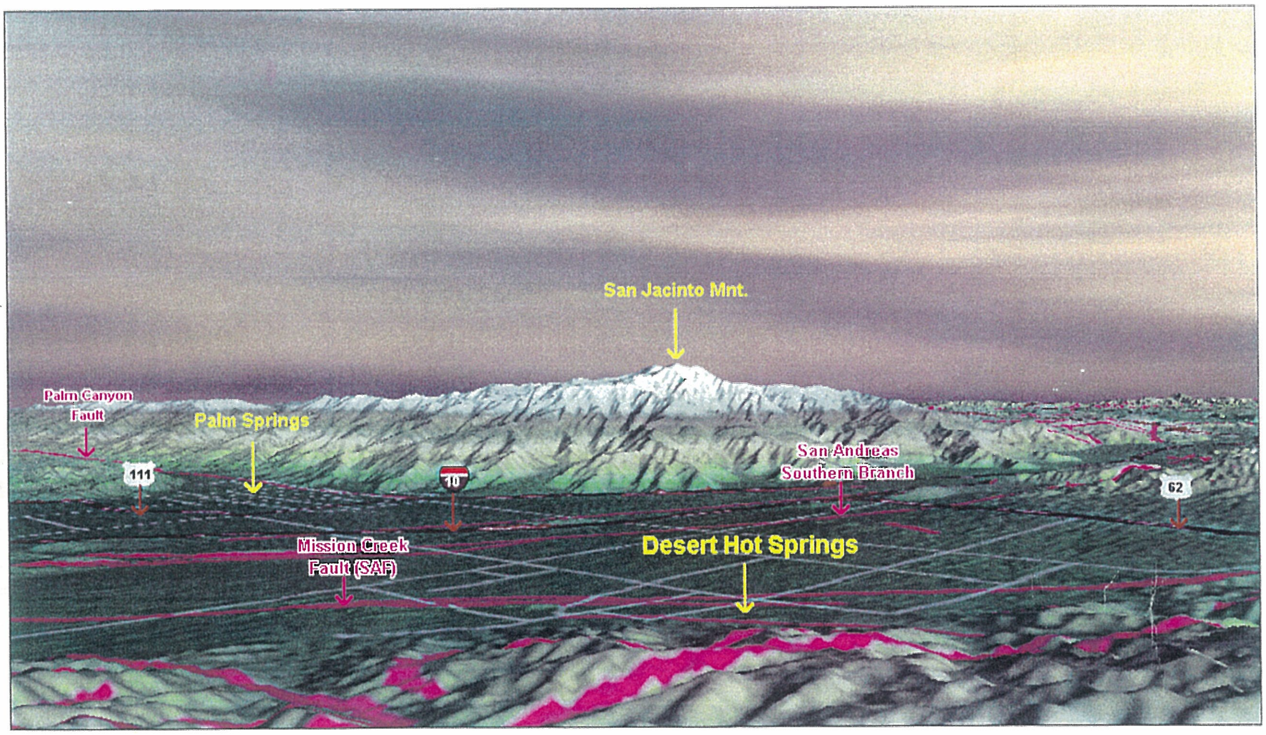
Appendix H:

Safety Element Technical Background Report

(PART 1 of 4)

Natural Hazard Mapping, Analysis, and Mitigation: a Technical Background Report in Support of the Safety Element of the New Riverside County 2000 General Plan



Prepared for the Department of Regional Planning, County of Riverside

August, 2000

Prepared by: ***Earth Consultants International***

Natural Hazard Mapping, Analysis, and Mitigation: a Technical Background Report in Support of the Safety Element of the New Riverside County 2000 General Plan

August 1, 2000

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Natural Hazard Mapping, Analysis, and Mitigation: a Technical Background Report in Support of the Safety Element of the New Riverside County 2000 General Plan

CHAPTER 1: SEISMIC HAZARDS

1.1 Introduction

While the County of Riverside is at risk from many natural and man-made hazards, the event with the greatest potential for loss of life or property and economic damage is an earthquake. This is true for most of southern California, since damaging earthquakes are frequent, affect widespread areas, trigger many secondary effects, and can overwhelm the ability of local jurisdictions to respond. In Riverside County, earthquake-triggered geologic effects include ground shaking, fault rupture, landslides, liquefaction, subsidence, and seiches, all of which are discussed below. Earthquakes can also cause human-made hazards such as urban fires, dam failures, and toxic chemical releases.

Earthquakes are caused by movement of rock along a break called a fault. The movement releases pent-up strain energy in the form of waves, which travel outward in all directions. These seismic waves cause the Earth to vibrate, and this shaking is what we feel in an earthquake.

Most earthquakes occur along plate boundaries. The outer portion of the Earth consists of enormous chunks of rock called plates, which slowly collide, separate, and grind past each other. Frictional forces resist plate movements and the plate edges lock together. Much strain energy builds up as plates keep trying to move. Eventually, frictional forces are exceeded, the locked edges move, and all the stored strain energy is released in seismic waves.

Earthquake risk is very high in the heavily populated, western portion of Riverside County, due to the presence of three of California's most active faults, the San Andreas, the San Jacinto and the Elsinore. Risk is moderate in the eastern portion of the County that includes Blythe.

In California, recent earthquakes in or near urban environments have caused relatively few casualties. This is due more to luck than design. For example, when a portion of the Nimitz Freeway in Oakland collapsed at rush hour during the 1989, M_w 7.1 Loma Prieta earthquake, it was unusually empty because so many were watching the World Series. Nonetheless, California's urban earthquakes have resulted in significant economic losses. Riverside County is at risk from larger, more damaging earthquakes than the moderate-sized, M_w 6.7 Northridge earthquake, which in 1994 caused 54 deaths and $20-$30 billion in damage.

Earthquakes are a fact of life in southern California. Although it is not possible to prevent them, 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 disaster. Local governments, emergency relief organizations, and residents must take action, to develop and implement policies and programs that can reduce the effects of earthquakes.

1.1.1 Faults

What is a fault?

Geologists visualize a fault as a plane of breakage between rocks, like a page between thick book covers, which meets the surface at some angle. Most of the major faults in southern California are ***strike-slip***. When a strike-slip fault ruptures in an earthquake, the rocks on either side of the fault move horizontally, in opposite directions. In a ***right lateral strike-slip*** fault movement, rock on the opposite side of the fault moves to the right. Principal faults of the San Andreas system are right lateral strike-slip. There are also ***dip-slip*** faults. With dip-slip earthquakes, the two sides of the fault move up or down relative to each other. When the overhanging side of the fault moves down, by convention it is called a ***normal dip-slip*** fault. When the overhanging side moves up, it is a ***reverse dip-slip*** fault. As always, nature is more subtle than our definitions, and in reality, many faults combine vertical and horizontal motion. These are called ***oblique-slip*** faults.

On average, strike-slip faults are nearly vertical. That is, they meet the horizontal surface of the earth at a 90 degree angle. In contrast, dip-slip faults typically meet the surface at a non-vertical angle, and usually dip from the horizontal in the range of 45 to 60 degrees. ***Thrust*** faults are a particular type of low-angle, reverse fault, which dip 25 to 35 degrees from the horizontal. The San Fernando, Northridge, Whittier Narrows and Sierra Madre earthquakes all occurred on thrust faults. Some faults do not extend all the way to the surface of the earth, and are referred to as "blind". These faults are difficult to detect before they cause an earthquake, although some do bend the surface into characteristic, small hills.

Why do we have faults in southern California?

In southern California, most of the faults have developed to allow for the motion between the North American and Pacific tectonic plates (Atwater, 1970). Most of the major fault zones in southern California are roughly parallel with the plate boundary, and accommodate horizontal motion across right-lateral strike-slip faults. Reverse/thrust faults occur where regions of the crust are pushed together and are thus experiencing compression. In the Transverse Ranges north of Riverside County, there are reverse faults undergoing compression. Normal faults occur in areas where the Earth's crust is being pulled apart and extending. Some regions in Riverside County that are extending are Lake Elsinore, Temecula Valley, Beaumont Plain, and the Imperial Valley.

Current faulting in southern California, associated with the boundary of tectonic plates, has been ongoing for the past few hundred million years. The San Andreas fault system has been active during about the past 20 million years (late Tertiary Period) and is obviously still active today. Some faults associated with earlier portions of the San Andreas Fault System have subsequently been abandoned and are no longer active (see Powell, 1993). There are yet older fault systems associated with tectonic plate interactions during the Paleozoic Era (570 to 245 million years ago), the Mesozoic Era (245 to 66 million years ago), and the early to mid Tertiary Period prior to the development of the San Andreas Fault System (66 to ~20 million years ago).

Faults are evaluated in terms of their location and lateral extent (zones), age (activity), total displacement, slip rate, and type (style of deformation, i.e., reverse, normal or strike-slip).

What is a fault zone?

A ***fault zone*** represents a collection of relatively smaller scale fault ***segments*** and fault ***strands*** which typically have a similar strike, dip, and sense of movement. However, faults can exist within a particular fault zone which display motion contrary to the overall motion. Sometimes a number of strands are collectively referred to as a fault segment, if the faults are closely associated and are believed capable of all rupturing (moving) during a single earthquake. Individual fault strands and fault segments within a major fault zone are often designated with separate names. The individual strand refers to a single, fairly continuous mappable fault at a map scale of approximately 1:24,000. For example, the Wildomar fault strand is part of the Temecula segment, which is part of the Elsinore fault zone.

How do we determine the age of a fault?

The estimated age ("activity") indicated for each fault in this Background Report is subdivided into categories based on the best estimate from the available data for the date of the last rupture on each fault. We adopted the age designations utilized in the California fault map prepared by Jennings (1994). The categories include:

- **Historical** (ruptured in past 200 years)
- **Active** (ruptured during past 11,000 years; Holocene)
- **Potentially Active** (rupture age < ~700,000 years ago; late Pleistocene)
- **Inactive**:
  - **Quaternary** (last ruptured < 1.6 million yeas ago)
  - **Pre-Quaternary** (age unknown but available evidence suggests that it has not ruptured during the past 1.6 million years).
  - **Late Cenozoic** (ruptures between 1.6 and 11.2 million years ago)

How Do We Measure Fault Movement?

Motion on faults is described by their ***total displacement*** (kilometers) and ***slip rate*** (provided in terms of millimeters per year-mm/yr). The total displacement is usually determined by evaluating geologic features that were around before the fault formed, and which have subsequently been split apart (offset) by the cumulative movement of many earthquakes on the fault over hundreds of thousands to millions of years. The slip rate is determined by a number of methods, all of which measure an amount of offset accrued during an estimated amount of time. The slip rate is then determined by dividing measured offset by the period of time required for the fault to accrue that much displacement. Slip rate data are utilized to estimate how fast a fault is storing up "energy" between earthquakes, and to estimate the recurrence time for large events.

The ***recurrence time***, sometimes referred to as "repeat time" or "return time", represents the average amount of time that elapses between major earthquakes on that fault. Repeat times for fault zones are estimated in a number of ways. The most specific involve fault trenching studies that investigate earthquakes that have occurred during the past thousands of years. Trenching studies have shown that faults with larger slip rates often have shorter recurrence times between major earthquakes. This makes sense. A large slip rate indicates rocks that are moving (due to current plate motions) at a relatively fast pace. But most of the time, the rocks are locked together by frictional forces at the fault. The more the rocks are trying to move, the faster strain energy will build up, and the more often will the forces of friction be exceeded. The fault will rupture and the rocks will move more often, releasing the strain energy in more frequent, large earthquakes.

1.1.2 Causes of Earthquake Damage

The ***three primary agents of earthquake damage***, ordered by their likelihood to occur extensively, are:

1) Strong Ground Shaking: This causes the vast majority of earthquake damage. There are many ways that seismic waves can cause damaging ground shaking, but few of them will affect any particular location in a single earthquake. Characterization of shaking potential can require analyses of maximum ground movement (displacement), velocity and acceleration, the duration of potential strong shaking, and the lengths (periods) of waves that control each of these factors during a given earthquake. Horizontal ground acceleration is frequently responsible for widespread damage to structures. It is commonly measured as a percentage of g, the acceleration of gravity. In general, the degree of shaking can depend upon:

Source effects - These include earthquake size, location, distance. The bigger and closer the earthquake is, the more likely damage will be. The exact way that rocks move along the fault can also influence shaking, as can the orientation of the fault in the ground. The 1995 Kobe, Japan earthquake was about the same size as the 1994 Northridge, CA, earthquake, but caused much worse damage, because in Kobe, the fault directed seismic waves into the city. During the Northridge earthquake, the fault directed waves away from populated 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 this can focus seismic energy at one location, and cause damage in unexpected areas.

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 increases shaking. This is identical to the behavior of ocean waves. As the waves slow down near shore, their crests grow higher. Sometimes, too, seismic waves get trapped at the surface and 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 match, tremendous damage can occur.

2) ***Liquefaction/Ground Failure:*** Portions of the County of Riverside are susceptible to liquefaction and landslides or rockfall, very destructive secondary effects of strong seismic shaking.

Liquefaction occurs primarily in saturated, loose, fine to medium-grained soils in areas where the groundwater table is within 50 feet of the surface. Shaking suddenly increases pore water pressure, causing the soils to lose strength and behave as liquid. Excess water pressure is vented upward through fissures and soil cracks and a water-soil slurry bubbles onto the ground surface. The resulting features are called "sand boils, sand blows" or "sand volcanoes." Liquefaction-related effects include loss of bearing strength, ground oscillations, lateral spreading, and flow failures or slumping. Site-specific geotechnical studies are the only practical and reliable way of determining the liquefaction potential of a site.

Landslides and Rockfall There are predictable relationships between local geology and mass wasting processes like landslides and rockfall. Slope stability is dependent on many factors and their interrelationships. Rock type and pore water pressure are possibly the most important factors, followed by slope steepness due to natural or man-made undercutting. In addition, many existing landslides and soil slumps have been mapped within the County, and where slopes have failed before, they will fail again. Field investigation enables identification of failure-prone slopes before an earthquake occurs.

3) ***Primary Ground Rupture/Faulting:*** Primary ground damage due to earthquake fault rupture typically results in a relatively small percentage of the total damage in an earthquake, but being too close to a rupturing fault can cause profound damage. It is difficult to reduce this hazard through structural design. The primary mitigative technique is to set back from, and avoid, active faults. The challenge comes in identifying all active faults. Faults throughout southern California have formed over millions of years. Some of these faults are generally considered inactive under the present geologic conditions. Other faults are known to be active. Such faults have either generated earthquakes in historical times (a scant 200 years), or show geologic and geomorphic indications of relatively recent movement. Faults that have moved in the relatively recent geological past are generally presumed to be the most likely candidates to generate damaging earthquakes in the lifetimes of residents, buildings or communities.

1.1.3 General Tectonic Setting

Earthquakes in Southern California occur as a result of movement between the Pacific and North American plates. Faults of the San Andreas system are used to mark the boundary between the plates, but the deformation, faulting and associated earthquakes occur in a broadly distributed zone that stretches from offshore to Nevada. Thus, the San Andreas is one of a system of plate-bounding faults. Most of the movement between the plates occurs along the San Andreas fault, which bisects Riverside County. The rest of the motion is distributed among northwest-trending, strike-slip faults of the San Andreas system (principally the San Jacinto, Elsinore, Newport-Inglewood and Palos Verdes faults); several east-trending thrust faults which bound the Transverse Ranges; and the Eastern Mojave Shear Zone (a series of faults east of the San Andreas, responsible for the 1992 Landers and the 1999 Hector Mine earthquakes).

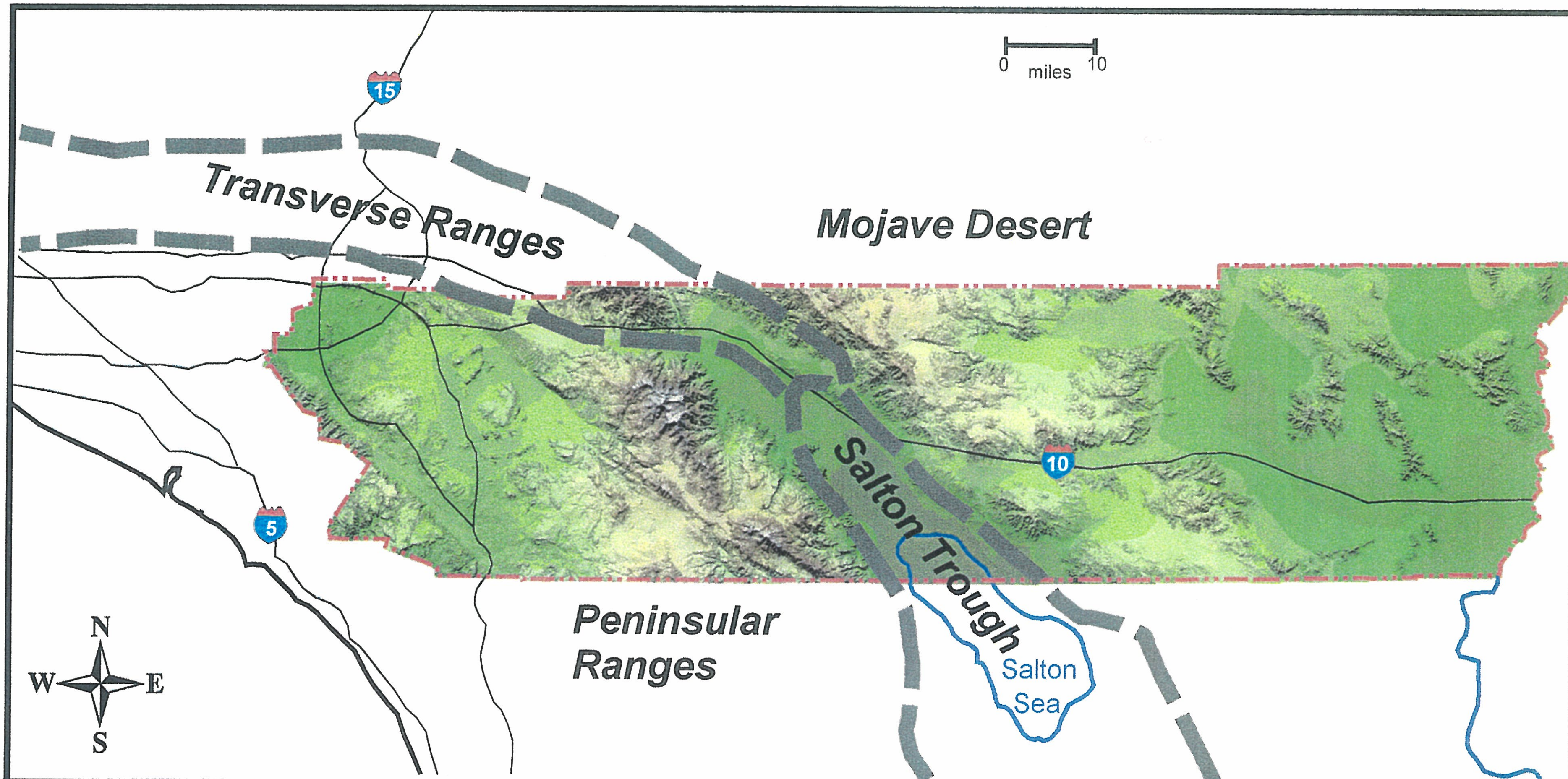
Given the 1986 Palm Springs, 1987 Whittier Narrows, 1987 Imperial Valley, 1991 Sierra Madre, 1992 Landers, 1994 Northridge, and 1999 Hector Mine earthquakes, southern Californians may feel that we have had our share of earthquakes in the last few years. However, some researchers suggest that far too few earthquakes have occurred in Southern California in the last 200 years to account for the rate of movement between the Pacific and North American plates. The data suggest that Southern California is due for either numerous, moderate (M_w 6 - 7), Northridge-like earthquakes, or a few, larger (M_w 7.2 or greater) earthquakes.

Earthquakes could occur in any of the four major geologic provinces in the County of Riverside. These provinces are characterized by different active tectonic stress regimes and geomorphology (Figure 1-1). In each province, the stresses of plate motion create different styles of faults and surficial features.

Peninsular Ranges: The western portion of Riverside County and most of its population are in the Peninsular Range province. The Santa Ana and San Jacinto Mountains are part of the Peninsular Ranges, and were built by movement along earthquake faults. This province is dominated by right-lateral strike-slip faulting associated with the San Jacinto and Elsinore faults. However, all types of faulting may be found in this block, such as in the Elsinore Trough. The communities of Temecula and Murrieta and many agricultural areas of southwestern Riverside County lie in this broad structural depression, formed by active faulting along faults of the Elsinore fault system.

Salton Trough: The desert communities and farmland of the Coachella Valley in central Riverside County are located within the Salton Trough province. Here, the plates are separating and spreading centers exist. The spreading centers continue to the south, into the Gulf of California. At present, the Salton Trough is cut off from the Gulf of California by an accumulation of sediment at the mouth of the Colorado River. The Trough is filled with sediment three miles thick, derived primarily from the Colorado River. Periodically during the last 10,000 years, the Trough has been inundated with water. The most recent inundation formed the Salton Sea in 1905.

Transverse Ranges: Throughout most of the western U. S. are northwest-trending geologic features, a consequence of current plate motions. The trend of the Transverse Range province is a startling exception. These mountains run west to east from west of Santa Barbara to east of San Bernardino. The easternmost San Bernardino Mountains lie in north-central Riverside County. Many of southern California's recent damaging earthquakes occurred on faults that have built the Transverse Ranges, including: the 1971 Sylmar M_w 6.7, the 1991 Sierra Madre M_w 5.8, and the 1994 Northridge M_w 5 6.7. Although most of this province is located north and west of Riverside County, populated areas such as Riverside, Norco and Corona are at risk from Transverse Range earthquakes occurring on the nearby Cucamonga or Sierra Madre fault systems, about 20 to 25 miles to the north.



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Map of Geologic Provinces of the Riverside County Area

Figure 1 - 1

Mojave Desert: The Mojave Desert province consists of the eastern half of the County, and includes the Blythe area. Compared to the rest of Riverside County, this province has a moderate to low rate of seismicity and very few mapped faults. However, just north of the County, there are numerous active right-lateral strike-slip faults in the Mojave Desert province. These have recently produced the 1992 Landers M_w 7.3 and the 1999 Hector Mine M_w 7.1 earthquakes.

More detailed information about the sediments and bedrock types in Riverside County can be found in Chapter 2 - Slope and Soil Instability Hazards.

1.1.4 Common Designations of Earthquake Hazard Potential

Earthquake Size and Impact: Earthquakes are classified according to their ***moment*** (a measure of the energy released when a fault ruptures), their ***magnitude*** (a measure of maximum ground motion) or their ***intensity*** (a qualitative assessment of an earthquake's effects at a given location). A 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, earthquakes can produce several intensities, because effects generally decrease with distance from the earthquake. The most commonly used seismic intensity scale, called the Modified Mercalli Intensity (MMI) scale, has 12 levels of damage. The higher the number, the greater the damage (Table 1-1).

The strength of seismic ground shaking at any given site is a function of many factors. Of primary importance are the size of the earthquake, its distance, the paths the waves take as they travel through the Earth, the rock or soils underlying the site, and topography (particularly whether a site sits in a valley, or atop a hill). The amount of damage also depends on the size, shape, age, and engineering characteristics of the affected structures.

The interaction of ground motion and human-made structures is complex. Governing factors include a structure's height, construction, and stiffness, a soil's strength and resonant period, and the period of high-amplitude seismic waves. Waves come in different lengths and thus repeat their motions with varying frequency. Long waves are called long period or low frequency. Short waves are called short period or high frequency. In general, long period seismic waves, which are characteristic of large earthquakes, are most likely to damage long period structures such as high-rise buildings and bridges. Shorter period seismic waves, which tend to die out quickly, will most often cause damage in nearby earthquakes, and they will damage shorter period structures such as one- and two-story buildings. Very short period waves are most likely to cause non-structural damage, such as to equipment. In different situations, ground displacement, velocity and acceleration can cause damage.

Planning and Design Earthquakes: The largest earthquake expected in an area under the current tectonic environment is termed the ***maximum credible*** (MCE) or characteristic earthquake. A ***maximum probable*** earthquake (MPE) is the earthquake most likely to occur in a specified period of time, (such as 30 to 500 years). Generally, the longer the time period (recurrence interval) between earthquakes, the larger the earthquake will be, because there has been time to store more strain energy. The recurrence interval of concern will depend on the planned use, lifetime, or importance of a facility, The more critical the structure, the longer the recurrence interval chosen and the larger the ***design earthquake,*** that is, the earthquake that a community is designed to withstand.

Geologists, seismologists, engineers and urban planners typically use maximum credible and maximum probable earthquakes to evaluate the seismic hazard of a region. If we plan for worst-case scenario, smaller earthquakes that are more likely to occur can be dealt with readily. Buildings and other structures must meet seismic design parameter values. For example, they must withstand a certain peak acceleration, a given duration of strong shaking, or a particular period of seismic waves. When these values are derived from maximum credible earthquakes, they help to establish safety margins.

Although earthquakes occur often in Southern California, hundreds or thousands of years can elapse between earthquakes on any particularly portion of a fault. Many southern California faults have not caused earthquakes in historic times, and fewer yet have caused a maximum credible earthquake in historic times. Therefore, estimates of maximum credible and maximum probable earthquakes for a given fault are based on the length of the fault, style of faulting, and other characteristics. Earthquake size often depends on how many segments of a fault give way at one time. The more segments that rupture, the greater the energy release and the bigger the earthquake.

When a fault has not ruptured in historic times, data obtained from trenching excavations across the fault (paleoseismic studies) provide valuable insight into how often the fault ruptures, and how big its earthquakes get.

Fault Activity: The State of California, under the guidelines of the Alquist-Priolo Earthquake Fault Zoning Act (Hart and Bryant, 1997), classifies faults according to the following criteria:

Active faults show proven displacement of the ground surface within about the last 11,000 years (Holocene Epoch); and

Potentially Active faults show evidence of movement within the last 1.6 million years.

The State definition of an active fault is designed to gauge the surface rupture potential of a fault. The assumption is that if a fault has not moved in the last 11,000 years, it is unlikely to be the source of a damaging earthquake in the future. For residential subdivisions, a fault that has not moved in the last 11,000 years, as determined from direct geologic evidence, is presumed to be ***not active***. These are reasonable assumptions, but it can be difficult to ascertain when a fault has moved.

Although potentially active faults are considered less likely to generate earthquakes than active faults, in reality, most potentially active faults have been insufficiently studied to determine whether they are active or not. In this study, both active and potentially active faults are treated as candidate earthquake sources.

Regardless of which fault causes an earthquake, there will always be ***aftershocks.*** By definition, these are smaller earthquakes that happen close to the ***mainshock*** (the biggest event of the sequence) in time and space. These smaller earthquakes occur as the earth adjusts to the regional stress changes created by the mainshock. The bigger the mainshock, the greater the number of aftershocks, and the larger they will be. Generally, it takes a magnitude of about 5.5 to damage buildings. Any major earthquake will produce aftershocks large enough to cause damage, especially to already-weakened structures.

On average, the largest aftershock is 1.2 magnitude units less than the mainshock, Thus, a magnitude 6.9 earthquake will tend to produce aftershocks up to magnitude 5.7 in size. This is an average, thus there are many cases where the largest aftershock is larger than the average would predict. Post-disaster response must take large, damaging aftershocks into account.

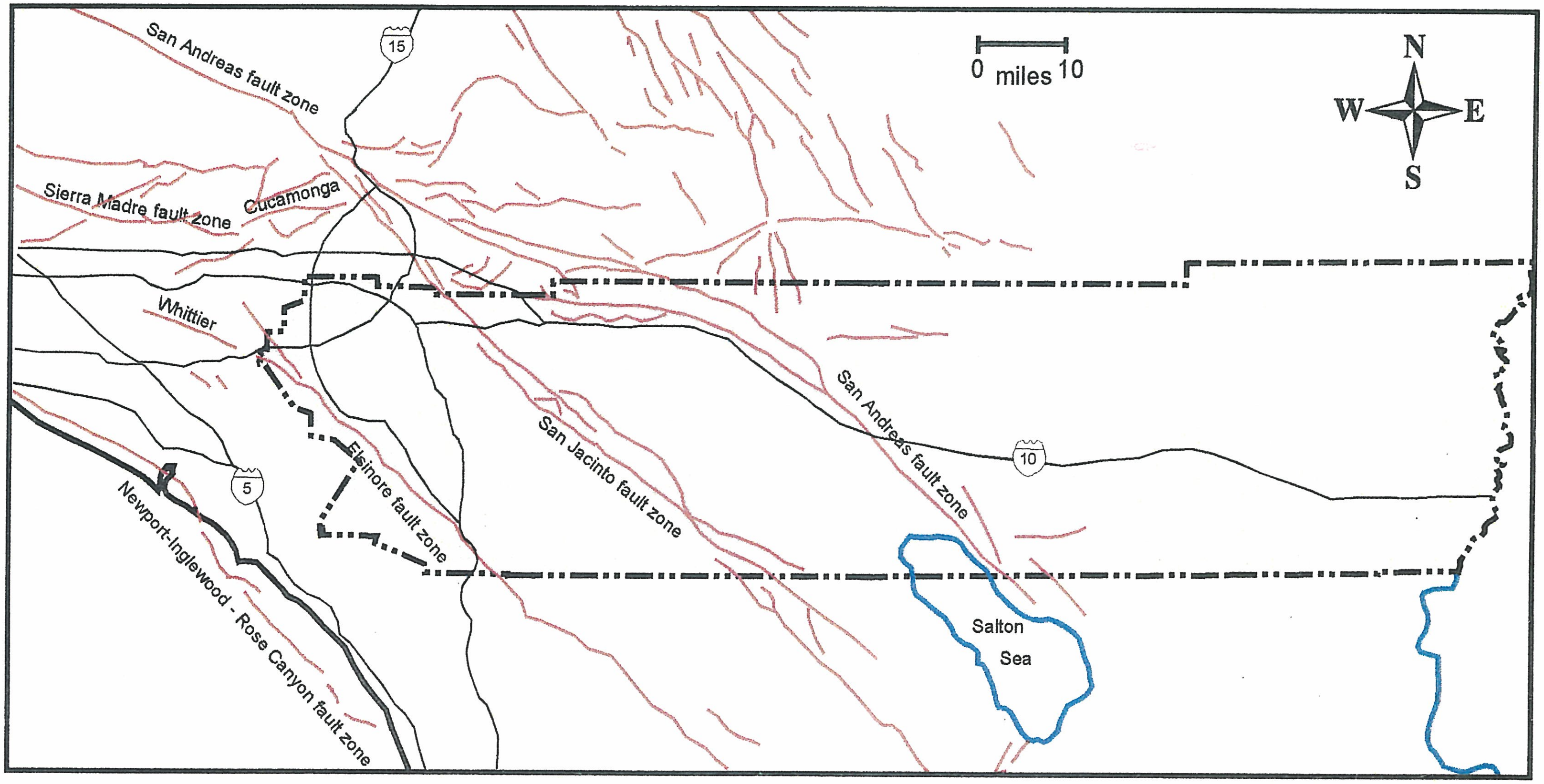

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Figure 1-2: Regional Faulting of the Riverside County Area

TABLE 1-1: ABRIDGED MODIFIED MERCALLI INTENSITY SCALE AND RELATION TO OTHER PARAMETERS

Intensity Value and Description		Average peak Velocity (centimeters per second)	Average peak acceleration (g is gravity = 9.80 meters per second squared)
I.	Not felt except by a very few under especially favorable circumstances (I Rossi-Forel)		
II.	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)		
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale)		
IV.	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like a heavy truck striking building. Standing automobiles rocked noticeably. (IV to V Rossi-Forel scale)	1-2	0.015g-0.02g
V.	Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale)	2-5	0.03g-0.04g
VI.	Felt by all, many frightened and run outdoors. Some heavy furniture moved, a few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale)	5-8	0.06g-0.07g
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (VIII Rossi-Forel scale)	8-12	0.10g-0.15g
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (VIII+ to IX Rossi-Forel scale)	20-30	0.25g-0.30g
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel scale	45-55	0.50g-0.55g
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks (X Rossi-Forel scale)	More than 60	More than 0.60g
XI.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely Out of service. Earth slumps and land slips in soft ground. Rails bent greatly.		
XII.	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.		

Primary Source: Bolt (1993)

1.1.5 Laws to Mitigate Earthquake Hazard

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 (A-P 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, 1997). This State law was a direct result of the 1971 San Fernando Earthquake, which was associated with extensive surface fault ruptures that damaged numerous homes, commercial buildings, and other structures. Surface rupture is the most easily avoided seismic hazard.

The A-P Act requires the State Geologist (Chief of the Division of Mines and Geology) to delineate "Earthquake Fault Zones" along faults which are "sufficiently active" and "well-defined." Sufficiently active faults show evidence of Holocene surface displacement along one or more or their segments. Well-defined faults are clearly detectable by a trained geologist as a physical feature at or just below the ground surface. 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. The A-P Act dictates that cities and counties withhold development permits for sites within an Alquist-Priolo Earthquake Fault Zone, until geologic investigations demonstrate that the sites are not threatened by surface displacements from future faulting (Hart and Bryant, 1997).

Alquist-Priolo Earthquake Fault Zone mapping has been completed by the State Geologist for the 45 quadrangles in Riverside County. The maps are distributed to all affected cities, counties, and state agencies for their use in planning and controlling new or renewed construction. Local agencies must regulate most development projects within the zones. Projects include all land divisions and most structures for human occupancy. State law exempts single family wood-frame and steel-frame dwellings which are less than three stories and are not part of a development of four units or more. However, local agencies can be more restrictive than state law requires.

Before a project can be permitted, cities and counties must require a geologic investigation to demonstrate that proposed buildings will not be constructed across active faults. An evaluation and written report of a specific site must be prepared by a licensed geologist. If an active fault is found, a structure for human occupancy cannot be placed over the trace of the fault and must be set back from the fault (generally 50 feet).

The A-P Act only addresses the hazard of surface fault rupture and is not directed toward other earthquake hazards. ***The Seismic Hazards Mapping Act***, passed in 1990, addresses non-surface fault rupture earthquake hazards, including strong ground shaking, liquefaction and seismically-induced landslides.

The California Department of Conservation, Division of Mines and Geology (DMG) is the principal State agency charged with implementing the 1990 Seismic Hazard Mapping Act (SHMA). Pursuant to the SHMA, the DMG is directed to provide local governments with seismic hazard zone maps that identify areas susceptible to amplified shaking, 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 DMG are referred to as "zones of required investigation". Site-specific geotechnical hazard investigations are required by SHMA when construction projects fall within these areas. The DMG , pursuant to the 1990 SHMA, has not completed any mapping for Riverside County, nor is any planned for the foreseeable future (DMG, 2000). However, this study provides seismic hazard mapping and information that meets the intent of the Seismic Hazards Mapping Act, and local agencies should require site-specific geotechnical hazard investigations based on this mapping.

Real Estate Disclosure Requirements. Effective June 1, 1998, the Natural Hazards Disclosure Act requires 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. 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. One is to use the new Natural Hazards Disclosure Statement as provided in Section 1102.6c of the California Civil Code. The other way is to use 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 can be substituted for the Natural Hazards Disclosure Statement only if the Local Option Statement contains substantially the same information and substantially the same warning as the Natural Hazards Disclosure Statement.

1.2 Major Earthquake Sources in Riverside County

Many faults have the potential to generate strong ground shaking, surface fault rupture and secondary damage in Riverside County (see Figure 1-2). For the faults that pose the greatest threat to the County, summaries of current technical data and professional views are described in the next sections. Additional detail on Riverside County faults is provided in Appendix C.

1.2.1 San Andreas Fault Zone

Because of its relatively frequent (high recurrence rate), large earthquakes, the San Andreas fault is considered the "Master Fault", controlling the seismic hazard in Southern California. In the vicinity of Riverside County, the San Andreas fault zone is comprised of three segments: 1) the San Bernardino Mountains segment, 2) the Coachella Valley segment, and 3) the Mojave Desert segment. Between Cajon and San Gorgonio Passes, the County is bisected by the San Bernardino segment. The Coachella Valley segment of the San Andreas runs along the northeastern margin of the Coachella Valley.

The last major earthquake on the southern San Andreas fault was the 1857 M_w 8.0 Fort Tejon quake that ruptured the San Andreas from central California, near Parkfield, to Cajon Pass, about 15 miles north of the County. For this study, the "Southern Segment" is considered a simultaneous rupture of the San Bernardino and Coachella Valley segments. Paleoseismic evidence indicates that such simultaneous rupture has occurred at least twice since 1450.

The San Bernardino Mountains segment extends in a westerly to northwesterly direction between the Cajon Pass area and the San Gorgonio Pass (Figure 1-3). This segment is structurally complex because the fault makes a left-step, and bends to trend in a more westerly direction. Associated compression is expressed as a zone of reverse, lateral and oblique-slip deformation that is accommodated by several subparallel fault strands. The most important of these are the Mission Creek, San Gorgonio Pass, and Banning faults.

Several estimates of slip rate obtained independently indicate that the San Bernardino Mountains segment has a slip rate of 24± 6 mm/yr, with an average recurrence interval of 146 years (WGCEP, 1995). Paleoseismic studies at Wrightwood indicate that there have been six surface-rupturing earthquakes on this segment since AD 1192, with the most recent five events occurring, on average, every 106 years. The most recent surface-rupturing earthquake on this segment is thought to have occurred in 1812 (Jacoby and others, 1988). Stein and others

(1992) indicate that the Landers earthquake sequence may have caused stress changes that advanced the occurrence of the next great San Andreas earthquake on this segment by 8 to 22 years. The Working Group on California Earthquake Probabilities (1995) estimated that this segment has a 28% probability of rupturing in the time period between 1994 and 2024 (Figure 1-3). An earthquake of magnitude 7.3 on the San Bernardino Mountains segment could produce peak horizontal ground accelerations as high as 0.53 g (Table 1-1) in Riverside County. If this fault segment breaks along with the Mojave or Coachella segments (e.g. Southern Segment, Table 1-2), a much larger portion of the County would be subjected to strong ground motions.

The Coachella Valley segment extends from the San Gorgonio Pass to the Salton Sea. It has not produced large, surface-rupturing earthquakes in historic times (Sieh and Williams, 1990). Paleoseismic studies suggest that the last surface-rupturing earthquake on this segment occurred around A.D. 1680. Studies at Indio indicate that prior to 1680, earthquakes on this fault segment occurred at an average recurrence interval of 220 years. The data also suggest that the Coachella Valley and San Bernardino Mountain segments ruptured simultaneously in earthquakes that occurred around 1680 and 1450. The segment is creeping at a rate of about 2-4 mm/year, and has a long-term slip rate of about 25 ± 5 mm/yr (WGCEP, 1995). This segment has an estimated 22% probability of rupturing before the year 2024 and is estimated capable of producing a magnitude 7.1 earthquake (WGCEP, 1995).

The Mojave segment extends from the Cajon Pass area, the southern limit of the 1857 rupture, (about 30 kilometers (km) north of Riverside County) north some 100 km (WGCEP, 1995). The 1988 Working Group calculated the recurrence interval for this segment using the 1857 displacement. The 1995 Working Group retained the slip rate of 30 mm/yr, characteristic displacement of 4.5 ± 1.0 m and derived repeat time of 150 years, but increased the uncertainties to ±8 mm/yr and ±1.5 m, respectively. Rupturing alone, the Mojave segment is estimated capable of producing a magnitude 7.1 earthquake.

Table 1-2: Fault Source Parameters for Riverside County

Fault Name and Geometry (1)	Distance from County (km)	Length		Slip Rate		Maximum Magnitude (2)	Maximum PGA (3)	Average Return Interval (yrs)	Comments
		(km)	+/-	(mm/yr)	+/-				
San Andreas-Coachella (rl-ss)	0	95	10	25	5	7.1	0.51	na	Slip rate based on Sieh and Williams (1990); Sieh (1986); Keller et al. (1982); Bronkowski (1981). Model assumes slip only in S. San Andreas events.
San Andreas-San Bernardino (rl-ss)	0	107	11	24	6	7.3	0.53	146	Slip rate reported by Weldon and Sieh (1985).
San Andreas (southern) (rl-ss)	0	203	20	24	6	7.4	0.48	220	Rupture of San Bernardino and Coachella segments. Slip rate based on Coachella segment.
San Andreas-Mojave (rl-ss)	>30	99	10	30	7	7.1	0.25	150	Slip rate based on Sieh (1984), Salyards et al. (1992), and WGCEP (1995).
San Jacinto-Coyote Creek (rl-ss)	0	40	4	4	2	6.8	0.48	175	Slip rate and fault length from WGCEP (1995).
San Jacinto-Anza (rl-ss)	0	90	9	12	6	7.2	0.52	250	Slip rate and fault length from WGCEP (1995).
San Jacinto-San Jacinto Valley (rl-ss)	0	42	4	12	6	6.9	0.49	83	Slip rate and fault length from WGCEP (1995).
San Jacinto-San Bernardino (rl-ss)	0	35	4	12	6	6.7	0.53	100	Slip rate and fault length from WGCEP (1995).
Elsinore-Temecula (rl-ss)	0	42	4	5	2	6.8	0.47	240	Slip rate and fault length from WGCEP (1995).
Elsinore-Glen Ivy (rl-ss)	0	38	4	5	2	6.8	0.48	340	Reported slip rates vary from 3.0-7.2 (Millman and Rockwell, 1986)
Whittier (rl-ss)	0	37	4	2	1	6.8	0.48	641	Slip rate based on Rockwell et al. (1990); Gath et al. (1992) description of offset drainage.
Chino-Central Ave. (rl-r-o)	0	28	3	1	1	6.7	0.47	882	Unconstrained slip rate based on assumptions of slip transfer between Elsinore and Whittier faults.

1. STYLE OF FAULT: (ss) strike slip, (r) reverse, (n) normal, (o) oblique SENSE OF SLIP: (rl) right lateral, (ll) left lateral
2. Maximum moment magnitude calculated from rupture area regressions (type "all") (from Wells and Coppersmith, 1994).
3. Maximum estimated horizontal peak ground acceleration as a percentage of gravity on bedrock, at closest Riverside County location (from CDMG).

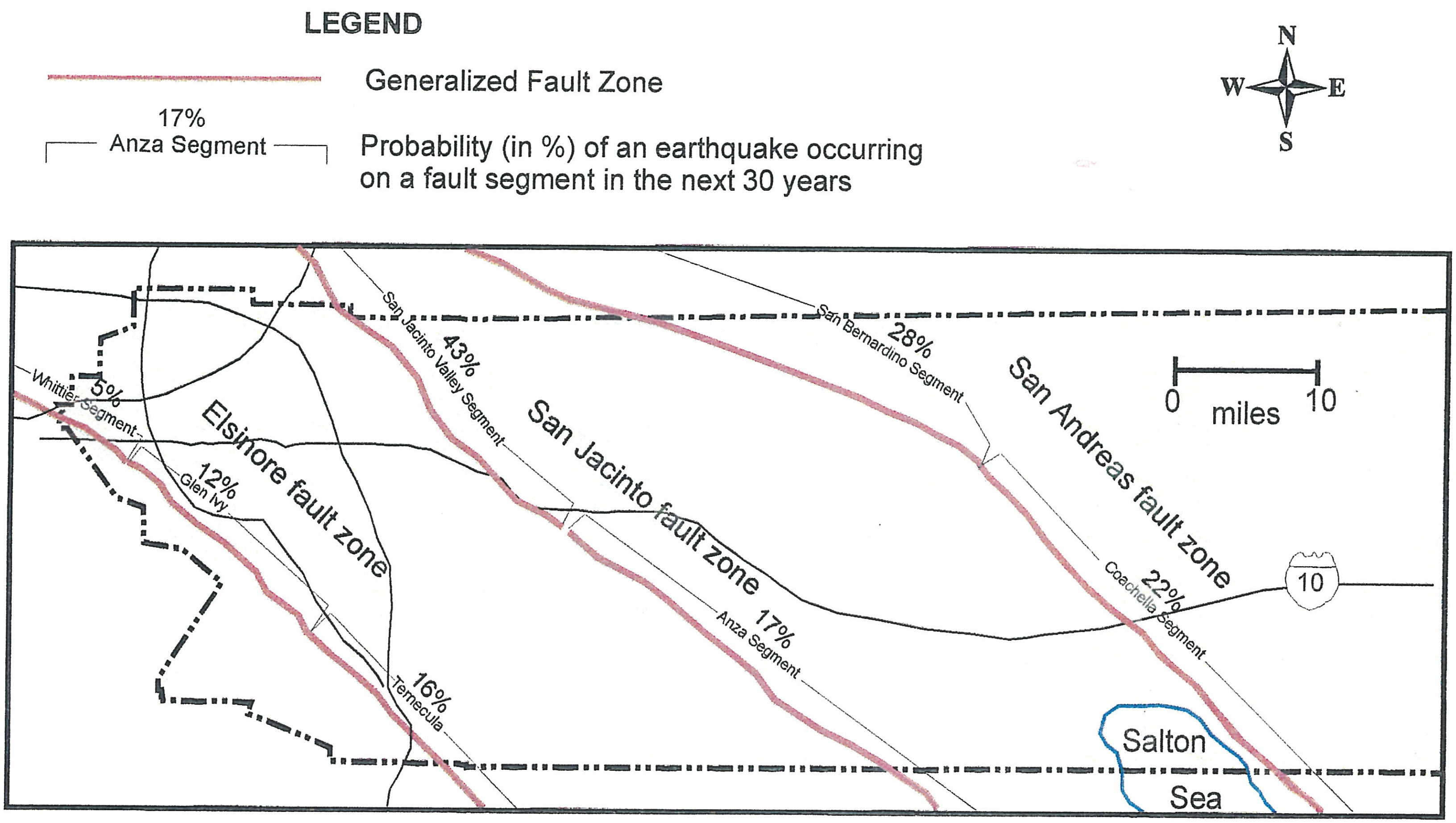

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Figure 1-3: Fault Segments and Earthquake Probabilities in Riverside County

1.2.2 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 fault zone 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 transform fault. The San Jacinto fault zone has a high level of historical seismic activity, with at least ten damaging (M_w 6 - 7) earthquakes having occurred on this fault zone between 1890 and 1986. Earthquakes on the San Jacinto in 1899 and 1918 caused fatalities in the Riverside County area. Offset across this fault is predominantly right-lateral, similar to the San Andreas fault, although Brown (1990) has suggested that dip-slip motion contributes up to 10% of the net slip. The segments of the San Jacinto fault that are of most concern to Riverside County are the San Bernardino, San Jacinto Valley and Anza segments.

Fault slip rates on the various segments of the San Jacinto are less well constrained than for the San Andreas fault, but the available data suggest slip rates of 12 ± 6 mm/yr for the northern segments of the fault, and slip rates of 4 ± 2 mm/yr for the southern segments (WGCEP, 1995). For large ground-rupturing earthquakes on the San Jacinto fault, various investigators have suggested a recurrence interval of 150 to 300 years (Petersen and Wesnousky, 1994). The Working Group on California Earthquake Probabilities (1995) has estimated that the San Bernardino, San Jacinto Valley and Anza segments have a 37%, 43%, and 17% probability, respectively, of rupturing in the period between 1994 and 2024.

Maximum credible earthquakes of magnitudes 6.7, 6.9 and 7.2 are expected on the San Bernardino, San Jacinto Valley and Anza segments, respectively, capable of generating peak horizontal ground accelerations of 0.48 to 0.53 g (Table1-1, 1-2) in the County of Riverside.

1.2.3 Elsinore Fault Zone

The Elsinore fault zone parallels the San Jacinto and is part of the same right-lateral crustal plate strain system as the San Andreas and the San Jacinto. Segments in Riverside County are the Whittier, Glen Ivy, Temecula, and Julian segments. The most apparent displacements on the Whittier-Elsinore have been vertical, as evidenced by the steep scarp (an earthquake-built cliff) along the Santa Ana Mountains. The Elsinore branches into the Whittier fault near Santa Ana Canyon, where it borders the Puente Hills to the southwest and the Chino fault to the northeast. Maximum credible earthquakes of M_w 6.7 to 6.8 are assigned for the Chino, Whittier, Glen Ivy and Temecula segments of the Elsinore fault. Major ground rupturing events on these fault segments would generate peak ground accelerations of 0.47 to 0.48 g for Riverside County (Table1-1, 1-2). WGCEP (1995) estimates probabilities of 5% to 16% for these events to occur in the 1994 to 2024 time period.

1.2.4 Cucamonga Fault Zone

The Cucamonga fault zone, a youthful member of the Transverse Ranges family of thrust faults (Morton and Matti, 1987), is not in Riverside County but creates a hazard there. It is the eastward extension of the Sierra Madre fault, one of the most hazardous of southern California's faults. The Cucamonga fault zone is the known Transverse Ranges fault that is closest to the County of Riverside. It is comprised of a series of east-west trending, north-dipping reverse faults that displace Holocene sediments (Ziony and Jones, 1989). This frontal fault zone extends from the southern margin of San Gabriel Mountains to the southern margin of the San Bernardino Mountains, disrupting modern alluvial fans and sediments associated with the upper Santa Ana River Valley. This provides evidence that the Cucamonga fault zone is active.

Measurements of the fault-plane dips and determination of surface offsets for thrust fault scarps suggest minimum slip rates between 4.5 and 5.5 mm/yr (Morton et al., 1987). Taking into account uncertainties in Carbon-14 age dating of offset materials, WGCEP (1988) assigned a slip rate of 5.0 ± 2.0 mm/yr and maximum magnitude of 7.0 to the Cucamonga fault.

1.3 Riverside County Seismicity

In Figure 1-4 and Table 1-3 are the epicenters and magnitudes of historical earthquakes that have caused significant ground shaking or secondary damage in Riverside County. These data are provided by the Southern California Earthquake Center Data Center (SCEC-DC, 1999). Several of these earthquakes have resulted in Modified Mercalli Intensity (MMI) VII (severe) ground shaking in Riverside County. Fatalities were reported in Riverside County as a result of San Jacinto fault earthquakes in 1899 and 1918. Recently, MMI VI shaking occurred in the southern Coachella Valley region of Riverside County during the October 1999 M_w 7.1 Hector Mine earthquake.

Table 1-3: Historical Earthquakes Impacting Riverside County

Date	Magnitude	Max MMI in Riverside County	Distance from Riverside County
Dec. 8, 1812; 7:00 am	7.5	VIII	Wrightwood; 18 miles north
July 22, 1899; 12:32 pm,	5.7	VII	Cajon Pass; 18 miles north
Dec. 25, 1899; 4:25 am	6.5	VIII	San Jacinto Valley, 6 fatalities in County
May 15, 1910; 7:47 am	6.0	VII	near Lake Elsinore
April 21, 1918; 2:32 pm	6.8	VIII	San Jacinto Valley, 1 fatality in County
March 10, 1933; 5:54 pm	6.4	V	Long Beach; 19 miles west
Dec. 4, 1948; 3:43 pm	6.0	VII	Desert Hot Springs
Sept. 12, 1970; 7:30 am	5.2	V	Lytle Creek; 18 miles north
July 8, 1986; 2:21 am	6.0	VII	North Palm Springs
Oct. 1, 1987; 7:42 am	5.9	IV	Whittier-Narrows; 21 miles west
June 26, 1988; 8:05 am	4.7	IV	Upland; 11 miles west
Feb. 28, 1990; 3:43 pm	5.4	V	Upland; 12 miles west
June 28, 1991; 7:43 am	5.8	IV	Sierra Madre; 18 miles northwest
April 22, 1992; 9:50 pm	6.1	VII	Joshua Tree
June 28, 1992; 4:57 am	7.3	VII	Landers; 8 miles north
June 28, 1992; 8:05 am	6.4	VI	Big Bear; 10 miles north
Jan. 17, 1994; 4:31 am	6.7	III	Northridge; 64 miles northwest
Oct. 16, 1999; 2:40 am	7.1	VI	Hector Mine; 20 miles north

LEGEND

Historical Earthquake Location, Year, and Magnitude

- Magnitude greater than 7.0
- Magnitude greater than 6.0 and less than 7.0
- Magnitude less than 6.0
- Generalized Fault

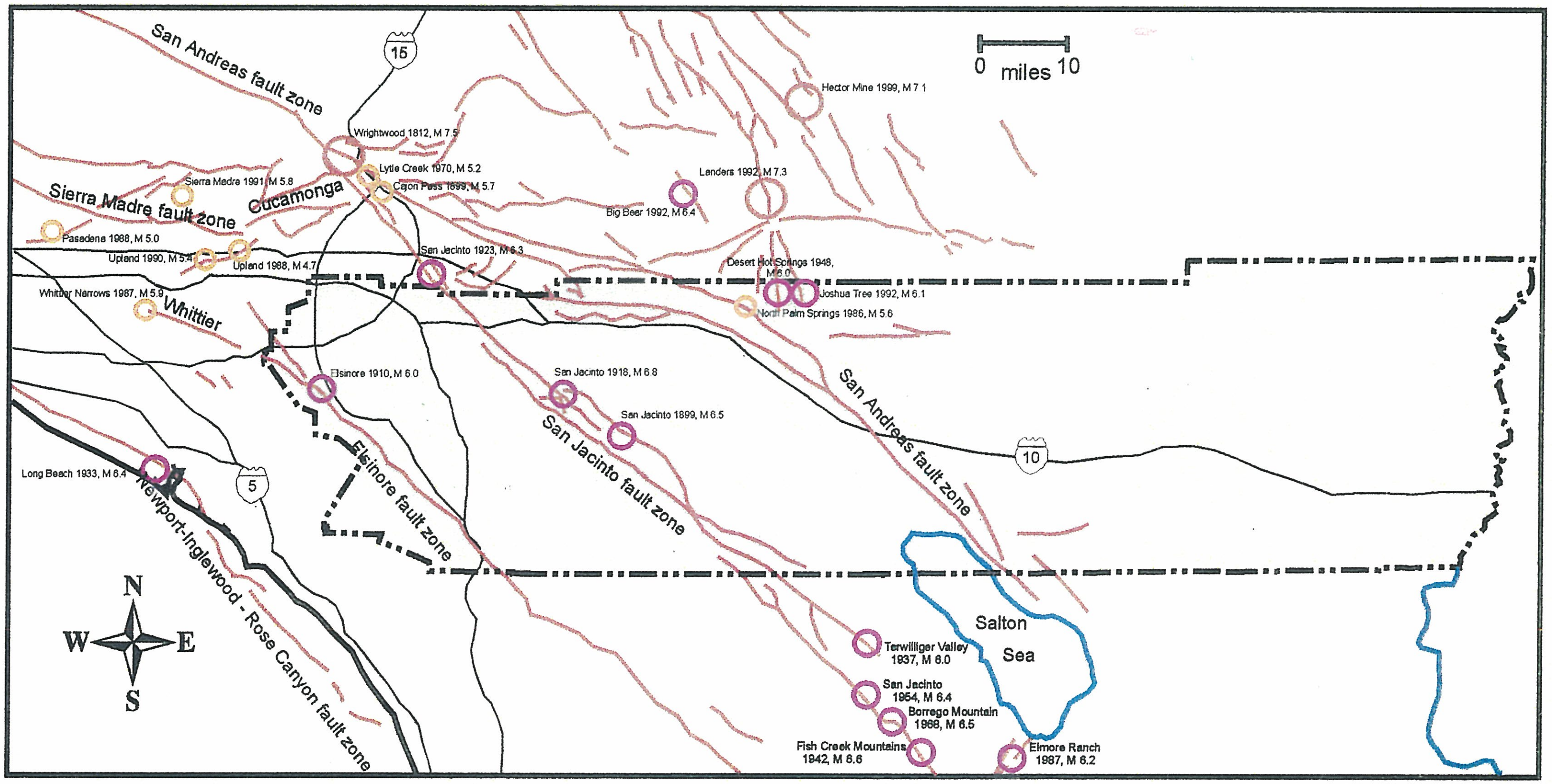

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Figure 1-4: Notable Historical Earthquakes in the Riverside County Region

1.3.1 Past Damaging Earthquakes

Below is a summary of historical earthquakes significant to Riverside County. Locations and sizes of earthquakes that occurred before good instrumental recordings became available (before ~1940) have been estimated. Generally, the older sizes and locations have big error margins.

1812 Wrightwood (formerly known as the "San Juan Capistrano Earthquake"): With a magnitude of approximately 7.5, this earthquake occurred on December 8, 1812 during the mid-morning hours. The epicenter is relatively uncertain, but, based upon tree ring and paleoseismology data (Jacoby and others, 1988; Sieh and others, 1989), appears to be on the San Andreas fault near Wrightwood, about 18 miles north of the County of Riverside. This earthquake is often referred to as the "San Juan Capistrano" earthquake, due to the death toll at the mission. It is thought that this quake ruptured the Mojave segment of the San Andreas, possibly resulting in as much as 106 miles of surface rupture -- roughly, the length of the San Andreas fault between Tejon Pass and Cajon Pass.

1899 Cajon Pass This estimated magnitude 5.7 earthquake was felt over most of southern California, with intensities reaching VIII in the epicentral area, somewhere near Lytle Creek and Cajon Pass, about 18 miles north of Riverside County. Triggered landslides blocked both the Lytle Creek Canyon road and the road through Cajon Pass. The heaviest damage to buildings occurred in San Bernardino, Highland, and Patton. Damage was also reported in Redlands, Pomona, Riverside, Pasadena, and Los Angeles, though it was mostly minor. No deaths were reported, and the number of injuries is uncertain (Townley, 1939).

1899 San Jacinto This devastating earthquake occurred in west-central Riverside County, near the town of San Jacinto, on December 25, 1899 at 4:25 am PST, with an estimated magnitude of 6.5. The epicenter of this earthquake was not well located, but involved the San Jacinto fault. The damage pattern suggests the epicenter shown on Figure 1-3. This location is not far from the epicenter of the 1918 San Jacinto earthquake. Damage was greatest in the towns of San Jacinto and Hemet, where nearly all brick buildings were either badly damaged or destroyed. Also hit hard was the Soboba Indian Reservation, where six people were killed by falling adobe walls. Chimneys were thrown down and walls cracked in Riverside. Other outlying areas reported minor damage.

1910 Elsinore The Elsinore earthquake struck on May 15, 1910 at 7:47 am, PST with an epicenter estimated near Lake Elsinore in western Riverside County. The earthquake most likely occurred on the Elsinore fault, and was preceded by moderate foreshocks on April 10 and May 12. The Elsinore earthquake was not a particularly strong or damaging quake. What is notable about this quake is that best estimates place it on the Elsinore fault zone, along which there are no historical recordings of earthquakes of magnitude 6 or larger.

1918 San Jacinto The approximately magnitude 6.8 earthquake occurred on April 21, 1918 at 2:32 pm PST on the San Jacinto fault in west-central Riverside County. According to intensity isoseismals that rely heavily on damage reports, most of the damage occurred in the business districts of the towns of San Jacinto and Hemet, where large masonry structures collapsed. Luckily, the earthquake struck on a Sunday afternoon, when the business districts were empty. Several people were injured and one death was reported. Two miners were trapped in a mine near Winchester, but were eventually rescued, uninjured.

1933 Long Beach This magnitude 6.4 earthquake struck on March 10, 1933 at 5:54 pm, PST, about 19 miles west of Riverside County. While referred to as the Long Beach earthquake due to the extensive damage in the Long Beach area, its epicenter was actually 3 miles south of Huntington Beach. This earthquake occurred on the Newport-Inglewood fault zone, a system of right-lateral strike-slip faults. There was no surface rupture associated with this earthquake, which resulted in 120 deaths and over $50 million in property damage. Most of the damaged buildings were of unreinforced masonry. Many school buildings were destroyed. Fortunately, however, the children were gone for the day. The Long Beach earthquake has the greatest death toll of any historical southern California earthquake. Yet the toll would have been much more tragic if the collapsed school buildings had been occupied. The fact that the relatively recent urban earthquakes (1971 M_w 6.7 Sylmar; 1989 M_w 7.1 Loma Prieta; and 1994 M_w 6.7 Northridge) all had far fewer fatalities despite much larger populations may stand as testimony to improvement of the life-safety aspects of modern building codes. This is the earthquake that changed building codes and required masonry to be reinforced. The 1933 Long Beach earthquake also led to the passage of the Field Act, which gave the State Division of Architecture authority and responsibility for approving design and supervising construction of public schools.

1948 Desert Hot Springs This magnitude 6.0 earthquake struck on December 4, 1948 at 3:43 pm PST. The fault involved is believed to be the Banning fault. Shaking was felt over a large area (central Arizona, parts of Mexico, Santa Catalina Island, and Bakersfield), and 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, plaster cracked and fell from many buildings. In San Diego, a water main broke. In Escondido and Corona, walls 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 Springs. 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 much damage, no lives were lost.

1970 Lytle Creek This magnitude 5.2 earthquake occurred on September 12th at 7:31 am PST about 18 miles north of Riverside County. The Lytle Creek earthquake struck the area near Cajon Pass, knocking a San Bernardino radio station off the air, and causing landslides and rockfalls in the Transverse Ranges. Several roads were blocked or partially blocked. The quake caused some unusual damage in areas a fair distance from the epicenter. Power was disrupted in the Santa Monica Mountains northwest of Hollywood. A high-pressure water system in a Riverside aerospace plant was damaged, leading to a subsequent boiler explosion that injured four people. More typical minor damage also occurred, primarily in the Lytle Creek area (intensity VII on the Modified Mercalli Scale) and to a lesser degree in the nearby towns of Colton, Crestline, Cucamonga, Fontana, Glendora, Highland, Mt. Baldy, Rialto, Rubidoux, and Wrightwood (Lander, 1971).

1986 North Palm Springs This magnitude 6.0 earthquake occurred on July 8, 1986 at 2:21 am PDT, along either the Banning fault or the Garnet Hill fault. The epicenter was about 6 miles northwest of Palm Springs in north-central Riverside County. The 1986 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. 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).

1987 Whittier Narrows This magnitude 5.9 earthquake occurred on October 1st at 7:42 am PDT, about 21 miles west of the County of Riverside. This earthquake occurred on a previously unknown, concealed thrust fault now known as the Puente Hills fault. It resulted in eight fatalities and $358 million in property damage (SCEC-DC, 1999). Severe damage was confined mainly to communities east of Los Angeles and near the epicenter, particularly the "Uptown" district of Whittier, the old downtown section of Alhambra and the "Old Town" section of Pasadena. These areas had high concentrations of unreinforced masonry buildings. Residences which sustained damage usually were constructed of masonry, were not fully anchored to foundations, or were houses built over garages with large door openings. Many chimneys collapsed and in some cases, fell through roofs. Wood frame residences sustained relatively little damage.

1988 Upland This magnitude 4.7 event occurred on June 26, about 3 km (2 miles) NW of Upland, about 11 miles west of Riverside County (Person, 1988). The event occurred on the San Jose fault. The 1988 Upland earthquake caused minor damage in the epicentral area, but would have been of relatively little note were it not for the possibility that it may have been triggered by the Whittier Narrows earthquake -- 9 months earlier, and 20 km away. These kinds of causal connections are of great interest as they offer some hope of more accurately forecasting earthquake probabilities.

1990 Upland This magnitude 5.4 earthquake occurred on February 28th (Person, 1990), about 12 miles of Riverside County on the San Jose fault. The 1990 Upland earthquake was much more damaging than the quake of 1988. In the 1990 earthquake, 38 people sustained minor injuries, and damage was considerable near the epicenter. The quake was felt as far to the northeast as Las Vegas, Nevada, and as far south as Ensenada, Mexico.

1991 Sierra Madre This magnitude 5.8 earthquake occurred on June 28th at 7:43 am PDT, about 12 miles northeast of Pasadena and 18 miles northwest of Riverside County. The earthquake occurred on the Clamshell-Sawpit Canyon fault, an offshoot of the Sierra Madre fault zone in the San Gabriel Mountains. Because of its depth and moderate size, it caused no surface rupture, though it triggered rockslides that blocked some mountain roads. Two deaths resulted from this earthquake - one person was killed in Arcadia, and one person in Glendale died from a heart attack. In all, at least 100 others were injured, though the injuries were mostly minor. Roughly $40 million in property damage occurred in the San Gabriel Valley. (SCEC-DC, 1999).

1992 Joshua Tree This magnitude 6.1 earthquake struck on April 22, 1992 at 9:50 pm PDT, in north-central Riverside County. This event was preceded by a magnitude 4.6 foreshock. The Joshua Tree earthquake raised some alarms due to its proximity to the San Andreas fault. A San Andreas Hazard Level B alert was declared, meaning that the San Andreas fault had a 5 - 25% chance of generating an even larger earthquake within 3 days. Roughly two months and 6,000 aftershocks later, a larger earthquake did occur, but to the north, near Landers, away from the San Andreas. Aftershocks of the Joshua Tree quake suggest that the causative fault is a north-northwest-trending, right-lateral strike-slip fault at least 15 km long (Jones and others, 1995). The Eureka Peak fault is a likely candidate.

