# Analysis of Seismic Activity and Potential Seismic Hazards of the Fontana Trend in Southern California

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October 2007

# Declaration of originality

This is to certify that the work is entirely my own and not of any other person, unless explicitly acknowledged (including citation of published and unpublished sources). The work has not previously been submitted in any form to the Manchester Metropolitan University or to any other institution for assessment for any other purpose.

Signed ________________________________________________

Date __________________________________________________

**Acknowledgments**

The author wishes to acknowledge the support of her husband, Charles Gooding, in her continued academic pursuits. He has offered great moral support for many years.

Frank Jordan, Registered Geologist, has also been of great help in many ways for many years. We have had many discussions of the nature of the Fontana Trend and southern California tectonics. He and the author also drove around the area searching for possible surface expression of the fault. He and several other members of the Inland Geological Society have been helpful in bouncing ideas back and forth.

The author would also like to acknowledge the support of her employer, LSA Associates (Riverside office Principal in Charge, Lynn Calvert-Hayes) for allowing me to take a week off to finish the dissertation and fellow employees (especially Meenaxi Panakkal) for much encouragement to finish and offering to read the finished work. Eric Stikes and the entire GIS/Graphics team also pitched in and worked long hours while I was off finishing the dissertation.

Thank you to all who helped in this endeavor. It has been a long time in the making.

**Abstract**

Southern California is a seismically active region with a large population. The Study Area is the Fontana Seismic Trend, an area of intense earthquake activity in western San Bernardino County. There has been not been much significant work done to quantify the potential seismic hazard posed by it. This dissertation will show that there is potential for a moderate seismic event on the Fontana Seismic Trend that will likely cause quite a bit of damage and disrupt lives. The major faults nearby have been studied extensively, but this is not the case for the Fontana Seismic Trend. When plotted on a map, the earthquake epicenters of the Fontana Seismic Trend display a significant linear pattern both two dimensionally and three dimensionally. In this dissertation, the location and direction of movement of the underlying fault were identified and configured to fit the earthquake data. Using the plotted fault location, direction of movement and length, the maximum potential event that might occur on this fault was also quantified. HAZUS-MH (a FEMA software extension to ArcGIS) was used to perform a seismic hazard analysis to find out what type of damage and casualties can be expected if a moderate event occurs on this fault. This dissertation discusses the methods used to determine the fault parameters and details the results from the seismic hazard analysis.

## Word Count

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| Number of Pages: | 85 |
| Number of Words: | 19400 |

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## CHAPTER ONE

### 1.0 Introduction

Southern California's Inland Empire is a geologically complex, seismically active region. The Study Area lies in the San Bernardino Valley, located in southwestern San Bernardino County and northwestern Riverside County, California (figure 1.1). The valley is surrounded by the San Bernardino Mountains on the east and northeast and the San Gabriel Mountains on the north. The western limit of the area is defined by the Chino Hills and the southern limit by the Santa Ana River and the City of Riverside.

Numerous reverse, strike-slip and thrust faults form the boundaries of this region and lie within the Study Area. There is daily seismic activity throughout much of the region. Some of the activity can be attributed to specific faults such as the San Jacinto, much cannot. There is an apparent linear pattern of seismicity in an area unrelated to previously recognized faults (figures 1.2, 1.3 and 1.4). Many geologists refer to this as the Fontana Trend or Fontana Seismicity Trend (Hauksson and Jones, 1991). This activity starts near the San Jacinto fault zone and trends in a southwesterly direction to the Chino fault. Very little work has been done regarding the origin of this seismicity in the past, but increasing interest has been shown in the last few years (Hauksson, 2000, Fontana General Plan, 2003 and Shaw, et al, 2004).

Map figures (except where noted) contained in the dissertation were created and symbolized using ArcGIS software by ESRI. Data used in the maps is from a variety of sources. DEM (Digital Elevation Model) data and Geological data came from the USGS (Unites States Geological Survey). Fault and Soil data is from the California Geological Survey. Groundwater barriers were digitized from three USGS paper maps and one California Division of Water Resources paper map. Earthquake and quake related data is from SCEC (Southern California Earthquake Center). Roads, city and boundary data (counties, states and countries) came packaged with ESRI software. Water features (streams and lakes) came from SAWPA (Santa Ana Watershed Project Authority). Census tract data and other data used in the HAZUS scenario came packaged with HAZUS software.

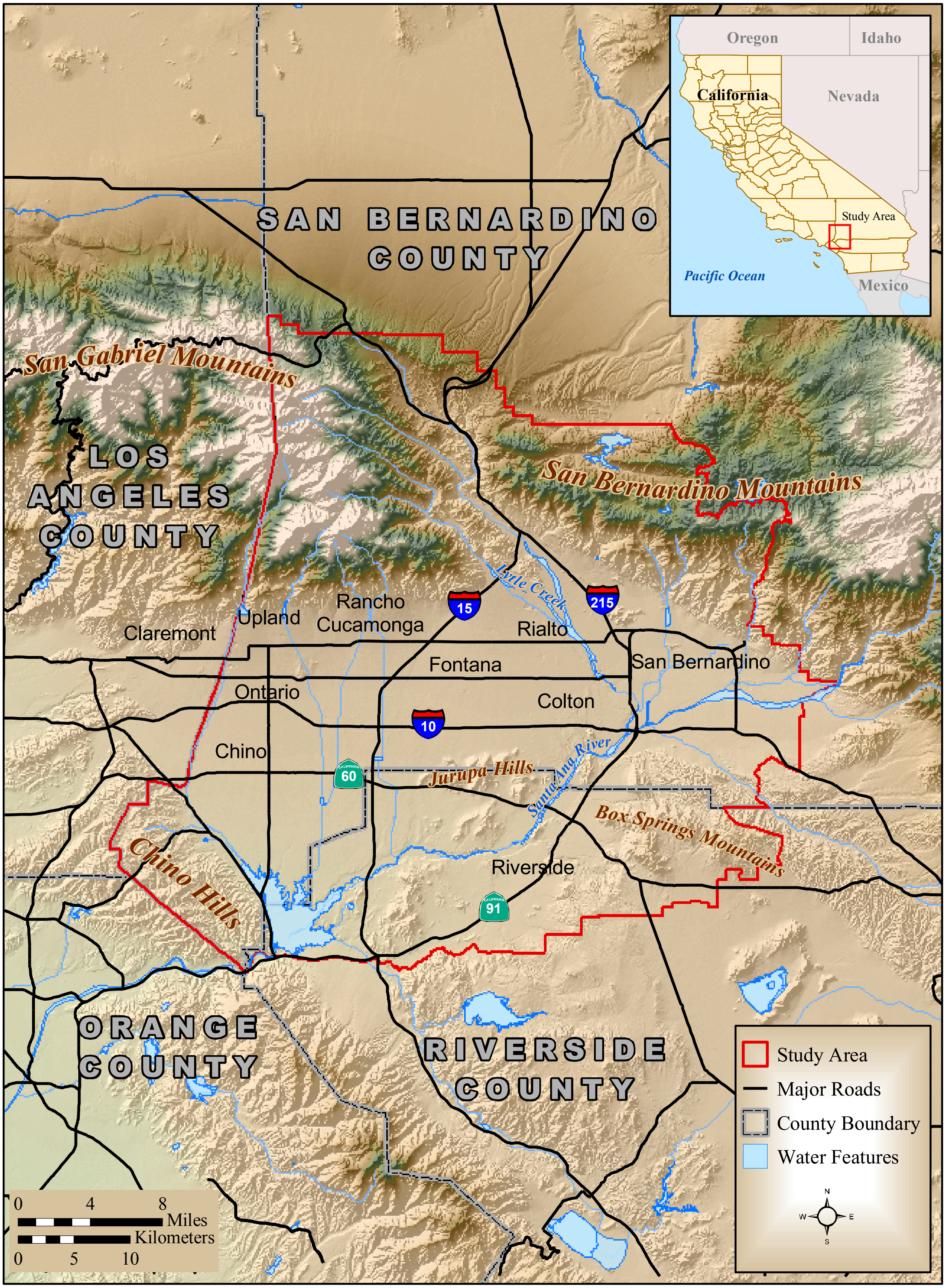



Figure 1.1: *Regional and Project Location Map* Source: USGS DEMs; SAWPA, 2003.

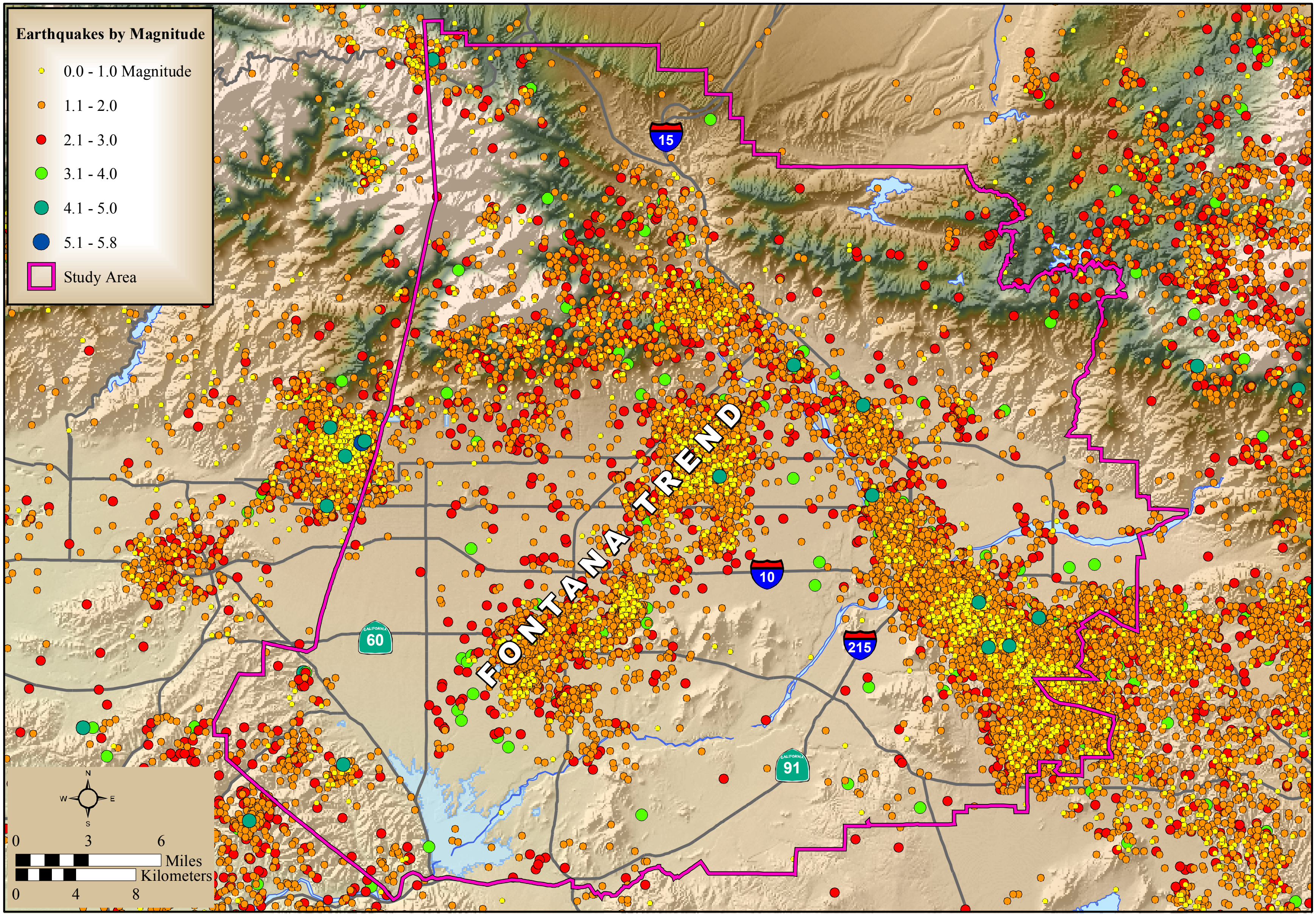



Figure 1.2: *Earthquakes by Magnitude, June 1932 to January 2006*

Source: SCEC, 2006; USGS DEMs; SAWPA, 2003.

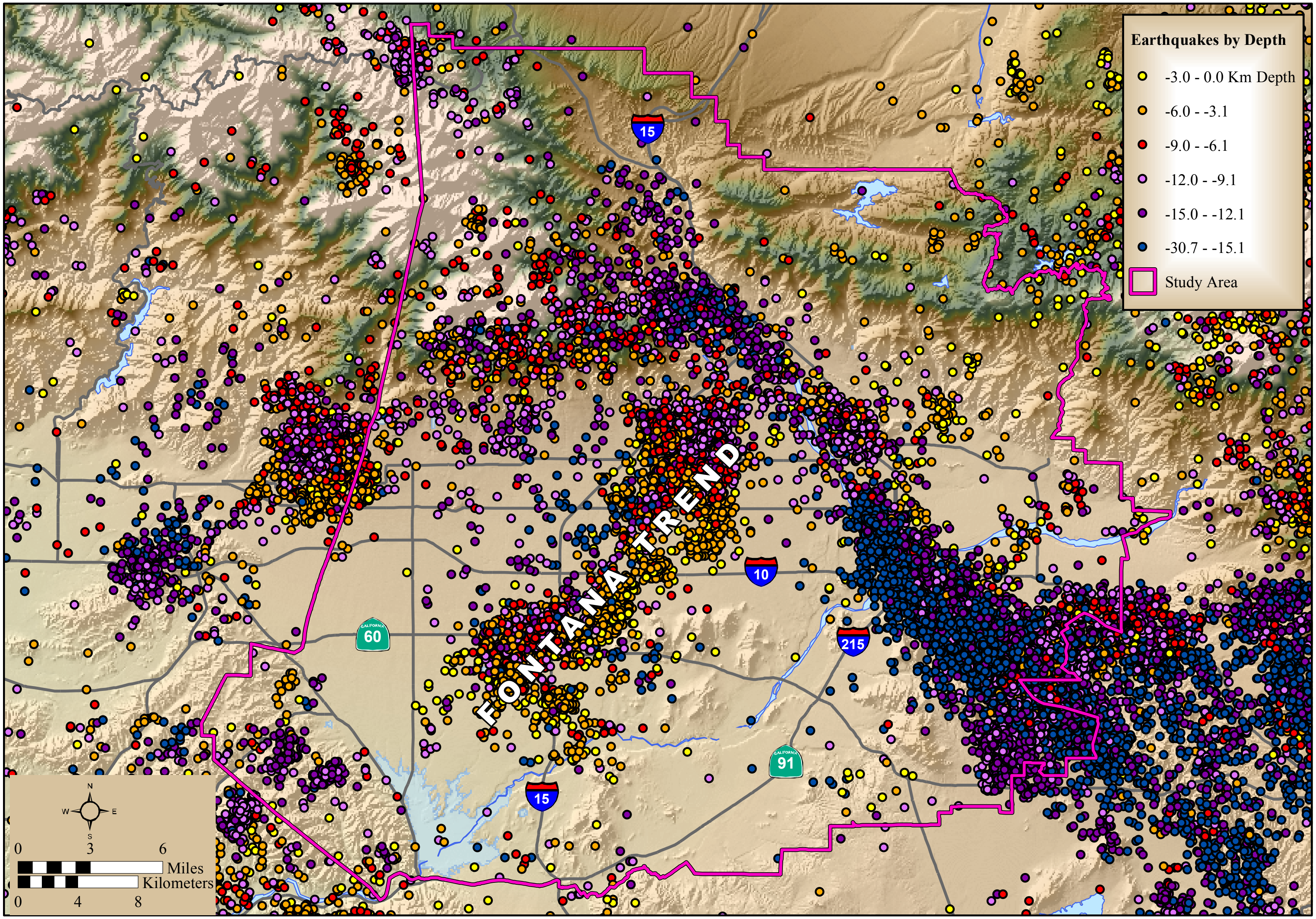



Figure 1.3: *Earthquakes by Depth, June 1932 to January 2006*

Source: SCEC, 2006; USGS DEMs; SAWPA, 2003.

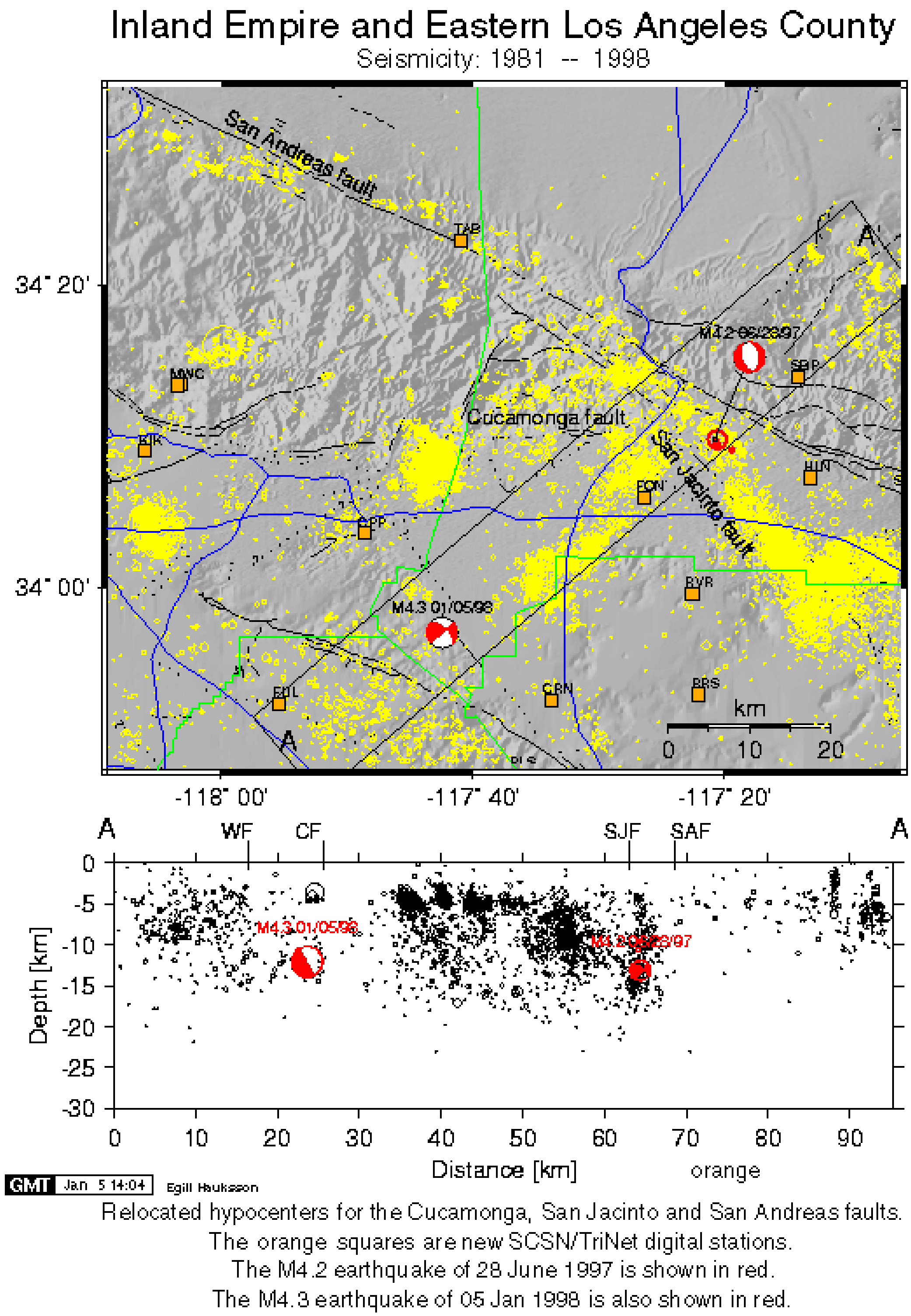



Figure 1.4. *Map showing seismic activity along the Fontana Trend with a cross-section. Published in 1998 for the Southern California Seismic Network on Southern California Earthquake Center's (SCEC) web site.*

## 1.1 Tectonic Setting

### 1.1.1 Geology of the San Bernardino Valley

The region is composed of large, fault-bounded blocks including the uplifted San Bernardino and San Gabriel Mountains and the alluvium-covered down-dropped Perris and San Bernardino Valley blocks (figures 1.5 and 1.6). These blocks have been displaced both horizontally and vertically with respect to each other. The faulting has a significant influence on the topography.

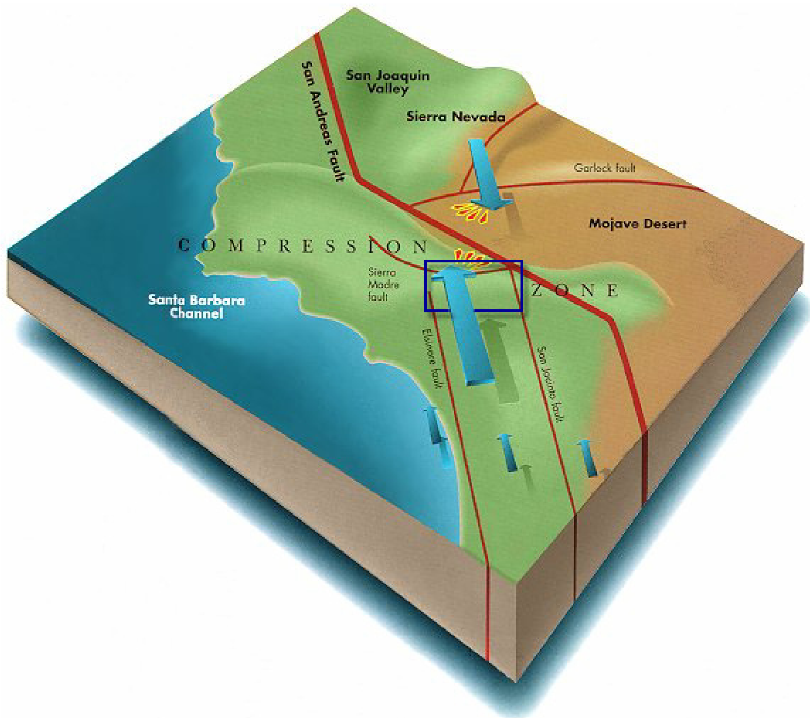



Figure 1.5 *A schematic block model of Southern California showing the motion of the Pacific and North American plates, and the big bend of the San Andreas fault where the plates squeeze together. Study Area is shown as a dark blue rectangle. Diagram is from the Southern California Earthquake Center.*

The crystalline metamorphic and igneous basement rocks, and metasedimentary rocks are important because they form the San Gabriel Mountains and San Bernardino Mountains that lie to north of and underlie the alluvium in the San Bernardino Valley. The crystalline basement complex includes diorite, granodiorite, granite, gabbro, and banded gneiss. The metasedimentary rocks are compacted gravel, sand, silt and clay, marine sediments, quartzites, phyllites and schists (Eckis, 1934). The Jurupa Hills and Slover Mountain to the south are composed of resistant crystalline and metamorphic rocks. Several other bedrock hills protrude above the alluvial deposits (Red Hill and Pedley Hills are two), providing barriers to groundwater flow.

The Miocene to Holocene alluvial deposits that cover most of the San Bernardino Valley are important to this study because they can mask faulting. The alluvial deposits are mostly fan deposits of sand and coarse gravel derived from the surrounding mountains. One of the largest of the alluvial fans was created by the outflow of Lytle Creek (a major tributary of the Santa Ana River) from the San Gabriel Mountains. It extends from the mouth of Lytle Creek Canyon south to the Jurupa Hills (figure 1.6). This fan is typical of the fans in the Study Area in its composition: poorly sorted clay, sand, gravel and boulders interbedded with lenticular deposits of silt and clay. It is underlain at depth by older alluvium that contains much weathered material. Another major fan and wash system is the Santa Ana River outflow from the San Bernardino Mountains. It covers much of the eastern and southern parts of the valley. Other tributaries contribute additional fan sediments all along the base of the San Gabriel Mountains and the Chino Hills.

