TECHNICAL BACKGROUND REPORT to the SAFETY ELEMENT of the GENERAL PLAN for the CITY of HESPERIA, SAN BERNARDINO COUNTY, CALIFORNIA

SEISMIC HAZARDS
GEOLOGIC HAZARDS
FLOODING HAZARDS
FIRE HAZARDS
HAZARDOUS MATERIALS MANAGEMENT

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EXECUTIVE SUMMARY

The Background Report to the Safety Element of the General Plan for the City of Hesperia describes and discusses the natural and some man-made hazards that have the potential to impact the city.

Hesperia lies across the boundary of two very distinct geomorphic provinces. The very southern edge of the city encroaches into the Transverse Ranges Province, a region whose characteristic features are a series of east-west trending ranges that include the San Gabriel and San Bernardino Mountains. The greater part of Hesperia, north of the mountains, lies within the Mojave Desert Province, an arid region of alluvial fans, desert plains, dry lakebeds, and scattered mountain ranges. These physical features are a direct consequence of the geologic and climatic processes that have affected this region in the last few million years. The most striking feature is the dramatic contrast between the Mojave Desert and the adjacent mountains – a direct result of movement along faults that have both elevated and down-dropped great blocks of the Earth's crust. As a result, the mountain ranges that form the backdrop to Hesperia are composed of rocks that have been sheared and intensely fractured under the strain of tectonic movement. Along the base of the mountains, multiple generations of overlapping alluvial fans have a range of ages coincident with the rise of the mountains.

The physiographic and geologic history of the Hesperia area control to a great extent the geologic hazards, as well as the natural resources, within the city. For example, Hesperia receives great quantities of runoff from the nearby mountains during storms, leading to flooding problems in some areas. Regional tectonic subsidence along the valley floor, concurrent with uplift of the adjacent mountains, is responsible to a great extent for the rapid deposition of poorly consolidated alluvium that is susceptible to consolidation and/or collapse. This same deep alluvium, however, provides a natural underground reservoir (aquifer) for ground water, the city's source of all its domestic water.

Most of the hazards covered herein are "natural" hazards, such as earthquakes (Chapter 1); slope instability, subsidence, and erosion (Chapter 2); floods and inundation due to dam failure (Chapter 3), and wildland fire (Chapter 4). These natural conditions do not pose a hazard in undeveloped areas, but when they interact with the built environment, they have the potential to become catastrophic. For example, flooding in an undeveloped area has no impact on buildings or infrastructure, and no one is likely to get hurt or killed. But when flooding occurs in a developed residential area, it has the potential to cause extensive damage and monetary losses. This does not need to happen, though. From past experience, we have learned how to measure, contain, and where necessary, avoid floodwaters. Similarly, we have learned how to design earthquake-resistant structures. The primary purpose of this document is to educate and inform the residents and officials of Hesperia of the potential natural hazards in the community. By doing so, you can take action to reduce the hazards specific to your area to a level that you, your family and your community are comfortable with. Through appropriate action, the hazard does not need to become a disaster. These are some of the topics that are covered in more detail in the following report. The man-made hazards covered in this document include structure and chemical fires (Chapter 4), and hazardous materials (Chapter 5).

Not all potential natural hazards are covered in this document. For example, although drought is a potentially significant hazard in the region, its regional impact requires a regional approach to the development of mitigation or contingency plans. Also, methods for drought prediction and forecasting are in their infancy, and thus not very reliable. Future generations of this document should consider a section on drought, including the development of mitigation measures to manage water supply. Similarly, there are no known volcanic sources near the city of Hesperia, but a major eruption of the volcanic field in Yellowstone, or Mammoth, could blanket the entire region in ash, with severe environmental, social and financial consequences. However, given the difficulties of predicting and planning for such a catastrophe, volcanic hazards are also not discussed herein. Other climatological hazards, such as extreme cold, hail, and snow avalanches do not occur often in southern California, and are therefore not discussed.

So, what is the best way to use this report? As the saying goes, "a picture is worth a thousand words." Thus, we recommend that you first refer to the maps that accompany this report. If you are like almost everyone else, you will want to look for the area where you live or work, or where you are thinking of moving. These maps will show you at a glance whether your area of interest is, for example, on or near an area susceptible to liquefaction, flooding, or in a fire hazard area. Keep in mind, however, maps are by necessity generalized, and therefore, the boundaries shown on the maps are only approximate – you do not want to be lulled into a false sense of security because your house lot is across the street from a contact between a hazardous and a non-hazardous zone. Or, alternatively, decide to move because you are currently living in an area zoned as hazardous. This is where reading the text becomes important. Read on the specific hazards that you are concerned about, then apply that knowledge to your lot and house. How old is your house? Is it tied down to its foundation? Does it have a fire-resistant roof? Are there protective berms upgradient that will divert runoff away from your structure? There are specific actions that you can take to make your house specifically, or Hesperia in general, a safer place.

Hesperia is located within the high desert portion of the Inland Empire, an area that is growing very rapidly: Hesperia's current population of more than 84,000 residents is expected to double by the year 2025. As the city grows in the next few decades, new development will be needed to meet the demand for homes. When meeting this demand, it is imperative to manage land use in a responsible way, as development disrupts natural processes, often leading to negative impacts on the environment as well as on the development and adjacent properties. The impacts of land development can be minimized, however, if both site-specific and regional planning elements are recognized and considered, the project incorporates knowledge gained from scientific research in developing and implementing a design appropriate to the area, and protective measures are constructed and maintained for the lifetime of the project.

Given that Hesperia is still a growing city, there is the opportunity to effect mitigation via avoidance and engineering design in currently undeveloped areas. In already developed areas of the city, mitigation may have to be implemented through the redevelopment process, and as a result, may require decades to complete. It is certainly also possible that, as new technological solutions or scientific knowledge is gained, some of the mitigation can be achieved through engineering manipulation of the existing structures.

This technical report is the foundation upon which the programs and policies in the Safety Element are based. In the end though, all mitigation is local. Without the support of the citizens of Hesperia, no governmental programs will be successful. It is hoped that this document will assist you in understanding the issues and the risks you and Hesperia face. Through such an understanding you will be ready to support and implement the programs necessary to reduce your community's risk to acceptable levels.

CHAPTER 1: SEISMIC HAZARDS

1.1 Introduction

In seismically active southern California, an earthquake has the potential to cause far-reaching loss of life or property, and economic damage. This is so because damaging earthquakes are relatively frequent, affect widespread areas, trigger many secondary effects, and can overwhelm the ability of local jurisdictions to respond. Earthquake-triggered geologic effects include ground shaking, surface fault rupture, landslides, liquefaction, subsidence, tsunamis and seiches. Some of these hazards can occur in the city of Hesperia, as discussed in detail below. Earthquakes can also lead to urban fires, reservoir failures, and toxic chemical releases. These man-related hazards are also discussed in this document.

Having said the above, recent earthquakes in or near urban environments in California have caused relatively few casualties. This is due both to luck and design. Earthquake researchers agree that recent earthquakes in California have not truly tested the performance of our built environment, and although newer buildings are generally safe, older structures have the potential to collapse or incur substantial structural damage. Shaking as a result of the M_W 7.1 Loma Prieta earthquake was surprisingly short for the size of the quake because the fault ruptured bilaterally, propagating both to the north and south at the same time. (M_W stands for moment magnitude, a measure of earthquake energy release, discussed below.) This, combined with the fact that traffic was uncommonly light because so many were watching the World Series limited the number of fatalities resulting from the collapse of a portion of the Nimitz Freeway in Oakland. The 1994, M_W 6.7 Northridge earthquake occurred before dawn, when most people were home safely in bed, and most of the energy released occurred away from the densely populated metropolitan area. Had this earthquake occurred later in the day, the collapse of the seven highway bridges alone would have resulted in a much higher death toll. Still, this moderate-sized event caused 54 deaths and nearly $30 billion in damage. These statistics give us pause when we realize that the southern California region is at risk from earthquakes that could release more than ten times the seismic energy of the Northridge earthquake.

It is therefore important to note that although it is not possible to prevent earthquakes, their destructive effects can be minimized. Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning, public education, emergency exercises, enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can significantly reduce the scope of an earthquake's effects and avoid disaster. The record shows that local government, emergency relief organizations, and residents can and must take action to develop and implement policies and programs to reduce the effects of earthquakes. Thus, this document not only discusses the potential hazards that can impact Hesperia, but also addresses effective action items and programs to help the City become more self-sufficient in the event of an earthquake.

1.2 Earthquake and Mitigation Basics

1.2.1 Definitions

The outer 10 to 70 kilometers of the Earth consist of enormous blocks of moving rock called tectonic plates. There are about a dozen major plates, which slowly collide, separate, and grind past each other. In the uppermost brittle portion of the plates, friction locks the plate edges together, while plastic movement continues at depth. Consequently, the near-surface rocks bend and deform near plate boundaries, storing strain energy. Eventually, the frictional forces are overcome and the locked portions of the plates move. The stored strain energy is then released in seismic waves.

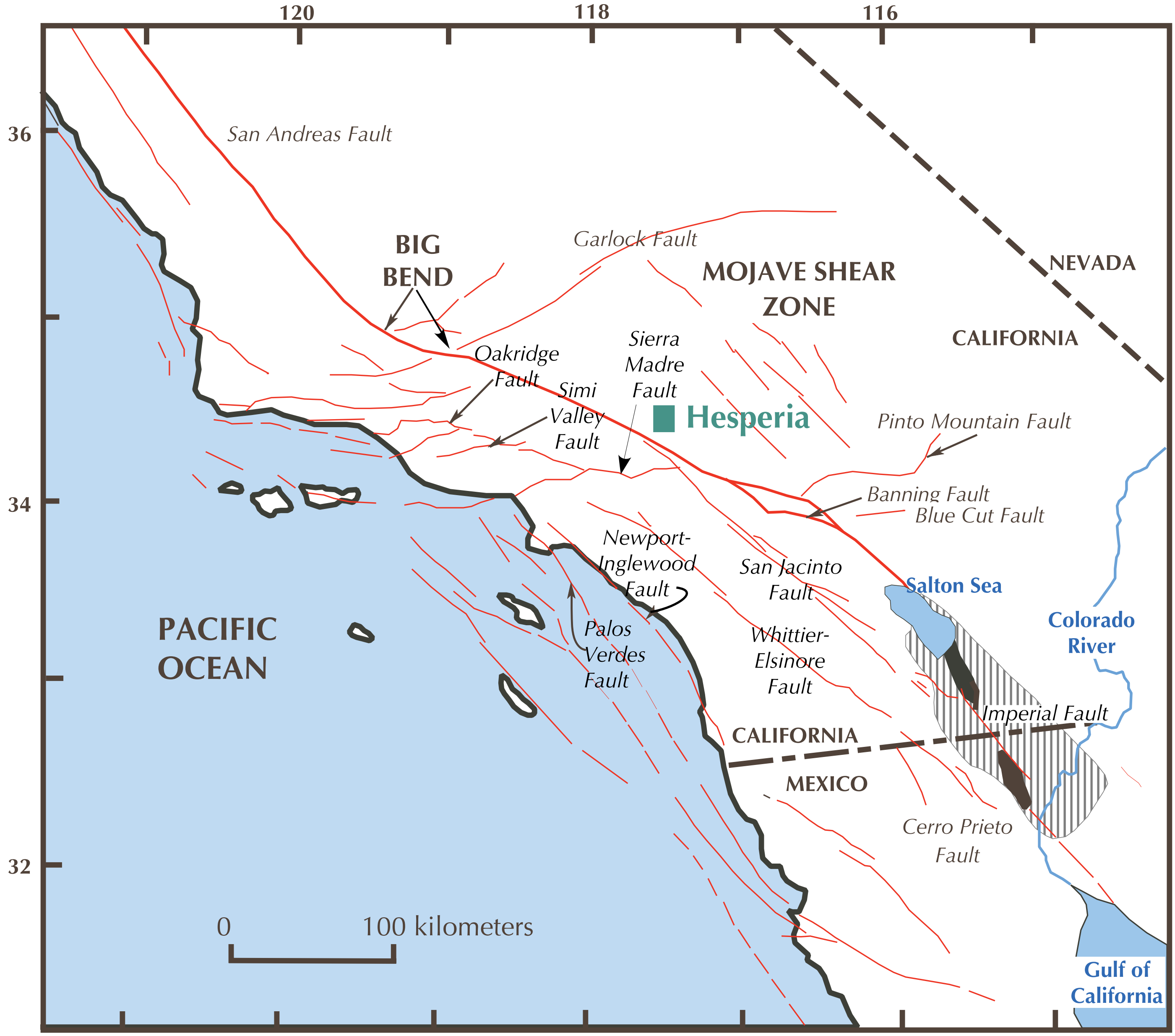
By definition, the break or fracture between moving blocks of rock is called a fault, and such differential movement produces a fault rupture. The point where the fault rupture originates is called the focus (or hypocenter). The released energy radiates out in all directions from the rupture surface causing the Earth to vibrate and shake as the waves travel through. This shaking is what we feel in an earthquake.

Although faults exist everywhere, most earthquakes occur on or near plate boundaries. Thus, southern California has many earthquakes, because it straddles the boundary between the North American and Pacific plates, and fault rupture accommodates their motion. Hesperia and most of eastern southern California are riding on the North American Plate, which is moving southeasterly (relative to the Pacific Plate), at about 50 mm/yr. This is about the rate at which fingernails grow, and seems unimpressive. However, it is enough to accumulate enormous amounts of strain energy over tens to thousands of years. Despite being locked in place most of the time, in another 15 million years (a short time in the context of the Earth's history), due to plate movements, downtown Los Angeles (which is on the Pacific Plate) will be hundreds of kilometers north of San Francisco (which like Hesperia, is mostly on the North American Plate).

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

Because the Pacific and North American plates are sliding past each other, with relative motions to the northwest and southeast, respectively, all of the faults mentioned above trend northwest-southeast, and are strike-slip faults. On average, strike-slip faults are nearly vertical breaks in the rock, and when a strike-slip fault ruptures, the rocks on either side of the fault slide horizontally past each other.

However, there is a kink in the San Andreas fault commonly referred to as the "Big Bend," located about 140 miles northwest of Hesperia (Figure 1-1). Near the Big Bend, the two plates do not slide past each other. Instead, they collide, causing localized compression, which results in folding and thrust faulting. Thrust faults meet the surface of the Earth at a low angle, dipping 25 to 35 degrees from horizontal. Thrusts are a type of dip-slip fault where rocks on opposite sides of the fault move up or down relative to each other. When a thrust fault ruptures, the top block of rock moves up and over the rock on the opposite side of the fault.