1992 Landers On the morning of June 28, 1992, most people in southern California were awakened at 4:57 am PDT by the largest earthquake to strike California in 40 years. Named "Landers" after a small desert community near its epicenter, the earthquake had a magnitude of 7.3 and occurred about 8 miles north of Riverside County. Centered in the Mojave Desert, approximately 120 miles from Los Angeles, the earthquake caused relatively little damage for its size (Brewer, 1992). It released about four times as much energy as the very destructive Loma Prieta earthquake of 1989, but fortunately, it did not claim as many lives (one child died when a chimney collapsed). The power of the earthquake was illustrated by the length of the ground rupture it left behind. More than 50 miles of surface rupture occurred. The average right-lateral strike-slip displacement was 10 - 15 feet, while a maximum of 18 feet observed. The earthquake ruptured 5 separate faults: Johnson Valley, Landers, Homestead Valley, Emerson, and Camp Rock faults (Rymer, 1992). Nearby faults also experienced triggered slip and minor surface rupture. The Landers earthquake triggered seismicity throughout the western United States. Before this occurred, the seismological community was convinced such triggering did not happen.

1992 Big Bear This magnitude 6.4 earthquake struck about 3 hours after the Landers earthquake on June 28, 1992. The epicenter was about 10 miles north of Riverside County. 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 Big Bear aftershocks, the causative fault appears to be a northeast-trending left-lateral fault. This orientation and slip are considered "conjugate" to the faults which slipped in the Landers rupture. Additionally, there is evidence that the Big Bear mainshock and aftershocks may have ruptured conjugate faults. 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.

1994 Northridge This magnitude 6.7, January 17, 1994 event was far enough from Riverside County to cause little or no direct damage. However, long-range economic impact of this $20-$30 billion earthquake affected all of southern California, and in fact had global consequences.

1999 Hector Mine 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. Modified Mercalli Intensity VI (Table 1-1) shaking was reported in the southern Coachella Valley, but most County felt reports were in the MMI V range (SCEC-DC, 1999). The Hector Mine earthquake is not considered an aftershock of the M_w 7.3 Landers earthquake of 1992, although subsequent analysis will explore the relationship between these two events, which occurred on similar, north-northwest trending strike-slip faults within the Mojave Shear Zone. Hector Mine ruptured the Lavic Lake fault. Geologists documented a 40-km long surface rupture and a maximum right-lateral strike-slip offset of about 5 meters.

1.3.2 Seismicity of Riverside County

Some History

Figure 1-5 and Plate 1-1 show the locations and sizes of 47,375 earthquakes that were recorded in and adjacent to Riverside County between 1868 and August, 1999. The map locates ***epicenters***, which are the surface projections of the earthquakes' initiation points inside the earth. The plotted earthquakes have magnitudes that range from 0.8 to 6.8. Almost all of these earthquakes (96%) are under magnitude 3.0, too small to be felt by people.

Our knowledge of seismicity improves as the quality of our recording methods improve. Before 1932, southern California had no network of ***seismometers*** (instruments that record ground shaking), and records of earthquakes were public reports like newspapers. People are less sensitive than seismometers to ground shaking. Consequently, before 1932, we only have records of the largest earthquakes - generally magnitude 4 and greater. On the map, there are 44 earthquakes before 1932.

The Southern California Seismic Network (SCSN), started in 1932, was the first regional seismic network, and it remains the most forward-thinking. Its contribution to hazard reduction and basic research cannot be overstated. The SCSN is a collaborative effort of the United States Geological Survey and the California Institute of Technology. Digital data from the SCSN is archived by the Southern California Earthquake Center Data Center.

From 1932 to 1981, as the SCSN grew, so did the catalog of smaller earthquakes. Since 1983, the SCSN has had a complete record of earthquakes to about the magnitude 1.8 level. This adds a huge number of earthquakes to the catalog, as the number of earthquakes increases approximately ten-fold with each decrease in magnitude point. So, for every magnitude 4 that occurs, there are 10 magnitude 3 earthquakes, 100 magnitude 2 earthquakes, and 1000 magnitude 1 earthquakes. Thus, 97% of the earthquakes in Figure 1-5 (Plate 1-1) have occurred since 1981.

Using a three-dimensional velocity inversion program, Hauksson (*in press*) accurately determined earthquake locations for all of the digitally catalogued SCSN data in southern California, that is, from 1981 to August, 1999. Figure 1-5 and Plate 1-1 map Hauksson's most reliable results within Riverside County, earthquakes with magnitudes greater than 0.8, observed by eight or more seismometer stations.

Determinations of earthquake locations and sizes have also improved considerably since 1868, due to the creation and growth of the SCSN. Currently, the SCSN has seismometers at more than 250 sites around southern California. This allows smaller earthquakes to be more accurately located, as well as simply detected. Before 1932, rough estimates of earthquake size and location were made by identifying regions where the most people felt the earthquake, or the most structures experienced damage. In 1935, Charles Richter developed the first quantitative method to calculate earthquake magnitude, called "the Richter scale" by the media, and "M_L, the local magnitude scale" by scientists. Richter's method was based on the amplitude of ground shaking on a Wood-Anderson seismometer situated 100 km from the earthquake. Local magnitude remains a fast and reliable method of determining earthquake size for smaller events, but underestimates the size of larger earthquakes. Magnitude based on energy release, ***M_w*, moment magnitude**, is more accurate for larger earthquakes (see Aki, 1966; Brune, 1968;

Hanks and Kanamori, 1979; Kanamori and Anderson, 1975). The larger earthquakes in Figure 1-5 and Plate 1-1 have M_w magnitudes, the others are M_L.

Prior to the existence of modern seismograph networks like the SCSN, to estimate the approximate location and size of an earthquake, a shaking map was constructed based on some version of the Mercalli Intensity Scale (Table 1-1). Such maps defined intensity zones based on observations of damage and other effects associated with ground shaking. These maps typically displayed a bull's-eye pattern, with the highest intensities in the middle. The earthquake was assumed to be near the center of the bull's-eye. For earthquakes that pre-date quantitative magnitude determinations, magnitudes can be estimated by using the magnitudes of more recent earthquakes that generated similar intensity maps.

Seismicity Patterns

In the time span of this map, nearly all of the earthquakes in Riverside County (and elsewhere) occur within known active fault zones. This holds true for earthquakes of all sizes. There are nine earthquakes in Figure 1-5 and Plate 1-1 with magnitudes greater than 6.0 (see section 1.3.1 and Table 1-3 for details of these events, see Figure 1-4 for their locations). One occurred on the southern portion of the Eureka Peak fault. The other eight occurred on the major fault zones: five, including the largest (M_w 6.8), ruptured the San Jacinto fault zone; two occurred on the San Andreas fault zone; and one was on the Elsinore fault zone.

Earthquakes on Figure 1-5 and Plate 1-1 can be classified as "significant" (larger events), "foreshocks and aftershocks" (earthquakes that are smaller than significant events, but close in time and space, and that are physically, causally related the significant event), and "background" or "microseismicity" (small earthquakes, not associated with significant events). Earthquakes observed along the Elsinore fault zone, the San Gorgonio Pass fault zone, between major fault zones, and in the eastern portion of the County are "background".

Note how the significant earthquakes are too infrequent to identify fault locations, but the smaller epicenters of "background" and "aftershocks" define the map traces of many faults. Some portions of the San Andreas fault in southern Riverside County have been documented to ***creep***, that is, the rocks along the fault slip readily, and this is thought to account for the abundant small earthquakes there (Jennings, 1994). The lack of small earthquakes on the rest of the southern San Andreas is one indication that this portion of the fault is locked in place by friction. After the next great earthquake(s) on the southern segments of the San Andreas, these locked segments will also be defined by epicenters of aftershocks.

It is also worth noting the paucity of earthquakes in the eastern half of the County. In part, this is an artifact of data coverage, as there are fewer seismometers in this portion of the network. However, the lack of earthquakes is also consistent with the lack of mapped active or potentially active faults in this region.

Depth of Seismicity

Most earthquakes occur in the upper 15 kilometers (about 9 miles) of the earth's crust, where rocks are cool and brittle enough to lock due to friction and store strain energy. Many major earthquakes begin 10-15 kilometers beneath the surface, near the bottom of the brittle portion of the crust (see dePalo and Slemmons, 1990). Then the fault rupture propagates up towards the surface. In the lower crust, deeper than 15 kilometers, the rocks are hotter and, when subjected to plate motion stresses, tend to be ductile and flow plastically. Thus the majority of earthquakes shown in Figure 1-5 and Plate 1-1 are shallower than 15 kilometers. However, there are notable exceptions.

The San Gorgonio Pass fault zone exhibits some of the deepest earthquakes in southern California. Here, abundant seismicity occurs at depths of 15 to 25 kilometers (Nicholson et al, 1986; Seeber and Armbruster, 1995; Magistrale and Sanders, 1996). This is thought to be because upper crustal material has been pushed deeper due to motion within this complex fault system. This upper crustal material is still relatively cold and brittle, and therefore continues to store strain energy.

1.3.3 Earthquake Geographic Information System Coverage for Riverside County

As part of this study, seismic data were imported into a geographic information system (GIS) coverage for Riverside County, described below. The data utilized were seismicity catalogs dating from 1931 (the beginning of the Southern California Seismic Network) to the present. Data tables linked to each event include magnitude, depth, and year.

Coverage Description: Earthquake locations in Riverside County (Plate 1-1)
Coverage distribution file name: quakes.e00; quakes3.e00 (quake.e00 represents all earthquake locations under 3.0. quakes3.e00 represents all earthquakes over 3.0.)

Coverage Area: Riverside County
Source: Earth Consultants International

Accuracy: The earthquakes are plotted to an accuracy of 1:24,000.

Earthquake Location References:

Earthquake locations for events occurring from 1858 to 1931:
Blake, T. F., 1996, EQFAULT- Computer software for deterministic site parameters, Version 2.20.

Earthquake locations for events occurring between 1932 to 1980:
Earthquake data recorded by the Southern California Seismic Network (SCSN, which is operated jointly by the Seismological Laboratory at Caltech and the U.S. Geological Survey, Pasadena, California), and catalogued by the Southern California Earthquake Center Data Center (SCEC-DC).

Earthquake locations for events occurring between 1981 to 1999:
Hauksson, E. (in press), Crustal structure and seismicity distribution adjacent to the Pacific and North America plate boundary in southern California: submitted to Journal of Geophysical Research.

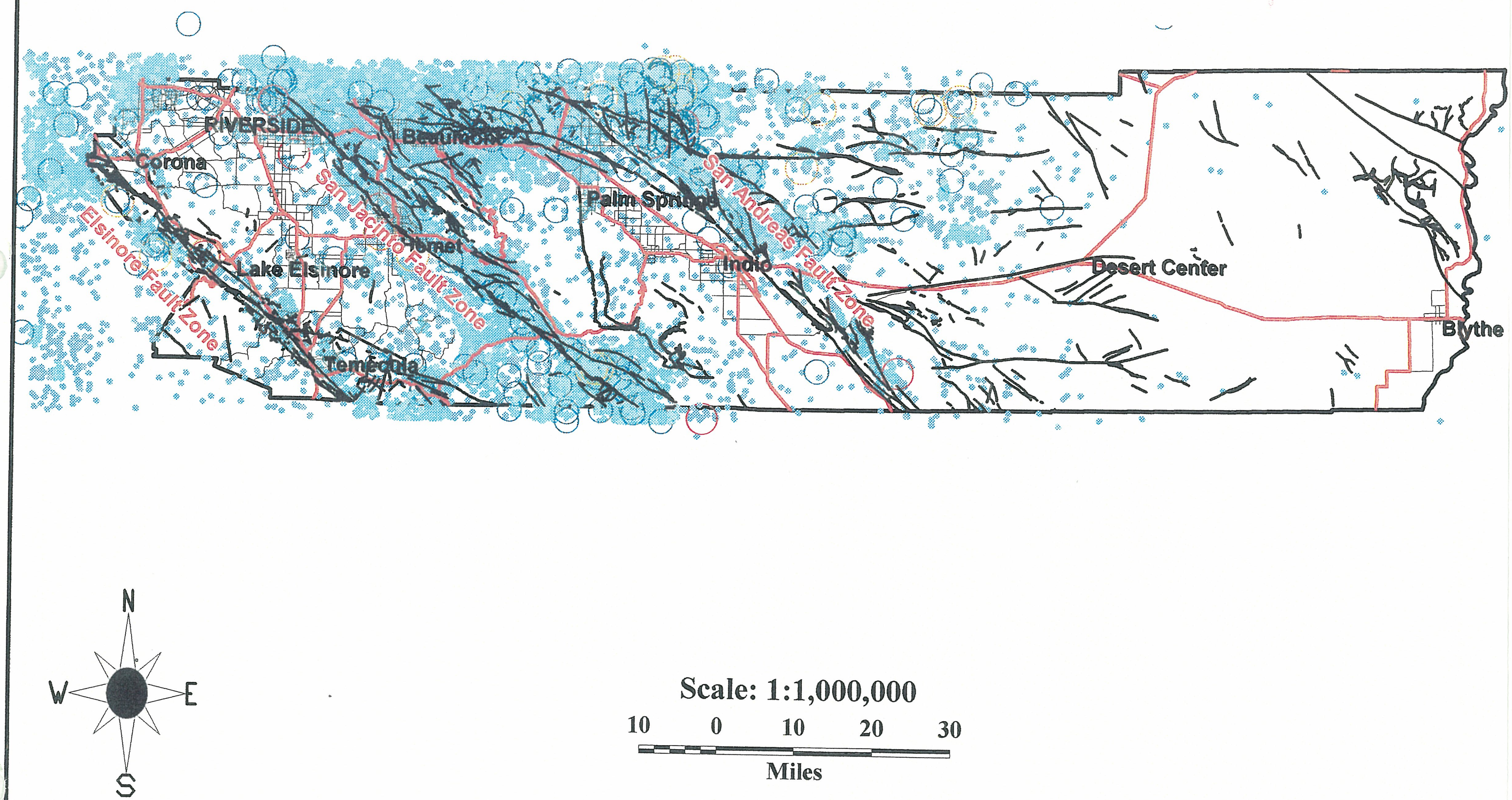


Figure 1-5: Seismicity of Riverside County (1890-1999)

(Summary of GIS Data, for additional detail see Plate 1-1 in-pocket)

Earth Consultants International

MAGNITUDE

- 6 to 7
- 5 to 6
- 4 to 5
- Less than 4

- Faults
- Highways
- Major Roads

1.4 Fault Rupture

Figure 1-6 and Plate 1-2 illustrate all fault traces mapped to date in Riverside County, regardless of geologic age. Not all of these traces are currently considered active based on guidelines of the Alquist-Priolo Earthquake Fault Zoning Act (Hart and Bryant, 1997). The State law classifies faults according to criteria detailed in 1.1.2. Additional fault information is provided in Appendix C.

Alquist-Priolo Earthquake Fault Zones (A-P Zones) have been designated by the California Division of Mines and Geology for the Elsinore, San Jacinto and San Andreas fault zones in Riverside County (Figure 1-7). In addition, the County of Riverside (1991) applied special studies zone criteria for the Agua Caliente fault zone between the Elsinore and San Jacinto faults in southern Riverside County (Figure 1-7). All of these faults have high rates of displacement (> 5 mm/yr, which is about the rate that fingernails grow) and thus are rapidly accumulating strain energy to be released in earthquakes. Inevitably, the A-P Zones will expand with time. As faults are studied, offshoot faults called splays are ongoingly discovered.

Within these A-P Zones and special studies zones, State and Riverside County law requires that proposed tracts of four or more dwelling units investigate the potential for and setback from ground rupture hazards. This is typically accomplished by excavation of a trench across the site, determining the location of faulting and establishing building setbacks. The exclusion of other types of buildings is arbitrary, and increases risk to the community. Given the high degree of earthquake hazard in Riverside County, special fault hazard studies should be completed for all proposed structures designed for human occupancy within the zones outlined on Figure 1-7 (and Plate 1-3, described in 1.4.2).

1.4.1 Geographic Information System Coverage of Faults

Detailed geographic information system coverage for faults (Plate 1-2) are provided as part of this study. These coverages, their resolution and data sources are described below:

Coverage Description: Faults in Riverside County
Coverage distribution file name: faults.e00
Coverage Area: Riverside County
Source: Earth Consultants International
Accuracy: 100 to 500 feet

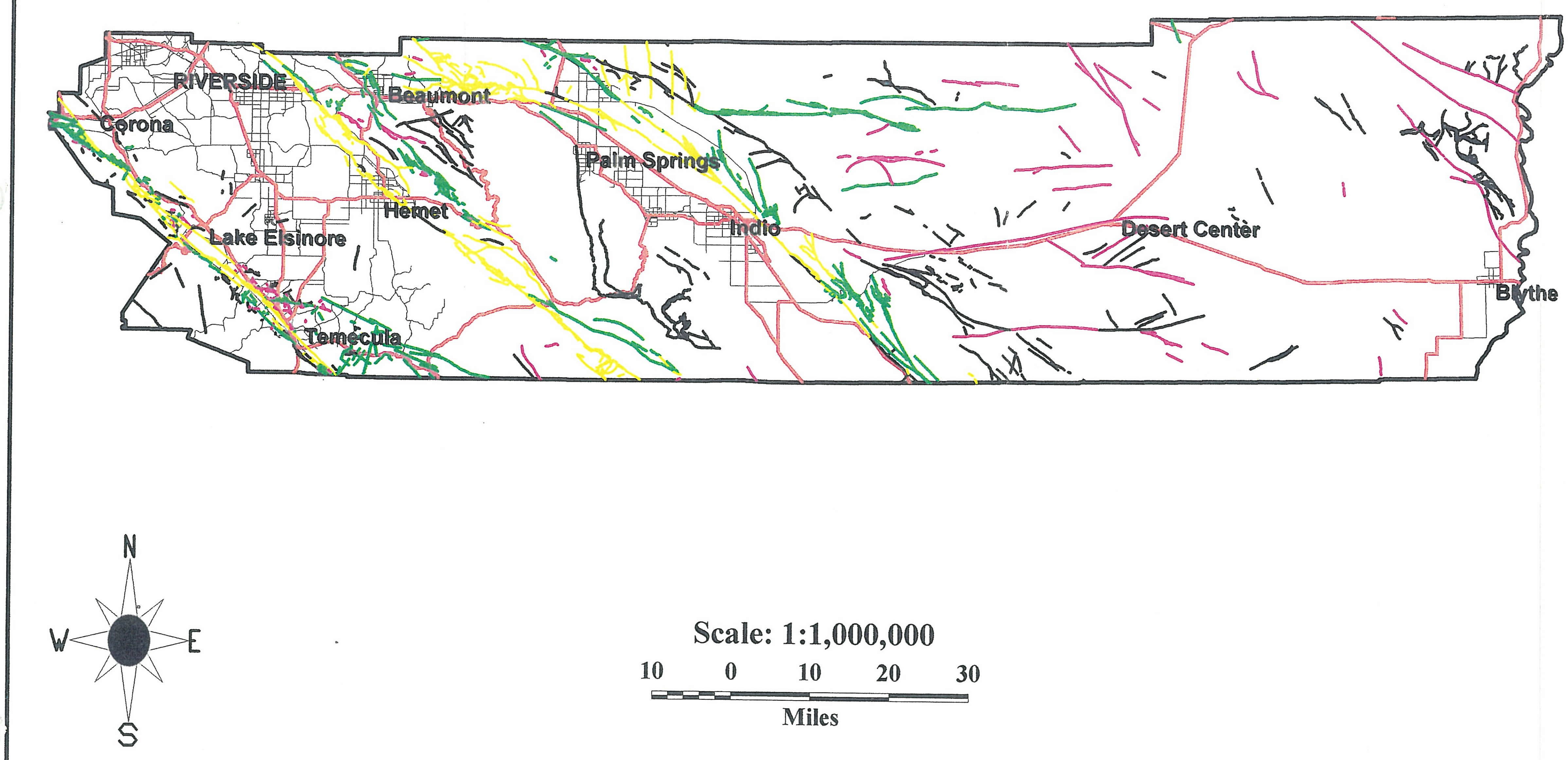
Figure 1-6:

Mapped Faulting

in

Riverside County

(Summary of GIS Data, for additional detail see Plate 1-2 in-pocket)



Earth Consultants International

Faults Activity

- Historic
- Historic (creep)
- Holocene
- Late Quaternary
- Quaternary
- Pre-Quaternary

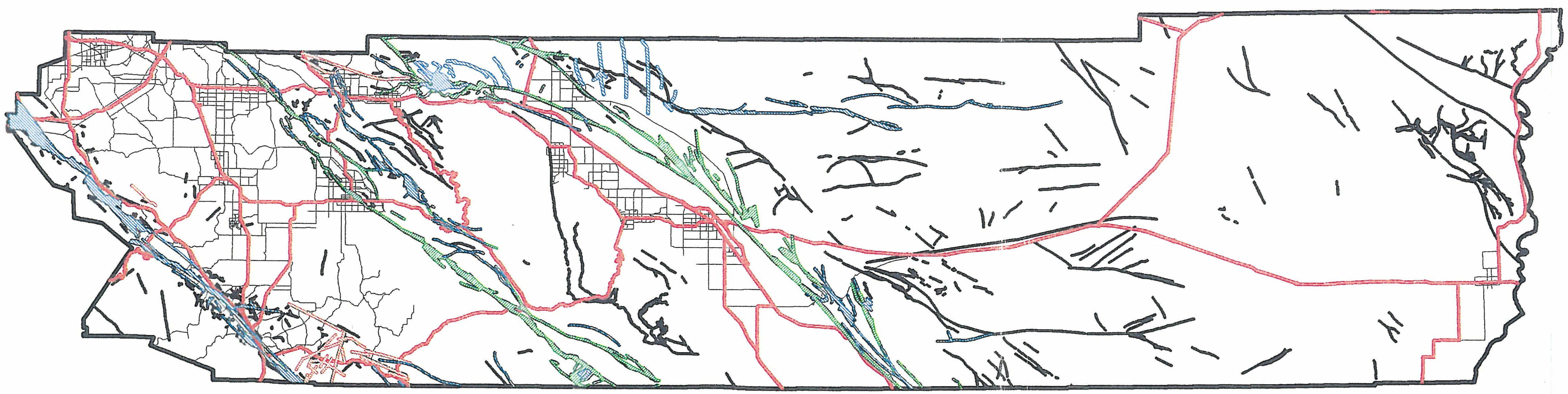
Major Roads

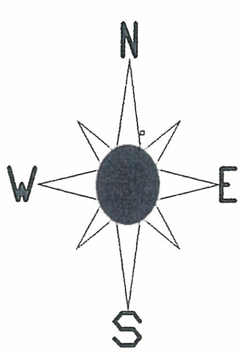
Highways

Figure 1-7:

Earthquake Fault Studies Zones in Riverside County

(Summary of GIS Data, for additional detail see Plate1-3 in-pocket)





Scale: 1:1,000,000

10 0 10 20 30

Miles

Earth Consultants International

Major Roads

Highways

Faults

Fault Zones

Alquist-Priolo Zone

Existing County Zone

Recommended Zone

More than 4,300 faults and fault segments are included in the GIS database. Data tables linked to the faults include the fault name, length, age and information on location (e.g. certain, concealed, queried, etc.). The faults shown on Plate 1-2 are typically accurate to within 100 to 500 feet; however, some faults are better constrained than others as a consequence of the geologic field relations (their visibility in the field), or the quality of the geologic maps from which the data were acquired. Most of the faults that are Holocene to Late Quaternary in age are accurate to within 100-300 feet because their locations were typically retrieved from detailed (small-scale) geologic maps. However, in regions where these faults are "concealed" by younger sediments, their locations become progressively less accurate.

Many of the Holocene to Late Quaternary age faults are shown to exist, even when buried under younger sediments, due to their potential to rupture through the sediments to the surface. The older, pre-Quaternary faults are typically not shown under young sediments, as they are not potentially active.

This coverage may not show all potentially active faults, either within the special studies zones (see Fault Zones, below) or outside their boundaries. The faults shown on the map were not field checked and the quality of available data is highly varied.

The source maps used for this coverage were 1974 State of California, Department of Conservation 7.5 minute quadrangle topographic maps. Other references for the fault locations compiled on Plate 1-2, can be found in Appendix D.

1.4.2 Geographic Information System Coverage of Fault Special Studies Zones

Detailed geographic information system coverage for fault special studies zones are provided as part of this study (Plate 1-3). These coverages, their resolution and data sources are described below:

Coverage Description: Fault Special Studies Zones in Riverside County
Coverage distribution file names: apzones.e00; apzonept.e00; apcounty.e00; ap-eci.e00
Coverage Area: Riverside County
Source: Earth Consultants International
Accuracy: 1:24,000.

The source maps digitized for this coverage were 1974, 1980, 1988, 1993 and 1995 Official Earthquake Fault Zone, State of California, Department of Conservation 7.5 minute quadrangle topographic maps (Table 1-4 and Figure 1-8).

Table 1-4:
Alquist-Priolo Earthquake Fault Zone Maps Available for Riverside County

Map Name	Date	Map Name	Date	Map Name	Date
Alberhill	1980	Joshua Tree South	1993	SE Idyllwild	1974
Beaumont	1995	Lake Mathews	1980	SE Morongo Valley	1974
Bucksnort Mtn	1974	Lakeview	1988	SE San Gorgonio Mtn	1974
Cabazon	1995	Mecca	1974	Seven Palms Valley	1980
Cathedral City	1974	Mortmar	1974	Sunnymead	1974
Clark Lake NE	1974	Murrieta	1990	SW Idyllwild	1974
Collins Valley	1974	Myoma	1974	SW Lost Horse	1974
Corona South	1980	NE Hemet	1974	SW Morongo Valley	1974
Desert Hot Springs	1980	NE Thousand Palms	1974	SW Palm Desert	1974
Durmid	1974	NW Idyllwild	1974	SW San Gorgonio Mtn	1974
El Casco	1995	Orocopia	1974	Temecula	1990
Elsinore	1980	Pechanga	1990	Thermal Canyon	1974
Frink NW	1988	Redlands	1977	Whitewater	1995
Hemet	1980	Salton	1974	Wildomar	1980
Indio	1974	San Jacinto	1980	Yucca Valley South	1993

LEGEND

Index of available official California Division of Mines and Geology Earthquake Fault Zone Maps, showing year of issue (R=revised), and approximate location of fault zone.

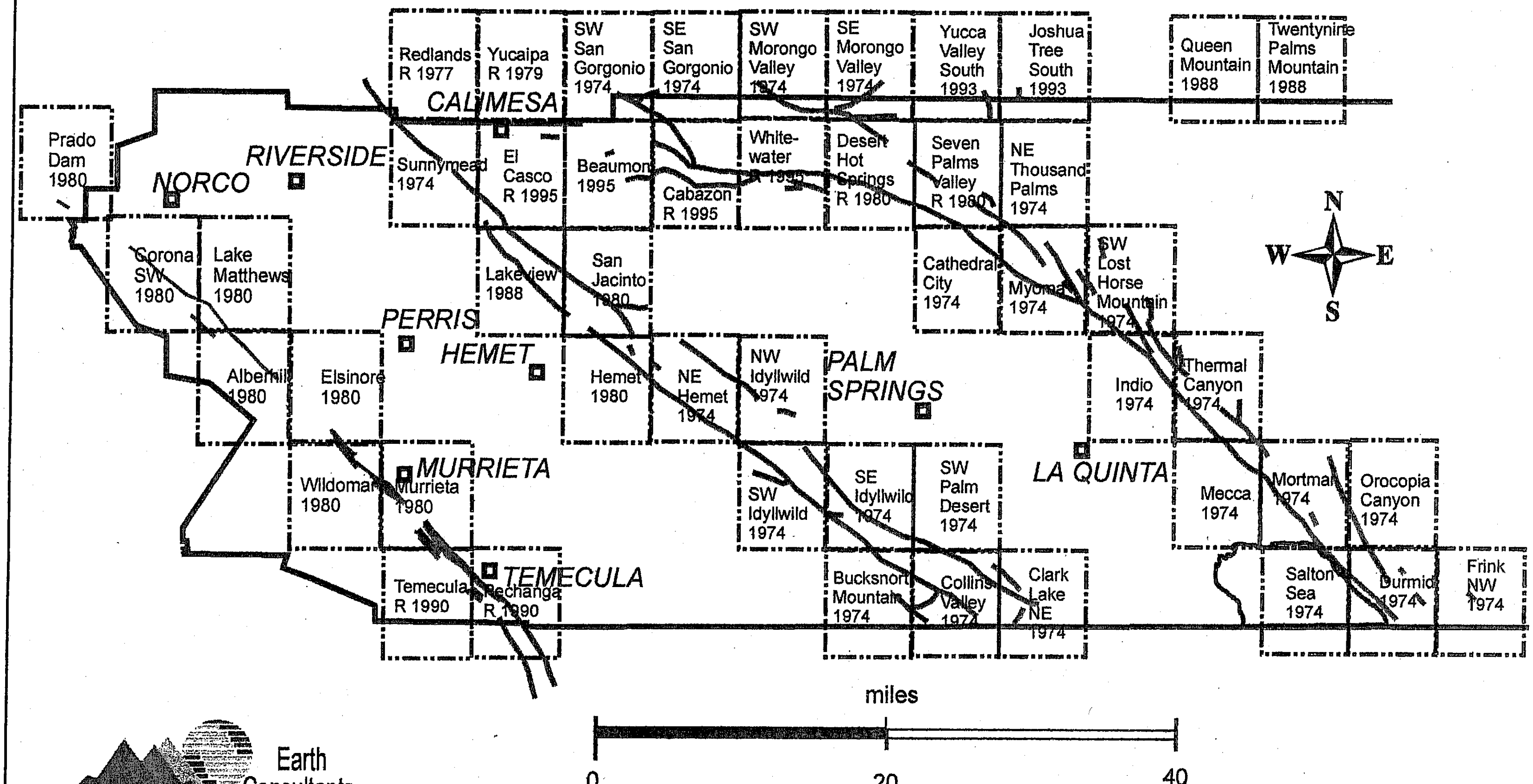


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Figure 1-8: Index of Official Earthquake Fault Zone Maps for Riverside County

1.5 Expected Earthquake Analyses

To increase the earthquake resistance of structures, institutions and communities, it is often useful to study the effects of a particular earthquake (a deterministic or design earthquake scenario). 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 takes into account the recurrence rates of likely, damaging earthquakes on each fault in the area, as well as the potential ground motion that may result from each of these earthquakes. As is true for most earthquake-prone regions, many potential earthquake sources pose a threat to the County of Riverside. Which earthquake to consider depends on the application of the analysis.

1.5.1 Design Earthquakes

A ***maximum probable earthquake*** (MPE) is the largest earthquake a fault is predicted capable of generating within a specified time period of concern, say 30 or 100 years. Maximum probable earthquakes are most likely to occur within the time span of most development, and therefore, are commonly used in assessing seismic risk. Nevertheless, the ***maximum credible earthquake*** (MCE), i.e. the largest earthquake a fault is believed capable of generating, is considered in a number of planning and engineering decisions. For example, MCEs are used in the design of critical facilities like dams, fire stations, and emergency operation centers. They are also used in urban and emergency planning to identify and mitigate the risk of worst-case scenarios.

For design purposes, a worst case scenario earthquake (the MCE) for Riverside County is a magnitude 7.9 based on the rupture of the entire southern segment of the San Andreas fault from Cajon Pass to the Salton Sea. While other scenarios will expose portions of the County to intense ground shaking locally that is locally as severe as the MCE, the MCE exposes most of the County to very high intensity ground shaking.

Below are estimate of several key ground shaking parameters near the fault rupture zone for the MCE, expressed as a percentage of gravity. Peak ground acceleration, the maximum acceleration achieved at a site, often turns out to be the earthquake effect that causes most damage to buildings. The periods, 0.3 seconds and 1.0 second represent lengths of seismic waves that commonly damage structures. All of these values are well above the threshold for heavy damage (see Table 1-1).

Table 1-5: Probable Earthquake Scenarios for Riverside County

Event		Maximum Magnitude (Mw)	Chance of Occurring in 30 Years	Comments
Fault	**Segment**			
San Andreas	San Bernardino	7.3	28%	Very high intensity ground shaking throughout the San Bernardino Valley, including north central Riverside County.
San Andreas	Coachella	7.1	22%	Very high intensity ground shaking throughout the Coachella Valley, impacting desert resort communities and agriculture.
San Jacinto	San Jacinto Valley	6.9	43%	Highest probability of occurrence of any southern California fault. Brought closer to failure as a result of stress field changes caused by the 1992 Landers earthquake.
San Jacinto	Anza Segment	7.2	17%	This event would be very destructive within the communities of Hemet and San Jacinto.
Elsinore	Temecula Segment	6.8	16%	Has not produced any significant earthquakes in historic time.
Elsinore	Glen Ivy Segment	6.8	16%	Would be very destructive in the communities of Lake Elsinore, Murrieta, and Temecula.
Whittier	Whittier	6.8	5%	Has not broken in over 1600 years (WGCEP, 1995). Would cause significant landsliding and lifeline damage in the Chino Hills - Corona area.

These design parameters for the MCE are utilized in the loss estimation presented in Section 1.8 of this report. With horizontal ground displacements as great as twenty-five feet along the fault and intense ground shaking that could last more than 60 seconds, damage and losses in the County as a result of the MCE or other major San Andreas fault earthquake would be extensive.

Additionally, the County of Riverside must consider events on several faults. Earthquakes that are likely to occur during the design life of most buildings could be generated by segments of the Elsinore, San Jacinto or San Andreas faults. These have been evaluated by the Working Group on California Earthquake Probabilities (1995) and illustrated in Figure 1-3. Based on this segmentation, there are seven probable earthquakes that threaten Riverside County, as shown in Table 1-5. The event with the greatest probability of occurrence in 30 years (43%)

is a M_w 6.9 rupture of the San Jacinto Valley segment of the San Jacinto fault. The San Jacinto event is considered the Maximum Probable Earthquake (MPE) for Riverside County.

Section 1.8 of this report provides loss estimates for eight specific (scenario) earthquakes and provides additional detail on the MCE and MPE based on these ground shaking parameters. These events will cause damage to vulnerable structures, such as potentially hazardous buildings, and may result in localized ground failures in the County. Fortunately, thanks to the County's mostly modern building stock, life-safety is threatened to a much lesser degree than it would be with older buildings. However, estimated economic losses are substantial (see 1.8).

1.5.2 Probabilistic Earthquake Hazard Assessment.

This type of hazard assessment is utilized by the U.S. Geological Survey in producing national seismic hazard maps that are modified and adopted into the Uniform Building Code (UBC). The most recent mapping produced for the 1997 UBC includes data from the California Division of Mines and Geology (DMG, 1996). Development of these maps requires three steps: 1) delineating earthquake sources; 2) defining the potential distribution of seismicity for each of these sources; and 3) calculating the potential ground motions from attenuation relations for all the model earthquakes. Attenuation relations estimate the amount that shaking will be modified (amplified or reduced) as waves travel from the fault plane to a locale.

USGS and DMG scientists in the National Seismic Hazard Mapping Program have produced maps indicating the probabilistic ground shaking parameters for the County of Riverside (Figure 1-9). Table 1-6 has been prepared to list the probabilistic ground shaking, in terms of peak horizontal ground acceleration on bedrock, associated with twenty-four of the County's incorporated cities. This table indicates that, with the exception of Blythe, the cities are exposed to very high and extremely high values that for the most part exceed 50% of the force of gravity with a 10% chance of occurring in 50 years. In addition, the communities along the San Jacinto fault (Moreno Valley, San Jacinto and Hemet) have a greater risk of ground shaking than those along the San Andreas. This is a result of the higher probability of a future San Jacinto earthquakes versus San Andreas earthquakes.

Values of peak horizontal ground acceleration at bedrock and are expressed as a percent of the force of gravity. Generally, values greater than 25-30% of gravity are capable of substantial damage to structures (see Table 1-1). Liquefaction and landslides can occur at 10% of gravity. When values exceed 100% of gravity, the force of gravity is exceeded and objects become airborne.

These probabilistic ground motion values for the County of Riverside are among the highest in southern California and are the result of the County's proximity to major fault systems with high earthquake recurrence rates.

The careful reader will have observed that the predicted ground accelerations in Table 1-2 are lower than those values in Table 1-6. In part, near-fault ground motions may be underestimated by the methods of Table 1-2. Additionally, the difference exists because Table 1-2's values are based on deterministic analyses. Because Riverside County is close to so many active faults, the probabilistic assessment of risk is higher than that for any individual fault.

Legend

General Ground Shaking Risk

- LOW = <10% g
- MODERATE = 10-20% g
- HIGH = 20-30% g
- VERY HIGH = 30-40% g
- EXT. HIGH = >40% g

Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

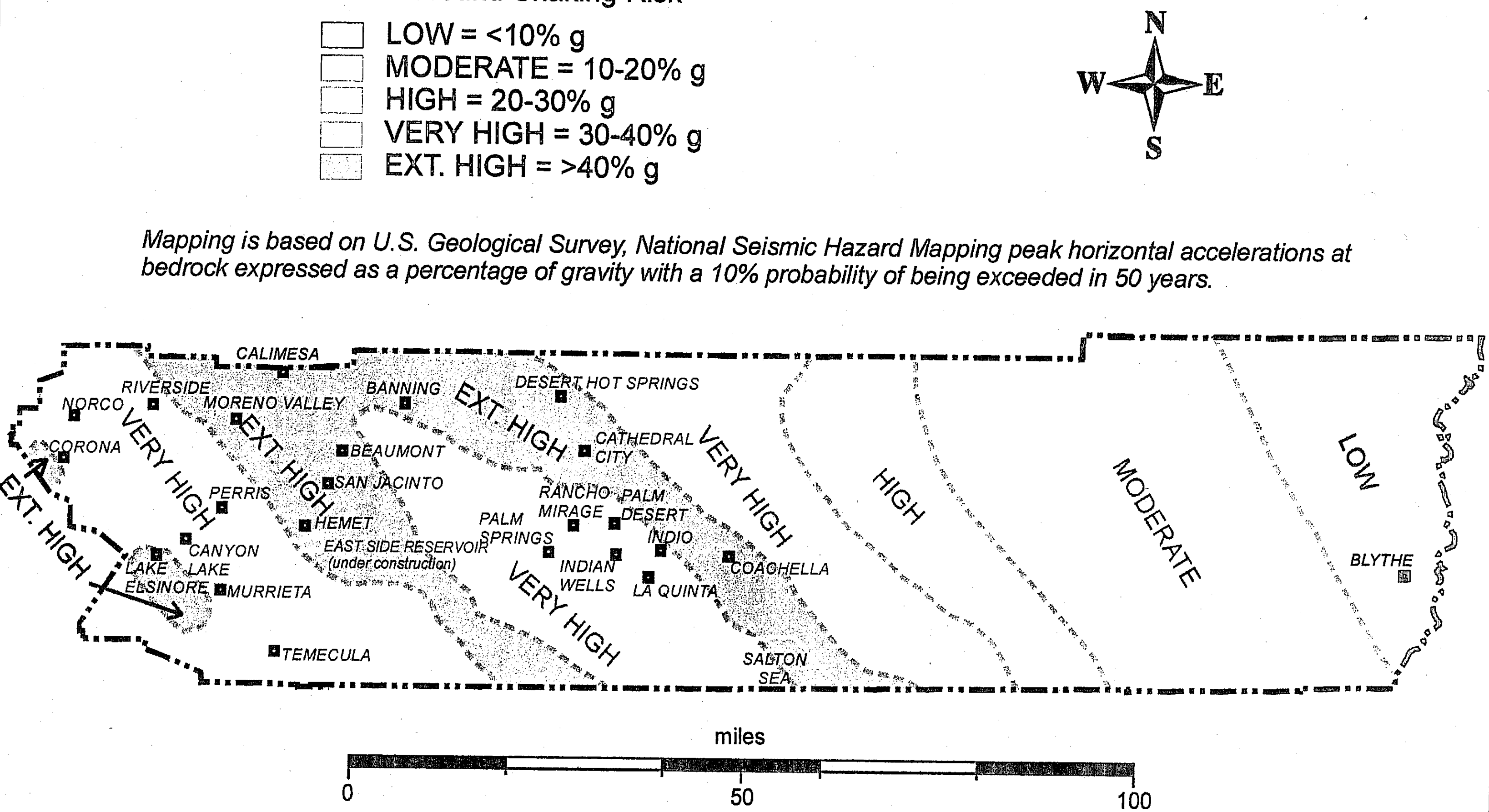

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Figure 1-9: Probabilistic Acceleration Contour Mapping for Riverside County

Table 1-6: Probabilistic Earthquake Accelerations for Riverside County

CITY	10% PE* in 50 yr	5% PE in 50 yr	2% PE in 50 yr
Moreno Valley	84.40	101.52	123.07
San Jacinto	82.30	99.44	120.14
Hemet	80.20	97.31	119.11
Desert Hot Springs	75.14	96.57	118.77
Beaumont	66.01	76.64	98.91
Calimesa	66.01	76.64	98.91
Coachella	61.90	78.13	103.10
Indio	61.90	78.13	103.10
Lake Elsinore	59.11	77.14	102.07
Corona	56.06	74.42	99.79
Murrieta	56.06	74.42	99.79
Temecula	56.06	74.42	99.79
Norco	56.06	74.42	99.79
Banning	55.86	69.91	79.83
Rancho Mirage	54.73	70.98	90.79
Perris	54.73	70.98	90.79
Canyon Lake	54.73	70.98	90.79
Riverside	53.64	65.41	76.20
La Quinta	48.45	61.17	76.00
Indian Wells	48.45	61.17	76.00
Palm Desert	48.45	61.17	76.00
Palm Springs	48.16	57.22	73.47
Cathedral City	48.16	57.22	73.47
Blythe	9.51	11.77	15.31

PE is probability of exceedence, e.g., the given value has a 10% chance of being exceeded in 50 years. Values are peak horizontal ground acceleration on bedrock and are expressed as a percent of the force of gravity.

1.5.3 Foreshocks on Strike-Slip Faults

A ***foreshock*** is an earthquake that is smaller than a mainshock, precedes it, and is causally related to it. Foreshocks are quite common. For California, Jones (1984) has determined that half of the magnitude 5.0 and greater, strike-slip earthquakes are preceded by immediate foreshocks (earthquakes within 72 hours and 10 kilometers of their mainshock). Almost all foreshocks occur less than 72 hours before the mainshock. If and when it becomes possible to distinguish foreshocks from background seismicity, foreshocks will become an effective short-term prediction tool. So far, scientists can only recognize foreshocks in hindsight, *after* the mainshock has occurred. Yet the existence of foreshocks can still help prepare for destructive earthquakes on the San Andreas fault.

In 1991, a Working Group, chaired by Jones and Sieh, made the following observations from Agnew and Jones (1991) and Jones (1984, 1985):

- When an earthquake occurs, it is either a foreshock or a "background" event.
- Since it is possible that the earthquake may be a foreshock, it increases the probability that a larger earthquake will occur within 72 hours and 10 km.
- How much the probability increases will depend on how anomalous it is, that is, on the background seismicity patterns in the vicinity.
- Smaller earthquakes are more common than larger earthquakes. A magnitude 1.0 earthquake anywhere along the San Andreas fault will only marginally increase the chance of a larger earthquake occurring within 72 hours.
- On the other hand, if a magnitude 5.0 earthquake occurs within 10 km of the San Andreas fault, the probability of a major (magnitude at least 7.5) earthquake within 72 hours increases significantly.
    - Around San Bernardino, where there is a fairly high level of background seismicity near the San Andreas fault, the occurrence of a magnitude 5.0 raises the short-term probability of a larger event by 1-5%.
    - Around Mecca Hills, northeast of the Salton Sea, there is very little background seismicity. A magnitude 5 is quite anomalous, and raises the short-term probability at least 25%.

Table 1-7 shows the Working Group calculations of the threshold magnitude required to raise the short-term probability by different specific amounts for different portions of the San Andreas fault. The areas are distinguished by their varying levels of background seismicity.

Table 1-7: Magnitude of possible foreshock required to reach a specified probability level for four microseismic regions of the southern San Andreas fault (Working Group, 1991).

Level Probability of M_w 7.5 in 72 hr	B 5-25%	C 1-5%	D 0.1-1%
San Bernardino	5.8	5.0	3.9
San Gorgonio	6.1	5.3	4.2
Palm Springs	5.2	4.5	3.4
Mecca Hills	4.9	4.2	3.1

From these observations and calculations, the Working Group developed a short-term hazard notification system for the southern San Andreas fault (Table 1-8). The system designated when U.S. Geological Survey scientists would notify their supervisors and emergency response personnel, regarding increased short-term probabilities along the southern San Andreas. Note that there is no "A level" alert, because the Working Group felt that there was not yet a "meaningful way to estimate short-term probability above 25%".

Table 1-8: Alert levels and response for anomalous earthquake activity along the southern San Andreas fault (from Working Group, 1991).

Level	Probability of M_w> 7.5 earthquake in next 72 hours	Expected time between occurrences of alerts at this level	USGS action
D	0.1% to 1%	6 months	Notify scientists involved in data collection and OES Ontario office
C	1% to 5%	5 years	As for Level D; also notify Comm. Officer, OES Sacramento, and USGS Menlo Park chief.
B	5% to 25%	28 years	As for Levels C and D, and also notify USGS Director, and CDMG State Geologist; start intensive monitoring

OES is Office of Emergency Services; CDMG is California Division of Mines and Geology

This system could be adapted by the County of Riverside to respond to short-term increases in hazard from the San Andreas fault. For example, at level D, emergency response equipment might be moved out of any collapsible structures, and some gas lines could be put on automatic cut-off. At level B, all non-essential leave for key personnel could be postponed.

Certainly, thoughtfulness and care must be exercised to construct a system that will enhance public safety without promoting rumors or fear. Also, the system must not be a substitute for long-term mitigation efforts. Such potential difficulties do not reduce the usefulness of short-term, pre-event response plans.

Over time, new data and additional research should allow similar systems to be developed for other major southern California faults.

1.5.4 Uses and Limitations of Seismic Hazard Mapping

The Seismic Hazard Maps developed for this study do not show areas that automatically should be excluded from development. Instead, they show areas where the potential for damage from the mapped hazard is great. Thus it is prudent to conduct geologic investigations to identify and mitigate the hazard prior to development. It is less costly to incorporate hazard mitigation into a structure before it is built than to later try to add mitigating features.

One-plan-fits-all design of mitigation features is not feasible. The hazards present at each site and the multiplicity of structural configurations makes it impossible to predict how much mitigation will cost without scrutiny of the individual site. In some areas, it may be possible to adequately mitigate liquefaction hazard by strengthening the foundation to withstand displacements of 1½ feet, typically costing only $3,000-4,000. Expert engineers indicate that in many locations this simple measure could reduce the payout for repair of liquefaction damage from an average of $65,000 to $70,000 to about $10,000 to $15,000. Insurance industry representatives indicate that such potential savings could be passed on to consumers in the form of lower earthquake insurance premiums. In other cases, however, the cost of mitigation is likely to be much greater. For example, expensive sites include those likely to experience more that 1 foot of liquefaction-caused displacement or with significant landslide hazard.

In the past, land-use planners have often assumed that lower density developments were appropriate where geologic hazards are present. However, planners may find that the high cost of mitigating liquefaction hazards along streams, bays, canals, and coastal zones requires a higher density of development to be economically feasible.

Due to the complex nature of earthquake occurrence, damage and mitigation, there will always be uncertainties associated with seismic hazard mapping. It must be remembered that:

- Seismic Hazard Zone Maps may not show all areas that have the potential for liquefaction, landsliding, strong ground shaking or other earthquake and geologic hazards.
- A single earthquake capable of causing liquefaction or triggering landslide failures will not uniformly affect the entire area zoned.
- The identification and location of liquefaction and earthquake-induced landslide hazard areas are based on available data, of variable quality. The information depicted on the maps has been drawn as accurately as possible at 1:24,000-scale.
- Information on the Seismic Hazard Zone Maps is not sufficient to serve as a substitute for the geologic and geotechnical site investigations required under the Seismic Hazard Mapping Act or the Alquist-Priolo Earthquake Fault Zoning Act.

1.6 Secondary Earthquake Hazards

Secondary earthquake hazards are those separate from, but induced by, the primary effects of strong ground shaking and fault rupture. Secondary geologic hazards include ground and slope failures and seiches, discussed below. (More broadly, secondary hazards also include non-geologic effects such as fires and toxic chemical spills).

1.6.1 Liquefaction

Liquefaction is a process by which water-saturated materials (including soil, sediment, and certain types of volcanic deposits) lose strength and may fail during strong ground shaking. Liquefaction is defined as "the transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore-water pressure" (Youd, 1973). Liquefaction occurs worldwide, commonly during moderate to great earthquakes. In California, liquefaction-related ground failures occurred in 1857 (Fort Tejon earthquake), 1906 (San Francisco earthquake), 1933 (Long Beach earthquake), 1971 (San Fernando earthquake), 1973 (Point Mugu earthquake), 1979 and 1981 (Imperial Valley earthquakes), 1989 (Loma Prieta earthquake), and 1994 (Northridge earthquake), and others. Four kinds of ground failure commonly result from liquefaction: lateral spread, flow failure, ground oscillation, and loss of bearing strength.

Lateral Spread: Lateral displacement of surficial blocks of sediment as the result of liquefaction in a subsurface layer is called a lateral spread. Once liquefaction transforms the subsurface layer into a fluidized mass, gravity plus inertial forces caused by the earthquake may move the mass downslope towards a cut slope or free face (such as a river channel or a canal). Lateral spreads most commonly occur on gentle slopes that range between 0.3° and 3°, and commonly displace the surface by several meters to tens of meters. Such movement typically damages pipelines, utilities, bridges, and other structures having shallow foundations. During the 1906 San Francisco earthquake, lateral spreads causing displacement of only a few feet damaged every major pipeline. Thus, liquefaction compromised the ability to fight fires - and fires caused about 85 percent of the damage to San Francisco.

Flow Failure: The most catastrophic mode of ground failure caused by liquefaction, flow failure usually occurs on slopes greater than 3°. The flows are principally liquefied soil or blocks of intact material riding on a liquefied subsurface zone. Displacements are commonly tens of meters, but in favorable circumstances, material gets displaced for tens of miles, at velocities of tens of miles per hour. The extensive damage to Seward and Valdez, Alaska, during the 1964 Great Alaskan earthquake was caused by submarine flow failures.

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 (upward flowing sediment). These can potentially damage structures and underground utilities.

Loss of Bearing Strength: When a soil loses strength and 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°.

Research into liquefaction in past earthquakes has linked liquefaction to certain hydrologic and geologic settings. Water-saturated, cohesionless, granular materials at depths of less than 50 feet are prone to liquefaction. To identify an area having significant potential for liquefaction, a liquefaction susceptibility map and a liquefaction opportunity map must be developed. The former depicts areas where the geology and hydrology are favorable for liquefaction. The latter summarizes information about the potential for strong earthquake shaking. When considered together, the two maps determine the liquefaction potential- the relative likelihood that an earthquake will cause liquefaction in an area.

1.6.2 Guidelines for Delineating Liquefaction Hazard Zones

In 1997 and 1998, the California Division of Mines and Geology (1997 and 1998) developed guidelines for delineating, evaluating, and mitigating seismic hazards in California. In 1999, a Southern California Earthquake Center sponsored group published "Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigating Liquefaction in California". The SCEC (1999) publication was a result of requests from city and county Building Officials for assistance in the development of procedures to implement the Seismic Hazards Mapping Act (see Section 1.1.3) for projects requiring their review. The guidelines in assessing liquefaction potential for this study are based on DMG (1997 and 1998), as well as SCEC (1999), and are summarized below:

Liquefaction Mapping Criteria: Liquefaction Hazard Zones are areas meeting one or more of the following criteria:

- Areas known to have experienced liquefaction during historic earthquakes. Field studies following past earthquakes indicate liquefaction tends to recur at many sites during successive earthquakes (Youd, 1984). There are many published accounts of liquefaction occurrences. Areas so delineated should be included in the Liquefaction Hazard Zones.

- All areas of uncompacted fills containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated. In some areas there has been a practice of creating useable land by dumping artificial fill on tidal flats or in large deep ravines. Standard geologic criteria are of little use in characterizing soils within these fills which are less homogeneous than natural deposits. For example, there is no reason to assume lateral stratification in these fills and the validity of extrapolating subsurface data is questionable. Evidence for filling can be found by examining maps showing old shorelines, by comparing old and modern topographic maps, by studying logs of boreholes, and by obtaining reports or original plans of specific projects involving reclaimed land.

- Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable. The vast majority of liquefaction hazard areas are underlain by recently deposited sand and/or silty sand. These deposits are not randomly distributed, but occur within a narrow range of sedimentary and hydrologic environments.

Geologic criteria for assessing these environments are commonly used to define bounds of susceptibility zones derived from other criteria, such as geotechnical analysis (Youd, 1991). Groundwater data should be compiled from well logs and geotechnical borings. Analysis of aerial photographs of various vintages may reveal zones of flooding, sediment accumulation, or evidence of historic liquefaction. Quaternary geology should be mapped and age estimates assigned based on ages reported in the literature, stratigraphic relationships and soil profile descriptions. In many areas of Holocene and Pleistocene deposition, geotechnical and hydrologic data are compiled. Geotechnical investigation reports with Standard Penetration Test (SPT) and/or Cone Penetration Test (CPT) and grain size distribution data can be used for liquefaction resistance evaluations.

For sand and silty sand, there are currently two reliable, in-situ (in place) approaches for quantitative evaluation of the soil's resistance to cyclic pore pressure generation and/or liquefaction. These are: (1) correlations and analyses based on in-situ Standard Penetration Test (SPT) (ASTM D1586) (ASTM, 1990) data, and (2) correlations and analyses based on in-situ Cone Penetration Test (CPT) (ASTM D3441) (ASTM, 1990) data.

Seed and others (1971, 1983, 1985), provide guidelines for performing "standardized" SPT, and also provide correlations for conversion of penetration resistance obtained using most of the common alternate combinations of equipment and procedures in order to develop equivalent "standardized" penetration resistance-- (N1)60. This "standardized" penetration resistance can then be used as a basis for evaluation of liquefaction resistance.

Cone penetration test (CPT) tip resistance (qc) may also be used as a basis for evaluation of liquefaction resistance, either by direct empirical comparison between qc-values to "equivalent" SPT resistance or by use of correlations between (N1)60 data and case histories of seismic performance (Robertson, et al., 1985; Seed and De Alba, 1986).

Some gravelly soils are also potentially vulnerable to liquefaction. The best available technique for quantitative evaluation of the liquefaction resistance of this type of deposit involves correlation and analysis based on in-situ penetration resistance measured using the very large scale Becker Hammer system (Harder, 1988).

The correlations of Seed et al. (1985), and the (N1)60 data can be used to assess liquefaction susceptibility. Since geotechnical analyses are usually made using limited available data, the susceptibility zones should be delineated by use of geologic criteria. Geologic cross sections, tied to boreholes and/or trenches, should be constructed for correlation purposes. The units characterized by geotechnical analyses are correlated with surface and subsurface units and extrapolated for the mapping project.

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes with LQ-Zones (potential liquefaction zones defined by the State Geologist under the Seismic Hazards Mapping Act that require site-specific geotechnical investigation for liquefaction hazards) will be that level defined by M_w 7.5-weighted peak ground acceleration (PGA) for UBC SD (stiff soil) soil conditions with a 10% probability of exceedance over a 50-year period.

Liquefaction mapping criteria in areas where geotechnical data are insufficient: In areas of limited or no geotechnical data, susceptibility zones are identified by geologic criteria as follows:

- Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

- Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

- Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Based on probabilistic mapping described earlier, only the easternmost portion of the County (Blythe region) has acceleration values below the criteria thresholds (Table 1-6).

Application of these criteria allows compilation of hazard maps that are useful for preliminary evaluations, general land-use planning and delineation of special studies zones where site-specific studies may be required before major development is approved (Youd, 1991). In developing a liquefaction hazard map for Riverside County, the Quaternary geology is taken from existing maps (Geologic Map for Riverside County, California), and described in detail within Chapter 2-Geologic Hazards of this Technical Background Report. Hydrologic data are compiled (Ground Water Contour Map for Riverside County, California; Plate 1-4), as described below.

1.6.2.1 Geographic Information System Coverage of Shallow Ground Water for Riverside County (Plate 1-4)

Coverage Description: Depth to Groundwater in Riverside County
Coverage distribution file name: gwcntrs.e00; gwwells.e00
Coverage Area: Riverside County
Source: Earth Consultants International
Accuracy: Only areas where groundwater exists within the upper 200 feet were mapped.

Groundwater was mapped using data from the Regional Water Quality board, Santa Ana Watershed Project Authority (SAWPA), and U.S. Geological Survey reports on groundwater within Riverside County. The groundwater is reported as the highest recorded elevation. Groundwater is only mapped in areas where sufficient data were available. There may be areas of perched water that have not been mapped throughout the county. Contours were created based on data collected from the various water districts through Santa Ana Watershed Project Authority. Reports located at the Regional Water Quality board were used to augment the data collected from the various water districts. All data were analyzed for highest historical recorded elevation. These data should be considered for regional analysis only.

The Western Municipal Water District (Mains, Steven E., *personal communication*, 1999) provided groundwater data from 56 agencies for over 2,300 wells. These data contain water levels from monitoring wells at selected service stations within Riverside and San Bernardino counties. The data include abandoned or destroyed wells. Many measuring point elevations are estimated from topographic maps and may be 5 to 10 feet in error. Also many agencies supply data using air lines that may have an accuracy of " several feet. Data were also obtained from the California Regional Water Quality Control Board, Santa Ana Region; Leaking Underground Storage Tank Information System (LUSTIS).

1.6.3 Liquefaction Hazard Zones in Riverside County

Based on the criteria described above and illustrated on the flow chart presented in Figure 1-10, a detailed Liquefaction Susceptibility Map for Riverside County was produced at a 1:250,000 scale (Plate 1-5). These data are summarized on the Generalized Liquefaction Susceptibility Map (Figure 1-11). Figure 1-11 includes the liquefaction potential zones described in Table 1-9.

Riverside County development policies should be implemented based on this liquefaction potential mapping (Table 1-9). Site-specific geotechnical liquefaction hazard investigations should be required for proposed construction projects in zones of moderate, high and very high liquefaction potential. The policy for construction projects involving critical facilities should extend to include all liquefaction ranks from "very low" to "very high". Based on relatively low potential for ground shaking, the region near Blythe (< 0.1 g, 10% probability of exceedance in 50 years) should be excluded from policies requiring hazard investigations for general construction projects. However, projects involving critical facilities should address liquefaction hazards if they are proposed within a potential liquefaction zone.

Table 1-9 SUPERCEDED APRIL 2004.

General Liquefaction Potential Zones for Riverside County

Rank	Ground Water Depth#	General+ Sediment Type	Recommended Policies*	
			General Construction	Critical Facilities
High	< 30 feet	very susceptible	study required	study required
Moderate	< 30 feet	susceptible	study required	study required
	30-50 feet	very susceptible	study required	study required
Low	> 30 feet	susceptible	none	study required
Very Low	30-50 feet	susceptible	none	study required
	50-100	very susceptible	none	study required
Extremely Low	50-100 feet	susceptible	none	study required
None	> 100 feet	susceptible	none	none
	no data	bedrock	none	none

*: Ground shaking potential in easternmost Riverside County is considered below the threshold for liquefaction, and site-specific investigations should not be required for general construction projects
#: Ground water depth is based on the historic high measurement
+: Very susceptible sediment type includes generally granular Holocene sediments; susceptible includes generally granular Pleistocene sediments.

	Very High	High		Moderate				Low			Very Low	
Depth to Groundwater	0-30'	0-30'	30-50'	0-30'	30-50'	50-100'	>100' or No data	30-50'	50-100'	>100' or No data	50-100'	>100' or No data
Holocene Sediments	Fine-grained Unconsolidated	Coarse-grained	Fine-grained		Coarse-grained	Fine-grained			Coarse-grained			
Pleistocene Sediments		Fine-grained		Coarse-grained	Fine-grained			Coarse-grained	Fine-grained		Coarse-grained	

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Liquefaction Hazard Rating Criteria

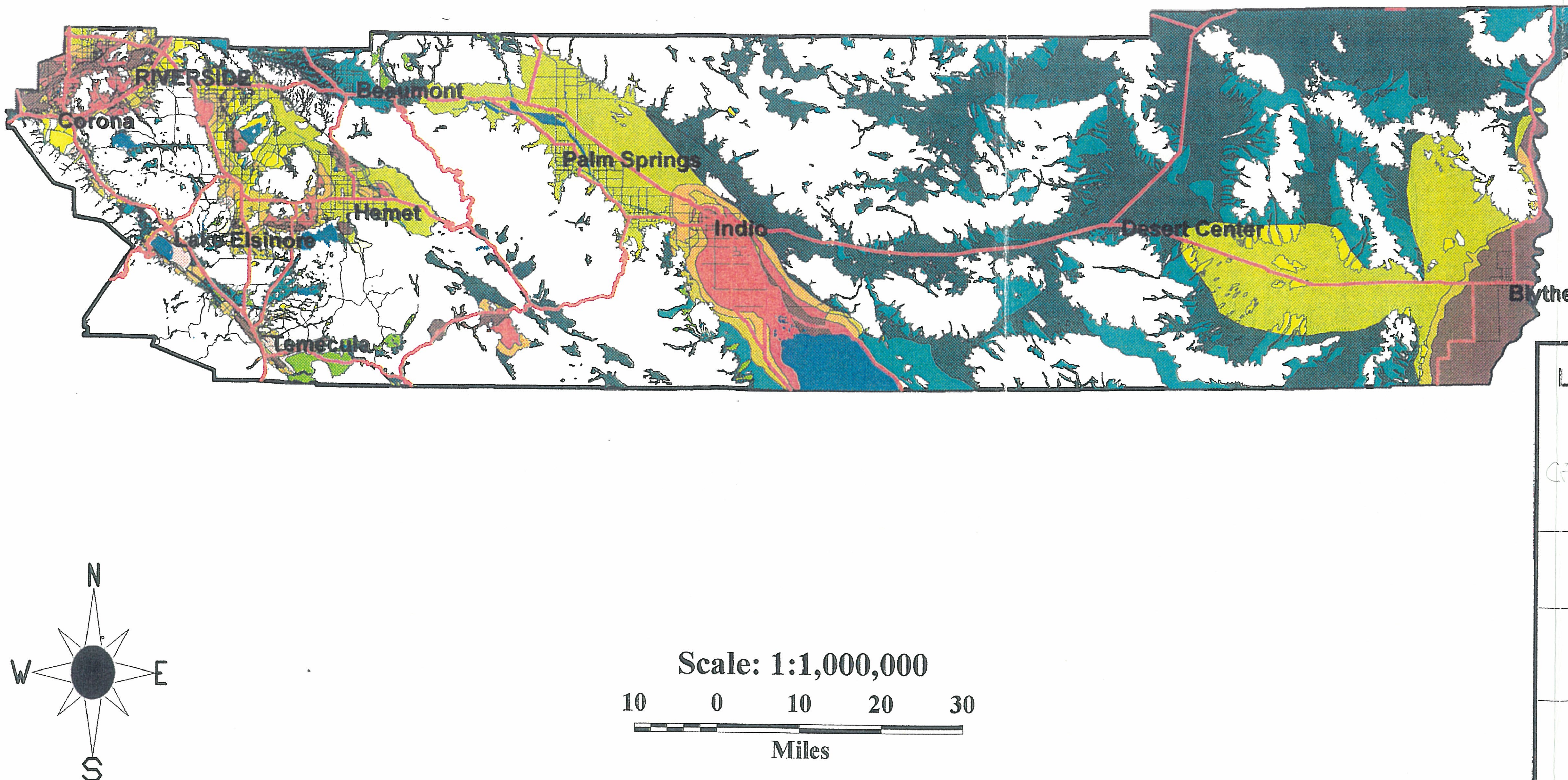
Figure 1-10

Figure 1-11:

Generalized Liquefaction Susceptibility Map Riverside County, California

(Summary of GIS Data, for additional detail see Plate 1-5 in-pocket)

Earth Consultants International



Liquefaction Susceptibility

		Zone	
Very High		101	Shallow Groundwater Susceptible Sediments
High		102	
Moderate		103	
Low		104	
Very Low		105	
Moderate		106	Deep Groundwater Susceptible Sediments
Low		107	
Very Low		108	
Moderate		109	No Groundwater Data Susceptible Sediments
Low		110	
Very Low		111	

Major Roads — Highways — Water Bodies: Lake, Pond, Sea

1.6.3.1 Geographic Information System Coverage of Liquefaction Hazards in Riverside County (Plate 1-5)

Coverage Description: Liquefaction Hazards in Riverside County
Coverage distribution file name: liquef.e00
Coverage Area: Riverside County
Source: Earth Consultants International
Scale: 1:250,000

Hazard mitigation policies for proposed projects in Riverside County based on the detailed liquefaction mapping shown on Plate 1-5 should be implemented as follows:

General Construction: special site-specific liquefaction hazard studies should be required in all areas mapped as "Shallow Ground Water, Susceptible Sediments" with the exception of the Blythe region.

