: 1:84,000

EXPLANATION

Damage (Labeled with Economic Loss in Dollars)

- Airport
- Radio Tower
- Potable Water System Facility
- Waste Water Facility
- >50% probability damage exceeds extensive
- >50% probability damage exceeds moderate
- >50% probability damage is slight to none

Earth Consultants International

Project Number: 3106/3218
Date: 2014

Utility and Communication Facilities Damage and Economic Loss

(Based on Two Earthquake Scenarios)

Coachella, California

Plate 1-9

the damaged area, in the delivery of water, food, and supplies to the earthquake-damaged areas. In the long-term, damage to the transportation system may impact the recovery of those businesses that rely on products shipped on these transportation systems. The HazUS model anticipates that the railway system in the study area will not suffer significant damage, but the railroad tracks have the potential to be damaged by liquefaction-induced lateral spreading both in the Coachella General Plan area (see Plate 1-3) and elsewhere along the Coachella and Imperial valleys. The railroad tracks also extend across the trace of the San Andreas fault both to the north and south of the Coachella area (for a more detailed discussion of the potential damage to the railroad system, refer to Chapter 5, Section 5.6).

1.9.6 Utility Systems Damage

Utility lifelines include potable water, wastewater, natural gas, crude and refined oil, electric power, and communications. The improved performance of lifelines in the 1994 Northridge earthquake relative to the 1971 San Fernando earthquake, shows that the seismic codes that were upgraded and implemented after 1971 have been effective. Nevertheless, the impact of the Northridge earthquake on lifeline systems was widespread and illustrated the continued need to study earthquake impacts, upgrade substandard elements in the systems, provide redundancies, improve emergency response plans, and provide adequate planning, budgeting and financing for seismic safety. Water supply facilities, such as dams, reservoirs, pumping stations, water treatment plants, and distribution lines are especially critical after an earthquake, not only for drinking water, but to fight fires. Possible failure of dams and above-ground water storage tanks as a result of an earthquake is discussed further in Chapter 3.

If site-specific lifeline utility data are not provided for these analyses, HazUS performs a statistical calculation based on the population served to develop an estimate of the total length of pipelines that comprise the potable water, natural gas, wastewater and oil systems. From this inventory, the model then calculates the expected number of leaks and breaks in these systems. The replacement value for the utility lifeline system in the Coachella study area is estimated at $109.9 million.

Table 1-15 summarizes the expected damage to the potable water, waste water, and natural gas systems in Coachella as a result of two different earthquake scenarios on the San Andreas fault. The models suggest that the potable water, waste water and natural gas systems in Coachella will experience extensive damage as a result of an M7.8 earthquake on the San Andreas fault, and moderate damage as a result of a smaller M7.1 event. The San Andreas ShakeOut earthquake scenario is expected to cause thousands of leaks and breaks in these systems. Where potable water lines extend across leach fields or occupy the same trench as sewer lines, breaks in these lines could result in contamination of the potable water supply. The potable water system in particular is estimated to be so extensively damaged that the community is anticipated to be without piped-in potable water for a minimum of three months (see Table 1-16). Given these results, Coachella residents should be strongly encouraged to store at least a seven-day supply of drinking water for the entire household (including pets), allowing families to be self-sufficient immediately following the earthquake, and giving the City and the Coachella Valley Water District some time to organize and develop alternate methods of water delivery to their residents and customers.

Table 1-15: Expected Utility System Pipeline Damage

Scenario	System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks	Economic Loss ($Millions)
San Andreas ShakeOut	Potable Water	516	19,038	4,759	105.33
	Waste Water	310	15,057	3,764	148.23
	Natural Gas	206	16,096	4,024	72.43
San Andreas Coachella	Potable Water	516	396	99	8.57
	Waste Water	310	313	78	28.55
	Natural Gas	206	335	84	1.51

Table 1-16 shows the expected performance of the potable water, and electric power systems using empirical relationships based on the number of households served in the area. As briefly discussed above, and according to the models, a M7.8 earthquake on the San Andreas fault is expected to have a significant negative impact on both the potable water and electric power services – essentially all households in the Coachella study area are expected to have no potable water for at least 90 days (3 months) following the earthquake, and possibly even longer. The number of pipe breaks is expected to be such that the entire water system is going to have to be recreated. Given that the M7.8 ShakeOut scenario is going to impact a very large area, "there will not be enough pipe and connectors or trained manpower to repair all the breaks quickly. The worst hit areas may not have water in the taps for 6 months" (Jones et al., 2008).