Tectonically controlled basement topography controls the thickness of the alluvial cover that ranges from 5 to over 400 meters, possibly as much as 2.5 kilometers (Fife et al., 1976; Morton and Matti, 1993). This tectonic movement has caused down-warped areas that readily fill with sediment and other areas that have been up-warped (most notably near the San Jacinto fault) and are covered by much thinner layers of sediment. Figure 1.7 shows the geology of the San Bernardino Valley Area (Morton and Miller, Geologic map of the San Bernardino and Santa Ana 30' x 60' quadrangles, California, 2006). The geology on the map has been generalized to combine similar rock types into broader categories for simplicity. For example, granite, monzonite, monzogranite, tonalite, granodiorite, and similar have been lumped into one granitic rocks category. The alluvial fan polygons depicted in figure1.6 were adapted from the geologic data and aerials.

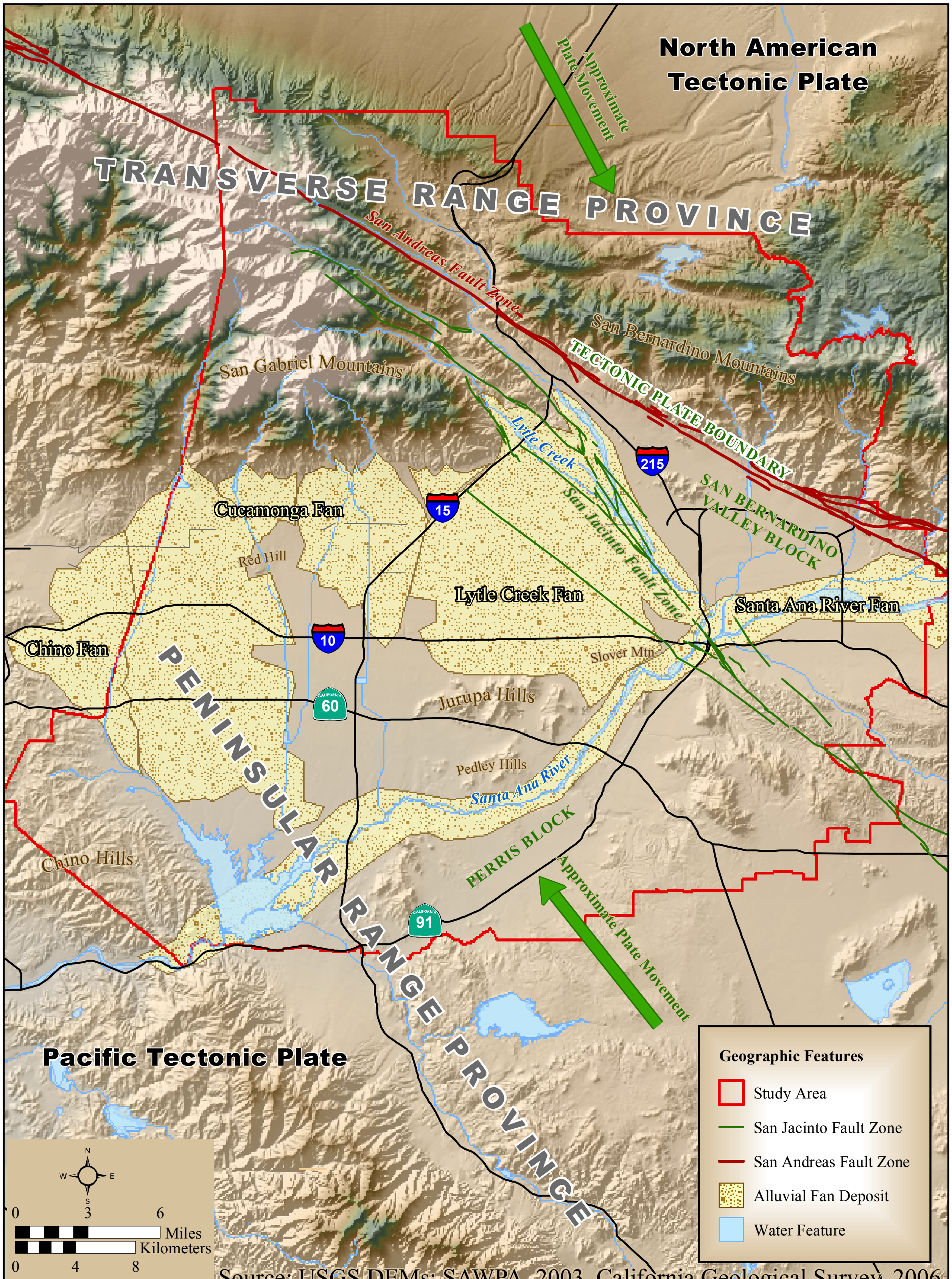



Figure 1.6: *Geomorphology and Tectonics of the Study Area*

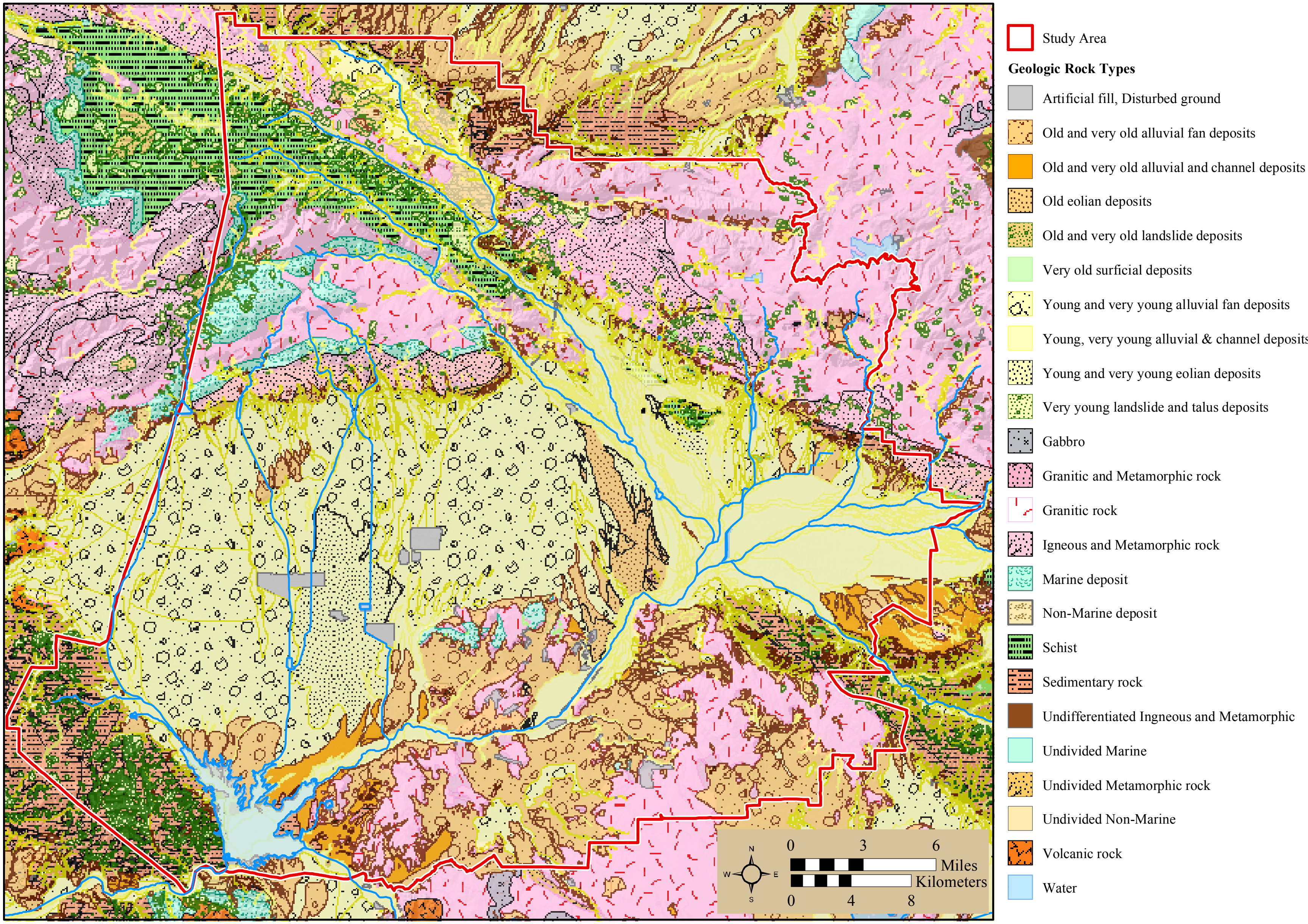



Figure 1.7: *Geology of the San Bernardino Valley Area* Source: USGS, 2006; USGS DEMs; SAWPA, 2003.

### 1.1.2 Area Faulting

There are three groups of faults in the San Bernardino Valley with different characteristics. There appears to be a tectonic relationship between the groups. As figure 1.8 shows, the general pattern of east-west trending thrust faults and folds may be a response to a restraining bend in the San Andreas transform system (Weldon, et al., 1993). The northwest-trending faults such as the San Jacinto fault are generally long, comparatively straight or gently curving, vertical, or near vertically dipping, right-lateral strike-slip faults. The east-trending faults such as the Cucamonga fault are mostly moderately dipping reverse faults, with the mountain blocks being thrust to the south over valley blocks (Eckis, 1934). The San Jose fault is representative of the third category, a northeast-trending left-lateral strike-slip fault. Additionally, several groundwater barriers have been identified in the San Bernardino valley. These are covered by alluvium and may be faults.

The San Andreas-San Jacinto fault system belongs to the first group. The system includes the San Jacinto and Rialto-Colton faults. Another group of northwest-trending faults, the Chino and Central Avenue faults, are present in the western part of the Study Area. The San Jacinto fault is a low, east-facing escarpment forming the east and northeast boundary of the Study Area. The Rialto-Colton fault forms the boundary between the Chino and Rialto-Colton groundwater basins and is sub-parallel to the San Jacinto fault. The Rialto-Colton fault trends southeastward from Barrier J (Woolfenden and Kadhim, 1997) to the Badlands (southeast of Colton – see figure 1.8). An unnamed fault lies about one-half mile west of and parallel to the San Jacinto fault in Rialto. Lithologic and borehole-geophysical data indicates vertical offset along its mapped length (Woolfenden and Kadhim, 1997). The Chino Fault lies on the western edge of the Study Area along the northeastern margins of the Chino Hills. It is a 21 km long (13 miles), steeply west-dipping reverse fault with some right-lateral offset (Heath et al., 1982). It is believed to be a northern segment of the Elsinore fault zone (Fife et al., 1976), which is a right-lateral strike-slip fault.

Several east-trending faults are also associated with the northwest-trending systems. These faults are part of a larger thrust fault complex, the Sierra Madre, which extends along the entire front of the San Gabriel Mountains. The principal east-trending fault is the Cucamonga fault zone, which consists of several faults. These include the Cucamonga, Red Hill and San Sevaine Canyon faults. These faults displace Holocene sediments in some areas (ECI, 1999). The Cucamonga fault is a moderately dipping reverse or thrust fault, about 30 km in length, marking the southern boundary of the eastern San Gabriel Mountains. It breaks into several strands in some areas, with the most recently active portion farthest from the mountain front (Powell, 1993). There is a component of left-slip along this fault (Powell, 1993). Another member of the Cucamonga fault zone, the Red Hill fault (also known as the Etiwanda Avenue fault), is a thrust fault. It is approximately 25 km long and dips to the north.

The San Jose Fault forms the northwestern boundary of the Study Area. It is an 18 km long northeast-trending left-lateral strike-slip fault with a possible minor reverse component (SCEC fault list). It dips steeply to the north. The 1988 and 1990 Upland earthquakes are believed to have occurred on the San Jose fault (Hauksson and Jones, 1991).

Dutcher and Garrett (1963) defined several barriers to groundwater flow associated with the faults in the Rialto-Colton area, naming them alphabetically A-H (figure 1.8). They may be faults, but since they show no surface rupture, this has not been verified. Barriers A, B, C, D, E and H are all parallel to the northwest-trending faults; J is parallel to the east-trending faults; while Barriers F and G are at an oblique angle to both systems. An unnamed barrier that is parallel to Barrier J appeared on D. Morton’s map accompanying the 1976 California Division of Mines and Geology Special Report 113, but stops at the edge of the map and is not visible on the adjacent map (figure 1.8). This barrier seems to follow the "Fontana Trend" for a short distance. This barrier also appears in the 2003-2004 City of Fontana General Plan as an “inferred fault” (ECI, 2003).

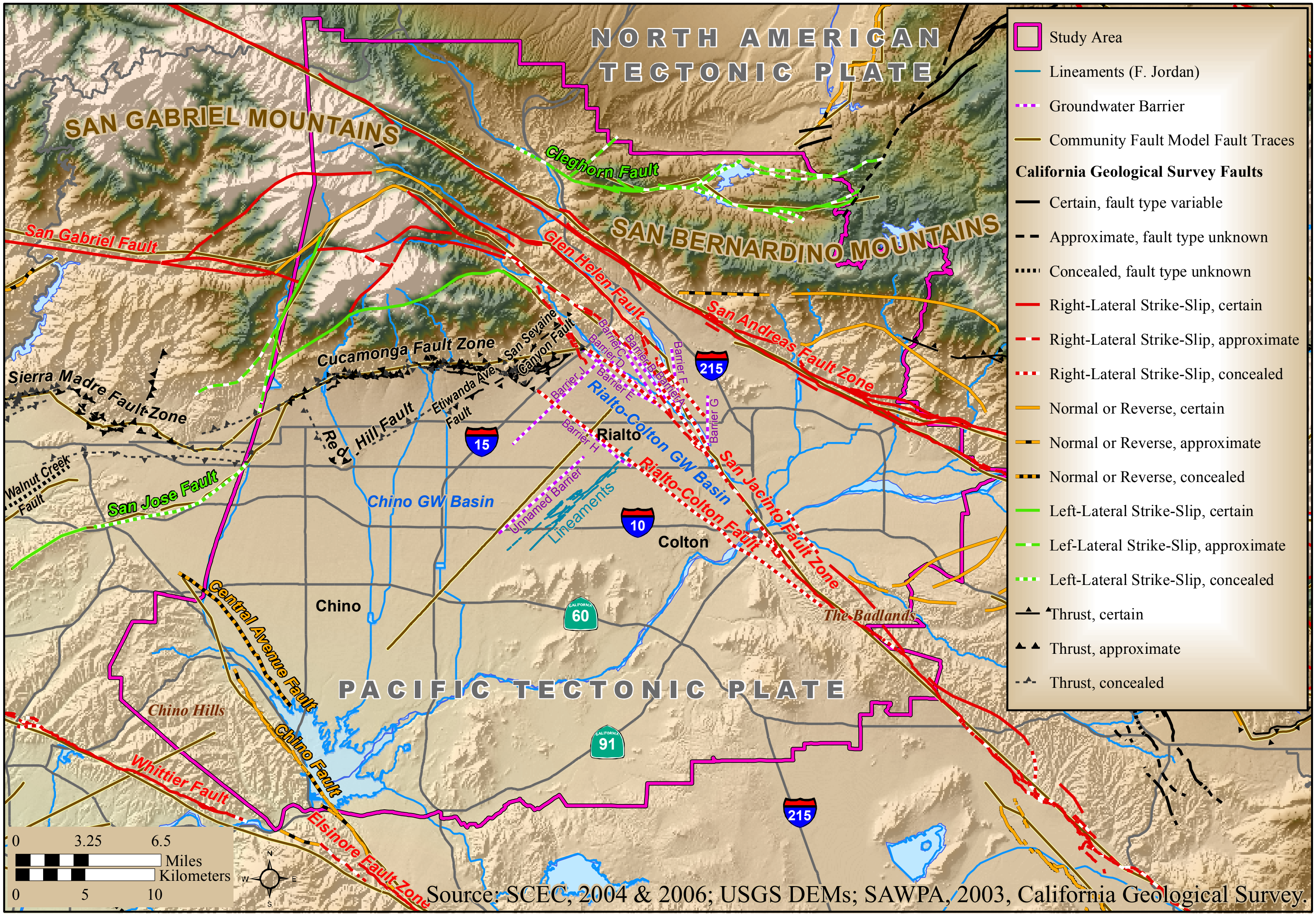



Figure 1.8: *Faults of the San Bernardino Valley Area*

### 1.1.3 Regional Tectonics

The region of southern California, which includes the San Bernardino Valley and the surrounding mountains, is one of the most tectonically active and complex in the country. Over the past few million years, the Pacific Tectonic Plate has moved steadily northwest past the North American Tectonic Plate at an oblique angle. Figure 1.5 reveals the some of the complex transpressional forces at work in the region that have caused the Transverse Ranges (which include the San Gabriel and San Bernardino Mountains) to rotate approximately 90 degrees clockwise and created the "Big Bend" (Ingersoll and Rumelhart, 1999). These same forces are pushing the Perris Block of the Pacific Plate toward the San Gabriel Mountains, forcing them to thrust up and over it (figure 1.7). Some recent work by Dr. Jason Saleeby and his colleagues at CalTech suggest this tectonic anomaly is in response to the shallow subduction of a spreading center under the North American Plate and subsequent formation of the transform boundary that is the San Andreas Fault (the author attended a talk given by Dr. Saleeby on March 2, 2006).

The tectonic response to these complex forces comes in the form of earthquake activity, faulting and folding. A single fault zone can have a complex history of strand development, abandonment and reactivation (Morton and Matti, 1993). Where there are several active fault zones, as in the San Bernardino Valley area, the activity will be complex. It is probable that the "Fontana Trend" is a fault within this complex zone. It might also be a flexural response to the forces pushing the Perris Block against or under the San Gabriel Mountains.

The maps in figures 1.2, 1.3 and 1.4 show an unexplained northeast-trending belt of seismicity that does not correspond completely to any previously recognized faults. The activity appears to start near the Chino and Central Avenue faults in the southwestern Chino area (figure 1.8). It trends in a northeasterly direction to the Fontana area where there appears to be some offset to the north. The trend continues northeast to the San Jacinto fault zone where there is a concentrated cluster of earthquakes. There are several possible explanations for this seismic trend.

1. It might be a single left-lateral strike-slip fault, similar to the San Jose fault as postulated by Hauksson and Jones, in their 1991 seismic study.

2. It might be two or more left-lateral en-echelon strike-slip fault segments with a step-over. The two offset parallel groundwater barriers suggest this. This is a similar structure to the faulting causing the Landers earthquake in the Mojave Desert in 1992.
3. There could be several right-lateral en-echelon strike-slip fault segments. The pattern of seismicity in the area near the unnamed barrier suggests this as a possibility, though less likely than a left-lateral fault zone.
4. The crystalline rocks of the Perris block could be down-warping or up-warping in response to transpressive forces, causing incipient fracturing at the flexure points. This could be a possible source for seismicity, though also unlikely.

To determine if which, if any, of these hypotheses is correct, it was necessary to collect more seismic data and conduct more research, which is one of the purposes of this dissertation. The additional research included reading articles written by experts in the area, discussing ideas with other geologists, viewing aerial photographs for evidence of faulting, obtaining focal mechanism data and determining which option best matched the information thus obtained. GIS plays an integral role in analyzing and visualizing the data. This process is detailed in section 3.1.1.

**CHAPTER 2**

## 2.0 Literature review

Understanding how earthquakes cause fault rupture is fundamental to understanding seismic hazards and how to predict what will happen when an earthquake event occurs. This is also integral to understanding the tectonics of a region; faults in a subduction zone will have different characteristic events than those in an extensional area. This is still a fairly new area of geologic study and multiple hypotheses concerning fault rupture are being debated. Olson and Allen talk about this in their 2005 Letter in Nature, "*The deterministic nature of earthquake rupture*". They discuss the "cascade" model of earthquake fault rupture. They contend that faults are divided into "patches", discreet segments of a fault that can rupture. Slip starts on a small fault patch or segment, and then continues on to rupture adjacent patches as long as the rupture energy is sufficient to initiate slip. The state of stress on the adjacent segments must also be favorable for the slip to occur. The larger the initial slip, the more patches will rupture, and the larger the earthquake event will be. We saw this happen in the June 1992 Landers earthquake in the southern California desert. The magnitude 7.3 event started on the Johnson Valley fault, then ruptured north and south to the Landers, Homestead Valley, Emerson and Camp Rock faults. Total rupture length was approximately 53 miles and slip ranged from 2 meters (about 6 feet) to 6 meters (about 18 feet). Movement was right-lateral. The magnitude and length of rupture was much larger than previously expected on any one of the faults. About three hours after the Landers earthquake, the 6.4 magnitude Big Bear earthquake occurred on a left-lateral fault about 40 kilometers (about 25 miles) to the west of Landers. Many seismologists believe that the Landers quake triggered the Big Bear quake (SCEC) and that they are conjugate faults (perpendicular to one another with opposite slip characteristics). The October 16, 1999 7.1 magnitude Hector Mine earthquake displayed movement similar to the Landers quake, rupturing a total of about 26 miles on the Lavic Lake and Bullion faults about 13 miles to the east of those ruptured in the Landers event (SCEC).

Donald Wells and Kevin Coppersmith wrote a paper in 1994 called "*New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface*

*Displacement*" for the Bulletin of the Seismological Society of America. In it they discuss methods to determine the largest earthquake event and the magnitude of an earthquake event that will likely occur on a fault. They used data from 421 earthquakes world-wide to produce formulas for determining the potential magnitude of an earthquake that might occur given specific fault parameters. Parameters used included fault characteristics, seismic moment, magnitude, focal mechanism, focal depth, slip type, surface and subsurface rupture length, displacement, downdip rupture width and rupture area. They further narrowed the events studied to 244 that were determined to have very reliable data. These events were studied in great detail to determine their parameters. From the information obtained, many statistical analyses were done to produce the formulas contained in several tables in the paper. This paper has been cited in a great many other papers published since 1994, so it is a very important contribution to the world of seismology.

"*Confronting Catastrophe*" discusses how and why disaster management decision makers should use GIS as an integral part of their planning process. The steps involved in disaster management include identification of potential disasters, mitigation planning, preparedness, disaster response and recovery. First, decision makers must identify potential disasters (earthquakes, flood, fire or similar) and what within their planning area will likely be affected. Each type of disaster requires different assessment and mitigation plans. Sometimes one disaster may trigger multiple problems – an earthquake can cause fires when gas lines rupture and flooding if a dam fails. Once potential disasters have been identified, mitigation planning can take place. Examples of GIS packages that are useful in the planning process are HAZUS (Hazards U.S.) and CATS (Consequences Assessment Tool Set). Assets must be identified and quantified before meaningful mitigation plans can be made. Assets may include, but are not limited to, police stations, fire stations and other emergency services, hospitals, schools, government buildings, highways, bridges, railways, airports, communication systems, utilities (including power generation facilities) and military facilities. Data for these and other assets should be the most current available and as complete as possible. Private assets such as manufacturing facilities, retail businesses, and distribution centers need to be considered in mitigation planning as well. Some of these may have hazardous chemicals or waste on site which may prove dangerous in an emergency. Population density and age also need to be taken into account. For instance, if there is a concentration of elderly in a specific area, they will require more assistance if evacuation is required. People in ethnic neighborhoods may not understand emergency instructions given to them in English. Part of the mitigation and response planning includes identifying populations most in need of shelter and the location of shelters to house them. Long term mitigation means updating building requirements to meet stringent earthquake standards, retrofitting older structures and limiting where new construction can be built. After a disaster, “combat GIS” needs to be implemented. The type of response depends on the nature and size of the disaster. Two hallmarks of combat GIS are speed and accuracy. Rapid response may save lives. Communication and cooperation between emergency responders, agencies and the GIS team is critical. After the September 11, 2001 disaster in New York, a large GIS response team from all over the country was assembled within hours to produce maps and very detailed data to identify possible hazards, potential survivor locations, street closures, restricted zones within the city, command post locations, building status and much more. Data was continually updated while archiving older versions for historic and environmental safety reasons (tracking decontamination site location changes was environmentally important). GIS is also critical to recovery plans. It can help identify where resources can best be used in the recovery and rebuilding effort. It can also identify the location of damaged or closed streets, shelters, damaged hospitals, power outages, and detailed building damage and much more. The location of debris which will need to be cleaned up and carted away is another important GIS function. HAZUS can be used for all of these functions.