Critical Facilities/Lifelines: special site-specific liquefaction hazard studies should be required in all areas of susceptible sediments, including the Blythe region.

1.6.4 Seismically-Induced Settlement

In some situations, strong ground shaking can cause the densification of soils, resulting in local or regional settlement of the ground surface. Local differential settlements damage structures. Regional settlements can damage pipelines by, for example, changing the gravity gradient on water and sewer lines and canals.

Whether seismically induced settlement will occur depends on the intensity and duration of ground shaking, and the relative density (the ratio between the in-place density and the maximum density) of the subsurface soils. Sediments in the County's alluvial valleys were deposited fairly rapidly, which may lead to conditions of low density sediments that can settle in an earthquake. Therefore, many of the valley regions that contain relatively recent sediments may be susceptible to some degree of seismic settlement. The areal extent of relatively young sediments with moderate to locally high potential for settlement may be correlated with areas of valley fill represented on subsidence susceptibility mapping described in Chapter 2-Soil and Slope Instability.

As demonstrated by past earthquakes, seismic settlement is primarily damaging in areas subject to differential settlement. These can include cut/fill transition lots build on hillsides, where a portion of the house is built over an area cut into the hillside while the remaining portion of the house projects over man made fill. During an earthquake, even slight settlement of the fill can lead to a differentially settled structure and significant repair costs. Therefore, cut and fill transition lots should be overexcavated and fill depths beneath structures should never vary by more than 100%.

Developments in areas subjected to seismically induced settlement should include specific subsurface geotechnical investigations that address the potential for seismically induced settlement on a site-specific basis. This hazard can be mitigated with proper site preparation that involves the densification of the subsurface soils, and with proper foundation design that can accommodate a limited degree of differential settlement due to seismic shaking.

1.6.5 Seismically-Induced Slope Instability

Seismically induced landsliding and rock falls can be expected to occur throughout the County in a major earthquake. Chapter 2 - Slope and Soil Instability Hazards of this Technical Background Report discusses slope stability and landsliding in the County in more detail, including the development of the Geographic Information System (GIS) coverage presented on the Landslide Susceptibility Zone Map for Riverside County. Development policies, based on the GIS mapping, include avoidance and mitigation of the hazard during construction. These mitigation measures will reduce the potential losses associated with this hazard. Figure 1-12 has been prepared to illustrate the regions of the County with existing landslides and slopes that are susceptible to instability during a significant earthquake.

Wilson and Keefer (1985) have reported that a ground acceleration of at least 0.10 g in steep terrain is necessary to induce earthquake-related rock falls, although exceeding this value does not guarantee that rock falls will occur. Since there are several faults capable of generating peak ground accelerations of over 0.10 g in Riverside County, there is a high potential for seismically induced rock falls and landslides to occur.

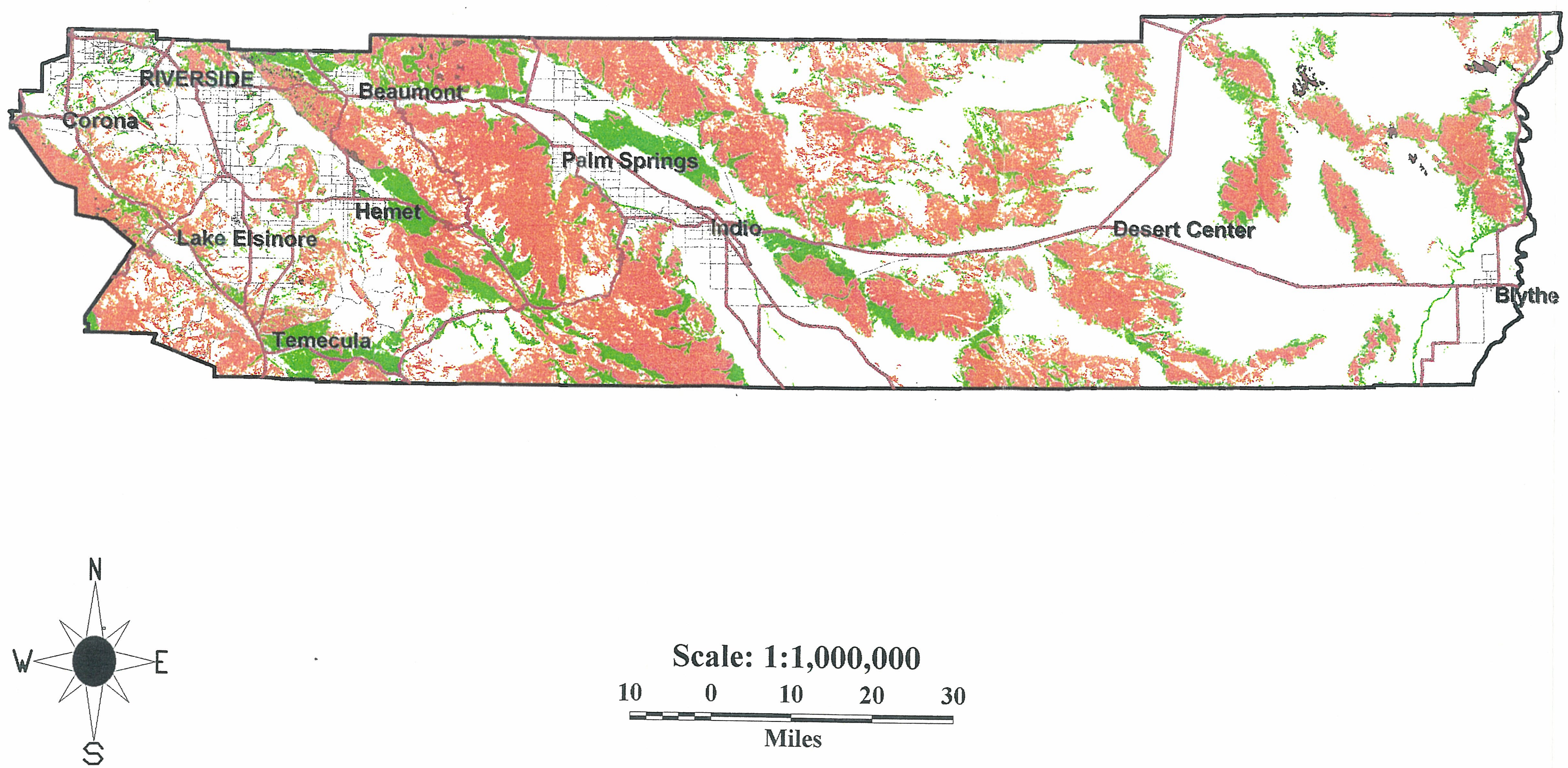


Figure 1-12: Earthquake-Induced Slope Instability Map

(Summary of GIS Data, for additional detail see Plate 2-3 in-pocket)

Earth Consultants International

Existing Landslides

High susceptiblity to seimically induced landslides and rockfalls.

Low to locally moderate susceptibility to seimically induced landslides and rockfalls.

Highways

Major Roads

A separate Southern California Earthquake Center (SCEC) committee dealing with the issues of implementation of SP 117 (DMG, 1997) for landslide hazards has been formed and is working on a companion to the liquefaction hazards document discussed earlier. Factors controlling the stability of slopes include: 1) the slope height and inclination, 2) the engineering characteristics of the earth materials comprising the slope, and 3) the intensity of ground shaking. Engineered slopes should be designed to resist seismically induced failure. Slope design should be based on pseudo-static stability analyses using soil engineering parameters. These should be established on a site-specific basis from detailed geotechnical investigations that include subsurface soil sampling and laboratory testing. The stability analyses should factor in the intensity of ground shaking expected in the County.

1.6.6 Seiches

The County's water tanks, reservoirs, lakes and swimming pools are enclosed bodies of water that are subject to potentially damaging oscillations on the water surface, called ***seiches***. A seiche can result from a number of factors including wind-driven currents, tides, variation in atmospheric pressure and ground shaking associated with near or distant earthquakes. In southern California, the greatest threat of seiches comes from earthquakes.

Whether an earthquake will create seiches depends upon a number of earthquake-specific parameters, including period or length of the seismic waves, earthquake location, and the style of fault rupture (e.g., dip-slip or strike-slip). Whether a seiche will cause damage can depend upon the size, shape and location of the body of water, storage tank strength, integrity of dam construction, underlying soil type, proximity of human-built structures, and local relief (variations in elevation).

Amplitudes of seiche waves associated with earthquake ground motion have typically been less than 0.5 meters high; however, some have exceeded 2 meters. 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 high in the Grand Coulee Dam reservoir, and seiches of similar magnitude in fourteen bodies of water in the state of Washington (McGarr and Vorhis, 1968). California earthquakes have generated (non-damaging) seiches in Florida swimming pools!

Lakes: Due to their relatively large size, proximity to major faults, and development near their shores, in Riverside County, Lake Elsinore and the Salton Sea create especial hazard from seiches.

Dams: An important method to decrease seiche hazard behind dams is to increase the freeboard distance (top of dam to top of water). This can be accomplished by either building up the dam, or by reducing the allowable reservoir storage capacity. Other mitigation measures include:

- replacing dams;
- adding buttresses and berms;
- flattening slopes;
- increasing drainages; and
- grouting foundations.

It seems likely that the threat to dam stability is increased if a dam simultaneously experiences forces associated with strong seismic ground shaking and seiches. Thus, to increase dam safety, these two hazards need to be considered together.

Swimming Pools: Damage from swimming pool seiches is a common problem. During seismic ground shaking, seiches created in private and public pools can expell considerable water. This often damages homes downslope, and sliding glass doors near the pool.

Water Tanks: Seiches damaged storage tanks during the 1992 Landers-Big Bear earthquakes and the 1994 Northridge earthquake. As a result, the American Water Works Association (AWWA) Standards for Design of Steel Water Tanks (D-100) now provide new criteria for seismic design (Lund, 1994).

1.7 Vulnerability of the Built Environment to Earthquake Hazards

This section assesses the earthquake vulnerability of structures and facilities common in the County of Riverside, as well as the status of existing earthquake hazard mitigation programs, including code and ordinance adoption and enforcement. This analysis is based on past earthquake performance of similar types of buildings in the U.S. Beyond the scope of this study are the effects of design earthquakes on particular structures within the County of Riverside. However, utilizing a recent standardized methodology developed for the Federal Emergency Management Agency (FEMA), general estimates of losses are provided in Section 1.8 of this report.

Although it is not possible to prevent earthquakes from occurring, their destructive effects can be minimized. Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning and enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can significantly reduce the scope of an earthquake disaster.

With these goals in mind, the State Legislature passed Senate Bill 547, addressing the identification and seismic upgrade of Unreinforced Masonry (URM) buildings. In addition, the law encourages identification and mitigation of seismic hazards associated with other types of potentially hazardous buildings, including pre-1971 concrete tilt-ups, soft-stories, mobile homes, and pre-1940 homes.

The County of Riverside's building stock is predominantly modern, and modern buildings do save lives. However, economic losses associated with structural and non-structural damage, loss of contents and repairs can be tremendous. For example, the losses associated with the Northridge earthquake approached $30 billion.

As discussed earlier, various geologic phenomena can be triggered by earthquakes to cause loss of life and property damage. Earthquakes can also cause localized, equally destructive hazards such as urban fires, dam failures, and toxic chemical releases. During the 1994 Northridge earthquake, many mobile homes shifted or fell off their foundations, which ruptured gas lines and started fires. This type of hazard is intensified by the relatively high density of homes within mobile home parks.

1.7.1 Potentially Hazardous Buildings and Structures

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". Building codes have generally been made more stringent following damaging earthquakes. However, pre-existing structures in the County of Riverside have generally not been upgraded to current building code standards, and may be hazardous during an earthquake. Structure built before the 1933 Long Beach earthquake are especially at risk.

Building damage is commonly classified as either structural or non-structural. ***Structural damage*** impairs the building's structural 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. Non-structural damage includes broken windows, collapsed or rotated chimneys, and fallen ceilings. During an earthquake, buildings get thrown from side to side, and up and down. Heavier buildings are subjected to higher forces than lightweight buildings, given the same acceleration. Damage occurs when structural members are overloaded, or differential movements between different parts of the structure strain the structural components. Larger earthquakes and longer shaking durations 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 us, however, that some buildings are far more likely to fail than others.

Unreinforced masonry buildings (URMs, Figure 1-13) are prone to failure due to inadequate anchorage of the masonry walls to the roof and floor diaphragms, due to the limited strength and ductility of the building materials, and sometimes due to poor construction workmanship. Using a statistical analysis, the number of URMs in Riverside County is estimated at about 4,000 (HAZUS '99 Inventory). However, Riverside County identified only five in the unincorporated areas during a 1990 study (Kack Fung, personal communication, 2000). There are surely URMs in older regions of incorporated cities within the County, but these have not been identified. The five known URM owners were notified by mail to comply with the State guidelines, but no unique URM ordinance has been passed by Riverside County. In addition, no other potentially vulnerable buildings have been inventoried.

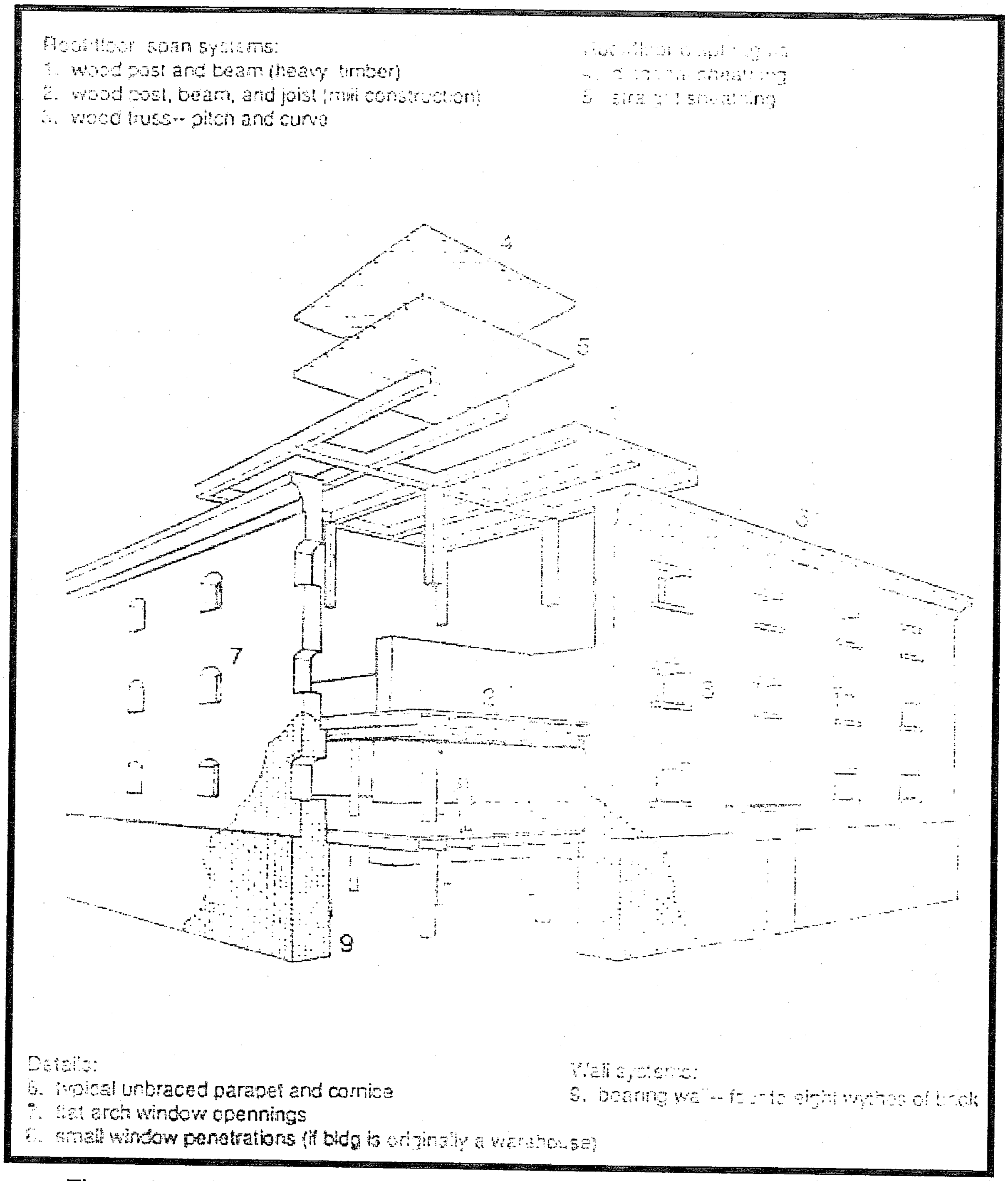


Figure 1-13: Unreinforced Masonry Building (URM). Prepared by the Applied Technology Council for the Federal Emergency Management Agency (1988), Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook: Earthquake Hazards Reduction Series 41, FEMA 154.

Unless URMs have been appropriately reinforced and strengthened, an earthquake may cause irreparable damage, and even collapse. Thus they pose a threat to life and property. There are many ways that damage may occur. Parapets and cornices that are not positively anchored to the roofs may fall out. Wall diaphragms are generally made of wood. These diaphragms are therefore very flexible, allowing large out-of-plane deflections at the wall transverse. This large drift can cause the masonry walls to collapse. Some tall URM buildings have thin walls that may buckle out-of-plane under severe lateral loads. If the wall is a non-load bearing wall, it may fail; collapse of a load-bearing wall will result in partial or total collapse of the structure. Deterioration of the mortar (often of lime and sand with little or no cement, having very little shear strength), and of the wood framing as a result of weather exposure may also contribute to the weakening and poor performance. Collapse of URMs generates much heavy debris.

Reinforced masonry buildings often perform well in moderate earthquakes if they are adequately reinforced and grouted, and if sufficient diaphragm anchorage exists. Poor construction workmanship or materials may lead to failure during a large earthquake. Other common building types are also known to perform poorly during moderate to strong earthquakes, although they have not been targeted for upgrading and strengthening. Of particular concern are ***soft-story buildings*** (those with a story, generally the first floor, lacking adequate strength or toughness due to few shear walls). Apartments above glass-fronted stores and buildings perched atop parking garages are common examples of soft-story buildings. No estimates of the number of soft-story buildings in Riverside County are currently available. 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, 1994). There are many other cases of soft-story collapses.

Structural damage to ***wood frame structures*** often results from 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 in an earthquake, unless they have no foundation or have a weak foundation constructed of unreinforced masonry or poorly reinforced concrete. In these, 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).

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). Thousands have died in collapses of these kinds of structures during earthquakes, such as in Mexico City (1985), Armenia (1988), Nicaragua (1972), El Salvador (1986), the Philippines (1990), and most recently Turkey (1999). Unfortunately, these lessons were not applied to California's parking structures. Many parking structures that failed spectacularly in Northridge (1994) consisted of pre-cast components (EERI, 1994). Many more such parking structures exist throughout the region. No estimates of the number in Riverside County are available.

Collapse of these types of structure leaves debris that requires heavy mechanical equipment to be removed. 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 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.

Tilt-up buildings have concrete wall panels, often cast on the ground, or fabricated off-site and trucked in, that are 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 Sylmar, California earthquake. Tilt-up buildings may generate heavy debris.

Statistical estimates (HAZUS '99 Inventory) indicate about 1,500 ***pre-cast concrete frame*** buildings in Riverside County. Their seismic performance varies, and is dependent on adequate design and construction (Figure 1-14). Pre-cast frames are often weakened due to stresses incurred during transportation and accumulated stresses from shrinkage and creep. Corrosion of the metal connectors between prefabricated elements may also occur, weakening the structure. Multi-story concrete and reinforced masonry buildings with concrete floor slabs may collapse ("pancake") with the floor slabs falling, nearly intact, one on top of the other, becoming closely stacked. The floor slabs prevent access to, and extrication of, victims. These slabs weigh up to 250 tons and generally need to be cut into smaller pieces and removed by heavy cranes - a time-consuming process.

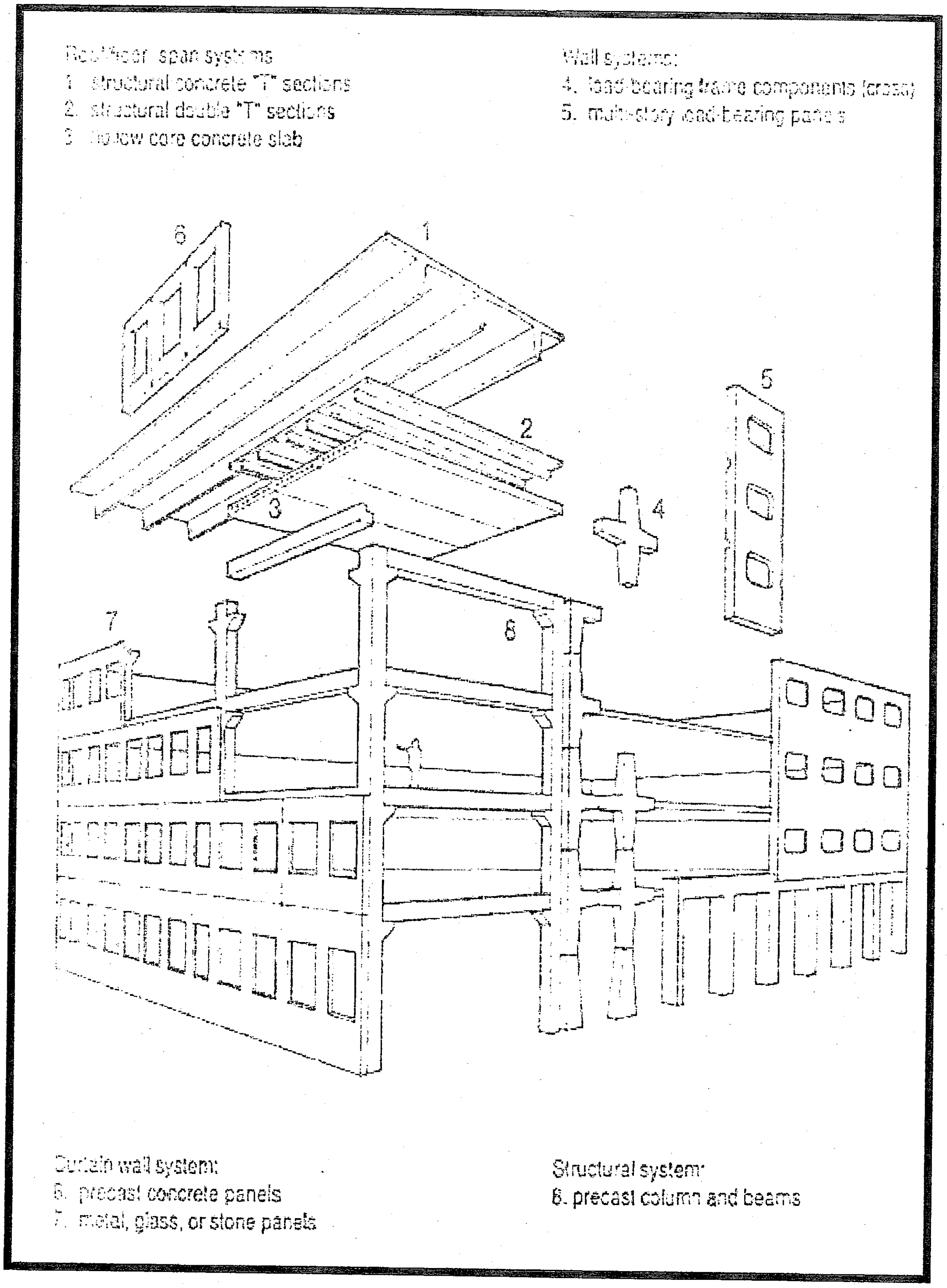


Figure 1-14: Precast concrete-frame construction. Prepared by the Applied Technology Council for the Federal Emergency Management Agency (1988), Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook: Earthquake Hazards Reduction Series 41, FEMA 154.

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 M_w 6.7, 1994 Northridge earthquake was confined column collapse (EERI, 1994), where infilling between columns confined the length of the columns that could move laterally in the earthquake.

Multi-story steel buildings generally also 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 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.

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 (and that have not been discussed above) 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 unengineered 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.

A building's vertical and/or horizontal shape can also be important. Simple, regular and ***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. Also, asymmetry in the placement of bracing systems that provide a building with earthquake resistance can result in twisting or differential motions.

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.

By inventory estimates, more than 70,000 ***mobile homes*** are located in the County of Riverside (HAZUS '99 Inventory). 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; 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 steep jackstands.

A community's first defense against dangerous buildings is to perform a building inventory, to locate, count and identify buildings by structural type and occupancy (usage). With an inventory, limited mitigation resources can be more effectively prioritized.

1.7.2 Essential Facilities

Critical facilities are those parts of a community's infrastructure that must remain operational after an earthquake, or facilities that pose unacceptable risks to public safety if severely damaged. Critical facilities include schools, hospitals, fire and police stations, emergency operation centers (EOC's) and communication centers. Figure 1-15 through 1-18 illustrate the locations of the County's hospitals, emergency response facilities (EOC's, fire and police stations), schools, and communication facilities in relation to ground shaking potential.

It is essential that critical facilities have no structural weaknesses that can lead to collapse. The Federal Emergency Management Agency (FEMA, 1985) has suggested the following seismic performance goals for health care facilities:

- The damage to the facilities should be limited to what might be reasonably expected after a destructive earthquake and should be repairable and not life-threatening.

- Patients, visitors, and medical, nursing, technical and support staff within and immediately outside the facility should be protected during an earthquake.

- Emergency utility systems in the facility should remain operational after an earthquake.

- Occupants should be able to evacuate the facility safely after an earthquake.

- Rescue and emergency workers should be able to enter the facility immediately after an earthquake and should encounter only minimum interference and danger.

- The facility should be available for its planned disaster response role after an earthquake.

High-loss facilities, if severely damaged, may result in a disaster far beyond the facilities themselves. Examples include nuclear power plants, dams and flood control structures, freeway interchanges, bridges, and industrial plants that use or store explosives, toxic materials or petroleum products. Figures 1-19 through 1-21 illustrate the locations of the County's dams, highway bridges and hazardous materials sites in relation to ground shaking potential.

Legend

General Ground Shaking Risk

- LOW = <10% g
- MODERATE = 10-20% g
- HIGH = 20-30% g
- VERY HIGH = 30-40% g
- EXT. HIGH = >40% g

H Location of Acute Care Hospital (based on HAZUS '99 inventory)

N W E S

Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

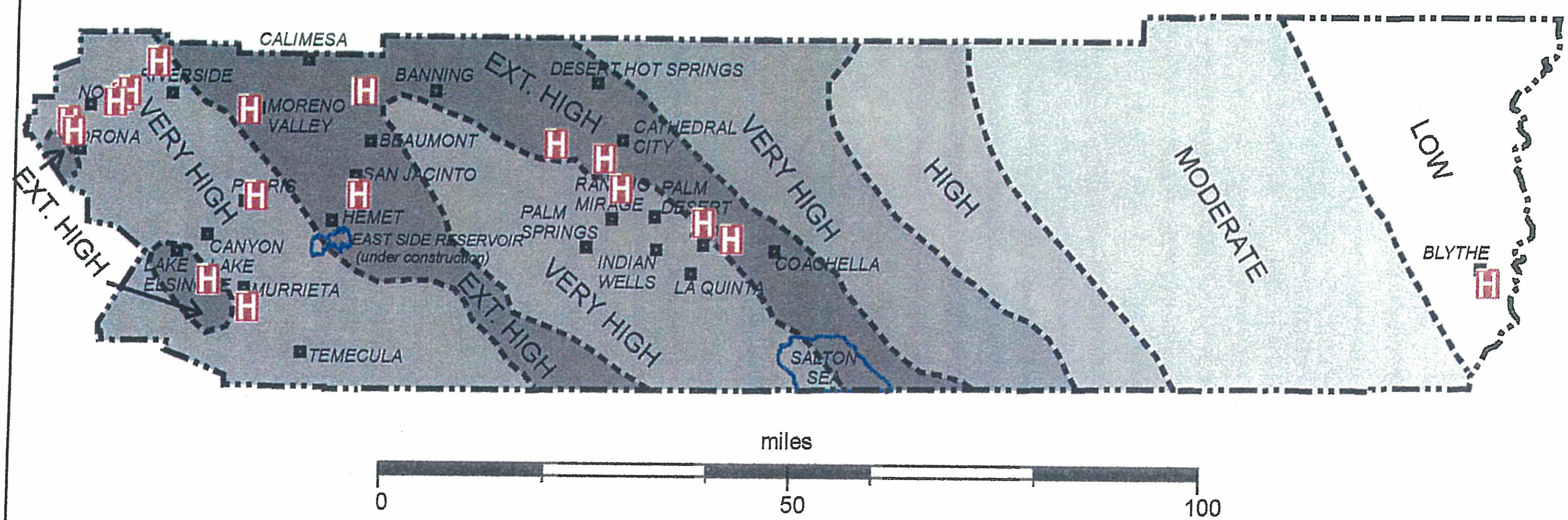


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Figure 1-15: Inventory of Hospital Locations in Relation to Ground Shaking Risk

Legend

General Ground Shaking Risk

- LOW = <10% g
- MODERATE = 10-20% g
- HIGH = 20-30% g
- VERY HIGH = 30-40% g
- EXT. HIGH = >40% g

Location of Emergency Response Facility
Fire, Police, or Emergency Operations Center
(based on HAZUS '99 inventory)

N W E S

Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

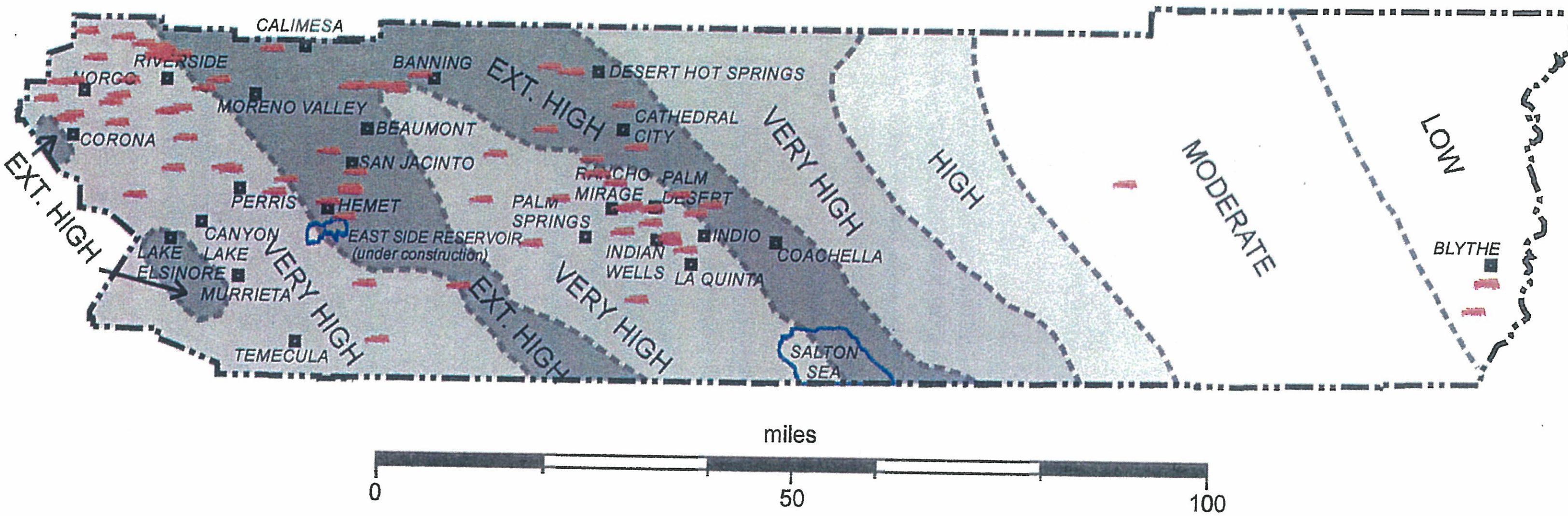

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Figure 1-16: Inventory of Emergency Response Facilities in Relation to Ground Shaking Risk

Legend

General Ground Shaking Risk

- LOW = <10% g
- MODERATE = 10-20% g
- HIGH = 20-30% g
- VERY HIGH = 30-40% g
- EXT. HIGH = >40% g

Location of School
(based on HAZUS '99 inventory)

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Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

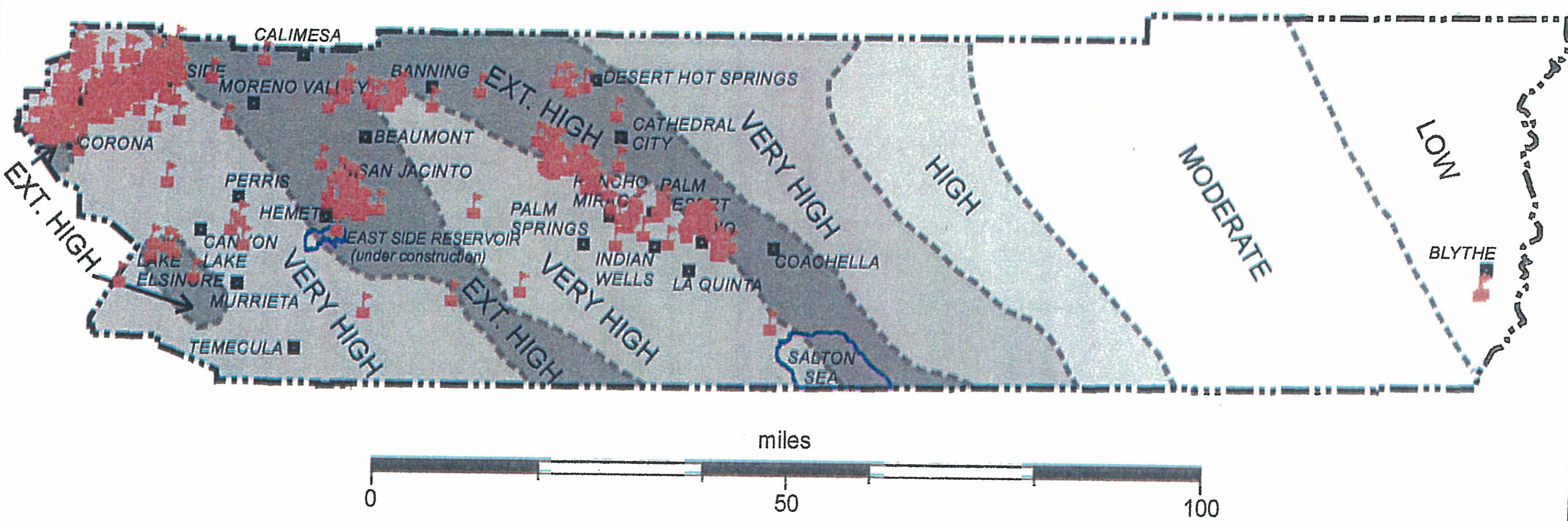

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Figure 1-17: Inventory of School Locations in Relation to Ground Shaking Risk

Legend

General Ground Shaking Risk

- LOW = <10% g
- MODERATE = 10-20% g
- HIGH = 20-30% g
- VERY HIGH = 30-40% g
- EXT. HIGH = >40% g

Location of Communication Facility: Television and radio stations and businesses with a commercial licence (based on HAZUS '99 inventory)

Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

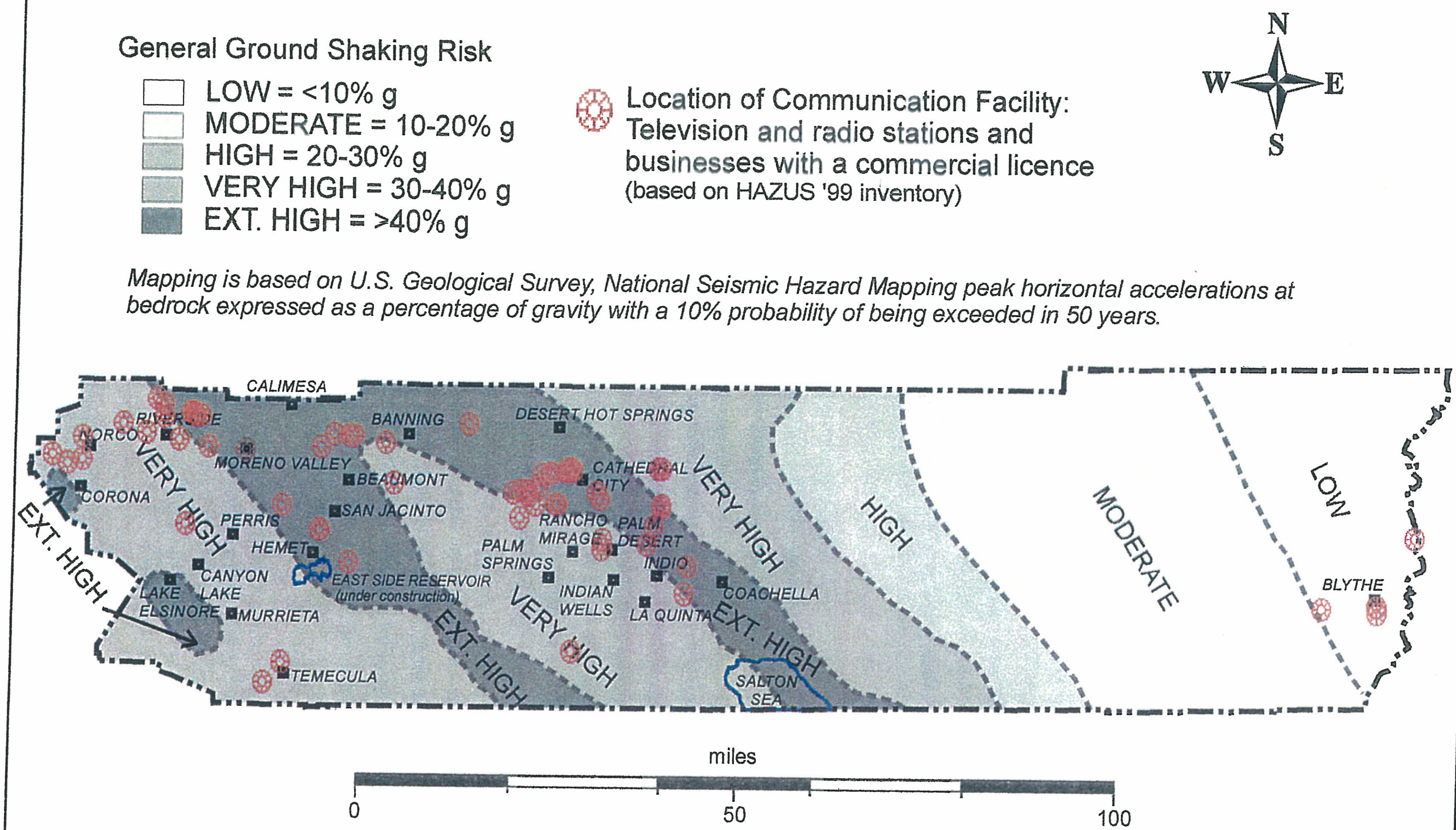

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Figure 1-18: Inventory of Communication Facilities in Relation to Ground Shaking Risk

Legend

General Ground Shaking Risk

- LOW = <10% g
- MODERATE = 10-20% g
- HIGH = 20-30% g
- VERY HIGH = 30-40% g
- EXT. HIGH = >40% g

▲ Location of Dam (based on HAZUS '99 inventory)

N S W E

Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

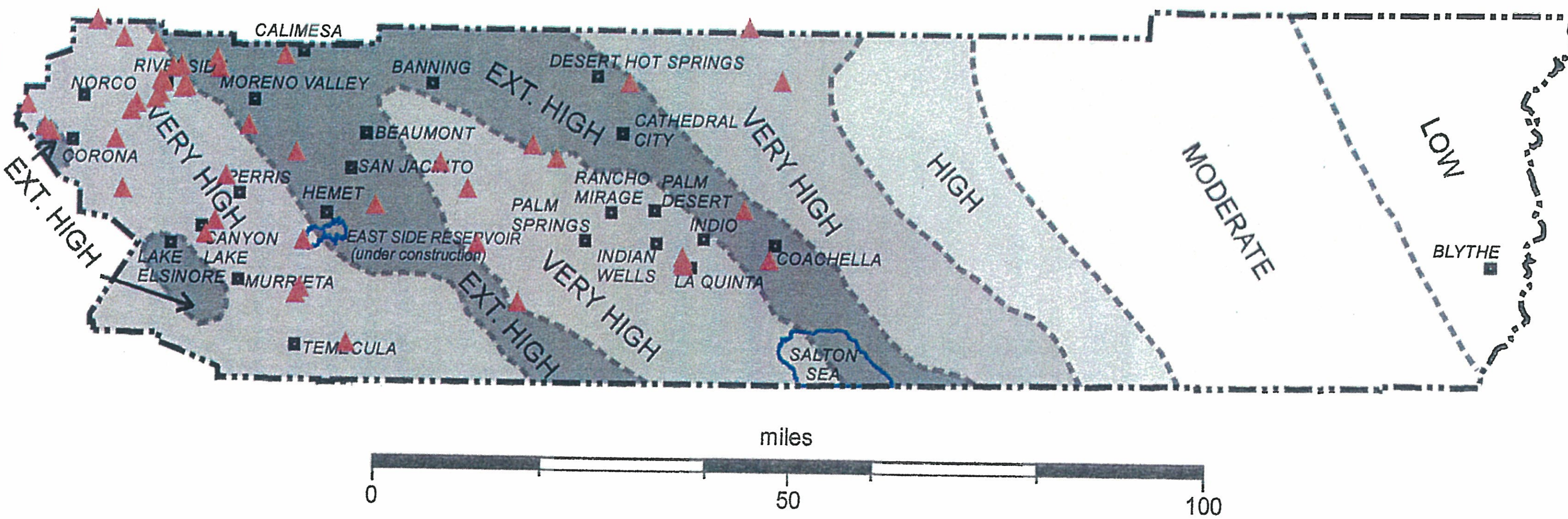

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Figure 1-19: Inventory of Dam Locations in Relation to Ground Shaking Risk

Legend

General Ground Shaking Risk
- LOW = <10% g
- MODERATE = 10-20% g
- HIGH = 20-30% g
- VERY HIGH = 30-40% g
- EXT. HIGH = >40% g

☒ Location of Highway Bridge (based on HAZUS '99 inventory)

N W E S

Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

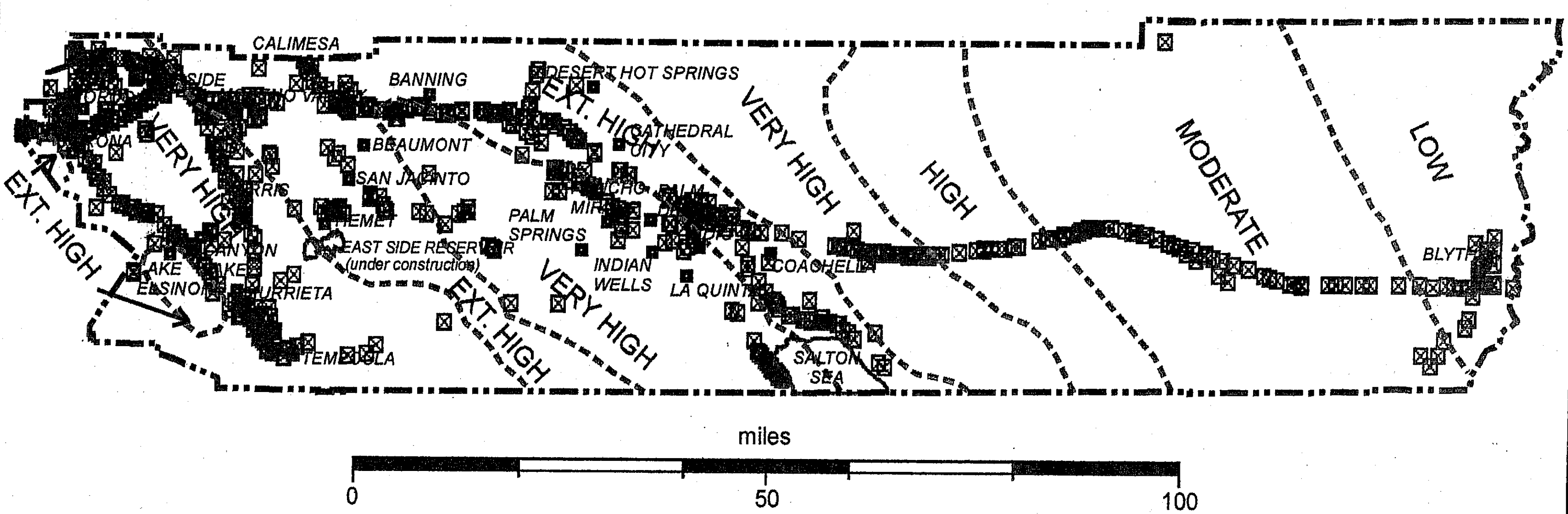

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Figure 1-20: Inventory of Highway Bridges in Relation to Ground Shaking Risk

Legend

General Ground Shaking Risk

LOW = <10% g
MODERATE = 10-20% g
HIGH = 20-30% g
VERY HIGH = 30-40% g
EXT. HIGH = >40% g

☠ Location of Hazardous Materials
(based on HAZUS '99 inventory)

N
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Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

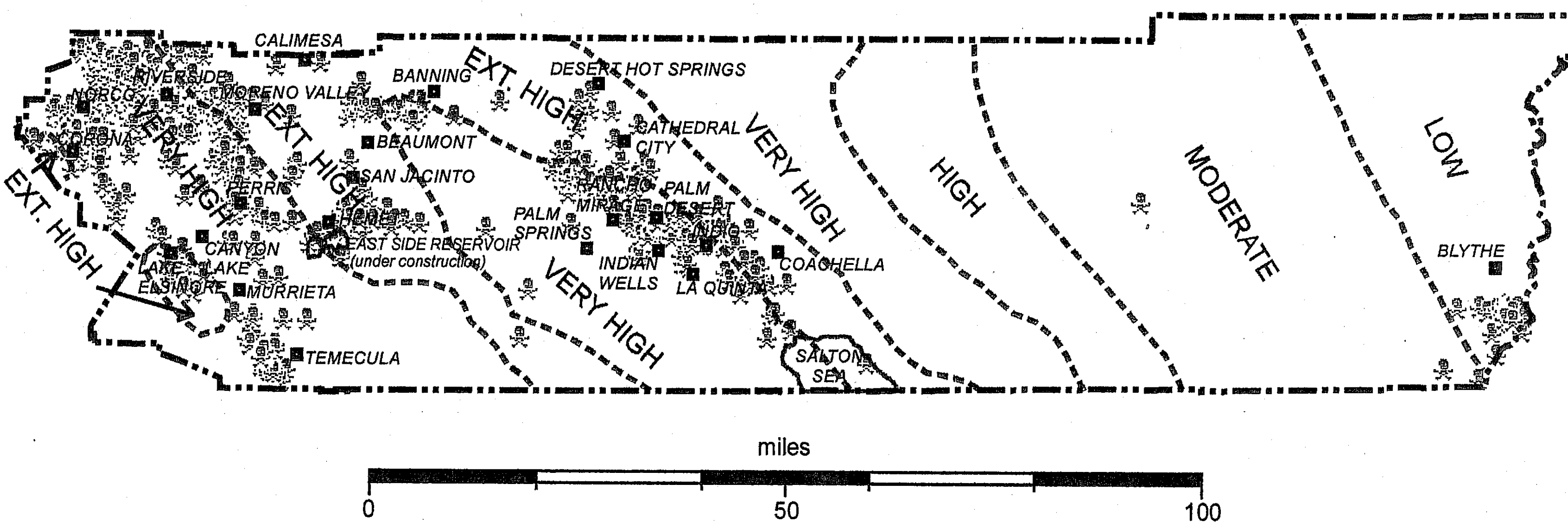

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Figure 1-21: Inventory of Hazardous Materials in Relation to Ground Shaking Risk

Dam Safety: Statutes governing dam safety are defined in Division 3 of the California State Water Code (California Department of Water Resources, 1986), which empowers the California Division of Dam Safety to monitor the structural safety of dams that are greater than 25 feet in dam height or 50 acre-feet in storage capacity.

Dams under this State jurisdiction are required to have inundation maps that show the potential flood limits in the remote possibility a dam is catastrophically breached. Dam inundation maps are prepared by dam owners primarily for contingency planning; it is stressed that they in no way reflect the structural integrity or safety of the dam in question. Dam owners are also required to prepare and submit emergency response plans to the State Office of Emergency Services, the lead State agency for the State dam inundation mapping program. Detailed dam inundation mapping and a discussion of dam vulnerability are presented in Chapter 3-Flood Hazards of this Technical Background Report. The County of Riverside is required by State law to have in place emergency procedures for the evacuation and control of populated areas within the limits of inundation below the dams. In addition, real estate disclosure upon sale or transfer of property in the inundation area is required under recent legislation (AB 1195 Chapter 65, June 9, 1998. Natural Hazard Disclosure Statement).

Most of the legislation regarding dam safety has developed as a result of dam failures, particularly the sudden, disastrous failure of the St. Francis Dam in 1928 (Babbitt, 1993); and damage to dams during earthquakes. During the 1971 San Fernando earthquake, for example, the Lower San Fernando Dam came within five feet of being breached, when the upstream slope slid into the reservoir and the crest settled 30 feet. This confirmed concerns that hydraulic fill dams could be severely damaged by earthquake-induced vibrations (Babbitt and Verigin, 1996).

High-occupancy facilities can potentially cause a large number of casualties or crowd-control problems. This category includes high-rise buildings, large assembly facilities, and large multifamily residential complexes.

Dependent-care facilities house populations with special evacuation considerations, such as preschools and schools, rehabilitation centers, prisons, group care homes, and nursing and convalescent homes.

Economic facilities are those that should remain operational to avoid severe economic impacts, such as banks, archiving and vital record keeping facilities, airports and ports, and large industrial and commercial centers.

1.7.3 Lifelines

Critical facilities, designed to remain functional during and immediately after an earthquake, may provide only limited services if lifelines are disrupted. Our understanding of the seismic hazards to new and existing lifeline facilities relies on several workshops and publications dedicated to the subject, including research completed as a result of the 1989 Loma Prieta earthquake. The issue of seismic hazard mitigation for lifelines is very complex, given the diversity of lifeline facilities. The general comments on the effect of strong ground motion to buildings apply to structures involved in lifeline service, such as the control tower in an airport, or the buildings that house the computers and telephone circuits that are central to communication lifelines. When properly designed, manufactured and laid out, buried pipelines are generally not damaged by strong ground motions, but can be severely disrupted in areas of surface rupture, liquefaction, or landslides. Freeway interchanges and bridges have been damaged by strong ground motions; certain bridge designs have been prioritized in retrofitting programs because of their poor past performance in regions of seismic activity.

A hazard analysis should focus on four lifeline categories: (1) water and sewer facilities, (2) transportation facilities, (3) electric power facilities, and (4) gas and liquid fuel lines. Retrofit and upgrading programs for lifelines generally require careful planning to ensure that the public is not inconvenienced by irregular or discontinued service. To implement an effective mitigation program, potential problem spots must be identified and prioritized in the extensive systems of cable and pipe used to distribute electrical energy, gas, telephone communications, and water, or to collect sewer and storm drain water.

Figures 1-22 through 1-24 illustrate the County's inventory of airports, highways, and rail facilities, as well as available data on water, oil and natural gas pipelines, in relation to the general ground shaking risk.

Legend

General Ground Shaking Risk

- LOW = <10% g
- MODERATE = 10-20% g
- HIGH = 20-30% g
- VERY HIGH = 30-40% g
- EXT. HIGH = >40% g

Location of Airport
(based on HAZUS '99 inventory)

N
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Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

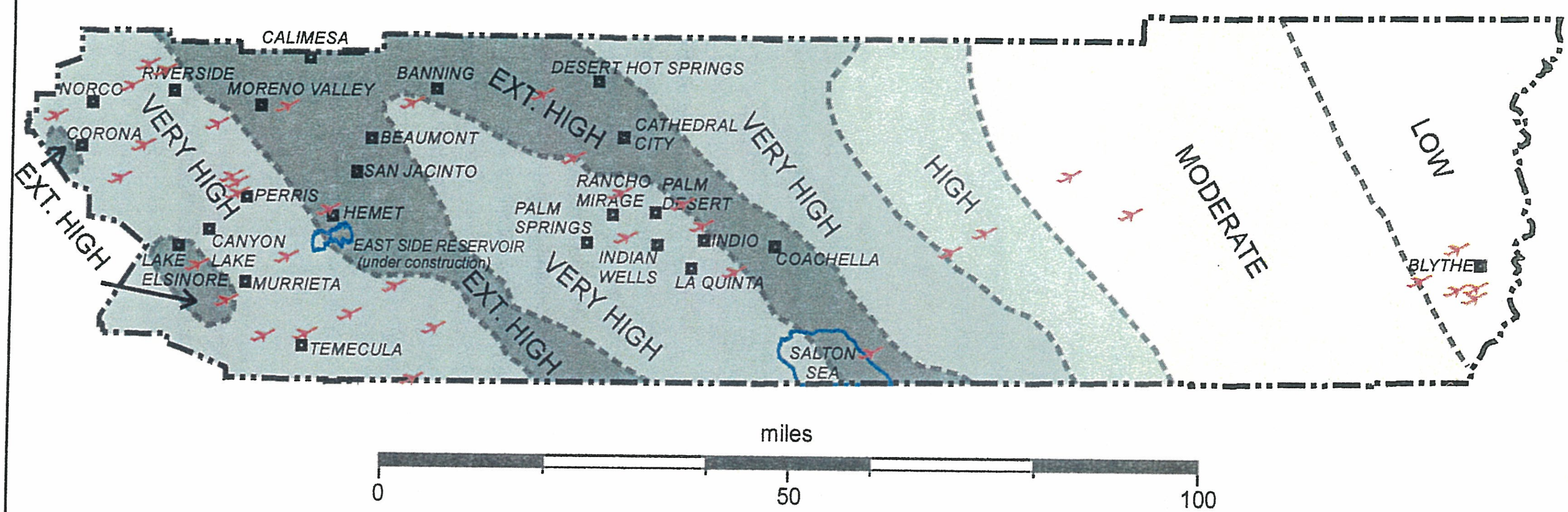

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Figure 1-22: Inventory of Airport Locations in Relation to Ground Shaking Risk

Legend

General Ground Shaking Risk

- LOW = <10% g
- MODERATE = 10-20% g
- HIGH = 20-30% g
- VERY HIGH = 30-40% g
- EXT. HIGH = >40% g

Location of Highway
(based on HAZUS '99 inventory)

Mapping is based on U.S. Geological Survey, National Seismic Hazard Mapping peak horizontal accelerations at bedrock expressed as a percentage of gravity with a 10% probability of being exceeded in 50 years.

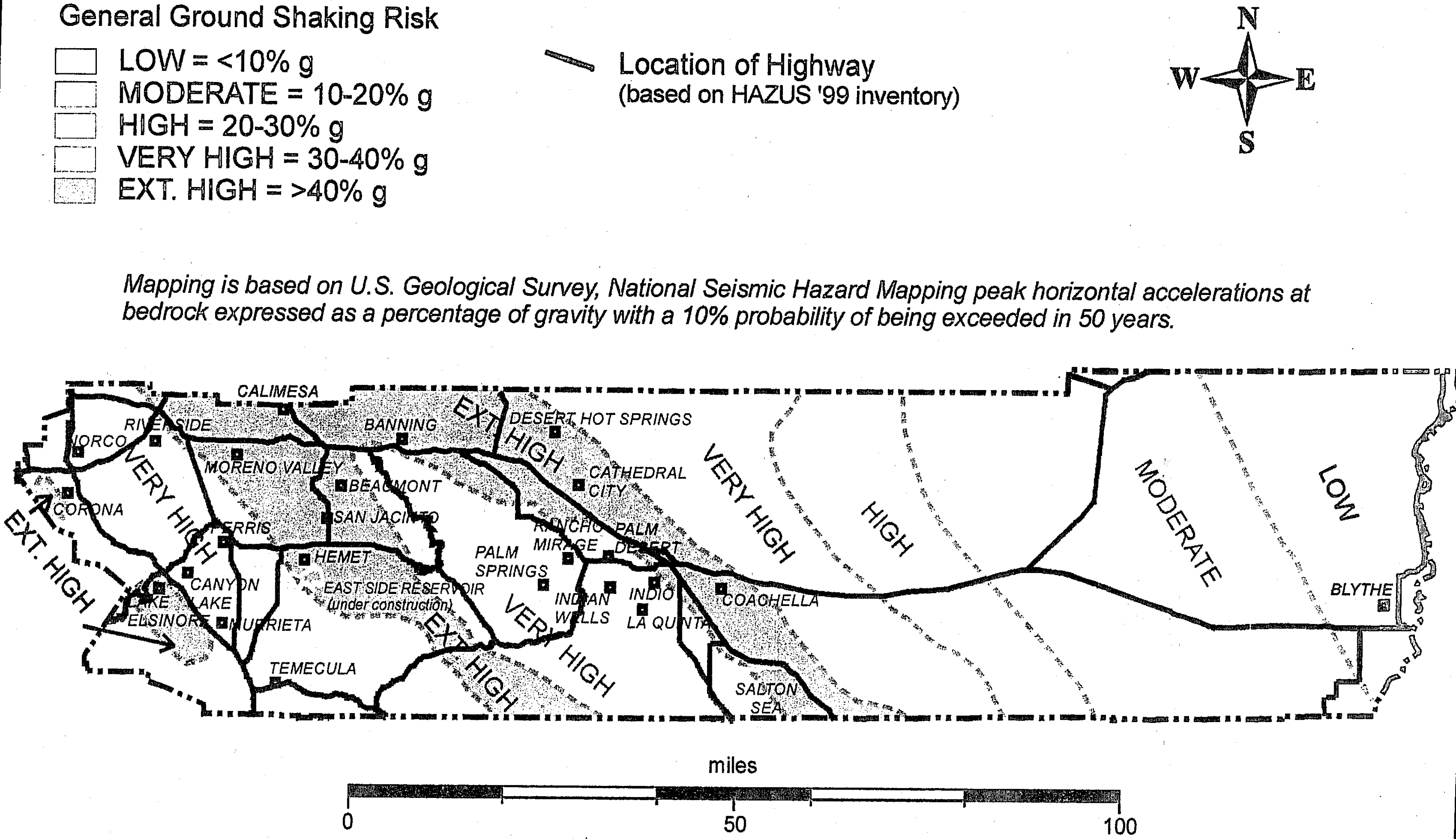

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Figure 1-23: Inventory of Highways in Relation to Ground Shaking Risk

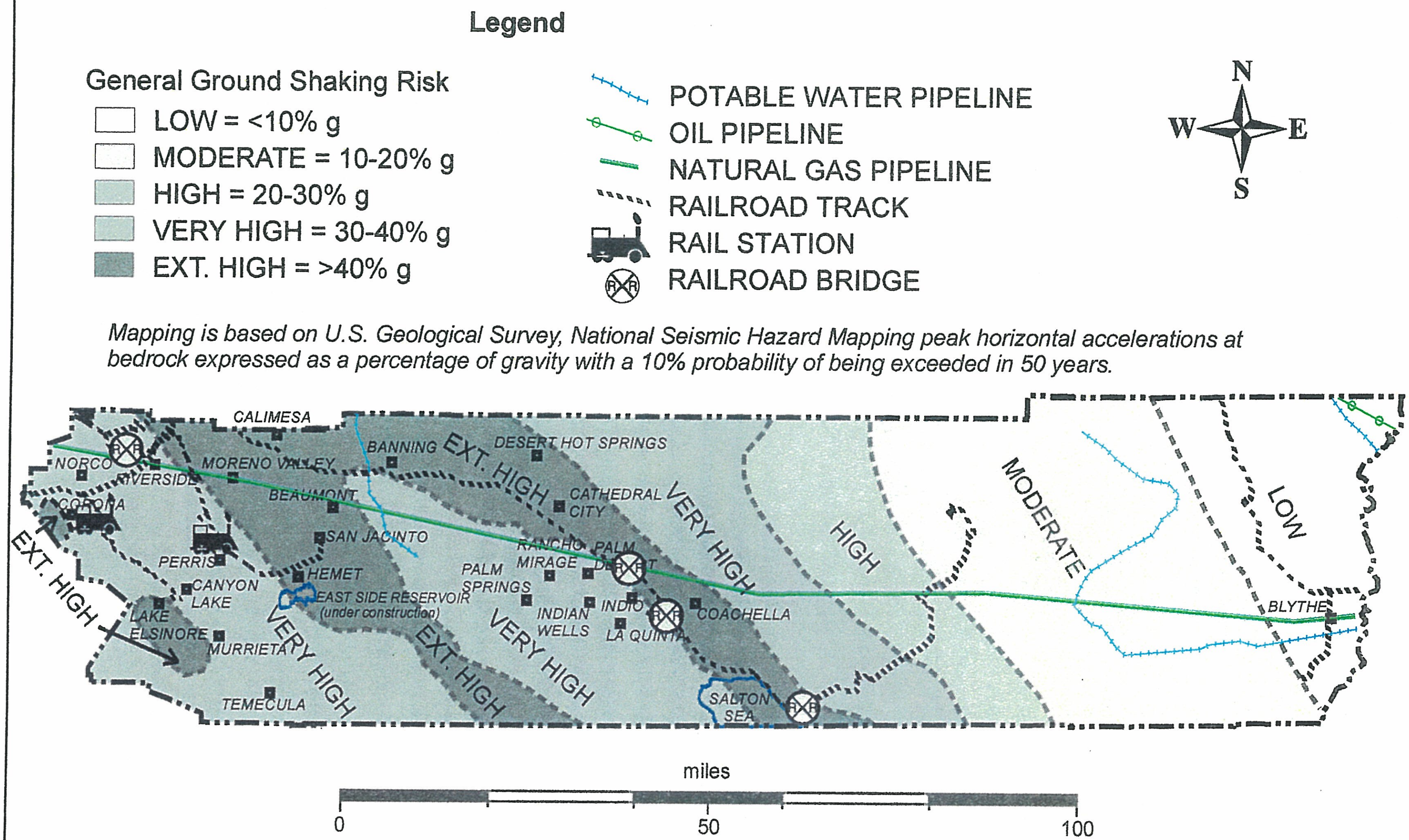

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Figure 1-24: Inventory of Rail Facilities, and Water, Oil, and Natural Gas Pipelines in Relation to Ground Shaking Risk

1.8 HAZUS Earthquake Scenario Loss Estimations for Riverside County

HAZUS™ is a standardized methodology for earthquake loss estimation based on a geographic information system (GIS). A project of the National Institute of Building Sciences, funded by the Federal Emergency Management Agency (FEMA), it is a powerful advance in mitigation strategies. The HAZUS project developed guidelines and procedures to make standardized earthquake loss estimates at a regional scale. 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, 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 producing result that are valid for the intended purposes.

Loss estimation is an invaluable tool, but must be used with discretion. A loss estimation analyzes casualties, damage and economic loss in great detail. It produces seemingly precise numbers that can be easily misinterpreted. A loss estimation's results, for example, may cite 4,054 left homeless by a scenario earthquake. This is best interpreted by its magnitude. That is, 4,000 homeless is clearly more manageable than 40,000 homeless; and an event that leaves 400,000 homeless would overwhelm a community's resources. However, a loss estimation that predicts 7,000 homeless should probably be considered equivalent to the 4,054 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 the important options.

The more community-specific the data that is 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 have been tailored to Riverside County by using the maps of soil type, liquefaction and landslide susceptibility done as part of this study. Loss estimations can be further refined with new census data, and an inventory of the buildings, lifelines and infrastructure specific to Riverside County.

Uncertainties are inherent is any loss estimation methodology. They arise in part from incomplete scientific knowledge concerning earthquakes and their effect upon buildings and facilities, and in part 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_w 6.0) damaging 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 new and experimental. While output from pilot studies has generally been credible, this module requires further testing.

1.8.1 Methodology and Terminology Used in Earthquake Loss Estimation

The flow chart in Figure 1-25 presents the modules (components) of a HAZUS analysis. HAZUS input and output are based on 1990 census tract boundaries. The census tracts that best cover the County of Riverside were chosen for this analysis, and are illustrated in Figure 1-26.