Source: Modified from Fuis and Mooney, 1990

MAP EXPLANATION

Fault

Onshore Spreading Center

New Crust (late Cenozoic)

Earth Consultants International

Project Number: 2617
Date: February 2010

Regional Fault Map

Figure 1-1

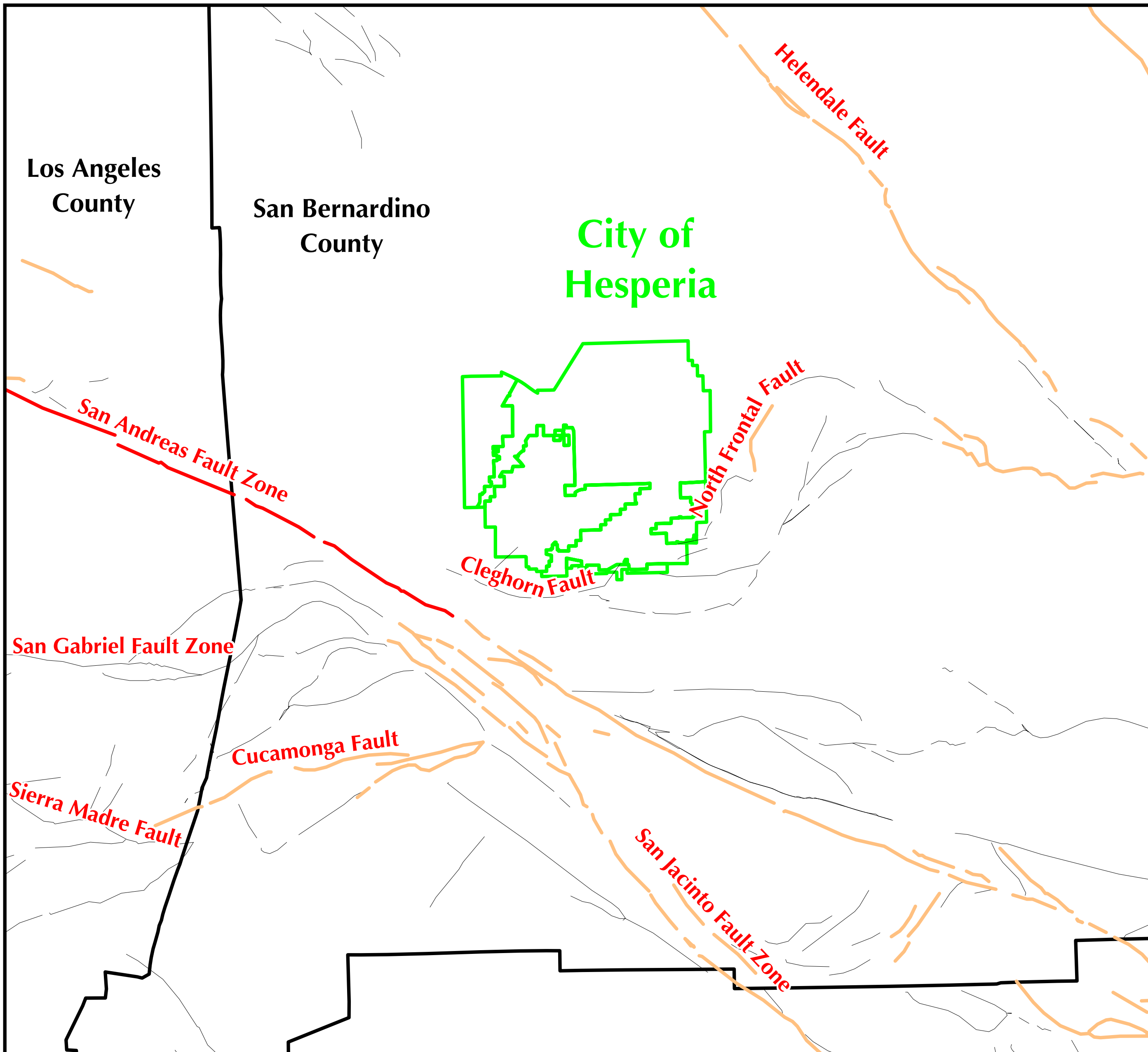
In southern California, ruptures along thrust faults have built the Transverse Ranges geologic province, a region with an east-west trend to its landforms and underlying geologic structures. This orientation is anomalous, virtually unique in the western United States, and is a direct consequence of the plates colliding at the Big Bend. Many of southern California's most recent damaging earthquakes have occurred on thrust faults that are uplifting the Transverse Ranges, including the 1971 San Fernando, the 1987 Whittier Narrows, the 1991 Sierra Madre, and the 1994 Northridge earthquakes.

Thrust faults can be particularly hazardous because many are "blind" thrust faults; that is, they do not extend to the surface of the Earth, and are therefore extremely difficult to detect before they rupture. Some of the latest earthquakes in southern California, including the 1987 Whittier Narrows earthquake and the 1994 Northridge earthquake, occurred on previously unknown blind thrust faults.

The city of Hesperia is located near the boundary between the North American and Pacific plates (on the North American side) and as a result, near the boundary of two very distinct geomorphic provinces. Specifically, the southern edge of the study area encroaches onto the Transverse Ranges Province, a region characterized by an east-west trend of its major ranges and faults. These ranges, which include the San Bernardino and San Gabriel Mountains, are "transverse" to the more common northwest-southeast trend characteristic of a large part of the southern California landscape, as defined by the San Andreas fault. North of the mountains, the greater part of Hesperia lies within the Mojave Desert Province, an arid region of alluvial fans, desert plains, dry lakebeds, and scattered mountain ranges. The east-west Garlock fault defines the northern boundary of this province, whereas the San Andreas fault defines its western boundary. Hesperia is near several seismically active earthquakes sources, including the San Andreas, North Frontal Fault, Cleghorn, Cucamonga, Helendale, and San Jacinto faults (see Figure 1-2). Of these, the San Andreas, Helendale and San Jacinto faults are predominantly right-lateral strike-slip, the North Frontal and Cucamonga faults are oblique-slip faults (thrust faults with some strike-slip component of movement), and the Cleghorn fault is a left-lateral strike-slip fault with a slightly normal component. Each of these faults, plus other regional seismic sources, will be discussed in more detail in Section 1.5.

1.2.2 Evaluating Earthquake Hazard Potential

When comparing the sizes of earthquakes, the most meaningful feature is the amount of energy released. Thus scientists most often consider seismic moment, a measure of the energy released when a fault ruptures. We are more familiar, however, with scales of magnitude, which measure amplitude of ground motion. Magnitude scales are logarithmic. Each one-point increase in magnitude represents a ten-fold increase in amplitude of the waves as measured at a specific location, and a 32-fold increase in energy. That is, a magnitude 7 earthquake produces 100 times (10 x 10) the ground motion amplitude of a magnitude 5 earthquake. Similarly, a magnitude 7 earthquake releases approximately 1,000 times more energy (32 x 32) than a magnitude 5 earthquake. Recently, scientists have developed the moment magnitude (M_w) scale to relate energy release to magnitude.



Modified from: Jennings, 1994.

Explanation

N
W E
S

0 8

Miles

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

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Local Active and Potentially Active Faults

Figure 1-2

An early measure of earthquake size still used today is the seismic intensity scale, which is a qualitative assessment of an earthquake's effects at a given location. Although it has limited scientific application, intensity is still widely used because it is intuitively clear and quick to determine. The most commonly used measure of seismic intensity is called the Modified Mercalli Intensity (MMI) scale, which has 12 damage levels (Table 1-1).

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

Few faults are simple, planar breaks in the Earth. They more often consist of smaller strands, with a similar orientation and sense of movement. A strand is mappable as a single, fairly continuous feature at a scale of about 1:24,000 (1 inch on paper represents 2,000 feet on the ground). Sometimes geologists group strands into segments, which are believed capable of rupturing together during a single earthquake. The more extensive the fault, the bigger the earthquake it can produce. Therefore, multi-strand fault ruptures produce larger earthquakes.

The bigger and closer the earthquake, the greater the damage it may generate. Thus fault dimensions and proximity are key parameters in any hazard assessment. In addition, it is important to know a fault's style of movement (i.e., is it dip-slip or strike-slip, discussed above), the age of its most recent activity, its total displacement, and its slip rate (all discussed below). These values allow an estimation of how often a fault produces damaging earthquakes, and how big an earthquake should be expected the next time the fault ruptures.

Total displacement is the length, measured in kilometers (km), of the total movement that has occurred along the fault over as long a time as the geologic record reveals. It is usually estimated by measuring distances between geologic features that have been split apart and separated (offset) by the cumulative movement of the fault over many earthquakes. Slip rate is a speed, expressed in millimeters per year (mm/yr). Slip rate is estimated by measuring an amount of offset accrued during a known amount of time, obtained by dating the ages of geologic features. Slip rate data also are used to estimate a fault's earthquake recurrence interval. Sometimes referred to as "repeat time" or "return interval", the recurrence interval represents the average amount of time that elapses between major earthquakes on a fault. The most specific way to derive the recurrence interval for a given fault is to excavate a trench across the fault to obtain paleoseismic evidence of earthquakes that have occurred during prehistoric time.

Paleoseismic studies show that faults with higher slip rates often have shorter recurrence intervals between major earthquakes. This makes sense because a high slip rate indicates rocks that, at depth, are moving relatively quickly. Thus the locked, surficial rocks are storing more strain energy, so the forces of friction will be exceeded more often, releasing the strain energy in more frequent, large earthquakes.

Table 1-1: Abridged Modified Mercalli Intensity Scale

Intensity Value and Description		Average Peak Velocity (cm/sec)	Average Peak Acceleration (g = gravity)
I.	Not felt except by a very few under especially favorable circumstances (I Rossi-Forel scale). Damage potential: None.	<0.1	<0.0017
II.	Felt only by a few persons at rest, especially on upper floors of high-rise buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale). Damage potential: None.	0.1 – 1.1	0.0017 – 0.014
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale). Damage potential: None.		
IV.	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like a heavy truck striking building. Standing automobiles rocked noticeably. (IV to V Rossi-Forel scale). Damage potential: None. Perceived shaking: Light.	1.1 – 3.4	0.014 - 0.039
V.	Felt by nearly everyone; many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale). Damage potential: Very light. Perceived shaking: Moderate.	3.4 – 8.1	0.039-0.092
VI.	Felt by all; many frightened and run outdoors. Some heavy furniture moved, few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale). Damage potential: Light. Perceived shaking: Strong.	8.1 - 16	0.092 -0.18
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (VIII Rossi-Forel scale). Damage potential: Moderate. Perceived shaking: Very strong.	16 - 31	0.18 - 0.34
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (VIII+ to IX Rossi-Forel scale). Damage potential: Moderate to heavy. Perceived shaking: Severe.	31 - 60	0.34 - 0.65
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel scale). Damage potential: Heavy. Perceived shaking: Violent.	60 - 116	0.65 – 1.24
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (X Rossi-Forel scale). Damage potential: Very heavy. Perceived shaking: Extreme.	> 116	> 1.24
XI.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.		
XII.	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.		

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

Faults have formed over millions of years, usually in response to regional stresses. Shifts in these stress regimes do occur over millennia. As a result, some faults change in character. For example, a thrust fault in a compressional environment may become a strike-slip fault in a transpressive (oblique compressional) environment. Other faults may be abandoned altogether. Consequently, the State of California, under the guidelines of the Alquist-Priolo Earthquake Fault Zoning Act of 1972 (Hart and Bryant, 1999), classifies faults according to the following criteria:

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

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

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

The Alquist-Priolo classification is used primarily for residential subdivisions. Different definitions of activity are used by other agencies or organizations depending on the type of facility being planned or developed. For example, longer periods of inactivity may be required for dams or nuclear power plants. An important subset of active faults are those with historical earthquakes. In California, that means faults that have ruptured since 1769, when the Spanish first arrived and settled in the area.

The underlying assumption in this classification system is that if a fault has not ruptured in the past 11,000 years, it is not likely to be the source of a damaging earthquake in the future. In reality, however, most potentially active faults have been insufficiently studied to determine their hazard level. Also, although simple in theory, the evidence necessary to determine whether a fault has or has not moved during the past 11,000 years can be difficult to obtain. For example, some faults leave no discernable evidence of their earthquakes, while other faults stop rupturing for millennia, and then are "reactivated" as the tectonic environment changes.

1.2.3 Causes of Earthquake Damage

Causes of earthquake damage can be categorized into three general areas: strong shaking, various types of ground failure that are a result of shaking, and ground displacement along the rupturing fault. The State definition of an active fault is designed to gauge the surface rupture potential of a fault, and is used to prevent development from being sited directly on an active fault. This helps to reduce damage from the third category. Below, the three categories are discussed in order of their likelihood to occur extensively:

1) Strong ground shaking causes the vast majority of earthquake damage. Horizontal ground acceleration is frequently responsible for widespread damage to structures, so it is commonly estimated as a percentage of g, the acceleration of gravity. Full characterization of shaking potential, though, requires estimates of peak (maximum) ground displacement and velocity, the duration of strong shaking, and the periods (lengths) of waves that will control each of these factors at a given location. We look to the recorded effects of damaging earthquakes worldwide to understand what might happen in similar environments here in the future. In general, the degree of shaking can depend upon:

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

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

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

We keep talking about periods. What do we mean? Waves repeat their motions with varying frequencies. Slow-to-repeat waves are called long-period waves. Quick-to-repeat waves are called short-period waves. Long-period seismic waves, which are created by large earthquakes, are most likely to reverberate and cause damage in long-period structures, like bridges and high-rises. ("Long-period structures" are those that respond to long-period waves.) Shorter-period seismic waves, which tend to die out quickly, will most often cause damage fairly near the fault, and they will cause most damage to shorter-period structures such as one- to three-story buildings. Very short-period waves are most likely to cause near-fault, interior damage, such as to equipment.

2) Liquefaction and slope failure are very destructive secondary effects of strong seismic shaking.

- Liquefaction typically occurs within the upper 50 feet of the surface, when saturated, loose, fine- to medium-grained soils (sand and silt) are present. Earthquake shaking suddenly increases pressure in the water that fills the pores between soil grains, causing the soil to lose strength and behave as a liquid. This process can be observed at the beach by standing on the wet sand near the surf zone. Standing still, the sand will support your weight. However, when you tap the sand with your feet, water comes to the surface, the sand liquefies, and your feet sink.

When soils liquefy, the structures built on them can sink, tilt, and suffer significant structural damage. Liquefaction-related effects include loss of bearing strength, ground oscillations, lateral spreading and flow failures or slumping. The excess water pressure is relieved by the ejection of material upward through fissures and cracks. A water-soil slurry bubbles onto the ground surface, resulting in features called "sand boils", "sand blows" or "sand volcanoes." Site-specific geotechnical studies are the only practical, reliable way to determine the liquefaction potential of a site.

- Landslides and Rockfall (Mass Wasting). Gravity inexorably pulls hillsides down and earthquake shaking enhances this on-going process. Slope stability depends on many factors and their interrelationships. Rock type and pore water pressure are arguably the most important factors, as well as slope steepness due to natural or human-made undercutting. Where slopes have failed before, they may fail again. Thus, it is essential to map existing landslides and soil slumps. Furthermore, because there are predictable relationships between local geology and the likelihood that mass wasting will occur, field investigations can be used to identify failure-prone slopes before an earthquake occurs. Combined with analyses of slope gradient, land use, and bedrock or soil materials, this information can be used to identify high-risk areas where mitigation measures would be most effective.

3) Primary ground rupture due to fault movement typically results in a relatively small percentage of the total damage in an earthquake, yet being too close to a rupturing fault can result in extensive damage. It is difficult to safely reduce the effects of this hazard through building and foundation design. Therefore, the primary mitigation measure is to avoid active faults by setting structures back from the fault zone. Application of this measure is subject to requirements of the Alquist-Priolo Earthquake Fault Zoning Act and guidelines prepared by the California Geological Survey – previously known as the California Division of Mines and Geology (CDMG Note 49). The final approval of a fault setback lies with the local reviewing agency.

Earthquake damage also depends on the characteristics of human-made structures. The interaction of ground motion with the built environment is complex. Governing factors include a structure's height, construction, and stiffness, which determine the structure's resonant period; the underlying soil's strength and resonant period; and the periods of the incoming seismic waves. Other factors include architectural design, condition, and age of the structure.

1.2.4 Choosing Earthquakes for Planning and Design

It is often useful to create a deterministic or design earthquake scenario to study the effects of a particular earthquake on a building or a community. Often, such scenarios consider the largest earthquake that is believed possible to occur on a fault or fault segment, referred to as the maximum magnitude earthquake (M_{max}). Other scenarios that have been used considered the Maximum Probable Earthquake (M_{PE}) or Design Basis Earthquake (DBE) (1997 Uniform Building Code – UBC; 2001 California Building Code - CBC). The DBE is defined as the earthquake with a statistical return period of 475 years (with ground motion that has a 10% probability of being exceeded in 50 years). The 2001 edition of the California Building Code (California Building Standards Commission - CBSC, 2001) used for public schools, hospitals, and other critical facilities the Upper Bound Earthquake (UBE), which has a statistical return period of 949 years and a ground motion with a 10% probability of being exceeded in 100 years. Seismic design parameters in the most recent version of the California Building Code (2007 edition) are based on the Maximum Considered Earthquake (MCE), with a ground motion that has a 2% probability of being exceeded in 50 years and a recurrence interval of about 2,500 years. [Seismic design parameters define what kinds of earthquake effects a structure must be able to withstand. These include peak ground acceleration, duration of strong shaking, and the periods of incoming strong motion waves.] As the descriptions above suggest, building codes have selected different earthquake scenario depending on the application, such as the planned use, lifetime or importance of a facility. Traditionally, the more critical the structure, the longer the time period used between earthquakes and the larger the design earthquake that has been used.