The Fontana Seismic Trend has not been studied to any extent in the past. More interest has been shown recently by area geologists. Some mention is made in several documents. In the seismic hazard portion of a 2003 Initial Study for a tank farm in Fontana, the Fontana Trend is mentioned: “*Three possible faults have been mapped at depth under the city of Fontana and its area of interest. Two of these form groundwater barriers. The third feature (**Fontana Seismic Trend**) is delineated by a pronounced concentration of small earthquakes, and may be expressed at the surface by a series of northeast trending lineaments that have not been investigated previously.*” It further discusses other faults in the area as well as liquefaction and landsliding potential. This is taken almost verbatim from the Fontana General Plan adopted in 2003.

Several researchers at the Harvard College Geology Department have been working in conjunction with SCEC to produce a "Community Fault Model". This is a 3-Dimensional model of active faulting in southern California (figure 2.1). It models more than 140 active faults. It allows researchers and analysts to visualize and analyze the faults. The research team has used surface geology combined with earthquake hypocenters and focal mechanisms, well bore, and seismic reflection data to model the faults. This is a new direction for pinpointing the location of faults. Traditional methods incorporate the hunt for surface rupture expression with trenching and focal mechanism studies. One of the ultimate goals of the research is to identify tectonic blocks (more than 75 have been identified so far) and model their direction, speed of movement and interaction with one another. All of this information is being used to model seismic wave propagation, which is then compared to actual events to determine how accurate the models are. They recognize the Fontana Trend as a fault in their model, although they are still calling it a seismicity trend. A shapefile version of their fault data was downloaded and added to the fault map (figure 1.8). The Fontana Trend is included.

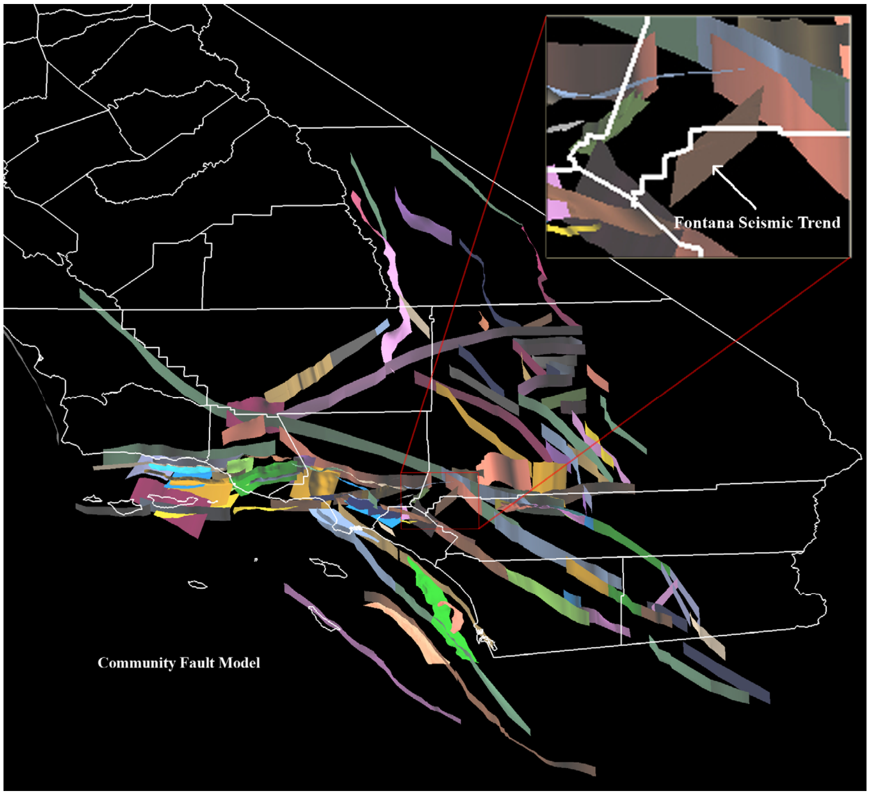



Figure 2.1: *Perspective view of the Community Fault Model with the Study Area enlarged in an inset. From the images on the SCEC Community Fault Model Web Site http://structure.harvard.edu/cfm/images.html*

In 2000 in an annual technical report for SCEC, Egill Hauksson discusses the Fontana Seismic Trend briefly, stating that it is related to the surface extensional tectonics and compressional tectonics at depth and the overall deformation of the region and that *"It is not associated with a mapped surface fault and is characterized by swarm like seismicity"*.

The October 1997 monthly Southern California Earthquake activity reports mentions the Fontana Trend briefly: *"… However, there was only one event larger than magnitude 3.5 recorded. This event, on the 14th, was a magnitude 3.9, strike-slip earthquake along the* ***Fontana trend*** *-- a linear feature identified by frequent small earthquake activity but not associated with a mapped surface trace. (It is probably a left-lateral fault buried beneath the sediments of the San Bernardino Valley.) The quake was widely felt in the region known as the "Inland Empire"."*

In the 1991 paper "T*he 1988 and 1990 Upland Earthquakes: Left Lateral Faulting Adjacent to the Central Transverse Ranges*" there are several mentions of the Fontana Trend. In the discussion of regional tectonics portion of the paper Hauksson and Jones refer to several active, southwest striking left-lateral faults. The Inland Empire has several of these: the San Jose, Red Hill, Indian Hill and the Fontana Seismicity Trend. One theory that they propose is that slip on the San Jose fault and other left lateral faults may be related to deformation of the range front associated with the collision of the Transverse Ranges (the San Gabriel Mountains are at the eastern end of the Transverse Ranges) and the Peninsular Ranges Blocks (the Perris Block being one). A second theory states that the left-lateral faults could represent secondary faulting related to the right-lateral strike-slip faults to the south (Chino Fault, San Jacinto Fault and others). The primary movement of the Peninsular Ranges is northwestward on right-lateral, strike-slip faults (San Jacinto to the east and the Elsinore-Whittier/Chino to the west). These faults/seismicity trends can be paired – the Fontana Trend is associated with the San Jacinto Fault and the San Jose Fault with the Chino fault. Slip is less on the left-lateral faults than on the right-lateral ones, but the combination of movement on both types of fault moves crustal material westward around the "big bend" of the San Andreas Fault. This sounds reasonable.

## 2.1 Aims of Research

The aim of research for this dissertation is to determine the cause of the seismic activity on the Fontana Seismic Trend and to assess the potential seismic hazard posed by it. There are several areas of investigation that need to be completed in order to accomplish these goals. These include:

- Since faulting is the mostly likely cause of the seismic activity displayed in the Fontana Trend, the first goal is to characterize the fault: type and direction of movement, and the strike and dip of the fault plane.
- Once the fault is characterized, determine what magnitude quake is likely to occur.
- Once the magnitude is quantified, create a HAZUS scenario using this information.

Some of the avenues of research for characterizing and locating a fault include:

1. First motion studies (also called focal mechanisms or moment tensor solutions) of selected seismic events. What do they indicate? Are they consistent? Find a way to show these three-dimensionally to determine where the fault plane might meet the surface.
2. Aerial photographs – to see if there are visible fault traces. The oldest, best quality photos available (1938 set) should be used. The San Bernardino County Flood Control District has good sets for several years. More recent ones don't show as much due to the large population growth in the valley, although they are usually of better quality.
3. Look at groundwater models – these may show groundwater barriers or other impediments to flow. This should reveal the depth to the basement rocks. Possible sources are the United States Geological Survey (USGS), local water agencies, the regional water board and county flood control. Groundwater barriers should appear on some of the USGS published maps.
4. Gravimetric, seismic or magnetic data may show subsurface anomalies indicating a fault trace. Local and regional agencies (water, county, USGS) should have data for some of the area.

5. Trench logs may be available for some portion of the Study Area, possibly revealing faulting. Several companies and agencies have conducted trench studies to determine where faulting exists in the valley. Maybe some of these studies have been conducted along the "Fontana Trend".

Once the fault has been characterized, the fault trace location needs to be digitized using the information obtained in the characterization process. Once the fault location and length is determined, it should be possible to ascertain what sort of seismic hazard it represents. There are accepted methods that can be used to calculate the maximum potential event for a fault. They take into account the depth of earthquake hypocenters, rupture length of fault segments, direction and type of movement on a fault and the likely amount of offset from an event. Once a maximum potential event has been calculated, that can be used to create a HAZUS scenario. The scenario will provide potential damage and casualty estimates for an event of the specified magnitude.

# CHAPTER 3

## 3.0 Materials and methods

This chapter details the methods used to determine what kind of slip movement might be present on the Fontana Trend and what sorts of physical evidence might indicate a fault. Also discussed is the method used to collect earthquake data. The procedures used to set up HAZUS to run an earthquake scenario are also discussed.

## 3.1 Characterization of the Fontana Seismic Trend

There are several methods that can possibly be used to determine the type of slip movement that characterizes a fault. Using more than one method is preferable in order to locate a fault more definitively. One method is trenching to reveal a fault's historic movement. Trenching allows the geologist to locate earlier events that have occurred on an active fault with known surface rupture. The geologist can recognize breaks in sediment layers that may truncate where the slip event stopped and then subsequent sediment deposition took place. In many cases, multiple breaks at different levels can be discovered and plotted (Compton, 1962). A chronological event history can then be constructed. It is especially helpful if carbon containing sediment can be dated to better determine an interval period between events. This is a good method if you have a well located fault, but is expensive and not useful if the fault location is not fairly certain, or if the sediments are massive and do not have observable layering. Trenching was not a viable option for this project.

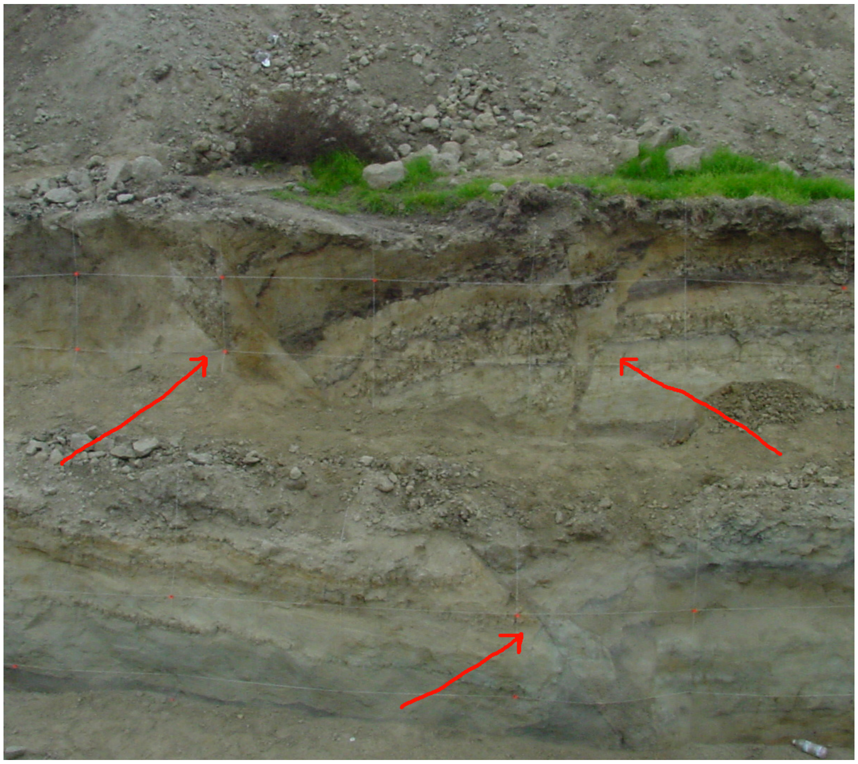


Figure 3.1. *Photograph of trench wall across the San Jacinto Fault in San Bernardino near the Interstate 215/Interstate 10 interchange. The location of the San Jacinto fault is well defined in this area. Photo taken by the author on November 27, 2004.*

A second method is to look for surface expression in locations where one might expect to find fault traces (Compton, 1962). Possible evidence of fault movement includes offset walls, fences or natural features such as streams or a fault scarp where the ground has been uplifted along a linear trace.

A third method is to look for lineaments (a linear topographic feature) or similar linear patterns on aerial photographs or a hillshade made from a DEM (Kennelly and Stickney, 2000). A line of foliage or trees (not planted ones) that is greener or more verdant than surrounding vegetation may indicate a fault trace (fig 3.2). A fault can be a conduit for water movement, so there may be more foliage along a fault than in nearby un-faulted ground (Compton, 1962). A rise in ground surface that follows a linear pattern may also indicate a fault and may be noted on an aerial. Frank Jordan, a local registered geologist, has mapped lineaments based on aerials. These are shown on figure 1.8.

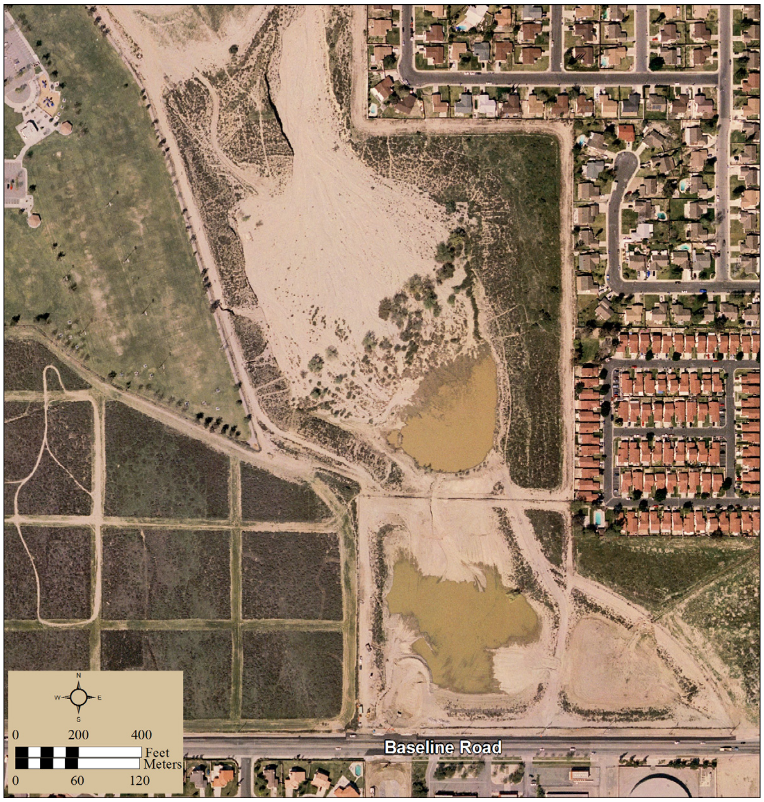



Figure 3.2. *2004 aerial of a tree line in a flood control channel that aligns with the proposed Fontana Fault. The author visited the site once, but could not find a definitive fault location. There is too much vegetation covering the slopes to see much. The green area to the west is a park. Residential areas lie to the east and south. The plowed field just south of the park is now developed. Source: Eagle Aerial photo*.

Another method is to use moment tensor solutions (focal mechanism diagrams) to determine the strike and dip of the fault plane (orientation of fault plane). The difficulty with this method is that there are two possible directions of slip for each moment tensor solution (figure 3.3), so several solutions are required to understand the movement on a particular fault.

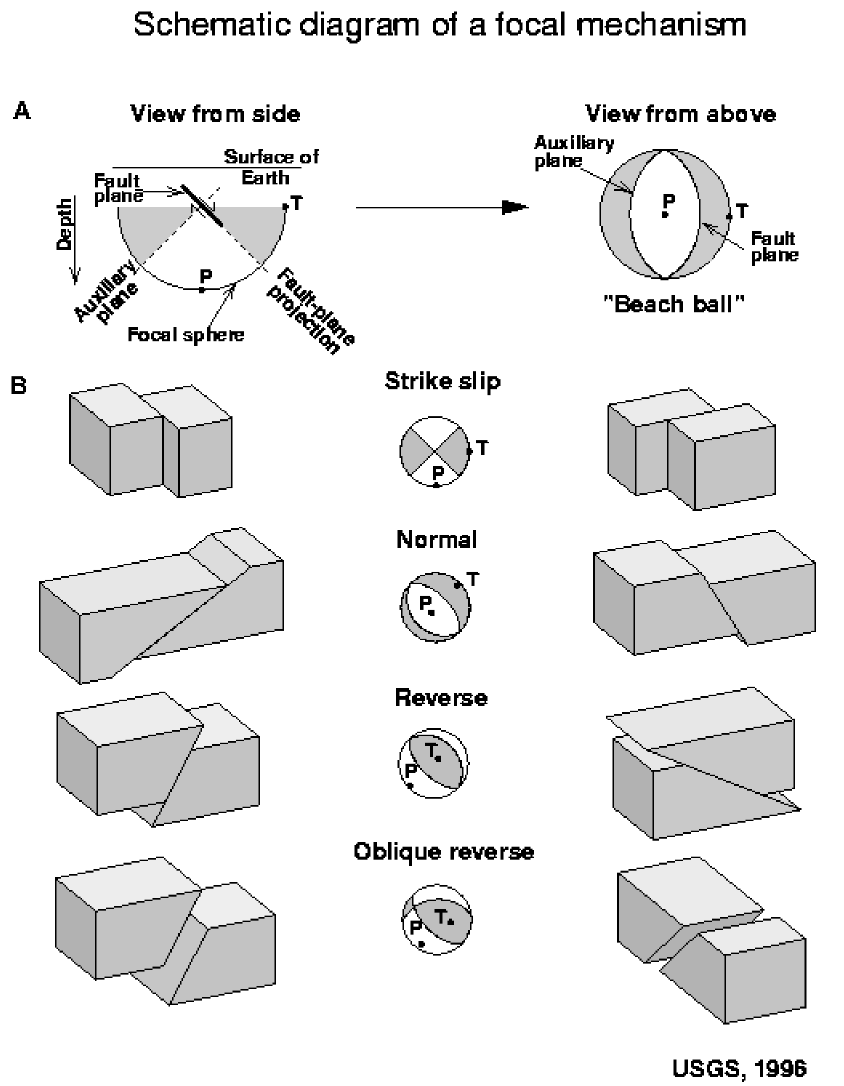



Figure 3.3 *Diagram of a focal mechanism or moment tensor solution or first motion study. These terms can be used interchangeably. Seismologists refer to the slip direction of an earthquake event and the orientation of the fault where the earthquake occurred as the focal mechanism or moment tensor solution. These are often shown on maps using a "beach ball" symbol. The two possible solutions for each type of "beach ball" are shown next to the symbol. If the strike slip version is tilted slightly, then there is likely a small vertical movement component to the slip.* (USGS)

### 3.1.1 Collection of Seismic Event Data

Earthquake location data was obtained from the Southern California Earthquake Center (SCEC). The SCEC web site has a searchable earthquake catalog. Parameters such as latitude, longitude, magnitude, and others can be specified to narrow the search. The data goes back to 1932 (though it is not complete prior to 1983) and is presented in a delimited text format.

After copying it into Word, the SCEC data was cleaned up a bit and imported into an Excel spread sheet and saved as a dBase IV (DBF) table (ArcView GIS and ArcMap require this format to create a shapefile). A few modifications to the data had to be made to meet ArcView/ArcMap requirements. The resulting spreadsheet was used to create an ArcView shapefile from the DBF table. Then a three-dimensional theme was created (z value being the hypocentral depth in kilometers, x and y values are latitude and longitude calculated in decimal degrees to three decimal places). This revealed a planar pattern to the hypocenters and a surficial linear pattern to the seismic activity (fig 3.4). The map in figures 1.2 and 1.3 show data for earthquakes of magnitude 1.0 or larger over a period of seventy-three years (1932 to January, 2006) – this is enough to see a pattern.

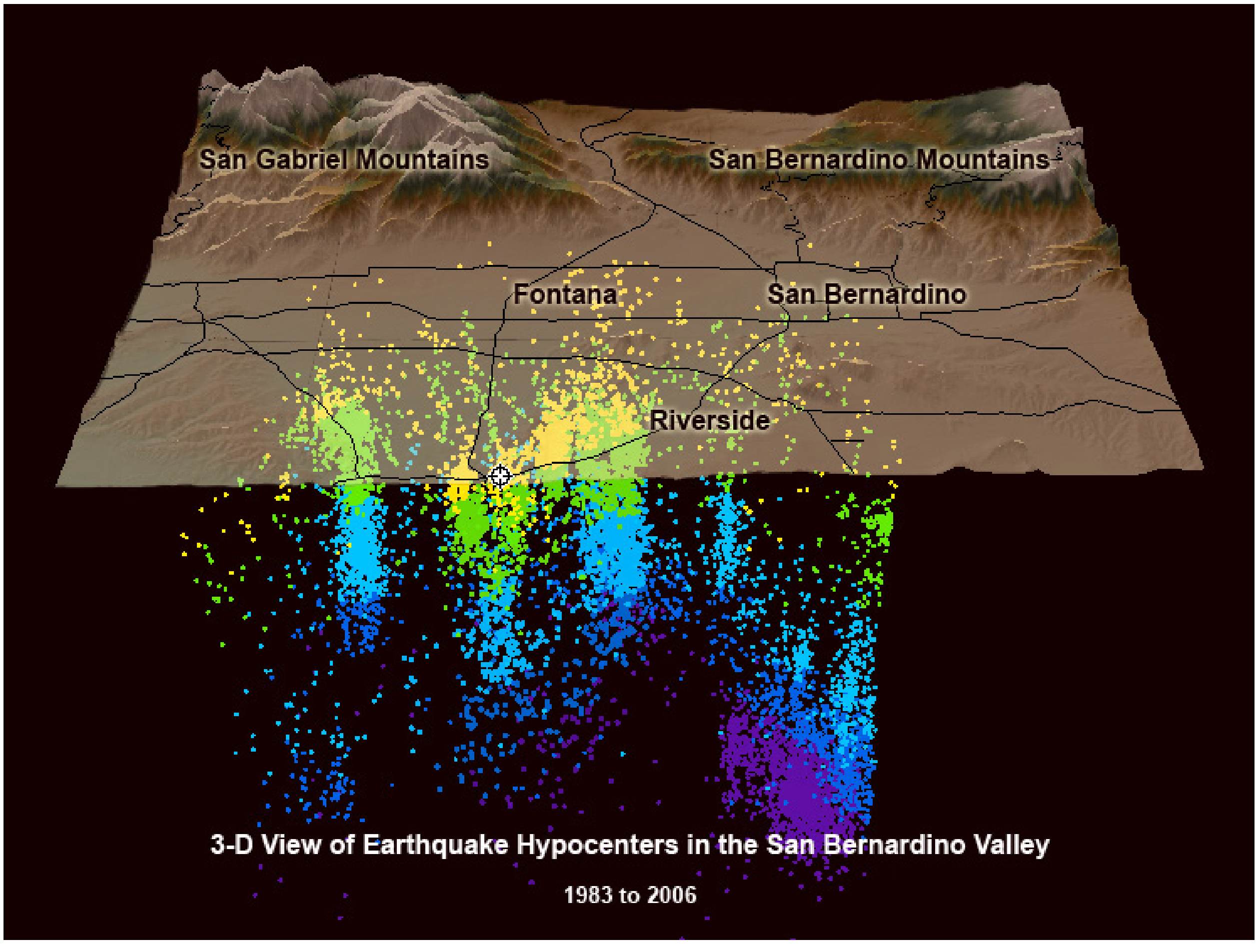



Figure 3.4. *Three Dimensional view of the hypocenters in the Study Area. View is toward the north. Change in color indicates depth (yellow is shallowest, purple is deepest) of hypocenters. Ground surface is semi-transparent for better visualization. Created in ArcScene using SCEC earthquake data and USGS DEM's (text added in Photoshop).*

Focal mechanisms (also called moment tensor solutions or moment magnitude solutions) were also available from SCEC for selected earthquakes within the Study Area. These were obtained to determine the direction and type of slip that occurred for selected events (data for events of 3.0 magnitude and higher since 1999 is available from the same SCEC site).