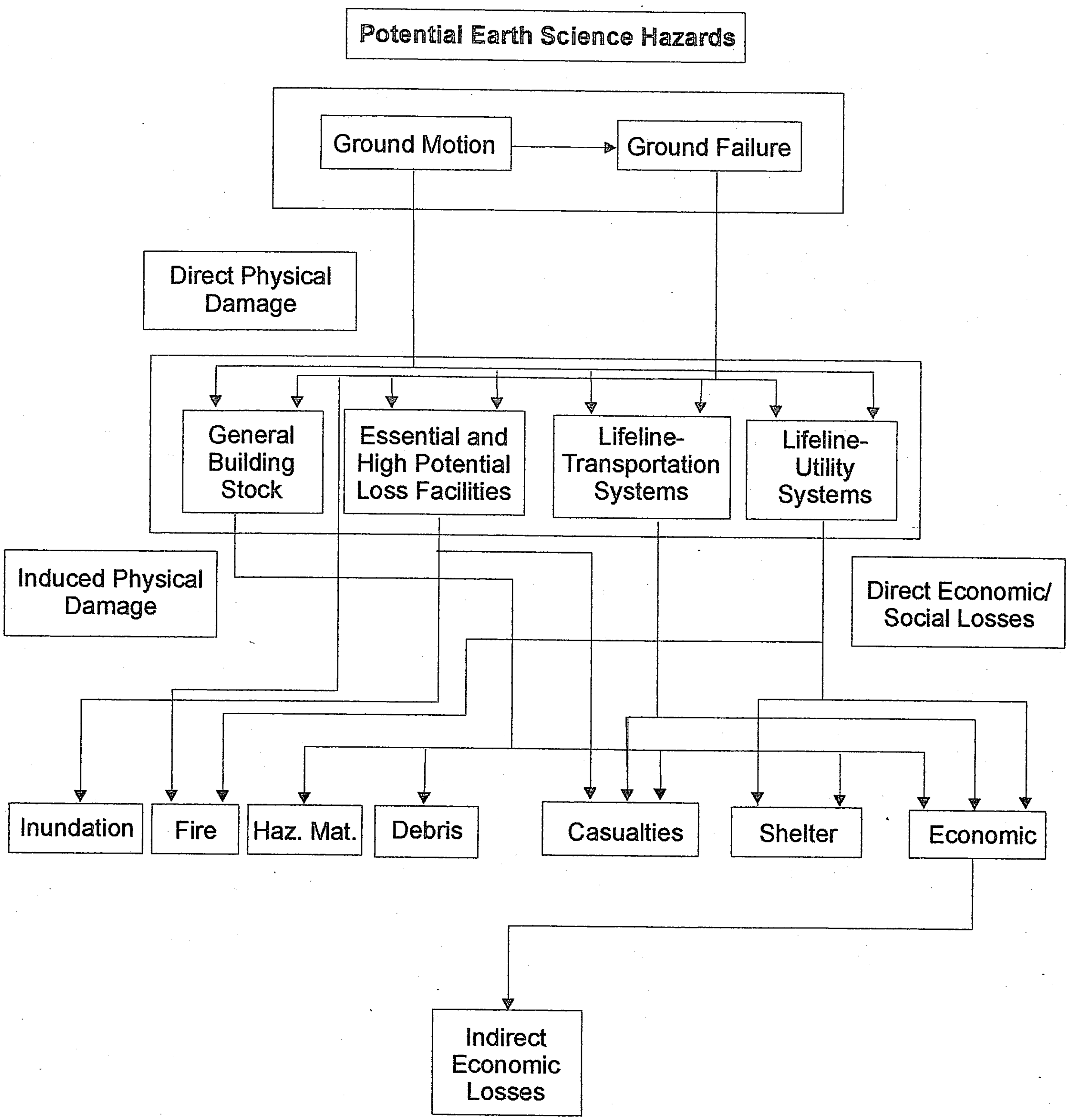

Figure 1-25: Flow Chart Illustrating HAZUS Methodology

Essential Facilities provide services to the community and should be functional after an earthquake. Essential facilities include hospitals, police stations, fire stations and schools. The essential facility HAZUS module determines the expected loss of functionality for these critical facilities. The damage state probabilities for essential facilities are determined on a site-specific basis (i.e., at each facility). Economic losses associated with these facilities are computed as part of the analysis of the general building stock. Data required for the analysis include occupancy classes (current building use) and building structural type, or a combination of essential facilities building type, design level and construction quality factor. In addition, the number of beds for each hospital and the number of fire trucks at each fire station are required. The fire truck information is used as input for the fire following earthquake analysis.

General Building Stock Type and Classification: HAZUS provides damage data for buildings based on these structural types:

Concrete
Mobile Home
Precast Concrete
Reinforced Masonry Bearing Walls
Steel
Unreinforced Masonry Bearing Walls
Wood Frame

and based on these occupancy (usage) classifications:

Residential
Commercial
Industrial
Agriculture
Religion
Government
Education

Building Damage Classification: Loss estimation for the general building stock are averaged for each census tract. Building damage classifications range from slight to complete. Examples for wood frame (the County's most numerous building type) and mobile homes (one of the County's most vulnerable building types) are provided below:

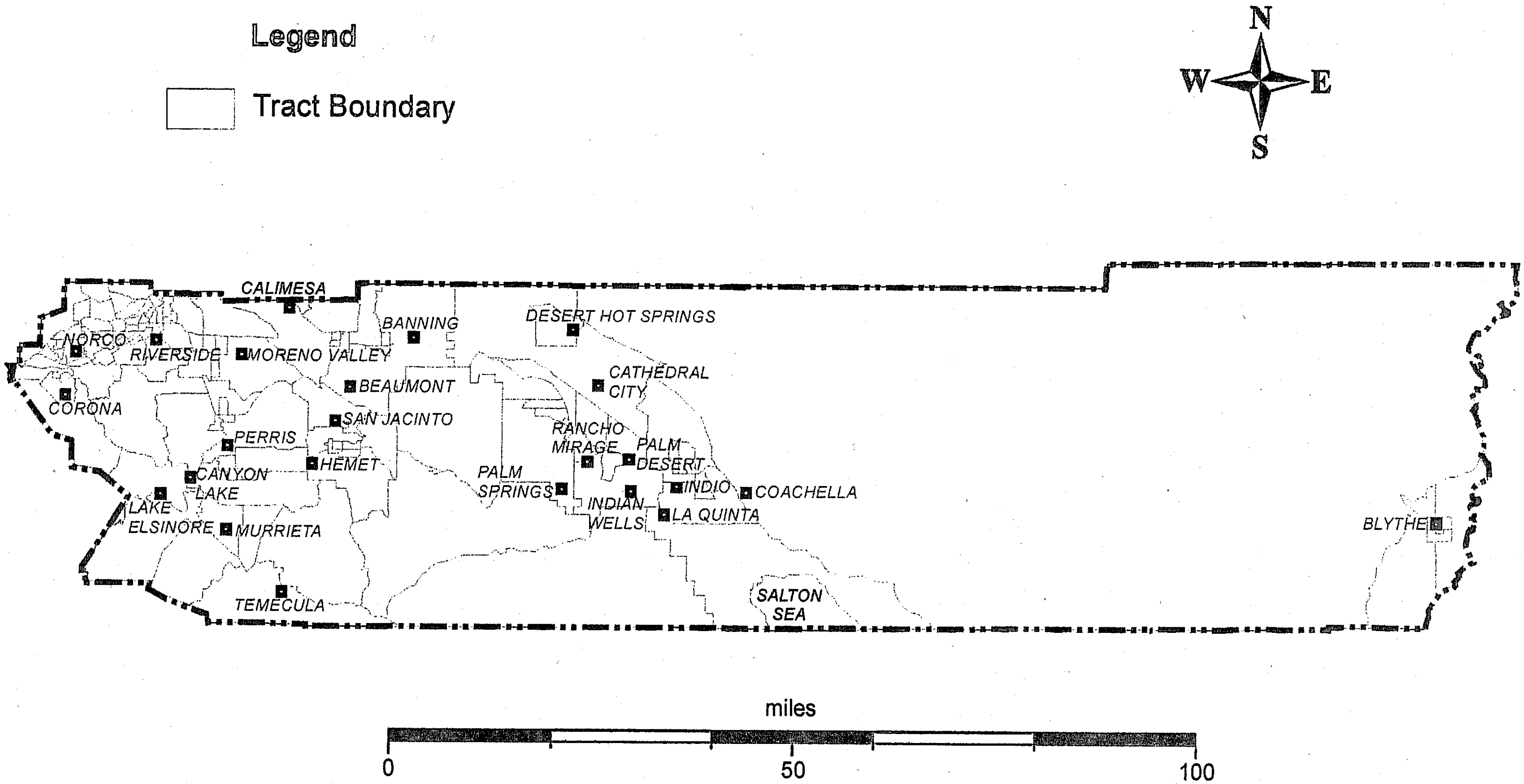

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Figure 1-26: Census Tract Boundaries HAZUS '99 Loss Estimation General Building Stock Inventory Aggregation

Wood, Light Frame:

- *Slight Structural Damage:* Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.
- *Moderate Structural Damage:* Large plaster or gypsum-board cracks 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 foundations 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 the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks. Approximately 5% of the total area with complete structural damage is expected to be collapsed.

Mobile Homes:

- *Slight Structural Damage*: Damage to some porches, stairs or other attached components.
- *Moderate Structural Damage:* Major movement of the mobile home over its supports resulting in some damage to metal siding and stairs and requiring resetting of the mobile home on its supports.
- *Extensive Structural Damage:* Mobile home has fallen partially off its supports, often severing utility lines.
- *Complete Structural Damage:* Mobile home has totally fallen off its supports, usually severing utility lines, with steep jackstands penetrating through the floor. Approximately 5% of the total area of buildings with complete structural damage is expected to be collapsed.

Incorporation of Historic Building Code Design Functions: 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 "High". Buildings built after 1940, but before 1973, are best represented by "Moderate". If built before about 1940 (i.e., before significant seismic codes were implemented), "Low" is most appropriate. The vast majority of buildings in the

County of Riverside fit "High" seismic design criteria.

Fires Following Earthquakes: Fires following earthquakes can cause severe losses. These losses can outweigh the losses from direct damage, such as collapse of buildings and disruption of lifelines. Many factors affect the severity of the fires following an earthquake, including but not limited to: ignition sources, types and density of fuel, weather conditions, functionality of water systems, and the ability of fire fighters to suppress the fires.

A complete fire-following-earthquake model requires extensive input about the readiness of local fire departments and the types and availability (functionality) of water systems. The fire following earthquake model presented here is simplified. With better understanding of fires that will be garnered after future earthquakes, forecasting capability will undoubtedly improve.

An estimated that about 70% of all fire ignitions start within minutes of the earthquake. The remaining ignitions start from an hour to a day after the earthquake. A typical cause of later ignitions is restoration of electric power. When power is restored, short circuits that occurred due to the earthquake become energized and can ignite fires. Similarly, when power is restored, items which have overturned, fallen onto range tops, etc., can ignite. If no one is present at this time, fire department response can be required.

Debris Generation: HAZUS estimates two types of debris. The first is debris that falls in large pieces, such as steel members or reinforced concrete elements. These require special treatment to break into smaller pieces before they are hauled away. The second type of debris is smaller and more easily moved with bulldozers and other machinery and tools. This type includes brick, wood, glass, building contents and other materials.

Estimating Casualties: Casualties are estimated based on the assumption 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 will most likely control the casualty estimates. In severe earthquakes where there will be a large number of collapses and partial collapses, there will be a proportionately larger number of fatalities. Data regarding earthquake-related injuries are 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 classification scale in Table 1-10.

Table 1-10 HAZUS 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

HAZUS can produce 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).

Displaced Households/Shelter Requirements: Earthquakes can cause loss of function or habitability of buildings which contain housing. Displaced households may need alternative short-term shelter, provided by family, friends, temporary rentals, or public shelters established by relief organizations such as the Red Cross or Salvation Army. 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.

Economic Losses: HAZUS estimates structural and nonstructural 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.

1.8.2 HAZUS Scenario Earthquakes

Eight specific earthquakes, called scenario events, were chosen for HAZUS loss estimation (Table 1-11). These include the maximum probable earthquake (MPE) and the maximum credible earthquake (MCE) for Riverside County, as defined in Section 1.1.2. The earthquake chosen to represent MPE ground shaking is a magnitude 6.9 earthquake on the San Jacinto Valley segment of the San Jacinto fault. The MCE is a M_w 7.9 earthquake rupturing the entire southern San Andreas fault.

Table 1-11: HAZUS Scenario Earthquakes for Riverside County

Event		Maximum Magnitude (Mw)	Chance of Occurring in 30 Years	Comments
Fault	Segment			
San Andreas	Southern	7.9	22%	Worst-case scenario event for Riverside County. Involves rupture of the entire San Andreas from Cajon Pass to the Salton Sea. This event is considered the Maximum Credible Earthquake (MCE) for Riverside County.
San Andreas	San Bernardino	7.3	28%	Very high intensity ground shaking throughout the San Bernardino Valley, including north central Riverside County.
San Andreas	Coachella	7.1	22%	Very high intensity ground shaking throughout the Coachella Valley, impacting desert resort communities and agriculture.
San Jacinto	San Jacinto Valley	6.9	43%	Highest probability of occurrence of any southern California fault. Brought closer to failure as a result of stress field changes caused by the 1992 Landers earthquake. This event is considered the Maximum Probable Earthquake (MPE) for Riverside County.
San Jacinto	Anza Segment	7.2	17%	This event would be very destructive within the communities of Hemet and San Jacinto.
Elsinore	Temecula Segment	6.8	16%	Has not produced any significant earthquakes in historic time.
Elsinore	Glen Ivy Segment	6.8	16%	Would be very destructive in the communities of Lake Elsinore, Murrieta, and Temecula.
Whittier	Whittier	6.8	5%	Has not broken in over 1600 years (WGCEP, 1995). Would cause significant landsliding and lifeline damage in the Chino Hills - Corona area.

1.8.3 Inventory Data used in the HAZUS Loss Estimations

The HAZUS inventory includes census tract data provided in the 1990 national census, as well as Dun and Bradstreet valuations for real estate compiled in 1994. The general building stock and population inventory data conform to census tract boundaries. Essential facilities and lifeline inventory are located by latitude and longitude. The HAZUS inventory data were developed at a national level and where specific data are lacking, statistical estimations were utilized. While the inventory is the best available for Riverside County, collecting inventory data at a local level would improve the loss estimations.

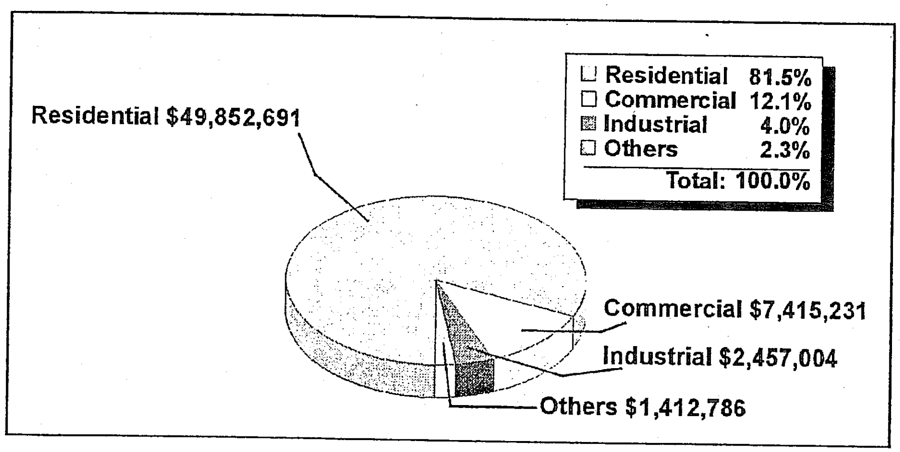
The County is 7,301 square miles and contains 124 census tracts (see Figure 1-26). There are over 402,000 households, with a total population of 1,170,400 people.

There are an estimated 402,000 buildings in the region with a total building replacement value (excluding contents) of $61,138 million dollars (1994 dollars). About 98% of the buildings (and 82% of the building value) are associated with residential housing. Figure 1-27 presents the relative distribution of value with respect to the occupancies.

The replacement value of the transportation system is estimated to be $17,551 million dollars (1994 dollars).

Wood frame building construction is estimated to comprise 66% of the building inventory. The remaining 34% is distributed among the other general building types.

Figure 1-27: County of Riverside Building Inventory by Occupancy Type



Critical Facility Inventory:

HAZUS breaks critical facilities into two groups: essential facilities and high potential loss (HPL) facilities. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. High potential loss facilities include dams, levees, military installations, nuclear power plants and hazardous material sites. For essential facilities, HAZUS tallies 18 hospitals in the region (total bed capacity of 2,682), 380 schools, 52 fire stations, 45 police stations and 12 emergency operation facilities. With respect to HPL facilities, there are 46 dams in the HAZUS inventory. Of these, 23 are classified as 'high hazard' by HAZUS. The inventory also identifies 1,978 hazardous material sites, but does not include them in the analysis.

Transportation and Utility Lifeline Inventory:

Within HAZUS, the lifeline inventory is divided between transportation and utility lifeline systems. The seven transportation systems include highways, railways, light rail, bus, ports, ferry and airports. There are six utility systems that include potable water, wastewater, natural gas, crude and refined oil, electric power and communications. The lifeline inventory data are provided in Tables 1-12 and 1-13.

Table 1-12: Transportation System Lifeline Inventory

System	Component	# locations/# Segments	Replacement value (millions of dollars)
Highway	Major Roads	70	11,439
	Bridges	1,306	4,054
		Subtotal	15,493
Railways	Rail Tracks	169	822
	Bridges	4	20
	Facilities	2	6
		Subtotal	848
Bus	Facilities	6	6
Airport	Facilities	39	252
	Runways	34	952
		Subtotal	1,204
		Total	**17,551**

Table 1-13: Utility System Lifeline Inventory

System	Component	#Locations/ #Segments	Replacement value (millions of dollars)
Potable Water	Pipelines	3	na
	Facilities	0	na
Waste Water	Pipelines	0	na
	Facilities	1	na
Natural Gas	Pipelines	2	na
	Facilities	0	na
Oil Systems	Pipelines	1	na
Electrical Power	Facilities	0	na
Communication	Facilities	85	na
When data are not available for this inventory, HAZUS applies a statistical estimate based on population exposure (J. Bouabid, *personal communication*, 2000).			

1.8.4 Estimated Losses Associated with Scenario Earthquakes

HAZUS loss estimations for Riverside County were run for the eight scenario earthquakes listed in Table 1-11. Relative representations of the loss estimates are presented in Figure 1-28 for all eight scenario events. Projected losses associated with two events (the MCE and MPE) are described in additional detail in the following sections.

Summaries of building damage, casualties, shelter requirements, and economic losses in Riverside County associated with the eight scenario earthquakes are provided in Tables 1-14 through 1-17, below:

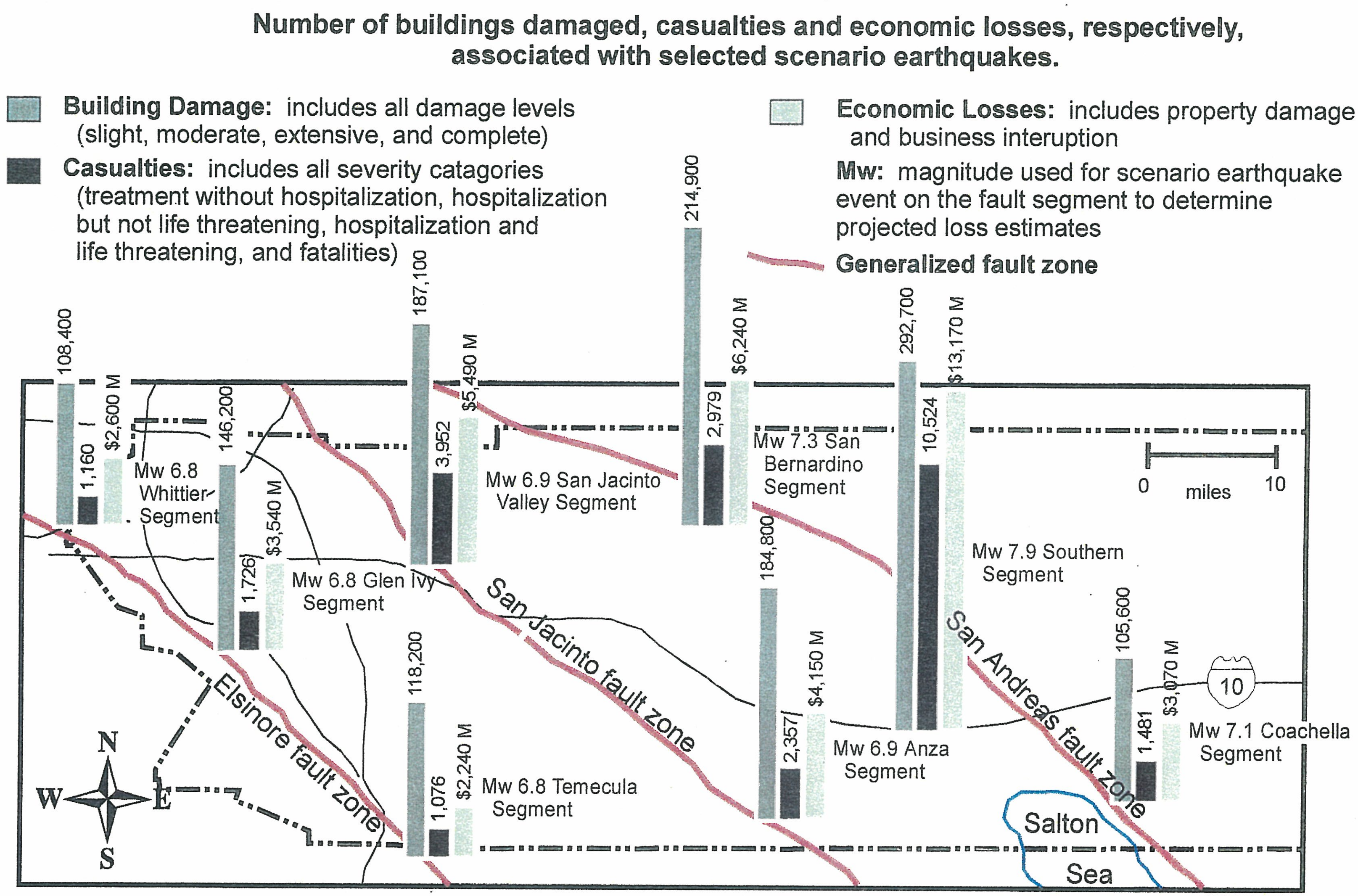


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Figure 1-28: Relative Projected Loss Estimations for Scenario Earthquakes

Table 1-14: Number of Buildings Damaged

Scenario Event	Building Damage				Total
	Slight	Moderate	Extensive	Complete	
San Andreas-Southern Segment M_W 7.9 ***(MCE)***	112,100	92,700	50,900	37,000	292,700
San Andreas-San Bernardino Segment M_W 7.3	109,400	69,200	26,600	9,600	214,900
San Andreas-Coachella Segment M_W 7.1	52,700	35,200	13,100	4,600	105,600
San Jacinto-San Jacinto Valley Segment M_W 6.9 ***(MPE)***	92,800	57,300	26,600	10,500	187,100
San Jacinto-Anza Segment M_W 7.2	97,100	57,400	22,800	7,400	184,800
Elsinore-Temecula Segment M_W 6.8	69,300	36,100	10,600	2,200	118,200
Elsinore-Glen Ivy Segment M_W 6.8	82,000	46,600	14,300	3,300	146,200
Elsinore-Whittier M_W 6.8	65,100	33,100	8,400	1,700	108,400

Table 1-15: Estimated Casualties

Scenario Event	Casualty Severity*				Total
	1	2	3	4	
San Andreas-Southern Segment M_W 7.9 ***(MCE)***	8,159	1,499	302	127	10,524
San Andreas-San Bernardino Segment M_W 7.3	2,455	410	83	31	2,979
San Andreas-Coachella Segment M_W 7.1	1,216	207	42	16	1,481
San Jacinto-San Jacinto Valley Segment M_W 6.9 ***(MPE)***	2,916	503	71	39	3,952
San Jacinto-Anza Segment M_W 7.2	1,974	325	37	21	2,357
Elsinore-Temecula Segment M_W 6.8	911	139	17	9	1,076
Elsinore-Glen Ivy Segment M_W 6.8	1,453	231	25	17	1,726
Elsinore-Whittier M_W 6.8	974	153	20	13	1,160

*: Severity Definitions

Severity 1: Medical treatment without hospitalization.
Severity 2: Hospitalization but not life threatening.
Severity 3: Hospitalization and life threatening.
Severity 4: Fatalities.

Table 1-16: Estimated Shelter Requirements

Scenario Event	Estimates*	
	Displaced Households (no. of households)	Short Term Shelter (no. of people)
San Andreas-Southern Segment M_W 7.9 ***(MCE)***	8,159	1,499
San Andreas-San Bernardino Segment M_W 7.3	2,455	410
San Andreas-Coachella Segment M_W 7.1	1,216	207
San Jacinto-S.J. Valley Segment M_W 6.9 ***(MPE)***	2,916	503
San Jacinto-Anza Segment M_W 7.2	1,974	325
Elsinore-Temecula Segment M_W 6.8	911	139
Elsinore-Glen Ivy Segment M_W 6.8	1,453	231
Elsinore-Whittier M_W 6.8	974	153

*: HAZUS estimates 2.4 persons displaced per household, but typically not all require shelter (most apparently leave the area or stay with others). HAZUS uses past earthquake experiences and demographics (income) to estimate the number of persons requiring short-term shelter.

Table 1-17: Estimated Economic Losses

Scenario Event	Economic Losses (millions)		
	Property Damage	Business Interruption	Total
San Andreas-Southern Segment M_W 7.9 ***(MCE)***	$10,150	$3,020	$13,170
San Andreas-San Bernardino Segment M_W 7.3	$4,180	$1,440	$6,240
San Andreas-Coachella Segment M_W 7.1	$2,340	$720	$3,070
San Jacinto-S.J. Valley Segment M_W 6.9 ***(MPE)***	$4,280	$1,220	$5,500
San Jacinto-Anza Segment M_W 7.2	$3,280	$870	$4,150
Elsinore-Temecula Segment M_W 6.8	$1,800	$450	$2,240
Elsinore-Glen Ivy Segment M_W 6.8	$2,820	$730	$3,540
Elsinore-Whittier M_W 6.8	$2,060	$550	$2,600

1.8.5 Estimated Losses Associated with a M_w 6.9 San Jacinto Fault Earthquake (MPE)

This event was chosen as the MPE because it has the greatest probability of occurrence (43%, Table 1-11) within the lifetimes of structures in the County of Riverside (30 years). The event would involve a rupture of the San Jacinto Valley segment of the San Jacinto fault. The relatively high probability is related to the San Jacinto's high slip rate (±12 mm/year), as well as the increase in stress along the fault caused by the 1992 Landers earthquake. HAZUS estimates as many as 39 fatalities, about 3,500 injuries and total economic loss of $5.5 billion (equivalent to 9% of the total replacement value of the region's buildings).

Building Damage

HAZUS estimates that over 94,000 buildings will be at least moderately damaged. This is about 23% of the total number of buildings in the region. An estimated 10,485 buildings will be completely destroyed. The definition of 'damage states' are described above. Table 1-18 below summarizes the expected damage by general occupancy for Riverside County buildings, while Table 1-19 summarizes the expected damage by general building type.

Table 1-18: Expected Building Damage by Occupancy
M_w 6.9 San Jacinto Fault Earthquake

Occupancy Type	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Residential	210,420	97.90	91,537	98.67	56,074	97.92	26,124	98.20	10,295	98.2
Commercial	2,980	1.39	833	0.90	799	1.40	325	1.22	137	1.31
Industrial	823	0.38	241	0.26	268	0.47	108	0.41	36	0.34
Agriculture	264	0.38	62	0.00	45	0.08	20	0.08	10	0.10
Religion	222	0.10	67	0.00	52	0.09	18	0.07	3	0.03
Government	73	0.03	4	0.00	5	0.01	2	0.01	0	0.00
Education	162	0.08	29	0.03	21	0.04	7	0.03	4	0.04
Total	214,944		92,773		57,264		26,604		10,485	

Table 1-19: Expected Building Damage by Building Type (all design levels) M_w 6.9 San Jacinto Fault Earthquake

Occupancy Type	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Concrete	988	0.5	313	0.3	267	0.5	146	0.4	47	0.5
Mobile Homes	18,481	8.6	13,256	14.3	21,418	37.4	15,279	59.3	6,218	57.4
Precast Concrete	889	0.4	204	0.2	246	0.4	132	0.6	61	0.5
Reinforced Masonry	15,030	7.0	3,842	4.1	4,295	7.5	2,778	10.7	1,125	10.4
Steel	10,409	4.8	4,586	4.9	6,500	11.4	3,976	15.2	1,595	14.9
URM	1,008	0.5	589	0.6	794	1.4	661	6.8	708	2.5
Wood	168,139	78.2	69,983	75.4	23,744	41.5	3,632	7.0	731	13.7

Essential Facility Damage

Before the earthquake, there are 18 hospitals with 2,682 hospital beds available for use. HAZUS estimates that 51% of these beds are available on the day of the earthquake, as well as by patients already in the hospital. After one week, 64% of the beds will be back in service. By 30 days, 81% will be operational.

Table 1-20: Expected Damage to Essential Facilities as a Result of a Mw 6.9 Earthquake on the San Jacinto Fault

Classification	Total	Number of Facilities With		
		At Least Moderate Damage	Complete Damage	Functionality > 50% at day 1
Hospitals	18	17	0	10
Schools	380	378	0	146
EOCs	12	11	0	6
Police Stations	45	43	0	30
Fire Stations	52	52	0	16

Transportation and Utility Lifeline Damage

Table 1-21, below, provides damage estimates based on available inventory.

Table 1-21: Expected Damage to the Transportation Systems as a Result of a M_w 6.9 Earthquake on the San Jacinto Fault

System	Component	Number of Locations				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Bridges	1,306	89	18	1,254	1,299
Railways	Bridges	4	0	0	4	4
	Facilities	2	0	0	2	2
Bus	Facilities	6	1	0	6	6
Airport	Facilities	39	7	0	39	39
	Runways	34	1	0	34	34

HAZUS performs a simplified system performance analysis for electric power (Table 1-22).

Table 1-22: Expected Electric Power System Performance as a Result of a M_w 6.9 Earthquake on the San Jacinto Fault

System	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Electric Power	402,426	93,996	17,668	825	0	0

Fire Following Earthquake

HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this MPE scenario, 124 ignitions will burn about 0.03% of the region's total area, displace about 360 people and burn about $19.0 million of building value.

Debris Generation

HAZUS estimates that 4.5 million tons of debris will be generated. Brick/Wood comprises 36% of the total, with the remainder Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 180,984 truckloads (@25 tons/truck) to remove the debris generated by the MPE.

Shelter Requirement

HAZUS estimates 9,345 households will be displaced due to the earthquake. Of these, 6,964 people will seek temporary shelter in public shelters.

Casualties

Table 1-23 provides a summary of the casualties estimated for this MPE.

Table 1-23: Casualty Estimates as a Result of a M_w 6.9 Earthquake on the San Jacinto Fault

		Level 1	Level 2	Level 3	Level 4
2 AM (maximum residential occupancy)	Residential	2,898	498	38	38
	Non-Residential	16	3	0	0
	Commute	2	3	4	1
	Total	2,916	503	42	39
2 PM (maximum educational, industrial and commercial)	Residential	1,119	193	14	14
	Non-Residential	866	157	20	20
	Commute	8	13	20	4
	Total	1,993	363	54	38
5 PM (peak commute time)	Residential	1,328	229	17	17
	Non-Residential	264	48	6	6
	Commute	20	33	48	10
	Total	1,613	309	71	32

Building-Related Economic Losses

Total building-related losses were $5.5 billion dollars, and 22% of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies, which made up over 68% of the total loss. Table 1-24, below, provides a summary of the losses associated with building damage.

Table 1-24: Building-Related Economic Loss Estimates (millions of dollars) as a Result of a M_w 6.9 Earthquake on the San Jacinto Fault

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss	Structural	615.3	158.3	48.1	31.0	**852.7**
	Non-Structural	2,061.2	368.2	107.2	81.1	**2,617.7**
	Content	519.1	167.0	73.8	35.1	**794.9**
	Inventory	N/A	3.6	11.7	0.9	**16.2**
	Subtotal	3,195.6	697.1	240.8	148.1	**4,281.6**
Business Interruption Loss	Wage	16.6	190.3	10.4	8.8	**226.0**
	Income	7.1	208.6	6.2	2.4	**224.4**
	Rental	160.2	67.2	4.9	4.6	**236.9**
	Relocation	378.7	105.1	12.8	39.3	**535.9**
	Subtotal	562.7	571.2	34.4	55.1	**1,223.3**
	Total	3,758.3	1,268.3	275.1	203.2	**5,504.9**

1.8.6 Estimated Losses Associated with a M_w 7.9 Southern San Andreas Earthquake

This event represents the Maximum Credible Earthquake (MCE) for Riverside County. The earthquake would rupture the San Andreas fault from Cajon Pass, north of the County, to the Salton Sea. It is an event that likely occurs only once every several hundred years, but should it occur tomorrow, HAZUS estimates that Riverside County would suffer about 120 deaths, nearly 9,800 injuries, and economic losses of $13.6 billion, about 22% of the total replacement value of the region's buildings.

Building Damage:

HAZUS estimates that over 181,000 buildings will be at least moderately damaged. This is over 45% of the buildings in the County. An estimated 37,013 buildings will be destroyed. Table 1-25 below summarizes the expected damage by building occupancy, while Table 1-26 summarizes expected damage by building type.

Table 1-25: Expected Building Damage by Occupancy
M_w 7.9 San Andreas Fault Earthquake

Occupancy Type	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Residential	107,383	98.18	110,856	98.89	90,754	97.89	49,686	97.66	35,937	97.1
Commercial	1,259	1.15	817	0.73	1,331	1.44	856	1.68	799	2.16
Industrial	399	0.36	233	0.21	375	0.40	224	0.44	179	0.48
Agriculture	128	0.12	80	0.00	94	0.10	43	0.08	41	0.11
Religion	104	0.10	73	0.00	97	0.10	41	0.08	36	0.10
Government	25	0.02	4	0.00	11	0.01	5	0.01	3	0.01
Education	78	0.07	32	0.03	49	0.05	20	0.04	18	0.05
Total	109,376		112,095		92,711		50,875		37,013	

Table 1-26: Expected Building Damage by Building Type (all design levels)
M_w 7.9 San Andreas Fault Earthquake

Occupancy Type	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Concrete	420	0.4	321	0.3	430	0.5	309	0.8	281	0.6
Mobile Hms.	2,123	1.9	6,125	5.5	18,971	20.5	25,484	59.3	21,949	50.1
Precast Concrete	415	0.4	204	0.2	370	0.4	276	0.7	267	0.5
Reinforced Masonry	7,546	6.9	4,360	3.9	6,240	6.7	4,932	10.8	3,992	9.7
Steel	3,387	3.1	3,485	3.1	7,807	8.4	7,310	13.7	5,077	14.4
URM	140	0.1	233	0.2	568	0.6	834	5.4	1,985	1.6
Wood	95,345	87.2	97,367	86.9	58,325	62.9	11,730	9.4	3,462	23.1

Essential Facility Damage:

Before the earthquake, the region had 2,682 hospital beds available for use. HAZUS estimates that only 20% of these beds are available on the day of the earthquake, as well as by patients already in the hospital. After one week, 34% of the beds will be back in service. Even after 30 days, only 57% will be operational.

Table 1-27: Expected Damage to Essential Facilities as a Result of a M_w 7.9 Earthquake on the San Andreas Fault

Classification	Total	Number of Facilities With		
		At Least Moderate Damage	Complete Damage	Functionality > 50% at day 1
Hospitals	18	18	0	2
Schools	380	380	0	3
EOCs	12	12	0	1
Police Stations	45	45	0	8
Fire Stations	52	52	0	4

Transportation and Utility Lifeline Damage:

Table 1-28, below, provides damage estimates based on available inventory.

Table 1-28: Expected Damage to the Transportation Systems as a Result of a M_w 7.9 Earthquake on the San Andreas Fault

System	Component	Number of Locations				
		Locations/ Segments	With at Least Mod. Damage	With Complete Damage	With Functionality > 50 %	
					After Day 1	After Day 7
Highway	Bridges	1,306	392	124	936	1,096
Railways	Bridges	4	1	0	4	4
	Facilities	2	0	0	2	2
Bus	Facilities	6	3	0	5	6
Airport	Facilities	39	14	1	36	39
	Runways	34	1	1	34	34

HAZUS performs a simplified system performance analysis for electric power (Table 1-29).

Table 1-29: Expected Electric Power System Performance as a Result of a M_w 7.9 Earthquake on the San Andreas Fault

System	Total # of Households	Number of Households without Service				
		At Day 1	At Day 3	At Day 7	At Day 30	At Day 90
Electric Power	402,426	210,867	121,080	50,577	4,470	0

Fire Following Earthquake

HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this MCE scenario, HAZUS estimates 124 ignitions that will burn about 0.06% of the region's total area, displace about 830 people, and burn about $51.0 million dollars of building value.

Debris Generation

HAZUS estimates 11.9 million tons of debris will be generated. Brick/Wood comprises 36%, with the remainder being Reinforced Concrete/Steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 474,338 truckloads (@25 tons/truck) to remove the debris generated by the MCE for Riverside County.

Shelter Requirement

HAZUS estimates 27,027 households will be displaced. Of these, 20,079 people will seek temporary shelter in public shelters.

Casualties

Table 1-30 provides a summary of the casualties estimated for this earthquake

Table 1-30: Casualty Estimates as a Result of a M_w 7.9 Earthquake on the San Andreas Fault

		Level 1	Level 2	Level 3	Level 4
2 AM (maximum residential occupancy)	Residential	8,102	1,479	122	122
	Non-Residential	51	10	1	1
	Commute	7	11	17	3
	Total	8,159	1,499	141	127
2 PM (maximum educational, industrial and commercial)	Residential	2,960	540	43	43
	Non-Residential	2,676	508	67	67
	Commute	36	56	85	17
	Total	5,672	1,104	195	127
5 PM (peak commute time)	Residential	3,515	642	52	52
	Non-Residential	841	160	21	21
	Commute	98	149	229	46
	Total	4,454	950	302	118

Building-Related Economic Losses

Total building-related losses were $13.2 billion dollars, and 25% of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies, which made up over 67% of the total loss. Table 1-31, below, provides a summary of the losses associated with building damage.

Table 1-31: Building-Related Economic Loss Estimates (millions of dollars) as a Result of a Mw 7.9 Earthquake on the San Andreas Fault

Category	Area	Residential	Commercial	Industrial	Others	Total
Building Loss	Structural	1,532.3	433.1	104.0	71.3	2,140.7
	Non-Structural	5,085.1	975.7	195.6	180.6	6,436.9
	Content	1,032.4	335.8	116.0	60.6	1,544.7
	Inventory	N/A	6.9	18.3	1.7	26.9
	Subtotal	7,649.8	1,751.5	433.9	314.2	10,149.3
Business Interruption Loss	Wage	69.6	566.5	21.4	18.5	676.0
	Income	29.5	742.3	12.8	5.6	790.3
	Rental	459.9	171.5	9.5	10.3	651.1
	Relocation	934.1	253.2	23.3	86.7	1,297.4
	Subtotal	1,493.1	1,733.5	67	121.1	3,021
	Total	**9,142.9**	**3,485.0**	**500.9**	**435.3**	**13,170**

1.9 Reducing Earthquake Hazards in the County of Riverside

This section identifies and discusses the opportunities available for seismic upgrading of existing development and capital facilities, including potentially hazardous buildings and other critical facilities. Many of the issues and opportunities available to the County apply to new development, redevelopment and infilling. Issues involving rehabilitation and strengthening of existing development are decidedly more complex, given the inherent economic and societal impacts.

To prioritize rehabilitation and strengthening projects, the County must consider where its resources are best spent to reduce earthquake hazards in the existing development, and how mitigation programs can be implemented to avoid undue hardship in the community. Certainly, potentially hazardous buildings, critical facilities, and high-risk lifeline utilities will have high priority.

Only the County can set its priorities. This hazard evaluation helps define the scope of the problem.

Recent California earthquakes, with their relatively low loss of life, have demonstrated that the best mitigation technique is our ongoing improvement of building codes as we incorporate lessons from damaging earthquakes, worldwide. Our most recent building codes (1997, adopted by the County of Riverside Department of Building and Safety in July 1999), are a prime example. However, while hazard is reduced by new building codes, it is simultaneously increased by population growth, which leads to development in vulnerable areas, and by the aging of the existing building stock.

It must be stressed that building codes are designed to protect lives, not structures. Under recent building code improvements, buildings will still be damaged, but are far less likely to fail catastrophically.

It also needs to be emphasized that all development choices have some hazards associated with them. Most can and have been mitigated by engineered solutions. The recognition that these solutions require maintenance to function properly has been an expensive lesson to many. The recognition that engineered solutions have a finite design life has yet to be appreciated because of the relative youth of the County's development. This is an expense that will be passed on to future generations. Minimizing engineered mitigation, and maximizing land use planning, is the most environmentally balanced - and in the long-term, the most economical - route to a sustainable, safe community.

1.9.1 1997 Uniform Building Code Impacts on the County of Riverside

Changes in the 1997 UBC represent the most significant increases in ground shaking criteria in the last 30 years. Two changes have special significance for the County of Riverside. The first change is a revision in soil types and amplification factors. The second change incorporates the proximity of earthquake sources in UBC seismic zone 4. Zone 4 is the highest hazard zone and includes most of the County of Riverside. The eastern portion of the County (Blythe Region; Figure 1-29) is Zone 3, so the 1997 near-source seismic provisions of the UBC do not apply. The Riverside County Department of Building and Safety defines the UBC seismic zones in the County as follows:

"The townships T2SR16E, T3SR17E, T4SR18E, T5SR19E, T6SR20E, T7SR21E, T8SR22E are inclusive to the UBC SEISMIC ZONE-4 and the townships lying East of listed above may be considered in the SEISMIC ZONE-3."

Buildings of short predominant period of ground shaking (low-rises) must now also consider soil effects. In the past, only long-period structures (high-rises) were influenced by UBC requirements. The new ground shaking basis for code design is more complicated, because of the wide range of soil types and the close proximity of seismic sources. For the County of Riverside, these code changes are warranted. The new soil effects are based on observations made as a result of the Mexico City and Loma Prieta earthquakes, and affect all new buildings in western and central Riverside County. Most of the western and central portions of the County are affected by the new, near-source design factors (see Figure 1-29). An Atlas, "Maps of Known Near-Source Zones in California and Adjacent Portions of Nevada" was prepared by the California Division of Mines and Geology and published by the International Conference of Building Officials for use with the 1997 UBC (ICBO, 1998). The 1997 UBC contains detailed descriptions of the incorporation of the new near-source and soil parameters; only a summary is provided below:

Soil Types and Soil Amplification Factors: The seismic design response spectra are defined in terms of two seismic coefficients Ca and Cv. These coefficients are functions of the following parameters:

- Seismic Zone (e.g. UBC Zone 0, 1, 2, 3, or 4)
- Soil Type, and
- Near Source Factors (UBC Zone 4 only)

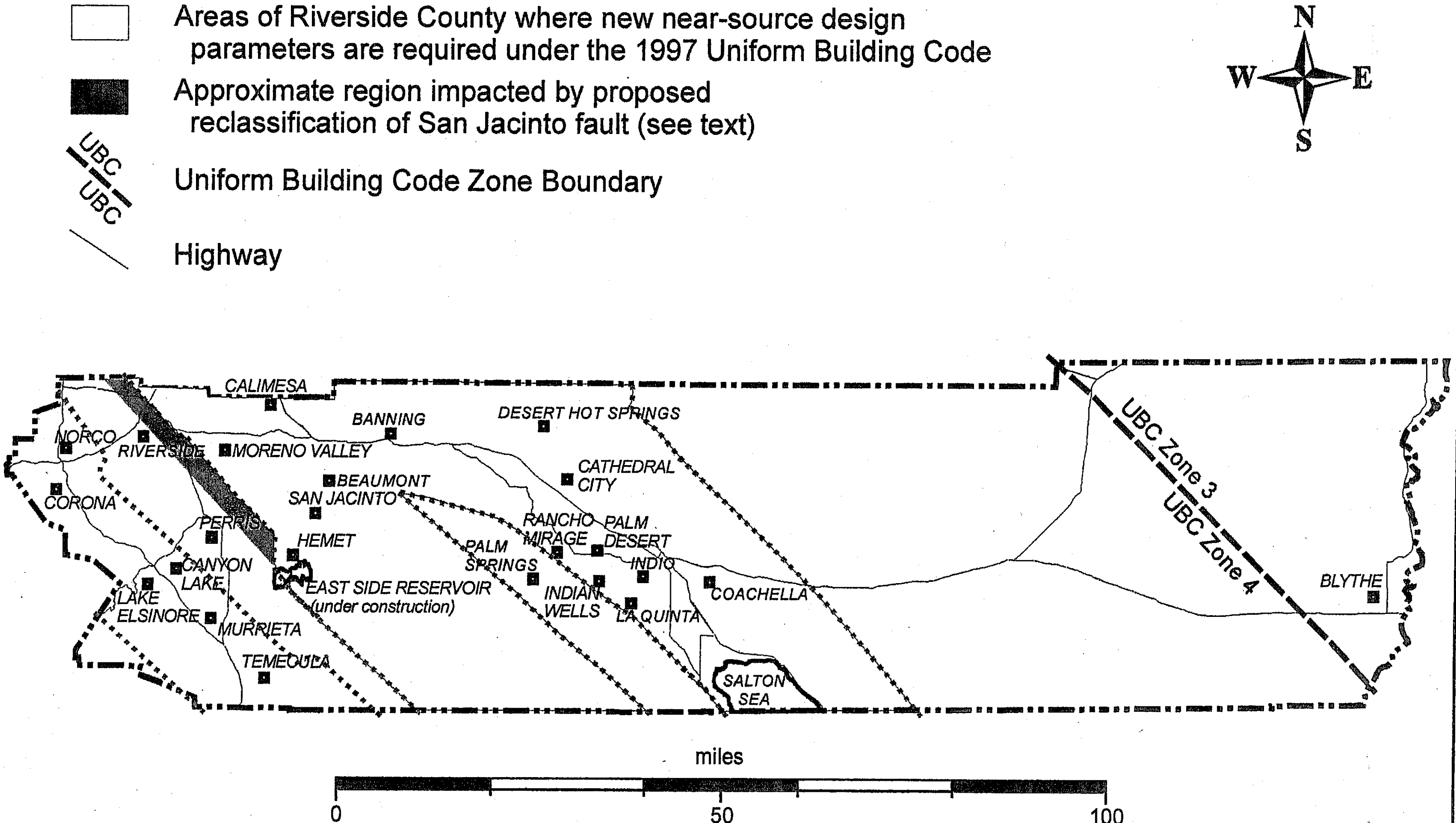
Legend

Areas of Riverside County where new near-source design parameters are required under the 1997 Uniform Building Code

Approximate region impacted by proposed reclassification of San Jacinto fault (see text)

UBC / UBC — Uniform Building Code Zone Boundary

Highway



Earth Consultants International

Natural Hazard Mapping, Analysis, and Mitigation: a Technical Background Report in Support of the Safety Element of the New Riverside County 2000 General Plan

Figure 1-29: Near Source Zone Regions Impacting Riverside County and UBC Zone Boundary

The UBC outlines six soils types, using the average soil properties in the top 100 feet of soil, sediment and rock. Based on geologic mapping prepared for this study, "Engineering Geologic Map of Riverside County", which is described in detail in Chapter 2-Geologic Hazards, we have prepared Figure 1-30 to illustrate the areal distribution of the UBC soil types. The engineering parameters associated with the UBC soil types are outlined, below in Table 1-32.

Table 1-32: 1997 Uniform Building Code Soil Profile Types

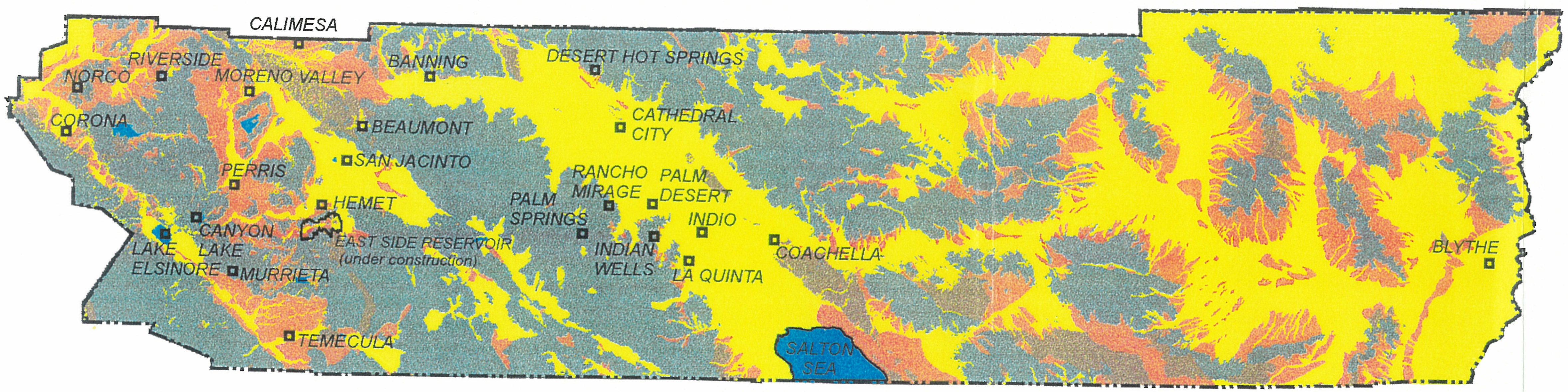
Soil Profile Type	Soil Profile Name/Generic Description	Average Soil Properties for the Upper 100 Feet		
		Shear Wave Velocity (feet/second)	Standard Penetration Test (blows/foot)	Undrained Shear Strength (psf)
S_A	Hard Rock	>5,000		
S_B	Rock	2,500 to 5,000		
S_C	Very dense soil and soft rock	1,200 to 2,500	>50	>2,000
S_D	Stiff soil profile	600 to 1,200	15 to 50	1,000 to 2,000
S_E	Soft soil profile	<600	<15	<1,000
S_F	Soil requiring site-specific evaluation.			

The detailed Geographic Information System (GIS) engineering geology coverage for Riverside County was converted to the basic UBC soil profiles illustrated on Figure 1-30 based on the following assumptions:

- S_A: Does not generally exist in California.
- S_B: Includes all igneous and metamorphic bedrock types.
- S_C: Includes all pre-Quaternary rock types, as well as Pleistocene soils described as "indurated"
- S_D: Generally Pleistocene soils, or soils described as "moderately consolidated"
- S_E: Generally Holocene soils, or soils described as "unconsolidated" or "weakly consolidated"

Figure 1-30: General Uniform Building Code Soil Types

The soil types illustrated herein are based on regional mapping and should not substitute for site-specific evaluation. This map is intended to be used with the 1997 Uniform Building Code, Tables 16-S and 16-T.



N
W E
S

Scale: 1:1,000,000

10 0 10 20 30

Miles

Earth Consultants International

Soil Profile Type	Soil Profile Name/Generic Description	Average Soil Properties for the Upper 100 Feet: Shear Wave Velocity (feet/second)	Standard Penetration Test (blows/foot)	Undrained Shear Strength (psf)
S_A	Hard Rock	>5,000		
S_B	Rock	2,500 to 5,000		
S_C	Very dense soil and soft rock	1,200 to 2,500	>50	>2,000
S_D	Stiff soil profile	600 to 1,200	15 to 50	1,000 to 2,000
S_E	Soft soil profile	<600	<15	<1,000
S_F	Soil requiring site-specific evaluation.			

Near Source Factors: Most of the western and central portions of the County of Riverside (see Figure 1-29) are subject to near source design factors based on the proximity of three major fault systems (Elsinore, San Jacinto, and San Andreas), as well as some smaller fault systems (Chino-Central Avenue, Burnt Mountain, and Eureka Peak). These parameters, new to the 1997 Uniform Building Code (UBC), address the proximity of potential earthquake sources (faults). In earlier versions of the UBC, these factors were present for the design of seismically isolated (base-isolation) structures, but were not applied to other structures until now. Ground shaking that was far more intense than expected occurred near the fault ruptures at Northridge in 1994 and at Kobe, Japan in 1995. The 1997 UBC also includes a near-source factor that accounts for directivity of fault rupture. The direction of fault rupture played 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 directed energy into the City and contributed to extensive damage. Since the rupture direction of a given source cannot be predicted, the UBC requires about a 20% general increase in estimated ground shaking to account for directivity.

Seismic Source Type: Near source factors include a classification of seismic sources based on slip rate and maximum magnitude potential. These parameters are used to classify three seismic source types (A, B and C), in Table 1-33, below.

Table 1-33: 1997 Uniform Building Code Seismic Source Types

Seismic Source Type	Seismic Source Description	Seismic Source Definition	
		Maximum Moment Magnitude, M	Slip Rate, SR (mm/yr)
A	Faults that are capable of producing large magnitude events and which have a high rate of seismicity.	$M_w \geq 7.0$ and	SR ≥ 5
B	All faults other than Types A and C.		
C	Faults which are not capable of producing large magnitude earthquakes and which have a relatively low rate of seismic activity.	$M_w < 6.5$	SR ≤ 2

Type A faults are active and capable of producing large magnitude events. Most segments of the San Andreas and associated faults are classified as Type A, including those in the County of Riverside. The Type A slip rate (>5 mm/yr) and magnitude (Mw 7.0 or greater) are common only to faults near boundaries of tectonic plates (Pacific and North American). Type C seismic sources are considered to be sufficiently inactive and not capable of producing large magnitude events such that potential ground shaking effects can be ignored. Type B sources include all faults that are neither Type A nor C, thus Type B includes most of the active faults in California. The San Andreas fault and most of the San Jacinto fault in Riverside County are Type A faults. The 1997 UBC requires that the locations and characteristics of these faults be established based on reputable sources such as the California Division of Mines and Geology (DMG) and the U.S. Geological Survey (USGS). The fault parameters used by the DMG (ICBO, 1998) in classifying seismic source zones in the County of Riverside, and the UBC "Type" assigned to the fault segments as a result, are summarized in Table 1-34, below.

Table 1-34: 1997 Uniform Building Code Near-Source Zones and Classifications of Faults in Riverside County

Source	Maximum Magnitude (M_w)	Slip Rate (mm/year)	Type
San Andreas - San Bernardino Segment	7.3	24	A
San Andreas - Southern Segment	7.4	24	A
San Jacinto - San Jacinto Valley Segment	***6.9***	***12***	***B***
San Jacinto - Anza Segment	7.2	12	A
Elsinore - Temecula Segment	6.8	5	B
Elsinore - Glen Ivy Segment	6.8	5	B
Elsinore - Whittier Segment	6.8	2.5	B
Chino - Central Avenue Fault	6.7	1	B
Burnt Mountain Fault	6.4	0.6	B
Eureka Peak Fault	6.5	0.6	B

The whole San Jacinto fault should be considered a seismic source Type A. The UBC source zone classification of the San Jacinto Valley segment of the San Jacinto fault as a type B fault is based on its maximum magnitude of 6.9. The UBC has a minimum M_w 7.0 for Type A. However, of any southern California fault, this fault segment has the highest probability of generating a large earthquake in the next 30 years (43%; WGCEP, 1995). It also has a high slip rate (±12 mm/year). Further, there are always uncertainties in identifying fault segments boundaries (and thus maximum magnitudes). For all these reasons, we recommend reclassifying the San Jacinto fault as a Type A. This reclassification would extend the near source zone an additional 5 kilometers as shown on Figure 1-29, and affect the near source factors for the area (Tables 16-S and 16-T; UBC, 1997). Reclassification would mitigate the potential for building damage in portions of the cities of Riverside, Moreno Valley and Perris.

To establish near-source factors for any proposed project in the County of Riverside, the first step is to identify and locate known active faults in the region. The International Conference of Building Officials (ICBO) has provided an Atlas of the location of known faults for California to accompany the 1997 UBC.

The rules for measuring distance from a fault are provided by the 1997 UBC. The criteria for determining distance to vertical faults, such as the San Andreas, are relatively straightforward. The distance to thrust faults (which meet the surface at a low angle) and blind thrust faults (which are shallow dipping but buried) is assumed as 0 for anywhere above the dipping fault plane to a depth of 10 kilometers. This greatly increases the areal extent of high ground shaking parameters, but is warranted based on observations of ground shaking at Northridge.

Summary: Seismic building codes are now undergoing their most significant changes since their inception. These improvements are a result of experience in recent earthquakes, as well as extensive research under the National Earthquake Hazard Reduction Program (NEHRP). Inclusion of soil and near-field effects in the 1997 UBC represents meaningful and important change. Seismic codes will continue to improve under the International Building Code, which is to replace the UBC beginning in the year 2000.

1.9.2 Retrofit and Strengthening of Existing Structures

The new building codes mitigate hazard in new construction. The retrofit and strengthening of existing structures requires the adoption of ordinances. The

County of Riverside is required by state law to adopt an ordinance aimed at retrofitting unreinforced masonry buildings (URMs). Although retrofit buildings may still incur severe damage during an earthquake, the mitigation results in a substantial reduction of casualties by preventing collapse.

Past earthquakes have shown that many other types of structures other than URMs are potentially hazardous. Structures built before the code incorporated lessons from the 1971 Sylmar earthquake are particularly susceptible to damage. These include pre-cast tilt-up concrete buildings, soft-story structures, unreinforced concrete buildings, as well as pre-1940 single-family structures. Other potentially hazardous buildings include irregular-shaped structures and mobile homes.

The County should consider a program to inventory its building stock. Buildings can be identified and inventoried following the recommendations set forth in publications such as "Rapid Visual Screening of Buildings for Potential Seismic Hazards: Handbook and Supporting Documentation" and " A Handbook for Seismic Evaluation of Existing Buildings and Supporting Documentation", both prepared by the Applied Technology Council in Redwood County, California, and supplied by the Federal Emergency Management Agency (FEMA publications 154 and 155, and 175 and 178, respectively).

Often, and understandably, communities seek to cut inventory costs by looking only for hazardous structures. However, it quickly becomes more cost-effective to perform a complete inventory than to return to the same databases and neighborhoods for new partial inventories, as additional hazardous building features are recognized by the engineering community. Knowing the total building stock allows more accurate loss estimations and more able prioritizing of limited resources.

The societal and economic implications of rehabilitating existing buildings are discussed in many publications, including "Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings - A Handbook and Supporting Report", "Typical Costs for Seismic Rehabilitation of Existing Buildings: Summary and Supporting Documentation," (FEMA Publications 174 and 173, and 156 and 157, respectively). Another appropriate source is the publication prepared by Building Technology, Inc. entitled "Financial Incentives for Seismic Rehabilitation of Hazardous Buildings - An Agenda for Action (Report and Appendices).

The building inventory phase of a seismic hazard mitigation program should incorporate GIS technology. The data base should include information such as the location, the date and type of construction, construction materials and type of structural framing system, structural conditions, number of floors, floor area, occupancy and relevant characteristics of the occupants (such as whether the building houses predominantly senior citizens, dependent care or handicapped residents), and information on other building characteristics that may pose a threat to life. In proper format, this information may be input into the HAZUS database and mitigation improvements could be tracked by running updated loss estimation calculations.

Once buildings are identified as potentially hazardous, a second, more thorough analysis may be conducted. This may be carried out by local officials, such as the County's building department, or building owners may be required to submit a review by a certified structural engineer. The review would assess the structural and non-structural elements and general condition of the building, and the building's construction documents (if available). Nonstructural elements should include the architectural, electrical and mechanical systems of the structure. Cornices, parapets, chimneys and other overhanging projections should be considered, as these may pose a significant threat to passers by, and to individuals who, in fear, may leave the building during shaking. State of repair of buildings should also be noted, including cracks, rot, corrosion, and lack of maintenance, as these conditions may decrease the seismic strength of a structure. Occupancy should be noted as this factor is very useful in prioritizing the buildings to be abated for seismic hazards.

For multi-story buildings, high occupancy structures, and critical facilities, the analysis should include an evaluation of the site-specific seismic environment (e.g., response spectra, estimates of strong ground motion duration, etc.), and an assessment of the building's loads and anticipated deformation levels. The resulting data should be weighted against acceptable levels of damage and risk chosen by the County for that particular structure. Once these guidelines are established, available mitigation techniques (including demolition, strengthening and retrofitting, etc.) can be evaluated, weighted, and implemented.

The County of Riverside should set a list of priorities to establish and conduct strengthening of hazardous buildings, once identified. Currently, there are no Federal or State mandated criteria established to determined the required structural seismic resistance capacity of structures. Retrofitting to meet the most current UBC standards may be cost-prohibitive, and therefore, not feasible. The County may develop its own criteria, following a comprehensive development and review process that involves experienced structural engineers, building officials, insurance representatives, and legal authorities. Selection of the criteria may follow review of the seismic performance of similar buildings that had been retrofit prior to an earthquake. For example, upgrading potentially hazardous buildings to 1973 standards may prove inefficient if past examples show that similar buildings retrofit to 1973 construction codes performed poorly and had to be demolished anyway. Many issues must be addressed, including justification for strengthening a building to a performance level less than the current code requirements, the potential liabilities and limitations on liability, and the acceptable damage to the structure after strengthening (FEMA, 1985).

Programs to encourage mitigation of potentially hazardous buildings can be voluntary or mandatory. Voluntary programs have been implemented with various degrees of success in California. Incentives to engender support among building owners include tax waivers, tax credits, and waivers from certain zoning restrictions. Other cities have mandated review by a structural engineer when a building is undergoing substantial improvements.

1.10 Earthquake Safety

An excellent guide for citizens to minimize earthquake hazard in their daily lives was put together by the U.S. Geological Survey in Pasadena. The 1995 guide, *Putting Down Roots in Earthquake Country,* is available on the Internet:

http://www.scecdc.scec.org/eqcountry.html

The sections below contain excerpts from *Putting Down Roots in Earthquake Country.*

1.10.1 Anatomy of a Safe Building

Buildings are built to withstand the downward pull of gravity. Earthquakes push on a building in all directions--up and down, but most of all, sideways. A safe building is one that can withstand the sideways push.

A safe building is built on a firm foundation. The foundation should be solid with a continuous perimeter. The house should be securely fastened to the foundation--so it cannot be pushed off--by drilling bolts through the mudsill and into the concrete of the foundation.

A safe building securely connects the building components together. Mortar in brick and masonry dissolves under even moderate shaking and should not be a structural element. A house with a crawl space (not a slab foundation) needs bracing of the cripple walls that surround the crawl space to resist the sideways push. The opening of a garage door supports nothing and other walls must compensate if that is the first floor of a multistory building.

A safe building is built of strong materials. Damaged concrete and rotten wood undermine the integrity of the building.

A safe building protects the plumbing. Broken water pipes will cause water damage and broken gas pipes are a great fire hazard. Pipes need some but not too much room to sway.

Most houses in southern California are not as safe as they could be. The following presents some common structural problems and how to recognize them. To fix them, you will need to obtain more information. Refer to the recommended resources in Section 1.10.5 and consult with a professional contractor or engineer.

- INADEQUATE FOUNDATIONS: Go into your crawl space and look at your foundation. If the foundation is damaged or built in the "pier and post" style, consult a contractor or engineer about replacing it with a continuous perimeter foundation. Look for bolts in the mudsills. They should be no more than 6 feet apart in single story and 4 feet apart in multi-story buildings. Adding bolts to unsecured houses is one of the most important steps toward earthquake safety. This can be done by a contractor or by someone moderately adept at home maintenance.

- UNBRACED CRIPPLE WALLS: Go into your crawl space and look for panels of plywood or diagonal wood sheathing connecting the studs of the cripple walls. You or a contractor can strengthen the cripple walls relatively inexpensively.

- SOFT FIRST STORIES: Look for large openings in the lower floor, such as a garage door or a hillside house built on stilts. Consult a professional to determine if your building is adequately braced.

1.10.2 Protecting the Contents of Your Home

Earthquake safety is more than keeping our buildings from falling down. We must secure the contents of our buildings to reduce the risk to both our lives and our pocketbooks.

Four people died in the Northridge earthquake because of damage to building contents, such as toppling bookcases. Many billions of dollars were lost due to nonstructural damage.

Nonstructural safety is up to you. The hazard hunt showed potential problem areas of your home. Here we show you just what you can do to secure possessions inside your home. You should secure anything 1) heavy enough to hurt you if it falls on you, or 2) fragile and/or expensive enough to be a significant loss if it falls.

Most hardware stores now carry earthquake safety kits or the raw materials for you to make your own earthquake fasteners.

- SECURING TABLETOP OBJECTS: TVs, stereos, computers, lamps, and chinaware are heavy and costly to replace. They can be secured with buckles and safety straps attached to the tabletop (which allow easier movement of the unit when needed) or with hook and loop fasteners glued to both table and unit. Glass and pottery objects can be secured with nondrying putty or microcrystalline wax, available at many stores.