Thousands of households are also expected to be without electric power following the earthquake, but repairs to this system are expected to occur more quickly. According to the model, nearly 7,400 households are expected to be without power on the first day after the earthquake, and by day 7, 2,600 households would still be without power. With very few exceptions, all households are expected to have electric power by day 90. Economic losses associated with the expected damage to utilities in the area resulting from the two earthquake scenarios are summarized in Plate 1-9.

Table 1-16: Expected Performance of Potable Water and Electric Power Services

Scenario	Utility	Number of Households without Service*				
		Day 1	Day 3	Day 7	Day 30	Day 90
San Andreas ShakeOut	Potable Water	9,190	9,190	9,190	9,190	9,190
	Electric Power	7,393	5,153	2,559	610	9
San Andreas Coachella	Potable Water	6,105	1,696	0	0	0
	Electric Power	0	0	0	0	0

*Based on Total Number of Households = 9,190

The smaller M7.1 earthquake scenario on the San Andreas fault is anticipated to leave more than 6,100 households without water for 24 hours, and nearly 1,700 households would have no water after three days. However, all households are anticipated to have water a week after the earthquake. This smaller earthquake is not expected to cause a loss in electric power in the region.

1.9.7 Shelter Needs

Earthquakes can cause loss of function or habitability of buildings that contain housing. Displaced households may need alternative short-term shelter, provided by family, friends, temporary rentals, or public shelters established by the City, County or by relief organizations such as the Red Cross. Long-term alternative housing may require import of mobile homes, occupancy of vacant units, net emigration from the impacted area, or, eventually, the repair or reconstruction of new public and private housing. The number of people seeking short-term public shelter is of most concern to emergency response organizations. The longer-term impacts on the housing stock are of great concern to local governments, such as cities and counties.

HazUS estimates that about 281 households in Coachella will be displaced due to the M7.8 San Andreas fault earthquake modeled for this study, and that about 558 people will seek temporary shelter in public shelters (see Table 1-17 below). Considering that the region is anticipated to be without piped-in potable water for more than three months, the displaced households number for the ShakeOut scenario given below may be significantly underestimated. A smaller M7.1 earthquake is anticipated to displace about 52 households, with approximately 103 people seeking temporary cover in public shelters. In both scenarios, those people displaced that do not seek short-term shelter in public facilities are expected to find alternate temporary housing with family or friends.

The actual number of people seeking shelter may also be larger than the estimates given because of the fairly large percentage of Hispanics or Latinos in the General Plan area. Past history has shown that Hispanics, especially those of Mexican and Central American ancestry, generally prefer to camp out in parks and other open spaces rather than return to their house soon after an earthquake, even if their house appears to be undamaged. This was observed in the greater Los Angeles area following the 1994 Northridge earthquake, as well as other previous earthquakes in California, such as the 1987 Whittier Narrows and 1989 Loma Prieta earthquakes (Tierney, 1994; Tierney, 1995; Andrews, 1995).

Table 1-17: Estimated Shelter Requirements

Scenario	Displaced Households	People Needing Short-Term Shelter
San Andreas – ShakeOut	281	558
San Andreas – Coachella	52	103

1.9.8 Debris Generation

HazUS estimates the amount of debris that will be generated by the scenario earthquakes. The model breaks the debris into two general categories: 1) brick/wood, and 2) concrete/steel. The distinction is made because of the different types of equipment required to handle the debris. The M7.8 San Andreas earthquake is estimated to generate a total of 350,000 tons of debris, with brick/wood amounting to about 34 percent (119,000 tons) of this total. Removing this debris would require approximately 14,000 truckloads (at 25 tons/truckload). The model estimates that the M7.1 earthquake on the San Andreas fault will generate 37,800 tons of brick and wood, and 52,200 tons of concrete and steel, for a total of 90,000 tons of debris. If the debris tonnage is converted to an estimated number of truckloads, it would require approximately 3,600 truckloads to remove the debris generated by this earthquake.

Table 1-18: Debris Generation (in Thousands of Tons)

Scenario	Brick, Wood & Others	Concrete & Steel	Total
San Andreas-Shakeout	119	231	350
San Andreas – Coachella	37.8	52.2	90

1.10 Summary and Recommendations

Since it is not possible to prevent an earthquake from occurring, local governments, emergency relief organizations, and residents are advised to take action and develop and implement policies and programs aimed at reducing the effects of earthquakes. Individuals should also exercise prudent planning to provide for themselves and their families in the aftermath of an earthquake. This is particularly important in the Coachella Valley area, and other areas immediately adjacent to or bisected by the southern San Andreas fault.