### 3.2 HAZUS software discussion

FEMA has an ArcGIS extension called HAZUS-MH (Hazards U.S. – Multi-Hazards), which can produce a scenario for a specified seismic event on a given fault. This will be used to determine possible results from an earthquake event. The HAZUS-MH Earthquake Model is designed to produce loss estimates for use by governmental agencies to assist in planning for mitigation, emergency preparedness, response and recovery when an earthquake happens. The second part of the study – the use of the HAZUS software – can benefit from the collection of additional data to plug into the model to better determine actual damage and casualties that might be possible from a seismic event. The data that is included with the software includes a building inventory for the immediately affected cities and demographic information for the same cities. Since much data comes with the software package, and that is what will be used. Additional datasets such as soil types, liquefaction and landslide zones can be used if available. Soil data is available, liquefaction and landslide zone data is not yet available for the Study Area (Los Angeles County and the San Francisco area have been mapped). Other data types that can be used if available include pipeline data (hard to obtain since 9/11).

Uncertainties are inherent in any loss estimation methodology. This is true for HAZUS-MH as well. These uncertainties arise in part from incomplete scientific knowledge concerning earthquakes and their effects upon buildings and facilities. They also result from the approximations and simplifications that are necessary for a comprehensive analysis. Incomplete or inaccurate inventories of the built environment, demographics and economic parameters add to the uncertainty. The building inventory provided with the software is based on national 2005 Dun and Bradstreet valuation data for all occupancy classes of the building inventory, so it is fairly good, but can be improved with local data input.

“*The methodology has been tested against the judgment of experts and, to the extent possible, against records from several past earthquakes. However, limited and incomplete data about actual earthquake damage precludes complete calibration of the methodology. Nevertheless, when used with embedded inventories and parameters, the HAZUS-MH Earthquake Model has provided a credible estimate of such aggregated losses as the total cost of damage and numbers of casualties. The Earthquake Model has done less well in estimating more detailed results - such as the number of buildings or bridges experiencing different degrees of damage. Such results depend heavily upon accurate inventories. The Earthquake Model assumes the same soil condition for all locations, and this has proved satisfactory for estimating regional losses. Of course, the geographic distribution of damage may be influenced markedly by local soil conditions*. In the few instances where the Earthquake Model has been partially tested using actual inventories of structures plus correct soils maps, it has performed reasonably well*” (HAZUS-MH user manual). *Soil data has been added to the scenario for this project.

The preliminary setup for running an earthquake scenario has several steps. The first step is to select a study region. This can be an entire state, an entire county (or multiple counties) or selected census tracts. To limit the extent of area studied and customize the area, the census tract option was selected. A maximum of 2000 census tracts can be selected for a study region due to geodatabase limitations. The selected area consists of 273 census tracts in southwestern San Bernardino and northwestern Riverside Counties. Since both counties are very large (39,020 square miles total), selecting the county option did not make sense.

The next step is to define the scenario earthquake event. The magnitude and location of the event are selected, giving consideration to fault locations. Historic events can be selected (the database has many) if an arbitrary event is not used. If additional datasets are available, those can also be defined. Appropriate soil data was selected for use with the scenario.

Once these steps are finished, the scenario can be run. Scenario analysis options are selected from a checklist to obtain the desired combination of results. These include building inventories, facility and infrastructure information of various types, induced damage, plus direct and indirect social and economic losses and more.

### 3.3 Collection of Data

HAZUS has a large amount of data packaged with the software. Additional data can be acquired to achieve better results for the defined earthquake scenario. This includes local building inventories, landslide data, liquefaction data, soil classification data and other similar kinds of data.

Soil data that will work with the HAZUS software was obtained from the State of California (California Geological Survey, 2002) (figure 3.5). The soil data classifications are classified according to the National Earthquake Hazard Reduction Program (NEHRP) and are based on geologic terms rather than biological suitability terms. Soil type can have a significant effect on the intensity of ground motion at a given site. The NEHRP has identified five soil types (A-E) (refer to table 3.1) based on the velocity at which a soil or rock type transmits shear waves (S-waves). Shaking is stronger in rocks where the velocity of S-waves is lower. As the waves pass from harder to softer rocks, their amplitude increases, so shaking is stronger. The HAZUS software takes soil type into account, if available, when calculating damage and shake intensity for the Study Area. An additional soil type F is occasionally used for special soils requiring site specific evaluations (soils very vulnerable to failure or collapse under seismic loading). None of these are found in the Study Area.

| **Soil Profile Type** | **Average Shear-Wave Velocity to 30 meter depth** | **Soil Profile Description** |
|---|---|---|
| Soil Type A | *Vs > 1500 m/sec* | Hard rock. Includes un-weathered intrusive igneous rock. Very little amplification. Eastern U.S. sites only. |
| Soil Type B | *1500 m/sec > Vs > 750 m/sec* | Rock. Includes volcanics, bedrock and gravels. |
| Soil Type C | *750 m/sec > Vs > 350 m/sec* | Soft rock and very dense soil. Includes some sandstones, mudstones, siltstone, very stiff clays and limestones |
| Soil Type D | *350 m/sec > Vs > 200 m/sec* | Stiff soil. Includes some muds, sands, gravels, silts and mud. Significant amplification of shaking by these soils is generally expected. |
| Soil Type E | *200 m/sec > Vs* | Includes water-saturated mud and artificial fill, peats, organic or very plastic clays. The strongest amplification of shaking is expected for this soil type. Building failure is expected. |

Table 3.1: *Soil Classification*

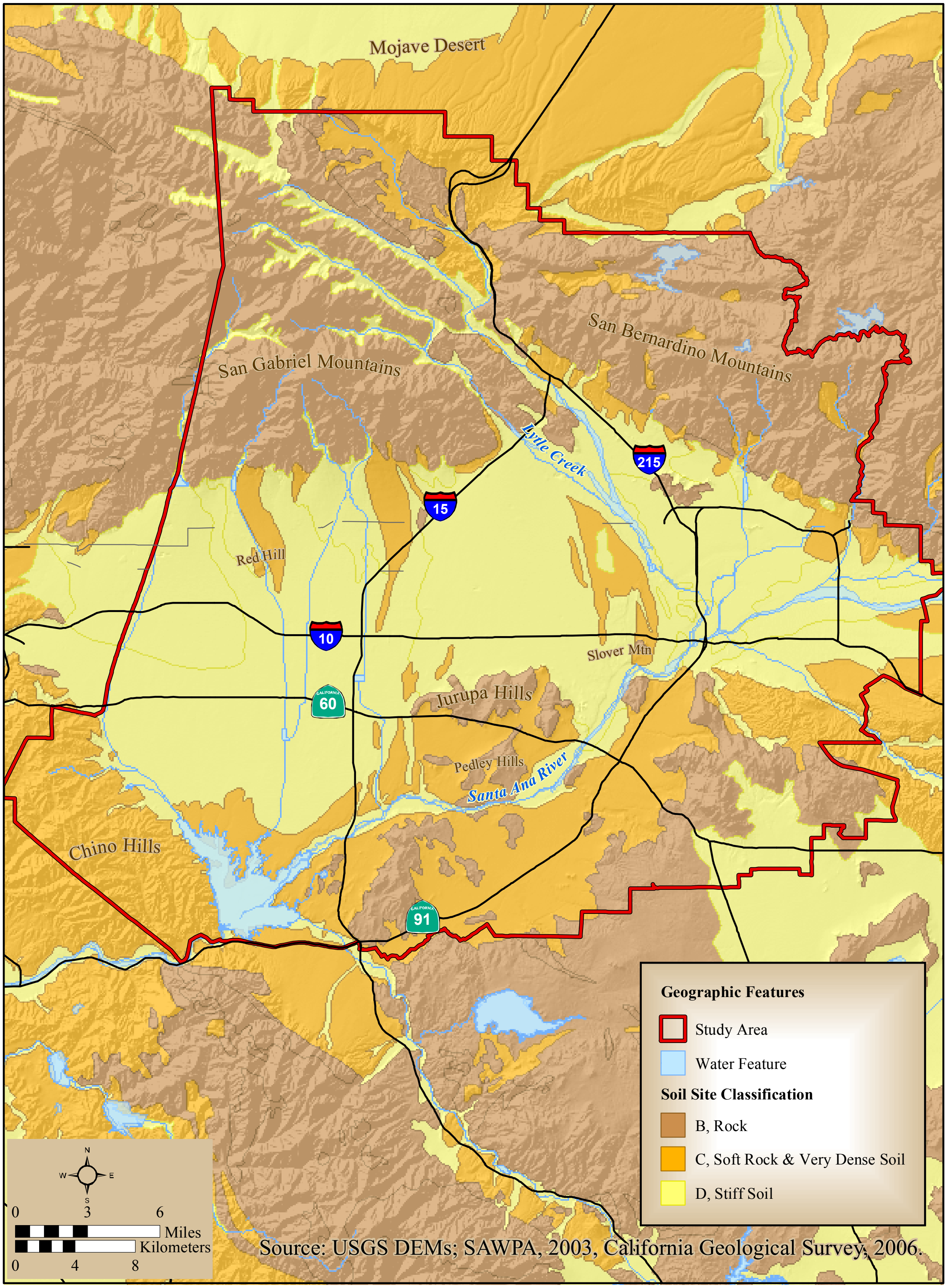



Figure 3.5: *Soils of the San Bernardino Valley Area*

CHAPTER 4

## 4.0 Results of Fault Study for Fontana Seismic Trend

Nine moment tensor solutions were used to approximate the location of the fault plane and its projection to the surface. The original depth, the adjusted depth to the hypocenter and the dip were used to determine the projected surface location of the fault plane for each event. As shown in figure 4.1, Visio was used to plot the distance from the hypocenter to the surface (using both depth values). Next, the dip was used to create a hypotenuse. A third leg connected the long leg of the right triangle and hypotenuse. This third leg was measured to produce the distance from the epicenter along the earth's surface to the intersection of the projected fault plane with the surface. This information was used in ArcMap to create a set of circles around each event location by specifying the surface distance using the buffer tool (figure 4.2).

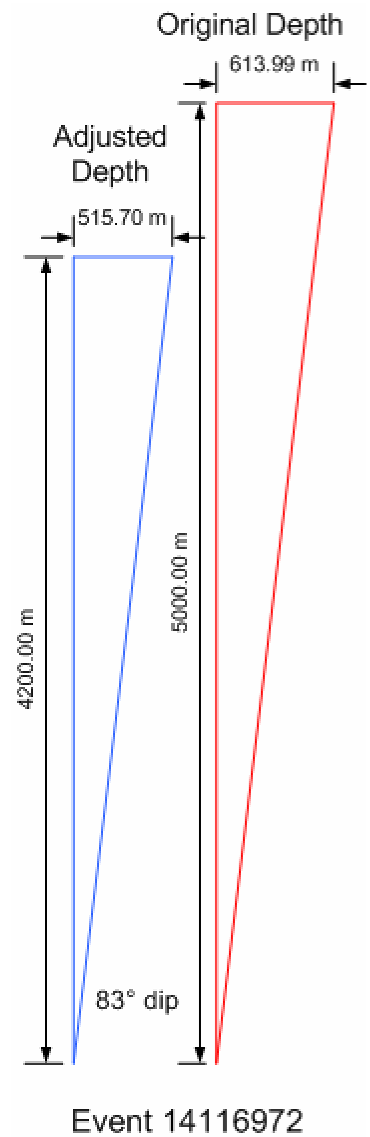



Figure 4.1. *Depiction of Visio drawing used to determine surface projection of fault plane.*

## 4.1 Type of fault and Potential Maximum Event

The Fontana Seismic Trend is most likely a left-lateral strike-slip fault. This conclusion was reached by literature research and by studying moment tensor solutions (a sample is shown in figure 4.3). Using the Wells and Coppersmith equations and length of proposed fault (estimated to be 27-36 kilometers long), a reasonable surface rupture length of 10 kilometers was chosen. Table 2A in their paper contains equations and factors for determining the moment magnitude of a quake.

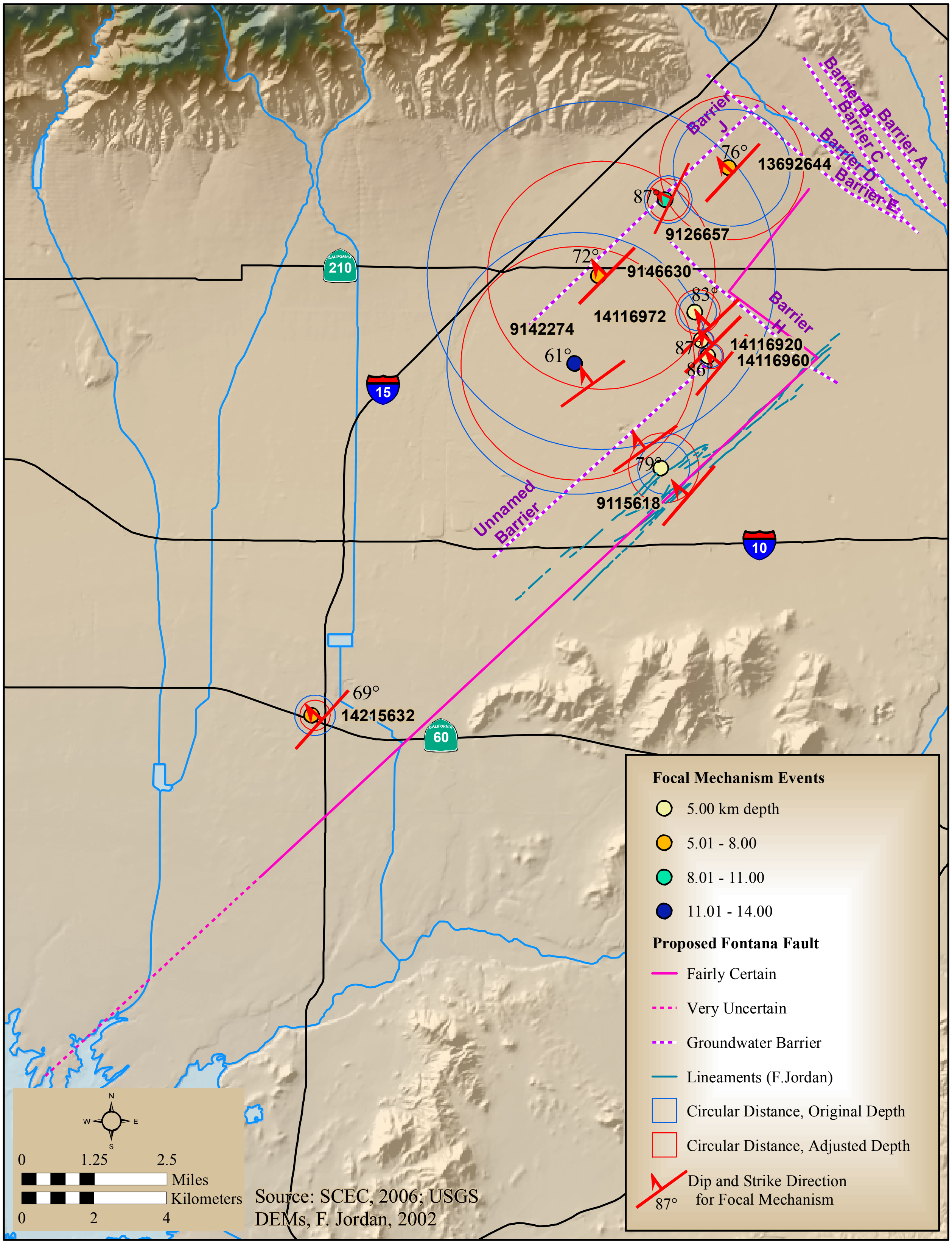



Figure 4.2: *Earthquakes with Focal Mechanism Solutions, October 1999 to March 2006 and Proposed Fontana Fault.*

M = a + b*log(SRL) where M = Moment Magnitude, a and b are coefficients and SRL is Surface Rupture Length in kilometers.

A portion of their Table 2A appears below. Only that portion of the table referring to strike-slip movement and surface rupture is shown.

| Equation | Slip Type | Number of Events | Regression Coefficients and standard errors | | Standard Deviation | Correlation Coefficient | Magnitude Range | Length/Width Range (km) |
|---|---|---|---|---|---|---|---|---|
| | | | a(sa) | b(sb) | | | | |
| M = a + b*log(SRL) | SS | 43 | 5.16(0.13) | 1.12(0.08) | 0.28 | 0.91 | 5.6 to 8.1 | 1.3 to 432 |

Table 3.2: *Calculating Earthquake Magnitude (Wells and Coppersmith)*

M = 5.16 + 1.12 * log(10) = 6.28 moment magnitude – rounded to one decimal place = 6.3.

The location of the largest event in the Study Area in recent history was used for the location of the scenario event. This event occurred on January 6, 2005 at a depth of 4.2 kilometers, corrected to 5 kilometers for moment tensor solution calculation purposes. It produced a moment magnitude 4.21 (local magnitude 4.42) earthquake at 2:35 PM Pacific Standard time. The location of the event was at latitude 34.125 and longitude -117.4387. The dip of the fault plane is 83 degrees to the northwest, with a strike of 224 degrees for the left-lateral solution (figure 4.3). Shaking was felt over a large area. To better understand the relationship between hypocenter, epicenter and fault plane, please refer to figure 4.4, which depicts a gently dipping fault plane (the Fontana trend is steeply dipping).

One interesting phenomenon discovered from plotting the hypocenter and buffer solutions in ArcMap confirmed something observed in earlier parts of the research. The hypocenters to the northwest are deeper than the ones to the southeast (figure 1.3). When plotted, the circles are much larger (as one would expect for deeper events) and come close to the outer bounds of the shallower events for the ones south of the Rialto-Colton Fault (figure 4.2). Another interesting fact: the deeper events have a shallower dip. This might mean there is more movement at depth than near the surface – the northwestward movement of the Perris Block is being slowed down by impacting against the San Gabriel Mountains more at the surface than at depth.

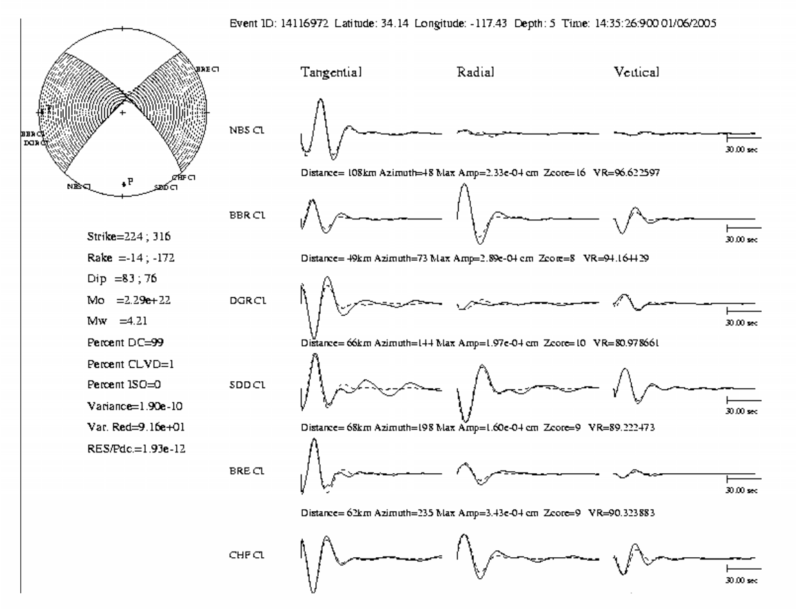



Figure 4.3. *Moment tensor solution for the 1/6/05 earthquake event. Note that the shape of "beach ball" indicates that this event occurred on a strike-slip fault.* (SCEC catalog)

Parameters defined for the earthquake event used for the scenario:

Longitude of epicenter: -117.43

Latitude of epicenter: 34.14

Earthquake magnitude: 6.30

Depth in kilometers: 4.20

Rupture length in kilometers: 11.00

Rupture orientation (degrees clockwise from north): 40.0

Attenuation function: WUS shallow crustal event – extensional

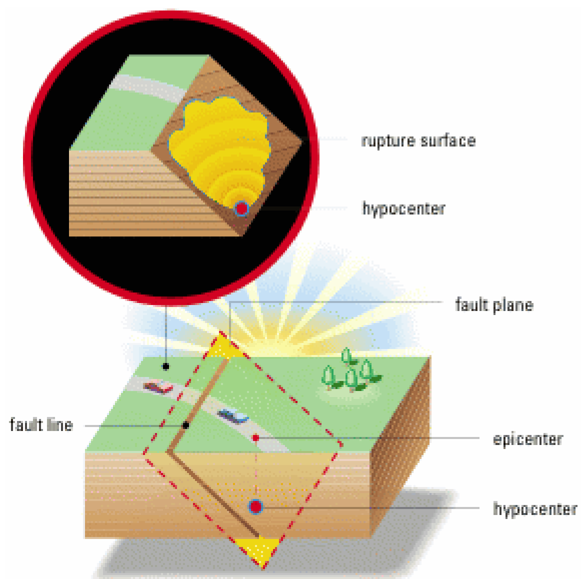



Figure 4.4: *Diagram of the relationship between the epicenter (on the earth's surface), the hypocenter (at the earthquake rupture start point) and the fault plane along which the earthquake rupture travels*. (Putting Down Roots in Earthquake Country)

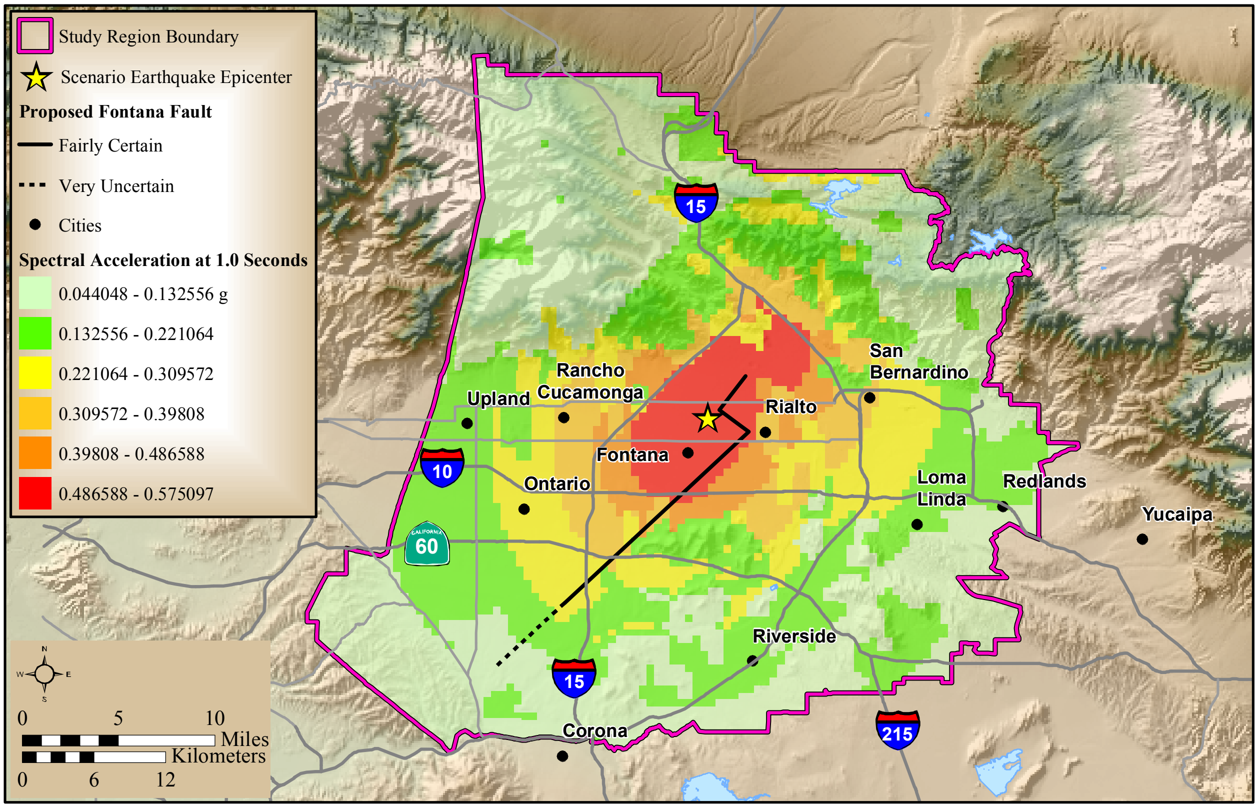
### 4.2 Potential Geologic Hazards

The earthquake-related hazards considered by the HAZUS methodology in evaluating casualties, damage, and resultant losses are referred to as Potential Earth Science Hazards (PESH). Most damage and loss caused by an earthquake is directly or indirectly the result of ground shaking. Thus, HAZUS evaluates the geographic distribution of ground shaking resulting from the defined scenario earthquake and expresses ground shaking using several quantitative parameters. These include peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration (SA). Other parameters such as fault rupture which causes surficial ground displacement, liquefaction and landsliding are also quantified if appropriate data is available. These last parameters can cause permanent damage to infrastructure, buildings, pipelines and other utilities.