- IN YOUR KITCHEN: Unsecured cabinet doors fly open during earthquakes, allowing glassware and china to crash to the floor. Many types of latches are available to prevent this--child-proof latches, hook and eye latches, or positive catch latches designed for boats. Gas appliances should have flexible connectors to reduce the risk of fire.

- OBJECTS FROM ABOVE: Ceiling lights and fans can be very heavy and present a significant safety hazard. These should be additionally supported with a cable bolted to the ceiling joist. The cable should have enough slack to allow it to sway. Framed pictures, especially glass-covered, should be hung from closed hooks so that they can't bounce off. Only soft art such as tapestries should be placed over beds or sofas.

- PROTECTING YOURSELF FROM BROKEN GLASS: Window glass can shatter during earthquakes and presents a significant hazard. Windows made from safety glass or covered with a strong mylar film are much safer. Be sure you use safety film and not just a solar filter.

- ANCHORING YOUR FURNITURE: Secure the tops of all, top-heavy furniture such as bookcases and file cabinets to the wall. Be sure to anchor to the stud, and not just to plasterboard. Flexible fasteners such as nylon straps allow tall objects to sway without falling over, reducing the strain on the studs.

Below is a checklist of items that frequently cause injury or are damaged in earthquakes:

THE HAZARD HUNT CHECKLIST

TABLETOP OBJECTS

- Televisions
- Stereo systems
- Art objects
- Glassware & vases
- Computers
- Monitors
- Speakers

IN YOUR KITCHEN

- Unlatched cupboards
- Microwave ovens
- Gas appliances

OBJECTS FROM ABOVE

- Hanging lights
- Ceiling fans
- Picture frames
- Hanging mirrors

GLASS

- Sliding glass doors
- Windows

TALL FURNITURE

- Tall bookcases
- File cabinets
- Armoires
- China cabinets

1.10.3 Personal Safety During an Earthquake

The previous sections have concentrated on making your environment safer before the next earthquake. What should you do during an earthquake? The next big earthquake will be less traumatic if you:

1) prepare an earthquake plan and practice it;
2) know what to do during a big earthquake; and
3) store supplies to make life more comfortable after the earthquake (see Section 1.10.4, After the Earthquake).

1.10.3.1 PREPARE A PLAN

How rational do you think you will be during the violent shaking of a major earthquake? Before the next earthquake, get together with your family or housemates to plan now what you will do during and after that event.

1) Teach everyone to "duck, cover, and hold."

2) Identify safe spots in every room, such as sturdy desks and tables, and interior walls.

3) Teach everyone who could be home alone how to turn off the gas--but only if they smell or hear a leak.

4) Establish an out-of-area contact person who can be called by all family members to relay information. In an emergency, out-of-area calls are often easier to place than local calls.

5) Store supplies and prepare a personal earthquake bag.

Practice your plan often before the next earthquake, so habit can overcome fear. Also work with your neighbors to prepare a neighborhood plan. You may have elderly or disabled neighbors who could need your help. The support of friends and neighbors could reduce the stress for everyone.

1.10.3.2 DUCK, COVER, AND HOLD

During an earthquake, duck or drop to the floor, take cover under a sturdy desk or table, and hold onto it so that it doesn't move away from you. Wait there until the shaking stops.

The area near the exterior walls of a building is the most dangerous place to be. Windows, facades, and architectural details are the first parts of the building to collapse. To stay away from this danger zone, stay inside if you are inside and outside if you are outside.

Do not try to run outside or to another room--severe shaking will make it difficult to move. Duck, cover, and hold--wherever you are. Doorways are no safer than elsewhere in the home. If your building actually begins to collapse, you are safest under a sturdy piece of furniture that can shield you from falling debris.

If you are

- *Indoors:* Duck, cover, and hold. If you are not near a desk or table, drop to the floor against an interior wall and protect your head and neck with your arms. Avoid exterior walls, windows, hanging objects, mirrors, and tall furniture.

- *In a high-rise:* Duck, cover, and hold. Avoid windows and other hazards. Do not use elevators. Do not be surprised if sprinkler systems or fire alarm activate.

- *Outdoors:* Move to a clear area if you can safely do so; avoid power lines, trees, signs, buildings, vehicles, and other hazards.
- *Driving:* Pull over to the side of the road, stop, and set the parking brake. Avoid overpasses, bridges, power lines, signs, and other hazards. Stay inside the vehicle until the shaking is over. If a power line falls on the car, stay inside until a trained person removes the wire.
- *In a kitchen:* Get away from the stove, refrigerator, and cabinets with heavy objects, leaving the kitchen if necessary. Get under a table. Duck, cover, and hold.
- *In a stadium or theater:* Stay at your seat and protect your head and neck with your arms. Don't try to leave until the shaking is over. Then walk out slowly watching for anything that could fall in the aftershocks.
- *In a mall:* Move away from display shelves. Look for sturdy furniture or an interior wall. Duck, cover, and hold.

1.10.4 After the Earthquake

Once the earthquake is over, then we will have to live with its aftermath--the risk of fire, the potential lack of utilities and basic services, and the certainty of aftershocks.

1.10.4.1 FIRE PREVENTION

Earthquakes cause fires. They break gas mains, causing fires, and break water mains, impeding the fighting of fires.

Some tips for reducing the risk:

- Brace your water heater to prevent gas leaks.
- Be sure your gas appliances have flexible attachments.
- Keep a wrench near the gas main and train family members who may be home alone how to use it.

- Shut off gas only if you smell gas or hear a leak.
- If you lose power, use flashlights instead of candles.
- The flame could cause an explosion if gas is leaking, or aftershocks could knock over the candle.
- Keep a fire extinguisher braced securely to the wall, and know how to use it.

1.10.4.2 WHAT YOU WILL NEED

Maintain personal earthquake bags. Keep them where they can be reached even if your building is badly damaged. Take them with you if you evacuate. These should include:

- Medications and medical consent forms for dependents
- Emergency cash
- Copies of vital documents such as insurance policies
- Spare eyeglasses and shoes
- Snack foods, high in water and sugar
- Working flashlights, radio, and extra batteries
- Lightsticks
- Personal hygiene supplies
- Comfort items such as games, crayons, writing materials, outgrown teddy-bears (children regress under stress)
- Electrical, water, transportation, and other vital systems can be disrupted for several days after a large earthquake.
- Emergency response agencies and hospitals could be overwhelmed and unable to provide you with immediate assistance.
- Be prepared to be on your own for 72 hours or more.
- Knowing first aid and having supplies will make life more comfortable and help you keep your sanity after the next earthquake.

Maintain a 72-hour to 1-week supply of the following items:

- Drinking water (minimum one gallon per person, per day)
- First aid kit and book
- Food that is nutritious and liked by family members
- Charcoal or gas grill for outdoor cooking
- Cooking utensils, including a manual can opener
- Extra food for pets, pet restraints
- Working flashlights with extra batteries and lightsticks
- Portable radio and extra batteries

- Plastic bags for tarps, waste, rain ponchos, and other uses
- Sturdy shoes and comfortable clothing

1.10.5 Recommended Resources

The following references provide additional information for earthquake mitigation and preparedness:

Many publications are available from the Governor's Office of Emergency Services (OES) or the Federal Emergency Management Agency (FEMA).

- Before, During, After, OES
- A Guide to Repairing and Strengthening Your Home Before the Next Earthquake, OES & FEMA
- Protecting Your Home and Business from Nonstructural Earthquake Damage, OES & FEMA
- An Ounce of Prevention: Strengthening Your Wood Frame House for Earthquake Safety, OES
- Tremor Troop: Earthquakes, A Teachers Package for K-6, produced by the National Science Teachers Association with support from FEMA

available from the American Red Cross:

- Are You Ready for An Earthquake?
- Your Family Disaster Plan
- Your Family Disaster Supplies Kit

AVAILABLE FROM PUBLISHERS AND BOOKSTORES:

Sieh, Kerry E. and LeVay, Simon, Earth in Turmoil : Earthquakes, Volcanoes, and Their Impact on Humankind (New York, NY: W H Freeman & Co; August 1999)

Bolt, Bruce A., Earthquakes. (New York, NY: W. H. Freeman, Fourth Edition 1999)

Calhoun, Fryar, Earthquake Survival Guide. (Berkeley, CA: Magnet Press, 1991)

Gere, James M., and Haresh C. Shah, Terra Non Firma: Understanding and Preparing for Earthquakes. (New York, NY: W. H. Freeman, 1984)

Iacopi, R., Earthquake Country. (Menlo Park, CA: Lane Publishing Co., 1978, 6th edition)

Kimball, Virginia, Earthquake Ready. (Santa Monica, CA: Roundtable Publishing, 1988)

Lafferty, Libby, Earthquake Preparedness. (La Cañada, CA: Lafferty & Associates, Inc., 1986)

Leach, Joel, Earthquake Prepared. (Northridge, CA: Studio 4 Productions, 1993)
Richter, C. F., Elementary Seismology (San Francisco, CA: W. H. Freeman, 1958)
Sharp, R., Field Guide: Geology of Southern California. (Dubuque, Iowa: Kendall/Hunt Publishing Co., 1994, 3rd edition)
Yanev, Peter, Peace of Mind in Earthquake Country. (San Francisco, CA: Chronicle Books, 1991)

VIDEOS:

An Ounce of Prevention: Strengthening Your Wood Frame House for Earthquake Safety, prepared by OES and available through Blockbuster Video.

AGENCIES:

The following agencies can supply information and materials concerning earthquake safety and preparedness:

Governor's Office of Emergency Services, Southern Region (Los Alamitos), 11200 Lexington Drive, Bldg.283, Los Alamitos, CA 90720-5002, (562) 795-2900, (562) 795-2877 FAX, Greg Renick (562) 795-2941, http://www.oes.ca.gov/

Federal Emergency Management Agency, 500 C Street, SW, Washington, D.C. 20472, http://www.fema.gov/

American Red Cross, Riverside County Chapter, PO Box 2646, Riverside, CA 92516-2646, Phone: 909-328-0013, Fax: 909-328-1222, http://www.redcross.org/

The following agencies can supply information and materials about geology and earthquake hazards:

California Department of Conservation, Division of Mines and Geology, P.O. Box 2980, Sacramento, CA 95812-2980, (916) 445-5716, http://www.consrv.ca.gov/dmg/

U.S. Geological Survey, Earth Science Information Center, 345 Middlefield Road, Menlo Park, CA 94025, (415)329-4390, http://quake.wr.usgs.gov/

Southern California Earthquake Center, University of Southern California, University Park, Los Angeles, California 90089-0742, 213/740-1560, http://www.scec.org/

1.11 Summary of Findings and Recommended Programs

Since it is not possible to prevent earthquakes, local governments, emergency relief organizations, and individuals must take action to reduce the effects of earthquakes. An effective seismic hazard reduction program should include the identification and mapping of geologic and seismic hazards, the improvement and enforcement of building and fire codes, and the expedient retrofitting and rehabilitation of weak structures. Individuals should also exercise prudent planning to provide for themselves and their families in the aftermath of an earthquake.

Aftershocks to major earthquakes will also be large enough to cause damage, and must be part of post-disaster planning.

Major Earthquake Sources in Riverside County

The earthquake effects that pose the greatest hazard are strong ground shaking, liquefaction and surface fault rupture. The faults that pose the greatest threat to Riverside County are described in more detail below:

San Andreas Fault Zone: The San Andreas fault is the "Master Fault", controlling the seismic hazard for Southern California. It bisects Riverside County. Paleoseismology studies indicate that San Andreas fault segments in the County have ruptured simultaneously at least twice (1680 AD and 1450 AD), generating a M_w 7.9, maximum credible earthquake each time. The segments can also rupture individually.

- *The San Bernardino Mountains segment* ruptures about every 146 years and has a 28% probability of rupturing before 2024. This segment can produce a magnitude 7.3 earthquake, with ground accelerations as high as 0.53 g throughout the County.

- *The Coachella Valley segment* has not produced large, surface-rupturing earthquakes in historic times, yet it continues to store strain energy. Paleoseismic studies suggest that the last surface-rupturing earthquake on this segment occurred around A.D. 1680. The segment has a 22% probability of rupturing before the year 2024 and can produce a magnitude 7.1 earthquake.

The **San Jacinto Fault Zone** has a high level of historical seismic activity, with at least ten moderate (M_w 6 - 7) earthquakes between 1890 and 1986. Fatalities in Riverside County resulted from San Jacinto earthquakes in 1899 and 1918. The San Bernardino, San Jacinto Valley and Anza segments of the San Jacinto fault have a 37%, 43%, and 17%

probability, respectively, of rupturing before 2024. Peak ground accelerations could reach 0.53 g.

In Riverside County, the **Elsinore Fault Zone** consists of the Temecula, Glen Ivy, Whittier and Chino segments. Maximum credible earthquakes of M_w 6.7 to 6.8 could occur on these segments, generating peak ground accelerations of about 0.48 g for Riverside County. WGCEP (1995) estimates probabilities of 5% to 16% for these events to occur in the 1994 to 2024 time period.

Riverside County Seismicity

Several historic earthquakes in Riverside County have resulted in up to Modified Mercalli Intensity VIII (severe) ground shaking. Most recently MMI VI was reported in the southern Coachella Valley region of Riverside County for the October 1999 M_w 7.1 Hector Mine earthquake. Several fatalities occurred due to the San Jacinto fault earthquakes in 1899 and 1918.

The two most seismically active faults in California are located in Riverside County (the San Jacinto and San Andreas faults). As a result, more than 45,000 earthquakes ($M>1.0$, 1931-1999) have been located in Riverside County. About 90% of the earthquake epicenters in Riverside County occur along the three major fault zones: San Andreas, San Jacinto, and Elsinore fault zones.

As part of this study, seismic data were imported into a geographic information system (GIS) coverage for Riverside County. The data utilized were seismicity catalogs dating from 1931 to 1999. Data tables linked to each event includes magnitude, depth, and year.

Existing Legislation

Earthquake Fault Zone Mapping for Riverside County: **The Alquist-Priolo Earthquake Fault Zoning Act** was passed in 1972 to mitigate the hazard of surface faulting to structures for human occupancy. Surface rupture is the most easily avoided seismic hazard. Earthquake Fault Zone mapping has been completed by the State Geologist for the 45 quadrangles in Riverside County.

Alquist-Priolo Earthquake Fault Zones have been designated by the California Division of Mines and Geology for the Elsinore, San Jacinto and San Andreas fault zones in Riverside County. The County of Riverside (1991) has applied special studies zone criteria for additional fault systems in the County.

Within these zones, State and Riverside County law requires that proposed tracts of four or more dwelling units investigate the potential for and setback from ground rupture hazards. Before a project can be permitted, a geologic investigation must demonstrate that proposed buildings will not be constructed across active faults. This is typically accomplished by excavation of a trench across the site. An evaluation and written report must be prepared by a licensed geologist. If an active fault is found, a structure for human occupancy cannot be placed over the trace of the fault and must be set back from the fault (generally 50 feet).

The County of Riverside must regulate most development projects within the earthquake fault zones. Projects include all land divisions and most structures for human occupancy. Single family wood-frame and steel-frame dwellings up to two stories not part of a development of four units or more are exempt. However, local agencies can be more restrictive than State law requires.

Since the fault zones in Riverside County have high rates of displacement (>5 mm/yr), and given that new offshoot faults are being ongoingly discovered, all proposed structures should be required to investigate the potential for and setback from ground rupture.

The Seismic Hazards Mapping Act, passed in 1990, addresses non-surface fault rupture earthquake hazards, including liquefaction and seismically induced landslides. However, no seismic hazard mapping pursuant to the 1990 State law has been completed in the County of Riverside, and none are planned to be released for the County through 2000 (DMG, 2000).

Real Estate Disclosure Requirements: Effective June 1, 1998, the Natural Hazards Disclosure Act requires 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. 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.

Geographic Information System Coverage of Faults

Detailed GIS coverage for faults and earthquake fault special studies zones are provided as part of this study. More than 4,300 faults and fault segments are included in the GIS database. Data tables linked to the faults include the fault name, length, age and other pertinent information.

Earthquake Analyses for Riverside County

There are two primary approaches to analyzing the effects of particular earthquakes. Design earthquake scenarios consider the rupture of a specified fault. Probabilistic seismic hazard assessment, considers the potential ground motions from earthquakes on many faults and the relative likelihood of each.

A maximum probable earthquake (MPE) is the largest earthquake a fault is expected to generate within a specific time period, usually 30 or 100 years. MPEs are most likely to occur within the life span of most development, and therefore, are commonly used in assessing seismic risk. . Riverside County's MPE, with a 43% probability of occurrence in 30 years, is a M_w 6.9 rupture of the San Jacinto Valley segment of the San Jacinto fault.

The maximum credible earthquake (MCE) is also often considered in planning and engineering decisions. An MCE is the worst-case scenario, the largest earthquake a fault is believed capable of generating. For Riverside County, the MCE is a M_w 7 .9 based on rupture of the entire southern segment of the San Andreas fault from Cajon Pass to the Salton Sea. The MCE exposes most of the County to very high intensity ground shaking that could last more than 1 minute. Horizontal ground displacements of 25 feet may occur, and losses could be extensive.

Seven other probable earthquake events are likely to occur during the design life of most buildings. These involve earthquakes generated by various segments of the Elsinore, San Jacinto and San Andreas faults. The probable earthquake events will cause damage to vulnerable structures, and may result in localized ground failures. Because of the County's mostly modern building stock, life-safety is not terribly threatened, but the estimated economic losses are substantial.

Probabilistic ground motion values for the County of Riverside are among the highest in southern California, due to the County's proximity to major fault systems with high earthquake recurrence rates. With the exception of the Blythe region, the incorporated cities of Riverside County are exposed to very high and extremely high values that exceed 50% of the force of gravity with a 10% chance of occurring in 50 years. Communities along the San Jacinto fault (Moreno Valley, San Jacinto and Hemet) have a greater risk of ground shaking than those along the San Andreas, because San Jacinto earthquakes have a higher probability of occurrence.

Short-Term Earthquake Alerts Based on Foreshock Probabilities

Half of the major earthquakes on strike-slip faults in California are preceded by immediate foreshocks (smaller earthquakes within 3 days and 10 kilometers of the mainshock). In 1991, for the southern San Andreas fault, a working group of scientists developed a notification system based on patterns of foreshock occurrences, and the likelihood that an anomalous earthquake might be a foreshock to a larger event.

This system could be adapted by the County of Riverside to respond to short-term increases in hazard from the San Andreas fault. Certainly, thoughtfulness and care must be exercised to construct a system that will enhance public safety without promoting rumors or fear. Also, the system must not be a substitute for long-term mitigation efforts. Such potential difficulties do not reduce the usefulness of short-term, pre-event response plans.

Over time, new data and additional research should allow similar systems to be developed for other major southern California faults.

Secondary Earthquake Hazards

Liquefaction is a process by which water-saturated materials lose strength and may fail during strong ground shaking.

Pursuant to the 1990 Seismic Hazard Mapping Act (SHMA), the California Department of Conservation, Division of Mines and Geology (DMG) provides seismic hazard zone maps that identify areas susceptible to amplified shaking, liquefaction, earthquake-induced landslides, and other ground failures. The DMG has not completed any SHMA mapping for Riverside County, nor is any planned through 2000 (DMG, 2000). However, this study provides seismic hazard mapping and information that meets the requirements of the Seismic Hazards Mapping Act, and local agencies should require site specific geotechnical hazard investigations based on this mapping.

In Riverside County, site-specific geotechnical liquefaction hazard investigations should be required for proposed construction projects in zones of moderate, high and very high liquefaction potential. The policy for construction projects involving critical facilities should extend to include all liquefaction ranks from "very low" to "very high".

Geographic Information System Coverage of Liquefaction Hazards in Riverside County

Hazard mitigation policies for proposed projects in Riverside County based on the detailed GIS liquefaction coverage should be implemented as follows: General Construction: special site-specific liquefaction hazard studies should be required in all areas mapped as "Shallow Ground Water, Susceptible Sediments" with the exception of the Blythe region; and Critical Facilities-Lifelines: special site-specific liquefaction hazard studies should be required in all areas of susceptible sediments, including the Blythe region.

Seismically Induced Settlement

In some situations, strong ground shaking can densify soils and cause local or regional ground settlement. Seismic settlement is primarily damaging in areas subject to differential settlement, such as cut/fill transition lots on hillsides. Even slight settlement of the fill can cause significant repair costs. Cut and fill transition lots be overexcavated and fill depths beneath structures should never vary by more than 100%.

Seismically Induced Slope Instability

Landslides and rock falls can be expected throughout the County in a major earthquake. Factors controlling the stability of slopes include: 1) the slope height and inclination, 2) the engineering characteristics of the earth materials comprising the slope, and 3) the intensity of ground shaking. Engineered slopes should be designed to resist seismically induced failure, based on pseudo-static stability analyses after detailed geotechnical investigations. Stability analyses must factor in the intensity of expected ground shaking.

Vulnerability of the Built Environment to Earthquake Hazards

Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning and enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can significantly reduce the scope of an earthquake disaster.

Senate Bill 547 addresses the identification and seismic upgrade of Unreinforced Masonry (URM) buildings. The law encourages identification and mitigation of seismic hazards associated with other types of potentially hazardous buildings, including: pre-1971 concrete tilt-ups, soft-stories, mobile homes, and pre-1940 homes

So far, only five URMs have been identified in the unincorporated regions during a 1990 study. The building owners were notified by mail to comply with the State guidelines. No unique URM ordinance has been passed by Riverside County and no other potentially vulnerable buildings have been inventoried. Statistical estimates expect that about 4000 URMs exist in the County.

The Seismic Hazard Maps developed for this study do not show areas that automatically should be excluded from development. Instead, they show areas where the potential for damage from the mapped hazard is great enough so as to make it geologic investigations prudent. It is far less costly to incorporate hazard mitigation into a structure before it is built than to later add mitigating features.

Potentially Hazardous Buildings and Structures

Most of the loss of life and injuries that occur during an earthquake are related to the collapse of hazardous buildings and structures. Building codes have generally been made more stringent following damaging earthquakes. However, structures in the County of Riverside built prior to improved building codes, have generally not been upgraded to current building code standards, and may, therefore, be hazardous during an earthquake.

Based on observations from past earthquakes, **unreinforced masonry buildings** (URMs) are prone to failure.

Several other common building types are also known to perform poorly, although they have not been targeted for upgrading and strengthening. Of these, of particular concern are **soft-story buildings** (those with a story, generally the first floor, lacking adequate strength or toughness, due to few shear walls, i.e., buildings where the first floor is the garage) and older concrete buildings. No good estimates exist concerning their numbers in Riverside County.

Wood frame buildings with stud walls can perform well in an earthquake, depending on the quality and construction of their foundations.

Pre-cast concrete frame buildings vary in their performance during earthquakes. Inventory estimates indicate about 1,500 pre-cast concrete frame buildings in Riverside County. 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 concern in terms of life loss because they slow down victim rescue. Speedy extrication of trapped victims is critical for victim survival. Establishment of Heavy Urban Search and Rescue teams as recommended by FEMA (1985) has improved victim extrication and survivability, but much more advance planning is needed.

During the 1994 Northridge earthquake, many **mobile homes** shifted or fell off their foundations, rupturing gas lines and starting fires. This hazard is intensified by the relatively high density of homes within mobile home parks. Inventory estimates indicate that more than 70,000 mobile homes are located in the County of Riverside.

Critical facilities are those parts of a community's infrastructure that must remain operational after an earthquake (e.g. hospitals, fire and police stations, emergency operation centers (EOC's) and communication centers), or facilities that pose unacceptable risks if severely damaged (e.g. public schools). There are an estimated 380 schools, 18 hospitals, 100 fire and police stations and 12 EOCs in Riverside County.

High-loss facilities, if severely damaged, may result in a disaster far beyond the facilities themselves. Examples include nuclear power plants, dams and flood control structures, freeway interchanges, bridges, and industrial plants that use or store explosives, toxic materials or petroleum products. Statistical estimates predict 46 dams and 1,978 hazardous waste sites in the County.

Dam Safety

Dams under State jurisdiction (e.g. over 50 feet in height or 50 acre-feet in storage capacity) are required to have inundation maps that show the potential flood limits in the remote possibility a dam is catastrophically breached. Dam inundation maps are prepared by dam owners. The County of Riverside is required by State law to have emergency procedures for the evacuation and control of populated areas within the limits of inundation. In addition, real estate disclosure upon sale or transfer of property in the inundation area is required under recent legislation (AB 1195 Chapter 65, June 9, 1998. Natural Hazard Disclosure Statement). Chapter 3-Flood Hazards of this Technical Background Report provides GIS coverages of potential inundation areas and an assessment of dam vulnerability.

HAZUS Earthquake Scenario Loss Estimations for Riverside County

HAZUS (Hazard U.S.) is designed to produce loss estimates for use by State, regional and local governments in planning for earthquake loss mitigation, emergency preparedness and response and recovery. HAZUS loss estimations are based on best available knowledge and data. The estimations were improved by the mapping of soil type, liquefaction and landslide susceptibility provided as part of this study. They can be further improved by inventories of buildings and infrastructure in Riverside County.

Loss estimation is a valuable mitigation tool. The numbers of casualties and losses provided by HAZUS are best interpreted as order of magnitude values.

Eight scenario earthquakes were chosen for HAZUS loss estimation. Additional details are provided for the two events that represent the maximum probable earthquake (MPE) and the maximum credible earthquake (MCE) for Riverside County.

Estimated Losses Associated with a M_w 6.9 San Jacinto Fault Earthquake (MPE)

A rupture of the San Jacinto Valley segment of the San Jacinto fault has the greatest probability of occurrence (43%) within the lifetimes of structures in the County of Riverside (30 years). HAZUS estimates:

- *Building Damage:* 94 thousand buildings at least moderately damaged (23% of the total number of buildings) in the region; 10,485 buildings will be completely destroyed.
- *Essential Facility Damage:* On the day of the earthquake, 51% of hospital beds are available. After one week, 64% will be back in service. By 30 days, 81% will be operational.
- *Electrical System Performance*: 93,996 out of 402,426 households (23%) will be without service the day of the earthquake.
- *Fire Following Earthquake:* Fires will displace about 360 people and burn about $19.0 million of building value.
- *Debris Generation:* 4,525 thousand tons of debris will be generated, and will require 180,984 truckloads (@25 tons/truck) to be removed.
- Shelter Requirement: 9,345 households to be displaced. 6,964 people will seek temporary shelter in public shelters.
- *Casualties:* A 2:00 am earthquake (maximum residential occupancy) creates the greatest number of casualties (3,500). A 5:00 pm (peak commute time) event causes 2,025 casualties.
- *Economic Loss:* Estimated total economic loss is $5.5 billion dollars, which is equivalent to 9% of the total replacement value of the region's buildings.

Estimated Losses Associated with a M_w 7.9 Southern San Andreas Fault Earthquake (MCE)

This event represents the Maximum Credible Earthquake (MCE) for Riverside County. It is an event that likely occurs only once every several hundred years, but should it occur tomorrow, HAZUS estimates:

- *Building Damage:* 181 thousand buildings (45% of total) will be at least moderately damaged; and 37,013 buildings will be completely destroyed.
- *Essential Facility Damage:* On the day of the earthquake, only 20% of hospital beds are available. After one week, 34% of the beds will be back in service. Even after 30 days, only 57% will be operational.
- *Electrical System Performance:* 210,687 out of 402,426 households (52%) will be without service the day of the earthquake.
- *Fire Following Earthquake:* Fires will displace about 830 people and burn about $51.0 million of building value.
- *Debris Generation:* 11,858 thousand tons of debris will be generated, and will require 474,338 truckloads (@25 tons/truck) for removal.
- *Shelter Requirement:* 27,027 households will be displaced. Of these, 20,079 people will seek temporary shelter in public shelters.
- *Casualties:* A 2:00 am occurrence (maximum residential occupancy) creates the greatest number of casualties (9,926). A 5:00 pm (peak commute time) event causes 5,824 casualties.
- *Economic Loss:* Total economic loss is $13.6 billion dollars, which is equivalent to 22% of the total replacement value of the region's buildings.

Reducing Earthquake Hazards in the County of Riverside

The County must prioritize rehabilitation and strengthening projects in existing development to best allocate resources for earthquake hazards reduction. The proposed mitigation programs should be implemented to avoid undue hardship in the community.

Our most recent building codes (1997), adopted by Riverside County in July 1999, are a prime example of incorporating earthquake lessons further reduce earthquake hazard. However, hazard increases with population growth (that encourages building in vulnerable areas) and with the aging of the existing building stock.

It must be stressed that building codes are designed to protect lives, not structures. Under recent building code improvements, buildings will still be damaged, but are far less likely to fail catastrophically.

It also needs to be emphasized that all development choices have some hazards associated with them. Most can and have been mitigated by engineered solutions. The recognition that these solutions require maintenance to function properly has been an expensive lesson to many. The recognition that engineered solutions have a finite design life has yet to be appreciated because of the relative youth of the County's development. This is an expense that will be passed on to future generations. Minimizing engineered mitigation, and maximizing land use planning, is the most environmentally balanced - and in the long-term, the most economical - route to a sustainable, safe community.

1997 Uniform Building Code Impacts on the County of Riverside

Two significant changes are incorporated into the 1997 Uniform Building Code (UBC) that affect the County of Riverside: revision of soil types and amplification factors; and incorporation of the proximity of earthquake sources in UBC seismic zone 4, which includes most of the County of Riverside. Due to the presence of the three major fault systems (Elsinore, San Jacinto and San Andreas), most of the western and central portions of the County are affected by the new near-source design factors. For Riverside County, the changes are warranted.

Seismic Source Type: Near source factors include a classification of seismic sources based on slip rate and maximum magnitude potential. The San Andreas fault and most of the San Jacinto fault in Riverside County are considered Type A faults.

The UBC source zone classification labels the San Jacinto Valley segment of the San Jacinto fault a Type B fault, but for several important reasons, it should be considered a seismic source Type A. This reclassification would extend the near source zone an additional 5 kilometers, and affect the near source factors for the area. Reclassification would mitigate the potential for building damage in portions of the cities of Riverside, Moreno Valley and Perris.

Seismic codes are now undergoing their most significant changes to date. Seismic codes will continue to improve under the International Building Code, which is to replace the UBC beginning in the year 2000.

Retrofit and Strengthening of Existing Structures

The new building codes address new construction. Retrofit and strengthening of existing structures requires the adoption of ordinances. The County of Riverside is required by State law to adopt an ordinance aimed at retrofitting unreinforced masonry buildings (URMs). Although retrofit buildings may still incur severe damage during an earthquake, the mitigation results in a substantial reduction of casualties by preventing collapse.

Other potentially hazardous buildings include irregular-shaped structures and mobile homes, soft-story structures, unreinforced concrete buildings, as well as pre-1940 single-family structures.

Building inventory is needed in Riverside County. The building inventory phase of a seismic hazard mitigation program should employ GIS technology. In proper format, this information may also be input into HAZUS to run updated loss estimations.

The mitigation program established by the County could be voluntary or mandatory. Voluntary programs to encourage mitigation of potentially hazardous buildings have been implemented with varying degrees of success in California, using various incentives. Some cities mandate a review by a structural engineer when a building is undergoing substantial improvements. Additional options are described in the Policy section (Chapter 5) of this Technical Background Report.

Natural Hazard Mapping, Analysis, and Mitigation: a Technical Background Report in Support of the Safety Element of the New Riverside County 2000 General Plan

CHAPTER 2: SLOPE AND SOIL INSTABILITY HAZARDS

2.1 Physiographic and Geologic Setting

The County of Riverside covers approximately 7,000 square miles of the geologically complex southern California region, from the Colorado River at the Arizona border to within ten miles of the Pacific Ocean. Riverside County spans portions of several major geologic provinces (Figure 2-1):

- ***Peninsular Ranges:*** The western portion of Riverside County and most of its population are in the Peninsular Range province. This province is dominated by right-lateral strike-slip faulting associated with the San Jacinto and Elsinore faults. However, all types of faulting may be found in this block. Temecula, Murrieta and many agricultural areas of southwestern Riverside County lie in the broad structural depression called the Elsinore Trough, formed and bounded by active faults of the Elsinore fault system. The Santa Ana and San Jacinto Mountains are part of the Peninsular Ranges, and were built by movement along earthquake faults.

- ***Salton Trough:*** The desert communities and farmland of the Coachella Valley in central Riverside County are located within the Salton Trough province. Here, the plates are separating and spreading centers exist. The spreading centers continue to the south, into the Gulf of California. At present, the Salton Trough is cut off from the Gulf of California by an accumulation of sediment at the mouth of the Colorado River. The Trough is filled with sediment three miles thick, derived primarily from the Colorado River. Periodically during the last 10,000 years, the Trough has been inundated with water. The most recent inundation formed the Salton Sea in 1905.

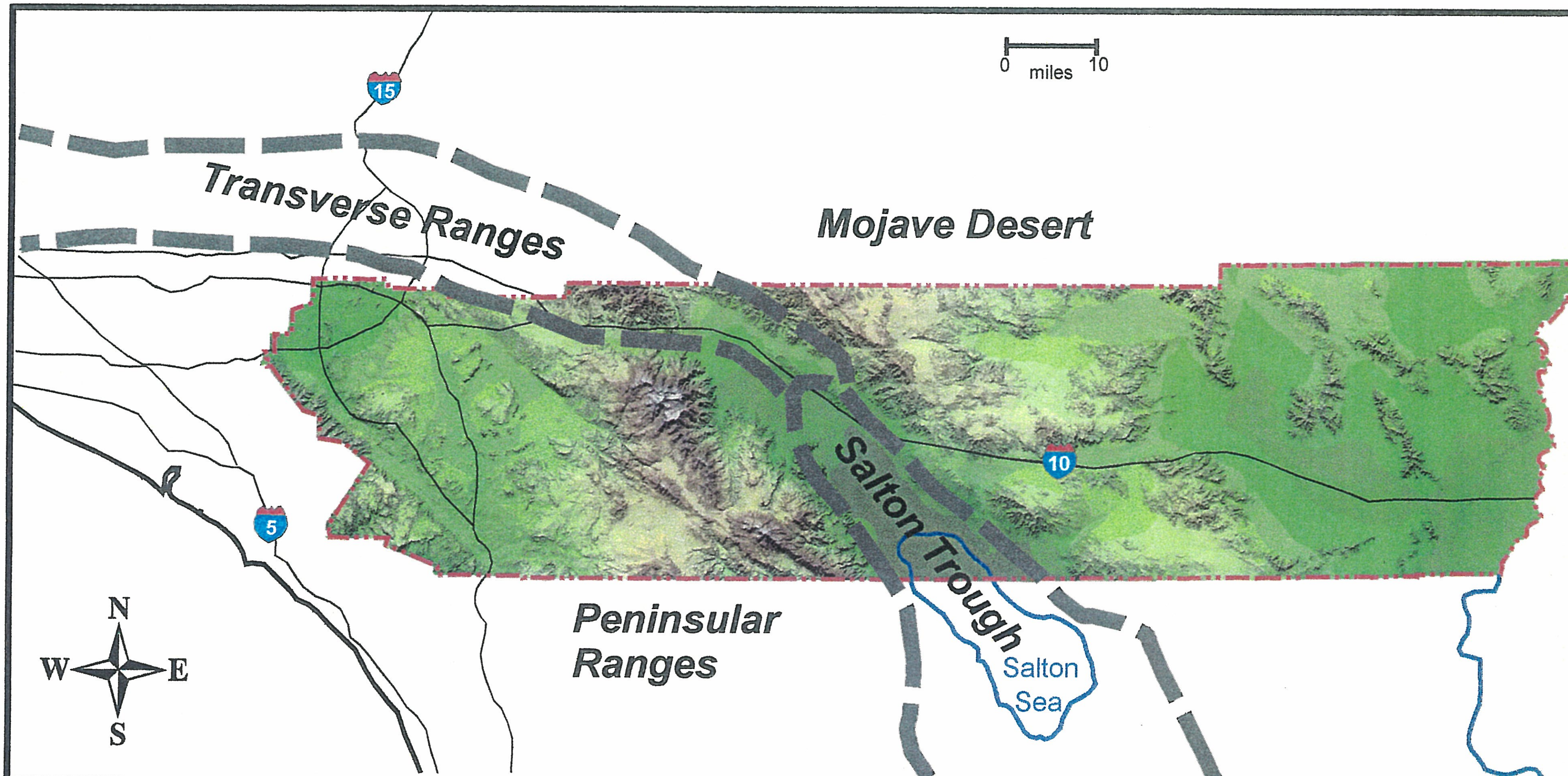
- ***Transverse Ranges:*** Throughout most of the western U. S. are northwest-trending geologic features, a consequence of current plate motions. The trend of the Transverse Range province is a startling exception. These mountains run west to east from west of Santa Barbara to east of San Bernardino. The easternmost San Bernardino Mountains lie in north-central Riverside County. Many of southern California's recent damaging earthquakes occurred on faults that have built the Transverse Ranges, including: the 1971 Sylmar M_w 6.7, the 1991 Sierra Madre M_w 5.8, and the 1994 Northridge M_w 6.7. Although most of this province is located north and west of Riverside County, populated areas such as Riverside, Norco and Corona are at risk from Transverse Range earthquakes occurring on the nearby Cucamonga or Sierra Madre fault systems, about 20 to 25 miles to the north.

- ***Mojave Desert:*** The Mojave Desert province consists of the eastern half of the County, and includes the Blythe area. Compared to the rest of Riverside County, this province has a moderate to low rate of seismicity and very few mapped faults. However, just north of the County, there are numerous active right-lateral strike-slip faults in the Mojave Desert province. These have recently produced the 1992 Landers M_w 7.3 and the 1999 Hector Mine M_w 7.1 earthquakes.

The bedrock exposures of Riverside County consist predominantly of igneous and metamorphic rock with some sedimentary units. These vary from hard rock underlying steep slopes in the San Jacinto Mountains to the weathered granitic rocks of Joshua Tree National Park and hillsides near the city of Riverside.

Alluvial (river) valleys between these mountain ranges contain sediments with significant variation in thickness. Some valleys are filled with a few hundred feet of Pleistocene and Holocene sediments (i.e., the sediments were deposited in the last 2.5 million years). Others, such as the Coachella, San Jacinto and Elsinore Valleys, contain several thousand feet to several miles of sediment. The thickest sediments have been deposited in basins that are being pulled apart by the movement of tectonic plates.

Generally, the hazards of subsidence and hydroconsolidation (soil collapse) are prevalent in valleys, while mass wasting (such as landslides and rockfall) threatens the mountainous regions (Figure 2-2).



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Map of Geologic Provinces of the Riverside County Area

Figure 2 - 1

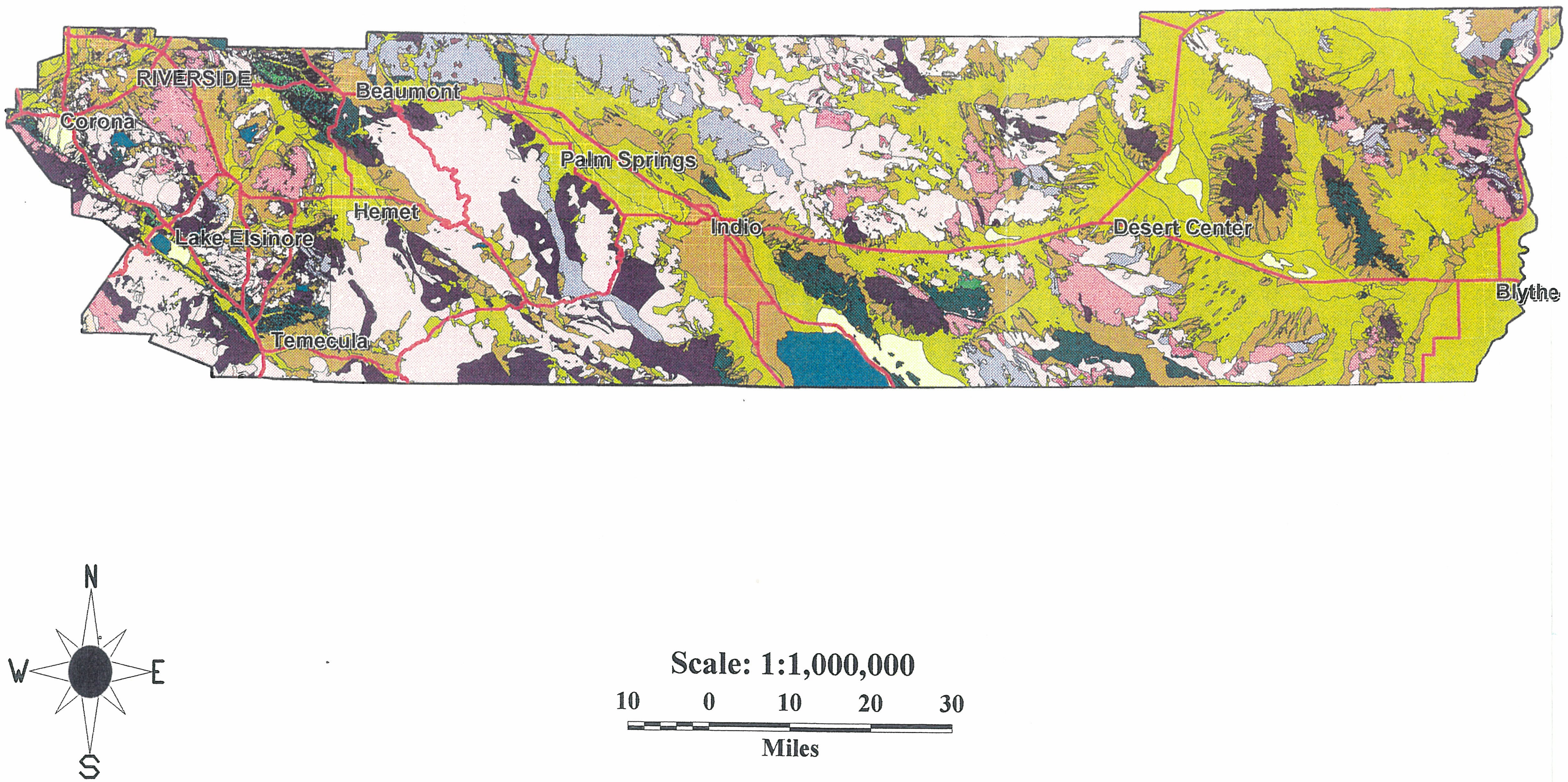

Figure 2-2:

Engineering Geologic Materials Map Riverside County California

(Summary of GIS Data, for additional detail see Plate 2-1 in-pocket)

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Explanation for the Engineering Geologic Materials Map of Riverside County, California

Surficial Materials

- Holocene-age, fine-grained unconsolidated sediments, including stream-, gravity-, lake-, and wind-deposited sediments. Deposits in this category include stream channel, alluvial fan, flood plain, colluvial, dune, and lucustrine sediments.
- Holocene-age, coarse-grained unconsolidated sediments, including stream- and gravity-deposited sediments. Includes alluvial fan, stream channel, and terrace deposits.
- Pleistocene-age, fine-grained unconsolidated to moderately consolidated sediments.
- Pleistocene-age, coarse-grained unconsolidated to moderately consolidated sediments.

Soft-Rock and Moderately Consolidated to Indurated Sediments

- Tertiary-age and older, fine-grained soft rock and moderately consolidated to indurated sediments; generally bedded or fractured. Bedding or fractures assumed to provide planes of weakness along which slope instability could occur.
- Tertiary-age and older, coarse-grained soft rock and moderately consolidated to indurated sediments; typically massive to thickly bedded.

Igneous Rocks of Various Ages, both Volcanic and Plutonic

- Massive Igneous rocks.
- Foliated and/or fractured igneous rocks.

Metamorphic Rocks of Various Ages, including Meta-igneous and Metasedimentary rocks

- Massive metamorphic rocks.
- Foliated and/or fractured metamorphic rocks.

Landslides

- Mapped landslides. For additonal information, refer to the landslide susceptibility map.

Water Bodies

- Lake or Sea

2.2 Geology and Engineering Geology Coverages

As part of this study we have prepared a detailed digital Engineering Geologic Materials map for Riverside County (Plates 2-1). The overall accuracy is 1:100,000. However, certain areas were digitized at greater detail (1;24,000), and others were digitized at lesser detail (1:250,000). The sources of the geologic data are listed in Table 2-1, below.

Table 2-1: Sources Digitized for Geologic Map Coverage
Riverside County, California

Map Name	Scale
Preliminary Geologic Map of the Blythe 30' by 60' Quadrangle, CA and AZ	1:100,000
Geologic Map of California, Salton Sea Sheet	1:250,000
Geologic Map of California, Santa Ana Sheet	1:250,000
Distribution and Geologic Relations of Fault Systems in the Vicinity of the Central Transverse Ranges, Southern California	1:250,000
Geologic Map of California, San Bernardino Quadrangle	1:250,000
Geologic Map of the Big Maria Mountains NE Quadrangle, Riverside County, California, and Yuma County Arizona	1:24,000
Geologic Map of California, Needles Sheet	1:250,000
Digital map of the Santa Ana Sheet, California – provided by Dr. Morton of the USGS	1:100,000

2.2.1 Development of GIS Engineering Geology Map

There are many ways to group rock and sediments with similar characteristics. For planning purposes, it is most appropriate to group features based on engineering properties, that is, the characteristics that have most importance to the built environment. For this report, more that 60,000 polygons *(area features)* were digitized from the geologic map data outlined above (Table 2-1) for Riverside County. These diverse geologic units were combined based on similar engineering properties. The properties were assigned based on the units' descriptions in the literature that accompanies the geologic maps (Table 2-1). Thus the assignments include many assumptions. The map is meant to provide general guidance to support land use decisions and policies. It should not replace or preclude site-specific observation and testing.

The general explanation of geologic and engineering geology unit symbols included with the digital data is as follows:

- The PType (petrologic type) was taken from the geologic maps at the time of digitization. 'Petrologic' includes the type of rock or sediment and its history of formation.

- The description for each of the PTypes was reviewed from the legend or other supporting literature.

- An abbreviated code of engineering attributes, named EType (engineering type), was created based on the PType analyses.

A matrix was developed to convert the geologic units (PType) to engineering type (EType) based on:

- Rock Type (sedimentary, igneous, metamorphic);
- Age (Holocene, Holocene-Pleistocene, Pleistocene, Tertiary-Pleistocene, Tertiary or older);
- Degree of Consolidation (unconsolidated, weakly consolidated, moderately consolidated, indurated, deeply weathered, friable);
- Depositional Environment (alluvial, eolian, marine, lucustrine);
- Texture (fine, coarse, undifferentiated);
- Structure (massive, bedded, slide complex, foliated, fractured).

2.3 Mass Wasting-Slope Instability Hazards

2.3.1 Introduction

Mass wasting is the down-slope movement of rock and regolith (rock products such as soil, sediment, weathered rock and wind-blown deposits) near the Earth's surface, mainly due to the pull of gravity. Mass wasting includes landslides, mudflows, rock falls and creep. It is an important part of the erosional process, as it moves material from higher elevations to lower elevations, where transporting agents like streams pick up the material and move it to even lower elevations. Mass wasting occurs continuously on all slopes; some mass wasting processes act very slowly, others occur very suddenly, often with disastrous results.

As human populations expand over more of the land surface, mass wasting processes become an increasing concern. In a typical year in the United States, mass wasting causes 25 to 50 deaths and over $1.5 billion in damages.

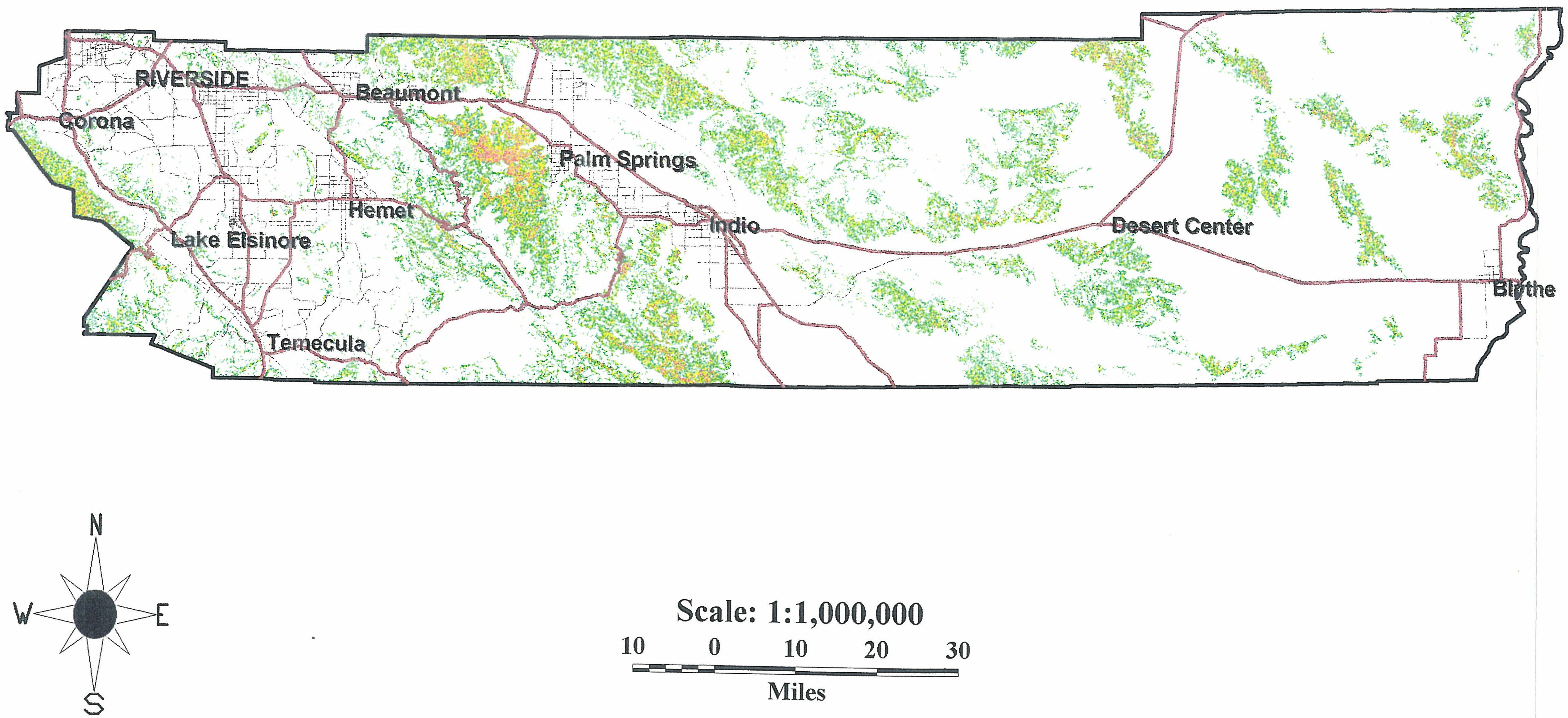
There are predictable relationships between local geology and mass wasting processes. Knowledge of these relationships can improve planning and reduce vulnerability. Slope stability is dependent on many factors and their interrelationships. Rock type and pore water pressure are possibly the most important factors, followed by slope steepness due to natural or man-made undercutting. The igneous and metamorphic basement rock forming much of the County's hillside terrain (Figure 2-3) is generally grossly stable in its natural condition. However, the steepness of the slopes result in locally precarious rocks that could fall as a result of earthquake ground shaking or intense rainfall. In addition, many existing landslides and soil slumps have been mapped within the County, and where slopes have failed before, they will fail again.

Every slope has an angle of repose (Figure 2-4). Slopes less than this angle can resist the pull of gravity and will be at rest. Slopes steeper than this angle will eventually fail. On average, the angle of repose is 35 degrees from horizontal, but varies widely. The looseness or consolidation of the material, planes of weakness and vegetation all affect angles of repose. Thickly forested slopes can maintain a 45 degree angle; however, slopes as shallow as 26 degrees have failed catastrophically in the San Francisco region. The most effective way for the County of Riverside to protect lives and property from mass wasting is to prohibit development on or near slopes that exceed about 30 degrees in steepness. Figure 2-3 illustrates slopes that should be preserved in their natural condition, due to mass wasting potential.

Figure 2-3:

Regions Underlain by Steep Slopes

(Summary of GIS Data, for additional detail see Plate 2-2 in-pocket)



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Slope Angle (in degrees)

- Less than 20
- 20-30
- 30-40
- 40 and Greater

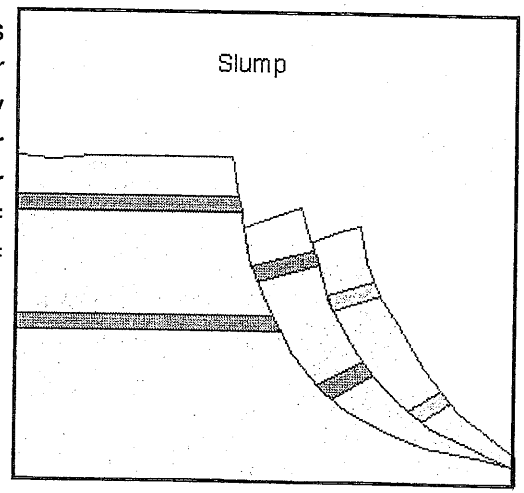
Types of Mass-Wasting Processes: In common usage, any down-slope movement of material is called a landslide. In actuality, landslides are only one of many types of mass wasting, distinguished by style and velocity of movement (Figure 2-4). The processes are separately identified, but are part of a continuum, and distinctions between them are not always sharp. Classification is thus sometimes difficult or arbitrary, but includes these broad categories:

- Slope Failures - a sudden downhill transport of material by sliding, rolling, falling, or slumping.

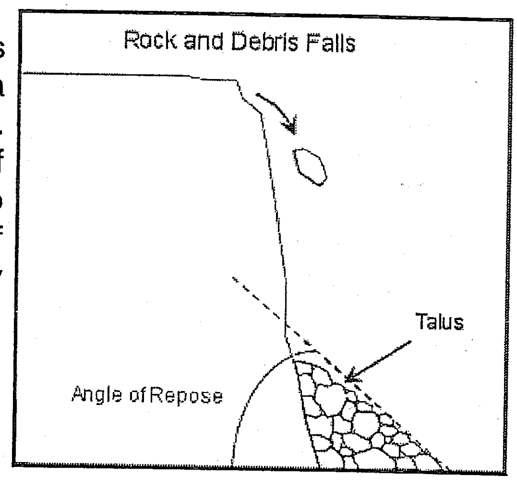
- Sediment Flows - Down-hill transport of rock and plant material mixed with water or air.

Figure 2-4: Slope Failure Types

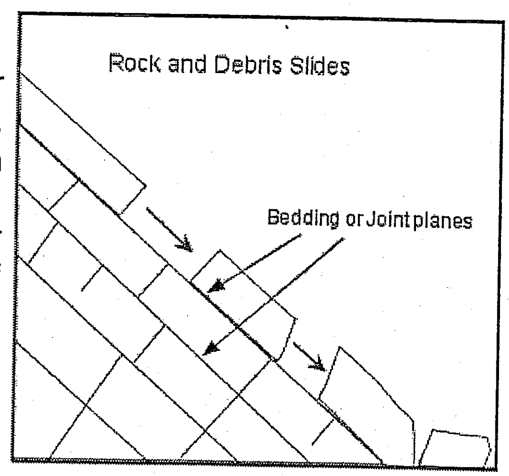
Slumps: Blocks of rock or regolith rotate as units along a concave-upward curved surface. The upper surface of each slump block remains relatively undisturbed. Slumps leave concave scars or depressions on a hill slope. They can be isolated or may occur in large complexes covering thousands of square meters. Slumps often form as a result of human activities, and thus are common along roads where slopes have been steepened during construction. Heavy rains and earthquakes can also trigger slumps.



Falls: Rock falls occur when a piece of rock becomes dislodged. Debris falls are similar, but involve a mixture of soil, regolith, vegetation, and rocks. Because this process involves the free fall of material, falls commonly occur where there are steep cliffs. A rock fall may be a single rock or a mass of rocks. Falling rocks can dislodge other rocks as they collide with the cliff. At the base of most cliffs is an accumulation of fallen material termed talus.



Slides: For many reasons, rock can have planar features that allow rock and debris to slide downhill. Common features include bedding planes, foliation surfaces and joint surfaces. Piles of talus (fallen material) are common at the base of a rock slide or debris slide. Unlike slumps, slides see no rotation of the sliding mass; nor does the mass of material maintain its original shape.



2.3.2 Rock Fall

Areas most at risk from rock fall lie below steep outcrops of relatively well-cemented rock. Such rock underlies much of the County's mountain ranges. Rock fall hazard in the County is high for hillside development, and for development located adjacent to steep slopes. Plate 2-2 and Figure 2-3 illustrate steep slopes where these are most likely to occur. Chapter 1, Seismic Hazards, addresses earthquake-induced rock fall.

2.3.3 Debris Flows

A debris flow is a mixture of rock and/or regolith with water or air. Whether debris will flow downhill depends on numerous factors, including: soil depth and composition, the kind of vegetation, the size and variety of tree roots, subtle variations in slope shape, existence of road cuts or drainage pipes, incongruities in underlying bedrock, and even the presence of animal burrows.

Fine-grained sedimentary rocks are most susceptible to debris flows, especially during exceptionally high rainfall periods. Typically, debris flows occur when a long saturation period is followed by intense bursts of rain, concentrated in just a few hours or days. Water, often traveling beneath the surface from miles away, fills the pores (spaces) in surficial material but not in bedrock or clay, which have far fewer pores and are less permeable (they lack connections between pores). This creates a saturated zone in the surficial material. As the water fills the pores between solid particles, it increases pore pressure and decreases the friction that holds material to a slope. At some point, gravity causes the mass to break loose and slide along the less permeable surface below.

Debris flows, like rockfalls, occur rapidly and without warning. The areas most at risk from debris flows include:

- Canyon bottoms, stream channels, and areas near the outlets of canyons or channels. Multiple debris flows that start high in canyons commonly funnel into channels. There, they merge, gain volume, and travel long distances from their sources.
- Downslope from swales (depressions). Debris flows commonly begin in swales on steep slopes.
- Roadcuts and other altered or excavated areas of slopes. Debris flows and other mass wasting events onto roadways are common during rainstorms,

and often occur during milder rainfall conditions than those needed for debris flows on natural slopes.

- Places where surface runoff of water is channeled, such as along roadways and below culverts.

Where one debris flow has occurred, others will inevitably follow. Much of the County of Riverside is underlain by alluvial fans, deposits that have been shed from streams exiting mountain ranges. These fans and stream washes are evidence of many debris flows in the recent geologic record. In the smallest, most common events, the impact to the County is from boulders transported onto roadways and improvements.

Occasionally, catastrophic debris flow events occur. The greatest southern California debris flow events of the 20th century occurred in 1934, 1938, 1969 and 1978, but there is generally a destructive event each decade. A significant debris flow occurred on July 11, 1999 in the community of Forest Falls, located along the south side of a Mill Creek Canyon in the southeastern part of the San Bernardino Mountains. High-intensity, short-duration rainfall caused the debris flow that resulted in loss of life and property, damaging over 30 homes and numerous automobiles.

Numerous man-made controls have been constructed to reduce the impact of these events on the County. The County operates more than 40 dams, and several hundred miles of levees and storm drains (Riverside County Flood Control and Water Conservation District, 2000).

Without the presence of extensive flood control devices, including large debris catchment basins, the areas downgradient or downstream from unstable slope areas shown on Plate 2-3 may be subject to catastrophic debris flow inundation. Mitigation of debris flow potential should first focus on these areas and geotechnical studies should address the hazard in these zones.

Specific areas susceptible to debris flows are not shown at the scale of the GIS landslide and slope stability map. However, debris flow potential should be evaluated on a site-specific basis for all development areas downgradient from canyons, alluvial fans and swales.

2.3.4 Development of a GIS Landslide and Slope Instability Map

As a major component of this project, we developed digital landslide and slope instability maps (Plate 2-3: Landslide and Slope Instability Map) for Riverside County. The mapping is based on slope steepness (Plate 2-2) and engineering geology characteristics (Plate 2-1: Engineering Geologic Materials Map).

To make the Landslide and Slope Instability Map of Riverside County (Plate 2-3), the following steps were taken:

- Created a slope map for Riverside County by producing a grid map of the U. S. Geological Survey (USGS) Digital Elevation Model (DEM). Vertical Mapper© was used, with grids of 30 meters per side (Plate 2-2).
- Created a grid map of the Engineering Geologic Materials Map (Plate 2-1). Vertical Mapper© was used, with 30 meter grid cells.
- Queried the two grid maps for areas that met parameters for slope instability and landslide susceptibility, as outlined by the flow chart presented in Figure 2-5.
- Drew Landslide Hazard Management Zone boundaries around highly susceptible areas.

BEDROCK SLIDES+

Bedrock Type	Landslide Susceptibility			
	Very High	High	Moderate	Low
	Slope (degrees)			
Foliated and/or Jointed Metamorphic or Igneous Bedrock	>30	20-30	10-20	na
Bedded Sedimentary Bedrock	>20	15-20	10-15	5-10
Nonfoliated and/or Massive Igneous or Metamorphic Bedrock	>40	30-40	20-30	na
Massive Sedimentary Bedrock	>30	20-30	10-20	na

ALLUVIAL OR SOIL SLIDES++

Geologic Material	Slope (degrees)	Landslide Type
Holocene and Pleistocene coarse-grained unconsolidated sediments	>15	Disrupted soil slide
Holocene and Pleistocene fine-grained unconsolidated sediments	>10	Soil slump
	5-10	Soil block slide

Debris flows were not evaluated. Soil lateral spreads considered in the liquefaction susceptibility map.

\+ Modified from: Sadler, Peter, M. and Morton, Douglas, M., Landslides in a Semi-Arid Environment with emphasis on the Inland Valleys of Southern California. Inland Geological Society, 1989.

++ Modified from: CDMG, Special Publication 117, 1997 Guidelines for evaluating and mitigating seismic hazards in California (http://www.consrv.ca.gov/dmg/pubs/sp/117/)

na Not analyzed

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Slope Failure and Landslide Susceptibility Rating Criteria

Figure 2-5

2.4 Expansive Soils

Expansive soils have a significant amount of clay particles which can give up water (shrink) or take on water (swell). The change in volume exerts stress on buildings and other loads placed on these soils. The occurrence of these soils is often associated with geologic units having marginal stability. The distribution of expansive soils can be widely dispersed, and they can occur in hillside areas as well as low-lying alluvial basins.

Expansion testing and mitigation are required by the current grading and building codes. Special engineering designs are used effectively to alleviate problems caused by expansive soils. These designs include the use of reinforcing steel in foundations, drainage control devices, over-excavation and backfilling with non-expansive soil. For new development, future problems with expansive soils can be largely prevented through proper site investigation, soils testing, foundation design, and quality assurance during grading operations as required by the Uniform Building Code, which the County has adopted. Active enforcement, peer review and homeowners' involvement are required to maintain these standards. Homeowners are important because moisture control and modified drainage can minimize the effects of expansive soils. Homeowners should be educated about the importance of maintaining a constant level of moisture below their foundation. Excessive swelling and shrinkage cycles can result in distress to improvements and structures.

Although expansive soils are now routinely alleviated through the County Building Code, problems related to past, inadequate codes constantly appear. Expansive soils are not the only cause of structural distress in existing structures. Poor compaction and construction practices, settlement and landslides can cause similar damage, but require different mediation efforts. Once expansion has been verified as the source of the problem, mitigation can be achieved through reinforcement of the existing foundation, or alternatively, through the excavation and removal of the expansive soils in the affected area.

2.5 Collapsible Soils

Hydroconsolidation, or soil collapse, typically occurs in recently deposited, Holocene (less than 10,000 years old) soils that were deposited in an arid or semi-arid environment. Soils prone to collapse are commonly associated with man-made fill, wind-laid sands and silts, and alluvial fan and mudflow sediments deposited during flash floods. The soils typically contain minute pores and voids. The soil particles may be partially supported by clay or silt, or chemically cemented with carbonates. When saturated, collapsible soils undergo a rearrangement of their grains and the water removes the cohesive (or cementing) material. Rapid, substantial settlement results. An increase in surface water infiltration, such as from irrigation, or a rise in the ground-water table, combined with the weight of a building or structure, can initiate settlement and cause foundations and walls to crack.

A well-documented case of property damage due to collapsible soils occurred in the Murrieta area (Shlemon and Hakakian, 1992). There, alluvium was left in place during rough grading, and later collapsed when ground water levels rose significantly. The ground water rose because of new golf course and residential irrigation. The Murrieta subsidence zone is discussed in more detail in section 2.6.1, below.