Geologists, seismologists, engineers, emergency response personnel and urban planners typically use maximum magnitude and maximum probable earthquakes to evaluate seismic hazard. The assumption is that if we plan for the worst-case scenario, we establish safety margins. Then smaller earthquakes that are more likely to occur can be dealt with effectively.

As is true for most earthquake-prone regions, many potential earthquake sources pose a threat to Hesperia. Thus, it is also important to consider the overall likelihood of damage from a plausible suite of earthquakes. This approach is called probabilistic seismic hazard analysis (PSHA), and typically considers the likelihood of exceeding a certain level of damaging ground motion that could be produced by any or all faults within a 62-mile (100-km) radius of the project site, or in this case, the city. PSHA has been utilized by the U.S. Geological Survey to produce national seismic hazard maps such as those used by the Uniform Building Code (ICBO, 1997), the International Building Code (ICC, 2006) and the California Building Code (CBSC, 2007).

Regardless of which fault causes a damaging earthquake, there will always be aftershocks. By definition, these are smaller earthquakes that happen close to the mainshock (the biggest earthquake of the sequence) in time and space. These smaller earthquakes occur as the Earth adjusts to the regional stress changes created by the mainshock. As the size of the mainshock increases, there typically is a corresponding increase in the number of aftershocks, the size of the aftershocks, and the size of the area in which they might occur.

On average, the largest aftershock will be 1.2 magnitude units less than the mainshock. Thus, a M_W 6.9 earthquake will tend to produce aftershocks up to M_W 5.7 in size. This is an average, and there are many cases where the biggest aftershock is larger than the average predicts. The key point is this: any major earthquake will produce aftershocks large enough to cause additional damage, especially to already-weakened structures.

Consequently, post-disaster response planning must take damaging aftershocks into account.

1.3 Laws To Mitigate Earthquake Hazard

1.3.1 Alquist-Priolo Earthquake Fault Zoning Act

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

The Act requires the State Geologist (Chief of the California Geological Survey) to delineate "Earthquake Fault Zones" along faults that are "sufficiently active" and "well defined." These faults show evidence of Holocene surface displacement along one or more or their segments (sufficiently active) and are clearly detectable by a trained geologist as a physical feature at or just below the ground surface (well defined). The boundary of an "Earthquake Fault Zone" is generally about 500 feet from major active faults, and 200 to 300 feet from well-defined minor faults. The Act dictates that cities and counties withhold development permits for sites within an Earthquake Fault Zone until geologic investigations demonstrate that the sites are not threatened by surface displacements from future faulting (Hart and Bryant, 1999).

Alquist-Priolo maps are distributed to all affected cities and counties for their use in planning and controlling new or renewed construction. Local agencies must regulate most development projects within the zones. Projects include all land divisions and most structures for human occupancy. State law exempts single-family wood-frame and steel-frame dwellings that are less than three stories and are not part of a development of four units or more. However, local agencies can be more restrictive than State law requires. There are currently no Alquist-Priolo Earthquake Fault Zones mapped within Hesperia's city limits. The closest Alquist-Priolo Earthquake Fault Zones to Hesperia include that on the North Frontal fault less than 2 miles to the east, and the San Andreas fault to the south (see Plate 1-2). Other faults closer to the city that have not been zoned are associated with the Cleghorn fault zone. Of these, a few fault traces have been mapped just inside the city's southern and eastern boundaries. Another fault trace has been mapped near the city's western boundary, and within its Sphere of Influence (see Plate 1-2). The recency of activity of these faults, and their future surface fault rupture hazard potential are discussed further in Section 1.6.1 below.

1.3.2 Seismic Hazards Mapping Act

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

The CGS, pursuant to the 1990 SHMA, has been releasing seismic hazards maps since 1997, with emphasis on the large metropolitan areas of Los Angeles, Orange and Ventura counties (funding for this program limits the geographic scope of this studies to these three counties in southern California). As a result, at this time, there are no State-issued (and therefore official) seismic hazard zone maps for the city of Hesperia. Nevertheless, the methodology that the CGS uses to prepare these maps is well documented, and can be duplicated in areas that the CGS has yet to map. To that end, and for the purposes of this study, we have followed a simplified version of the CGS methodology to identify areas in the city of Hesperia that are susceptible to liquefaction. The methodology used and the resulting analysis of liquefaction susceptibility in the city of Hesperia are described in more detail in Section 1.7.1.

1.3.3 Real Estate Disclosure Requirements

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

California State law also requires that when houses built before 1960 are sold, the seller must give the buyer a completed earthquake hazards disclosure report, and a copy of the booklet entitled "The Homeowner's Guide to Earthquake Safety." This publication was written and adopted by the California Seismic Safety Commission. The most recent edition of this booklet is available from the web at www.seismic.ca.gov/. The booklet contains a sample of a residential earthquake hazards report that buyers are required to fill in, and it provides specific information on common structural weaknesses that can fail, damaging homes during earthquakes. The booklet further describes specific actions that can be taken by homeowners to strengthen their homes.

The Alquist-Priolo Earthquake Fault Zoning Act and the Seismic Hazards Mapping Act also require that real estate agents, or sellers of real estate acting without an agent, disclose to prospective buyers that the property is located in an Earthquake Fault or Seismic Hazard Zone. There are currently no official Alquist-Priolo or Seismic Hazard maps for Hesperia, but areas of the city impacted by natural hazards, as described in this document, should be disclosed to prospective buyers, following the provisions of the Natural Hazards Disclosure Act.

1.3.4 California Environmental Quality Act

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

1.3.5 Uniform Building Code and California Building Code

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

Then, in 1994, to further the concept of uniformity in building design, the ICBO joined with the two other national building code publishers, the Building Officials and Code Administrators International, Inc. (BOCA) and the Southern Building Code Congress International, Inc. (SBCCI), to form a single organization, the International Code Council, (ICC). In the year 2000, the group published the first International Building Code (IBC) as well as an entire family of codes, (i.e. building, mechanical, plumbing and fire) that were coordinated with each other. As a result, the last (and final) version of the UBC was issued in 1997. After the formation of the ICC and the publication of the IBC, the California legislature did not address the matter of updating the CBC with a building code other than the UBC. In fact, the California Building Standards Commission, after careful review of the 2000 IBC, chose not to use the IBC, but instead continued to adopt the old 1997 UBC for the CBC. The 2001 CBC (based on the 1997 UBC) was used throughout the State from

2001 to 2007, often with local, more restrictive amendments based upon local geographic, topographic or climatic conditions.

In 2003, California considered adopting the National Fire Protection Association (NFPA) 5000 building code as the State's next building code. Specifically, on July 29, 2003, the California Building Standards Commission recommended adoption of the NFPA 5000 code as the basis for California's next building code. However, state agencies that reviewed the proposed building code found it to be incomplete, requiring the adoption of substantial amendments, many transcribed directly from the 1997 CBC, to bring it to the level provided by the 2001 CBC. For this and other reasons, including the cost of developing the amendments and training state, county and city officials responsible for the enforcement of the code, on March 8, 2005, the Coordinating Council of the California Building Standards Commission recommended rescission of the 2003 decision to adopt the NFPA 5000, and instead recommended adoption of the latest International Building Code (IBC) as the basis for the next CBC. Thus, the California Building Standards Commission (BSC) reviewed the 2006 IBC, and using the IBC as a basis, prepared the 2007 edition of the CBC. This latest building code became available to the public on July 1, 2007, and became effective on January 1, 2008. [The 2010 California Building Code will become available later this year, and should become effective on January 2011. For more recent information regarding the latest building code, refer to the California Building Standards Commission website at www.bsc.ca.gov/].

It should be emphasized that the building codes provide <u>minimum</u> requirements. In some cases these requirements may not be adequate, particularly in the areas of faulting and seismology, where the pool of knowledge is rapidly growing and evolving. Consequently, it is important that geotechnical consultants working in the city, as well as reviewers of their work, keep up to date on current research.

1.3.6 Unreinforced Masonry Law

Enacted in 1986, the Unreinforced Masonry Law (Section 8875 et seq. of the California Government Code) required all cities and counties in Seismic Zone 4 (zones near historically active faults, per the building code at the time) to identify potentially hazardous unreinforced masonry (URM) buildings in their jurisdictions, establish a URM loss reduction program, and report their progress to the State by 1990. The owners of such buildings were to be notified of the potential earthquake hazard these buildings pose. Some jurisdictions did implement mandatory retrofit programs, while others established voluntary programs. A few cities only notified the building owners, but did not adopt any type of strengthening program. Since 1997, California has required all jurisdictions to enforce the 1997 Uniform Code for Building Conservation (UCBC) Appendix Chapter 1 as the model building code, although local governments may adopt amendments to that code under certain circumstances (ICBC, 2001; SSC, 2006). The UCBC standards are meant to significantly reduce but not necessarily eliminate the risk to life from collapse of the structure. Prior to 1997, local governments could adopt other building standards that preceded the UCBC, and in fact, in many jurisdictions, retrofits were conducted in accordance with local ordinances that may only partially comply with the latest UCBC. The 2007 California Building Code (CBC) includes building standards for historical buildings (2007 California Historical Building Code, Part 8 of Title 24), and building standards for existing buildings (2007 California Existing Building Code, Part 10 of Title 24, based on the 2006 International Existing Building Code).

The Hesperia area is located near historically active faults. Therefore, and in compliance with the Unreinforced Masonry Law, the City inventoried the URMs in its jurisdiction. In the year 2003, Hesperia reported to the Seismic Safety Commission that only one URM building (the old school house) has been identified in the city, and that this building is of historical significance but has not been officially designated as such. The owner of this building has been notified of the hazards associated with this type of construction, and the need to mitigate the URM to be at least in compliance with the State Historical Building Code. According to the 2003 report by the Seismic Safety Commission, Hesperia was considering the implementation of a Historical Structure/Site Ordinance. Ordinance 77, Historic Structure/Site Ordinance has since been adopted (Dave Reno, Principal Planner, Cit of Hesperia, personal communication, November 12, 2009). This ordinance establishes the procedure by which a structure of historical significance would be retrofitted. Since the old school house, however, has not been officially designated a historical structure by City Council, Ordinance 77 at this time does not apply to this building.

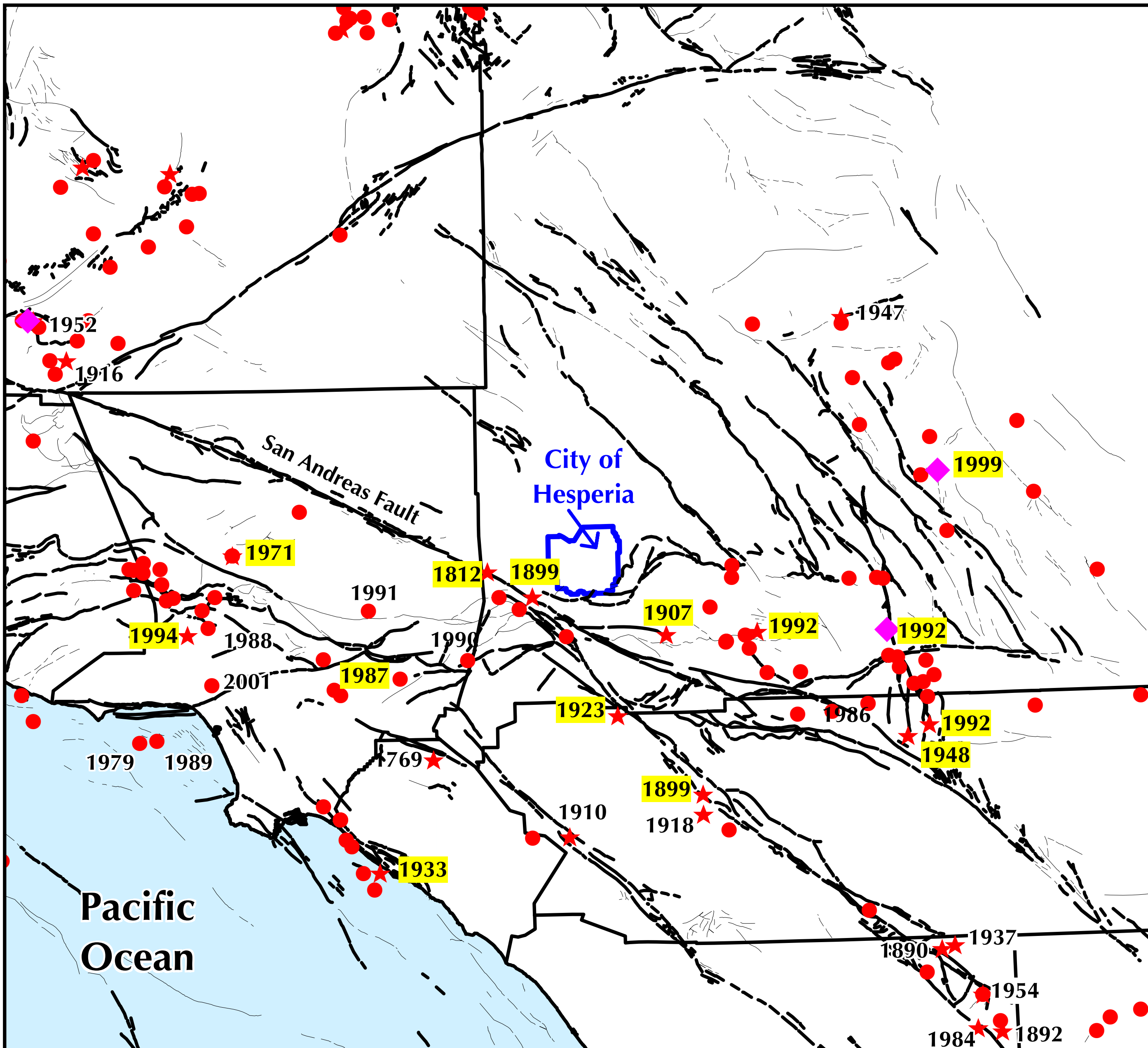
1.4 Notable Earthquakes in the Hesperia Area

Figure 1-3 shows the approximate epicenters of some of the earthquakes that have resulted in significant ground shaking in the southern California area, including Hesperia, since before the 1800s. The most significant of these events are described below. Plate 1-1 shows the approximate epicentral locations of earthquakes in and around the city instrumentally detected between 1932 and 2006. Earlier earthquakes are not shown since prior to 1932 there were no instruments available to measure the location and magnitude of an earthquake. The map shows that only a few small earthquakes have been reported in Hesperia with most seismic activity in the area occurring to the south, most likely associated with the Cleghorn fault and the San Andreas fault zones.

1.4.1 Wrightwood Earthquake of December 8, 1812

This large earthquake occurred on December 8, 1812 and was felt throughout southern California. Based on accounts of damage recorded at missions in the earthquake-affected area, an estimated magnitude of 7.5 has been calculated for the event (Toppozada et al., 1981). Subsurface investigations and tree ring studies show that the earthquake likely ruptured the Mojave section of the San Andreas fault near Wrightwood, and may have been accompanied by a significant surface rupture between Cajon Pass and Tejon Pass (Jacoby, Sheppard and Sieh, 1988). The worst reported damage caused by the earthquake occurred significantly west of the San Andreas fault at San Juan Capistrano Mission, where the roof of the church collapsed, killing 40 people. The earthquake also damaged walls and destroyed statues at San Gabriel Mission and damaged missions in the Santa Barbara area. Strong aftershocks caused earthquake-damaged buildings to collapse for several days after the mainshock.

This earthquake would have been felt strongly in the Hesperia area, with peak ground accelerations estimated at about 0.16g to 0.2g.