As mentioned previously, soil type can have a significant effect on the intensity of ground motion at a particular site. This is especially true in southern California where deep sediment filled basins are adjacent to hard rock hills and mountains. Studies were done for southern California in the early part of this decade comparing earthquakes scenarios that were run both with and without using correct soil data as part of the scenario. When soil data was included, the results were much closer to what was observed in actual earthquake events than the scenarios that were run without the correct soil information. Soil, as defined in this methodology is classified in terms of geology (Frankel, et al, 2002).

#### 4.2.1 Potential Ground Motion and Effects

Spectral Acceleration (SA) is a measure of the maximum forces of a mass having a particular natural vibration period. Taller buildings have longer vibration periods than shorter ones. The energy of an earthquake varies depending on the time since the initial slip and the distance a location is from the slip point. HAZUS can calculate possible amplification of building motion and subsequent damage due the sympathetic response of a building to the earthquake motion by using Spectral Acceleration algorithms. Results for Spectral Acceleration for the scenario are shown in figure 4.5. There is not much difference between the 1 second and 0.3 second maps. Soil type imparts a noticeable affect on the shape of the acceleration energy. Hard rock areas



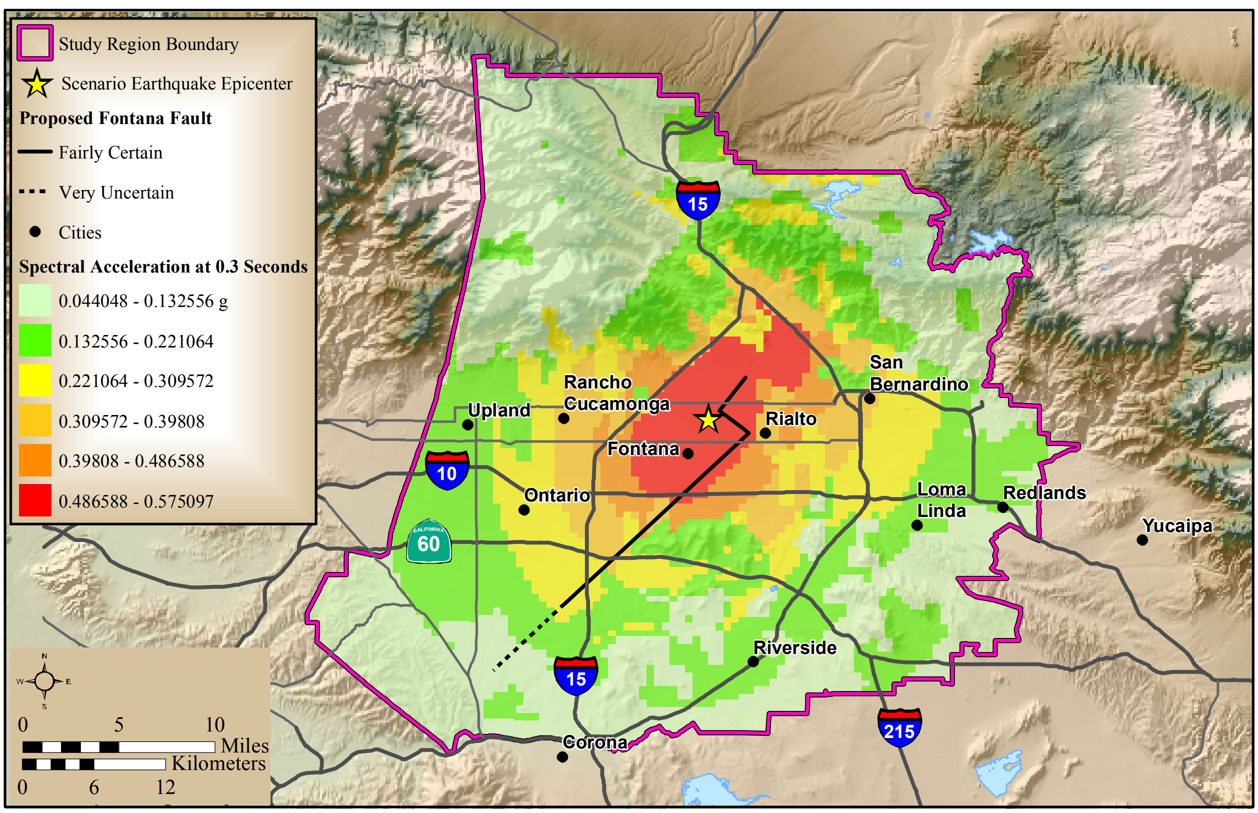



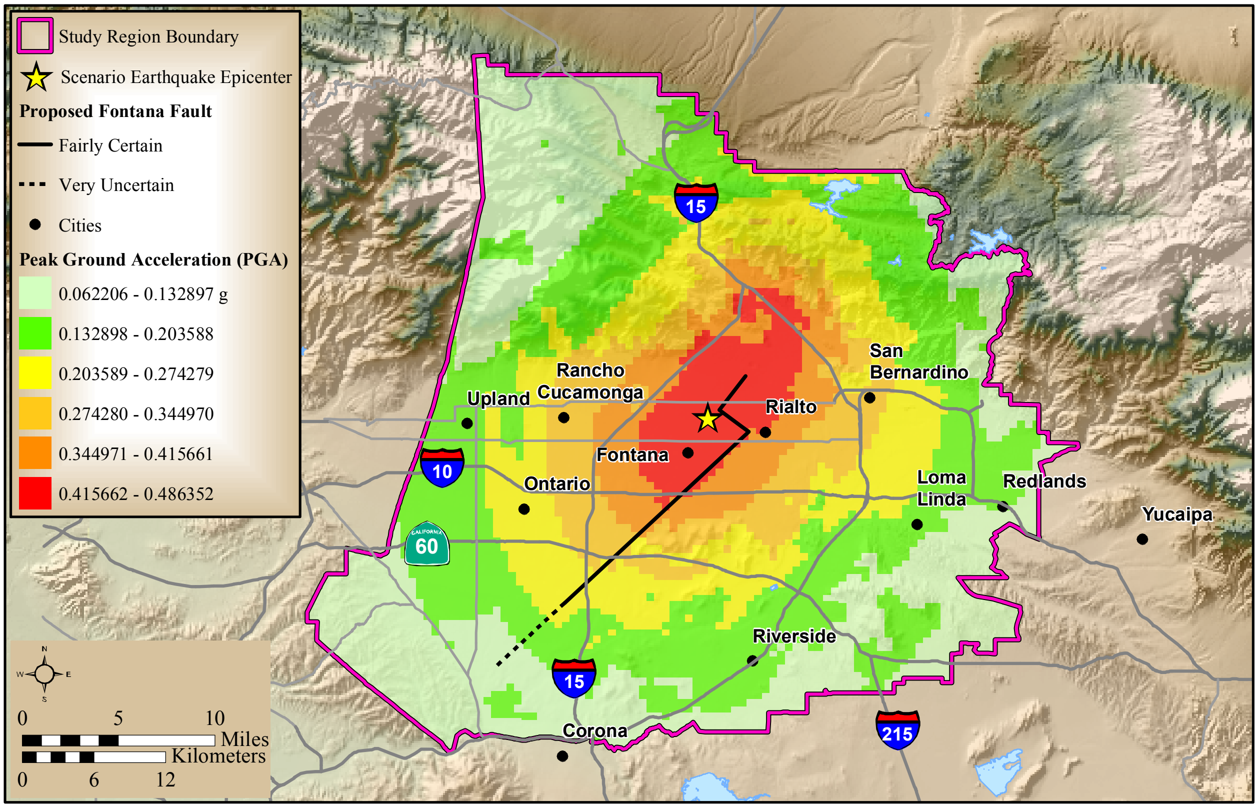

Figure 4.5: *Spectral Acceleration (SA) at 1.0 seconds and 0.3 seconds*

(Jurupa Hills and the San Gabriel Mountains) have much less acceleration energy than nearby sedimentary areas.

Peak Ground Acceleration (PGA) is a measure of the maximum force experienced by a mass located at the surface of the earth and is measured as a percentage of the acceleration of the force of gravity (g). It measures how fast the ground shakes – pipelines are most affected by PGA. This is moderated by soil type. For moderate to large events, the pattern of PGA is usually complicated due to small scale geologic differences that can change the acceleration, amplitude and waveform characteristics of the rupture. The figure 4.6 upper map shows PGA for the scenario event. Some fairly violent shaking will occur near the epicenter. Soil type has some mitigating influence, but not as much as for spectral acceleration.

Peak Ground Velocity (PGV) is a good indicator of the extent of damage the earthquake will cause. Typically, for moderate to large events, the pattern of peak ground velocity reflects the pattern of the earthquake faulting geometry, with largest amplitudes in the near-source region, and in the direction of rupture. Differences between rock and soil sites play a part, but the overall pattern is usually simpler than the peak acceleration pattern. Severe damage and damage to flexible structures is best related to ground velocity. Units of measure are in centimeters per second (cm/sec). The figure 4.6 lower map shows PGV for the scenario quake. Soil type appears to have more effect here than in the PGA map. A number of buildings will be destroyed or damaged beyond repair. More of these will be near the epicenter and along the strike of the fault than elsewhere.

HAZUS contains default attenuation relationships that define how ground motion decreases as a function of distance from the source. An attenuation relation is an equation or a table that describes how earthquake ground motion decreases as the distance from the earthquake increases. Because earthquake ground motion increases with magnitude, the attenuation relation also depends on magnitude. These relationships are based on the approach used by the USGS in the 2002 update of the National Seismic Hazard Maps (Frankel, 2002). Ten attenuation functions are available for the western United States as part of the software. These are grouped together in various combinations according to event type. Because the scenario event was for a left-lateral



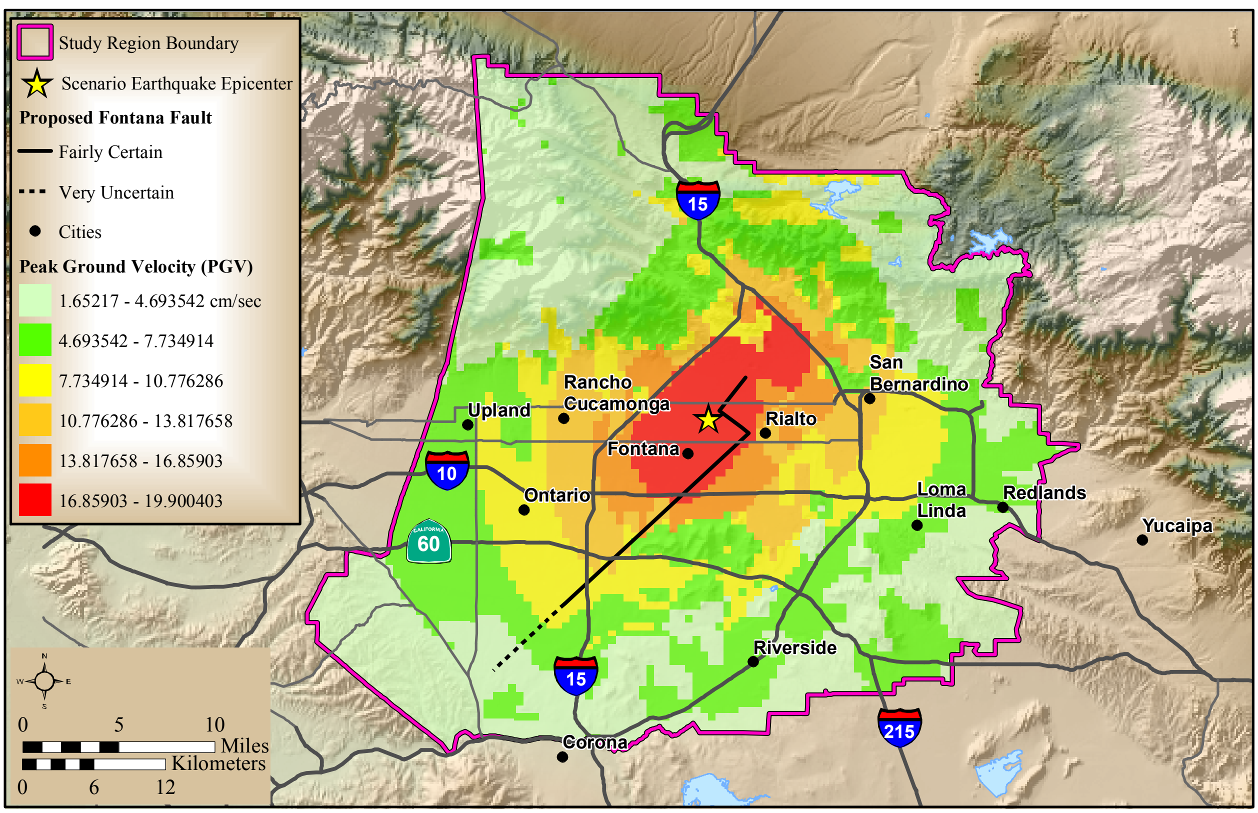




Figure 4.6: *Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV)*

strike slip fault, the Western United States shallow crustal event, extensional attenuation option was selected (other choices were shallow crustal event – non-extensional, Cascadian subduction event, deep event [> 35 km in depth], or Hawaiian event). It was the only option for a strike-slip fault.

### 4.2.2 Potential Ground Failure and Permanent Displacement

Three types of ground failure can be modeled in HAZUS. These are liquefaction, landsliding and surface fault rupture. Each of these causes permanent ground deformation. Permanent ground deformation is a measure of how much the surface of the ground has moved in inches due to the earthquake.

Liquefaction is a failure of the ground due high ground water saturating weak, unconsolidated soils, which then turns to liquid during strong shaking from an earthquake. The soil becomes a viscous fluid, causing problems for any structures built on it. Liquefaction data for the Study Area is not currently available, so this is not calculated.

Landsliding occurs when rocks or soil on a slope lose stability and move down the slope rapidly. Determining whether a particular area will slide is a complex issue. Landslide susceptibility is based on rock or soil type, groundwater conditions (dry or wet) and slope angle. The less cemented the rock/soil is and the wetter the conditions and the steeper the slope, the more likely a landslide is to occur. Each site has a maximum shake level that must be exceeded before a landslide will happen. Susceptible areas have been mapped for regions to the west of the Study Area, but not within the Study Area yet.

### 4.2.3 Potential Surface Rupture

A fault may rupture the ground surface during an earthquake. This increases ground shaking at a site. The ground is ruptured when the energy of the slip is enough to break the surface of the ground instead of stopping beneath the surface. The potential surface rupture for this scenario is approximately 11 kilometers. How much displacement will take place is unknown.

# CHAPTER 5

## 5.0 Results of Earthquake Scenario

After some test scenarios to see what sort of spatial extent the scenario earthquake might affect, the author selected census tracts to include in the Study Area that are within 15 to 20 miles of the epicenter. HAZUS provides summary reports that summarize all of the input parameters for the scenario as well as summaries of the results. These and the HAZUS technical manual provided all of the results and information for Chapter 5, except where noted. Because HAZUS is an ArcGIS extension, it allows the user to map most of the study results. Representative maps are included in this chapter. These were created with the base map data used in the other maps combined with the HAZUS generated results.

The geographical size of the Study Area is 931.61 square miles and contains 273 census tracts. There are more than 511,000 households in the Study Area and it has a total population of 1,713,281 people (2000 United Sates Census Bureau data). The area has more people now, but that data will not be readily available until after the next census in 2010. Due to this factor, the casualty estimates are probably lower than they would be with more recent data.

There are an estimated 451 thousand buildings in the region with a total building replacement value (excluding contents) of $98,948,000,000. Approximately 99.00 % of the buildings (and 82.00% of the building value) are associated with residential housing. These are based on the 2005 valuation data provided with HAZUS, so are probably fairly good. Some areas have had an increase in building over the last two years (most notably north Fontana), but that should not significantly impact the overall results.

The replacement value of the transportation is estimated to be $6,095,000,000. The replacement value of the utility lifeline systems is estimated to be $2,090,000,000.

## 5.1 Potential Damage to Infrastructure

| System | Component | Number of Locations / Segments | Replacement Value (millions of dollars) |
|---|---|---|---|
| **Potable Water** | Distribution Lines | Not Applicable | 215.10 |
| | Facilities | 4 | 157.20 |
| | | Subtotal | **372.30** |
| **Waste Water** | Distribution Lines | Not Applicable | 129.10 |
| | Facilities | 13 | 1021.60 |
| | | Subtotal | **1150.70** |
| **Natural Gas** | Distribution Lines | Not Applicable | 86.00 |
| | Facilities | none | 0.00 |
| | | Subtotal | **86.00** |
| **Electrical Power** | Facilities | 7 | 908.60 |
| | | Subtotal | **908.60** |
| **Communication** | Facilities | 23 | 2.70 |
| | | Subtotal | 2.70 |
| | | Total | **2520.30** |

Table 5.1: *Utility infrastructure inventory*

| | Number of Locations | | | | |
|---|---|---|---|---|---|
| System | Total Number | With at least moderate damage | With complete damage | With functionality >50% | |
| | | | | After day 1 | After day 7 |
| **Potable Water** | 4 | 1 | 0 | 3 | 4 |
| **Waste Water** | 13 | 0 | 0 | 4 | 13 |
| **Electrical Power** | 7 | 3 | 0 | 4 | 7 |
| **Communication** | 23 | 0 | 0 | 23 | 23 |

Table 5.2: *Expected Utility Facility Damage*

| System | Total Pipeline Length (kilometers) | Number of Leaks | Number of Breaks |
|---|---|---|---|
| **Potable Water** | 10,754 | 1,524 | 381 |
| **Waste Water** | 6,453 | 1,205 | 301 |
| **Natural Gas** | 4,302 | 1,288 | 322 |

Table 5.3: *Expected Utility System Pipeline Damage (Site Specific)*

| | Total Number of Households | Number of Households without Service | | | | |
|---|---|---|---|---|---|---|
| | | At Day 1 | At Day 3 | At Day 7 | At Day 30 | At Day 90 |
| **Potable Water** | 511,470 | 53,797 | 38,763 | 13,471 | 0 | 0 |
| **Electric Power** | | 32,749 | 18,109 | 6,275 | 1,031 | 51 |

Table 5.4: *Expected potable water and electric power system performance*.

There will likely be quite a lot of infrastructure damage, causing interruption of essential services for several days for a lot of people. By the end of the first week, most people should have their services back, though there will be some areas – most likely at sites closest to the epicenter that will take much longer.

### 5.1.1 Water structures and potable water supply

The typical potable water system is comprised of transmission and distribution pipelines, water treatment plants, wells and storage tanks pumping plants. In addition, the system usually has terminal reservoirs.

Pipelines have several components: transmission aqueducts and distribution pipes and facilities. Transmission Aqueducts are typically large size pipes larger than 20 inches in diameter or channels (canals) that convey water to the treatment plant. The source can be a reservoir, lake, river or similar water feature. Damageability of channels is not considered in the loss estimation methodology.

Distribution of water can be accomplished by gravity, or by pumps in conjunction with on-line storage. These are only considered at the facility level.

Water treatment plants generally consist of a number of physical and chemical unit processes connected in series, for the purpose of improving water quality. A conventional Water treatment plant consists of a coagulation process, followed by a sedimentation process, and finally a filtration process. Water treatment plants can be small, medium or large with increasing capacity and more elaborate facilities.

Wells typically have a capacity between 1 and 5 million gallons per day. Wells are used in many cities as a primary or supplementary source of water supply. Wells include a shaft from the surface down to the aquifer, a pump to bring the water up to the surface, equipment used to treat the water, and sometimes a building which encloses the well and equipment. There are many of these in the Study Area. Much of the area's water comes from wells drawing water from the various aquifers. Runoff, local streams and water from the State Water Project provide the recharge for these groundwater basins through settling basins and reservoirs.

Water storage tanks can be steel, concrete (anchored or unanchored) or wood tanks. Typical capacity of storage tanks is in the range of 0.5 million gallons a day to 2 million gallons a day. Most of the tanks in the Study Area are steel or concrete.

Pumping plants usually have a building, one or more pumps, electrical equipment, and in some cases, backup power systems. Pumping plants are classified as either small pumps with less than 10 million gallons a day capacity or medium/large pumps with more than 10 million gallons a day capacity. Pumping plants are further classified by whether the subcomponents (equipment and backup power) are anchored or not.

Terminal reservoirs are very often lakes (man made or natural) and are usually located near and upstream of the water treatment plant. Vulnerability of terminal reservoirs and associated dams is marginally assessed in the loss estimation methodology. Therefore, even though reservoirs are an essential part of a potable water system, it is assumed in the analysis of water systems that the amount of water flowing into water treatment plants from reservoirs right after an earthquake is essentially the same as before the earthquake.

| **Number of facilities** | **Average for Damage State** | | | | |
|---|---|---|---|---|---|
| | None | Slight | Moderate | Extensive | Complete |
| 4 | 0.28 | 0.40 | 0.25 | 0.06 | 0.01 |

Table 5.5: *Potable water system facility damage. One facility is estimated to have at least moderate damage; none will likely have extensive or complete damage.*

| Total Households | Number of Households without Water | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | At Day 1 | | At Day 3 | | At Day 7 | | At Day 30 | | At Day 90 | |
| | Count | % | Count | % | Count | % | Count | % | Count | % |
| **511.470** | **53,797** | **10.50** | **38,763** | **7.60** | **13,471** | **2.60** | **0** | **0** | **0** | **0** |

Table 5.6: *Potable water system performance. All households should have potable water available by 30 days after the earthquake.*

As a result of the scenario earthquake event, only one potable water facility will have some damage (refer to table 5.5). Some water delivery pipelines will most likely rupture, disrupting delivery to about 10.5% of households and businesses in the Study Area. By 30 days after the earthquake the necessary facilities and delivery system should all be repaired and water will be available to everyone again, as indicated in table 5.6.

### 5.1.2 Waste water and treatment facilities

A waste water system typically consists of collection sewers, interceptors, waste water treatment plants and lift stations.