In the County of Riverside, collapsible soils occur predominantly at the base of the mountains, where Holocene-age alluvial fan and wash sediments have been deposited during rapid runoff events. In addition, some windblown sands may be vulnerable to collapse and hydroconsolidation. Typically, differential settlement of structures occurs when lawns or plantings are heavily irrigated in close proximity to the structure's foundation. Forensic indications of collapsible soils include:

- tilting floors;
- cracking or separation in the structure;
- sagging floors; or
- non-functional windows/doors.

2.6 Ground Subsidence

Ground subsidence, the loss of surface elevation due to removal of subsurface support, occurs in nearly every state in the United States. It is typically a gradual settling or sinking of the ground surface with little or no horizontal movement, although fissures (cracks and separations) are common. Subsidence is one of the most diverse forms of ground failure, ranging from small or local collapses to broad regional lowering of the earth's surface. While subsidence typically occurs throughout a susceptible valley, additional displacement and fissures occur at or near the valley margin. Susceptible valleys are predominantly filled with unconsolidated sand, and silty sand that includes thin layers of silt and clayey silt. Fine-grained alluvium and organic matter often underlie the fissure areas (Kupferman, 1995). Two types of fissures are reported in the literature: the first are generally straight and correspond to the traces of faults, while the second are more curvilinear on the surface and appear to correspond to the alluvium-bedrock contact at valley margins.

The causes of subsidence are as diverse as the forms of failure, and include dewatering of peat or organic soils, dissolution in limestone aquifers, first-time wetting of moisture-deficient low-density soils (hydrocompaction), natural compaction, liquefaction, crustal deformation, subterranean mining, and withdrawal of fluids (ground water, petroleum, geothermal). Most of the damaging levels of subsidence are induced by human activities. In the areas of southern California where ground subsidence has been reported, the phenomenon is usually associated with the extraction of oil, gas or ground water from below the ground surface, or the organic decomposition of peat deposits, with a resultant loss in volume. Ground subsidence can also occur as a response to natural forces such as earthquake movements, and the evolution of a sedimentary basin as it folds and subsides. Earthquakes can cause abrupt elevation changes of several feet.

Damage caused by subsidence is a world-wide phenomenon that annually costs governments and individuals hundreds of millions of dollars to investigate and to mitigate. According to the National Research Council (1991), the estimated yearly cost of subsidence in the U.S. is about $125 million. Ground subsidence can disrupt surface drainage, reduce aquifer system storage, form earth fissures (cracks and separations), and damage wells, buildings, roads and utility infrastructure. Regional subsidence generally damages structures that are sensitive to slight changes in elevations, such as canals, sewers, and drainages. In the County of Riverside, risk due to regional subsidence is greatest at valley margins.

Subsidence and fissuring have been well-documented in Riverside County (Proctor, 1962; Morton, 1977; Kupferman, 1995) since the early 1960s. Most of the early cases affected only agricultural land or open space. Since the late 1980s, increased urbanization has seen impact on structures designed for human occupancy. In Riverside County, subsidence and fissuring have been caused by falling groundwater tables and by hydrocollapse when groundwater tables rise (Shlemon and Hakakian, 1992). In addition, many fissures have occurred along active faults that bound the San Jacinto Valley and Elsinore Trough. Some controversy surrounded the initial recognition of these features in the late 1980s and early 1990s. However, there is agreement on the geotechnical conditions that can lead to subsidence and earth fissure formation.

Plate 2-4 shows regions of documented subsidence and regions that may be susceptible to subsidence. The latter include all alluvial valley regions. Subsidence has only been documented in three areas (Figure 2-6):

- the Elsinore Trough, including Temecula and Murrieta.
- the San Jacinto Valley from Hemet to Moreno Valley.
- the southern Coachella Valley.

These areas are all potentially sensitive to the withdrawal of ground water. Depending on the depth and mechanical properties of the aquifer and the overlying sediments, they can subside if groundwater resources are not managed properly. Mitigation of ground subsidence usually requires a regional approach to groundwater conservation and recharge. Such mitigation measures are difficult to implement if the geology of the aquifer and overlying sediment are not well understood. Furthermore, conservation efforts can be quickly offset by rapid growth and attendant heavy water requirements (golf courses, for example, consume about 8 acre-feet of water per acre per year). Further, it is not uncommon for several jurisdictions to utilize a continuous groundwater aquifer, and then mitigation requires regional cooperation among all agencies.

2.6.1 Elsinore Trough

Two separate areas of active subsidence are known in the Elsinore Trough (Shlemon and others, 1995), a broad structural depression called a graben, which has been formed by active faulting in the Elsinore fault system (Figure 2-7). Subsidence in the two areas, near the communities of Temecula and Murrieta, was caused by different mechanisms.

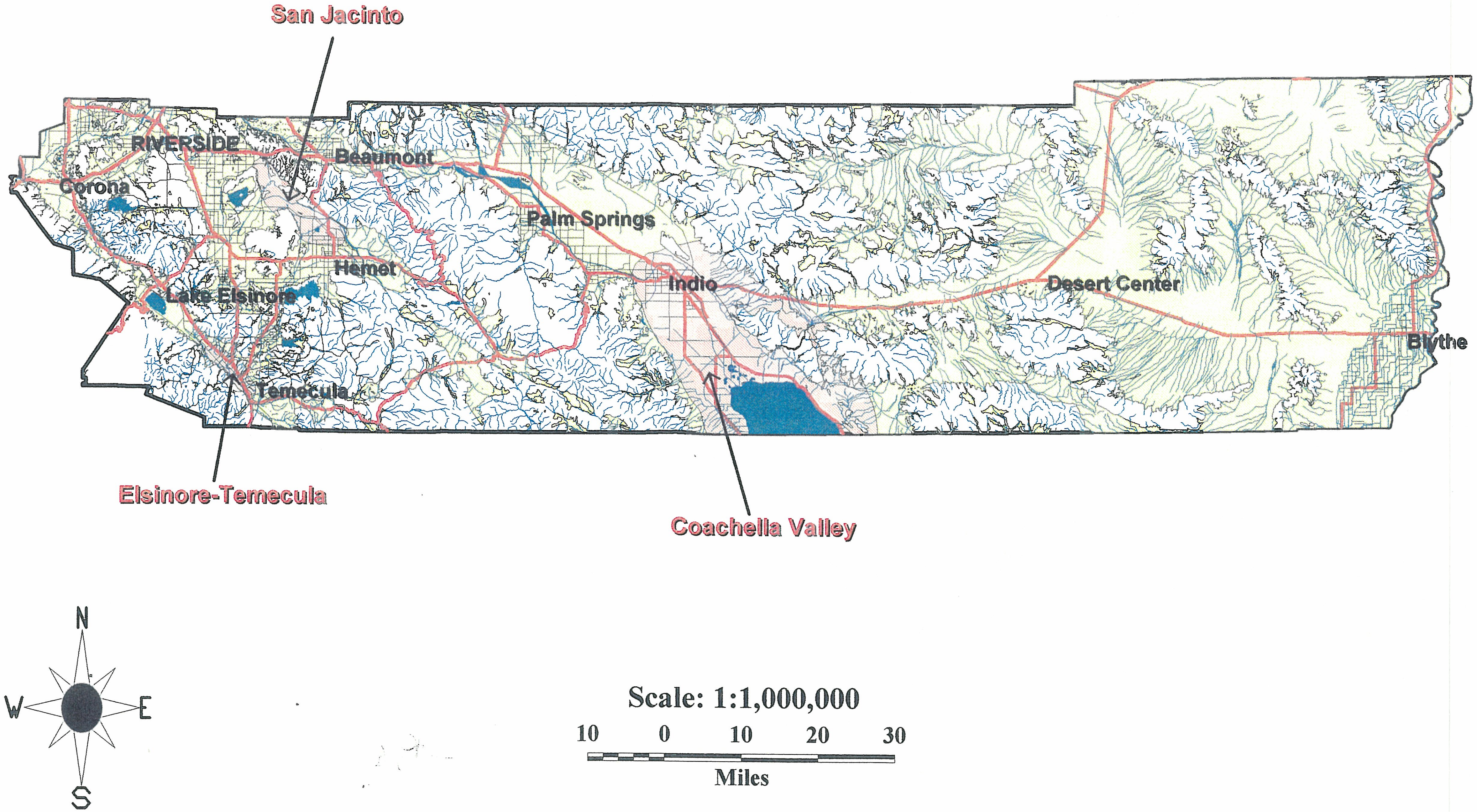

Figure 2-6: Documented Subsidence Areas in Riverside County

(Summary of GIS Data, for additional detail see Plate 2-4 in-pocket)

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Subsidence Zones

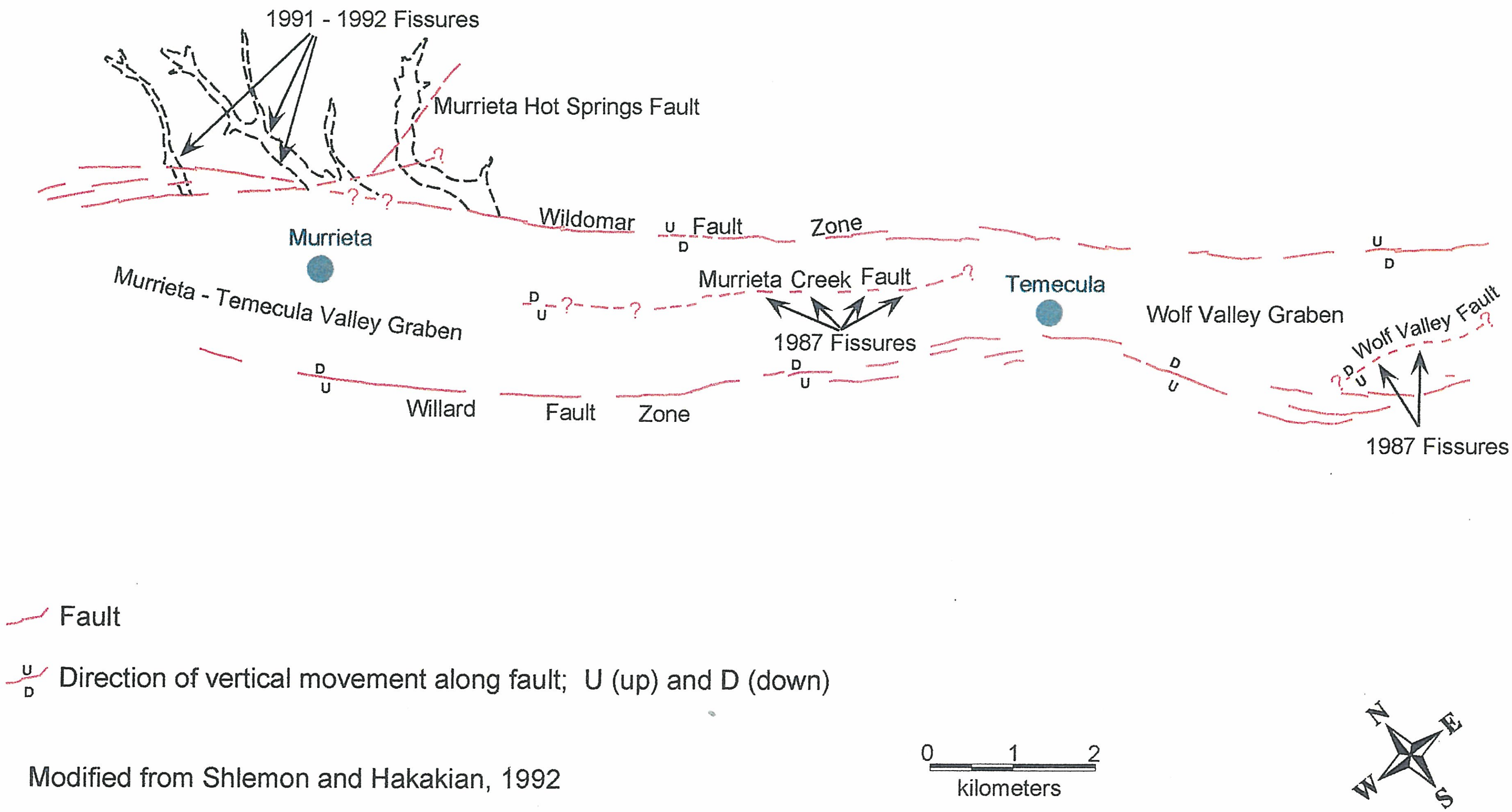
- Areas with Documented Subsidence
- Susceptible Areas

Water Bodies
Lake, Pond, Sea

Major Roads

Water Rivers
Stream, River, Canal or Ditch

Highways



Modified from Shlemon and Hakakian, 1992

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General Map of the Temecula-Murrieta Area Showing Graben-Bounding Faults, and Major Fissure Areas

Figure 2 - 7

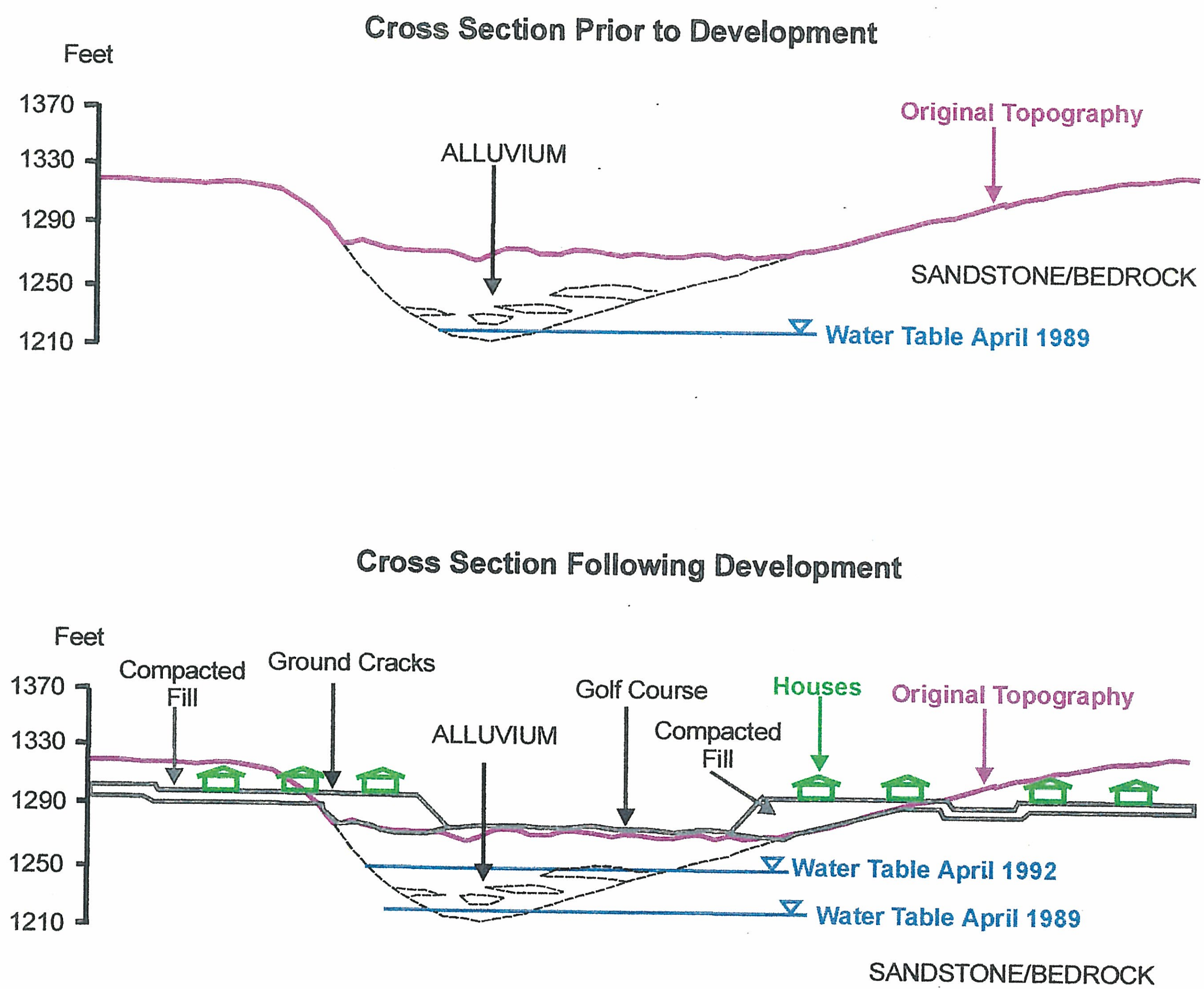
Temecula: The Temecula fissures first appeared in 1987. Short, parallel ground fissures advanced across 7 miles from Wolf Valley in the south to the Temecula-Murrieta valleys in the north (Figure 2-7). By 1991, alleged damages to residential and commercial structures exceeded $50 million (Corwin and others, 1981). The Temecula-area fissures occur in northwest-trending valleys informally designated as the Murrieta, Temecula and Wolf Valley grabens (low areas bounded by faults). In this case, the grabens are approximately one mile wide and bounded by faults of the Elsinore fault system. Studies of the Temecula fissures led to the discovery of two previously unrecognized active faults, the Wolf Valley and the Murrieta Creek. These two faults primarily control the distribution of the Temecula fissures (Shlemon and Hakakian, 1992). Many hypotheses have been proposed to explain the generation of the Temecula fissures. The two most often preferred are:

1) Accelerated pumping of ground water caused deep compaction. Tensile stresses (which pull ground apart) concentrated along nearby, graben-bounding faults.

2) Aseismic creep (fault movement that does not produce earthquakes) occurred along the Wolf Valley and Murrieta Creek faults.

Groundwater pumping is now the favored hypothesis (Shlemon and Davis, 1992), due to the observation that, in the days and weeks prior to subsidence, several new wells began pumping. Since the cessation of pumping, the fissures have not increased in number or size.

Murrieta: The Murrieta fissures first occurred in 1990, primarily in the "California Oaks" subdivision. About 50 discrete fissure areas have formed in and around the 10,000-home development. In litigation, damages associated with the Murrieta fissures were alleged to exceed $100 million by 1992 (Shlemon and Hakakian, 1992). These fissures are similar in appearance to the Temecula fissures, however, they occur within stream-filled channels (Figure 2-8). They occur primarily at the transition between bedrock and alluvium (stream deposits) (Figure 2-8). In places, the alluvium thickness locally exceeds 75 feet, and as much as 60 feet of alluvium was left in-place after site grading. These stream sediments were then surcharged with about 10 feet of compacted fill, and residential structures were built over the fill. Subsequent geotechnical studies (Shlemon and Hakakian, 1992) indicate that ground water levels have risen as much as 50 feet. The rise is attributed to irrigation of a golf course and residential lots.



Modified from Shlemon and Hakakian 1992

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Schematic Cross-Sections Illustrating Collapsible Alluvium and Fissure Formation for the Murrieta Area

Figure 2 - 8

2.6.2 San Jacinto Valley

In the San Jacinto Valley, the ground water table has declined more than 120 feet (Lofgren, 1976). This decline resulted in about three feet of maximum surface subsidence between 1939 and 1959 (Proctor, 1962). Holzer (1984) estimated that most of the subsidence (70-80%) resulted from groundwater withdrawal, with the remainder from subsidence of the sedimentary basin due to local tectonic forces associated with movement of the San Jacinto fault system.

2.6.3 Coachella Valley

The Coachella Valley is filled with more than 10,000 feet of sediments, of which the upper 2,000 feet are water-bearing deposits. The most important source of groundwater recharge to the lower Coachella Valley is the Colorado River (Tyley, 1974). Minor sources of recharge include groundwater inflow from adjacent areas, infiltration of precipitation that falls on the valley floor, and local runoff from the mountains that border the area.

The groundwater basin in the Coachella Valley is currently in a state of overdraft. Groundwater levels are declining at an increasing rate as a result of valley-wide mining for ground water. Water levels declined up to 50 feet from the early 1920s to the late 1940s. In 1949, water from the Colorado River was imported through the Coachella Canal and pumping of ground water decreased. Groundwater levels recovered throughout most of the valley from the 1950s to the 1970s, with some basin recharge attributed to leakage from unlined water canals. Since the late 1970s, the demand for water has exceeded the deliveries of imported surface water, and ground water levels have been declining again as a result of increased pumping. By 1996, in many areas, groundwater levels fell beneath the historical low. These recent declines in water level have the potential to induce new or renewed land subsidence in the Coachella Valley (Ikehara and others, 1997).

In 1948, ground fissuring was observed in the city of La Quinta (Ikehara and others, 1997). This fissuring occurred during a period of rapid ground water withdrawal (Figure 2-9), and therefore, appears related. The 1948 ground fissure occurred near Avenue 52 and Adams Street, in close proximity to the margin of the Coachella Valley and the alluvial contact with rock of the Santa Rosa Mountains. Based on a 1948 photograph presented in Ikehara and others (1997) obtained for this study, the fissure is 20 feet long and up to one foot wide. A recurrence of this or similar ground fissures would clearly result in damage to overlying structures.

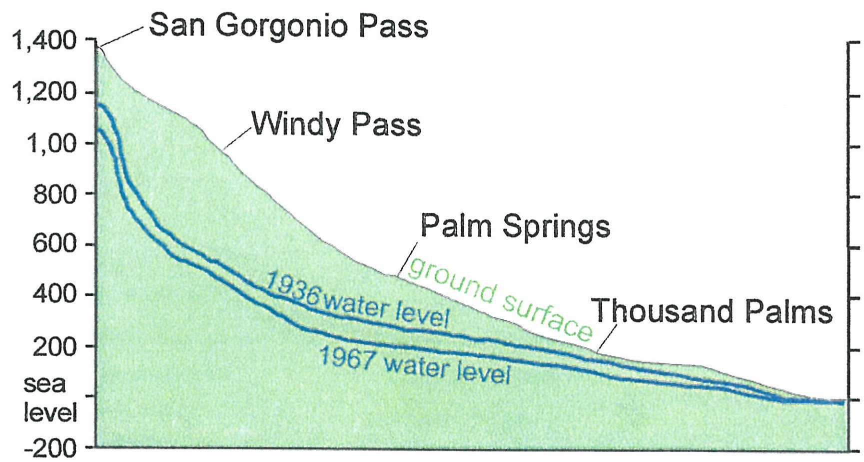
Recent studies by the U.S. Geological Survey (USGS) have determined that long-term declines in water levels of sufficient magnitude to induce land subsidence have occurred in portions of the Coachella Valley. In 1996 the USGS (Ikehara and others, 1997) established a precise geodetic network to monitor elevation changes and thus land subsidence in the lower Coachella Valley. It currently monitors 17 locations. Of the 15 measurement locations with historical elevation data, fourteen indicate cumulative subsidence from -0.2 to -0.5 feet since the 1930s. However, the magnitude of these subsidence determinations is within the range of uncertainty (±0.2 feet), so these measurements do not unequivocally indicate that subsidence has occurred.

Where data were available, the USGS plotted historical subsidence over time and compared this to water level changes in nearby wells. Subsidence occurred during periods of water level decline, and rebound occurred during intervening periods of water level recovery. This correspondence suggests that land subsidence is occurring, and a significant part of the measured subsidence likely has occurred since 1991, about the time when water levels began declining below their previously recorded low levels (Steve Robbins, personal communication, 1999).

The U.S. Geological Survey (Ikehara and others, 1997) plans to precisely measure elevation every 2-3 years to determine the magnitude and extent of subsidence. In addition, monitoring of well water-levels is required to assess the relationship between ground water overdraft and regional subsidence.

As is true elsewhere, mitigation of subsidence in the Coachella Valley will require a regional approach to groundwater conservation and recharge. Because overdraft of the Coachella Valley groundwater basin is caused by all water users in the area, and it is not feasible to predict exactly where ground fissures will appear, one potential mitigation measure is to fund structural repairs or replacement with costs passed on to water users through the Coachella Valley Water District.

Figure 2-9: A comparison of water-table profiles in the Coachella Valley between 1936 and 1967 shows that water levels declined in most of the valley as a result of increased groundwater withdrawls, but in the extreme southeastern part of the valley, water levels remained the same because of historic leakage from the unlined Coachella Canal.



Modified from: Tyley, S. J., 1974, Analog model study of the ground-water basin of the upper Coachella Valley, California: U. S. Geological Survey Water-Supply paper 2027, 77p.

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Groundwater Table Profile of the Upper Coachella Valley

Figure 2-9

Currently, groundwater recharge in the Coachella Valley area is minimal. The Coachella Valley Water District operates a pilot recharge facility south of Lake Cahuilla near Avenue 62 and Madison Street, in the city of La Quinta. The facility has been in operation since 1996 and has shown that recharge is feasible there (Steve Robbins, personal communication, 1999). Design of a full-scale facility at this location will likely begin within the next several years.

2.6.4 Development of a GIS Subsidence Hazard Map for Riverside County

A digital Subsidence Hazard Map for Riverside County was prepared at a scale of 1:250,000 (Plate 2-4). The accuracy of the Subsidence Hazard Map is about 1:100,000. Plate 2-4 focuses on land subsidence initiated exclusively by the withdrawal of ground water from alluvial valleys. As discussed in preceding sections, this is a widespread problem which has been implicated in several areas of documented subsidence.

Surface Classification - To facilitate the subsidence analysis and prediction, the ground surface of the study area was divided into three categories based upon the data collected (Plate 2-4):

1) Areas of documented subsidence
2) Areas of potential subsidence
3) Areas of low to no potential for subsidence.

Areas of potential subsidence are generally underlain by Holocene- and Pleistocene-age alluvial sediments, with the potential for the presence of groundwater. The concept is that alluvial valleys, especially is underlain by thick sediment sequences, have the potential to subside.

2.7 Wind Erosion

Wind-induced soil movement, or wind erosion, is a common and serious environmental problem attracting global attention. Wind erosion damages land and natural vegetation by removing soil from one place and depositing it in another. It mostly affects dry, sandy soils in flat, bare areas, but wind erosion may occur anywhere that soil is loose, dry, and finely granulated. It causes soil loss, dryness, deterioration of soil structure, nutrient and productivity losses, air pollution, and sediment transport and deposition. The presence of dust particles in the air is a source of several major health problems. Atmospheric dust causes respiratory discomfort, may carry pathogens that cause eye infections and skin disorders, and reduces highway and air - traffic visibility. Dust storms can cause additional problems. Buildings, fences, roads, crops, trees and shrubs can all be damaged by blowing soil, which acts as an abrasive.

Soil movement is initiated as a result of wind forces exerted against the surface of the ground. For each specific soil type and surface condition there is a minimum velocity required to move soil particles. This is called the threshold velocity. Once this velocity is reached, the quantity of soil moved is dependent upon the particle size, the cloddiness of particles, and the wind velocity. Suspension, saltation, and surface creep are the three types of soil movement which occur during wind erosion (Figure 2-10). While soil can be blown to virtually any height, over 93% of soil movement takes place within one meter of the ground.

Wind and wind-blown sand are an environmentally limiting factor throughout much of Riverside County. Approximately 20% of the land area of Riverside County is vulnerable to "high" and "very high" wind erosion susceptibility (Figure 2-11). The Coachella Valley, the Santa Ana River Channel in northwestern Riverside County, and the community of Hemet are zones of high wind erosion susceptibility.

2.7.1 Coachella Valley

Wind-blown sand is a well-recognized hazard for developments in the Coachella Valley, with greatest activity in the central region from Palm Springs to the northern portion of La Quinta. Wind-blown sand has forced abandonment of dwellings and subdivided tracts in the central Coachella Valley (Sharp, 1980). Utility poles in the area are frequently armored with sheet metal around the base to protect against wind erosion. Caltech investigators interested in measuring the destructive effects of wind near Garnet Hill located several sample plots with sampling materials that included 2 to 3-inch thick lucite rods, common bricks, hard crystalline rock, and gypsum-cement cubes. As a result of wind erosion, one lucite rod was severed, and many of the brick and rock samples were eroded up to several centimeters per year.

High winds often blow down the axis of the Coachella Valley and shelter from these winds controlled the location of initial development in the upper Coachella Valley. Most of the early development of the winter recreational resort communities began in the lee of the protecting mountains. The Coachella Valley area, is undergoing rapid development and changes in land use that increase wind-blown sand problems. Development has now moved into the central axis of the valley, the high-wind areas. These growing communities need additional mitigation measures.

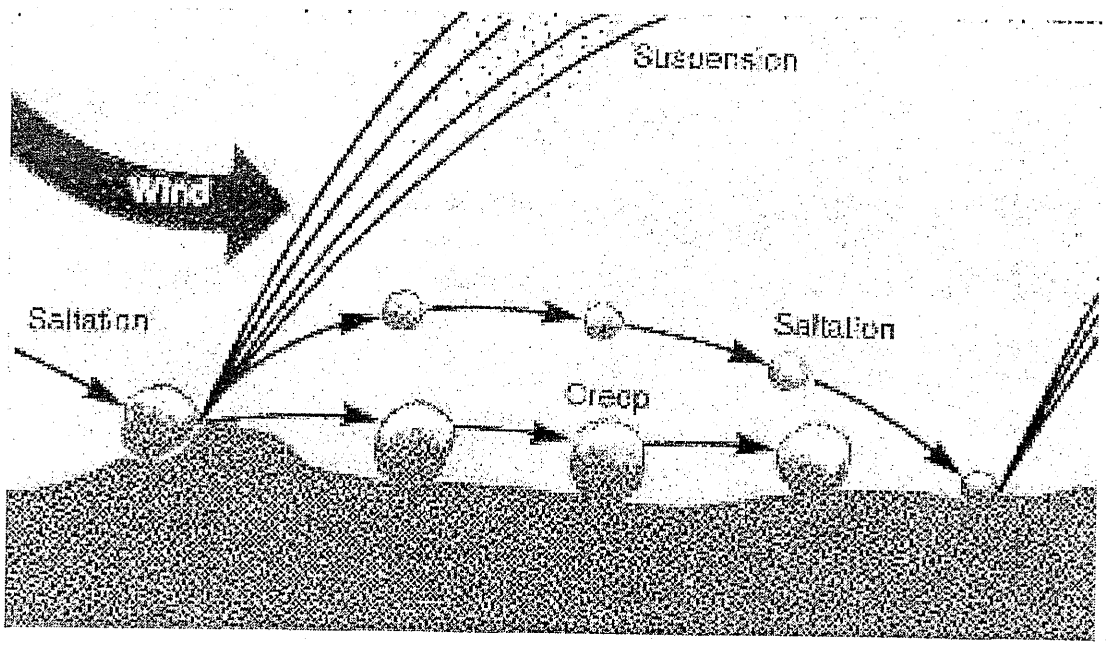


Figure 2-10: Wind-induced soil movement is initiated as a result of wind forces exerted against the surface of the ground and includes suspension, saltation, and surface creep. Soil can be blown high into the atmosphere, however, most soil movement takes place at or below one meter.

According to El-Aghel (1984), five physical factors determine the distribution and intensity of the wind-blown sand hazard in the Coachella Valley:

- <u>Orientation of hill and mountain masses</u>: Mountains bordering the valley have their long axes aligned northwest-southeast and thus offer little resistance to the free flow of air down the long axis of the Coachella Valley. The narrow San Gorgonio Pass accelerates the wind, which improves its ability to pick-up and transport sand.

- <u>Nature of the bedrock</u>: Granitic and metamorphic rocks that comprise the local mountains readily weather to grain sizes that are easily transported by wind.

- <u>Location of the Whitewater River Floodplains</u>: The Whitewater River is the main stream feeding the upper Coachella Valley. It drains much of the adjacent parts of the San Bernardino Mountains. During floods, large quantities of sand and gravel are deposited on the Whitewater floodplains, at the eastern end of San Gorgonio Pass, where wind velocities are the greatest.

- <u>Slope of the valley floor</u>: From the summit of the San Gorgonio Pass (elevation about 1,200 feet) to the Salton Sea (below sea-level), the valley floor slopes without interruption, thereby allowing air to move unhindered.

- <u>Climate</u>: The Coachella Valley is a desert. Its sparse vegetation exposes surficial materials to wind. Precipitation in the adjacent mountains is often short and intense, leading to torrential run-off and considerable deposition on the valley floor.

The primary source of sand in the Coachella Valley is the Whitewater River. Increases in the amount of wind-blown sand are related to episodic flooding of the Whitewater River (Sharp, 1964, 1980). A 15-fold increase in wind erosion rates was noted following heavy floods (Sharp, 1980). These floods changed the character of the Whitewater River drainage from stony to sandy. Typically, within a few months, the drainage bottom returned to a predominantly stony appearance.

Mitigation of wind-blown sand erosion is directly related to reduction of flood potential of the Whitewater River, and presents an important mitigation opportunity for Riverside County. Hedges and other barriers are unlikely to be as effective in mitigating wind erosion.

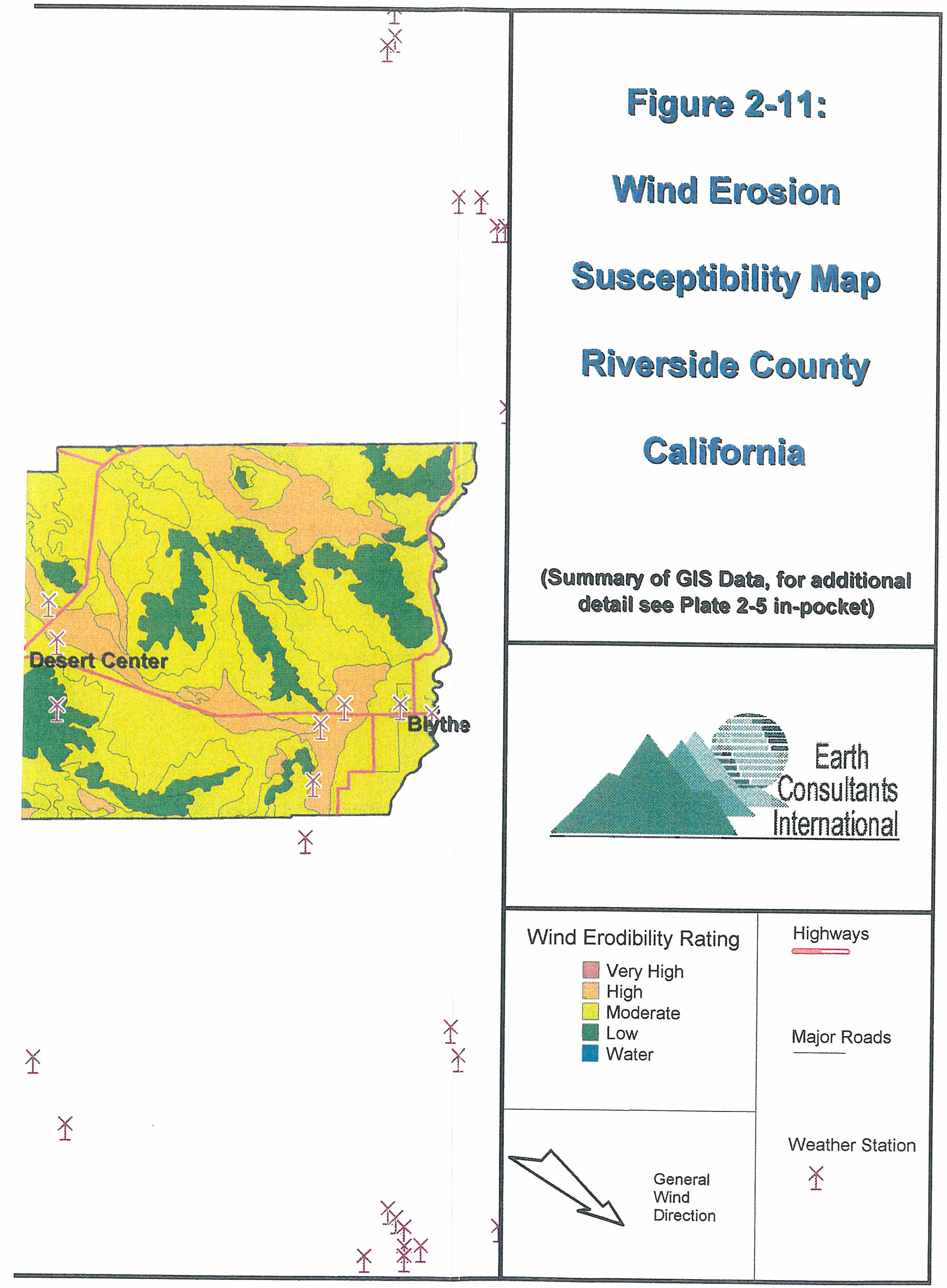


Figure 2-11: Wind Erosion Susceptibility Map Riverside County California

(Summary of GIS Data, for additional detail see Plate 2-5 in-pocket)

Man has exacerbated the wind erosion conditions by removing native vegetation, building roads and other infrastructure across the valley floor. Recreational land uses, especially use of off-road vehicles, accelerates erosion in the area.

2.7.2 Development of a GIS Wind Erosion Susceptibility Map for Riverside County

A digital Wind Erosion Susceptibility Map was prepared as part of this study. The wind hazard map is generally considered accurate to 1:100,000, and is presented in Plate 2-5 at a scale of 1:250,000.

Map information from the U.S. Department of Agriculture State Soil Geographic (STATSGO) data base was captured as 1:250,000 scale USGS topographic quadrangle units. STATSGO included a soils map of the state of California that was refined for Riverside County. These data included a classification of the soil within each polygon for wind erosion susceptibility. This wind erodibility number was used to assign each polygon a WER (Wind Erodibility Rating). WER classification was assigned as follows:

1 = Very Highly susceptible to wind erosion
2 = High susceptibility
3 = Moderate susceptibility
4 = Low susceptibility
5 = Water

Digital data for this mapping are provided to the County of Riverside and should be utilized to support land use decisions.

2.8 Recommendations for Mitigation of Soil Instability Hazards

2.8.1 Regulation and Governance

Land use and development in Riverside County is regulated by the Riverside County Comprehensive General Plan, County Building and Grading Ordinances *(including the Uniform Building Code)*, the California Environmental Quality Act (CEQA), and specific resolutions adopted by the County Board of Supervisors (Kupferman, 1995). Since July 1, 1999, the County of Riverside has enforced the 1997 Uniform Building Code (UBC) by State Mandate, per California Health and Safety Code, Section 18938. This Technical Background Report will be utilized to support and implement policies for a new Safety Element of the County General Plan. In addition, under the California Environmental Quality Act (CEQA), the County of Riverside is required to prepare initial studies addressing potential adverse impact of proposed projects. Additional mitigation of geologic hazards in Riverside County is established by the Land Use Ordinance of Riverside County, Ordinance 348, amended October 21, 1999.

2.8.2 Mitigation of Slope Instability

As a result of this study, a GIS-based Landslide and Slope Instability Map has been prepared for Riverside County. The mapping defines "Landslide Management Zones". Proposed development in these areas should be required to conduct geotechnical studies to determine slope stability and provide mitigation measures where needed.

Slopes steeper than 10% can be made unstable by activities of man. Therefore, it is recommended that the County adopt hillside development guidelines. Hillside development guidelines should enforce existing grading codes, and can require aesthetic guidelines that improve the hillside appearance and preserve slope stability. For example, guidelines could require that slopes be returned to their natural appearance and steepness after grading and undergrounding for a reservoir.

To reduce debris flow potential, not only do the existing debris basins require continued maintenance, but environmental preservation of the mountain ranges is required. Development of the hillside terrain will only increase the potential for debris flows. Thus the County should actively pursue natural preservation of these ranges. The County should also establish an education and warning system to activate following significant wildland fires on the hillsides above the County. This can include mailers to households in the affected areas, public meetings, and/or door-to-door education.

The best mitigation measure is to preserve steep slopes as natural, however, for regions altered by development or fire, engineering mitigation measures are required. For individual homeowners, below are some general rules suggested by the L.A. County Department of Public Works (1999) to be followed in most cases involving flood waters, debris and erosion:

- NEVER underestimate the power of debris flows.
- TRY to direct debris flows away from improvements.
- AVOID trying to control or confine the flows more than is absolutely required.
- CLEAR a path for the debris.
- ALWAYS place protection to deflect debris, not to dam or stop it.
- DEBRIS will often enter a building through windows - board them up.
- REMEMBER to protect the home first, then consider what time and money are available to protect other less valuable objects such as swimming pools or landscaping.
- TRY to install more permanent measures to protect your home. In general, the problem of debris flows will exist for several years after a burn. Sandbags usually last for only a year.
- ALWAYS work with adjacent affected property owners.
- BE prepared to sacrifice the use of portions of your property to achieve the greatest amount of protection.
- AVOID altering drainage patterns that could worsen conditions for your neighbor.
- DO NOT wait until the storm season to start your planning and installation of flood, debris, and erosion control facilities. Start as soon as possible. Once debris flows and flood waters begin, it is usually too late to install protection.
- PROTECTION is not always pleasing to the eye and appearance should not dictate location or type of installation.
- BE prepared to personally observe and maintain installations during storm periods, for in many cases a minor correction will prevent major failure. However, do not take any unnecessary risks.
- SHOULD flood, debris, and erosion control problems appear to warrant facilities in excess of minor corrective measures such as sandbags and diversion ditches, it is recommended that a geologist or soils engineer be consulted for additional advice.

The key to erosion control is adequate planting to hold soil in place. However, planting can also increase fire hazards during warm weather. To reduce future fire hazards and still provide effective erosion control, the following are recommended guidelines:

- Clear native brush within 30 feet of buildings and limit brush height to 18 inches within 70 feet of buildings. A limited number of specimen shrubs and trees can be allowed within 30 feet of a building, depending on local fire codes.

- Eliminate or reduce chaparral-type plants that serve as fuel for fires and control their regrowth. Keep landscape clean.
- Remove litter under trees and shrubs and prune out dead growth. Remove dead and dry portions of ground cover and succulents. Leave space (15 to 20 feet) between remaining shrubs and trees to curtail the spread of fire.
- Use planting techniques similar to landscaping in newly developed areas for recently burned watersheds.
- Minimize erosion with quick-growing, fire-retardant ground cover, planted with burlap mat, straw mulch, or chemical nutrients throughout areas to be protected.
- Avoid using ice plant on slopes because it tends to "drag" surface soils down when saturated.
- Select only fire-retardant ornamentals.
- Plant fire-retardant shrubs or trees where ground cover or grass ends.
- Stress rapid growth ground cover.
- Increase effectiveness of fire-retardant plantings with a high-pressure sprinkler system.
- Remember rains can normally be expected to start in October, so plan accordingly.

Section 3316.1 of the Uniform Building Code provides for erosion control of slopes primarily utilizing landscaping. Highlights of this section include:

- The faces of cut-and-fill slopes shall be prepared and maintained to control erosion and to provide stability.
- All slopes equal to or greater than 3 feet in vertical height shall be planted with drought-tolerant grass or ground cover in order to protect the slope from erosion and instability. As deemed necessary by the building official, other slopes shall also be planted.
- Slopes exceeding 15 feet in vertical height shall be planted with drought-tolerant shrubs, spaced at no more than 10 feet on center; or trees, spaced not to exceed 20 feet on center, or a combination of such shrubs and trees at equivalent spacings, in addition to a drought-tolerant grass or ground cover.
- A written statement shall be submitted by a landscape architect or slope control specialist certifying that the plant is drought-tolerant and suitable for erosion control and slope stabilization purposes.
- Landscape plans shall be submitted for all slopes required to be planted.

2.8.3 Mitigation of Expansive Soils

Expansion testing and mitigation are required by the current grading and building codes. Special engineering designs include the use of reinforcing steel in foundations, drainage control devices, over-excavation and backfilling with non-expansive soils. Active enforcement, peer review and homeowner's involvement are required to maintain these standards. Although expansive soils are now routinely alleviated through the County Building Code, problems related to past inadequate codes constantly appear. Homeowners should be informed and educated about the importance of maintaining a constant level of moisture below their foundation. Excessive watering, or allowing expansive soils to become too dry, both have negative consequences. Excessive swelling and shrinkage cycles can result in distress to improvements and structures.

2.8.4 Mitigation of Collapsible Soils

Sampling and laboratory testing for collapsible soils is required under the County-enforced Uniform Building Code. Collapse potential may be mitigated by removal and recompaction under optimum moisture conditions, pre-saturation of foundation soils, and improvements to post-development site drainage. Special attention must be paid to avoid saturation of foundation soils after construction. For example, there should be positive drainage away from the foundation, and planters with open bottoms should be avoided in areas adjacent to foundations.

The raw data for mapping this hazard in the County of Riverside exists in the form of Bureau of Reclamation Soil Survey Maps. While the mapping of collapsible soils is beyond the scope of this project, a future study should be directed at preparing a collapsible soils distribution map.

2.8.5 Ground Subsidence

In regions of active or potential subsidence, four distinct regulations require proposed development to prepare geotechnical reports that address subsidence and outline mitigation where required. These regulations include:

- Safety Element of the General Plan;
- Uniform Building Code;
- California Environmental Quality Act; and
- County Subsidence Report Zones.

As a result of past experience, the County of Riverside has developed extensive methodology to mitigate ground subsidence hazard and reduce associated losses. During preliminary site investigations, geotechnical consultants are required to evaluate the potential for subsidence and fissuring. In cases where subsidence and fissuring are discovered during development, the Riverside County Board of Supervisors adopt a local "Subsidence Report Zone" (Kupferman, 1995). The purpose of a report zone is to prevent construction of structures for human occupancy on known or potential earth fissures.

As a case history, the Riverside County Geologist (Kupferman, 1995) has outlined the County Board of Supervisors' adoption of a Subsidence Report Zone, following the discovery of earth fissures in the Temecula area:

1. In 1987, a northwest-trending, curvilinear system of earth fissuring about 3 km long was observed in recently graded residential tracts.

2. Ground cracks and water levels in nearby wells were monitored by consultants for the developers.

3. The developers and their geotechnical consultants notified Riverside County of the problem and the County ceased issuance of building permits for areas in the vicinity of the cracks.

4. About three months later, similar northwest-trending features were noticed in a commercial part of Temecula. Attorneys and expert consultants (ground water, geotechnical and geologic) were retained by the County for legal and technical assistance.

5. In early 1988, the Riverside County Board of Supervisors resolved to create a Subsidence Report Zone. The zone included areas of known and suspected fissuring, and spanned the alluvial areas of Temecula Valley between two mapped fault zones (Figure 2-7). The zone was approximately 1.6 km wide and 15 km long. Before issuing further building permits, the board required special geotechnical studies that addressed the fissuring, and a licensed structural engineer to certify that proposed structures within this zone were safe for their intended use. Reports submitted to satisfy these requirements ranged from one-page opinions to detailed trenching investigations. Initially, reports were submitted and accepted by the Building and Safety Department if these reports included the required certification. Subsequently, more detailed subsurface investigation reports were reviewed and approved by the County Geologist.

6. Initial site-specific studies indicated that fissuring coincided with active (Holocene) faulting. The County notified the State Division of Mines and Geology, which began a study in accordance with the Alquist-Priolo Special Studies Zone Act (APSSZ) (Hart, 1990). This

resulted in establishment of a state Special Studies Zone (SSZ) where the fissures coincided with active (Holocene) faulting. Planned development within these zones was required to comply with the APSSZ Act. The new special studies zones were 0.2 - 0.3 km wide and 2.0 - 4.0 km long. The original, larger Subsidence Report Zone also remained in effect.

7. Two years after initial adoption, the Subsidence Report Zone and the Board of Supervisors' resolution was changed. The new resolution kept the original zone intact, removed the certification by a structural engineer, and retained the requirement that fissuring should be addressed by geotechnical engineers for projects within the Zone.

8. The SSZ and the larger Subsidence Report Zone are still in place; however, most of the area is now incorporated into cities. Indications are that the cities are still implementing these zones.

9. No new cracks have occurred within the Subsidence Report Zone since it was established. The original fissures within the narrow state Special Studies Zone continue to show periodic movement.

10. The original, wide Subsidence Report Zone was ruled an appropriate safeguard. It did not substantially slow development, and allowed building to proceed with controls that evaluated the potential for fissuring.

As reported by Kupferman (1995), two additional Subsidence Report Zones have since been created by the County Board of Supervisors:

Murrieta Area-California Oaks: In 1991, a Subsidence Report Zone was created in the Murrieta area, as a result of ground cracking at the California Oaks project (see section 2.6.1). This cracking was determined to be a result of a rising ground water table, rather than a falling ground water table. Shlemon and Hakakian (1992) attribute the cracking at California Oaks to be the result of saturation of collapsible alluvium that was left in-place during rough grading. The limits of the Subsidence Report Zone for the Murrieta area was based on natural hydrologic and political boundaries (Kupferman, 1995). Shortly after creation of this Zone, the area was adopted into the city of Murrieta and continues to be enforced by the city.

The cracking at California Oaks led to modifications in County policies. The County Department of Buildings and Safety adopted a set of technical guidelines for the review of geotechnical reports. The guidelines require that a project geotechnical consultant must document observations and inspections during grading; and that the County Geologist review and approve geotechnical reports for all grading projects (Kupferman, 1995).

Silverhawk Development: In 1994, a third Subsidence Report Zone was established. The establishment of this Zone was pre-emptive, as no ground fissuring had yet been observed. However, geotechnical data, and similarities in geology, topography, hydrology and grading with the previously established California Oaks zone, warranted its establishment. This third Subsidence Report Zone was removed following the preparation of geotechnical studies by the project developer.

2.8.5.1 Recommended Minimum Requirements to Address Subsidence Potential:

This Technical Background Report recognizes the hazard of subsidence and ground fissuring in Riverside County and supports the implementation of a Safety Element policy to require preliminary soils engineering and engineering geologic reports. Prior to issuance of grading permits, the potential for subsidence must be addressed in regions identified by this study as active or susceptible. This recommendation is supported by the Uniform Building Code.

At a minimum, geotechnical investigations and reports that address subsidence potential should:

- Identify and locate any faults, scarps, and fissures in the vicinity.
- Review available land level lines of past ground surface movement in the vicinity, including degree of differential subsidence across nearby faults and proximity of regional subsidence bowls.
- Review groundwater development in the vicinity, including the location of nearby, high-capacity wells. Review available historic water level data from nearby wells.
- Review available maintenance records of nearby wells for signs of possible subsidence-induced damage.
- Review subsurface units from available well drillers' logs.

At a minimum, conclusions should discuss:

- Location (or absence) of all surface ruptures on or adjacent to the site.
- Type of faults and nature of anticipated offset, including direction of relative displacement, and maximum possible displacement.
- Statement of relative risk, addressing the probability or relative potential for future surface displacement. This may be stated in semi-quantitative terms such as low, moderate, or high, or in terms of slip rates determined for specific fault segments.
- Degree of confidence in, and limitations of, the data and conclusions.

At a minimum, recommendations should provide:

- Set-back distances from faults and fissures. State, Federal or local guidelines may dictate minimum standards otherwise.
- Mitigative measures for appropriate structures that cannot avoid crossing faults and fissures. Examples include, but are not limited to, critical pipelines, aqueducts, flood channels, railroads, and roadways.
- Discussion of the need for additional studies, or inspection during construction.

2.8.6 Mitigation of Wind Erosion

As mentioned, the most effective mitigation of this hazard is to curtail the primary source of sand in the Coachella Valley – periodic flooding of the Whitewater River. Mitigation of this would require a multi-million dollar upstream dam and maintenance to remove trapped sediment. Lining the Whitewater River channel would reduce the sand supply, but reduce the favorable aspects of ground water infiltration. While building and maintaining a dam may be economically justifiable based on the continued wind-blown sand damage throughout the valley, it is more likely that local, smaller-scale mitigation measures will continue to be implemented.

2.9 Summary

Physiographic and Geologic Setting

- The hazards of subsidence and hydroconsolidation are concentrated in valley regions filled with sediments, while mass wasting (e.g. landsliding, rockfall) is associated with the mountainous regions primarily underlain by igneous and metamorphic rock.

- The bedrock exposures of Riverside County consists predominantly of igneous and metamorphic rock with some sedimentary units. They vary from hard rock underlying steep slopes of the San Jacinto Mountains to the weathered granitic rocks of Joshua Tree National Park and hillsides near the city of Riverside.

- Alluvial (river) valleys between these mountain ranges contain sediments with significant variation in thickness. Some valleys contain a few hundred feet of Pleistocene and Holocene sediments, whereas others, such as the Coachella, San Jacinto and Elsinore valleys, contain several thousand feet to several miles of sediment. The thickest sediments have been deposited in basins that are being pulled apart by the movements of tectonic plates.

Development of GIS Engineering Geology Map

- Detailed digital Geologic and Engineering Geologic maps for Riverside County have been prepared for this study. The accuracy of the overall Geology and Engineering Geology maps are 1:100,000. However, certain portions of the map were digitized at greater detail (1;24,000), and other areas were digitized at lesser detail (1:250,000).

- More that 60,000 polygons *(area features)* were digitized from geologic map data for Riverside County. These diverse geologic units were combined based on similar engineering properties. The map is meant to provide general guidance to support land use decisions and policies. It is developed from regional data and includes many assumptions in assigning engineering properties based on descriptions of geologic units. Therefore, the data should not replace or preclude site-specific observation and testing.

Slope Stability

- Landslide Management Zones (LMZ) represent regions susceptible to slope instability and should generate slope stability studied prior to issuing development permits. Without the presence of extensive flood control devices, including large debris catchment basins, the areas outlined by the LMZs may be subject to debris flow inundation. Mitigation of debris flow potential in should be directed at development in these areas. Occasionally, catastrophic debris flows occur. The greatest southern California debris flows of the 20th century occurred in 1934, 1938, 1969 and 1978, but there is generally a destructive event each decade. Most often, the impact to the County will be boulders transported onto roadways and improvements by smaller, more common events.

- The angle of repose for slopes averages 35 degrees, but varies widely. However, slopes as shallow as 26 degrees have failed catastrophically. An effective way for the County of Riverside to protect lives and property is to prohibit development on or near slopes that exceed about 30 degrees in steepness, measured from the horizontal.

- To reduce hazard from debris flows and other mass wasting, debris basins require continued maintenance, and environmental preservation of mountain ranges is required. Development of hillside terrain increases the potential for slope instability. Thus the County should actively pursue natural preservation of these ranges. The County should also establish an education and warning system that can be activated following significant wildland fires on the hillsides above the County. This can include mailers to households in the affected areas, public meetings, and/or door-to-door education.

Development of a GIS Landslide and Slope Instability Map

- As a major component of this project, we developed digital landslide and slope instability mapping for Riverside County. The mapping is based on slope steepness, as well as engineering geology. The general procedures followed to create the Landslide and Slope Instability Map, included:

    - *Creation of a slope map for Riverside County by producing a grid map of the U. S. Geological Survey (USGS) Digital Elevation Model (DEM) for the County in Vertical Mapper© with a grid cell size of 30 meters on each side.*

- *Creation of a grid map of the Engineering Geologic Materials Map map in Vertical Mapper© using a 30 meter grid cell size.*

- *Queries of both grid maps for areas that meet the parameters for slope instability and landslide susceptibility.*

Expansive Soils

- Expansive soils contain clay particles that can give up water (shrink) or take on water (swell). Mitigation can be achieved through reinforcement of an existing foundation, or alternatively, through the excavation and removal of the expansive soils in the affected area. Moisture control and modified drainage can also minimize the effects of expansive soils. For new development, problems with expansive soils can be largely prevented through proper site investigation, soils testing, foundation design, and quality assurance during grading operations as required by the Uniform Building Code.

Collapsible Soils

- Collapsible soils in the County of Riverside are predominantly found near the mountains, in Holocene alluvial fans and washes deposited during rapid stream runoff. In addition, some windblown sands may be vulnerable to collapse and hydroconsolidation. Typically, differential settlement of structures occurs when lawns or plantings are heavily irrigated in close proximity to the structure's foundation.

- Collapsible soils caused damage, possibly exceeding $100 million, to homes in the Murrieta area of Riverside County. In the Murrieta case, alluvium left in-place during rough grading later collapsed when ground water levels rose significantly as a result of new golf course and residential irrigation.

Ground Subsidence

- Damage caused by subsidence is a world-wide phenomenon that annually costs hundreds of millions of dollars to investigate and to mitigate. Land subsidence and associated fissuring have been well-documented in Riverside County. Most of the early cases affected agricultural land or open space. Since the late 1980s, increased urbanization has seen impact on structures designed for human occupancy.

- While subsidence typically occurs throughout a susceptible valley, additional displacement and fissures occur at or near the valley margin. In the County of Riverside, regional subsidence hazard is greatest at the valley margins.

- In Riverside County, ground subsidence and fissuring have resulted both from falling ground water levels, and rising ground water levels. Many of the fissures have occurred along active faults that bound the San Jacinto Valley and Elsinore Trough. Some controversy surrounded the initial recognition of these features in the late 1980s and early 1990s.

- Regions deemed susceptible to subsidence include all the alluvial valley regions. Three areas of documented subsidence have been defined:

    - The Elsinore Trough, including the communities of Temecula and Murrieta.
    - The San Jacinto Valley from Hemet to Moreno Valley.
    - The southern Coachella Valley.

Elsinore Trough-Ground Subsidence

- Two separate areas of subsidence have been documented in the Elsinore Trough, attributed to two different causes.

    - ***Temecula***: The Temecula fissures first occurred in 1987 and formed short, parallel ground cracks over about 7 miles, from Wolf Valley on the south to the Temecula-Murrieta valleys on the north. By 1991, alleged damages to residential and commercial structures exceeded $50 million. Many hypotheses have been considered to explain the Temecula fissures. Of these, rapid ground water pumping is now favored. Several new wells began pumping several days to several weeks prior to the subsidence; and since the cessation of pumping, the fissures have neither grown nor multiplied.

    - ***Murrieta***: The Murrieta fissures first occurred in 1990, primarily in the "California Oaks" subdivision. In litigation, damages associated with the Murrieta fissures were estimated to exceed $100 million by 1992. These fissures are similar in appearance to the Temecula fissures, however, they occur within alluvial filled channels. The Murrieta fissures are believed to have been triggered by golf course and residential irrigation.

San Jacinto Valley-Ground Subsidence

- Ground water table declines in the San Jacinto Valley have exceeded 120 feet and resulted in about three feet of surface subsidence between 1939 and 1959. The subsidence is attributed to a combination of ground water withdrawal, and tectonic basinal subsidence associated with movement along the San Jacinto fault system.

Coachella Valley-Ground Subsidence

- Back in 1948, ground fissuring was observed in the city of La Quinta. This regional subsidence occurred during a period of rapid ground water withdrawal. Water level had declined as much as 50 feet between the early 1920s and the late 1940s, before water from the Colorado River was imported through the Coachella Canal in 1949. When this surface water was introduced, pumping of ground water decreased, and water levels recovered throughout most of the valley from the 1950s to the 1970s. Some of the basin recharge was also attributed to the leakage from unlined water canals.

- Currently, the ground water basin in the Coachella Valley is in a state of overdraft. Ground water levels are declining at an increasing rate. Since the late 1970s, the demand for water has exceeded the deliveries of imported surface water. Ground water levels in 1996 were in many areas lower than the historical low ground water levels. These observed declines in water level have the potential to induce new or renewed land subsidence in the Coachella Valley.

- As is true in many places, mitigation of subsidence in the Coachella Valley will require a regional approach to ground water conservation and recharge. These mitigation measures are expected to be difficult to implement. Currently, ground water recharge in the Coachella Valley area is minimal. The Coachella Valley Water District operates a pilot recharge facility south of Lake Cahuilla that has been in operation since 1996 and has shown that recharge is feasible. Design of a full scale facility at this location will likely begin within the next several years.

- The U.S. Geological Survey plans to precisely measure elevation every 2-3 years to determine the magnitude and extent of subsidence. In addition, monitoring of well water-levels is required to assess the relationship between ground water overdraft and regional subsidence.

Wind Erosion

- Wind erosion is a serious environmental problem attracting global attention. Soil movement is initiated as a result of wind forces against the surface of the ground.

- The presence of dust particles in the air is the source of several major health problems. Atmospheric dust causes respiratory discomfort, may carry pathogens that cause eye infections and skin disorders, and reduces highway and air - traffic visibility. Dust storms can cause additional problems as well. Buildings, fences, roads, crops, trees and shrubs can all be damaged by abrasive blowing soil.

- Wind and wind-blown sand is an environmentally limiting factor throughout much of Riverside County. Approximately 20% of the land area of Riverside County is vulnerable to "high" and "very high" wind erosion susceptibility. The Coachella Valley, the Santa Ana River Channel in northwestern Riverside County, and the community of Hemet are zones of high wind erosion susceptibility.

- Wind-blown sand is a well recognized hazard for developments in the Coachella Valley; it has forced abandonment of dwellings and subdivided tracts in the central Coachella Valley.

- The primary source of sand in the Coachella Valley is the Whitewater River. increases in the amount of wind-blown sand are related to episodic flooding of the Whitewater River. A 15-fold increase in wind erosion rates was noted following heavy floods. Mitigation of wind-blown sand is directly related to mitigation of flood potential on the Whitewater River. Efforts to control the wind using hedges and other barriers will not be as effective in mitigating wind erosion.

Regulatory Framework for Mitigation of Geologic Hazards

- Land use and development in Riverside County is regulated by the Riverside County Comprehensive General Plan, County Building and Grading Ordinances *(including the Uniform Building Code)*, the California Environmental Quality Act (CEQA), and specific resolutions adopted by the County Board of Supervisors.

Natural Hazard Mapping, Analysis, and Mitigation:
a Technical Background Report in Support of the Safety Element
of the New Riverside County 2000 General Plan

CHAPTER 3: FLOOD HAZARDS

3.1 Overview

During the 20th century, floods were the number-one natural disaster in the United States in terms of number of lives lost and property damage. Flood currents often move at high velocities and possess tremendous destructive power. Their lateral forces can demolish buildings and erode bridge foundations and footings, leading to collapse. Since 1965, eleven Gubernatorial and Presidential flood disaster declarations have been made for Riverside County.

Flood Facts:

- Most lives are lost when people are swept away by flood currents.
- Most flood-related deaths are due to flash floods.
- Fifty percent of all flash flood fatalities are vehicle-related.
- Most property damage results from inundation by sediment-laden water.
- Most homeowners' insurance policies do not cover flood water damage.
- Individuals and business owners can protect themselves from property losses by purchasing flood insurance through FEMA's National Flood Insurance Program.

There are four principal types of flood hazard:

Stream Flooding: The County of Riverside is vulnerable to flooding associated with several major drainages, including but not limited to the Santa Ana, San Jacinto and Whitewater, as well as smaller scale and flash flood events on many of the alluvial fans that flank the County's hillsides. Large-scale developments have utilized golf courses and greenbelts as part of a network of channels that collect flood flows on the upstream side of a project, carry it safely through the project, and disperse it on the downstream side. However, given the low permeabilities of the underlying bedrock, heavy runoff from the surrounding hills and mountains during strong storms cannot be prevented. A multi-hazard mitigation opportunity exists, as control of flooding on the Whitewater River will also reduce the sand supply and subsequent wind-blown sand hazard for the area, as discussed in Chapter 2.

Bridge Scour: Bridge foundations are vulnerable to scouring during a flood. Major bridge crossings that are vital to the County of Riverside should be designed and built to withstand scouring.

Dam Inundation: More than twenty dam failure inundation paths would affect the County of Riverside. In addition, canals and levees may be vulnerable to the earthquake-induced effects of liquefaction, lateral spreading and primary fault rupture. Liquefaction and lateral spreading damaged Imperial Valley canals during earthquakes in 1979 and 1987, and local flooding resulted.

Earthquake-Induced Flooding (Tsunamis and Seiches): In Riverside County, the susceptibility to tsunami (seismic sea wave) inundation is nil. However, an earthquake may cause local flooding by creating seiches (reverberating waves) in enclosed bodies of water, or by damaging water storage facilities.

The floods of the early and mid-1990s have caused an increased awareness of the potential for personal and structural losses and damages, particularly in the highly urbanized parts of flood plains and alluvial fans throughout California. Near the mountains, a combination of steep slopes and high rates of rainfall rapidly concentrate runoff, causing flows with high velocities and large peak discharges. As peak flood flows reach valley floors, large amounts of debris are deposited and compound the flooding problem. Areas of newer development that are upslope from older urban areas cause increased runoff and new flooding problems in the older areas. Ground subsidence, common in parts of California, reduces the level of flood protection provided by existing infrastructure, and increases the area, depth, and duration of flooding in the areas of subsidence. (Subsidence hazards in Riverside County are discussed in detail in Chapter 2 of this Technical Background Report.) Localized flooding can occur on the alluvial fans descending from steep hillsides. Flood flows on alluvial fans often take unpredictable paths.

Floods that affect the County of Riverside can be attributed to three different types of storm events. The first are general winter storms that combine high-intensity rainfall and rapid melting of the mountain snowpack. The second type is due to tropical storms out of the southern Pacific Ocean, such as tropical storm Kathleen in September 1976, that caused $15 million in damages in the Coachella Valley area. The third type is summer thunderstorms, such as those experienced in 1941 and 1948 (FEMA, 1996). These create flash floods. Water collects rapidly and runs off quickly from steep mountains into adjoining valleys. These floods have sharp peak discharges, high velocities and short durations. They also carry a large amount of debris, due to the mountains' steepness and lack of vegetative cover.