Earthquake Sources and Design Earthquake Scenarios:

- The San Andreas fault is the most significant seismic source in the Coachella General Plan area. The fault extends across the city, intersecting the region's infrastructure, which in this area includes the Interstate 10 freeway, the Coachella Canal, and several significant oil and gas pipelines and fiber optic cables. The section of the fault that extends across the city, referred to as the Coachella section, last ruptured about 320 to 330 years ago (around A.D. 1680), and is estimated to have a 59 percent probability of causing an earthquake of at least magnitude 6.7 in the next 30 years. Therefore, all development in the Coachella General Plan area should be designed to withstand strong ground shaking.

- A number of historic earthquakes have caused moderate ground shaking in Coachella. Moderate to strong ground shaking due to future earthquakes on regional sources, including other sections of the San Andreas fault, should be expected and designed for.

- Geologists, seismologists, engineers and urban planners typically use maximum magnitude and maximum probable earthquakes to evaluate the seismic hazard of a region, the assumption being that if we plan for the worst-case scenario, smaller earthquakes that are more likely to occur can be dealt with more effectively.

- The San Andreas and San Jacinto faults have the potential to generate earthquakes that would be felt strongly in the Coachella region. Unfortunately, we cannot predict when a fault will break causing an earthquake, but we can anticipate the size of the resulting earthquake and estimate the level of damage that the earthquake would generate in the region. The southern section of the San Andreas fault closest to Coachella is thought capable of generating a M7.8 to 8.0 earthquake. Individual segments of this section of the fault could generate M7.2 to M7.5 earthquakes. Similarly, the sections of the San Jacinto fault closest to Coachella are thought capable of generating earthquakes of M6.6 to M7.2. Most other faults within 100 km (62 miles) of the city can generate earthquakes as large or larger than the M_w 6.7 Northridge earthquake, the single most-expensive earthquake yet to impact the United States.

- The loss estimation analyses conducted for this study indicate that the San Andreas fault will generate be the worst-case earthquake for Coachella. A M7.8 earthquake, which is not the largest the fault is capable of generating, would result in significant damage in the city, with economic losses estimated at more than $884 million. A smaller M7.1 earthquake on the Coachella section of the fault zone is anticipated to cause more than $260 million in damages in the Coachella General Plan area. The San Jacinto fault is not expected to cause as much damage in the General Plan area because the maximum magnitude earthquake that it is capable of generating is significantly smaller, and it is also farther away.

Fault Rupture and Secondary Earthquake Effects:

- The main strands of the San Andreas fault extend in a southwesterly direction through the Coachella General Plan area. When this fault ruptures next, large displacements in the order of 20 feet or more could be expected locally. Any improvement that straddles the fault zone can be expected to be significantly impacted.

- The California Geological Survey (CGS) has not conducted mapping in the Coachella area under the Seismic Hazards Mapping Act. This report presents a liquefaction susceptibility map that was prepared using a similar method used by the California Geological Survey (CGS). Shallow ground water levels (less than 30 feet from the ground surface) have been reported historically in the western part of the General Plan area. Although the groundwater levels have dropped recently as a result of increased pumping of the underlying aquifers, increased recharge of the basin could result in a rise in the water levels to past historical highs. Trenches excavated in the region as part of fault investigations have exposed evidence for past liquefaction events in the area, indicating that if shallow groundwater is present, these deposits could liquefy again. Studies in accordance with the guidelines prepared by the CGS should be conducted in those areas identified as susceptible to liquefaction, at least until sufficient studies have conclusively shown whether or not the sediments are indeed susceptible to liquefaction.

- Soil slides and soil slumps may occur in the hillside areas in the eastern and northeastern portions of the Coachella General Plan area.

- Precariously perched rocks are common on the hillsides in the northeastern and southeastern portions of the Coachella General Plan area. Earthquake-induced ground shaking could dislodge some of these rocks, posing a rockfall hazard to areas adjacent to and below these slopes.

- Those areas of Coachella underlain by youthful unconsolidated alluvial sediments may be susceptible to seismically induced settlement. Geotechnical studies to evaluate this potential hazard should be conducted in areas underlain by Holocene sediments where developments are proposed. If the sediments are found to be susceptible to this hazard, mitigation measures designed to reduce settlement should be incorporated into the design.