Collection sewers are closed conduits that normally carry sewage with a partial flow. Collection sewers may be sanitary sewers, storm sewers, or combined sewers. The most commonly used sewer material is clay pipe. Concrete pipes are mostly used for storm drains and for sanitary sewers carrying non-corrosive sewage. For the smaller diameter range, plastic pipes are also used.

Interceptors are large diameter sewer mains. They are usually located in areas with the lowest elevation. Pipe materials used for interceptor sewers are similar to those used for collection sewers.

Lift stations are important parts of the waste water system. Lift stations serve to raise sewage over topographical rises. If the lift station is out of service for more than a short time, untreated sewage will either spill out near the lift station, or back up into the collection sewer system. In this study, lift stations are classified as either small or medium/large, depending on capacity.

Three sizes of waste water treatment plants are considered: small, medium and large, depending on capacity. A waste water treatment plants carry on the same processes as a water treatment plant with the addition of secondary and possibly tertiary treatment subcomponents.

| **Number of facilities** | **Average for Damage state** | | | | |
|---|---|---|---|---|---|
| | None | Slight | Moderate | Extensive | Complete |
| 13 | 0.36 | 0.37 | 0.22 | 0.04 | 0.00 |

Table 5.7: *Waste water facility damage. Damage to waste water facilities will be most likely be slight.*

As shown in table 5.7, waste water facilities will be damaged some. Of the thirteen facilities in the Study Area, none should be damaged so badly that they will not be fully operational after day seven.

### 5.1.3 Gas systems

A natural gas system typically consists of compressor stations, distribution lines and pipelines. No pipelines or compressor stations are within the Study Area. Of the distribution lines within the Study Area, there will be a number of leaks and breaks due to rupture (table 5.3).

### 5.1.4 Electric Power

The only components of an electric power system considered in the loss estimation methodology are substations, distribution circuits, and generation plants. There are seven within the Study Area.

| **Total Households** | **Number of Households without Power** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **At Day 1** | | **At Day 3** | | **At Day 7** | | **At Day 30** | | **At Day 90** | |
| | **Count** | **%** | **Count** | **%** | **Count** | **%** | **Count** | **%** | **Count** | **%** |
| **511.470** | **32,749** | **6.40** | **18,109** | **3.50** | **6,275** | **1.20** | **1,030** | **0.20** | **51** | **0.00** |

Table 5.8: *Electrical power system performance.*

As indicated in table 5.8, most households in the Study Area will not lose power after the earthquake event. But there will still be a few without power after three months. Of the seven electrical power facilities in the Study Area, three will sustain at least moderate damage, and will not be operational after day one. All should be operational by day seven.

### 5.1.5 Communication

Communication facilities within the Study Area include one television station and twenty-two radio stations or transmitters. The television station is a local Public Broadcasting Station, the radio stations/transmitters are an assortment of different sizes and powers with a wide variety of facilities. None will sustain much damage. Repair cost estimates range from $1,000 for stations away from the epicenter to $16,000 for stations near the epicenter. None will be incapacitated enough not to be able to transmit on day one (table 5.9).

| Number of Facilities | Functionality (%) | | | | |
|---|---|---|---|---|---|
| | At Day 1 | At Day 3 | At Day 7 | At Day 30 | At Day 90 |
| 23 | 91.20 | 98.00 | 98.80 | 99.80 | 99.90 |

Table 5.9: *Communication facility functionality*

### 5.2 Potential Damage to Population

HAZUS estimates the number of people that will be injured and killed by the earthquake. The casualties are broken down into four severity levels that describe the extent of the injuries. The levels are described as follows:

- Severity Level 1: Injuries will require medical attention but hospitalization is not needed.
- Severity Level 2: Injuries will require hospitalization but are not considered life-threatening
- Severity Level 3: Injuries will require hospitalization and can become life threatening if not promptly treated.
- Severity Level 4: Victims are killed by the earthquake or sustain mortal injuries.

The casualty estimates are provided for three times of day: 2:00 am, 2:00 pm and 5:00 pm. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The residential occupancy load should be at its maximum at 2:00 am, the educational, commercial and industrial sector loads are maximized at the 2:00 pm estimate time, and 5:00 pm represents peak commute time.

| | | Level 1 | Level 2 | Level 3 | Level 4 | Total |
|---|---|---|---|---|---|---|
| 2 AM | Commercial | 10 | 2 | 0 | 1 | 13 |
| | Commuting | 0 | 0 | 0 | 0 | 0 |
| | Educational | 0 | 0 | 0 | 0 | 0 |
| | Hotels | 4 | 1 | 0 | 0 | 5 |
| | Industrial | 17 | 4 | 0 | 1 | 22 |
| | Other Residential | 369 | 61 | 5 | 9 | 444 |
| | Single Family | 540 | 61 | 2 | 4 | 607 |
| | **Total** | **940** | **129** | **8** | **14** | **1,091** |
| 2 PM | Commercial | 679 | 145 | 20 | 38 | 882 |
| | Commuting | 1 | 1 | 1 | 0 | 3 |
| | Educational | 216 | 45 | 6 | 12 | 279 |
| | Hotels | 1 | 0 | 0 | 0 | 1 |
| | Industrial | 126 | 27 | 3 | 7 | 163 |
| | Other Residential | 86 | 14 | 1 | 2 | 103 |
| | Single Family | 117 | 14 | 1 | 1 | 133 |
| | **Total** | **1,226** | **246** | **32** | **60** | **1,564** |
| 5 PM | Commercial | 562 | 121 | 17 | 32 | 732 |
| | Commuting | 15 | 20 | 34 | 7 | 76 |
| | Educational | 21 | 4 | 1 | 1 | 27 |
| | Hotels | 1 | 0 | 0 | 0 | 1 |
| | Industrial | 79 | 17 | 2 | 4 | 102 |
| | Other Residential | 137 | 23 | 2 | 3 | 165 |
| | Single Family | 206 | 24 | 1 | 1 | 232 |
| | **Total** | **1,021** | **208** | **57** | **49** | **1,335** |

Table 5.10: *Summary of the casualties estimated for this earthquake scenario event*

There is a fairly large difference in casualty levels depending on when the earthquake occurs (table 5.10). If the earthquake happens in the early morning, most people will be at home in bed. This seems to be the safest place to be. Projected deaths for this time frame are only 14 compared with 60 at 2 pm. Commercial buildings are the most dangerous places to be. Commercial buildings include retail and wholesale trade, personal and repair service, professional and technical services, banks, hospitals, medical offices and clinics, entertainment and recreational, theaters, and parking structures. Other residential buildings include mobile homes, multi-family dwellings, temporary lodging, institutional dormitories and nursing homes.

### 5.3 Potential Damage to Building Stock

HAZUS estimates that there are approximately 451,000 buildings in the Study Area that have an aggregate total replacement value of $98,948,000,000.

In terms of building construction types found in the Study Area, wood frame construction makes up about 92% of the building inventory. This makes sense since most of the housing in the area is wood frame construction. The remaining percentage is distributed between the other general building types.

HAZUS estimates that about 40,317 buildings will be at least moderately damaged. This is more than 9.0% of the total number of buildings in the Study Area. There are an estimated 930 buildings that will be damaged beyond repair, mostly in the residential sector. Table 5.11 below summarizes the expected damage by general occupancy for the buildings in the region. Table 5.12 summarizes the expected damage by general building type.

| | **None** | | **Slight** | | **Moderate** | | **Extensive** | | **Complete** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Count | (%) | Count | (%) | Count | (%) | Count | (%) | Count | (%) |
| Agriculture | 19 | 0.01 | 5 | 0.00 | 3 | 0.01 | 1 | 0.01 | 0 | 0.01 |
| Commercial | 3,174 | 1.03 | 901 | 0.88 | 678 | 1.97 | 203 | 4.13 | 36 | 3.90 |
| Education | 15 | 0.00 | 20 | 0.00 | 1 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Government | 75 | 0.02 | 20 | 0.02 | 13 | 0.04 | 3 | 0.07 | 0 | 0.04 |
| Industrial | 696 | 0.23 | 203 | 0.20 | 172 | 0.50 | 54 | 1.09 | 11 | 1.14 |
| Other Residential | 17,870 | 5.78 | 8,453 | 8.24 | 7,531 | 21.85 | 2,766 | 56.20 | 384 | 41.20 |
| Religion | 113 | 0.04 | 33 | 0.03 | 20 | 0.06 | 6 | 0.12 | 1 | 0.11 |
| Single Family | 287,151 | 92.90 | 92,926 | 90.62 | 26,046 | 75.57 | 1,888 | 38.36 | 498 | 53.5 |
| Total | 309,113 | | 102,543 | | 34,465 | | 4,921 | | 931 | |

Table 5.11 *Expected building damage by occupancy.*

| | **None** | | **Slight** | | **Moderate** | | **Extensive** | | **Complete** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Count | (%) | Count | (%) | Count | (%) | Count | (%) | Count | (%) |
| Wood | 291,995 | 94.46 | 94,933 | 92.58 | 26, 201 | 76.02 | 1,767 | 35.91 | 497 | 53.38 |
| Steel | 1,305 | 0.42 | 374 | 0.36 | 352 | 1.02 | 110 | 2.23 | 19 | 2.04 |
| Concrete | 1,268 | 0.41 | 406 | 0.40 | 251 | 0.73 | 81 | 1.64 | 12 | 1.29 |
| Precast Concrete | 787 | 0.25 | 244 | 0.24 | 235 | 0.68 | 78 | 1.59 | 13 | 1.35 |
| Reinforced Masonry | 4,522 | 0.23 | 854 | 0.83 | 768 | 2.23 | 252 | 5.12 | 21 | 2.30 |
| Unreinforced Masonry | 364 | 0.12 | 136 | 0.13 | 107 | 0.31 | 38 | 0.78 | 16 | 1.68 |
| Manufactured Housing | 8,873 | 2.87 | 5,594 | 5.46 | 6, 552 | 19.01 | 2,595 | 52.73 | 353 | 37.97 |
| Total | 309,113 | | 102,543 | | 34,465 | | 4,921 | | 931 | |

Table 5.12 *Expected building damage by building type (all design levels)*

### 5.4 Potential Damage to Essential Facilities

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.

Essential facilities in the Study Area consist of 18 hospitals with a total bed capacity of 4,768 beds, 22 fire stations, 49 police stations and 4 emergency operation facilities. There are 568 schools (elementary, middle schools, high schools and colleges). With respect to HPL facilities, there are 28 dams identified within the Study Area. Of these, 18 of the dams are classified as ‘high hazard’. The inventory also includes 251 hazardous material sites, but there are no military installations or nuclear power plants.

Before the earthquake, the region had 4,768 hospital beds available for use. On the day of the earthquake, the HAZUS model estimates that 4,157 hospital beds (87.00%) will be available for use by patients already in the hospital and those injured by the earthquake (table 5.13). After one week, 99.00% of the beds will be back in service. By 30 days after the event, 100.00% will be operational (table 5.14). This should be sufficient to provide the necessary care for victims of the earthquake.

| **Number of Facilities** | | | | | |
|---|---|---|---|---|---|
| Classification | Total | At least moderate damage > 50% | Complete damage > 50% | With functionality > 50% on day 1 | Functionality (%) at Day 1 |
| **Hospitals** | 18 | 0 | 0 | 18 | 91.67 |
| **Schools** | 568 | 0 | 0 | 475 | 73.70 |
| **Emergency Operational Centers** | 4 | 0 | 0 | 4 | 75.90 |
| **Police Stations** | 49 | 0 | 0 | 45 | 73.50 |
| **Fire Stations** | 22 | 0 | 0 | 21 | 77.80 |

Table 5.13 *Expected damage to essential facilities.*

| Hospital Size | Total Number of Beds | At Day 1 | | At Day 3 | | At Day 7 | | At Day 30 | | At Day 90 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of Beds | Percent | Number of Beds | Percent | Number of Beds | Percent | Number of Beds | Percent | Number of Beds | Percent |
| Large Hospital | 4,135 | 3,434 | 87.55 | 3,448 | 87.81 | 4,051 | 98.64 | 4,129 | 99.88 | 4130 | 99.89 |
| Medium Hospital | 598 | 554 | 93.84 | 554 | 93.98 | 594 | 99.45 | 598 | 99.90 | 598 | 99.90 |
| Small Hospital | 35 | 33 | 95.60 | 33 | 95.7 | 35 | 99.7 | 35 | 99.90 | 35 | 99.90 |
| **Total** | **4,099** | **3,668** | **89.50** | **3,676** | **89.70** | **4,053** | **98.90** | **4,094** | **99.90** | **4,095** | **99.90** |

Table 5.14: *Expected number of beds available in hospitals after the earthquake*

### 5.5 Potential Damage to Transportation and Lifeline Systems

Within HAZUS, the lifeline inventory is divided between transportation and utility lifeline systems. There are seven transportation systems that include highways, railways, light rail, bus, ports, ferry and airports. There are six utility systems that include potable water, wastewater, natural gas, crude & refined oil, electric power and communications. There are no light rail (commuter railway traffic uses the same tracks as freight rail traffic), port, ferry or oil facilities in the Study Area, so they are excluded from the tables. The lifeline inventory data are provided in tables 5.15 and 5.16.

The total value of the lifeline inventory is more than $8,185,000,000. This inventory includes over 671 kilometers of highways, 848 bridges and 21,508 km of pipes.

| System | Component | Number of locations / Number of Segments | Replacement value (millions of dollars) |
|---|---|---|---|
| **Highway** | Bridges | 848 | 2,000.80 |
| | Segments | 49 | 3082.90 |
| | | Subtotal | **5083.70** |
| **Railways** | Bridges | 39 | 6.60 |
| | Facilities | 8 | 20.60 |
| | Segments | 278 | 445.20 |
| | | Subtotal | **172.40** |
| **Bus** | Facilities | 4 | 5.1 |
| | | Subtotal | **5.1** |
| **Airport** | Facilities | 9 | 57.90 |
| | Runways | 13 | 476.80 |
| | | Subtotal | **534.60** |
| | | Total | **6,095.95** |

Table 5.15 *Study Area Transportation Inventory*

| | | Number of Locations | | | | |
|---|---|---|---|---|---|---|
| **System** | **Component** | **Locations/Segments** | **With at least moderate damage** | **With complete damage** | **With functionality > 50%** | |
| | | | | | **After Day 1** | **After Day 7** |
| **Highway** | Segments | 49 | 0 | 0 | 49 | 49 |
| | Bridges | 848 | 2 | 0 | 843 | 848 |
| **Railways** | Segments | 278 | 0 | 0 | 278 | 278 |
| | Bridges | 39 | 0 | 0 | 39 | 39 |
| **Bus** | Facilities | 4 | 0 | 0 | 4 | 4 |
| **Airport** | Facilities | 9 | 1 | 0 | 9 | 9 |
| | Runway | 13 | 0 | 0 | 13 | 13 |

Table 5.16: *Study Area damage estimates for the transportation system.*

***Note:*** Roadway segments and railroad tracks are assumed to be damaged by ground failure only. If ground failure maps are not provided, damage estimates to these components will not be computed. Since ground failure maps (liquefaction and landsliding) are not currently available, segment damage is unknown.

### 5.5.1 Freeways, Highways and Roadways

Highway roads are classified as major roads and urban roads. Major roads include interstate and state highways and other roads with four lanes or more. Parkways are also classified as major roads. Urban roads include inter-city roads and other roads with two lanes. These are assumed to be damaged by ground failure only. If ground failure maps are not provided, damage estimates to these components will not be computed. Since ground failure maps (liquefaction and landsliding) are not currently available, road segment damage is unknown.

### 5.5.2 Bridges

Bridges are classified based on the following structural characteristics:

- Seismic Design
- Number of spans: single vs. multiple span bridges
- Structural type: concrete, steel, others
- Pier type: multiple column bent piers, single column bents and pier walls

- Abutment type and bearing type: monolithic vs. non-monolithic; high rocker bearings, low steel bearings and neoprene rubber bearings
- Span continuity: continuous, discontinuous (in-span hinges), or simply supported.
- The seismic design of a bridge is taken into account in terms of the (*a*) spectrum modification factor, (*b*) strength reduction factor due to cyclic motion, (*c*) drift limits, and (*d*) the longitudinal reinforcement ratio.

This classification scheme incorporates various parameters that affect damage into the fragility analysis and provides a means to obtain better fragility curves when data becomes available.

| **Number of Bridges** | **Average for Damage State** | | | | |
|---|---|---|---|---|---|
| | None | Slight | Moderate | Extensive | Complete |
| 848 | 0.94 | 0.03 | 0.01 | 0.01 | 0.01 |

Table 5.17: *Highway bridge damage.*

| **Number of Bridges** | **Functionality (%)** | | | | |
|---|---|---|---|---|---|
| | At Day 1 | At Day 3 | At Day 7 | At Day 30 | At Day 90 |
| 848 | 96.40 | 97.50 | 98.10 | 98.30 | 98.90 |

Table 5.18: *Transportation highway bridge functionality.*

The results of the HAZUS scenario show that two bridges of the 848 in the Study Area should have at least moderate damage (tables 5.17 and 5.18). None will likely be completely damaged. Five should be less than 50% functional on day one, but by day seven all should be back in service, maybe not all lanes, but at least some. Many of the major highway bridges have been earthquake retrofitted in recent years. New bridges are all built to much more stringent standards than previous ones. The 1994 Northridge quake caused a change in bridge building requirements. Bridges that were thought to be sturdy collapsed, causing a great many traffic problems until they could be rebuilt.

### 5.5.3 Railways

The class Railway Tracks refers to the assembly of rails, ties, and fastenings, and the ground on which they rest. Only one classification is adopted for these components. Destruction of or damage to tracks assumes ground failure. There is no ground failure computed in this scenario since the requisite liquefaction maps are not available at this time.

The classes of railway bridges are analogous to those of major bridges in highway systems. It is assumed that they have at least one span greater than 500 feet. Railway bridges are classified based on the design criteria adopted in the design of these bridges. These classifications are:

- Seismically designed/retrofitted bridges. These bridges are either designed with seismic considerations or were retrofitted to comply with the seismic provisions.
- Conventionally designed bridges. These bridges are designed without taking seismic considerations into account.

Railway system facilities include urban and suburban stations, maintenance facilities, fuel facilities, and dispatch facilities.

- Urban and Suburban stations are generally key connecting hubs that are important for system functionality. In the western U.S., these buildings are mostly made of reinforced concrete shear walls or moment resisting steel frames.
- Fuel facilities include buildings, tanks (anchored, unanchored, or buried), backup power systems (if available, anchored or unanchored diesel generators), pumps, and other equipment (anchored or unanchored).
- Dispatch facilities consist of buildings, backup power supplies (if available, anchored or unanchored diesel generators), and electrical equipment (anchored or unanchored).
- Maintenance facilities are housed in large structures that are not usually critical for system functionality as maintenance activities can be delayed or performed elsewhere. These building structures are often low-rise steel braced frames.

| **Number of Bridges** | **Average for Damage State** | | | | |
|---|---|---|---|---|---|
| | None | Slight | Moderate | Extensive | Complete |
| 39 | 0.97 | 0.02 | 0.01 | 0.01 | 0.00 |

Table 5.19: *Railroad bridge damage*

| Number of Bridges | Functionality (%) | | | | |
|---|---|---|---|---|---|
| | At Day 1 | At Day 3 | At Day 7 | At Day 30 | At Day 90 |
| 39 | 98.10 | 98.70 | 99.10 | 99.20 | 99.50 |

Table 5.20: *Transportation highway bridge functionality.*

All of the railroad bridges and facilities are expected be mostly functional after the earthquake. None are likely be damage enough to be out of service (tables 5.19 and 5.20).

### 5.5.4 Buses

A bus system's basic components are urban and suburban stations, fuel facilities, dispatch facilities, and maintenance facilities.

- Urban and suburban stations are often key connecting hubs that are important for system functionality. In the western U.S., these buildings are mostly made of reinforced concrete shear walls or moment resisting steel frames.
- Fuel facilities are the same as those defined for railroads.
- Dispatch facilities are also the same as those defined for railroads.
- Maintenance facilities for bus systems are also have the same definition as those for railroads.

There are four bus facilities in the Study Area. Two are public transit and two are private transit facilities. One of the private and one of the public transit facilities are likely to have at least slight damage, but none will be damaged completely.

### 5.5.5 Airports

An airport system consists of six components: control tower, runways, terminal buildings, parking structures, fuel facilities, and maintenance facilities.

- The control tower is defined as a building and the necessary equipment for air control and monitoring.
- Runways consist of well paved "flat and wide surfaces". Damage estimates were not calculated and are unknown for this feature since liquefaction maps are not available.

- Terminal buildings are similar to railway urban stations in that many of the functions performed and services provided to passengers are the same or similar. These are usually constructed of structural steel or reinforced concrete.
- Fuel and maintenance facilities are defined in the same manner as those for railroads.
- Hangar facilities and parking structures are usually constructed of structural steel or reinforced concrete.

Of the nine airport facilities in the Study Area, one (Rialto Municipal Airport) is expected to have at least moderate damage. Repair costs for the Rialto Airport facilities are estimated to be $2,397,000. It is very near the epicenter. It is scheduled to be torn down in the next couple of years, to be replaced by a mixed use area, with shopping centers, offices and homes.

### 5.6 Potential Direct Economic and Social Loss

The total economic loss estimated for the earthquake is $3,789,900,000, which includes building and lifeline related losses based on the region's available inventory. The following three sections provide more detailed information about these losses.

#### 5.6.1 Building Losses

The building losses are broken into two categories: direct building losses and business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with the 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.