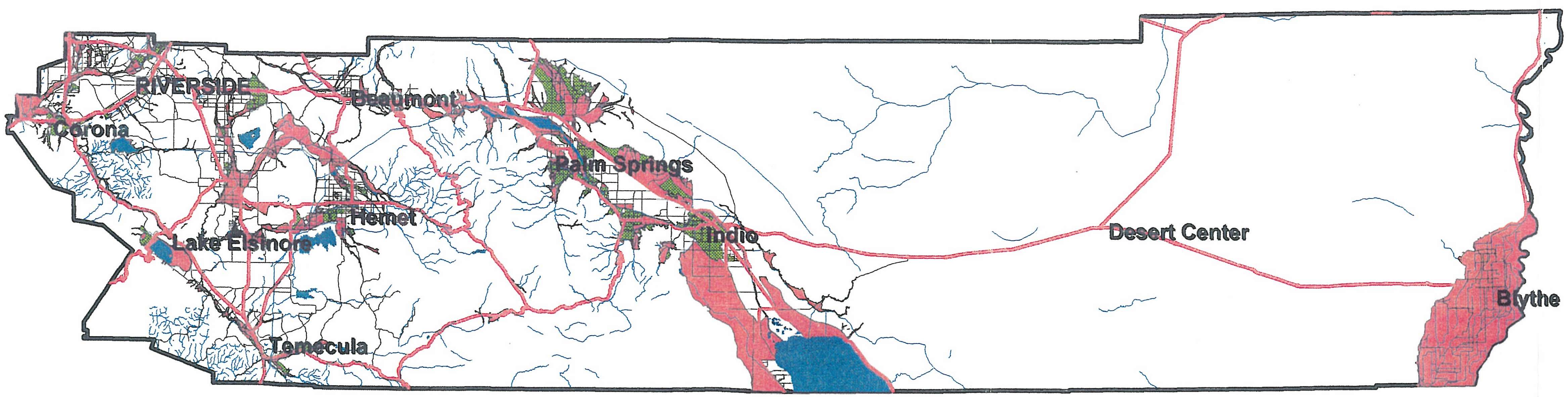
The need for improved flood conveyance structures and levee designs to reduce potential flood hazards has resulted in studies that focus on collection and analysis of precipitation and flood data. Rainfall-runoff and hydraulic models are being utilized to analyze flood potential, adequacy of flood protective measures, surface- and ground water interchange characteristics, and the variable efficiency of mobile (sand bed) flood channels.

State of California Government Code Section 65302 (g) requires local governments to assess the potential impact that flooding, and failure of dams or other water retention structures, might have on their jurisdiction. This chapter reviews published flood inundation maps and a directory of dams showing inundation limits. Safety Elements of General Plans must assess the impact of flooding from storm activity such as a 100-year flood event. A 100-year flood event is a relatively large flood that has a 1/100 chance of occurring in any one year, and a 26% chance of occurring during a typical 30 year home mortgage.

It is important to understand that every storm has an equal likelihood of seeing a 100 year flood. The 100 year recurrence interval represents the long-term average period between floods of a specific size. The fact that a 100 year flood has just occurred in no way decreases the chance of another 100 year flood.

Smaller-scale flooding generally associated with overburdened storm drain and canal systems can damage property and hinder emergency activities such as fire department access or evacuation. Consequently, the potential for more frequently occurring, small-scale flooding is also assessed in this report.

The County of Riverside participates in the National Flood Insurance Program. Consequently, Flood Insurance Rate Maps (FIRMs) prepared by the Federal Emergency Management Agency (FEMA) to show potential flood zones are available for areas within County limits. These maps were used to provide the general boundaries of the 100-year and 500-year flood inundation area shown on Figure 3-1.



N
W E
S

Scale: 1:1,000,000

10 0 10 20 30

Miles

Figure 3-1:

100- and 500-Year

Flood Hazard Zones

of Riverside County

California

(Summary of GIS Data, for additional detail see Plate 3-2 in-pocket)

Earth Consultants International

Flood Prone Areas

- 100 Year Flood Zone
- 500 Year Flood Zone

Water Rivers

Stream, River, Canal

Highways

Water Bodies

Lake, Pond, Sea

Major Roads

3.2 Previous Flood Disasters Affecting Riverside County

The length of this section indicates the ongoing severity of the flood problem in Riverside County, as elsewhere.

3.2.1 Floods Meriting Disaster Proclamations

The following flood disasters affecting Riverside County resulted in either a Gubernatorial Proclamation of a State of Emergency or Presidential Major Disaster Declaration (California Governor's Office of Emergency Services, 2000):

1965 Heavy Rainfall: Abnormally heavy and continuous rainfall
Declared: ***Riverside (11/24/65)***, San Bernardino, Ventura (11/26/65), San Diego (12/23/65)
Damage: public-$5,826,239; private-$16,017,500; TOTAL-$21,843,739

1966 Winter Storms: Abnormally heavy and continuous rainfall
Declared: Kern, ***Riverside***, Tulare (12/9/66), San Bernardino, San Luis Obispo (12/13/66), Monterey (12/16/66), City of Escondido (San Diego County 12/16/66), Inyo (12/23/66)
Damage: public-$14,599,391; private-$14,161,650; TOTAL-$28,761,041

1969 Storms: Storms, flooding
Declared: Los Angeles, San Luis Obispo (1/23/69), Fresno, Inyo, ***Riverside***, San Bernardino, Santa Barbara, Tulare, Ventura (1/25/69), Amador, El Dorado, Kern, Kings, Madera, Modoc, Mono, Monterey, Orange, Placer, Sacramento, San Joaquin, Shasta, Solano, Stanislaus, Tuolumne (1/28/69), Mariposa, Merced (1/29/69), Calaveras, San Benito, Sierra (2/8/69), Contra Costa, Humboldt, Mendocino, Sonoma (2/10/69), Plumas, Tehama, Yuba (2/16/69), Butte, Marin, Yolo (3/12/69)
47 dead, 161 injured
Damage: public-$185 million; private-$115 million; TOTAL-$300 million

1976 High Winds and Flooding: High winds, heavy rains and flooding
Declared: Imperial, ***Riverside (9/13/76)***, San Bernardino, San Diego (9/22/76)
Damage: public-$65,743,671; private-$54,389,100; TOTAL-$120,132,771

1977 Threat of Floods/Mudslides
Declared: Monterey, ***Riverside (9/8/77)***
Damage: $6.110 million estimated

1978 Winter Storms
Declared: Inyo, Mono, San Diego, San Luis Obispo (3/9/78), Kings, Monterey (2/27/78), Kern, Los Angeles, Orange, ***Riverside***, San Bernardino, Santa Barbara, Tulare, Ventura

(2/13/78)
14 dead, at least 21 injured
Damage: public-$73,456,185; private-$44,346,600; TOTAL-$117,802,785; 2538 homes destroyed

1979 Severe Storms: Severe flooding, excessive rains, flash floods
Declared: ***Riverside (7/26/80)***
Damage: public-$2,972,100; private-$22,895,000; TOTAL-$25,867,100

1980 Winter Storms: Rain, winds, mud slides, and flooding (See Section 3.2.3 for details.)
Declared: Santa Barbara (2/21/80), Los Angeles, Orange, ***Riverside***, Ventura (2/19/80), San Bernardino, San Diego (2/7/80)
Damage: public-$164,990,642; private-$75,755,500; agricultural-$75,894,675; TOTAL-$316,640,817.

1982-83 Winter Storms: Heavy rains, high winds, flooding, levee breaks
Declared: Contra Costa, San Joaquin, Sacramento (12/8/82), Marin, San Mateo, Los Angeles, San Diego (1/27/83), Alameda, Orange, San Benito, Santa Barbara, Santa Clara, Santa Cruz, Shasta, Sonoma, Ventura, Trinity (1/31/83), Colusa, Lake, Mendocino, Monterey, San Luis Obispo, Solano, Yolo (2/7/83), Butte, Glenn, Kern, Kings, San Bernardino, Sutter Tehama, Merced (3/3/83), Del Norte, Fresno, Madera, Napa, Placer, ***Riverside***, Stanislaus, Tulare (3/15/83), Humboldt, Mariposa, Nevada, Yuba (3/21/83)
Damage: public-$151,185,870; private-$158,641,170; agricultural-$213,789,992; TOTAL $523,617,032

1983 Colorado River Flooding
Declared: ***Riverside***, San Bernardino (6/23/83), Imperial (6/28/83)
Damage: public-$1,393,915; private-$3,246,400; TOTAL-$4,640,315; 32 homes destroyed; 114 homes and 13 businesses damaged.

1983 Summer Storms: High winds, storms, and flooding
Declared: Inyo, ***Riverside***, San Bernardino (8/29/83)
3 deaths
Damage: public $9,589,275, private $15,102,080, agricultural $9,997,800; TOTAL -$34,689,155

1992-93 Late Winter Storms: Snow, rain, and high winds
Declared: Alpine, Los Angels (2/19/93), Humboldt, Napa, Santa Barbara, Culver City and the City of Los Angeles (2/8/93, for event beginning 1/25/93), Contra Costa, Mendocino, Sonoma (1/25/93, for event beginning 1/25/93), Fresno, Imperial, Madera, Monterey, San Bernardino, Sierra, Tehama, Trinity, and Tulare (1/21/93, for event beginning 1/19/93),

Modoc, Orange, ***Riverside (1/19/93***, for event beginning 1/15/93), Lassen, Siskiyou (1/15/93, for event beginning 1/13/93), Plumas (1/13/93, for event beginning 1/12/93), San Diego (1/7/93, for event beginning 1/7/93)
20 deaths, 10 injuries
Damage: public property-$32,215, TOTAL-$600 million

1995 Severe Winter Storms

Declared: Los Angeles, Orange (1/6/95), Humboldt, Lake, Sonoma (1/9/95), Butte, Colusa, Contra Costa, Del Norte, Glenn, Kern, Lassen, Mendocino, Modoc, Monterey, Napa, Placer, Plumas, San Luis Obispo, Santa Barbara, Santa Clara, Santa Cruz, Tehama, Ventura, Yolo, Yuba (1/10/95), Alpine, Amador, Nevada, ***Riverside***, Sacramento, San Bernardino, San Mateo, Shasta, Sutter, Trinity (1/11/95), San Diego (1/13/95), Alameda, Marin (1/14/95), Fresno, Kings (1/17/95), El Dorado (2/15/95), Madera, Solano (2/17/95), Siskiyou (3/14/95)
11 deaths
Damage: public-$299.6 million; individual-$128.4 million; businesses $58.4 million; highways-$158 million; ag-$97 million; TOTAL-$741.4 million; damage to homes: major-1,883; minor-4, 179; destroyed-370.

1995 Late Winter Storms

Declared: all California counties (except Del Norte)
17 deaths
Damage: public property-$190.6 million; individual-$122.4 million; business-$46.9 million; highways-$79 million; ag-$651.6 million; TOTAL-approximately $1.1 billion; damage to homes: major-1,322; minor-2,299; destroyed-267

1998 El Nino

Declared: Alameda, Amador, Butte, Calaveras, Colusa, Contra Costa, Fresno, Glenn, Humboldt, Kern, Kings, Lake, Los Angeles, Marin, Mendocino, Merced, Monterey, Napa, Orange, ***Riverside (2/2/98)***, Sacramento, San Benito, San Bernardino, San Diego, San Francisco, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Siskiyou, Solano, Sonoma, Stanislaus, Sutter, Tehama, Trinity, Tulare, Ventura, Yolo, Yuba.
17 deaths
Damage: $550 million

3.2.2 Historic Flood Flows

For any hazard, an essential mitigation step is to understand the phenomenon in detail. The U.S. Geological Survey has operated several stream gages along Riverside County's drainages. The type of data available include peak discharge and graphs of daily mean discharge in cubic feet per second, as well as stage in feet above gage datum. The historical stream flow data indicate that peak flows typical occur in January, February, and March.

To provide a general indication of the relative severity of historical floods throughout Riverside County, FEMA (1996) compiled flood gage data (Table 3-1) that have been updated with information from The U.S. Geological Survey (2000). In addition to gage data, historic levels of Lake Elsinore (Table 3-2) provide an indication of the flood history of Riverside County. Reports of flooding accounts since 1969 in Riverside County have been summarized by FEMA (1996), Chin and others (1991), and Kupferman (1994):

- ***February 1969***: Two distinct periods of heavy rain struck Riverside County during January and February of 1969, producing the most runoff since March of 1938. Four persons lost their lives and $40 million in damage to public and private property was reported.

- ***October 1974***: An extremely high-intensity thunderstorm in October of 1974 resulted in widespread flooding and property damage in western Riverside County. The sudden flooding associated with this storm included unpredictable braiding and fanning of flood flows on alluvial fans.

- ***September 1976***: On September 10 and 11, 1976, the southwestern side of the Coachella Valley was subjected to intense rainfall associated with Tropical Storm Kathleen. This storm resulted in $14.6 million in damages to Cathedral City, Rancho Mirage, Palm Desert, La Quinta, and Oasis. Isolated thunderstorms struck many of the same areas again on September 23rd and 24th, causing an additional $4.4 million in damage.

- ***August 1977***: During its passage over the Coachella Valley in August 1977, Tropical Storm Doreen caused flooding in Indio, Palm Desert, Thousand Palms, and Desert Hot Springs.

- ***March 1978***: During February and March of 1978, several successive periods of heavy rain resulted in $9 million in flood damage within Riverside County. The regions suffering the greatest damage included the Palm Springs area adjacent to the Whitewater River, the Corona area, Murrieta Creek, and portions of the Santa Margarita and Santa Ana basins.

- ***July 1979***: Intense local thunderstorms on July 20, 1979, in the hills above Rancho Mirage and Cathedral City, resulted in the flooding of 130 homes and $6.4 million in damage. One person was killed by flash flooding.

- ***February 1980***: The 1980 floods were the most costly on record for Riverside County. Ten deaths and more than $70 million in property damage were recorded. Another $10 million was spent to fight floods and rehabilitate flood control structures. (See Section 3.2.3, for more detail on the 1980 flooding).

- ***September 1981***: A local thunderstorm on September 7th in the Lakeview Mountains caused flooding of Lakeview Wash, about 6 miles southeast of March Air Force Base. Sixteen residences had interior damage.

- ***1992-93 Winter Storms***: Storm damage in Riverside County as a result of the 1992-93 winter storms included flooding, slope failure, erosion, rising ground water, and unanticipated seepage and contamination. Flood damage was reported along Temecula and Murrieta creeks. The new National Pollutant Discharge Elimination System (see Section 3.8.3) is directed at mitigating sediment erosion at grading sites.

Table 3-1: Historical Stream Gage Data for Riverside County

Location	Drainage Area (square miles)	Period of Record	Date	Peak Discharge (cfs)
San Jacinto River near San Jacinto	141	1920 to present	February 16, 1927	45,000
			February 21, 1980	17,300
			March 2, 1938	14,300
			February 6, 1937	14,000
			January 25, 1969	7,410
			November 22, 1965	6,300
Bautista Creek near Hemet	39.4	1947-1969	April 3, 1958	1,440
			July 19, 1955	1,170
			February 25, 1969	650
Bautista Creek at Valle Vista	47.2	1969 to present	February 21, 1980	11,400
			March 28, 1980	1,390
			August 17, 1977	1,050
Murrieta Creek at Temecula	222	1924 to present	January 4, 1916	23,300
			February 21, 1980	21,800
			January 23, 1943	17,500
			March 2, 1938	16,800
			March 1, 1978	14,800
			February 25, 1969	10,400
Temecula Creek near Aguanga	131	1957 to present	April 3, 1958	3,540
			February 21, 1980	3,420
			January 29, 1980	2,640
			January 25, 1969	2,550
			February 25, 1969	2,550

Whitewater River at Whitewater	57.5	1948 to present	March 2, 1938	42,000
			November 22, 1965	24,000
			January 25, 1969	16,200
			February 25, 1969	13,500
			December 6, 1966	5,500
			March 4, 1978	5,000
			February 21, 1980	3,200

Table 3-2: Peak Elevation Levels of Lake Elsinore

DATE	ELEVATION OF LAKE ELSINORE (feet)
April 1980	1265.7
April 1916	1265.6
April 1917	1260.7
May 1922	1259.7
May 1927	1259.0
May 1938	1258.9
April 1918	1258.7
June 1941	1258.6

3.2.3 Winter Floods of 1980

A series of six Pacific cyclones struck southern California during February 13-21, 1980 (Chin and others, 1991). Resultant flooding caused 18 deaths and about $500 million in damages. For Riverside County, the floods of 1980 are the worst on record, responsible for ten deaths and more than $70 million in damages. Historical flooding events in 1862, 1864 and 1938 may have been larger in terms of peak discharges, but may have been of comparable flood sizes. Those floods occurred prior to construction of many of southern California's dams and reservoirs, which reduce peak discharge. In 1980, extensive flooding along banks of reservoirs and streams, including failure of the San Jacinto River levees, led to a Presidential Disaster Declaration.

About $4 million was spent for flood fighting and other emergency operations, and another $6 million for rehabilitation projects following the flood. This was the single largest expenditure of funds for flood fighting and rehabilitation in any southern California county during the 1980 floods. The levee breaks along the San Jacinto River had the largest consequences of any southern California event associated with the 1980 flooding. The levee breaks left many homeless, and caused damages of $29 million to urban areas and $1.9 million to agricultural area. Chin and others (1991) provide detailed documentation of the impacts of the 1980 storms for each affected river basin in Riverside County:

Santa Margarita River Basin: Vail Lake on Temecula Creek, about 10 miles east of Temecula in southwestern Riverside County, spilled for the first time since its construction in 1948. The maximum spill from Vail Lake reached 8,000 cubic feet per second (cfs). Murrieta Creek, which converges with Temecula Creek to form the Santa Margarita River, experienced a peak flow of 21,800 cfs at the city of Temecula, its highest flow on record.

Santa Ana River Basin: The Santa Ana River is the largest coastal stream in southern California. The basin includes the San Jacinto River and Lake Elsinore, where much of the flood disaster was centered. The contents of the Prado Flood Control reached 111,000 acre-feet on February 22nd, the second highest level on record. Mudflows and slope failures along the Santa Ana due to saturated soils caused extensive property damage throughout the Santa Ana River Basin. Upstream of Riverside County, debris flows destroyed more than 60 homes in the Harrison Canyon area of San Bernardino. By reducing peak discharge, reservoirs probably prevented worse disaster. In the flood of January 22, 1862, the largest in the history of the Santa Ana River basin, an estimated peak flow of 320,000 cfs destroyed the settlement of Agua Mansa in northern Riverside County. Discharges in the vicinity of this location were about 100,000 on March 2, 1938 and about 19,500 cfs on February 18, 1980. The reduction over time is a direct result of upstream reservoirs. With the recent completion of the Seven Oaks Dam, even more flood mitigation is in place.

San Jacinto River: The San Jacinto River flows northwestward from its headwaters in the San Jacinto Mountains, passes near the town of San Jacinto in the San Jacinto Valley, and turns southwestward toward Lake Elsinore about 30 miles downstream from San Jacinto. Many years ago the course of the river was altered and the reach past San Jacinto and through the valley was leveed. On the morning of February 21, 1980, the levee upstream of the city of San Jacinto failed, and the flood water reverted to its original channel. Additional levees further north also failed. Flood water spread out across valley farmlands and into town.

Lake Elsinore: One of the major disasters of the 1980 flooding occurred at Lake Elsinore. Prior to the importation of Colorado River water in 1965, the lake was dry for many years. Much urbanization developed around the lake during years of low water levels. Since the importation of Colorado River water, a lake of about 6 square miles has been maintained. Prior to 1980, outflow is known to have occurred only in 1872, 1883-84, and 1916-17. During these rare occurrences, water flows northward out of the lake through Temescal Creek. Since it had been so long since outlflow had occurred, gravel had built up at the Temescal Creek outlet. Not until February 23rd did the U.S. Army Corp of Engineers began dredging the outlet. Inflow to Lake Elsinore from the San Jacinto River peaked at 8,000 cfs on February 22nd, and the lake surface reached its maximum elevation of 1,265 feet on March 20th. In the low-lying areas around the lake, 874 dwellings and facilities were damaged, and 2,000 residents were displaced. Nearly all the 400 mobile homes in the threatened area were relocated in time to prevent damage.

3.3 Flood Problem Areas

The most widely distributed flood map product is the Flood Insurance Rate Map (FIRM). The Federal Emergency Management Agency (FEMA) is mandated by the Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 to evaluate flood hazards and provide FIRMs for local and regional planners to further promote sound land use and floodplain development. Flood risk data presented on FIRMs are based on historic, meteorologic, hydrologic, and hydraulic data, as well as open-space conditions, flood control works and development. To prepare a FIRM that illustrates the extent of flood hazards in a flood-prone community, the Federal Emergency Management Agency (FEMA) conducts an engineering study referred to as Flood Insurance Study (FIS). Using information gathered in these studies, FEMA engineers and cartographers delineate Special Flood Hazard Areas (SFHAs) on FIRMs. SFHAs are those areas subject to inundation by a flood that has a 1-percent or greater chance of being equaled or exceeded during any given year. This type of flood is referred to as a base or 100-year flood. The base flood is a regulatory standard used by Federal agencies and most states, to administer floodplain management programs, and is also used by the National Flood Insurance Program (NFIP) as the basis for insurance requirements nationwide.

For the County of Riverside, FEMA (1996) has updated a Flood Insurance Study (FIS) originally completed in 1985 for the unincorporated areas of the County. The FIS evaluates principal flood problems and flood protection measures for the County of Riverside. According to the FIS for the County of Riverside (FEMA, 1996), most of the major floods in the County have occurred as a result of general winter storms. However, serious flooding, including potentially lethal flash flooding, has also occurred as a result of summer thunderstorms, particularly in the desert areas. Riverside County's precipitation averages vary from more that 30 inches per year in the San Jacinto Mountains to less than 5 inches per year in the Blythe region.

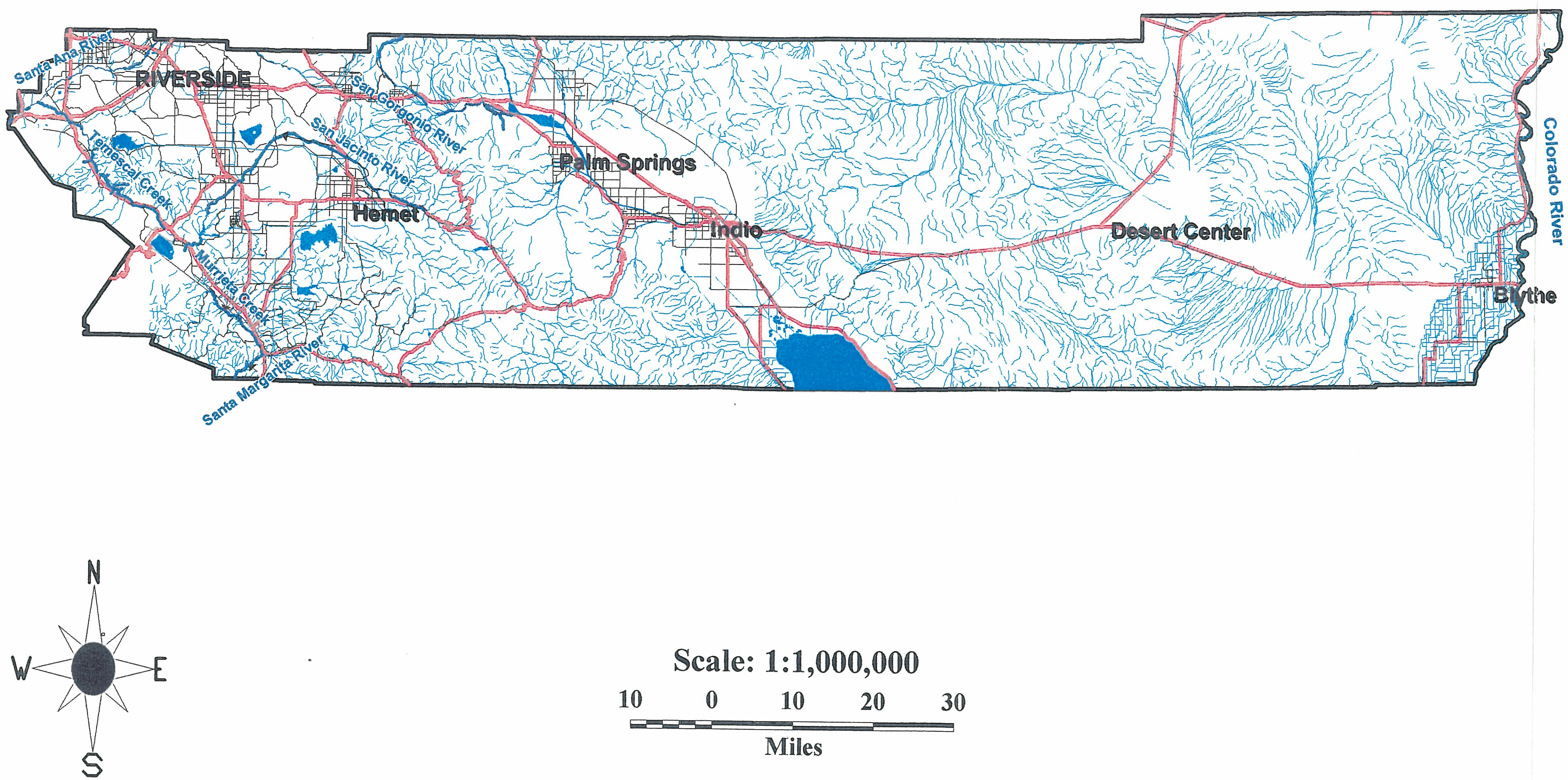
The major rivers in the western portion of the County are dry most of the year and pose flood threats to developments within the flood plain during general storms of long duration (FEMA, 1996). These rivers are the Santa Ana, San Jacinto, San Gorgonio and Santa Margarita rivers, as well as Temescal and Murrieta creeks (Figure 3-2). Plate 3-1 has been prepared at 1:250,000 scale to illustrate the drainages of Riverside County.

When a major storm moves into the area, water collects rapidly as surface runoff. Resultant flood flows have predominantly short durations and sharp peaks. Major floods along the San Jacinto River resulting from intense rainfall have been shown to typically peak in approximately 1.5 days with a total duration of flooding of 4 days.

Figure 3-2:

Drainage Systems of Riverside County

(Summary of GIS Data, for additional details see Plate 3-1 in-pocket)



Earth Consultants International

Tributaries to the major rivers present additional flood hazards. Flooding in these streams is caused mostly by local thunderstorms. Flood flows are of typically short duration, but can cause extensive damage as a result of high velocities associated with the tributary drainages.

The desert areas extending to the east from the Palm Springs area are susceptible to sheet flow flooding, with flow depths generally less than 2.0 feet. These type of flows leave the mouths of canyons and often follow unpredictable paths.

During major floods, flood water carries heavy debris loads and causes considerable damage from deposition. For example, the Santa Ana River carried a total sediment load of more than 11 million tons of sediment during the storms of 1969 (Chin and others, 1991). In addition, considerable damage is caused by erosion and scouring by high-velocity flows.

Findings of the FEMA FIS, as well as additional information from the County water districts, the U.S. Geological Survey and the Army Corp of Engineers, are summarized below. Except as noted, the data cover the last 100 years:

San Gorgonio River: Flooding on the San Gorgonio River caused damage during 1938, 1965, 1966 and 1969. During the floods of 1969, the San Gorgonio River attained an estimated peak discharge of 17,000 cubic feet per second (cfs), which resulted in loss of life and extensive damage in the Cabazon area.

San Jacinto River: The San Jacinto River has flooded during 1916, 1927, 1931, 1937, 1938, 1966, 1969, 1980, and 1993. Its largest flood of record occurred on February 16, 1927 with a peak discharge of 45,000 cfs near the city of San Jacinto. Agricultural, railway, and highway properties were extensively damaged. In addition, failure of its levee system in 1980 resulted in extensive damage.

Murrieta Creek: Nine major floods have been reported for Murrieta Creek, during 1862, 1884, 1916, 1938, 1943, 1969, 1978, 1980, and 1993.

Santa Ana River: Flooding of the Santa Ana River is known to have resulted in many damaging floods in 1862 *(estimated >300,000 cfs)*, 1867, 1884, 1891, 1916, 1938, 1969, 1980 and 1993. Prior to extensive dam and reservoir controls, the Santa Ana River had a large flood event about every five years.

Perris Valley: Due to increased urbanization (Guay, 1996), the Perris Valley region has a growing risk of flood hazards. The Perris Valley Storm Drain and the San

Jacinto River are the major sources of flooding for the area. They have previously inundated primarily agricultural land east and southeast of the city of Perris. The valley is extremely flat, causing flood waters to move slowly and spread over a large area. In addition, there is sudden constriction of flood flows at the entrance to the upper end of Railroad Canyon, south of the city of Perris. This causes ponding and backs up the flood plain for seven miles upstream (FEMA, 1996). The Perris Valley Storm Drain that drains March Air Force Base to the north, generates similar flooding.

Increased urbanization increases flood potential by increasing the percentage of impervious surfaces. When water cannot penetrate into the ground, more flooding ensues. Urban areas in Perris Valley have more than tripled since the early 1970s, from 10% to 36% urban. Guay (1996) demonstrated that these additional impervious areas have increased storm water runoff volumes and peak discharges.

Desert Hot Springs: The city of Desert Hot Springs is situated on deposits created by past flooding events from Big Morongo Wash and canyons of the Little San Bernardino Mountains. Clearly, the Desert Hot Springs region is subject to flooding from Big Morongo Wash and its tributaries.

Coachella Valley: Although mean annual precipitation on the floor of the Coachella Valley is low (4 inches), high and intense precipitation in the surrounding mountains can have a significant impact on the valley floor many miles away.

Coachella Valley floods are typically of short duration, high peak volumes and carrying large amounts of debris. This is due to the arid climate and the steep, high mountains. When a major storm moves in, water collects rapidly and runs off quickly, creating flash floods in the Coachella Valley.

Whitewater River Basin: Historical records dating back to 1769 were reviewed by the Army Corp of Engineers. In the Whitewater River basin, a major flood occurs on average every ten years. Floods occurred in 1825, 1833, 1840, 1850, 1859, 1862, 1867, 1876, 1884, 1886, and 1891. More recent, and thus more accurate records indicate that there were floods in January 1916, December 1921, April 1926, February 1927, February 1937, March 1938, and December 1940. Most recently, substantial floods occurred in November 1965, December 1966, January 1969, February 1969, and September 1976. The greatest storm on record was in March, 1938, with peak discharge estimated at 42,000 cubic feet per second - almost twice the peak of the second largest storm (November 22, 1965, 24,000 cfs).

3.3.1 Earthquake Hazard to Local Water Tanks/Reservoirs

Earthquakes can generate floods by causing the failure of water retention structures such as reservoirs. Flood control and reservoir facilities, even when empty, can be damaged by strong ground shaking, and pose an inundation hazard if they are not repaired soon after an earthquake and prior to the next wet season. Another common agent of earthquake damage is a seiche. A seiche is a seismically-induced wave that reverberates on the surface of water in an enclosed or semi-enclosed basin like a lake, reservoir, bay or harbor. The wave period (how quickly it repeats its motion) will vary depending on the dimensions of the basin. The periods that can damage a structure will depend on the physical characteristics of the structure, including size, shape and materials. Seiches can continue to oscillate for a time after the earthquake shaking ceases.

Seismically-induced inundation can also occur if strong ground shaking causes structural damage to above-ground water tanks. If a tank is not adequately braced and baffled, sloshing water can lift the tank off its foundation, splitting the shell, damaging the roof, and bulging the bottom of the tank (causing "elephants foot") (EERI, 1992). Movement can also shear the pipes leading to the tank, allowing water to escape through the broken pipes. This type of damage was reported in the Landers, Big Bear and Northridge earthquakes. Houses downgradient from a damaged water tank in the Santa Clarita area were inundated due to the Northridge earthquake. Thanks to lessons learned from recent earthquakes, new standards for design of steel water tanks were adopted in 1994 (Lund, 1994). The new tank design includes flexible joints that can accommodate movement in any direction.

3.3.2 Bridge Scour

Scour at highway bridges involves sediment transport and erosion processes that remove streambed material from the bridge vicinity. Scour can occur within the main channel, on the flood plain, or both. Scour processes are generally classified into separate components:

- **Pier scour** occurs when flow impinges against the upstream side of the pier. The flow is forced downward, causing scour of the streambed adjacent to the pier.

- **Abutment scour** happens when flow impinges against the abutment. Flow changes direction and mixes with adjacent main-channel flow, scouring the abutment toe.

- **Contraction scour** occurs when flood-plain flow is forced back through a narrower opening at the bridge. This increases velocity and can produce scour.

- Total scour for a particular site combines effects from all three components.

While different materials scour at different rates, the eventual scour attained is similar regardless of material. It depends primarily on the duration of peak streamflow acting on the material (Lagasse and others, 1991).

Nationwide, several catastrophic collapses of highway and railroad bridges have occurred due to scouring and a subsequent loss of foundation support. This has led to a nationwide inventory and evaluation of bridges (Richardson and others, 1993). The State of California participates in the bridge scour inventory and evaluation program. In addition, California's program to seismically retrofit bridges includes underpinning foundations. In western Riverside County, this should help reduce the vulnerability of foundations to scour. However, since the eastern portion of the County has only a moderate seismic risk, scheduling bridges in these areas for seismic underpinning is of lower priority.

3.4 Geographic Information Systems Flood Mapping

Flood data were collected and digitized as part of this study. These data are shown at 1:250,000 on Plate 3-2, and summarized on Figure 3-1. The flood maps used to create this map had varying scales. The overall map is accurate to no less than 1:24,000.

These digital data come from a collection of resources. Flood Insurance Rate Maps (FIRM) maps, with completion dates ranging from 1980 to 1999, were compared to the existing County data. The combined maps were then compared to the Q-3 digital flood coverage data set from FEMA (1999). In addition, the U.S. Geological Survey's flood prone map information (Table 3-3) was used to complete the flooding map. The following procedures were followed during the creation of the Flood and Inundation Susceptibility Map of Riverside County (Plate 3-2) :

Flood Insurance Rate Maps (FIRM) from the Federal Emergency Management Agency (FEMA) were digitized for unincorporated parts of Riverside County.

FEMA has three categories for flood zones:

Zone A- Special flood hazard areas inundated by 100-year flood.

- Subzone A- No base flood elevations determined.
- Subzone AE- Base flood elevations determined.
- Subzone AH- Flood depths of 1 to 3 feet (usually areas of ponding); base flood elevations determined.
- Subzone AO- Flood depths of 1 to 3 feet (usually sheet flow or sloping terrain); average depths determined for areas of alluvial fan flooding, velocities also determined.
- Subzones A1-30- Areas of 100-year flood; base flood elevations and flood hazard factors determined.
- Subzone A99- To be protected from 100-year flood by Federal flood protection system under construction; no base elevations determined.

Zone B- Areas between limits of the 100-year flood and 500-year flood; or certain areas subject to 100-year flooding with the average depths less than one (1) foot or where the contributing drainage area is less than one (1) square mile; or areas protected by levees from the base flood.

Zone X- Areas of 500-year flood; areas of 100-year flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 100-year flood.

Table 3-3: U. S. Geological Survey Flood Prone Area Maps Digitized for this Study

Map Name	Scale	Date
Alberhill	1:24,000	1973
Beaumont	1:24,000	1975
Blythe	1:24,000	1974
Blythe NE	1:24,000	1975
Desert Hot Springs	1:24,000	1971
El Casco	1:24,000	1976
Fontana	1:24,000	1976
Guasti	1:24,000	1977
Indio	1:24,000	1976
Lake Mathews	1:24,000	1974
McCoy Wash	1:24,000	1975
Mecca	1:24,000	1973
Mortmar	1:24,000	1976
Oasis	1:24,000	1976
Palm Springs	1:24,000	1973
Palo Verde	1:24,000	1976
Rancho Mirage	1:24,000	1976
Redlands	1:24,000	1975
Ripley	1:24,000	1975
San Jacinto	1:24,000	1976
Seven Palms Valley	1:24,000	1971
Sitton Peak	1:24,000	1974
Steele Peak	1:24,000	1974
Sunnymead	1:24,000	1974

Temecula	1:24,000	1973
Thermal Canyon	1:24,000	1973
Whitewater	1:24,000	1971
Wildomar	1:24,000	1973
Yucaipa	1:24,000	1976

Q-3 digital flood data were obtained from FEMA (1999) and added to the map to cover incorporated as well as unincorporated parts of the County that the FIRM data did not cover.

U. S. Geological Survey (USGS) 7.5' quadrangle Flood Prone Areas maps (Table 3-3) were digitized and added to the map to cover areas not mapped by FEMA. The USGS only covers 100-year flooding in its Flood Prone Areas maps. Zone A is defined as flood-prone areas that have a 1 in 100 chance, on the average, of being inundated during any year. Flood prone areas have been delineated without consideration of present or future flood control storage that may reduce flood levels. Four subzones are represented:

Subzone L- Approximate area occasionally flooded if levees are breached.
Subzone O- Approximate area occasionally flooded.
Subzone I- Flood prone area subject to inundation from local thunderstorms.
Subzone S- Flood prone areas from sheet flow.

The current flood map for the County of Riverside was compared to the map compiled for this study (Plate 3-2) to insure that all county data were represented in the new map. One small area in the city of Riverside was taken from the county map and added to the new map. As a results of this study, areas prone to 100-year flooding were added along the west side of the Salton Sea and the western parts of Blythe for areas not covered by any of the afore mentioned data sets. Data sets for these areas are missing or nonexistent, yet these areas are flood prone, based on flood level elevations of the surrounding areas, and topography of the areas.

3.4.1 Benefits of Flood Mapping Using Geographic Information Systems

Many existing Flood Insurance Rate Maps (FIRMs) are based on flood probability estimates that may now be out-of-date. FIRMs are typically hand-drawn on paper maps that have limited vertical accuracy or can not be easily matched to "real-world" geographical coordinates (Jones and other, 1998). They are based on elevation data that, in many cases, have been or will be superseded by more accurate data. In addition paper FIRM maps are relatively expensive and time-consuming to update.

Existing flood maps need continual updating. In the nearly 20 years since original studies were completed, additional information has become available about peak flows and flood plain elevations that will significantly change the flood estimates these maps display. However, complete restudies using traditional methods are expensive and time consuming, so it is unlikely that the maps can be updated quickly enough to meet demand.

Flood maps updated with Geographic Information Systems techniques have many advantages. They are:

- Relatively inexpensive. According to Jones and others (1998), costs are about 10-20 percent of a re-study using traditional methods. Therefore, frequent updates are more feasible.

- Typically more detailed. Digital maps can provide information like depth-of-flood, identify areas where uncertainty in flood or land elevations causes uncertainty in extent of flood inundation, and easily combine with other digital data, such as locations of roads and buildings.

3.4.2 Essential Facility Inventory Exposed to Flood Hazards in Riverside County

An advantage of GIS data is the ability to run simple queries on digital data sets. For example the inventory of essential facilities and hazardous materials sites available from national data sets (FEMA, 1999) can be overlain on the 100 and 500 year flood hazard zones. The results of these queries are presented in Table 3-4.

Table 3-4: Facilities in Riverside County Exposed to Flood Hazards

Facility Type	Total No. in County*	No. in Flood Hazard Zones
Airports	39	14
Hospitals	18	4
Police Stations, Fire Stations and Emergency Operation Centers	109	47
Schools	380	92
Highway Bridges	1,306	446
Hazardous Materials Sites	1,978	695

*: Based on HAZUS '99 various national-level inventories

3.5 County Flood Control and Reservoir Projects

3.5.1 Seven Oaks Dam

The Seven Oaks Dam was completed in 1999 by the U.S. Army Corps of Engineers, Los Angeles District, as part of the Santa Ana River Mainstem Project. The dam sits on the Santa Ana River in the upper Santa Ana Canyon about 14 miles northeast of Riverside County. It is an important flood control structure for the Santa Ana River channel through northwestern Riverside County. Historical flood flows on the Santa Ana have exceeded 300,000 cfs.

The Seven Oaks Dam project consists of a zoned, earth-filled embankment, spillway, outlet tunnel, air shaft, gate chamber, and intake structure tower. Seven Oaks is the 12th highest dam in the country and provides flood protection to the growing urban communities of Orange, Riverside, and San Bernardino counties. It operates in tandem with Prado Dam, about 40 miles downstream. During the early part of each flood season, runoff is stored behind the dam in order to build a debris pool to protect the outlet works (U.S. Army Corp of Engineers, 2000). Small releases are made on a continual basis to maintain the downstream water supply. During a flood, Seven Oaks Dam will store water destined for Prado Dam for as long as the reservoir pool at Prado Dam is rising. When the flood threat at Prado Dam has passed, Seven Oaks will begin to release its stored flood water at a rate which does not exceed the downstream channel capacity. At the end of each flood season, the reservoir at Seven Oaks will be gradually drained and the Santa Ana River will flow through unhindered.

3.5.2 Prado Dam

Prado Dam is a flood control and water conservation project constructed and operated by the U.S. Army Corps of Engineers, Los Angeles District. Completed in 1941, the project is built at the upper end of the Lower Santa Ana River Canyon, at a natural constriction controlling 2,255 square miles of the 2,450 square mile Santa Ana River watershed. The dam embankment is located in Riverside County approximately 2 miles west of the City of Corona. Portions of the reservoir are in both Riverside and San Bernardino Counties (California Division of Safety of Dams, 2000). The dam is approximately 30 miles upstream of the Pacific Ocean. Prado Dam is the downstream element of the Santa Ana River flood control system. Its purpose is to collect runoff from uncontrolled upstream drainage areas along with releases from other storage facilities.

The historic maximum release from Prado Dam was 5,992 cubic-feet per second (cfs) on February 22, 1980 (California Division of Safety of Dams, 2000).

Historically, releases larger than 5,000 cfs have been damaging to downstream improvements. Downstream channel improvements are currently underway as part of the Corps of Engineers' Santa Ana River project. These will dramatically increase the downstream channel capacity to over 30,000 cfs.

3.5.3 Lake Elsinore

Throughout its history, Lake Elsinore has been subject to flooding and drying, depending on runoff amounts. Every year the lake loses an average of 15,000 acre-feet (one acre-foot is approximately 325,900 gallons) to evaporation, which drops the surface level more than 4.5 feet. When the lake is low, fish have died and recreational use has stopped. In the last 75 years, annual inflow to has exceeded 15,000 acre-feet only 15 times. The lake went dry in the 1960s. It flooded in 1980 and again in 1983, causing millions of dollars in damages. The lake nearly went dry in 1991, then the "March miracle" rains the next year raised the level more than six feet. El Niño conditions filled the lake in 1993 and in 1995 (Elsinore Valley Municipal Water District, 2000).

The Lake Elsinore Management Project was designed to help ease this "feast or famine" cycle. Completed in 1995, the Project restructured the boundaries of the lake to prevent flooding, minimize evaporation, and enhance wetlands. The Project also improves water quality. In wet years, runoff from the 782 square mile San Jacinto Watershed pours into Lake Elsinore, which is the lowest point in the watershed. Currently, natural runoff is the only source of water for the lake. In the past, when runoff caused up-stream reservoirs to spill, Lake Elsinore often filled, but rarely discharged. In the past, as the lake began to evaporate, salt concentrations would rise, affecting water quality. The Project enables more frequent discharges from the lake during heavy runoff.

3.5.4 East Side Reservoir Project

The East Side Reservoir Project is situated in the Domenigoni/Diamond valleys, four miles southwest of the city of Hemet. Rock excavations began in 1995, and dam construction began in 1996. The reservoir will be called Diamond Valley Lake and will provide additional water supplies for drought protection and peak summer needs by 2001 (Metropolitan Water District, 2000).

More than 110 million cubic yards of clay, sand, and rock was required for this largest earth fill dam project in the United States. The project will be southern California's largest reservoir, with a capacity of 800,000 acre-feet (261 billion gallons). It almost doubles southern California's surface storage capacity and is intended to secure six months of emergency storage in the event of a major earthquake. The project cost is estimated at about $2 billion and consists of three earth and rock fill dams ranging in height from 130 to 285 feet. Water will be delivered from the Colorado River Aqueduct through the San Diego Canal and from the California State Water Project through the new 12-foot diameter, 45-mile Inland Feeder Project.

3.5.5 Inland Feeder Project

The Inland Feeder Project more than doubles the water delivery capacity of the east branch of the State Water Project and helps replenish local groundwater basins. The project begins in the Devil Canyon area north of the city of San Bernardino and ties into Metropolitan Water District's Colorado River Aqueduct south of Lake Perris, near the city of San Jacinto. The approximately 44 mile long feeder passes through or near the communities of Riverside, Perris, Moreno Valley, and San Jacinto Valley. It will be an important source of water for the Eastside Reservoir Project, delivering about 1,000 cubic feet per second, or about 646 million gallons a day. The estimated cost of the project is $1.2 billion, with a completion date of 2004 (Metropolitan Water District, 2000).

The Inland Feeder Project crosses the San Andreas fault system just north of the Riverside County line, and crosses the San Jacinto fault system at several places. Many of California's aqueduct systems cross active fault systems, as they are difficult to avoid. It is important that earthquake emergency planning include major disruptions of water supply.

3.5.6 Murrieta Creek-Flood Control Master Plan

The Master Plan is to channelize Murrieta Creek and its major tributaries using several concrete-lined open channels and a small network of underground storm drains. The proposed system will carry storm runoff through the rapidly developing Murrieta Creek valley to the valley's south end, where Murrieta Creek and Temecula Creek converge to form the Santa Margarita River.

3.5.7 Lake Mathews

The County of Riverside Flood Control and Water Conservation District has obtained funding for a $20 million Drainage Water Quality Management Plan for the Lake Mathews Watershed Project. The Project objective is to address nonpoint source pollution in Lake Mathews and Cajalco Creek, which drains into Lake Mathews. This will be primarily accomplished by construction of a series of wetlands. Lake Mathews is the terminal reservoir for the Colorado River Aqueduct. It is owned and operated by the Metropolitan Water District and provides drinking water for approximately 15 million people.

3.5.8 Whitewater River

The Whitewater River is the principal drainage course through the Coachella Valley that includes the desert resort community of Palm Springs. It is typically dry, but when it carries water it flows southeasterly. From the city of La Quinta southward, the Whitewater River is contained by the Coachella Valley Stormwater Channel, which flows northeast, around the city of Indio, and eventually into the Salton Sea. The Whitewater drains areas as far away as the summit of San Gorgonio Pass, and the steep southern and eastern slopes of Mount San Gorgonio, with a total drainage area of approximately 850 square miles.

The Whitewater River from Point Happy to the Salton Sea is a man-made channel, the Coachella Valley Stormwater Channel. It generally follows the historical path of the Whitewater River and is mostly unlined, with an average cross-section width of 250 feet, depth of 30 feet, and levees extending 10 feet above the surrounding ground. The Coachella Valley Water District maintains the channel, including straightening and grading as necessary.

3.5.9 Salton Sea

The most recent body of water to inundate the Salton Trough is the Salton Sea. The western six miles of the present Salton Sea lies within Riverside County and the remainder is in Imperial County. The Sea was formed accidently in 1905 (Coachella Valley Water District, 2000).

Around 1900, a private canal company constructed the Alamo Canal to irrigate Imperial Valley farmland with water from the Colorado River. Because technology and funds were not then available to construct a canal through the sand dune range which separates Imperial Valley from the Colorado River, the Alamo Canal diverted water from the river near the Mexican border and went around the sand dunes.

The canal intake silted up in 1904 and the company attempted to cut another opening for the All-American Canal System. In autumn of 1905, before work was completed, floods eroded the cut and widened it until the entire Colorado River was diverted into the Salton Sink. Many efforts failed to return the river to its natural course. The river flowed unchecked into the sink until February 1907, when Southern Pacific Railway finally closed the gap by building a trestle over the place where the banks were breached and dumping thousands of tons of rock into the stream bed. The surface of the Salton Sea stood at 195 feet below sea level when the break was repaired, and water lapped at the southern edge of Mecca.

Other than occasional flash floods, the sea's only source of water is farm drainage from Imperial, Mexicali and Coachella valleys. Evaporation during the summer months causes the sea's elevation to fluctuate about one foot annually. Total evaporation is about 6.5 feet a year. The Sea reached its lowest elevation, 250 feet below sea level, in 1925, and since has gradually risen to its present elevation of 227-228 feet below sea level.

In the late 1970s and 1980s, major flash flooding in Imperial and Coachella Valleys and flood controlled releases from Colorado River dams negated local conservation efforts to control the rising sea (Coachella Valley Water District, 2000). In 1979 and 1980, for the first time since Hoover Dam was built, all major reservoirs on the Colorado system were full and water was released for flood orders. The additional Colorado River water flowed to Mexico, where it was put to use irrigating increased acreage in the Mexicali Valley. Because Mexicali farmland also drains to the Salton Sea, a portion of the released water eventually wound up in the Salton Sea. Major flash floods hit the desert nearly every year from 1976 to 1983. The sea's elevation increased 9 inches during the flooding of September 1976, alone .

Because the sea has no natural outlet, salinity has been increasing and there is concern that it will someday be unable to sustain fish life. Riverside County has entered into a Joint Powers Agreement with the Coachella Valley Water District, Imperial County and Imperial Irrigation District to find a solution that saves the sea's recreational value without reducing its function as a repository for irrigation drainage waters. The Imperial Irrigation District faces State mandates to reduce waste flows to the Sea. Also, the Imperial Irrigation District and the Metropolitan Water District of southern California have an agreement to divert conserved Colorado River water from Imperial to coastal cities. Full implementation could reduce flows into the Salton Sea.

Rising water causes problems for recreational facilities around the Sea, most of which are located at water's edge. With the relatively flat shoreline, a slight increase in elevation can cause flooding. As more land has been placed under cultivation, more water from the Colorado has been brought in for irrigation, creating additional drainage water, which has increased the elevation of the Sea. Improved irrigation practices and a cutback in California's use of Colorado River water after the Central Arizona Project is completed are expected to contribute to a gradual decrease in the sea's elevation during the next two decades (Coachella Valley

Water District, 2000).

3.5.10 Riverside County Flood Control and Water Conservation District Projects

A list and summary of proposed Riverside County Flood Control and Water Conservation District projects for fiscal year 2000 is summarized in Table 3-5, and the motivation for each project is described below:

Table 3-5: Flood Control Project Request FY 2000
Riverside County Flood Control District

AREA	DESCRIPTION	AMOUNT
SANTA ANA RIVER at NORCO BLUFFS	Construction-General	$2,200,000
SANTA MARGARITA and MURRIETA CREEK SUB-BASIN	Feasibility Study - Flood Control	$232,000
	Preconstruction Engineering & Design	$100,000
SAN JACINTO RIVER	Reconnaissance Study - Flood Control & other purposes	$100,000
SANTA ANA RIVER – MAINSTREAM	Construction-General	$23,000,000
PRADO DAM	Construction-General	$5,000,000

Santa Ana River At Norco Bluffs: The Santa Ana River passes along the northerly border of the city of Norco. The southerly bank of the river is a bluff, varying from 46 to 96 feet above the streambed. Atop the bluff is a residential neighborhood. In the floods of January and February 1969, flow impingement on the riverbank undermined the toe of the slope, causing severe bank sloughing. The bluff retreated 50 to 60 feet to the south. No improvements were lost, but the threat became apparent. The floods of 1978 and 1980 caused another 30 to 40 feet of bluff retreat, and the loss of a single family residence.

Santa Margarita, Murrieta Creek Sub-Basin: Murrieta Creek passes through the cities of Murrieta and Temecula in southwest Riverside County, then confluences with Temecula Creek to form the Santa Margarita River, which flows into San Diego County, through the Camp Pendleton Marine Base, and into the Pacific Ocean. Murrieta and Temecula experienced severe flood damage in January 1993, estimated in excess of $10 million dollars, from Murrieta Creek overflow. Camp Pendleton also suffered extensive flood damage, estimated at $88 million, to facilities and aircraft due to Santa Margarita River overflow. For the past several years, a coalition of local citizens, community leaders, environmentalists, and developers have worked closely with the District to identify solutions to the flooding problems within the Murrieta Valley. A U. S. Army Corps of Engineers Feasibility Study addressing flood control, environmental enhancement, and recreation for Murrieta Creek was initiated in April 1998.

San Jacinto River: The 730-square mile San Jacinto River watershed drains into Lake Elsinore in western Riverside County. The San Jacinto River originates in the San Jacinto Mountains and passes through the cities of San Jacinto, Perris, Canyon Lake and Lake Elsinore. The river is an important regional resource that provides water supply, wildlife habitat, drainage and recreation values to the region. The only major flood control structures on the river are levees in the city of San Jacinto built by the Corps of Engineers in the early 1960s. In the 30-mile reach of the river between Lake Elsinore and the city of San Jacinto, only minor channelization exists. The river is characterized by expansive overflow areas, including the Mystic Lake area (Riverside County Flood Control and Water Conservation District, 1999). The San Jacinto River has caused major flooding damage to agricultural areas and rendered Interstate 215 and several local arterial transportation routes impassable.

Santa Ana River Mainstem Project: The Water Resources Development Act of 1986 (Public Law 99-662) authorized the Santa Ana River Mainstem project, which includes improvements and various mitigation features, set forth in the Chief's Report to the Secretary of the Army. The Boards of Supervisors of Orange, Riverside, and San Bernardino Counties continue to support this critical project as stated in past resolutions to Congress. Significant construction has been completed on the lower Santa Ana River Channel and on the San Timoteo Creek Channel. Construction activities on Oak Street Drain and the Mill Creek Levee have been completed. Seven Oaks Dam construction is complete. For FY 2000, appropriations were requested by the Riverside County Flood Control and Water Conservation District (1999) to address various endangered species issues, as well as maintenance and construction projects along the Santa Ana River Channel.

Prado Dam: The Prado Dam portion of the Santa Ana River Mainstem project continues to advance to an eventual construction start (Riverside County Flood Control and Water Conservation District, 1999). Engineering design for the dam embankment and outlet works is approximately 90% complete. Design work has been initiated on the various interior dikes included in the project, and additional design contracts are ready to be let for the balance of engineering work necessary prior to construction.

3.6 Dam Failure

3.6.1 Dam Inventory Data for Riverside County

Data for Riverside County dams were obtained from the National Inventory of Dams (2000), based on 1998-99 data submitted by local agencies. The National Inventory of Dams (NATDAM) database (FEMA, 1993) is undergoing the addition of 19 new fields and will include dam retrofit information in the future. A summary of the dam inventory data available through NATDAM is presented in Table 3-6. NATDAM hazard classification is based entirely on the downstream hazard potential, as follows:

- ***LOW HAZARD POTENTIAL***: Dams where failure or misoperation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner's property.
- ***SIGNIFICANT HAZARD POTENTIAL***: Dams where failure or misoperation results in no probable loss of human life but can cause economic loss, environment damage, disruption of lifeline facilities, or affect other concerns. These dams are often located in predominantly rural or agricultural areas, but could be located in areas with population and significant infrastructure.
- ***HIGH HAZARD POTENTIAL***: Dams where failure or misoperation will probably cause loss of human life.

Table 3-6: National Inventory of Dam (NATDAM) Data for Riverside County

Dam Name	River	Nearest City	Height (feet)	Storage (acre-feet)	Year Built	Drainage Area (square miles)	Haz. Type *
VAIL	TEMECULA CREEK	TEMECULA	152	62,000	1949	306	H
QUAIL VALLEY	SAN JACINTO RIVER	LAKE ELSINORE	37	178	1959	1.6	S
EL CASCO	SAN TIMOTEO CR	REDLANDS	19	188	1879	0.09	S
RAILROAD CANYON	SAN JACINTO RV	LAKE ELSINORE	94	19,367	1928	664	H
LAKE HEMET	SAN JACINTO RIV	VALLE VISTA	135.00	19,112	1895	67	H
FOSTER	LILY CREEK	IDYLLWILD	38.00	56	1945	0.85	L
FAIRMOUNT PARK	SANTA ANA RV	RIVERSIDE	12.00	330	1923	22	S
MOCKINGBIRD CAN	MOCKINGBIRD CAN	RIVERSIDE	74.00	2,905	1914	13.13	H
HARRISON STREET	HARRISON CREEK	RIVERSIDE	50.00	350	1954	2.03	H
WIDE CANYON	WEST WIDE CANYON	FUN VALLEY	84.00	1,490	1968	33.5	S
BOX SPRINGS	BOX SPRINGS CR	RIVERSIDE	49.00	630	1960	4	H
PIGEON PASS	PIGEON PASS	SUNNYMEAD	36.00	1,400	1958	8.71	H
SYCAMORE	SYCAMORE CANYON	RIVERSIDE	63.00	1,510	1956	10.7	H
ALESSANDRO	ALESSANDRO CR	RIVERSIDE	66.00	530	1956	4.63	H
WOODCREST	WOODCREST CREEK	RIVERSIDE	44.00	420	1954	5.32	H
JURUPA BASIN	JURUPA WASH	ENNIS	22.00	291	1983	1.69	S
MARY STREET	ALESSANDRO WASH	CASA BLANCA	40.00	570	1981	6.7	H

DECLEZ DETENTION	SAN SEVAINE CR	GLEN AVON HEIGHTS	30.00	480	1984	10.7	H
TAHQUITZ CR DEBRIS	TAHQUITZ CREEK	AGUA CALIENTE	32	-9.9	1991	18	H
SUNNYMEAD RANCH	RECHE CANYON	SUNNYMEAD	41	540	1985	2	H
PRENDA	PRENDA CREEK	RIVERSIDE	44	291	1954	1.93	H
LEE LAKE	TEMESCAL CREEK	CORONA	47	2,800	1919	53	S
METZ ROAD DB	SAN JACINTO RIV	PERRIS	12	154	1981	1	S

Table 3-6: National Inventory of Dam Data for Riverside County (continued)

Dam Name	River	Nearest City	Height (feet)	Storage (acre-feet)	Year Built	Drainage Area (square miles)	Haz. Type *
TAHCHEVAH	TACHEVAH CREEK	PALM SPRINGS	42	1,720	1964	3.2	H
OAK STREET	OAK STREET CR	CORONA	36	400	1979	6.02	H
MABEY CANYON	MABEY CREEK	CORONA	46	111	1974	1.5	H
HENRY J MILLS RES	OFFSTREAM	RIVERSIDE	23	103	1979	0	L
SKINNER CLEARWELL	OFFSTREAM	TEMECULA	44	410	1991	0	S
DUNN RANCH	HAMILTON CR	ANZA	44	126	1987	0.2	S
ROBERT A SKINNER	TUCALOTA CREEK	TEMECULA	109	62,800	1973	51	H
MATTHEWS	CAJALCO CR	CORONA	264	222,400	1918	40	H
PERRIS	BERNASCONI PASS	PERRIS	130	154,852	1973	10	H
LAKEVIEW	SAN JACINTO RIV	NA	37	990	1994	NA	H
EASTSIDE	DOMENIGONI VALLEY CR	NA	284	NA	2001	13	H
GOODHART CAN DTN BN	GOODHART CANYON	WINCHESTER	15	1,038	NA	3.8	H

HENRY J MILLS # 2	OFFSTREAM	NA	34	92	NA	0.1	S
HJ MILLS RECLAM	OFFSTREAM	NA	48	98	NA	0.03	S
PRADO DAM	SANTA ANA RIVER	ORANGE	106	295,581	1941	2,233	H
EAST SIDE DETENTION DIKE NO. 1	WHITEWATER RIVER	THERMAL	42	21,000	1949	NA	L
EAST SIDE DETENTION DIKE NO. 2	WHITEWATER RIVER	THERMAL	48	18,000	1949	NA	L
WEST SIDE DETENTION DIKE NO. 2	WHITEWATER RIVER	NA	37	630	1968	NA	L
WEST SIDE DETENTION DIKE NO. 3	WHITEWATER RIVER	NA	22	1,300	1970	NA	L
WEST SIDE DETENTION DIKE NO. 4	WHITEWATER RIVER	NA	48	4,900	1968	NA	L

*: NID hazard types are defined in text

3.6.2 Dam Inundation Potential Along the Colorado River

The portions of the County along the Colorado River corridor could suffer from catastrophic failure of dams well outside of the County. From south to north, the dams along the Colorado River upstream of the County of Riverside are summarized below:

- ***Palo Verde*** Diversion ***Dam***: Located 9 miles north of Blythe, the dam is a mix of concrete and earth embankment with a structural height of 43 feet and a hydraulic height of 10 feet.

- ***Headgate Rock Dam***: Located near Parker, Arizona, the dam has a structural height of 70 feet and hydraulic height of 52 feet.

- ***Parker Dam***: Located 12 miles north of Parker, Arizona, this concrete arch dam was completed in 1938. The dam has a structural height of 320 feet and a hydraulic height of 75 feet. Lake Havasu is the reservoir created by the dam and it has a storage capacity of 648,000 acre-feet.

- ***Davis Dam***: Located near Laughlin, Nevada, Davis Dam is a zoned, earth-fill dam built completed in 1950. The dam has a structural height of 200 feet, and creates the Lake Mohave reservoir with a total capacity of 1.8 million acre-feet.

- ***Hoover Dam***: Located about 36 miles south of Las Vegas in the Black Canyon of the Colorado River, Hoover Dam is the highest and third largest concrete dam in the United States. Construction of the dam began in 1931 during the Great Depression and the dam was completed in 1936. The dam has a structural height of 726 feet. The reservoir (Lake Mead) has a storage capacity of 28.5 million acre-feet.

The U.S. Bureau of Reclamation (1993) evaluated inundation potential along the Colorado River by modeling failure of combinations of Hoover, Davis and Parker dams, as follows:

1) Failure of Hoover Dam resulting in the subsequent failure of Davis Dam and Parker Dam *(peak flow=24.2 million cubic feet per second (cfs)).*
2) Failure of Davis Dam resulting in the subsequent failure of Parker Dam *(peak flow=3.4 million cfs).*
3) Failure of Parker Dam *(peak flow=600,000 cfs).*
4) A major storm inflow routed through Hoover Dam *(peak flow=341,000 cfs).*

The mapping prepare by the U.S. Bureau of Reclamation (1993) is digitized and presented on Plate 3-3, as well as Figure 3-3. The results are summarized for the Blythe area in Table 3-7. Blythe has a listed population of about 8,000, which triples during the winter months. Its elevation of about 207 feet above sea-level is well under the modeled water surface elevations for catastrophic failure of any combination of Colorado River dams. Fortunately, in the unlikely case there is a catastrophic failure, a minimum of 23 hours is estimated before the flood waters reach the Blythe region.

Table 3-7: Inundation Modeling of Colorado River Dams

Conditions at Blythe (elevation = ±207 feet)			
Scenario	**Peak Flow (cfs)**	**Max. Water Surface Elevation (feet)**	**Travel Time (hours)**
Failure of Hoover, Davis and Parker	6.1 million	331	33
Failure of Davis and Parker	500,000	283	43
Failure of Parker	360,000	280	23
Major storm release from Hoover	313,000	279	

3.6.3 GIS Dam Inundation Mapping for Riverside County

We prepared a digital map of the coverages of Potential Dam Inundation zones for Riverside County at a scale of 1:250,000 (Plate 3-3). The original map data were obtained from various sources (Table 3-8), and at various scales. The overall map is good to an accuracy of 1:100,000.

The different types of dams included in our digital database and the number of that type found in Riverside County are:

- Earth (35)
- Gravity (1)
- Earth and Rock (2)
- Variable Radius Arch (2)
- Hydraulic Fill (1).

Dam Inundation maps were obtained from the California Office of Emergency Services (OES). The maps were digitized from the set of files described in Table 3-8. Inundation mapping was available for 23 dams whose inundation paths affect the County, and digital data include flood wave travel times when available. These maps are intended to be used by State and local officials for the development and approval of dam failure emergency procedures as described in Section 8589.5 of the California Government code, a portion of the Emergency Services Act. The maps also provide information needed to make natural hazard disclosure statements required under recent legislation (AB 1195 Chapter 65, June 9, 1998, Natural Hazard Disclosure Statement).

The inundation hazard rating scale developed for this mapping is based on dam age, construction material, height, storage capacity versus drainage area and pathway hazard potential. The hazard ratings are provided with the digital data for each inundation pathway (Plate 3-3), summarized in Figure 3-3, and described below:

- ***High*** (rating 4 - 5) (Red, Plate 3-3) - Dams that holds back a lake or significant amounts of water year around. These have large reservoirs and large drainage basins. If construction materials are gravity or hydraulic fill, dams automatically fall into this category due to potential seismic failure.

- ***Moderate*** (rating 2 - 3) (Orange, Plate 3-3) - Dams that hold back a lake or significant amounts of water year around, that are constructed with earth fill materials. These dams have significant heights and large drainage areas, but pathways from them do not immediately flow towards populated areas.

- ***Low*** (rating 1) (Blue, Plate 3-3) - These hold water outside the rainy season and thus are not debris basins. Made of rock or earth materials, these are usually small impoundments with no direct path to populated areas.