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

N
W E
S

0 20
Miles

Explanation

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

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Regional Seismicity Map

Figure 1-3

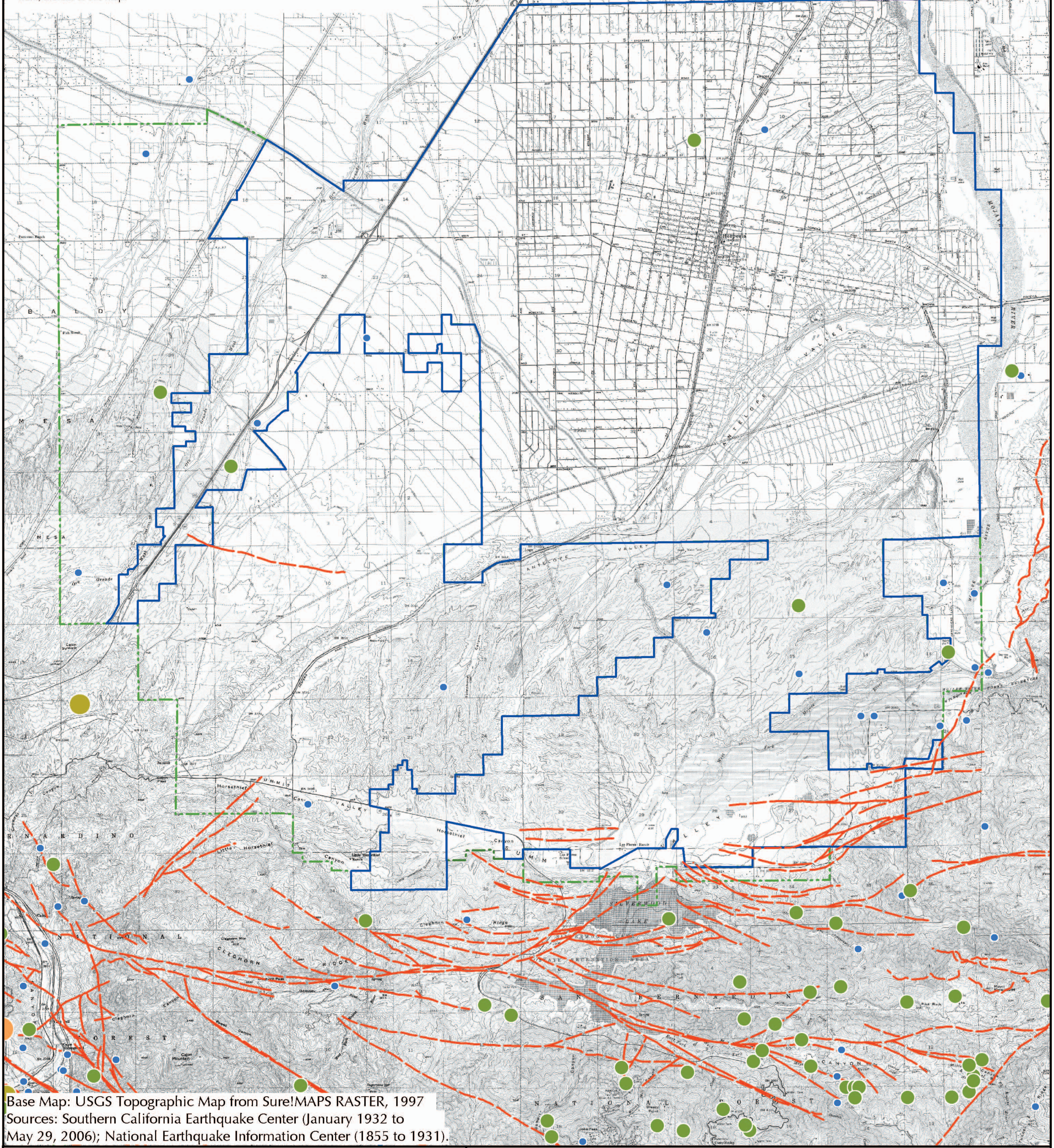
NOTES:

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

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

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

Earth Consultants International (ECI) makes no representations or warranties regarding the accuracy of the data from which these maps were derived. ECI shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to any claim by any user or third party on account of, or arising from, the use of this map.



Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Sources: Southern California Earthquake Center (January 1932 to May 29, 2006); National Earthquake Information Center (1855 to 1931).

N
W E
S

0 7000 14000 Feet

0 2000 4000 Meters

Scale: 1:84,000

Explanation

Earthquake Magnitude

- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- <2

- Fault or lineament, solid where location known, dashed where approximate, dotted where inferred (for more information refer to Plate 1-2)
- Hesperia City Limit
- Hesperia Sphere of Influence

Earth Consultants International

Project Number: 2617
Date: February 2010

Historical Seismicity Map (1932-2006)

Hesperia, California

Plate 1-1

1.4.2 Unnamed Earthquake of 1855

This earthquake occurred on July 11, 1855 and was felt across southern California from Santa Barbara to San Bernardino. Light to moderate damage was reported in the Los Angeles area, where 26 houses experienced cracked walls and the bell tower of the San Gabriel Mission was knocked down (www.sfmuseum.org/alm/quakeso.html). Because damage was limited primarily to the Los Angeles area, this earthquake is thought to have occurred on a local fault such as the Hollywood-Raymond, Whittier or Newport-Inglewood faults, or on one of the many blind thrust faults that underlie the area.

1.4.3 Cajon Pass Earthquake of 1899

This earthquake occurred on July 22, 1899 at 12:32 P.M., Pacific Standard Time (PST). The epicenter of this earthquake was roughly located 15 miles northwest of San Bernardino, and about 13 miles from Hesperia (see Figure 1-3). The earthquake is thought to have had a local magnitude (M_L) of between 5.7 and 6.5, although these are estimates only, as there were no instruments to measure the size of an earthquake at that time. The tremor was reportedly felt throughout southern California, with some areas in the Lytle Creek and Cajon Pass reporting intensities as high as VIII or IX in the Rossi Intensity Scale (Rossi-Forel equivalents to the Modified Mercalli intensity scale are shown on Table 1-1). Given its location, the earthquake may have been caused by either the San Andreas or San Jacinto faults. The strong ground shaking caused extensive landsliding in the epicentral region; landslides blocked both the Lytle Creek Canyon Road and the road through Cajon Pass (Townley, 1939). Buildings in San Bernardino, Highland and Patton reportedly suffered extensive damage; buildings in Redlands, Pomona, and Riverside suffered some damage; minor damage was reported as far away as in Los Angeles and Pasadena. The earthquake apparently did not cause any fatalities.

1.4.4 San Jacinto Earthquake of 1899

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

1.4.5 San Bernardino Earthquake of 1907

An earthquake of magnitude 5.4 (approximately) occurred on September 20, 1907 at 1:54 A.M. PST in the San Bernardino area, to the southeast of Hesperia. This tremor probably did not cause any significant damage in the area, as there is very little information on it.

1.4.6 North San Jacinto Fault Earthquake of 1923

This earthquake occurred about 7 miles south of San Bernardino on July 22, 1923, at 11:28

P.M. PST. The M_L 6.3 earthquake on the San Jacinto fault caused minor damage primarily in the cities of San Bernardino and Redlands, where chimneys collapsed and windows broke. Two public buildings in San Bernardino, the San Bernardino County Hospital and the Hall of Records, were badly damaged, and extensive damage was sustained by the State Hospital building in Patton. However, most of the buildings that sustained damage were deemed of poor construction. Slight damage was reported in Los Angeles. Two people were critically injured, but no deaths were reported. The shaking was felt as far away as Needles and Santa Barbara.

1.4.7 Long Beach Earthquake of 1933

The M_w 6.4 Long Beach earthquake occurred on March 10, at 5:54 P.M. PST, following a strong foreshock the day before. The earthquake ruptured the Newport-Inglewood fault, and was felt from the San Joaquin Valley to Northern Baja. The epicenter was located on the boundary between Huntington Beach and Newport Beach, although the earthquake was called "the Long Beach earthquake" because the worst damage was focused in the city of Long Beach. In the Hesperia area, the earthquake is estimated to have produced Modified Mercalli Intensities of about IV (http://pasadena.wr.usgs.gov/shake/ca/STORE/XLong_Beach/ciim_display.html).

The earthquake killed 115 people and caused $40-50 million in property damage (www.scecdc.scec.org/quakedex.html). Primary ground rupture of the Newport-Inglewood fault was not observed, although secondary cracking, minor slumping, and lateral movement of unconsolidated sediments occurred throughout the region. Road surfaces along the shore between Long Beach and Newport Beach were damaged by settlement of road fills that had been placed on marshy land. In urban areas, unreinforced masonry buildings were most severely damaged, especially in areas of artificial fill or water-soaked alluvium. In one part of Compton, most buildings built on unconsolidated sediments and artificial fill were destroyed. In Long Beach, many buildings collapsed, were pushed off their foundations, or had walls or chimneys knocked down. In Newport Beach, 800 chimneys were knocked down at the roofline and hundreds of houses were destroyed (www.anaheimcocom.com/quake.htm). Many strong aftershocks occurred through March 16th.

The regional significance of this earthquake is that damage to school buildings was especially severe, which led to the passage of the Field and Riley Acts by the State legislature. The Field Act regulates school construction and the Riley Act regulates the construction of buildings larger than two-family dwellings.

1.4.8 Desert Hot Springs Earthquake of 1948

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

1.4.9 San Fernando (Sylmar) Earthquake of 1971

This magnitude 6.6 earthquake occurred on the San Fernando fault zone, the westernmost segment of the Sierra Madre fault, on February 9, 1971, at 6:00 in the morning local time. The surface rupture caused by this earthquake was nearly 12 miles long, and occurred in the Sylmar-San Fernando area, approximately 60 miles (100 km) from Hesperia. The maximum slip measured at the surface was nearly six feet. The earthquake caused over $500 million in property damage and 65 deaths. Most of the deaths occurred when the Veteran's Administration Hospital collapsed. Several other hospitals, including the Olive View Community Hospital in Sylmar suffered severe damage. Newly constructed freeway overpasses also collapsed, in damage scenes similar to those that occurred 23 years later in the 1994 Northridge earthquake. Loss of life could have been much greater had the earthquake struck at a busier time of the day. As with the Long Beach earthquake, legislation was passed in response to the damage caused by the 1971 earthquake. In this case, the building codes were strengthened and the Alquist-Priolo Special Studies (now call the Earthquake Fault Zone) Act was passed in 1972.

1.4.10 Whittier Narrows Earthquake of 1987

The Whittier Narrows earthquake occurred on October 1, 1987, at 7:42 in the morning local time, with its epicenter located approximately 50 miles (80 km) from Hesperia (Hauksson and Jones, 1989). This magnitude 5.9 earthquake occurred on a previously unknown, north-dipping concealed thrust fault (blind thrust) now called the Puente Hills fault (Shaw and Shearer, 1999). The earthquake caused eight fatalities, over 900 injured, and $358 million in property damage. Severe damage was confined mainly to communities east of Los Angeles and near the epicenter. Areas with high concentrations of URMs, such as the "uptown" district of Whittier, the old downtown section of Alhambra, and the "Old Town" section of Pasadena, were severely impacted. Several tilt-up buildings partially collapsed, including tilt-up buildings built after 1971, that were constructed to meet improved building standards, but were of irregular configuration, revealing seismic vulnerabilities not previously recognized. Residences that sustained damage usually were constructed of masonry, were not fully anchored to their foundations, or were houses built over garages with large openings. Many chimneys collapsed and in some cases, fell through roofs. Wood-frame residences, in contrast, sustained relatively little damage, and no severe structural damage to high-rise structures in downtown Los Angeles was reported.

1.4.11 Joshua Tree Earthquake of 1992

This magnitude 6.1 earthquake struck on April 22, 1992 at 9:50 P.M. PDT, approximately 15 miles north of Palm Desert. This event resulted from right-lateral strike-slip faulting and was preceded by a magnitude 4.6 foreshock. The Joshua Tree earthquake raised some alarms due to its proximity to the San Andreas fault. A San Andreas Hazard Level B was declared following this quake, meaning that the San Andreas fault was given a 5 to 25% chance of generating an even larger earthquake within 3 days. Roughly two months and 6,000 aftershocks later, the Landers earthquake broke the surface of the Mojave Desert in the largest quake to hit southern California in 40 years, showing that the concern caused by the Joshua Tree earthquake was at least partially warranted. The aftershocks of the Joshua Tree quake suggested that the fault that slipped in the shock is a north to northwest-trending, right-lateral strike-slip fault at least 15 km long (Jones and others, 1995). Based on these data, and the location of the shocks, researchers suggest that the Eureka Peak fault may have been the fault responsible for this earthquake.

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

1.4.12 Landers Earthquake of 1992

On the morning of June 28, 1992, most people in southern California were awakened at 4:57 by the largest earthquake to strike California in 40 years. Named "Landers" after the small desert community near its epicenter, the earthquake had a magnitude of 7.3. More than 50 miles of surface rupture associated with five or more faults occurred as a result of this earthquake. The average right-lateral strike-slip displacement was about 10 to 15 feet; the maximum was up to 18 feet. Centered in the Mojave Desert, approximately 120 miles from Los Angeles, the earthquake caused relatively little damage for its size (Brewer, 1992). It released about four times as much energy as the very destructive Loma Prieta earthquake of 1989, but fortunately, it did not claim as many lives (one child died when a chimney collapsed). The power of the earthquake was illustrated by the length of the ground rupture it left behind. The earthquake ruptured five separate faults: Johnson Valley, Landers, Homestead Valley, Emerson, and Camp Rock faults (Sieh and others, 1993). Other nearby faults also experienced triggered slip and minor surface rupture. Seismic intensities of level VI were reported in the Hesperia area (http://pasadena.wr.usgs.gov/shake/ca/STORE/XLanders/ciim_display.html).

1.4.13 Big Bear Earthquake of 1992

This magnitude 6.4 earthquake struck little more than 3 hours after the Landers earthquake on June 28, 1992 at 8:05:30 A.M. PDT. This earthquake is technically considered an aftershock of the Landers earthquake (indeed, the largest aftershock), although the Big Bear earthquake occurred over 20 miles west of the Landers rupture, on a fault with a different orientation and sense of slip than those involved in the main shock. From its aftershocks, the causative fault was determined to be a northeast-trending left-lateral fault. This orientation and slip are considered "conjugate" to the faults that slipped in the Landers rupture. The Big Bear earthquake did not break the ground surface, and, in fact, no surface trace of a fault with the proper orientation has been found in the area. The Big Bear earthquake caused a substantial amount of damage in the Big Bear area, but fortunately, it claimed no lives. However, landslides triggered by the quake blocked roads in the mountainous areas, aggravating the clean-up and rebuilding process (SCEC-DC, 2001).

1.4.14 Northridge Earthquake of 1994

On the morning of January 17th, 1994, at 4:31 PST, a M_w 6.7 earthquake struck the San Fernando Valley. This moderate-sized tremor was the most expensive earthquake in United States history, due primarily to its proximity to the heavily populated northern Los Angeles area. The rupture occurred in the San Fernando Valley on the previously unidentified eastern continuation of the Oak Ridge fault, which is a blind thrust fault and thus does not break the surface. The earthquake produced widespread ground accelerations of 1.0 g, some of the highest ever recorded for an earthquake of its size. The earthquake caused 57 deaths, 1,500 injuries and damaged 12,500 structures, knocking out of commission several major freeways for days to months. Although most damage was focused in the northern Los Angeles area, intensities of level VI (Table 1-1) were recorded in the Hesperia area.

1.4.15 Hector Mine Earthquake of 1999

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

1.5 Potential Sources of Seismic Ground Shaking

Seismic shaking is the geologic hazard that has the greatest potential to severely impact the Hesperia area, given that the city is located near several significant seismic sources (faults) that have the potential to cause moderate to large earthquakes (see Table 1-2). As discussed in Section 1.4 above, some of these faults caused moderate-sized earthquakes in the last century; however, given their length, many are thought capable of generating even larger earthquakes in the future that would cause strong ground shaking in Hesperia and nearby communities. The proximity of Hesperia to many regionally significant seismic sources should encourage City officials to diligently attend to seismic hazard mitigation.

In order to provide a better understanding of the shaking hazard posed by these faults, we conducted a deterministic seismic hazard analysis for City Hall and several other randomly selected points in the city using the software program EQFAULT by Blake (2000). This analysis estimates the Peak Horizontal Ground Accelerations (PHGA) that could be expected at these locations due to earthquakes occurring on any of the known active or potentially active faults within about 62 miles (100 km). The fault database (including fault locations and earthquake magnitudes of the maximum magnitude earthquakes for each fault) used to conduct these seismic shaking analyses is that used by the California Geological Survey (CGS) and the U.S. Geological Survey (USGS) for the National Seismic Hazard Maps (Peterson and others, 1996; Cao et al., 2003). However, as described further in the text, recent paleoseismic studies suggest that some of these faults may actually generate even larger earthquakes than those used in the analysis. Where appropriate, this is discussed further below.