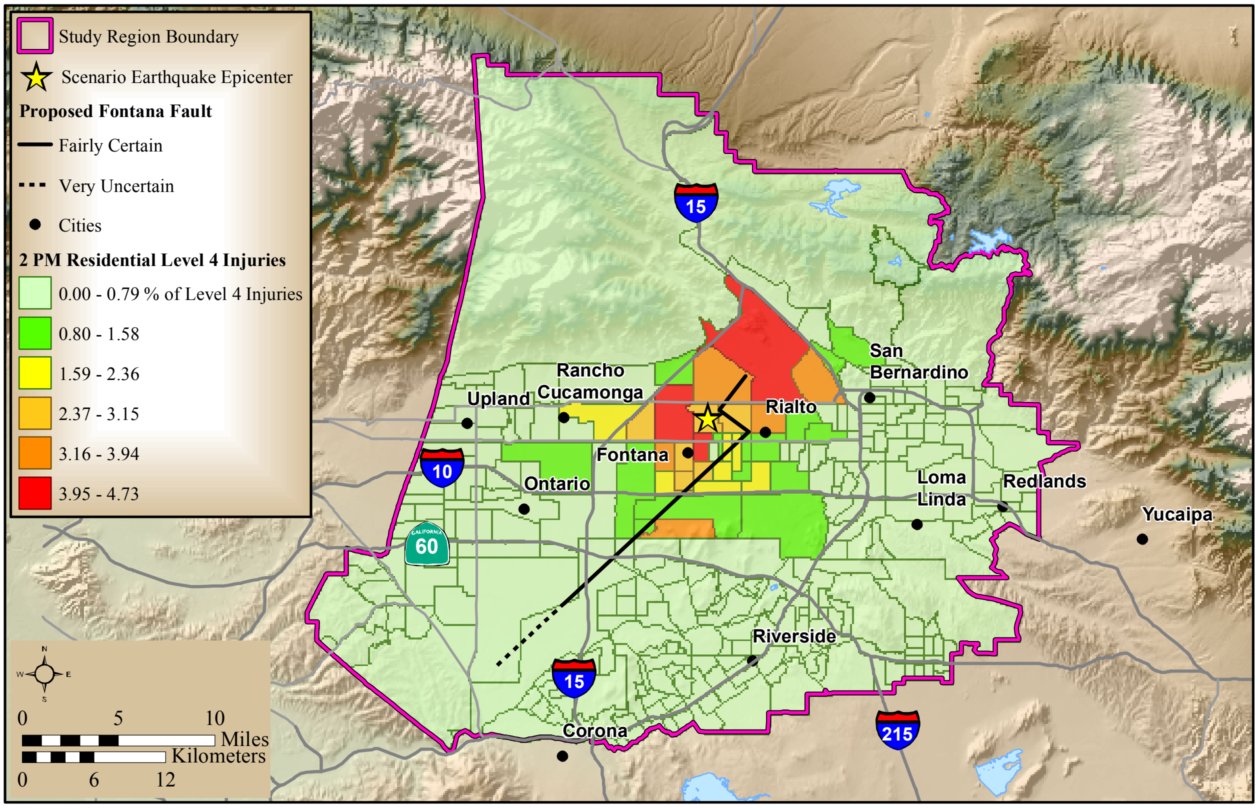
The total building-related losses were estimated to be $3,522,150,000. Nine percent of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up more than 67% of the total loss. Table 5.21 provides a summary of the losses associated with the building damage.

| Occupancy Type | Exposure (thousands of dollars) | Building Damage by Count Number of Buildings | | | | | |
|---|---|---|---|---|---|---|---|
| | | None | Slight | Moderate | Extensive | Complete | **Total** |
| Residential | 81,559,958 | 305,022 | 101,379 | 33,577 | 4,654 | 882 | 437,613 |
| Commercial | 12,589,342 | 3,174 | 902 | 678 | 203 | 37 | 4,993 |
| Industrial | 3,442,481 | 696 | 202 | 172 | 54 | 11 | 1,135 |
| Agriculture | 128,224 | 19 | 5 | 3 | 1 | 0 | 28 |
| Religion | 592,173 | 113 | 33 | 20 | 5 | 1 | 131 |
| Government | 142,546 | 75 | 20 | 13 | 3 | 0 | 112 |
| Education | 493,682 | 14 | 3 | 2 | 0 | 0 | 19 |
| **Total** | 98,948,406 | 309,113 | 102,543 | 34,465 | 4,921 | 931 | 451,973 |

Table 5.21: *Building exposure and building damage by count by general occupancy.*

### 5.6.2 Casualties

The number and location of casualties depends on the time of day of the earthquake, the day of the week, the time of year and most importantly, the magnitude of the earthquake. HAZUS assumes there is a strong correlation between the amount of building damage (both structural and non-structural) and the number and severity of casualties. In smaller earthquake events, most of the casualties will most likely be caused by non-structural damage (toppling bookcases or appliances, falling interior objects or comparable). Large magnitude earthquakes will cause many more buildings to collapse completely or partially, which will lead to a proportionately larger number of fatalities and serious injuries. According to the HAZUS Technical Manual, data for injuries related to earthquakes is not of very good quality. Information about the type of structure in which the casualty took place or the cause of the injury is often missing. Table 5.10 is a summary of casualties by occupancy type, time of day and severity of injury. Figure 5.1 is a representative map showing casualties by census tract for the 2 AM and 2 PM scenarios for the residential occupancy classification. Figure 5.2 shows the same for commercial sites. Other maps for other classifications show similar results. As one would expect, the most casualties are in census tracts that are closest to the epicenter. The areas immediately around the epicenter and just to the east are less populated than areas to the west, south and northeast. There is quite a bit of open space and Rialto airport adjacent to the epicenter (personal observation and knowledge).




Residential Level 4 expected casualties 2 AM = 4 fatalities, 2 PM = 1 fatality.

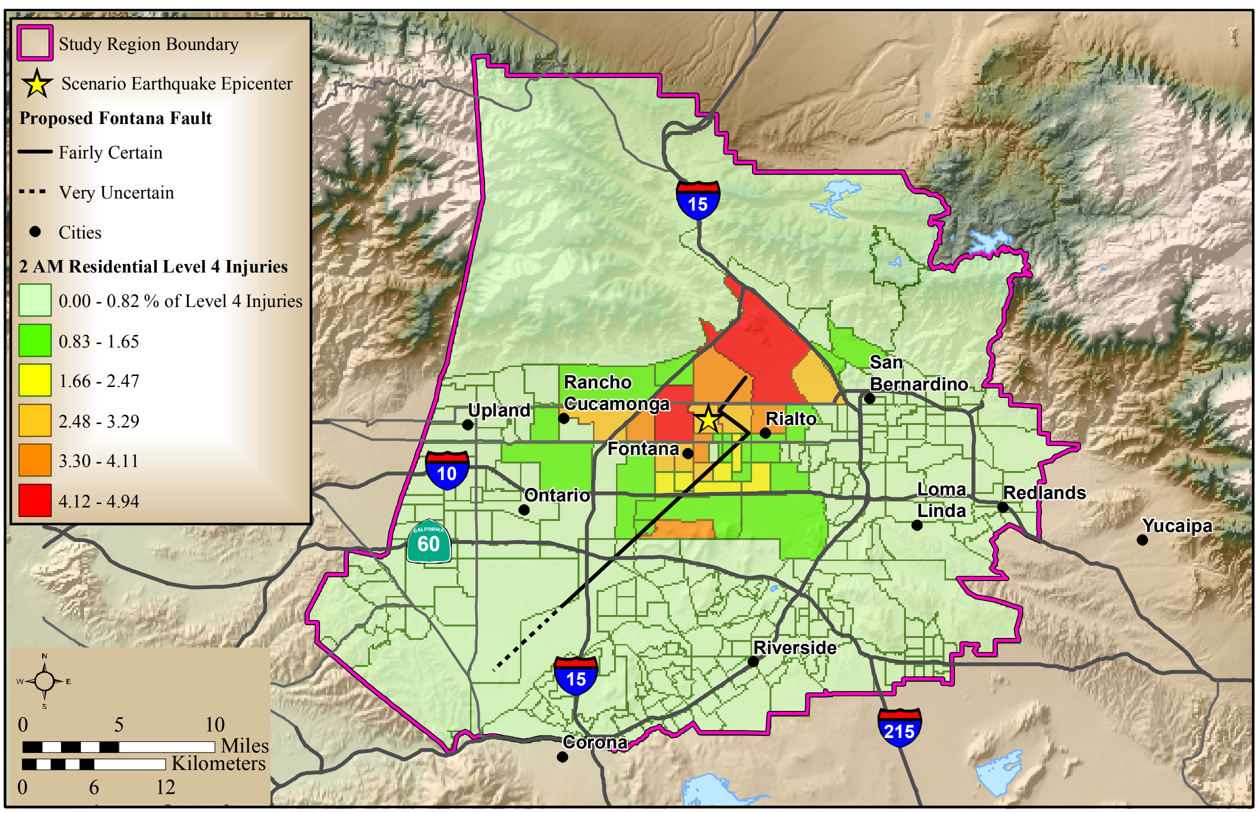
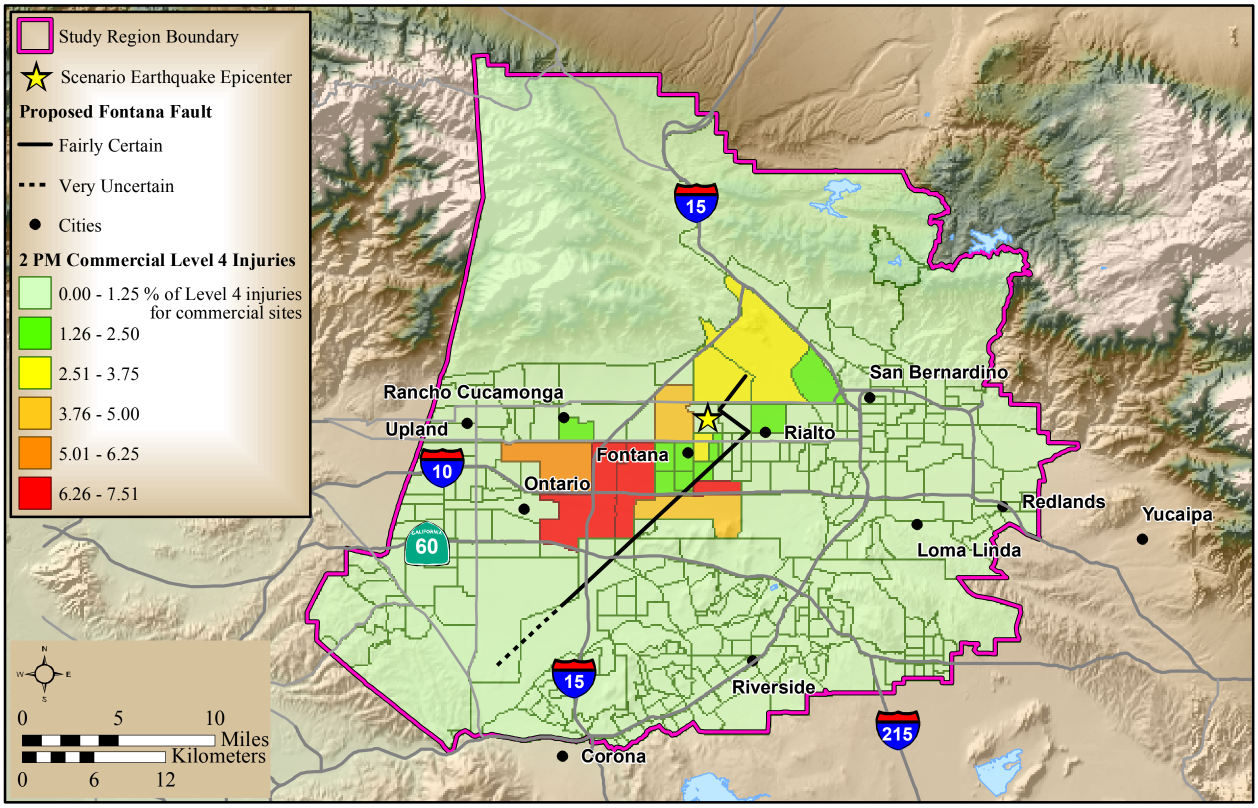



Figure 5.1: *Estimated Residential Level 4 Injuries for the 2 AM and 2 PM scenarios*




Commercial Level 4 expected casualties 2 AM = 1 fatality, 2 PM = 38 fatalities.

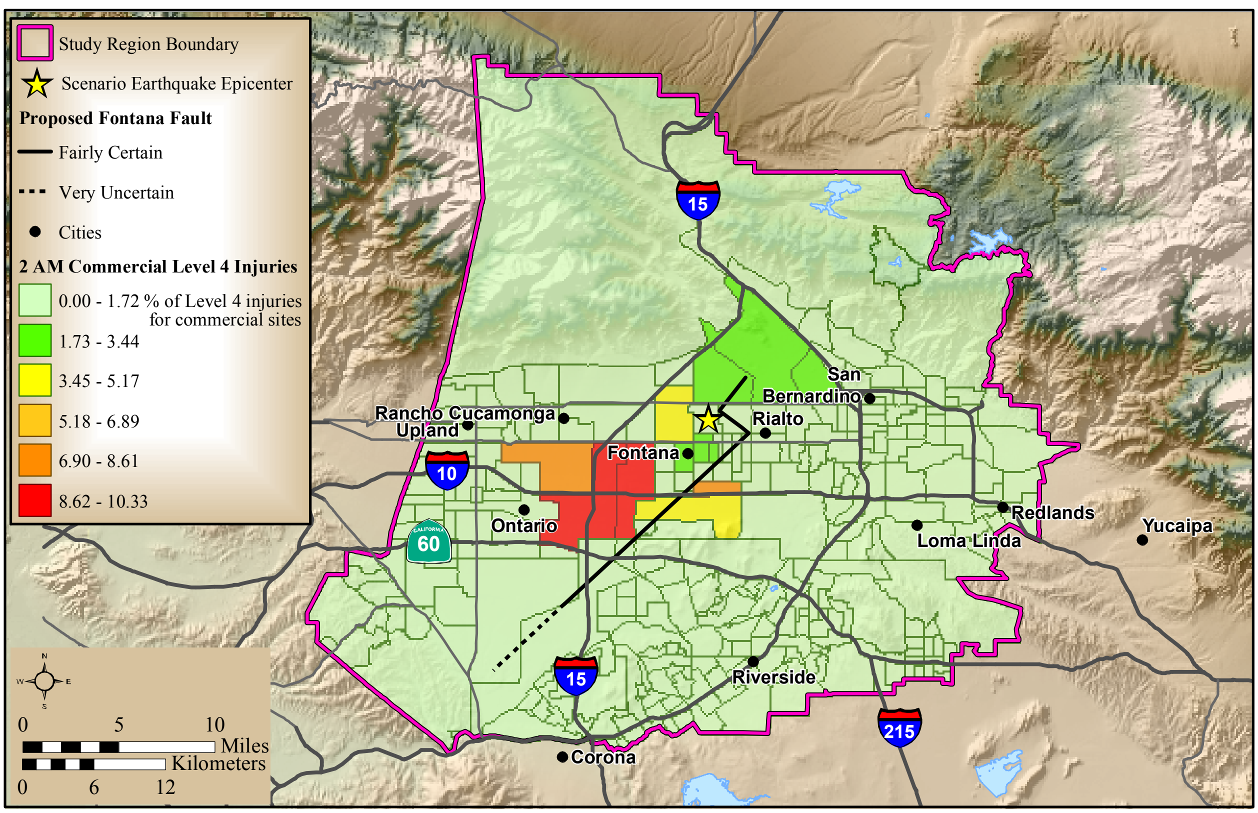



Figure 5.2: *Estimated Commercial Level 4 Injuries for the 2 AM and 2 PM scenarios*

#### 5.6.2.1 Casualty Causes

Estimated casualties are those related directly to the earthquake event. These are from structural failure (buildings or bridges) or non-structural (things falling on someone). This includes injury from falling parts on the exterior of buildings (bricks, parapets, signage and other similar items). Estimates do not include casualties from other causes such as heart attack, auto accident (unrelated to structural damage), post earthquake search and rescue or cleanup and other similar concurrent or subsequent casualties. Fire after earthquake is not a significant cause of casualties in California (unlike Japan). Most of the dams in the Study Area are flood control dams, which are empty most of the time. There are a few dams that could rupture due to earthquake if they are full when the event occurs, but these are far enough away from the epicenter, that it is unlikely that they would fail.

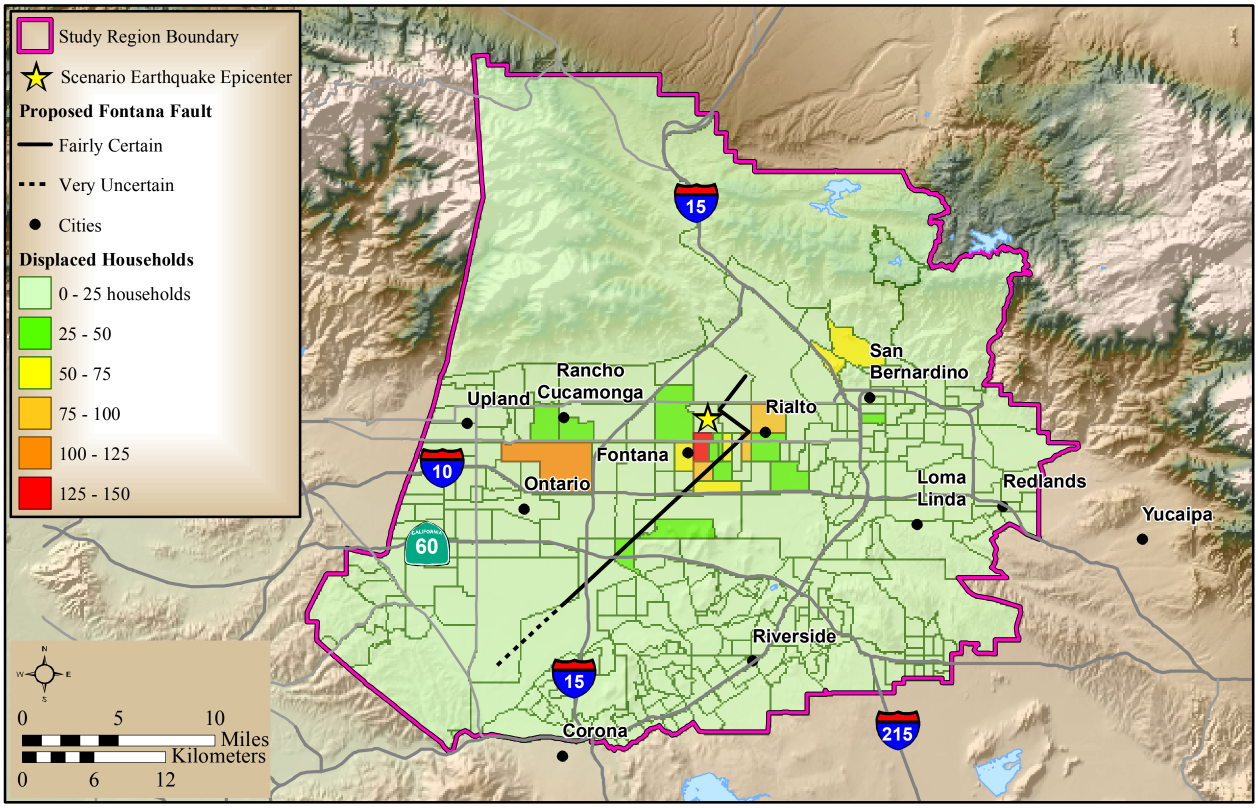
### 5.6.3 Displaced Households Due to Loss of Habitability and Short Term Shelter Needs

HAZUS estimates the number of households that are expected to be displaced from their homes due to the earthquake and the number of displaced people that will require accommodations in temporary public shelters as shown in figure 5.3. The model estimates that 2,277 households will be displaced due to the earthquake. Of these, 659 people (out of a total population of 1,713,281) will seek temporary shelter in public shelters. The remaining displaced persons will most likely seek shelter with family and/or friends.

### 5.6.4 Cost of Building Repair and Rebuilding

HAZUS provides estimates of the structural and nonstructural repair costs caused by structural damage and the associated loss of building contents and business inventory. Building damage can also cause additional losses by restricting the building's ability to function properly. To account for this, business interruption and rental income losses are also estimated.

Significant building damage can have a ripple effect throughout the community. Residential damage can mean people will not be able to make it to work because their homes, belongings and/or vehicles are no longer available or usable. Damage to businesses and business inventory may mean workers no longer have a place of employment and the business owners no longer




Total expected displaced households: 2,271; Expected number of persons needing public shelter: 659

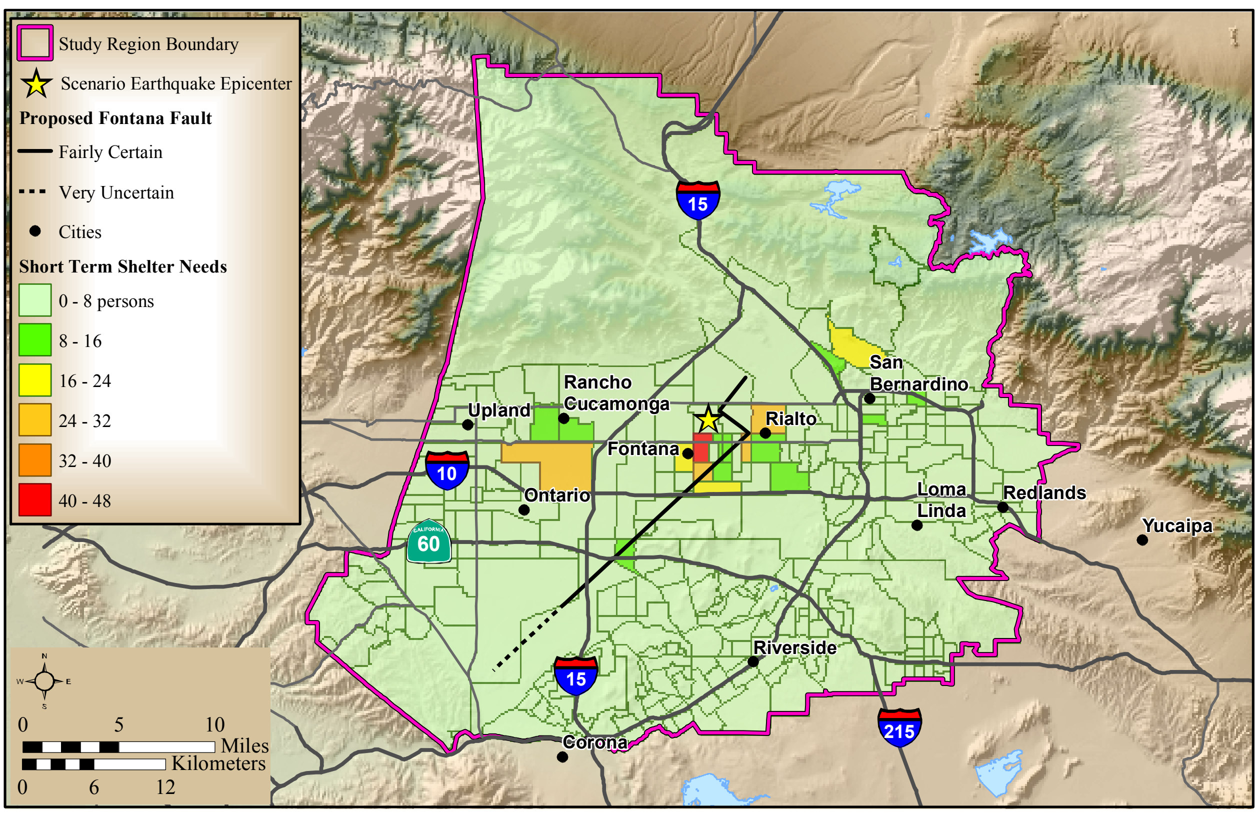



Figure 5.3: *Estimated Displaced Households and Potential Shelter Needs(PGV)*

have a source of income, and now they have additional repair expense. In addition, they are now unable to provide needed products or services to the community.

Damage to infrastructure also impacts governmental budgets as well as impacting the usual movement of the populace (damaged roadways and bridges can cause big delays or detours which in turn affect efficiency).

Estimated costs for the scenario for structural losses are $442,900,000 and non-structural are $2,015,350,000. The largest percentage by far is expected in the residential sector ($220,760,000 and $1,177,890,000 respectively).

### 5.6.5 Building Contents and Inventory Losses

Building contents are defined as furniture, equipment that is not integral with the structure, computers and other supplies. Contents are not just business related, but also include residential contents. Contents do not include inventory or non-structural components such as lighting, ceilings, mechanical and electrical equipment and other fixtures. HAZUS assumes that most content damage, such as overturned cabinets and equipment or equipment sliding off tables and counters, is a function of building accelerations. Therefore, acceleration sensitive non-structural damage is considered to be a good indicator of contents damage.

Business inventories vary considerably depending on the type of business. For example, the value of inventory for a high tech manufacturing facility would be very different from that of a retail store. Thus, it is assumed for the HAZUS model that business inventory for each occupancy class is based on annual sales. Since losses to business inventory most likely occur from stacks of inventory falling over, objects falling off shelves, or from water damage when pipes break, it is assumed, as it was with building contents, that acceleration sensitive non-structural damage is a good indicator of losses to business inventory.

Damage to contents is expected to be in the neighborhood of $738,660,000 with the largest portion (63%) of that in the residential sector (table 5.22). Inventory is strictly a business loss and that is expected to be $24,390,000.

| Capital Stock Losses (In thousands of dollars) | |
|---|---|
| Cost Structural Damage | 442,896 |
| Cost Non-Structural Damage | 2,015,352 |
| Cost Contents Damage | 738,663 |
| Inventory Loss | 24,392 |
| Loss Ratio % | 2.07 |
| **Income Losses (In thousands of dollars)** | |
| Relocation Loss | 8,387 |
| Capital Related Loss | 75,112 |
| Wages Losses | 100,268 |
| Rental Income Loss | 120,613 |
| **Total Loss** | 3,525,683 |

Table 5.22: *Direct economic losses for buildings*

### 5.6.6 Relocation Expenses

Relocation costs may be incurred when the level of building damage is such that the building or portions of the building are unusable while repairs are being made. While relocation costs may include a number of expenses, only the costs involved in moving to a new location are considered. The scenario estimates that relocation expenses will total around $300,840,000, with more than 2/3 of that borne by the commercial sector (table 5.22).