Earthquake Hazard Reduction:

- Most of the loss of life and injuries that occur during an earthquake are related to the collapse of hazardous buildings and structures, or from non-structural components, including contents, in those buildings. The HazUS analyses conducted for this study indicate that more than 74 percent of the residential structures other than single-family homes (that is, multi-family residential buildings, including duplexes, condominiums and apartments) will suffer at least moderate damage as a result of an earthquake on the San Andreas fault. Nearly 59 percent of the industrial structures, 58 percent of the agricultural, and 54 percent of commercial structures are also expected to be at least moderately damaged by a San Andreas fault earthquake. Similarly, about 50 percent of the education, government and religion buildings in the study area will suffer at least moderate damage. Nearly 95 percent of the manufactured homes in the area will be damaged.

- The HazUS results indicate that the worst time for an earthquake to occur on the San Andreas fault is during the day, during maximum education, commercial and industrial laods. Because many of the buildings damaged generate heavy debris, an earthquake during the day is anticipated to generate dozens of Level 3 and 4 injuries, in addition to hundreds of Level 1 and 2 injuries.

- The regional hospitals are not expected to be functional immediately following an earthquake on the San Andreas fault, and able to meet the demand for medical care in the aftermath of a San Andreas earthquake in the area. Emergency management personnel and planners need to develop a contingency plan that provides for medical care at facilities other than the local hospitals, in addition to agreements with hospitals outside of the region that can provide assistance with Level 3 and 4 casualties. Given the extensive damage anticipated to the transportation system, most victims that need to be transported elsewhere for treatment will have to be airlifted out of the area.

- The inventory and retrofit of potentially hazardous structures, such as pre-1952 wood-frame buildings, concrete tilt-ups, pre 1971- reinforced masonry, soft-story buildings and especially mobile homes, are recommended.

- The best mitigation technique in earthquake hazard reduction is the constant improvement of building codes with the incorporation of the lessons learned from past earthquakes. This is especially true in areas not yet completely developed. In addition, current building codes should be adopted for re-development projects that involve more than 50 percent of the original cost of the structure. Current building codes incorporate two significant changes that impact the city of Coachella. First, there is recognition that soil types can have a significant impact on the amplification of seismic waves, and second, the proximity of earthquake sources will result in high ground motions and directivity effects. However, for those areas of Coachella already developed, and given that building codes are generally not retroactive, the adoption of the most recent building code is not going to improve the existing building stock, unless actions are taken to retrofit the existing structures. Retrofitting existing structures to the most current building code is in most cases cost-prohibitive and not practicable. However, specific retrofitting actions, even if not to the latest code, that are known to improve the seismic performance of structures should be attempted.

- While the earthquake hazard mitigation improvements associated with the latest building code address new construction, the retrofit and strengthening of existing structures requires the adoption of ordinances. The City of Coachella should consider the implementation of a mandatory ordinance aimed at retrofitting older wood-frame residential buildings that are not tied-down to their foundations, pre-cast concrete buildings, steel-frame buildings, soft-story structures, and manufactured housing. Although retrofitted buildings may still incur severe damage during an earthquake, their mitigation results in a substantial reduction of casualties by preventing collapse.

- Adoption of new building codes does not mitigate local secondary earthquake hazards such as liquefaction and ground failure. Therefore, these issues are best mitigated at the local level.

Avoiding areas susceptible to earthquake-induced liquefaction or settlement is generally not feasible. The best alternative for the City is to require "special studies" within these zones for new construction, as well as for significant redevelopment, and require implementation of the engineering recommendations for mitigation.

- Effective management of seismic hazards in Coachella includes technical review of consulting reports submitted to the City by licensed engineering geologists and/or civil engineers having competence in the evaluation and mitigation of seismic hazards (CCR Title 14, Section 3724). Because of the interrelated nature of geology, seismology, and engineering, most projects will benefit from review by both the geologist and civil engineer. The California Geological Survey has published guidelines to assist reviewers in evaluating site-investigation reports (CDMG, 1997; CGS, 2008).

- The HazUS analyses suggest that the potable water, wastewater and electric systems in Coachella will be extensively damaged by an earthquake on the San Andreas fault, with thousands of leaks and breaks anticipated in the potable water system. Hardest hit areas may be without water at the tap for up to six months. The City and its lifeline service providers should consider retrofitting the older pipelines in these systems, to reduce the number of potential breaks as a result of corrosion and age, in addition to developing plans to truck in water that is delivered directly to the City residents. Residents of the Coachella area should be encouraged to store at least a 7-day supply of water for all family members, including pets, so that they can be self-sufficient immediately following the earthquake, until the City can arrange for water to be trucked in.