PGHA depends on the size of the earthquake, the proximity of the rupturing fault, and local soil conditions. Effects of soil conditions are estimated by use of an attenuation relationship derived empirically from an analysis of recordings of earthquake shaking in similar soils during earthquakes of various sizes and distances. Given that most of the developed portion of Hesperia is underlain by semi-consolidated and unconsolidated soft sediments, we used alluvium for the deterministic analyses conducted for this study, and the attenuation relationship of Campbell and Bozorgnia (2000).

Based on the ground shaking analyses described above, those faults that can cause peak horizontal ground accelerations of about 0.1g or greater (Modified Mercalli Intensities greater than VII) in the Hesperia area are listed in Table 1-2. For a map showing most of these faults, refer to Figures 1-1 and 1-3. Those faults included in Table 1-2 that have the greatest impact on the Hesperia area, or that are thought to have a higher probability of causing an earthquake, are described in more detail in the following pages. The locations of active faults near the city are shown on Figure 1-3 and on Plate 1-2 (for those faults through or immediately adjacent to the city). The deterministic analyses indicate that should the North Frontal, San Andreas, or Cleghorn fault rupture, PGHA values of as much as 0.5g could be experienced in Hesperia. Shaking at these levels can cause significant damage to older structures, and moderate damage to even newer buildings constructed in accordance with the latest building code provisions.

Table 1-2 shows:

- The approximate distance, in miles and kilometers, between the fault and various points in the city of Hesperia;
- The maximum magnitude earthquake (M_{max}) each fault is estimated capable of generating;
- The peak ground accelerations (PGA), or intensity of ground motion expressed as a fraction of the acceleration of gravity (g), that could be experienced in different areas of the city of Hesperia if the M_{max} occurs on the faults listed; and
- The Modified Mercalli seismic Intensity (MMI) values calculated for various parts in the city.

The peak ground accelerations and intensities summarized in Table 1-2 are shown from largest to lowest for each fault; these should be considered as average values, since different areas of the city are expected to feel and respond to each earthquake differently in response to site-specific conditions. In general, peak ground accelerations and seismic intensity values decrease with increasing distance away from the causative fault. However, local site conditions, such as deep basins or reflection off of hard rock forming the San Bernardino Mountains to the south can amplify the seismic waves generated by an earthquake, resulting in localized higher accelerations than those listed here. Please note that the PHGA analyses conducted for this study provide a general indication of relative earthquake risk throughout the city of Hesperia. For individual projects however, site-specific analyses that consider the precise distance from a given site to the various faults in the region, as well as the local near-surface soil types, should be conducted. These site-specific analyses should also consider the degree of amplification that could be provided by the soft sediments that underlie the study area.

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

Fault Name	Distance to Hesperia β (mi)	Distance to Hesperia β (km)	Magnitude of M_{max}*	PGA (g) from M_{max}	MMI from M_{max}
North Frontal Fault (West)	2 – 14.5	3.2 – 23	7.2	0.58 – 0.23	X - IX
San Andreas (Whole Southern)	4 – 16.5	6.5 – 26.5	8.0	0.49– 0.34	X - IX
San Andreas (San Bernardino – Coachella)	4 – 16.5	6.5 – 26.5	7.7	0.47 – 0.29	X - IX
San Andreas (1857 Rupture or Cholame – Mojave)	7 – 17.5	11 – 28	7.8	0.46 – 0.3	X - IX
San Andreas (San Bernardino)	5.5 – 16.5	9.5 – 26.5	7.5	0.45 – 0.26	IX
Cleghorn	3 – 12	5 – 19.5	6.5	0.42 – 0.18	X- VIII
San Andreas (Mojave)	7 – 17.5	11 – 28	7.4	0.42 – 0.23	X- IX
Cucamonga	9 – 19	14.5 - 30.5	6.9	0.35 – 0.16	IX - VIII
Helendale – South Lockhart	13 - 24	21 - 38	7.3	0.27 – 0.16	IX - VIII
San Jacinto (San Bernardino)	9 - 20	14.5 - 32	6.7	0.26 – 0.12	IX - VII
Sierra Madre	20 –29	32 – 47.5	7.2	0.18 – 0.12	VIII - VII
Lenwood – Lockhart – Old Woman Springs	28 – 39	45 – 62.5	7.5	0.15 – 0.10	VIII- VII
San Jacinto (San Jacinto Valley)	23 – 31.5	37.5 - 50	6.9	0.11 – 0.08	VII

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

In addition to the ground shaking values calculated using a deterministic analysis, we also ran the interactive ground motion module from the California Geological Survey (http://www.consrv.ca.gov/CGS/rghm/pshamap/pshamap.asp) to estimate the ground motions at Hesperia's City Hall that have a 10% probability of being exceeded in 50 years. [Unlike deterministic analyses that consider the largest possible earthquake that each of the known faults in the area is thought capable of producing, probabilistic analyses consider the likelihood of exceeding a certain level of damaging ground motion that could be produced by any or all faults within 62 miles (100 km).] For Hesperia, the level of ground motion estimated to have a 10% probability of being exceeded in 50 years is 0.47g, using alluvium as the underlying material. This level of ground motion is consistent with the results of the deterministic analyses, and indicates that many of the faults near Hesperia have high earthquake recurrence rates. As discussed above, these levels of shaking are in the moderate to high range for southern California, and can be expected to cause damage, particularly to older and/or poorly constructed buildings.

Another way to communicate the seismic shaking hazard is by the use of ShakeMaps. A ShakeMap is a representation of the various levels of ground shaking throughout the region where an earthquake occurs. ShakeMaps are compiled from the California Integrated Seismic Network (CISN) – a network of seismic recording instruments placed throughout the state, and are automatically generated following moderate to large earthquakes. Preliminary real-time maps are posted within minutes on the Internet (http://earthquake.usgs.gov/eqcenter/shakemap/) giving disaster response personnel an immediate picture of where the most damage is likely to be.

Although several shaking parameters can be illustrated on ShakeMaps, such as peak acceleration and peak velocity, most people can relate more easily to maps illustrating the *intensity* of ground shaking. Intensity is a qualitative assessment of an earthquake's effect at a given location based on how it felt to those that experienced it and how much damage it caused (see Section 1.2.2). Using actual instrumental ground motion recordings and comparing them to observed Modified Mercalli Intensities from recent California earthquakes, scientists can now estimate shaking intensities within a few minutes after an earthquake.

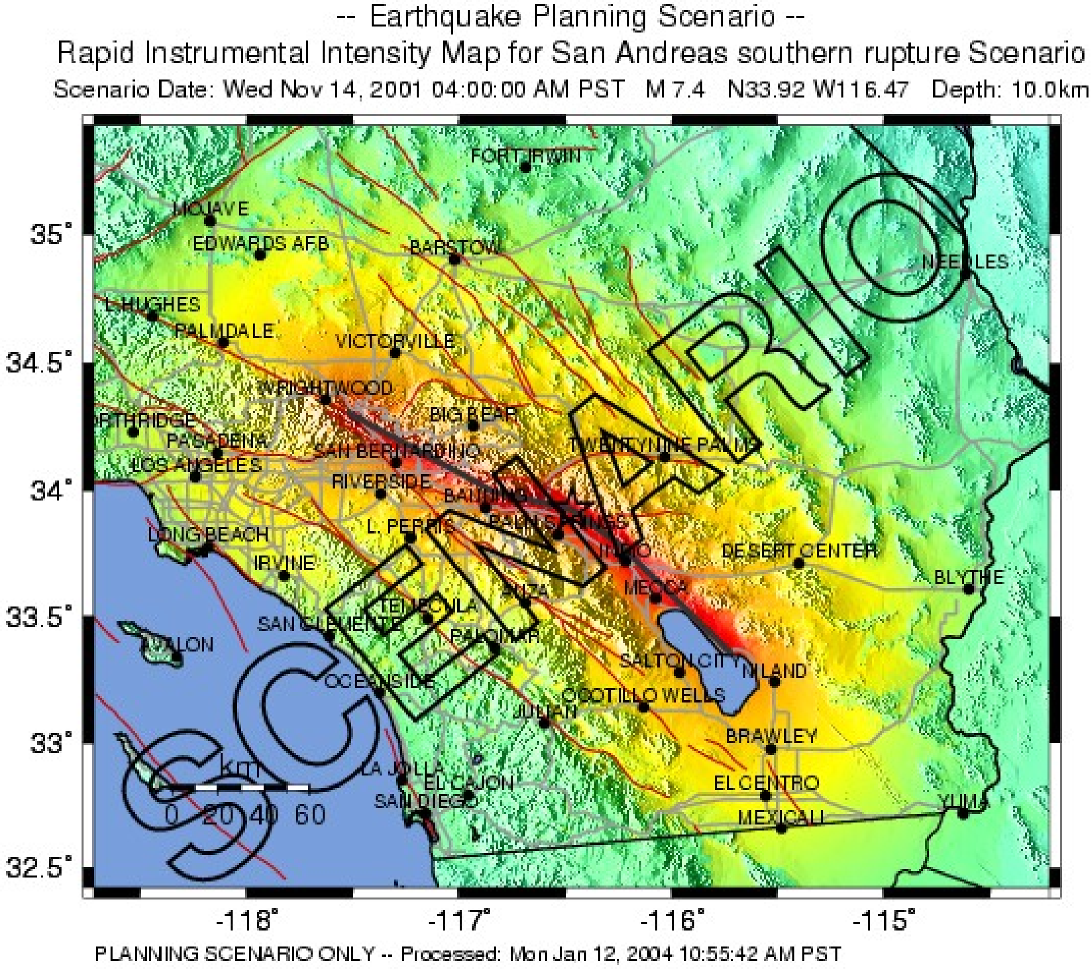
ShakeMaps can also be used for planning and emergency preparedness by creating hypothetical earthquake scenarios. These scenarios are not predictions – knowing when or how large an earthquake will be in advance is still not possible. However, using realistic assumptions about the size and location of a future earthquake, we can make predictions of its effects, and use this information for loss estimations and emergency response planning. Figure 1-4 is an Intensity ShakeMap for a hypothetical magnitude 7.4 earthquake that ruptures the southern San Andreas fault south and southwest of the city of Hesperia. The ShakeMap shows that the area in and around Hesperia would experience Modified Mercalli Intensities of about VIII, with much higher levels felt immediately to the south, closer to the San Andreas fault.

1.5.1 North Frontal Fault

Given its proximity to Hesperia, the North Frontal fault has the potential to generate the strongest seismic shaking at the city. This south-dipping, partially blind reverse fault zone along the eastern flank of the San Bernardino Mountains consists of several fault splays that have a combined total length of approximately 65 km (40 miles). Several of the fault splays interact with other nearby faults; the most significant of these is the Helendale fault, which seems to right-laterally offset the North Frontal fault zone, dividing it into two main segments (referred to as the East and West segments; Meisling, 1984). The West segment, which is about 22 miles (35 km) long, is at its closest approach less than 2 miles (3.2 km) from Hesperia.

The North Frontal fault is thought to have moved in the past 10,000 years, making it an active fault. However, the fault has not been studied in detail, and its recurrence interval, slip rate and other fault parameters are not well understood, although a slip rate of about 0.5 mm/yr is attributed to it. Furthermore, movement on this fault is thought to be responsible for an average uplift rate of about 1 mm/yr of the San Bernardino Mountains. Based on its length, the West segment of the North Frontal fault zone is thought capable of generating a maximum magnitude 7.2 earthquake. An earthquake of that size on this fault would be felt in Hesperia with peak ground accelerations of between about 0.58g and 0.23g, resolving in Modified Mercalli intensities as high as X.

Figure 1-4: ShakeMap for a Hypothetical Magnitude 7.4 Earthquake on the Southern San Andreas Fault



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

Source: http://earthquake.usgs.gov/eqcenter/shakemap/sc/shake/SAF_south7.4_se/download/intensity.jpg

1.5.2 San Andreas Fault

The San Andreas fault is the principal boundary between the Pacific and North American plates. The fault extends over 750 miles (1,200 kilometers), from near Cape Mendocino in northern California to the Salton Sea region in southern California. This fault is considered the "Master Fault" in southern California because it has frequent, large earthquakes and controls the seismic hazards of the area. Many refer to an earthquake on the San Andreas fault as "The Big One," however, as shown above, at least one other fault closer to Hesperia has the potential to cause stronger ground shaking, and therefore more damage, than the San Andreas fault. Nevertheless, the San Andreas fault should be considered in all seismic hazard assessment studies in southern California given its high probability of causing an earthquake in the near future. A group of scientists referred to as the 2007 Working Group on California Earthquake Probabilities (WGCEP, 2008) has calculated that the southern San Andreas fault has a 59% probability of causing an earthquake of at least magnitude 6.7 in the next 30 years.

Large faults, such as the San Andreas fault, are often divided into segments in order to evaluate their future earthquake potential. The segmentation is based on physical characteristics along the fault, particularly discontinuities that may affect the rupture length. In central and southern California the San Andreas fault is divided into five segments named, from north to south, Cholame, Carrizo, Mojave, San Bernardino Mountains, and Coachella Valley. At its closest approach, the southern portion of Hesperia is about 4 miles (6.5 kilometers) from the San Bernardino Mountains segment, and 7 miles (11 km) from the Mojave segment. Each segment is assumed to have a characteristic slip rate (rate of movement averaged over time), recurrence interval (time between moderate to large earthquakes), and displacement (amount of offset during an earthquake).

While this methodology has some value in predicting earthquakes, historical records and studies of prehistoric earthquakes show it is possible for more than one segment to rupture during a large quake or for ruptures to overlap into adjacent segments. For example, the last major earthquake on the southern portion of the San Andreas fault (and the largest earthquake reported in California) was the 1857 Fort Tejon (M 8) event. The 1857 earthquake ruptured the Cholame, Carrizo, and Mojave segments of the fault, resulting in displacements of as much as 27 feet (9 meters) along the rupture zone. These fault segments are thought to have a recurrence interval of between 104 and 296 years. Peak ground accelerations in Hesperia as a result of the 1857 earthquake are estimated to have been as high as 0.32g. However, another similar earthquake that ruptured the entire southern San Andreas fault, with its epicenter along the section of fault closest to Hesperia, could generate even higher peak ground accelerations in Hesperia, estimated at between 0.46g and 0.3g (see Table 1-2).

The **Mojave segment** of the San Andreas fault is 83 miles (133 km) long, extending from approximately Three Points southward to just northwest of Cajon Creek, at the southern limit of the 1857 rupture (WGCEP, 1995). Using a slip rate of 30±8 mm/yr and a characteristic displacement of 4.5±1.5 meters (m), the WGCEP (1995) derived a recurrence interval for this segment of 150 years. [[In 2002, the CGS assigned this segment a slip rate of about 34±5 mm/yr, whereas more recently, the 2007 WGCEP assigned it a slip rate of 28±3.5 mm/yr, which could resolve into a slightly longer recurrence interval]. The Mojave segment is estimated to be capable of producing a magnitude 7.4 earthquake, which could result in peak ground accelerations in Hesperia of 0.42g to 0.23g. The WGCEP (1995) calculated that this segment has a 26% probability of rupturing sometime between 1994 and 2024.

The **San Bernardino Mountains segment** is 49 miles (78 km) long and extends from approximately Cajon Creek southwestward to the San Gorgonio Pass. This segment is a structurally complex zone that is poorly understood, and for which there are scant data on fault behavior. Using a slip rate of 24±5 mm/yr and a characteristic displacement of 3.5 ±

1.0 m, the WGCEP (1995) derived a recurrence interval of 146 years. [The CGS (Cao, 2003) uses a slip rate of 24±6 mm/yr for this fault segment, whereas the 2007 WGCEP assigned a slip rate of 22±6 mm/yr to the northern section of the San Bernardino Mountains segment.] The San Bernardino Mountains segment of the San Andreas fault is estimated to be capable of producing a magnitude 7.5 earthquake, which could result in peak ground accelerations in Hesperia of between 0.45g and 0.26 g. If this fault segment ruptures in conjunction with the Mojave and/or Coachella Valley segments, higher ground motions would be expected. This segment was estimated to have a 28% probability of rupturing in the period between 1994 and 2024 (WGCEP, 1995).