### 5.6.7 Loss of Income (including Rents)

Business activity generates several types of income. Businesses generate profits, and a portion of this is paid out to individuals (as well as to pension funds and other businesses) as dividends, while another portion, retained earnings, is plowed back into the enterprise. Businesses also make interest payments to banks and bondholders for loans. They pay rental income on property and make royalty payments for the use of tangible assets. Those in business for themselves, or in partnerships, generate a category called proprietary income, a portion of which reflects their profits and salaries paid to themselves. Finally, the biggest category of income generated/paid is associated with labor. In most urban regions of the U.S., wage and salary income comprises the majority of total personal income payments.

## 5.7 Potential Indirect Economic and Social Loss

HAZUS provides limited results for the indirect economic effects of the scenario event to assist financial institutions and government planners to anticipate losses and develop programs to compensate for them. The indirect economic impact information also enables users to motivate policy-makers to consider the cost-benefit implications of mitigation activities.

| Year | Loss | Total | Percentage (%) |
|---|---|---|---|
| First Year | Employment Impact (number of people) | 26,657 | 6.22 |
| | Income Impact (millions of dollars) | 57 | 0.28 |
| Second Year | Employment Impact (number of people) | 11,470 | 2.68 |
| | Income Impact (millions of dollars) | (36) | -0.18 |
| Third Year | Employment Impact (number of people) | 279 | 0.07 |
| | Income Impact (millions of dollars) | (100) | -0.49 |
| Fourth Year | Employment Impact (number of people) | 14 | 0.00 |
| | Income Impact (millions of dollars) | (115) | -0.56 |
| Fifth Year | Employment Impact (number of people) | 0 | 0.00 |
| | Income Impact (millions of dollars) | (116) | -0.56 |
| Year 6 to 15 | Employment Impact (number of people) | 0 | 0.00 |
| | Income Impact (millions of dollars) | (116) | -0.56 |

Table 5.23: *Indirect Economic Impact with outside aid. There should be aid from governmental relief and private donations.*

The first year following the earthquake will be the most difficult. Many jobs will be lost initially. After rebuilding and recovery, there should be a return to the previous economic health (table 5.3).

## 5.8 Potential Induced Damage from Inundation

Dam inundation maps are only available for a few dams in California. None exist for the dams within the Study Area. Even though they are classified as high hazard because of their location, many of the dams in the Study Area are flood control dams or detention basin dams. These are empty most of the time, so do not normally pose a danger. Those that have water in them all of the time are outside the area with high PGA values. Since inundation maps are not available, no threat was calculated, so the potential for inundation damage is unknown.

### 5.9 Potential Induced Damage from Fire following Earthquake

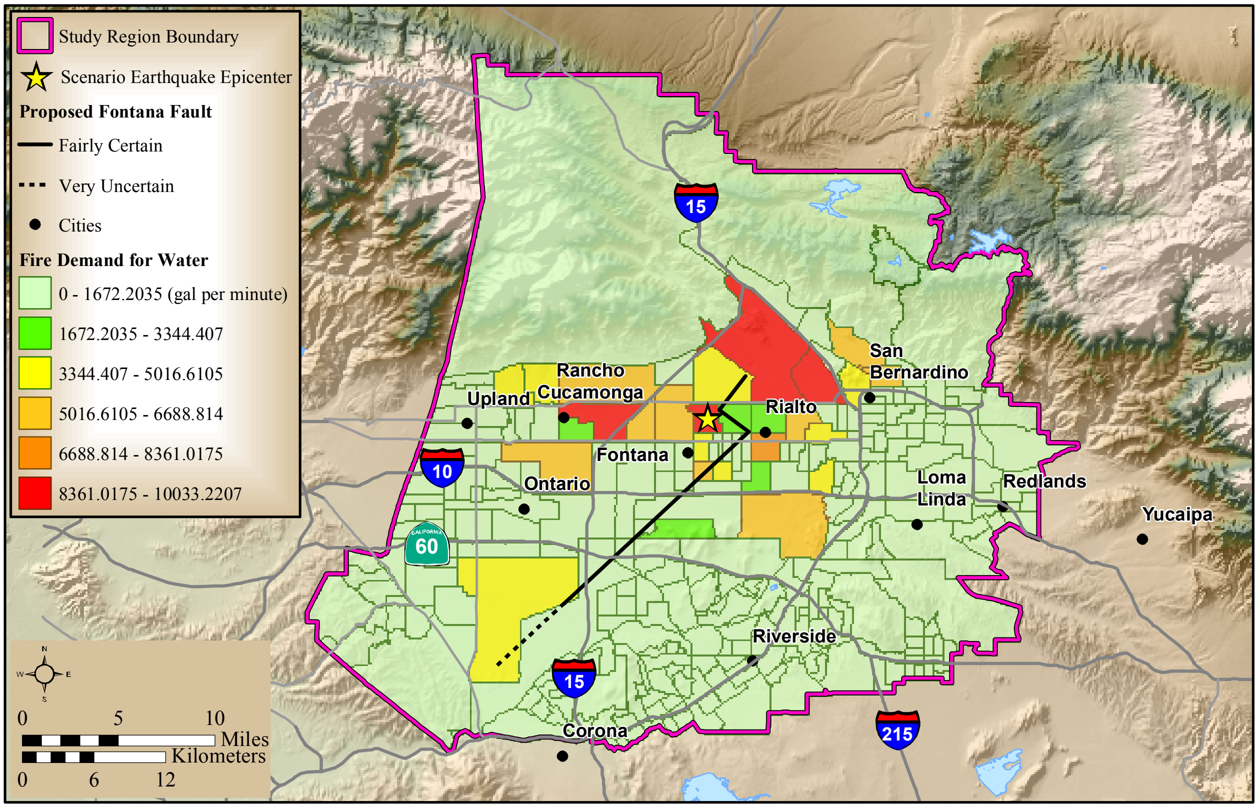
Fires often occur after an earthquake. These can be caused by a number of sources. Broken gas lines, spilled flammable liquids sparked by an ignition source, as well as many other causes. Because of the number of fires and the lack of water to fight the fires (water mains are often ruptured), they can often burn out of control. HAZUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area. For this scenario, the model estimates that there will be 32 ignitions that will burn about 0.37 square miles (0.04 % of the Study Area's total area). The model also estimates that the fires will displace about 1,409 people and cause about $67,000,000 in building damages (table 5.24).

| Number of Ignitions | Population Exposed | Value Exposed (thousands of dollars) |
|---|---|---|
| 32 | 1,410 | 67,657 |

Table 5.24: *Fire after earthquake exposure*

#### 5.9.1 Ignition Sources and Potential Start Locations

The most likely start locations will be in Rialto, Fontana and North San Bernardino (figure 5.4). All of these locations have older frame buildings with shingle roofs. Fire ignitions are probably not related to a single parameter, whether it is the size of the earthquake or the Peak Ground Acceleration or other factor. Fire ignitions can start for a number of reasons. Unanchored items (such as heaters, water heaters or similar) can topple, causing short circuits, ruptured gas lines or fuel spills. This can cause a fire if an ignition source is present. Underground utilities (such as gas lines) can provide a fuel source for ignition if they rupture. Buildings with multiple stories (especially older ones) can shift causing short circuits in electrical wiring between floors. In the San Bernardino area, time of year is also critical. During the summer months, the vegetation becomes very dry and can ignite and spread fire easily. During the fall and winter, Santa Ana winds often blow with gusts up to 100 miles per hour or more. This can cause a small fire to grow quickly into a fire storm (the October 2003 fires burned hundreds of homes and many square miles of vegetation). Also, more gas appliances are in use during winter to heat homes,



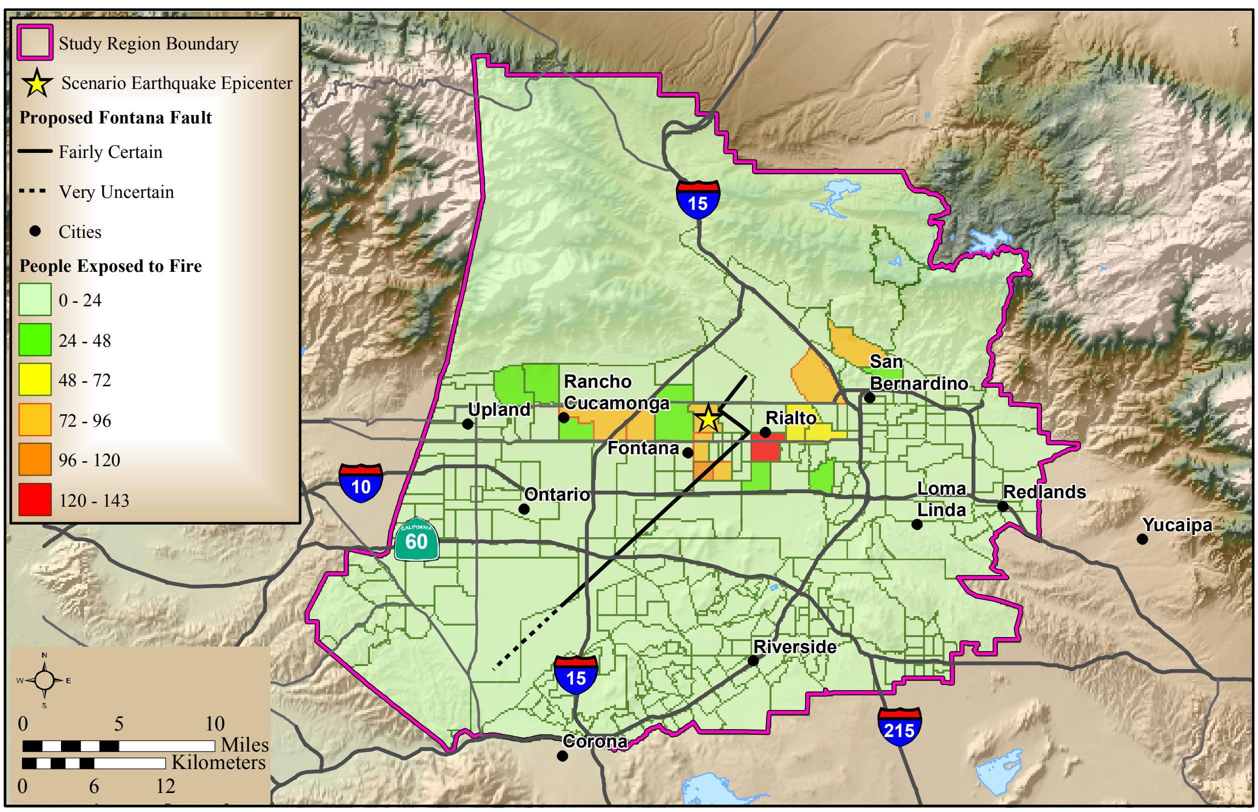




Figure 5.4: *Fire following earthquake water demands and people at risk*

increasing the likelihood of these starting a fire. Most fires (about 70%) that start as a direct result of the earthquake start within a few minutes of the shaking. The remaining fires usually start within a day, usually due to the restoration of electrical power – short circuits caused by the quake or appliances toppled by shaking can now be an ignition source.

### 5.9.2 Timing of Discovery, Report , Response and Spread

Discovery of structure fires usually happens fairly quickly, especially if the building is occupied. It may be difficult to report the fire or for the fire department to respond after a quake due to lack of infrastructure and debris in streets. Fires that are not put out quickly can spread rapidly to adjacent structures or vegetation, especially if the weather conditions are not favorable.

### 5.9.3 Structure and Brush Fires – requirements

Structure fires usually require large amounts of water at high pressure to gain control of the fire and put it out. The type of structure and contents also determine how much water will be needed: apartment buildings require more than single family residences, commercial or industrial buildings require more water than small apartment buildings, and petroleum fires require even more. If the earthquake has damaged the water pipes, the needed amount or pressure may not be available.

## 5.10 Potential Induced Damage from Debris and Associated Costs

HAZUS estimates the amount of debris that will be generated by the earthquake. The model breaks the debris into two general categories: a) Brick and Wood and b) Reinforced Concrete and Steel. This distinction is made because of the different types of material handling equipment required to handle the debris.

The model estimates that a total of 984,000 tons of debris will be generated. Of the total amount, Brick and Wood comprises about 41.00% of the total (402,000 tons), with the remainder being Reinforced Concrete/Steel (582,000 tons). If the debris tonnage is converted to an estimated number of truckloads, it will require 39,360 truckloads (at 25 tons per truck) to remove the debris generated by the earthquake.

# CHAPTER 6

## 6.0 Discussion and conclusions

Southern California is a very geologically complex and seismically active area. There has been a lot of interest and work done by the geological community in much of the area. An unstated goal of this project was to add to the ever increasing knowledge base.

The first stated goals were to determine the reason for the Fontana Seismicity Trend and to determine what sort of fault is causing the on-going seismic events. After much research, discussion with fellow geologists, studying and plotting focal mechanisms, looking at aerial photography for lineaments and other similar work, the conclusion was reached that the Fontana Trend is most likely two steeply dipping left-lateral strike-slip fault segments with a step-over that uses the existing Rialto-Colton Fault as a conduit between the two segments (figure 4.4). Even though the “inferred fault” shown in the Fontana General Plan and Morton’s 1974 map and the newer location of the Fontana Seismicity Trend in the Community Fault Model show it as single strand, the author does not feel that this fits the earthquake data. The other two options were also rejected because they also did not fit the data. Tectonically, this appears to be a conjugate fault for the San Jacinto Fault (Hauksson and Jones, 1991). If the Landers and Big Bear quake scenario were to take place here (an event on the right-lateral San Jacinto could trigger an event on its conjugate, left-lateral Fontana), a much larger event could happen. For this portion of the study, a best-fit plane for the hypocenters would have been an ideal way to show the configuration of the fault, but the author does not have the requisite knowledge to do this and it stumped all who were asked. Instead, the author thought that creating a right triangle (figure 4.1) in Visio would give the desired results for representative hypocenters.

The next objective was to determine how large an event might occur. When all three fault segments are combined, the length exceeds 27 kilometers (35 if the uncertain portion at the southwestern end is included). The uncertain segment lacks focal mechanism data and the earthquake hypocenters do not form as linear a pattern as the more certain segments. Using

Wells and Coppersmith's information, a potential 10 kilometer surface rupture could yield a 6.28 magnitude event.

The location of a smaller, previous event for which there was focal mechanism data was then used to create a HAZUS scenario using the 6.28 (rounded to 6.3) magnitude value. HAZUS comes with a lot of data, but more can be added to return better results. The only additional data that was used was soil data. A detailed building inventory, adding more buildings to reflect recent building in the area, would probably increase the loss estimates. Obtaining liquefaction maps, landslide maps, and dam inundation maps when they become available would also improve the results. Filling in some of the pipeline and other missing utility data would also enhance the results. More accurate population data would also add to the loss estimates. The census data used is seven years old and there are more people in the area now than there were then, so casualty estimates are probably low. There was not enough room in this dissertation to provide all the detailed information that HAZUS can generate.

The scenario earthquake was a moderate one. Even a moderate one can cause quite a bit of damage and disrupt lives. The Fontana Seismic Trend needs to be studied more extensively and be seen as the potential hazard that the author believes it is. Sites should be identified that could be trenched to determine if the fault location is correct. Further investigation of the flood control channel in figure 3.2 should be done. Seismic refraction studies should be done (they have been done for areas further east) to help characterize the underground structure. More definitive groundwater flow studies should also be done.

## APPENDIX

### Acronyms:

**CGS:** California Geological Survey (formerly California Department of Mines and Geology)

**ESRI:** Environmental Systems Research Institute. They produced the GIS software used in this project.

**FEMA:** Federal Emergency Management Agency

**HAZUS:** Hazards U.S. **–** a software extension for ArcGIS

**SAWPA:** Santa Ana Watershed Project Authority

**SCEC:** Southern California Earthquake Center

**USGS:** United States Geological Survey

### Glossary of Terms (not explained fully in body of dissertation)

Source: SCEC

**Alluvium:** loose material such as clay, silt, sand, gravel and rocks that wash down from nearby hills and mountains and are deposited in lower areas such as valleys.

**Conjugate faults:** this describes a pair of intersecting (or nearly intersecting) faults that have opposite slip motions (e.g., right-lateral and left-lateral) that allows tectonic block rotation that they bound to be accommodated. They will sometimes rupture at about the same time.

**Dip:** the angle between a geologic surface (fault plane for one) and the horizontal. The direction of dip is the direction a ball would roll if placed on the surface. The dip of a surface is always perpendicular to the strike of that surface.

**Epicenter:** the point on the earth's surface directly above the point of origin (hypocenter) of an earthquake.

**Fault:** a fracture or zone of fracture in the earth along which there has been displacement of the sides relative to one another (displacement can be vertical, horizontal or some combination)

**Focal mechanism:** (also called moment tensor solution or first motion study) the direction and sense of slip on a fault plane at the point of origin (hypocenter) of an earthquake, as inferred from the first seismic waves that arrive at surrounding seismic recording stations. These are often drawn as “beach ball” symbols. The black areas denote compressional forces, the white dilational forces.

**Hypocenter:** the point of origin or focus of an earthquake. It is defined by latitude, longitude and depth.

**Magnitude:** a general term for a measurement of the strength or energy of an earthquake as determined by seismographic data. Seismologist generally use **moment magnitude** now to describe an earthquake’s energy since it relates to the amount of energy released rather than the Richter scale which uses surface wave magnitude rather than the total energy released.

**Normal fault:** a fault characterized by predominantly vertical displacement – the hanging wall moves downward with respect to the footwall. This is usually a sign of tectonic extension.

**Reverse fault:** a fault characterized by predominantly vertical displacement – the hanging wall moves upward with respect to the footwall. This is usually a sign of tectonic compression.

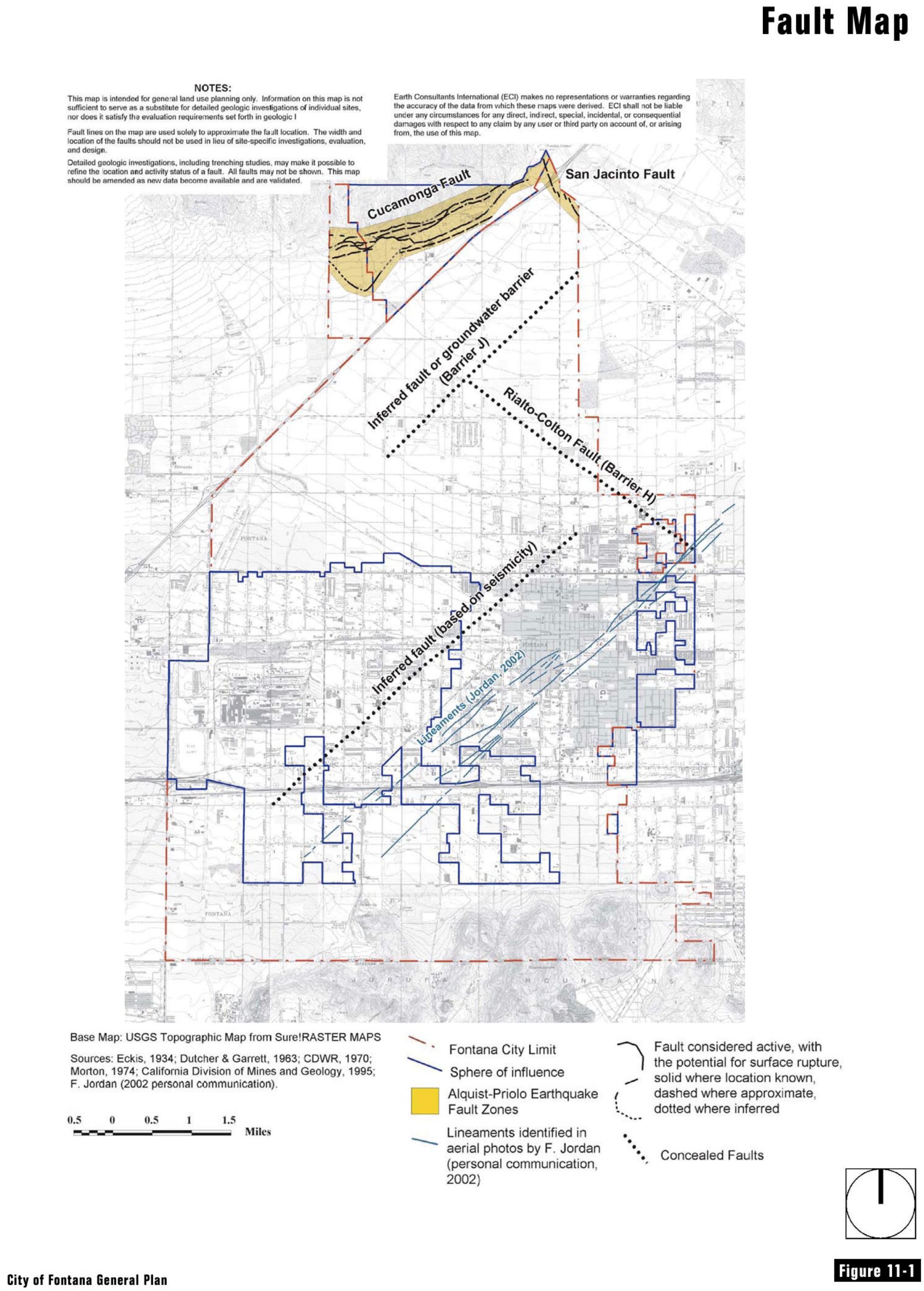
**Strike-Slip or lateral fault:** a fault whose predominant sense of slip is a lateral motion. If a person stands on one side of the fault facing across it, objects on the opposite side will move right in right-lateral faults and left in left-lateral faults.

**Strike:** The direction or trend of the line marking the intersection of a fault plane with the horizontal. Strike is always at a right angle to the dip.

**Surface rupture:** the breakage of ground along the surface trace of a fault caused by the intersection of the fault surface area ruptured during an earthquake with the Earth’s surface.

**Thrust Fault:** a fault characterized by predominantly vertical displacement with a dip of 45 degrees or less **–** the hanging wall moves upward with respect to the footwall. This is usually a sign of tectonic compression.

**Transverse Ranges:** the mountains formed by compression associated with the Big Bend of the San Andreas Fault zone - primarily the San Gabriel and San Bernardino Mountains. They are called transverse because they stretch east-west, unlike the north-south trending Sierra Nevada and Peninsular Ranges. Thus, they are transverse to most other California mountains and to the overall tectonic motion at this plate boundary.




Fault map with lineaments from the 2003 Fontana General Plan

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http://www.scecdc.scec.org/pictures/chino98.gif GIF image of seismic activity map for the Inland Empire 1981 – 1998. From Southern California Earthquake Center (SCEC) – created by Hauksson, E. (figure 1.4) (Accessed December 6, 2003)

http://www.data.scec.org/catalog_search/CMTsearch.php Searchable Southern California Seismic Network (SCSN) moment tensor database on the Southern California Earthquake Center (SCEC) web site, a cooperative effort of the U.S. Geological Survey and CalTech. Data is available for events 3.0 and larger since 1999. (Accessed many times, most recently, August 19, 2007)

http://www.data.scec.org/catalog_search/date_mag_loc.php Searchable earthquake database on the Southern California Earthquake Center (SCEC) web site, a cooperative effort of the U.S. Geological Survey and CalTech. Accessed many times, most recently, August 10, 2007.