- ***Debris basins*** (Brown, Plate 3-3) - These hold water during rainy periods.

These hazard classifications differ from the National Inventory of Dams (NATDAM) classification system (FEMA, 1993), which includes in the high hazard category any dam with the potential to cause loss of life. Therefore, more detail concerning the evaluation of risk is provided by this study.

Table 3-8: Dam Failure Inundation Map Sources

Dam	Map Numbers	Scale	Analysis By:
Alessandro	1,2,3	1:9,600	Neste, Brudin & Stone, Inc.
Box Springs	1,2	1:9,600	Neste, Brudin & Stone, Inc.
Colorado River	6,7,8	1:126,720	Dept. of Interior, Bureau of Reclamation
Foster	1,2	1:6,000	Neste, Brudin & Stone, Inc.
Harrison Street	1,2,3	1:9,600	Neste, Brudin & Stone, Inc.
Henry J. Mills	1	1:12,000	Nelson N. Lee
Lake Hemet	1,2,3,4,5	1:63,360	Neste, Brudin & Stone, Inc.
Lake Mathews	1,2	1:24,000	Metropolitan Water District
Lee Lake	1	1:24,000	Krieger & Stewart
Mabey Canyon	1	1:24,000	Neste, Brudin & Stone, Inc
Mary Street	1,2,3	1:9,600	Neste, Brudin & Stone, Inc.
Mockingbird Canyon	1	1:24,000	Robert L. Taylor
Perris	1,2,3,4	1:24,000	Dept. of Water Resources
Pigeon Pass	1,2,3	1:24,000	Neste, Brudin & Stone, Inc
Prado	2,3	1:24,000	US Corps of Engineers
Prenda	1,2,3	1:9,600	Neste, Brudin & Stone, Inc.
Railroad Canyon	1	1:63,360	Krieger & Stewart
Robert A. Skinner	2,3	1:24,000	Nelson N. Lee
Sycamore	1,2	1:9,600	Neste, Brudin & Stone, Inc.
Tahchevah	1	1:24,000	Neste, Brudin & Stone, Inc.
Vail	1,2,3	1:24,000	James M. Montgomery
Wide Canyon	1	1:24,000	Riverside County FCWCD
Woodcrest	1,2,3	1:9,600	Neste, Brudin & Stone, Inc.

Figure 3-3:

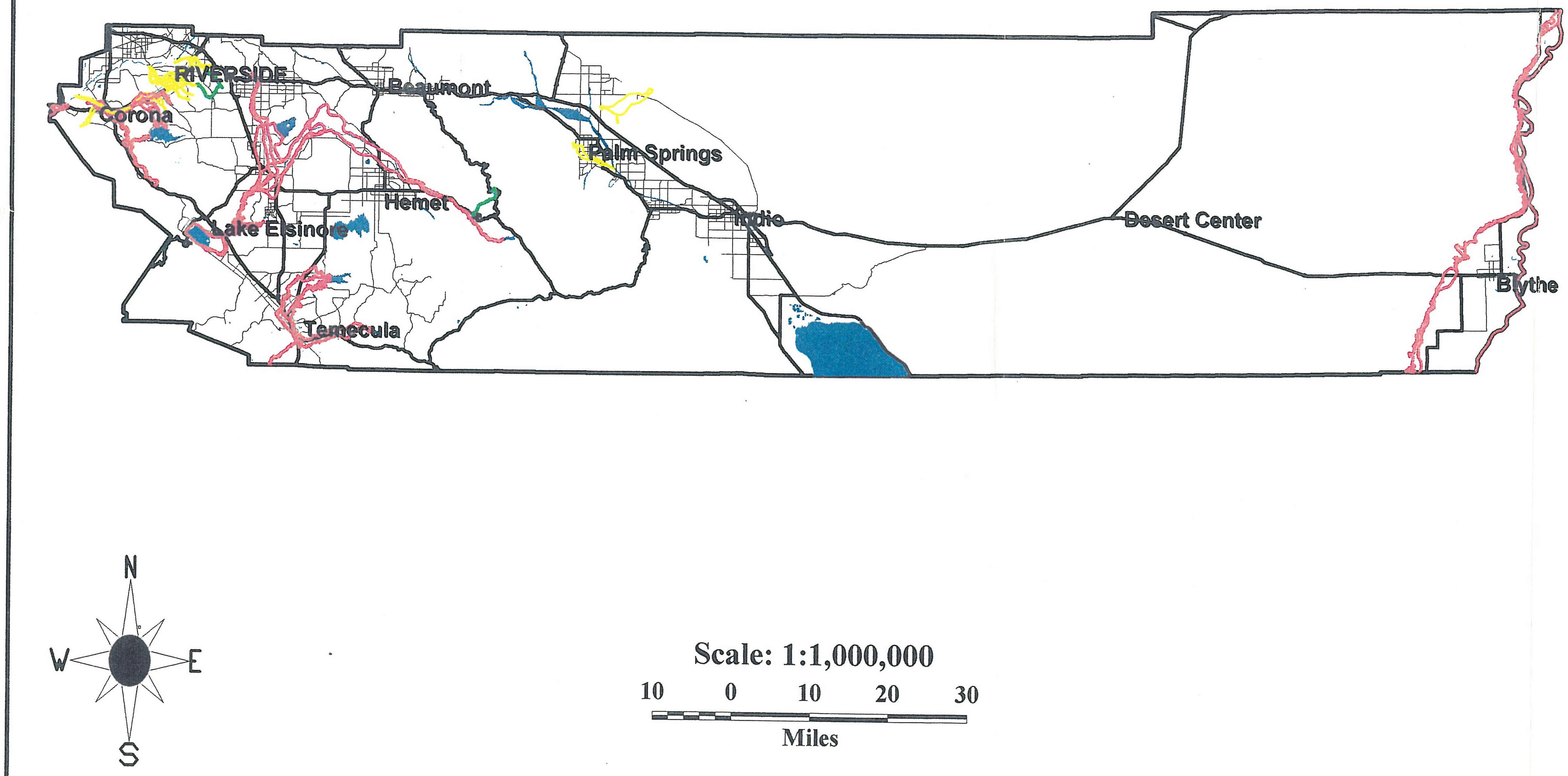
Dam Failure

Inundation Zones

of Riverside County

(Summary of GIS Data, for additional detail see Plate 3-3 in-pocket)

Earth Consultants International



Dam Hazard Zones

- High
- Moderate
- Low

(see text for definitions)

Highways

Major Roads

Water Bodies

Lake, Pond, Sea

3.6.4 Performance of Dams in Earthquakes

Several California dams have been tested by earthquakes, the most notable being the 1971 San Fernando and the 1989 Loma Prieta. In 1971 the Lower San Fernando Dam was damaged, and although it did not fail, evacuation of more than 70,000 persons below the dam was required. The earthen Austrian Dam was damaged in the 1989 Loma Prieta earthquake.

A wide variety of creative solutions have been applied to improve the seismic stability of dams in California. Although there have been major advances in analysis techniques, rehabilitations have not changed radically. Multiple arch dams are still being stiffened and embankment dams buttressed. The performance of Austrian Dam during the 1989 Loma Prieta Earthquake reinforces concerns about damage to the tops of earth dams by earthquakes (Babbitt, 1993).

Experience has shown that dams must be made safe before the earthquake hits. Afterwards, there are too many obstacles to hinder quick detection and treatment of earthquake damaged dams, or to implementing evacuation plans if they are needed. Provisions for emergency response are prudent, but they are not substitutes for pre-earthquake rehabilitation. Babbitt recounts some examples of obstacles encountered:

- Key response personnel were not available. They had been injured or their families needed them.
- Communications were blocked. When telephone and radio facilities were not damaged, they were overloaded.
- Access to dams was difficult. Roads and bridges are designed to lower standards than dams. They should not be expected to survive earthquakes that damage dams.
- Repair materials, equipment and operators were in short supply.
- Helicopters were not available for inspections. News media and high level officials tied them up.

The California Division of Safety of Dams requires that dams have gravity outlets and that their operation be regularly demonstrated. Dam owners must provide dam break inundation maps to the State Office of Emergency Services so that local jurisdictions can prepare evacuation plans. Each of these measures has proven useful in dealing with earthquake and other emergencies at dams.

Two facets of the 1971 Lower San Fernando Dam incident are especially germane:

(1) The reservoir behind the damaged dam had to supply a large portion of the water for Los Angeles for two weeks while severe damage to the supply aqueducts was repaired. This scenario could be repeated in Riverside County following a major earthquake. Many of the County's aqueduct systems cross major fault systems at numerous locations.

(2) A major public awareness effort was required to gain support for construction of the Los Angeles Dam, the functional replacement for Lower San Fernando Dam (Babbitt, 1993).

The new dam was constructed in the old dam's basin. The old dam was repaired and the area between the dams is maintained dry to provide double protection for the downstream area where 70,000 people were evacuated after the 1971 earthquake.

3.6.5 Seismic Retrofit Projects

No single agency tracks the status of dam improvement projects for California. However, the National Inventory of Dams (U.S. Army Corp of Engineers, 2000) plans to include retrofit information in future inventories. Retrofit information should be added to the County's digital database provided by this study.

Pigeon Pass Dam: The California Division of Safety of Dams (2000) describes an improvement project for Pigeon Pass Dam, which is owned and operated by the Riverside County Flood Control District. Pigeon Pass Dam, is a 30-foot high, 2,900-foot long clayey sand embankment structure that forms a 912 acre-foot flood control reservoir in the Sunnymead area of Riverside County. The foundation is alluvium of various ages. The outlet is ungated, allowing the reservoir to empty within hours after rainfall ceases on the 9 square mile drainage area. In December 1978, transverse cracks were discovered in the embankment. The causes of the cracks were determined to be a combination of embankment shrinkage and differential foundation settlement due to hydrocompaction and possibly seismic shaking. The largest crack was repaired by excavating and placing compacted embankment. The proximity of a nearby active fault, the San Jacinto at 4 miles, dictated that repairs include more than treating identified cracks. During an earthquake, cracks could rapidly reopen or new ones form in the rather brittle embankment, particularly where the dam is founded on cohesionless soils. Mitigation measures undertaken for Pigeon Pass Dam included a chimney drain placed in a trench in the downstream slope to act as a crack stopper. The work was safely accomplished in a short time (Babbitt, 1993).

Railroad Canyon Dam: The Railroad Canyon Dam received a $6 million face lift in 1997 to withstand greater seismic and flood forces, in accordance with Federal weather criteria and the State Division of Safety of Dams (Elsinore Valley Municipal Water District, 2000).

Lake Mathews: A major seismic hazard reduction project is underway at Lake Mathews reservoir, about 5 miles south of the city of Riverside. The purpose is to reduce the seismic vulnerability of Lake Mathews outlet facilities and to ensure a reliable supply of water following a major earthquake. The project cost is estimated at about $100 million, with a completion date of May 2004 (Metropolitan Water District, 2000).

3.6.6 Mitigation Alternatives-Storage Restrictions

Reservoir storage restrictions can provide effective, rapid ways to increase dam safety, but can prove troublesome in the long term. Temporary storage restrictions have improved the safety of 21 dams in California (Babbitt, 1993). These operating restrictions are placed soon after analyses identify stability problems. The engineers who do the stability analyses usually recommend the restriction depth. The restrictions allow time to design and finance repairs, find alternate water supplies and to conduct environmental studies. Reducing the allowable reservoir storage directly reduces the damage potential should an earthquake rupture the dam. It also reduces seepage pressures in dams and foundations and eliminates liquefaction potential wherever problem soils are completely drained.

Permanent storage restrictions are being used on only 12 California dams (Babbitt, 1993). These restrictions can be difficult to maintain. Dam operators and regulators change and documents get lost. There is pressure to lift restrictions during periods of drought and other crises. If long-term restrictions are used, the conditions at the reservoirs must make the restrictions easy to maintain. Lowered or notched spillways are a more foolproof method of implementing storage restrictions.

3.7 Flood Hazard Reduction in Riverside County

The statutes governing dam safety are defined in Division 3 of the California State Water Code (California Department of Water Resources, 1986). It empowers the California Division of Safety of Dams to monitor the structural safety of dams that are greater than 25 feet in dam height or 50 acre-feet in storage capacity.

State law generally makes local government agencies responsible for flood control in California. Paragraph (c) of Section 8401 of the Water Code states: "The primary responsibility for planning, adoption, and enforcement of land use regulations to accomplish flood plain management rests with local levels of government." Similarly, Section 65300 of the Government Code requires that each county and city develop and adopt a comprehensive, long-term general plan for the physical development of the jurisdiction.

As part of the County's general plan requirements, the land use element of the plan must identify areas that are subject to flooding. The County's general plan also must include a safety element to help protect the community from unreasonable risks associated with flooding. The water portion of the conservation element must be developed in coordination with any countywide water agency and with all districts and city agencies that control water for any purpose within the city or county for which the plan is prepared. The conservation element may cover land and water reclaimed within the city or county.

While local agencies operate and maintain many flood control facilities, funding for the construction of such facilities often is shared among Federal, State and local agencies. Additionally, local agencies independently fund many local projects without financial assistance from the Federal or State governments. The cost of maintaining the facilities is a local responsibility.

Table 3-9 summarizes agencies with local flood control responsibilities in Riverside County. Local governments are authorized to appropriately zone river basin lands within their jurisdictions. However, State and Federal agencies (Department of Water Resources, the U.S. Army Corps of Engineers and Federal Emergency Management Agency) often provide assistance to local planning and zoning commissions by determining the probability of flooding and the potential flood damage, and by assisting with ordinances that minimize development in flood plains.

Table 3-9:
Local Agencies with Flood Control Responsibilities in Riverside County*

NAME OF AGENCY	CONTACT PERSON, TITLE	PHONE NUMBER	GEOGRAPHIC AREA OF SERVICE
Riverside County Flood Control & Water Conservation District	David Zappe, General Manager	909-275-1250	Western half of Riverside County.
Coachella Valley Water District	Tom Levy, General Manager	760-398-2651	Majority of Coachella Valley.
Palo Verde Irrigation District [1]	Gerald Davisson, District Manager	760-922-3144	Palo Verde Valley in extreme eastern Riverside County and a portion of Imperial County.
Imperial Irrigation District [1]		619-339-9416	Imperial Valley - Imperial County and southeastern Riverside County.
County Service Areas 103 & 121 [2]	Mel Bohlken, Administrator	909-275-1110	CSA 103 serves Wildomar in southwest Riverside County and CSA 121 serves Thousand Palms in the Coachella Valley.
Desert Water Agency	Jack Oberle, General Manager	619-323-4971	Certain territory in Riverside County but excludes waters of the Whitewater River system.
San Gorgonio Pass Water Agency [3]	Steve Stockton, General Manager	909-845-2577	Certain territory in Riverside County.

*source: California Department of Finance (1997)
1 This district performs agricultural/local drainage rather than regional flood control.
2 The two County Service Areas maintain local retention basins.
3 While the agency has authority to acquire and control storm water, its actions in this regard have been limited to taking "runoff" water from local rivers and streams to replenish the groundwater on lands within the agency's jurisdiction.

3.7.1 National Flood Insurance Program

In 1968, Congress created the National Flood Insurance Program (NFIP) in response to the rising cost of taxpayer-funded disaster relief for flood victims and the increasing amount of damage caused by floods. The NFIP makes

Federally-backed flood insurance available in communities that agree to adopt and enforce floodplain management ordinances to reduce future flood damage. National Flood Insurance is available in the County of Riverside.

The NFIP is managed by the Federal Emergency Management Agency's Federal Insurance Administration and Mitigation Directorate. The Federal Insurance Administration manages the insurance component of the NFIP, and works closely with FEMA's Mitigation Directorate, which oversees the floodplain management aspect of the program. The NFIP's policy retention rate is 88.6%, which means more than 11 percent of policyholders are lost each year. Yet the NFIP is self-supporting for the average historical loss year, which means that operating expenses and flood insurance claims are not paid for by the taxpayer, but through premiums collected for flood insurance policies.

Owners of all structures within the projected inundation area of the 100-year flood (Special Flood Hazards Area, SFHA) are required to purchase and maintain flood insurance as a condition of receiving a Federally related mortgage or home equity loan on that structure. However, nationwide estimates indicate that 75% of households in SFHAs do not have a National Flood Insurance Policy (NFIP). Structures located in SFHAs have a 26 percent chance of being flooded over the course of a 30-year mortgage. The likelihood that a building will catch fire over the same 30-year period is about 4 percent. A structure in a SFHA is far more likely to experience a flood than a fire. However, homeowners in SFHAs are far more likely to carry fire insurance (90%) than flood insurance (25%).

Floods do not just occur in the SFHAs where flood insurance coverage is required by law. Some 20 to 25 percent of the NFIP's claims come from structures located outside a designated SFHA.

3.7.2 Riverside County Flood Control District

The Riverside County Flood Control District is the largest agency in Riverside County that is responsible for flood control, including most of the western County. During the District's fifty year history, it has developed an extensive flood control system in western Riverside County including 35 dams, debris basins and detention basins, 48 miles of levees, 188 miles of open channel and 182 miles of underground storm drain (Zappe, 1997). Proper operation and maintenance of the flood control system is critical to protect the lives and properties of the residents of western Riverside County, and is essential to ensure that economic activity and transportation corridors are not disrupted during times of flooding.

3.7.3 Flood Protection Measures

Flood protection can involve a variety of changes to structures and property that can vary in complexity and cost. Basic improvements may be done by individuals. However, complicated or large-scale changes and any that affect the structure of the house or its electrical wiring or plumbing, should be carried out only by a professional contractor licensed to work in the County.

One example of flood protection is to add a waterproof veneer to exterior walls. This is something that only a licensed contractor should do. Then, when flooding is imminent, seal all openings, including doors, to prevent the entry of water. In areas where flood waters are less than 2 feet deep, a house can be severely damaged if water reaches the interior. The damage to walls and floors can be expensive to repair, and the house may be uninhabitable while repairs are underway.

As shown in Figure 3-4, the veneer can consist of a layer of brick backed by a waterproof membrane. Before the veneer is applied, the siding is removed and replaced with exterior-grade plywood sheathing. If necessary, the existing foundation footing is extended to support the brick. Changes are also made to the interior walls so that they will resist moisture damage. In the area below the expected flood level, standard batt insulation is replaced with washable closed-cell foam insulation, and any wood blocking inside the wall cavity is made of exterior-grade lumber.

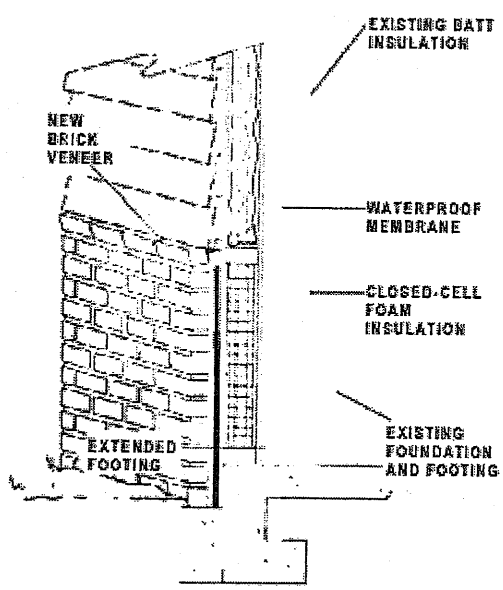


Figure 3-4: Adding Waterproof Veneer to Exterior Wall. FEMA 384, 1999

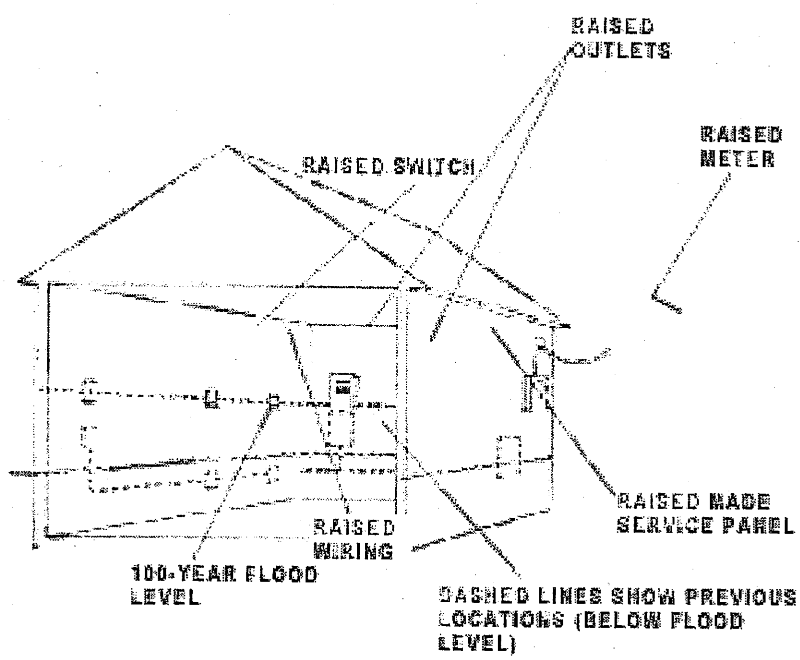


Figure 3-5: Raising Electrical Systems, FEMA 384, 1999

Another flood mitigation measure is to raise the electrical system components of a home in a SFHA (Figure 3-5). Electrical system components, including service panels (fuse and circuit breaker boxes), meters, switches, and outlets, are easily damaged by flood water. If they are inundated for even short periods, they will probably have to be replaced. Even more seriously, they can short circuit and cause fires. Raising electrical system components helps avoid those problems. Also, an undamaged, functioning electrical system will help assist in flood clean up and repairs.

All components of the electrical system, including the wiring, should be raised at least one foot above the 100-year flood level. In an existing house, this work usually will require the removal of some interior wall sheathing (drywall, for example). When repairing a flood-damaged house or building a new house, the electrical system should be elevated above the 100-year flood level as a matter of course. Like all electrical work, this should be done by a licensed contractor.

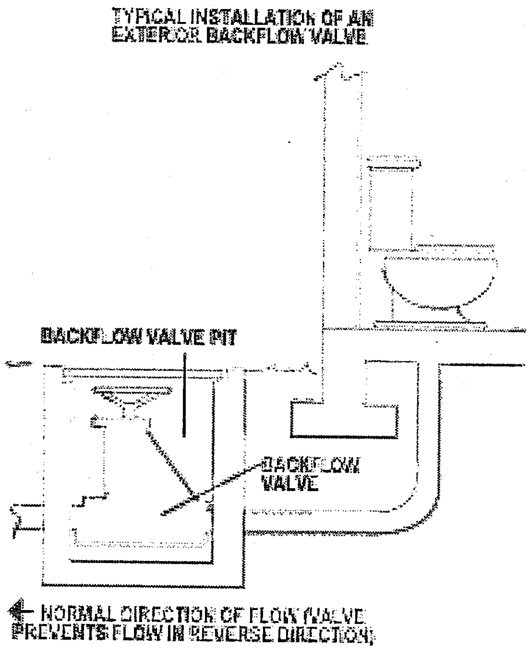


Figure 3-6: Sewer Backflow Valve Installation
FEMA 384, 1999

In some flood-prone areas, flooding can cause sewage to back up into houses through drain pipes. This causes damage that is difficult to repair and creates health hazards. A good way to protect a house from sewage backup is to install backflow valves, which are designed to block drain pipes temporarily and prevent flow into the house (Figure 3-6). Backflow valves are available in a variety of designs that range from the simple to the complex. Some designs must be operated by hand, so the effectiveness will depend on the amount of warning of impending flooding. Among the simpler valves are a flap or check valve, which will open to allow flow out of the house but close when the flow reverses. These valves operate automatically but do not provide as strong a seal.

3.7.4 Flood Safety

The Riverside County Flood Control and Water Conservation District (2000) provides general flood safety information to help educate the public.

Floods can take several hours to days to develop:

- A **flood watch** means a flood is possible in your area.
- A **flood warning** means flooding is already occurring or will occur soon in your area. If it is raining a lot, or if you are in a mountainous area, it's a good idea to keep listening to local radio or TV stations (not stations far away from you). If you hear about a flash flood watch for your area, stay on high ground.
- If you hear a **flash flood warning**, climb to higher ground immediately. Leave your car, camping gear, or other belongings where they are. You may have only minutes to escape. Flash floods can also happen without warning. If you hear a rumbling sound, if animals are running away from where your are, or if you feel the ground shaking, climb to higher ground immediately.

After a flood, keep yourself and your family safe by following these important safety tips:

Do not walk through flowing water: Drowning is the number one cause of flood deaths. While most of these drownings occur during flash floods, a mere six inches of moving water can knock you off your feet. Use a pole or stick to make sure that the ground is still there if you must move through an area where the water is standing but not flowing.

Do not drive through a flooded area: More people drown in their cars than anywhere else. Don't drive around road barriers; the road or bridge may be washed out. Six inches of moving water can carry a small car away! But much bigger vehicles are also at risk.

Stay away from flood control facilities: Warn your children about the dangers of playing in or near flood control facilities such as drainage channels, storm drains, open drainage ditches, natural streams, gutters and inlets to drainage facilities.

Stay away from power lines and electrical wires: Electrocution is also a major killer in floods. Electrical current can travel through water. Report downed power lines to your utility company or local emergency manager.

Turn off your electricity when you return home: Some appliances, such as television sets, can shock you even after they have been unplugged. Don't use appliances or motors that have gotten wet unless they have been taken apart, cleaned and dried.

Watch for animals, especially snakes: Small animals that have been flooded out of their homes may seek shelter in yours. Use a pole or stick to poke and overturn items, to help scare away small animals.

Look before you step: After a flood, the ground and floors are covered with debris including broken bottles and nails. Floors and stairs that have been covered with mud can be very slippery.

Carbon monoxide exhaust kills: Only use a generator or other gasoline-powered machine outdoors. The same goes for camping stoves. Fumes from charcoal are especially deadly - never cook with charcoal in an enclosed area.

Think before you drink: After flooding, drinking water often becomes contaminated. Do not drink your tap water until you have been told it is safe to do so.

Clean everything that got wet: Flood waters have picked up sewage and chemicals from roads, farms, factories and storage buildings. Spoiled food and flooded cosmetics and medicines are health hazards. When in doubt, throw them out.

Take good care of yourself: Recovering from a flood is a big job. It is tough on both the body and the spirit. Yand your family should expect to feel the disaster's effects for some time. Rest often and take good care of yourself and your loved ones.

3.8 The Future of Flood Hazard Mitigation

This topic is discussed in more detail within the Policy chapter (Chapter 5) prepared for this Safety Element. Substantial changes in flood hazard mitigation methods are in progress. These changes are a result of environmental legislation such as the Endangered Species Act, and improvements in the understanding and analysis of flood hazards in arid environments. Nationwide, there is a move to leave nature in charge of flood control. The advantages include lower cost, preservation of wildlife habitat and improved recreation potential. However, this type of flood mitigation is difficult to implement in areas where development has already occurred, as well as regions susceptible to sheet flow. Where water spreads across broad areas, mitigation without channels or culverts is problematic.

Flood control structures have often been built piecemeal over the years, and new development may funnel water into older systems without enough capacity. Building a new major channel now costs about $2 million per mile, while maintenance of an existing major project averages about $12,000 per mile (Ingley, 2000). These issues have been mitigated in recent years by the preparation of Master Plans by local storm control agencies.

Environmental legislation that protects rare and endangered species will continue to make construction of flood control structures difficult. In arid environments, twice as many species and about 250 percent more plant cover are associated with natural wash areas, compared with surrounding land (Ingley, 2000). The County should consider a "Flood-prone Land Acquisition Program" that will reduce the costs associated with flooding and mitigation. Developers will still be able to profit from if wash corridors are left intact, as home buyers will pay premiums to live near these open spaces.

3.8.1 Wetlands

As part of its Eastside Reservoir project, the Metropolitan Water District purchased 9,000 acres for the Southwestern Riverside County Multi-Species Reserve, including lands around the reservoir, Lake Skinner, and the 2,500-acre Dr. Roy E. Shipley Reserve.

Behind Prado Dam in Riverside County, Orange County Water District operates 465 acres of constructed freshwater wetlands to reduce the nitrogen levels in the Santa Ana River. The river provides much of the county's coastal plain groundwater recharge. The Prado wetlands are home to several rare and endangered bird and waterfowl species. More than 226 acres are set aside as habitat for the endangered least Bell's vireo and southwestern willow flycatcher.

3.8.2 Conflicts with Environmental Legislation

Flood control programs and methods are currently undergoing dramatic change. Softer, non-structural solutions implementing flood plain management principles are replacing concrete-based structural measures of the past. Where structures are absolutely necessary, they incorporate softer, more environmentally-friendly materials and designs where feasible. But millions of citizens of Riverside County still rely on the existing flood control systems that have been constructed to ensure protection of their lives and property. There is currently a heavy regulatory burden on local government, who worry that they cannot maintain existing systems of flood control facilities which provide the backbone of protection for the public's health and safety. The head of the Riverside County Flood Control District (Zappe, 1997) calls for reform of the Endangered Species Act.

It seems that everything about the Endangered Species Act is controversial, including debate about its effectiveness and what revisions it may need. Certainly, any legislation that can have such complex, profound and wide-reaching impact needs ongoing scrutiny, as it may have unintended consequences.

In order to participate in the National Flood Insurance Program, the Federal Emergency Management Agency (FEMA) requires that Riverside County and its incorporated cities maintain the carrying capacity of all flood control facilities, and floodways. Communities which fail to meet their maintenance responsibility are subject to expulsion from the National Flood Insurance Program, loss of other Federal aid, and even exposure to suits by FEMA for recovery of flood insurance and disaster payments.

According to Zappe (1997), effectiveness of flood control efforts to protect public safety has been diminished by the regulatory activities of Federal agencies including the U.S. Army Corp of Engineers (Corps), the Environmental Protection Agency (EPA), and the U.S. Fish and Wildlife Service (Service). These agencies have effectively been given veto power over local flood control maintenance activities under authority of the Federal Clean Water Act (CWA) and the Federal Endangered Species Act (ESA). Although these laws have been on the books for many years, their impacts have grown as Federal agencies have issued new and more stringent regulations. As the Service has added new listings of endangered species, formerly routine maintenance activities of existing flood control facilities, have become subject to Federal permit and mitigation requirements, along with the attendant delays and increased costs.

Under the Federal Clean Water Act, three separate permits are required to operate and maintain flood control systems (Zappe, 1997):

- A National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater Permit is required to discharge storm waters to "waters of the United States".

- A Section 404 Dredge and Fill Permit must be obtained from the Corps for any project which discharges fill to waters of the United States. Under Section 7 of the ESA, the Corps is required to consult with the Service where a permitted activity may jeopardize an endangered or threatened species or critical habitat. The EPA retains veto power over any permit issued by the Corps.

- A Section 401 Water Quality Certification or Waiver must be obtained before any given 404 Permit becomes valid. This process has been delegated by EPA to the State Water Resources Control Board.

Zappe (1997) cites many examples of threats to health and safety in Riverside County as a result of this regulatory environment:

- In January, 1993, the Old Town area of Temecula suffered $10 million dollars of property damage in major flooding from overflow at Murrieta Creek. No one was killed, but a number of citizens escaped their cars just before they were swept away. Some businesses never fully recovered and folded. Prior to the flood, Federal officials had refused to allow mechanical clearing of vegetation and removal of accumulated sediment on the creek, due to concerns about the endangered least Bell's vireo. Only after the damage occurred did they allow the flood control maintenance to take place.

- During the early 1990s, the Riverside County Flood Control District wanted to control burrowing rodents in two large earth fill dams, Alessandro Dam in the city of Riverside, and Pigeon Pass Dam in the city of Moreno Valley. The U.S. Fish and Wildlife Service said no because filling of rodent burrows could result in an incidental "taking" of the endangered Stephens' kangaroo rat. Failure to control burrowing rodents in these large earth fill dams could have led to a catastrophic failure. Fortunately, adoption of a habitat conservation plan for the endangered rat has resolved this issue.

- In the mid 1990s, for more than two years, the Riverside County Flood Control District was prevented from making critical repairs to Santa Ana River levees, a Federally-constructed flood control project owned and operated by the District, The District is mandated to maintain these levees by the Federal government (U.S. Army Corps of Engineers), but could not do so because two endangered woolly-star plants were discovered in the general area of the remedial work.

- The Potrero Creek Debris Basin, near San Jacinto, filled to capacity during the winter of 1994/95. Permits to excavate the basin and remove debris were sought in July 1995. The Corps and the Service requested site surveys for the endangered Stephens' kangaroo rat, the endangered slender-horned spine flower, and two other sensitive species, the San Bernardino kangaroo rat and the Los Angeles pocket mouse. This resulted in a delay of the debris removal project until January of 1996, late in the rainy season.

Flood control agencies have also had difficulties getting permits for new flood control projects (Zappe, 1997), including:

San Jacinto River Flood Control Project near Perris: In 1988, the Riverside County Flood Control District began 6 years of negotiations with the Service to address concerns about a potentially endangered plant, the San Jacinto Saltbush. The District added significant environmental enhancements desired by the Service, in hopes of avoiding an endangered listing of the Saltbush. These enhancements included adding a 100-foot wide riparian corridor for the entire 10 mile length of the project, and providing an additional 250-foot wide corridor of land contiguous to the channel for mitigation and protection for the Saltbush and several other plant species of concern to the Service. In order to provide guarantees, the Flood Control District, the County of Riverside and the city of Perris executed a Memorandum of Understanding (MOU) with the Service and the California Department of Fish and Game. The MOU provided for development of a habitat corridor plan for the San Jacinto River subject to review and approval by the Service, and a final draft plan was submitted to the Service for consideration and approval in November 1993. The District emphasizes that the MOU and corridor plan were developed voluntarily and working directly with representatives of the Service, to address Service concerns. Later, the Service proposed listing of the Saltbush and three other species as endangered, unilaterally abrogating the MOU.

Zappe (1997) recommends several specific reforms to the Endangered Species Act:

- A categorical exemption should be added to provide for routine maintenance and emergency repair of all existing flood control facilities and appurtenant structures which protect public health and safety, including dams, debris basins, detention basins, open channels and highway drainage structures.

- Standards should be established for the quality of the science required to justify a proposed listing, and the science and administrative record should be subject to review and approval by an independent panel of qualified scientists before a proposed listing may be published in the Federal Register.

- Criteria should be established for distinguishing true species from subspecies, and only true species should qualify for listing.

- The time period for public comment, and/or for requesting a public hearing, concerning the proposed listing of a species should be increased. In addition, proposals to list a species should be published prominently in newspapers of broad general circulation.

- Early consultation with potentially affected local government, including counties and incorporated cities, should be mandatory before a proposed listing is published in the Federal Register.

- Processing and review of permit applications, and habitat conservation plans should be subject to specific time periods for completion, and should be deemed approved if not completed within the allotted time.

3.8.3 National Pollutant Discharge Elimination System (NPDES)

The County of Riverside participates in the National Pollutant Discharge Elimination System, or NPDES Program. The Program is under guidance of a permit filed with the California Regional Water Quality Control Board, to fulfill the requirements of the Federal Clean Water Act amendments of 1987. This permit is currently required by all cities and counties with a storm drain system that serves a population of 100,000 or more.

On October 29, 1999, Phase II of the NPDES was signed into law. Phase II sets the population threshold at 50,000, and decreases the size threshold for construction site permits from 5 acres to 1 acre.

Under the NPDES, the County is responsible for six minimum control measures. These minimum measures consist of:

- public education and outreach on storm water impacts,
- public involvement/ participation,
- illicit discharge detection and elimination,
- construction site storm water runoff control,
- post-construction storm water management in new development and redevelopment, and
- pollution prevention/good housekeeping for municipal operations.

In order to comply with the Federal law, the County should continue to participate in the NPDES program. Based on observations of extensive erosion at construction grading sites during the 1992-93 storms (Kupferman, 1994), the County should also enforce the new construction site NPDES permit requirements for one-acre and larger projects.

3.9 Summary

During the 20th century, floods were the number-one natural disaster in the United States in terms of lives lost and property damage. Since 1965, eleven Gubernatorial and Presidential flood disaster declarations have been declared for Riverside County.

Previous Flood Disasters

A series of six Pacific cyclones struck southern California during February 13-21, 1980. The floods of 1980 are the worst on record for Riverside County, resulting in ten deaths and more than $70 million in damages. Extensive flooding along banks of reservoirs and streams, including failure of the San Jacinto River levees, led to a Presidential Disaster Declaration.

The San Jacinto River and Lake Elsinore, where much of the flood disaster was centered, are part of the Santa Ana River Basin. The flood of January 22, 1862, the largest recorded in the history of the Santa Ana River basin, destroyed the settlement of Agua Mansa in the northern portion of Riverside County with an estimated peak flow of 320,000 cfs based on old flood marks. Discharges in the vicinity were about 100,000 cfs on March 2, 1938 and 19,500 cfs on February 18, 1980. The reduction in peak discharges over time is a direct result of upstream reservoirs, and with the recent completion of Seven Oaks Dam, even more flood mitigation is in place.

On the morning of February 21, 1980, the levee upstream of the city of San Jacinto failed, and the flood water reverted to its original channel. The levee breaks along the San Jacinto River had the largest consequences of any event associated with the 1980 flooding in southern California. The levee breaks left many homeless, and resulted in damages of $29 million to urban areas and $1.9 million to agricultural area. Another major disaster associated with the 1980 flooding occurred at Lake Elsinore at the terminus of the San Jacinto River. Since it had been so long since outlflow had occurred from Lake Elsinore, gravel had built up at the Temescal Creek outlet. Not until February 23rd did the U.S. Army Corp of Engineers began dredging the outlet. Inflow to Lake Elsinore from the San Jacinto River reached a peak of 8,000 cfs on February 22nd, and the lake surface reached its maximum elevation of 1,266 feet on March 20th. In the low-lying areas around the lake, 874 dwelling and buildings were damaged, and 2,000 residents were displaced.

Flood Problem Areas

The most widely distributed flood map product is the Flood Insurance Rate Map (FIRM). Flood risk data presented on FIRMs are based on historic, meteorologic, hydrologic, and hydraulic data, as well as open-space conditions, flood control works and development.

The County of Riverside participates in the National Flood Insurance Program. Consequently, Flood Insurance Rate Maps (FIRMs) prepared by FEMA showing potential flood zones are available for areas within County limits.

- ***San Gorgonio River***: Flooding on the San Gorgonio River caused damage during 1938, 1965, 1966 and 1969. During the floods of 1969, the San Gorgonio River attained an estimated peak discharge of 17,000 cubic feet per second (cfs), which resulted in loss of life and extensive damage in the Cabazon area.

- ***San Jacinto River***: The San Jacinto River has flooded during 1916, 1927, 1931, 1937, 1938, 1966, 1969, 1980, and 1993. Its largest flood of record occurred on February 16, 1927 with a peak discharge of 45,000 cfs near the city of San Jacinto. Agricultural, railway, and highway properties were extensively damaged. In addition, failure of its levee system in 1980 resulted in extensive damage.

- ***Murrieta Creek***: Nine major floods have been reported, during 1862, 1884, 1916, 1938, 1943, 1969, 1978, 1980, and 1993.

- ***Santa Ana River***: Flooding of the Santa Ana River is known to have resulted in many damaging floods in 1862 *(estimated >300,000 cfs)*, 1867, 1884, 1891, 1916, 1938, 1969, 1980 and 1993. Prior to extensive dam and reservoir controls, the Santa Ana River had a large flood event about every five years.

- ***Perris Valley***: Due to increased urbanization, the Perris Valley region has a growing risk of flood hazards. (Guay, 1996). The valley is extremely flat, causing flood waters to move slowly and spread out over a large area. Increased urbanization increases flood potential by increasing the percentage of impervious surfaces in a given region. Urban areas in Perris Valley have more than tripled in the last 20 years.

- ***Desert Hot Springs***: The city of Desert Hot Springs sits on deposits from past floods from Big Morongo Wash and canyons of the Little San Bernardino Mountains.

- ***Coachella Valley***: Although the mean annual precipitation on the floor of the Coachella Valley is low (4 inches), high and intense precipitation in the steep, high surrounding mountains poses hazard. Floods that affect the Coachella Valley are typically of short duration, high peak volumes and carry large amounts of debris.

Tributaries to the major rivers in Riverside County present additional flood hazards. Flooding in these streams is caused mostly by local thunderstorms. The desert areas extending to the east from the Palm Springs area are susceptible to sheet flow flooding. These type of flows leave the mouths of canyons and often follow unpredictable paths.

During major floods, flood water carries heavy debris loads and causes considerable damage from deposition. For example, the Santa Ana River carried a total sediment load of more than 11 million tons of sediment during the storms of 1969.

Earthquake Hazard to Local Water Tanks/Reservoirs

Earthquakes cause floods by causing failure of water retention structures such as reservoirs. Seismically-induced inundation can occur if strong ground shaking causes structural damage to above-ground water tanks. Damage is also generated by seiches. A seiche is an earthquake-induced wave that reverberates on the surface of water in an enclosed or semi-enclosed basin, such as a reservoir, lake, bay or harbor. Also, if a tank is not adequately braced and baffled, sloshing water can lift it off its foundation, splitting the shell, damaging the roof, and bulging the bottom of the tank. Movement can also shear off the pipes leading to the tank, allowing water to escape through the broken pipes. New tank design includes flexible joints that can accommodate movement in any direction.

Bridge Scour

Nationwide, several catastrophic collapses of highway and railroad bridges have occurred due to scouring and a subsequent loss of support of foundations. Scour at highway bridges involves sediment-transport and erosion processes that remove streambed material from the bridge vicinity. The State of California participates in the bridge scour inventory and evaluation program. In addition, California's seismic retrofit program of bridges includes underpinning of foundations. This may help reduce the vulnerability of foundations to be undermined by scour. However, since the eastern portion of the County has only a moderate seismic risk, bridges in these areas may be of lower priority for seismic underpinning.

Geographic Information Systems Flood Mapping for Riverside County

Flood data were collected and digitized as part of this study. The flood maps used to create this map had varying scales, but the overall map is accurate to no less than 1:24,000. These digital data come from a collection of resources. Flood Insurance Rate Maps (FIRM) maps, with completion dates ranging from 1980 to 1999, were compared to the existing County data. The combined maps were then compared to the Q-3 digital flood coverage data set from FEMA. The U.S. Geological Survey's flood prone map information was used to complete the flooding map.

Benefits of Flood Mapping Using Geographic Information Systems

Flood maps updated with Geographic Information Systems techniques include many advantages. They are relatively inexpensive with costs merely 10-20 percent those of a re-study using traditional methods. Thus, frequent updates are more feasible. In addition, digital maps are more detailed, and can provide depth-of-flood details, identify areas where uncertainty in flood or land elevations causes uncertainty in extent of flood inundation, and can be easily analyzed with other digital data, such as locations of roads and buildings.

Essential Facility Inventory Exposed to Flood Hazards in Riverside County

The inventory of essential facilities and hazardous materials sites available from national data sets were overlain on flood hazard zones for the County. The results of these queries indicate that: 14 of 39 Airports; 4 of 18 Hospitals; 47 of 109 Police Stations, Fire Stations and Emergency Operation Centers; 92 of 380 Schools; 446 of 1,306 Highway Bridges; and 695 of 1,978 Hazardous Materials Sites in the County are located in the 100 or 500 year flood zones.

County Flood Control and Reservoir Projects

- ***Seven Oaks Dam*** : The Seven Oaks Dam was completed in 1999 by the U.S. Army Corps of Engineers, Los Angeles District, as part of the Santa Ana River Mainstem Project. It is an important flood control structure for the Santa Ana River channel through northwestern Riverside County. The Seven Oaks Dam operates in tandem with Prado Dam, about 40 miles downstream. Historical flood flows on the Santa Ana have exceeded 300,000 cfs.

- ***Prado Dam***: Prado Dam is a flood control and water conservation project located at the upper end of the Lower Santa Ana River Canyon, a natural constriction controlling 2,255 square miles of the 2,450 square mile Santa Ana River watershed. The dam embankment is approximately 2 miles west of the City of Corona. Portions of the reservoir are in both Riverside and San Bernardino Counties. Historically, releases larger than 5,000 cfs have been damaging to downstream improvements. However, when current downstream channel improvements are completed, the downstream channel capacity will increase dramatically to over 30,000 cfs.

- ***Lake Elsinore***: Throughout its history, Lake Elsinore has been subject to "feast or famine" flooding and drying, depending on runoff amounts. The lake loses an average of 15,000 acre-feet (an acre-foot is approximately 325,900 gallons) a year to evaporation, dropping the surface level more than 4.5 feet per year. In wet years, runoff from the 782 square mile San Jacinto watershed pours into Lake Elsinore, which is the lowest point in the watershed.

- ***East Side Reservoir Project***: The East Side Reservoir project almost doubles southern California's surface storage capacity and secures six months of emergency storage in the event of a major earthquake. The project is situated in the Domenigoni/Diamond valleys, four miles southwest of the city of Hemet. The reservoir will provide additional water supplies for drought protection and peak summer needs by 2001. Water will be delivered from the Colorado River Aqueduct through the San Diego Canal and from the California State Water Project through the new 12-foot diameter, 45-mile Inland Feeder Project.

- ***Inland Feeder Project***: The Inland Feeder Project more than doubles the water delivery capacity of the east branch of the State Water Project and helps replenish local groundwater basins. The approximately 44 mile long feeder passes through or near the communities of Riverside, Perris, Moreno Valley, and San Jacinto Valley. The Inland Feeder Project crosses the San Andreas fault system just north of the Riverside County line, and crosses the San Jacinto fault system at several places. Many of California's aqueduct systems cross active faults, as they are difficult to avoid. It is important that earthquake emergency planning anticipates major disruptions of water supply.

- ***Salton Sea***: The most recent body of water to inundate the Salton Trough is the Salton Sea. It formed accidently when 1905 floods eroded a cut in a bank of the Colorado River. The cut was made during construction of the All-American Canal. The entire Colorado River was diverted. Presently, the western six miles of Salton Sea lies within Riverside County and the remainder is in Imperial County. With the Sea's relatively flat shoreline, a slight increase in elevation can cause flooding, as most of the recreational facilities are located at water's edge. In the late '70s and '80s, major flash flooding in Imperial and Coachella Valleys and flood controlled releases from Colorado River dams negated local conservation efforts to control the rising sea. Improved irrigation practices and a cutback in California's use of Colorado River water after completion of the Central Arizona Project are expected to contribute to a gradual decrease in the sea's elevation during the next two decades.

Dam Failure

Records maintained at the California Office of Emergency Services provided potential inundation maps for 23 dams affecting Riverside County. We prepared a geographic information system digital coverage of potential dam inundation zones for Riverside County at a scale of 1:250,000. Digital data include flood wave travel times when available. These maps are intended to be used by State and local officials for the development and approval of dam failure emergency procedures as described in Section 8589.5 of the California Government code. The maps can also provide information for natural hazard disclosure statements required under recent legislation (AB 1195 Chapter 65, June 9, 1998. Natural Hazard Disclosure Statement).

Dam Inundation Potential Along the Colorado River

The portions of the County along the Colorado River corridor could potentially suffer from catastrophic failure of dams well outside of the County. The U.S. Bureau of Reclamation prepared a study that evaluated inundation potential along the Colorado River by modeling combinations of failures of Hoover, Davis and Parker dams. Blythe, which has a listed population of about 8,000 that triples during the winter months, sits 207 feet above sea-level - well under the modeled water surface elevations for catastrophic failure of any combination of Colorado River dams. Fortunately, in the unlikely case there is a catastrophic failure, a minimum of 23 hours is estimated before the flood waters reach the Blythe region.

Performance of Dams in Earthquakes

Several California dams have been tested by earthquakes. The experience has shown that dams must be made safe before earthquakes occur. After the earthquake strikes, there are too many obstacles to protect the public with quick detection and treatment of earthquake damaged dams, or implementation of evacuation plans. After recent earthquakes, key response personnel were not available, communications were blocked, access to dams was difficult, repair materials, equipment and operators were in short supply, and helicopters were not available for inspections.

In 1971, the San Fernando earthquake damaged the damaged Lower San Fernando Dam. The reservoir had to supply a large portion of the water for Los Angeles for two weeks while severe damage to the supply aqueducts was repaired. This scenario could be repeated in Riverside County following a major earthquake, as many of the County's aqueduct systems cross major faults at numerous locations.

A wide variety of creative solutions have been used to improve the seismic stability of dams in California. Although there have been major advances in analysis techniques, rehabilitations have not changed radically. Multiple arch dams are still being stiffened and embankment dams buttressed. Reservoir storage restrictions are effective ways to rapidly increase dam safety, but can prove troublesome in the long term.

Seismic Retrofit Projects

No one agency tracks the status of dam improvement projects for California. However, the National Inventory of Dams (U.S. Army Corp of Engineers, 2000) plans to include retrofit information in future inventories. Retrofit information should be added to the County's digital database provided by this study.

- ***Pigeon Pass Dam:*** In December 1978, cracks were discovered in the embankment. The causes of the cracks were determined to be a combination of embankment shrinkage and differential foundation settlement due to hydrocompaction and possibly seismic shaking. Because the San Jacinto fault is within 4 miles of the dam, seismic retrofit was undertaken. Mitigation measures included a chimney drain placed in a trench in the downstream slope to act as a crack stopper.

- ***Lake Mathews***: A major seismic hazard reduction project is underway at Lake Mathews reservoir about 5 miles south of the city of Riverside. The purpose is to reduce the seismic vulnerability of Lake Mathews' outlet facilities, and to ensure a reliable supply of water following a major earthquake.

- ***Storage Restrictions***: Temporary storage restrictions have been used to improve the safety of 21 dams in California. These operating restrictions are placed soon after analyses identify stability problems. They allow time to design and finance repairs, and find alternate water supplies. Reducing the allowable reservoir storage directly reduces the damage potential should an earthquake rupture the dam. Permanent storage restrictions are being used on only 12 California dams. These restrictions can be difficult to maintain, as there is pressure to lift restrictions during periods of drought and other crises. Lowered or notched spillways are a more foolproof way to implement storage restrictions.

Flood Hazard Reduction

State law generally makes local government agencies responsible for flood control in California. Paragraph (c) of Section 8401 of the Water Code states: "The primary responsibility for planning, adoption, and enforcement of land use regulations to accomplish flood plain management rests with local levels of government." As part of the

County's general plan requirements, the land use element of the plan must identify areas that are subject to flooding. The County's general plan also must include a safety element for the protection of the community from unreasonable risks associated with flooding.

While local agencies operate and maintain many flood control facilities, funding for the construction of such facilities often is shared among Federal, State and local agencies. In addition, local agencies independently fund many local projects without financial assistance from the Federal or State governments. The cost of maintaining the facilities is a local responsibility.

National Flood Insurance Program (NFIP)

Owners of all structures within the projected inundation area of the 100-year flood (Special Flood Hazards Area, SFHA) are required to purchase and maintain flood insurance as a condition of receiving a Federally related mortgage or home equity loan on that structure. Over the course of a 30-year mortgage, structures located in SFHAs have a 26 percent chance of being flooded, while the likelihood that the building will catch fire is about 4 percent. Yet homeowners in SFHAs are far more likely to carry fire insurance (90%) than flood insurance (25%). Floods do not just occur in SFHAs where flood insurance coverage is required by law. About 20 to 25 percent of the NFIP's claims come from structures located outside a designated SFHA.

Flood Protection Measures

Flood protection can involve a variety of changes to structures and property that can vary in complexity and cost. Basic improvements may be done by individuals. However, complicated or large-scale changes, and those that affect the structure of the house, its electrical wiring or plumbing, should be carried out only by a professional contractor licensed to work in the County.

The Future of Flood Hazard Mitigation

Substantial changes to flood hazard mitigation methods are taking place. These changes are a result of environmental legislation, and improvements in the understanding and analysis of flood hazards in arid environments. Nationwide, there is a move to leave nature in charge of flood control. The advantages include lower cost, preservation of wildlife habitat and improved recreation potential. However, this type of flood mitigation is difficult to implement in areas where development has already occurred, as well as regions susceptible to sheet flow. Where water spreads across broad areas, mitigation without channels or culverts is problematic. Flood control structures have often been built piecemeal over the years, and new development may funnel water into older systems without enough capacity. These issues have been mitigated in recent years by the preparation of Master Plans by local storm control agencies.

Environmental legislation that protects rare and endangered species will continue to make construction of flood control structures difficult. In arid environments, twice as many species and about 250 percent more plant cover are associated with natural wash areas, compared with surrounding land. The County should consider a "Flood-prone Land Acquisition Program" that will reduce costs of flooding and mitigation. Developers will still be able to profit from leaving wash corridors intact, as home buyers will pay premiums to live by these open spaces.

Wetlands

As part of its Eastside Reservoir project, the Metropolitan Water District purchased 9,000 acres for the Southwestern Riverside County Multi-Species Reserve. Behind Prado Dam in Riverside County, the Orange County Water District operates 465 acres of constructed freshwater wetlands.

National Pollutant Discharge Elimination System (NPDES)

The County of Riverside participates in the National Pollutant Discharge Elimination System, or NPDES Program. On October 29, 1999, Phase II of the NPDES was signed into law. Phase II lowers the population threshold for permit requirements from 100,000 to 50,000, and drops the threshold for construction site permits from 5 acres to 1 acre. Based on observations of extensive erosion at construction grading sites during the 1992-93 storms, the new construction site NPDES permit requirements are warranted.

Conflicts with Environmental Legislation

Flood control programs and methods are currently undergoing dramatic change. Softer, non-structural solutions utilizing flood plain management principles are replacing concrete-based structural measures of the past. But millions of citizens of Riverside County still rely on the existing flood control systems that have been constructed to ensure protection of their lives and property.

In order to participate in the National Flood Insurance Program, the Federal Emergency Management Agency (FEMA) requires that Riverside County and its incorporated cities, maintain the carrying capacity of all flood control facilities, and floodways. Communities which fail to meet their maintenance responsibility are subject to expulsion from the

National Flood Insurance Program, loss of other Federal aid, and even exposure to suits by FEMA for recovery of flood insurance and disaster payments.

Yet, maintenance of flood control systems has been complicated by the regulatory activities of several Federal agencies including the U.S. Army Corp of Engineers, the Environmental Protection Agency, and the U.S. Fish and Wildlife Service, under authority of the Federal Clean Water Act (CWA) and the Federal Endangered Species Act (ESA).

The Riverside County Flood Control District (District) is the largest agency in Riverside County that is responsible for flood control. Proper operation and maintenance of their flood control system is critical to protect lives, properties, economic activity and transportation corridors in western Riverside County.

District director Zappe (1997) argues that reform of environmental laws, particularly the Endangered Species Act, is necessary to ease a regulatory burden on local government, and ensure safety of existing systems of flood control. Zappe (1997) cites many examples of threats to health and safety as a result of regulation. He recommends several specific reforms to the Endangered Species Act. In particular, he calls for a categorical exemption involving routine maintenance and emergency repair of all existing flood control facilities.

Natural Hazard Mapping, Analysis, and Mitigation: a Technical Background Report in Support of the Safety Element of the New Riverside County 2000 General Plan

CHAPTER 4: WILDLAND FIRE HAZARDS

4.1 Overview

Major wildland and earthquake-induced fires can overwhelm local emergency response resources and are an ongoing threat in Riverside County, which has suffered six fire disasters since 1970. This study rates much of the County as potential wildland fire area, a finding that is in agreement with the State of California Department of Forestry and Fire Prevention. In such areas, special State statutes govern development, property owners must do preventative maintenance, and, in general, planning and preparedness are required to avoid disasters.

Wildland fire, also called chaparral or brush fire, is typically associated with the indigenous vegetation in the mountain and foothill areas of southern California. This vegetation has a very high oil content that creates severe fire danger. Wildland fires can also occur in suburban and rural areas of the County, which juxtapose developed lands with uncultivated lands, undeveloped lands, timber, range, watershed, brush or grasslands.

At present, more than 8 million people have homes and businesses in California's wildland areas. In Riverside County, as elsewhere, more people than ever are living and playing in wildland intermix areas. Wildland-urban interfaces create extremely dangerous and complex fire conditions which pose a tremendous threat to public and firefighter safety. Often, as wildland fires meet structural developments, vegetation ceases to burn but catastrophic fire continues, for a mile or more, sustained by structures igniting.

Wildland fire is a serious and growing hazard, posing a great threat to life and property, particularly when it spreads into developed areas. However, wildland fire is also a natural process. In the past, the presumption has been that all fire is bad and should be extinguished promptly. This has caused fire-starved vegetation to grow more dense, which weakens vegetation in a struggle for living space and increases destruction by pests and disease. Dead and dying plants add fuel for fire. In addition, in many areas, the absence of fire has altered or disrupted the cycle of natural plant succession and the wildlife habitats. Recognizing this, land management agencies are now committed to finding ways, such as prescribed burning, to reintroduce fire into natural ecosystems, while acknowledging the continued importance of fire-fighting and suppression.

Fires in fire-starved areas burn more intensely. They are more costly to control and create greater risk of losses to the people, resources, and improvements in wildland areas. In addition, many other factors are contributing to make wildfires hotter and more destructive. California has extended droughts, which increase dead and dying vegetation, volumes of dry fuel per acre, and the number of days of low humidity. Federal policy that sets aside federal lands, without an aggressive pre-fire management program, further limits fuel management and adds ignition sources. Then, in many portions of Riverside County, fire danger can be worsened by steep, rugged topography, which allows wildland fire to spread quickly and makes it more difficult to fight.

Santa Ana winds greatly increase fire danger. Named by the early settlers at Santa Ana, these hot, dry winds typically develop when a strong, but stalled, high-pressure system near Idaho and Salt Lake (the Great Basin High) meets a weak, low-pressure system just off shore in southern California (Chen, 2000). In these conditions, the easterlies (winds from the east) are turned north and south, where they are channeled and thus strengthened by the many canyons in the Great Basin. The result is hot, powerful, and very dry winds that blow across southern California, especially through the mountain passes.

The greatest demands on fire suppression resources occur when there are multiple ignitions. Thus, widespread fires following an earthquake, coupled with Santa Ana winds, constitute a worst-case fire suppression scenario. Because of dry vegetation and recurring Santa Ana winds, the fire danger for Riverside County is considered extremely high during 25% of each year, throughout the months of August, September and October. Because of many large, active faults in Riverside County, the probability of a major earthquake is high, year-round. Therefore, there is a statistically significant chance that this worst-case fire suppression scenario could occur.

The Oakland Hills fire of October, 1991 (the "Tunnel" fire, Table 4-1) demonstrates the seriousness of multiple ignitions. The Oakland Hills fire was a firestorm. When fires grow into firestorms, we have catastrophes. Insurance companies define a catastrophe as an event that triggers at least $25 million in claims or more than 1,000 individual claims. Riverside County may develop a different definition. Regardless of such fine points, the Safety Element of the General Plan exists to avoid such incidents.

During the Oakland Hills fire, numerous single- and multi-family residential structures were simultaneously ignited by burning cinders that were fanned by winds. In this mode of fire spread, termed "branding", wind can transport burning cinders a mile or more. Roofs are the most vulnerable portion of a building or structure to branding. Wood-shingle roofs are particularly fire-prone, thus current code prohibits the use of untreated wood shingles or shakes for new or replacement roofing. Wood-shingle roofs are prevalent in residential areas of Riverside County.

As can be seen in Table 4-1, disastrous wildland fires start in many ways. The most common cause of urban and wildland fires is man. However, the effectiveness of current fire safety efforts, and the extent of loss during fire disasters, can be readily evaluated using an earthquake scenario. Thus, this chapter provides loss estimation scenarios for major earthquake-induced fires, with and without Santa Ana winds.

Using an earthquake to model worst-case fire scenario hazards may also help us to remember a key point. Fire prevention and suppression are not the only services provided by fire departments. Other obligations, like search and rescue, can reduce fire suppression resources after a catastrophe, and this must be factored into emergency preparedness planning.

4.1.1 Previous Fire Disasters

Unfortunately, damaging fires are a fact of life throughout California. In 1994 alone, more than 525,000 acres were destroyed in California wildland fires, making it one of many billion dollar pay-out years for insurers. In 1995, the California Department of Forestry and Fire Prevention (CDF) battled 6,621 blazes that damaged or destroyed 121 structures. To date, the most destructive fire in California history was the fast-moving 1991 Oakland Hills fire, called the "Tunnel" fire (Table 4-1).

Table 4-1 lists the twenty largest California wildland fires, their locations, causes and extent of devastation. They are ranked according to number of structures lost. Note the great variation in acres burned. Many of the older fires on this list would be far more devastating today, as area populations have grown.

In Riverside County, the most severe fire disaster to date occurred in October 1993, Powerlines knocked down by Santa Ana winds started a fire that destroyed 107 homes and burned 25,100 acres in Riverside County (Table 4-1 and 4-2). Gubernatorial Proclamations of a State of Emergency and Presidential Major Disaster Declarations (Office of Emergency Services, 2000) affecting Riverside County have been declared on that and five other occasions in the last 30 years (Table 4-2). Historical fires and their locations within the County are illustrated on Figure 4-1.

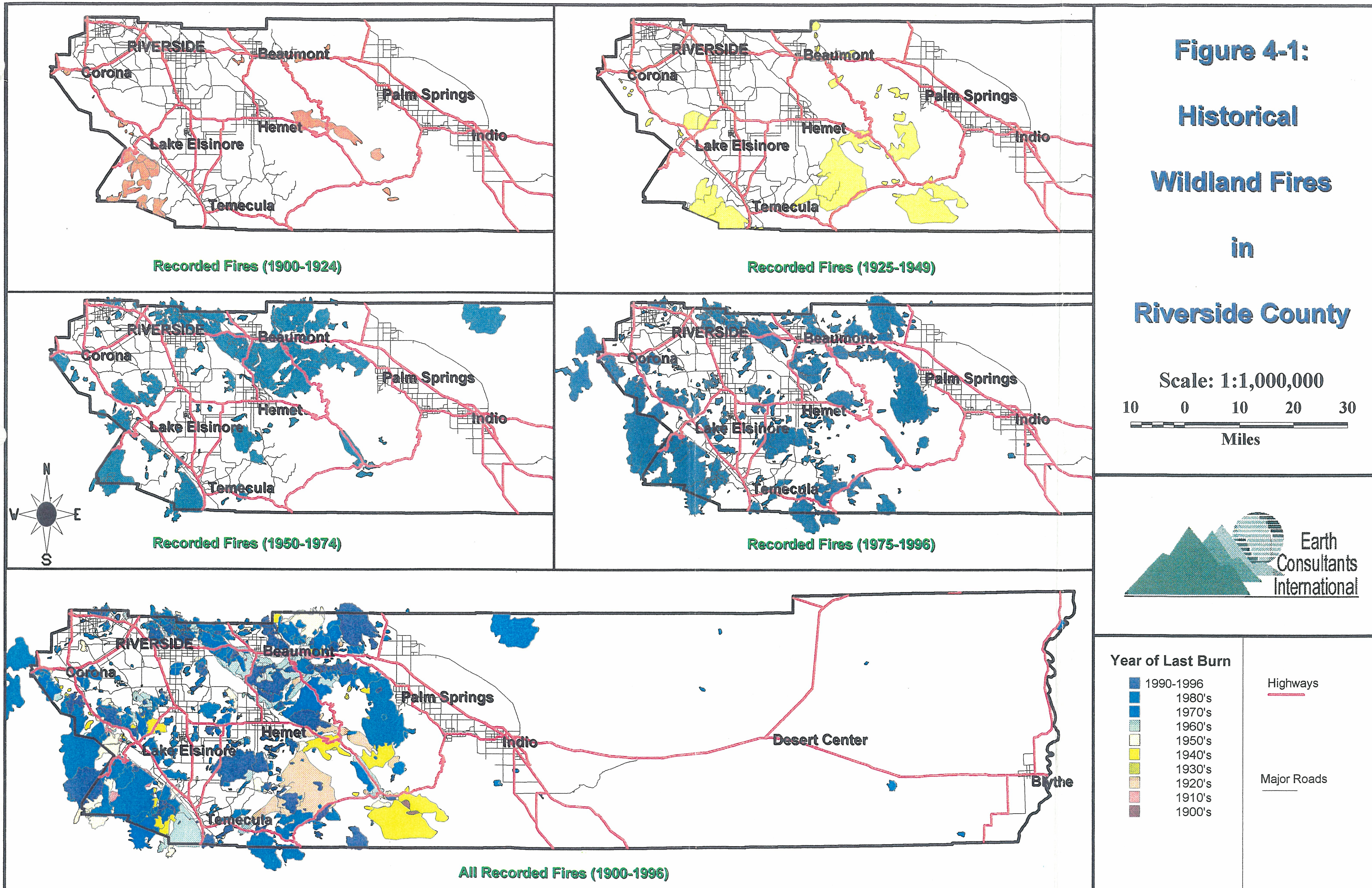


Figure 4-1: Historical Wildland Fires in Riverside County