The **Coachella Valley segment** extends 114 km from approximately San Gorgonio Pass to the Salton Sea. This segment has not produced any large, surface-rupturing earthquakes in historic times (Sieh and Williams, 1990). Paleoseismic studies suggest that the last surface-rupturing earthquake on this segment occurred around 1680 A.D. The data also suggest that the Coachella Valley and San Bernardino Mountain segments ruptured simultaneously in earthquakes that occurred around 1680 and 1450 A.D. Using a slip rate of 25 ± 5 mm/yr and a characteristic displacement of 4.0 +4,-2 m, the 1995 WGCEP derived a recurrence interval of 220 ±13 years for this segment. More recently, the 2007 WGCEP assigned a slip rate of 20±6 mm/yr to this segment. Rupture of both the Coachella Valley and San Bernardino Mountains segments together is thought would produce a magnitude 7.7 earthquake, which could result in peak ground accelerations in Hesperia of between 0.47g and 0.29g. The Coachella Valley segment has a 22% probability of rupturing sometime between 1994 and 2024.

1.5.3 Cleghorn Fault

The Cleghorn fault is an approximately 19-miles (30-km) long, steeply north-dipping, left-lateral strike-slip fault with a slight normal component of movement. The fault extends across Silverwood Lake, and therefore it is also referred to as the Silverwood Lake fault. Meisling and Weldon (1989) suggest that the fault zone has had about 200 meters of motion in the last 50,000 to 100,000 years, which resolves into a slip rate of between 2 and 4 mm/yr. However, some researchers have suggested that this rate is overstated, as the fault is not sufficiently well expressed in the landscape to support such a rate of slip. The fault is thought to have last moved in either the late Quaternary or Holocene, although Hart and others (1989) suggest that Holocene displacement and surface ruptures reported on this fault are actually a manifestation of landsliding and not faulting. A magnitude 6.5 earthquake on this fault is thought capable of generating horizontal peak ground accelerations in the Hesperia area of between about 0.42g and 0.18g, with Modified Mercalli Intensities in the X to VIII range.

1.5.4 Cucamonga Fault

The Cucamonga fault zone is a youthful, 25-km-long element of the Transverse Ranges family of thrust faults (Matti and others, 1982; Morton and Matti, 1987) that extends along the southern front of the San Gabriel Mountains from San Antonio Canyon eastward to the Lytle Creek area, where it appears to be truncated by the Lytle Creek fault, one of the many faults that form the San Jacinto fault zone (Burnett and Hart, 1994).

Paleoseismic (trenching) studies of the Cucamonga fault suggest that this fault has a slip rate of between 4.5 and 5.5 mm/yr (Matti and others, 1982; Matti and others, 1992).

Taking into account the uncertainties in carbon-14 dating, the 1988 WGCEP assigned a slip rate of 4.0±2.0 mm/yr to the fault, whereas more recently, the CGS assigned this fault a slip rate of 5.0±2.0 mm/yr. Morton and Matti (1987) and Matti and others (1992) estimate an average recurrence interval on this fault of 625 years, but additional studies are necessary to confirm this. Based on its length, the Cucamonga fault is thought capable of generating a maximum credible earthquake of magnitude 6.9. Such an event would generate peak horizontal ground acceleration in the Hesperia area of between about 0.35g and 0.16g, with Modified Mercalli intensities in the IX to VIII range.

1.5.5 Helendale – South Lockhart Fault

The Helendale fault is a right-lateral strike-slip fault that is 56 miles (90 km) long, and one of the northwest-trending faults that collectively appear to be accommodating between 9 and 23% of the motion between the North American and Pacific Plates. Combined, these faults are referred to as the Eastern California Shear Zone. The Helendale fault cuts through and offsets the North Frontal fault zone, as described above. The Helendale fault also seems to form a continuous fault with the South Lockhart fault to the north. The South Lockhart fault is a right-lateral strike-slip fault with a minor dip-slip component (Bryant, 1987c). The central and southern segments of the South Lockhart fault display evidence of Holocene rupture, including deformed Holocene sediments and well-defined scarps (Bryant, 1987). The northern segment of the South Lockhart fault is poorly defined and does not show evidence of Holocene rupture, indicating that the whole fault may not rupture at the same time. Rupture of multiple segments of both the Helendale and the South Lockhart faults may result in a large-magnitude earthquake that would be greater than if the South Lockhart, or the Helendale fault ruptured alone.

Petersen and Wesnousky (1994) calculated a slip rate for the Helendale fault of 0.8 mm/yr and a recurrence interval for large surface-rupturing events of 3,000 to 5,000 years. Paleoseismic studies of the Helendale fault indicate, however, a recurrence interval of 6,000 to 11,000 years (Bryan and Rockwell, 1995). Paleoseismic studies on the South Lockhart fault are required to resolve this discrepancy. It is possible that the actual slip rate on this fault is less than 0.8 mm/yr, or that the South Lockhart fault ruptures more often than the Helendale fault. Based on the data available at this time, the California Geological Survey uses a maximum earthquake of magnitude 7.3 to estimate the ground motion hazard resulting from the combined Helendale-South Lockhart faults. An earthquake of that size is anticipated to generate horizontal peak ground accelerations in Hesperia of about 0.27g to 0.16g, with Modified Mercalli Intensities of IX to VIII.

1.5.6 San Jacinto Fault Zone

The San Jacinto Fault Zone consists of a series of closely spaced faults that form the western margin of the San Jacinto Mountains. The zone extends from its junction with the San Andreas fault in San Bernardino, southeasterly toward the Brawley area, where it continues south of the international border as the Imperial fault. This fault zone has a high level of historical seismic activity, having generated at least ten moderate (M 6 - 7) earthquakes between 1890 and 1986. Offset across the fault traces is predominantly right-lateral, similar to the San Andreas fault, although Brown (1990) has suggested that vertical motion contributes up to 10% of the net slip. The San Jacinto fault zone has been divided into seven segments. Each segment, in turn, consists of a series of subparallel faults. The segments of the San Jacinto fault closest to Hesperia are the San Bernardino and San Jacinto Valley segments.

Fault slip rates on the various segments of the San Jacinto are less well constrained than for the San Andreas fault, but the data available suggest slip rates of 12 ±6 mm/yr for the northern segments of the fault (including the San Bernardino and San Jacinto Valley segments) and slip rates of 4 ± 2 mm/yr for the southern segments (WGCEP, 1995). Various investigators have suggested a recurrence interval for large ground-rupturing earthquakes on the San Jacinto fault of between 150 and 300 years (Petersen and Wesnousky, 1994). It is unknown when the traces of the San Jacinto fault closest to Hesperia last ruptured. Radiocarbon dating of faulted and unfaulted deposits trenched at Sycamore Flat suggest that the San Jacinto fault trace last broke in this area between 280(±70) and 490(±70) years before present (Jeff Johnston, 1994 personal communication, as reported in Burnett and Hart, 1994). If these dates are correct, the San Bernardino segment of the San Jacinto fault is near or at the end of its strain cycle, and therefore capable of generating an earthquake in the not too distant future. The Working Group on California Earthquake Probabilities (1995) gave the San Bernardino and San Jacinto Valley segments a 37% and 43% probability, respectively, of rupturing sometime between 1994 and 2024.

A maximum credible earthquake of magnitude 6.7 on the San Bernardino segment of the San Jacinto fault has the potential to generate peak horizontal ground accelerations of between 0.26g and 0.12g in the Hesperia area. Similarly, a 6.9 earthquake on the more distant San Jacinto Valley segment would generate peak horizontal ground accelerations in Hesperia of between 0.11g and 0.08g (see Table 1-2).

1.5.7 Sierra Madre Fault

The Sierra Madre fault zone is a northeast-dipping reverse fault complex approximately 47 miles (75 km) long that extends along the base of the San Gabriel Mountains from the San Fernando Valley to San Antonio Canyon (Lamar et al., 1973; WGCEP, 1988), where it continues southeastward as the Cucamonga fault. Structurally, the Sierra Madre and Cucamonga faults are interpreted as related segments of a through-going frontal fault zone, with the Cucamonga fault zone transferring strain onto the Sierra Madre fault zone to the west (Morton and Matti, 1987).

Until recently there was very limited geomorphic evidence for quantifying either slip rate or earthquake recurrence along most of the Sierra Madre fault's length. The fault zone has been divided into five segments, and each segment seems to have a different rate of activity. The northwestern-most segment, the San Fernando segment, ruptured in 1971, causing the M_w 6.7 San Fernando (or Sylmar) earthquake. As a result of this earthquake, the Sierra Madre fault has been know to be active. Trenching studies of this fault after the 1971 earthquake led Bonilla (1973) to infer a 200-year recurrence interval for the San Fernando segment. In the 1980s, Crook et al., (1987) studied the Transverse Ranges using general geologic and geomorphic mapping, combined with a few trenching studies, to suggest that the segments of the Sierra Madre fault east of the San Fernando segment have not generated major earthquakes for several thousand years, and possibly for as long as 11,000 years. Then, in the mid 1990s, Rubin and others (1998) trenched a section of the Sierra Madre fault in Altadena, and determined that this segment has ruptured at least twice in the last 15,000 years, causing magnitude 7.2 to 7.6 earthquakes. Farther east, at

Horsethief Canyon, Tucker and Dolan (2001) trenched the east Sierra Madre fault and obtained data consistent with Rubin et al.'s (1998) findings, with the last rupture on this segment dated to about 8,000 years ago.

In 1988, a group of scientists called the Working Group on California Earthquake Probabilities (WGCEP) extrapolated the Cucamonga fault rate of 4.0 ± 2.0 mm/yr to the Sierra Madre fault, but in 2003, the California Geological Survey (CGS), assigned a lower slip rate to this fault of 2.0 ± 1.0 mm/yr (Cao et al., 2003). This revised rate recognizes that the Sierra Madre fault appears to rupture in infrequent, but large magnitude earthquakes, consistent with the paleoseismic record. In fact, using Rubin et al.'s (1998) and Tucker and Dolan's (2001) data, the Sierra Madre fault may slip at a rate of as little as 0.6 mm/yr. Using a slip rate of 0.6 mm/yr and a slip per event of 5 meters resolves into a recurrence interval of about 8,000 years. If, as the recent studies suggest, the last rupturing event on the eastern segments of the fault occurred about 8,000 years ago, it is possible that the section of the Sierra Madre fault closest to the Hesperia area is near the end of its cycle, and therefore likely to generate an earthquake in the not too distant future. The CGS (2003) estimates that the Sierra Madre fault is capable of producing a magnitude 7.2 earthquake. An earthquake of that size could generate peak horizontal ground accelerations in Hesperia of between about 0.18g and 0.12g.

1.5.8 Lenwood – Lockhart – Old Woman Springs Faults

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

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

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

Although the Lenwood and Lockhart faults form essentially a continuous, 90-miles (150-km) long system, there is no evidence that both of these faults have ruptured together in the past. Nevertheless, such an event might be possible, as evidenced by rupture of 5 separate fault segments during the Landers earthquake. For the purposes of this study, these faults, together with the Old Woman Springs fault, are assumed to rupture together in a magnitude 7.5 maximum earthquake. Such an event would generate peak ground accelerations in Hesperia of about 0.15g to 0.10g, with Modified Mercalli Intensities in the VIII to VII range. If only one of these faults ruptures in an earthquake, the smaller magnitude event would cause lesser ground motions in the city than those reported above.

1.6 Potential Sources of Fault Rupture

1.6.1 Primary Fault Rupture

Primary fault rupture refers to fissuring and offset of the ground surface along a rupturing fault during an earthquake. Primary ground rupture typically results in a relatively small percentage of the total damage in an earthquake, but being too close to a rupturing fault can cause severe damage to structures. As discussed previously, development constraints within active fault zones were implemented in 1972 with passage of the California Alquist-Priolo Earthquake Fault Zoning Act. The Alquist-Priolo Act prohibits the construction of new habitable structures astride an active fault and requires special geologic studies to locate and evaluate whether a fault has ruptured the ground surface in the past about 11,000 years. If an active fault is encountered, structural setbacks from the fault are defined.

There are no faults zoned by the State of California within the Hesperia General Plan area. The closest Alquist-Priolo Earthquake Fault Zones to the Hesperia area include the North Frontal fault approximately 2 miles east, and the San Andreas fault approximately 4 miles southwest. Sections of both of these zones are shown on Plate 1-2. However, the State Geologist is still assessing many faults in California, and not all active faults have been zoned yet. In fact, some of the faults just recently zoned are faults that had not been studied previously, but were found to be active when they ruptured in an earthquake.

The Cleghorn fault zone south of Hesperia, as discussed in Section 1.5.3, is thought to be active, although it is unknown when it last ruptured during an earthquake. Estimates of total left-lateral displacement on this fault, of about 3.5 to 4 km (Meisling and Weldon, 1989; Morton and Miller, 2003) are in part based on the reconstruction of the offset older faults to the north and south of the Cleghorn fault shown on Plate 1-2. Although these older faults may no longer be major players in the tectonics of the area, they could slip a small amount during an earthquake on a nearby fault, such as the San Andreas fault (see the discussion on secondary fault rupture hazards below, in Section 1.6.2). In fact, several of the faults on the east side of Summit Valley, within and just south of the General Plan area are still evident in the landscape, as observed in recent aerial photographs, suggesting that they may still be active. Similarly, the north- to northeast-trending faults that extend across Hesperia's southeastern corner may also be transferring strain between the San Andreas fault and the North Frontal fault. Until studied further, critical facilities, such as water reservoirs, hospitals, schools, and fire stations should not be placed across the trace of these faults without first conducting site-specific studies to evaluate these faults' recency of activity and potential future surface fault rupture hazard.

The sole fault mapped by Morton and Miller (2003) through the western part of the General Plan area, between the California Aqueduct on the east, and the 15 Freeway on the west, appears not to impact the landscape, and is therefore considered less likely to pose a future surface fault rupture hazard.

NOTES:

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

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

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

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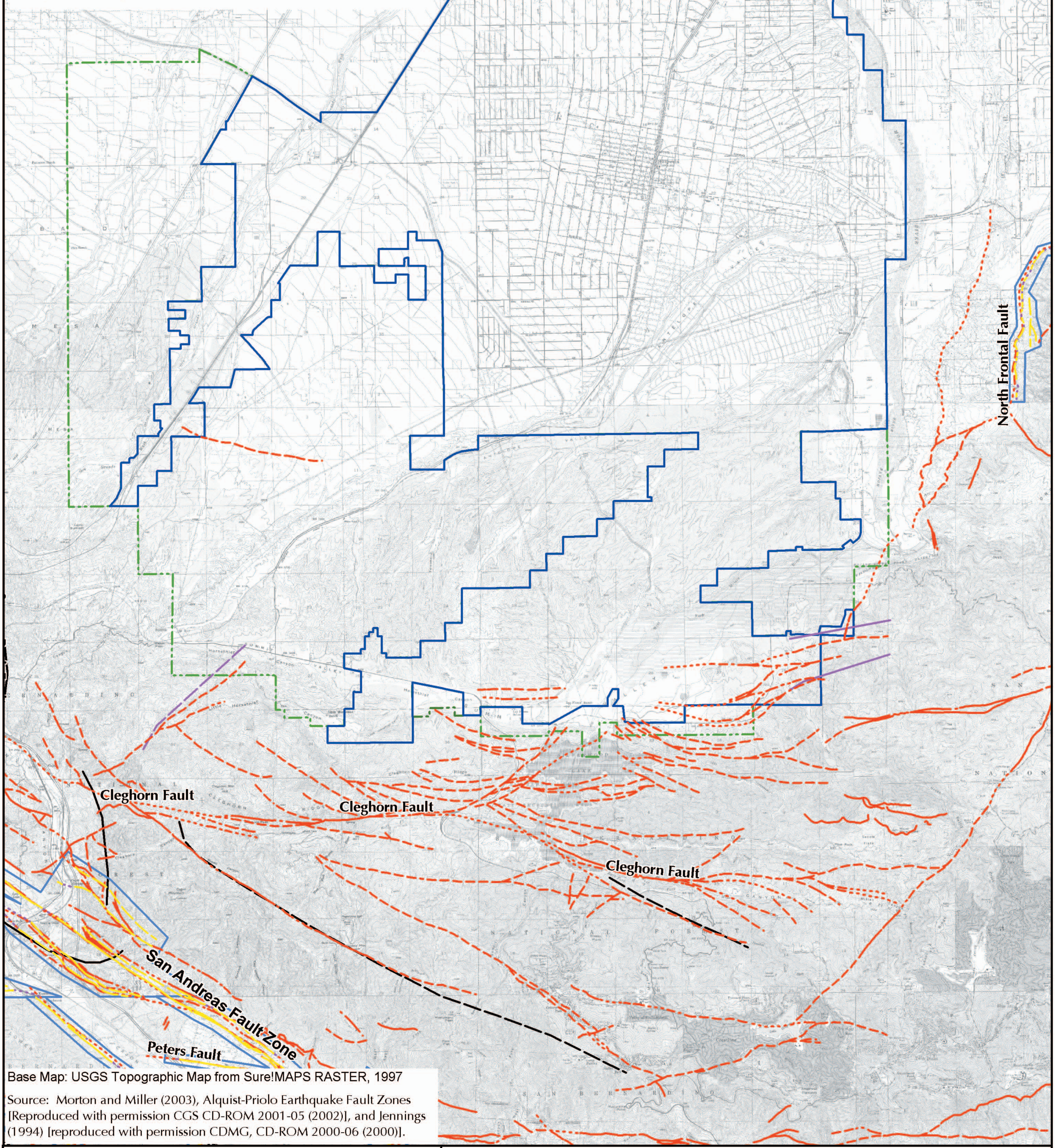

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997

Source: Morton and Miller (2003), Alquist-Priolo Earthquake Fault Zones [Reproduced with permission CGS CD-ROM 2001-05 (2002)], and Jennings (1994) [reproduced with permission CDMG, CD-ROM 2000-06 (2000)].

N W E S

0 8000 16000 Feet

0 2000 4000 Meters

Scale: 1:96,000

Explanation

Faults; solid where location is known, dashed where approximate, dotted where inferred.

- Fault. From Morton and Miller (2003).
- Alquist-Priolo Earthquake Fault. From CGS (2002).
- Alquist-Priolo Earthquake Fault Zone. From CGS (2002).
- Quaternary faults. From Jennings (1994).
- Pre-Quaternary faults. From Jennings (1994).
- Hesperia City Limit
- Hesperia Sphere of Influence

HESPERIA

Earth Consultants International

Project Number: 2617
Date: February 2010

Fault Map

Hesperia, California

Plate 1-2

1.6.1.1 Mitigation of Primary Fault Rupture

In most cases, it is impractical to reduce the damage potential of surface fault rupture by engineering design; therefore, the most often used and most appropriate mitigation measure is to simply avoid placing structures on or near active fault traces. The intent of the Alquist-Priolo Earthquake Fault zones is to require that geologic investigations, which may include fault trenching, be performed if conventional structures designed for human occupancy are proposed within the zone. These studies must evaluate whether or not an active segment of the fault extends across the area of proposed development, following the guidelines for evaluating the hazard of fault rupture presented in Note 49, published by the CGS, which is available on the world wide web at http://www.consrv.ca.gov/CGS/rghm/ap/index.htm.

Based on the results of these geologic studies, appropriate structural setbacks may be recommended to prevent the siting of the proposed structures directly on top or within a certain distance from the fault. A common misperception regarding setbacks is that they are always 50 feet from the active fault trace. In actuality, geologic investigations are required to characterize the ground deformation associated with an active fault. Based on these studies, specific setbacks are recommended. If a fault trace is narrow, with little or no associated ground deformation, a setback distance less than 50 feet may be recommended. Conversely, if the fault zone is wide, with multiple splays, or is poorly defined, a setback distance greater than 50 feet may be warranted. State law allows local jurisdictions to establish minimum setback distances from a hazardous fault, and some communities have taken a prescriptive approach to this issue, establishing specific setbacks from a fault, rather than allowing for different widths depending on the circumstances. For example, the City of West Hollywood requires a 50-foot setback from the Hollywood fault for conventional structures, and 100-foot setback for critical and high-occupancy facilities.

1.6.2 Secondary Fault Rupture and Related Ground Deformation

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

Secondary fault rupture refers to ground surface displacements along faults other than the main traces of active regional faults. Unlike the regional faults, these subsidiary faults are not deeply rooted in the Earth's crust and are not capable of producing damaging earthquakes on their own. Movement along these faults generally occurs in response to movement on a nearby regional fault. The zone of secondary faulting can be quite large, even in a moderate-sized earthquake. For instance, in the 1971 San Fernando quake, movement along subsidiary faults occurred as much as 2 km from the main trace (Ziony and Yerkes, 1985).

Secondary faulting in thrust fault terrain is very complex, and numerous types of faulting have been reported. These include splays, branches, tear faults, shallow thrust faults, and back-thrusts, as well as faults that form in the shallow subsurface as a result of folding in sedimentary layers. Identified by Yeats (1982), fold-related types include flexural slip faults (slippage along bedding planes), and bending-moment faults (tensional or compressional tears in the axis of folding). A striking example of flexural slip along bedding planes occurred during the Northridge earthquake, when numerous bedding plane faults ruptured across the surface of newly graded roads and pads in a subdivision near Santa Clarita. The ruptures were accompanied by uplift and warping of the nearby ground (Treiman, 1995).

Secondary ground deformation includes fracturing, shattering, warping, tilting, uplift and/or subsidence. Such deformation may be relatively confined along the rupturing fault, or spread over a large region (such as the regional uplift of the Santa Susana Mountains after the Northridge earthquake). Deformation and secondary faulting can also occur without primary ground rupture, as in the case of ground deformation above a blind (buried) thrust fault.

As discussed in the previous section, several of the faults near and along the southern boundary of the Hesperia General Plan study area could move sympathetically with movement on a regional fault such as the San Andreas. Although offsets due to secondary faulting are typically measured in inches or fractions of inches, if structures placed across these features are not designed property, structural damage can be expected.

1.6.2.1 Mitigation of Secondary Fault Rupture and Ground Deformation

Geotechnical investigations for future development and redevelopment should consider this hazard. The methodology for evaluating these features is similar to that used for evaluating primary fault rupture (CGS Note 49, as discussed in Section 1.6.1.1).

Lazarte et al. (1994) outlined three approaches to mitigation of fault rupture hazard, which could be applied to secondary deformation as well. The first is avoidance using structural setback zones. The second is referred to as "geotechnical engineering." This method consists of placing a compacted fill blanket, or a compacted fill blanket reinforced with horizontal layers of geogrid, over the top of the fault trace. This is based on observations that the displacement across a distinct bedrock fault is spread out and dissipated in the overlying fill, thus reducing the severity of the displacement at the surface. The third method is "structural engineering." This refers to strengthening foundation elements to withstand a limited amount of ground deformation. This is based on studies of foundation performance in the Landers earthquake showing that structures overlying major fault ruptures suffered considerable damage but did not collapse. Application of the second and third methods requires a thorough understanding of the geologic environment and thoughtful engineering judgment. This is because quantifying the extent of future displacement is difficult, and there are no proven engineering standards in place to quantify the amount of mitigation needed (for instance how thick a fill blanket is needed). However, extensive research in this area is being conducted by Bray (2001). This will hopefully lead to an increase in the use of these techniques to mitigate the hazard of secondary ground deformation, provided that the CGS and local regulatory agencies are willing to consider and approve the use of alternatives to structural setbacks.

1.7 Geologic Hazards Resulting from Seismic Shaking

1.7.1 Liquefaction and Related Ground Failure

Liquefaction is a geologic process that causes various types of ground failure. It typically occurs in loose, saturated sediments primarily of sandy composition, in the presence of ground accelerations over 0.2g (Borchardt and Kennedy, 1979; Tinsley and Fumal, 1985). When liquefaction occurs, the sediments involved have a total or substantial loss of shear strength, and behave like a liquid or semi-viscous substance. Liquefaction can cause structural distress or failure due to ground settlement, a loss of bearing capacity in the foundation soils, and the buoyant rise of buried structures. The excess hydrostatic pressure generated by ground shaking can result in the formation of sand boils or mud spouts, and/or seepage of water through ground cracks.

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

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

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

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

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

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

As indicated above, there are three general conditions that need to be met for liquefaction to occur. The first of these – strong ground shaking of relatively long duration – can be expected to occur in the Hesperia area as a result of an earthquake on any of the several active faults in the region (see Section 1.5 above). The second condition – geologically young, loose, unconsolidated sediments – occurs locally throughout the Hesperia area, typically along the active drainages and on the young alluvial fans (note the distribution of very young wash – Qw, very young fan – Qf, young fan – Qyf, and very young colluvial – Qc deposits on Plate 2.1). The third condition – water-saturated sediments within about 50 feet of the surface – has occurred and occurs locally within the Mojave River floodplain, where several wells show historical water levels shallower than 30 feet below the surface (some of these wells are identified on Plate 1-3). The areas of Hesperia where young unconsolidated sediments and historical shallow groundwater conditions co-exist are shown on Plate 1-3 as susceptible to liquefaction. Although between 1930 and 1990 groundwater levels in Hesperia, as in most of the Movaje groundwater basin, have generally dropped significantly due to increased pumping from wells, water levels in the Mojave River floodplain have remained either fairly steady, or have risen since 1994, when recharge of the basin with imported water from the State Water Project began (Stamos et al., 2004). The shallowing of the water table is more prevalent downriver from the Rock Springs Outlet, near the southeastern corner of the General Plan area, where recharge water is released. Rising water levels in the floodplain are also in part due to the reclaimed wastewater released into the Mojave River about 2 miles downstream of the Forks, and at the Las Flores Ranch (Schlumberger Water Services, 2004).

Most of the rest of Hesperia is underlain by what is referred to as the regional aquifer, with water stored within the unconsolidated to slightly consolidated alluvial fan deposits of Holocene to Tertiary age (Stamos et al., 2001; 2004). The youngest sediments overlying these areas, as shown on Plate 2-2, are unconsolidated and could be susceptible to liquefaction if shallow ground water were present. However, ground water in the regional aquifer typically occurs 300 to 500 feet below the ground surface, and with increased pumping of water wells, the water levels are expected to drop even further. Therefore, those portions of Hesperia elevated above the Mojave River floodplain are not considered susceptible to liquefaction.

NOTES:

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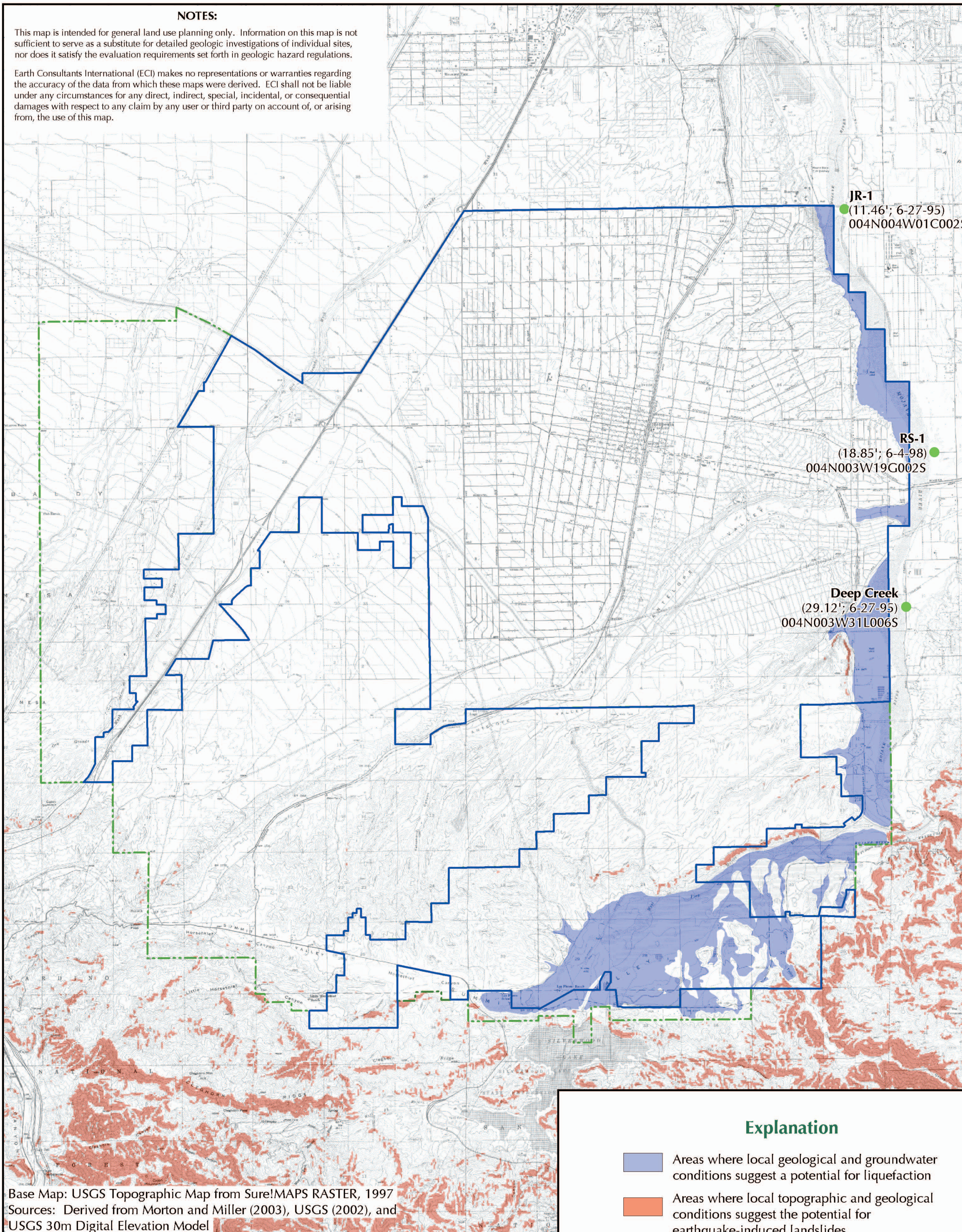


Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Sources: Derived from Morton and Miller (2003), USGS (2002), and USGS 30m Digital Elevation Model

N S W E

0 7000 14000 Feet

0 2000 4000 Meters

Scale: 1:84,000

Explanation

Areas where local geological and groundwater conditions suggest a potential for liquefaction

Areas where local topographic and geological conditions suggest the potential for earthquake-induced landslides

RS-1 Groundwater Monitoring Well in the Mojave River floodplain basin with historical groundwater levels within 30 feet of the ground surface. (Water depth, date measurement was made). Number next to well is the State Well Number.

Hesperia City Limit

Hesperia Sphere of Influence

Earth Consultants International

Project Number: 2617
Date: February 2010

Seismic Hazard Zones

Hesperia, California

Plate 1-3

1.7.1.1 Mitigation of Liquefaction

Although an official Seismic Hazards map does not exist for this area, the liquefaction-susceptible areas delineated in Plate 1-3 were identified following the methodology that the California Geological Survey uses to prepare the official maps. Therefore, until the State issues an official map for Hesperia, Plate 1-3 should be used as if it were the official map, and site-specific liquefaction susceptibility studies should be conducted in the mapped areas prior to any proposed development. In accordance with the SHMA, all projects within a State-delineated Seismic Hazard Zone for liquefaction must be evaluated by a Certified Engineering Geologist and/or Registered Civil Engineer (this is typically a civil engineer with training and experience in soil engineering). Most often however, it is appropriate for both the engineer and geologist to be involved in the evaluation, and in the implementation of the mitigation measures. Likewise, project review by the local agency must be performed by geologists and engineers with the same credentials and experience.

In order to assist project consultants and reviewers in the implementation of the SHMA, the State has published specific guidelines for evaluating and mitigating liquefaction (CDMG, 1997; CGS, 2008). Furthermore, in 1999, a group sponsored by the Southern California Earthquake Center (SCEC, 1999) published recommended procedures for carrying out the California Geological Survey guidelines. In general, a liquefaction study is designed to identify the depth, thickness, and lateral extent of any liquefiable layers that would affect the project site. An analysis is then performed to estimate the type and amount of ground deformation that might occur, given the seismic potential of the area. Mitigation measures generally fall in one of two categories: ground improvement or foundation design. Ground improvement includes such measures as removal and recompaction of low-density soils, removal of excess ground water, in-situ ground densification, and other types of ground improvement (such as grouting or surcharging). Special foundations that may be recommended range from deep piles to reinforcement of shallow foundations (such as post-tensioned slabs). Mitigation for lateral spreading may also include modification of the site geometry or inclusion of retaining structures. The types (or combinations of types) of mitigation depend on the site conditions and on the nature of the proposed project (CDMG, 1997; CGS, 2008).

1.7.2 Seismically Induced Settlement

Under certain conditions, strong ground shaking can cause the densification of soils, resulting in local or regional settlement of the ground surface. During strong shaking, soil grains become more tightly packed due to the collapse of voids and pore spaces, resulting in a reduction of the thickness of the soil column. This type of ground failure typically occurs in loose granular, cohesionless soils, and can occur in either wet or dry conditions. Unconsolidated young alluvial deposits are especially susceptible to this hazard. Artificial fills may also experience seismically induced settlement. Damage to structures typically occurs as a result of local differential settlements. Regional settlement can damage pipelines by changing the flow gradient on water and sewer lines, for example.

As shown in Plate 2-2, certain areas of Hesperia are underlain by young, unconsolidated alluvial deposits and artificial fill (note the distribution of all Holocene-aged deposits and artificial fill). These sediments are susceptible to seismically induced settlement.

1.7.2.1 Mitigation of Seismically Induced Settlement

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

1.7.3 Seismically Induced Slope Failure

Strong ground motions can worsen existing unstable slope conditions, particularly if coupled with saturated ground conditions. Seismically induced landslides can overrun structures, people or property, sever utility lines, and block roads, thereby hindering rescue operations after an earthquake. Over 11,000 landslides were mapped shortly after the 1994 Northridge earthquake, all within a 45-mile radius of the epicenter (Harp and Jibson, 1996). Although numerous types of earthquake-induced landslides have been identified, the most widespread type generally consists of shallow failures involving surficial soils and the uppermost weathered bedrock in moderate to steep hillside terrain (these are also called disrupted soil slides). Rock falls and rock slides on very steep slopes are also common. The 1989 Loma Prieta and Northridge earthquakes showed that reactivation of existing deep-seated landslides can also occur (Spittler et al., 1990; Barrows et al., 1995).

A combination of geologic conditions leads to landslide vulnerability. These include high seismic potential; rapid uplift and erosion resulting in steep slopes and deeply incised canyons; highly fractured and folded rock; and rock with inherently weak components, such as silt or clay layers. The orientation of the slope with respect to the direction of the seismic waves (which can affect the shaking intensity) can also control the occurrence of landslides. Ground water conditions at the time of the earthquake also play an important role in the development of seismically induced slope failures. For instance, the 1906 San Francisco earthquake occurred in April, after a winter of exceptionally heavy rainfall, and produced many large landslides and mudflows, some of which were responsible for several deaths. The 1987 Loma Prieta earthquake however, occurred in October during the third year of a drought, and slope failures were limited primarily to rock falls and reactivation of older landslides that was manifested as ground cracking in the scarp areas but with very little movement (Griggs et al., 1991).

Hesperia has not been mapped as being located within a State-delineated Seismic Hazard Zone for seismically induced landsliding because this mapping program has not yet been funded for San Bernardino County. Although most of Hesperia is characterized by relatively level to gently sloping terrain, there are a few natural slopes in Hesperia that could be vulnerable to seismically induced slope failure. These areas are shown on Plate 1-3, and a more detailed description of slope instability issues is provided in Chapter 2. In addition to the slopes identified within the city, there are many areas in the San Bernardino Mountains in and to the south of Hesperia that could fail during an earthquake. This has the potential to significantly impede traffic through the area immediately and for several days after an earthquake, which could indirectly impact Hesperia's residents and visitors, in addition to restricting access to and from the area by emergency response teams.

1.7.3.1 Mitigation of Seismically Induced Slope Failure

Existing slopes that are to remain adjacent to or within developments should be evaluated for the geologic conditions mentioned above. In general, slopes steeper than about 15 degrees are most susceptible, however failures can occur on flatter slopes if unsupported weak rock units are exposed in the slope face. For suspect slopes, appropriate geotechnical investigation and slope stability analyses should be performed for both static and dynamic (earthquake) conditions. For deeper slides, mitigation typically includes such measures as buttressing slopes or regrading the slope to a different configuration. Protection from rockfalls or surficial slides can often be achieved by protective devices such as barriers, retaining structures, catchment areas, or a combination of the above. The runout area of the slide at the base of the slope, and the potential bouncing of rocks must also be considered. If it is not feasible to mitigate the unstable slope conditions, building setbacks should be imposed.

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

1.7.4 Deformation of Sidehill Fills

Sidehill fills are artificial fill wedges typically constructed on natural slopes to create roadways or level building pads. Deformation of sidehill fills was noted in earlier earthquakes, but this phenomenon was particularly widespread during the 1994 Northridge earthquake. Older, poorly engineered road fills were most commonly affected, but in localized areas, building pads of all ages experienced deformation. The deformation was usually manifested as ground cracks at the cut/fill contacts, differential settlement in the fill wedge, and bulging of the slope face. The amount of displacement on the pads was generally about three inches or less, but this resulted in minor to severe property damage (Stewart et al., 1995). This phenomenon was most common in relatively thin fills (about 27 feet or less) placed near the tops or noses of narrow ridges (Barrows et al., 1995). This hazard is not expected to occur in Hesperia, except potentially along some of the approaches to the bridges that extend across the I-15 or the Mojave River, where minor settlement of the bridge embankment could result in a step up of a few inches to the actual bridge. Failure of sidehill fills could also occur locally in the foothills of the San Bernardino Mountains, on lots where grading involving the placement of fill was required to make a level pad.

1.7.4.1 Mitigation of Sidehill Deformation

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

1.7.5 Ridgetop Fissuring and Shattering

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

Ridgetop shattering may occur locally in the southern part of Hesperia, in the San Bernardino Mountains and in the foothills at the base of the mountains, to the south and east of Summit Valley Road.

1.7.5.1 Mitigation of Ridgetop Fissuring and Shattering

Projects located or proposed in steep hillside areas should be evaluated for this hazard by a Certified Engineering Geologist. Although it is difficult to predict exactly where this hazard may occur, avoidance of development along the tops of steep, narrow ridgelines is probably the best mitigation measure. For large developments, recontouring of the topography to reduce the conditions conducive to ridgetop amplification, along with overexcavation below finish grades to remove and recompact weak, fractured bedrock might reduce this hazard to an acceptable level.

1.7.6 Seiches

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

Amplitudes of seiche waves associated with earthquake ground motion are typically less than 0.5 m (1.6 feet high), although some have exceeded 2 m (6.6 ft). A seiche in Hebgen Reservoir, caused by an earthquake in 1959 near Yellowstone National Park, repeatedly overtopped the dam, causing considerable damage to the dam and its spillway (Stermitz, 1964). The 1964 Alaska earthquake produced seiche waves 0.3 m (1 ft) high in the Grand Coulee Dam reservoir, and seiches of similar magnitude were reported in fourteen bodies of water in the state of Washington (McGarr and Vorhis, 1968).

Seiches due to seismic shaking could occur in Silverwood Lake, and in any other lake and recharge basin present throughout the city, if they happen to have water at the time of the earthquake. Seiching could result in sloshing of water out of the lakes and basins and onto the immediately adjacent surrounding areas. In unlined basins, sloshing of water against the basin sides could cause the surrounding soil berms to experience erosion, and locally, some surficial slope failures. Similarly, water in swimming pools is known to slosh during earthquakes, but in most cases, the sloshing does not lead to significant damage. Sloshing of water inside water reservoirs is discussed further in Chapter 2.

1.7.6.1 Mitigation of Seiches

The degree of damage to small bodies of water, such as to shallow lakes, basins, and swimming pools, is likely to be minor. However, property owners down-gradient from bodies of water that could seiche during an earthquake should be aware of the potential hazard to their property should a lake or pool lose substantial amounts of water during an earthquake. Site-specific design elements, such as baffles, to reduce the potential for seiches are warranted in tanks and in open reservoirs or ponds where overflow or failure of the structure may cause damage to nearby properties. Damage to water tanks in recent earthquakes, such as the 1992 Landers-Big Bear sequence and the 1994 Northridge, resulted from seiching. As a result, the American Water Works Association (AWWA) Standards for Design of Steel Water Tanks (D-100) provide new criteria for seismic design (Lund, 1994).

1.7.7 Tsunami

A tsunami is a sea wave caused by any large-scale disturbance of the ocean floor that occurs in a short period of time and causes a sudden displacement of water. Tsunamis can be caused by shallow underwater earthquakes, submarine landslides, underwater volcanic explosions, oceanic meteor impacts, and even underwater nuclear explosions. Tsunamis can travel across an entire ocean basin, or they can be local.

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

1.8 HazUS Earthquake Scenario Loss Estimations for the City of Hesperia

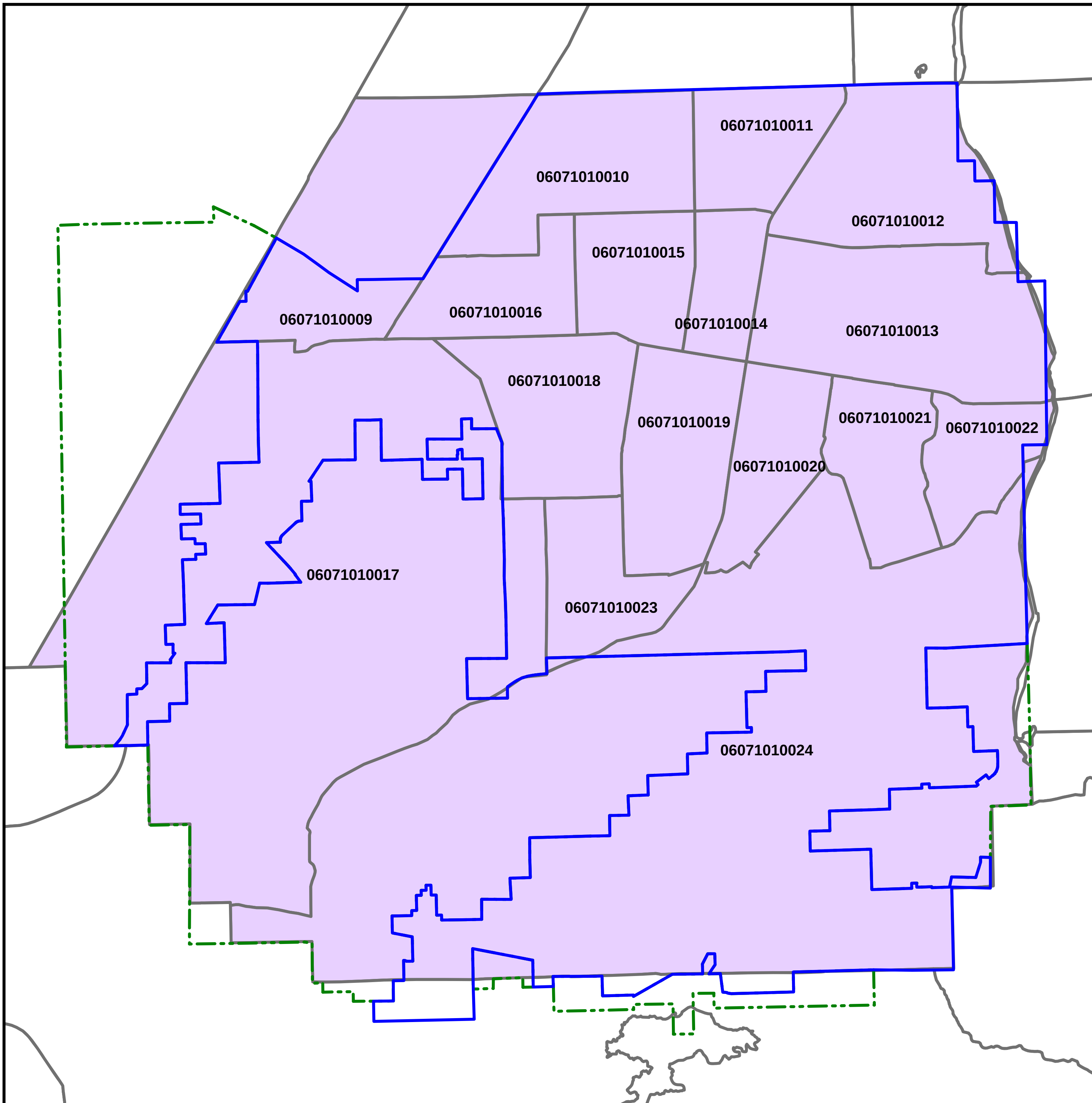
HazUS-MH™ is a standardized methodology for earthquake loss estimation based on a geographic information system (GIS). [HazUS-MH stands for Hazards US – Multi-hazard.] A project of the National Institute of Building Sciences, funded by the Federal Emergency Management Agency

(FEMA), HazUS is a powerful advance in mitigation strategies. The HazUS project developed guidelines and procedures to make standardized earthquake loss estimates at a regional scale. With standardization, estimates can be compared from region to region. HazUS is designed for use by state, regional and local governments in planning for earthquake loss mitigation, emergency preparedness, response and recovery. HazUS addresses nearly all aspects of the built environment, and many different types of losses. The methodology has been tested against the experience of several past earthquakes, and against the judgment of experts. Subject to several limitations noted below, HazUS can produce results that are valid for the intended purposes.

Loss estimation is an invaluable tool, but it must be used with discretion. Loss estimation analyzes casualties, damage and economic loss in great detail. It produces seemingly precise numbers that can be easily misinterpreted. Loss estimation's results, for example, may cite 4,054 left homeless by a scenario earthquake. This is best interpreted by its magnitude. That is, an event that leaves 4,000 people homeless is clearly more manageable than an event causing 40,000 homeless people; and an event that leaves 400,000 homeless would overwhelm a community's resources. However, another loss estimation that predicts 5,000 people homeless should probably be considered equivalent to the 4,054 result. Because HazUS results make use of a great number of parameters and data of varying accuracy and completeness, it is not possible to assign quantitative error bars. Although the numbers should not be taken at face value, they are not rounded or edited because detailed evaluation of individual components of the disaster can help mitigation agencies ensure that they have considered all the important options.

The more community-specific the data that are input to HazUS, the more reliable the loss estimation. HazUS provides defaults for all required information. These are based on best-available scientific, engineering, census and economic knowledge. The loss estimations in this report have been tailored to Hesperia by using a map of soil types for the city.

HazUS-HM relies on 2000 Census data, which are reported by geographical areas or tracts. Sixteen (16) census tracts cover most of the Hesperia General Plan area (i.e., the City and its Sphere of Influence); these 16 census tracts were used in the HazUS-HM analysis, and their coverage, in relation to the study area, is shown on Figure 1-5. This figure shows that the largest area not included in the census tracts used in the analysis is that portion of the Sphere of Influence west of the Bureau of Light and Power Road and south of the California Aqueduct. A narrow band of the General Plan area along and south of Highway 173 was also not included. A review of recent aerial photographs suggests that the areas not included in the analysis are not extensively populated – the area west of the Bureau of Light and Power Road area is characterized by very low density housing in large parcels, whereas the area south of Highway 173 is predominantly vacant – and therefore that the population numbers used by HazUS are not off significantly. Other areas in the Sphere of Influence that were considered in the analysis do have an influence on the population numbers. Specifically, and according to HazUS, the 2000 census population for the 16 tracts considered was 69,074, while the City of Hesperia reports that its population in 2000, without including the Sphere of Influence, was 62,582. Therefore, the areas in the Sphere of Influence considered in the analysis added less about 7,000 to the year 2000 population count.



N
W E
S

0 9000 18000 Feet

0 2000 4000 Meters

Scale: 1:108,000

Explanation

Census Tract

Hesperia City Limit

Hesperia Sphere of Influence

Earth Consultants International

Project Number: 2617
Date: February 2010

Census Tract Boundaries

Used in the HazUS Analyses

Figure 1-5

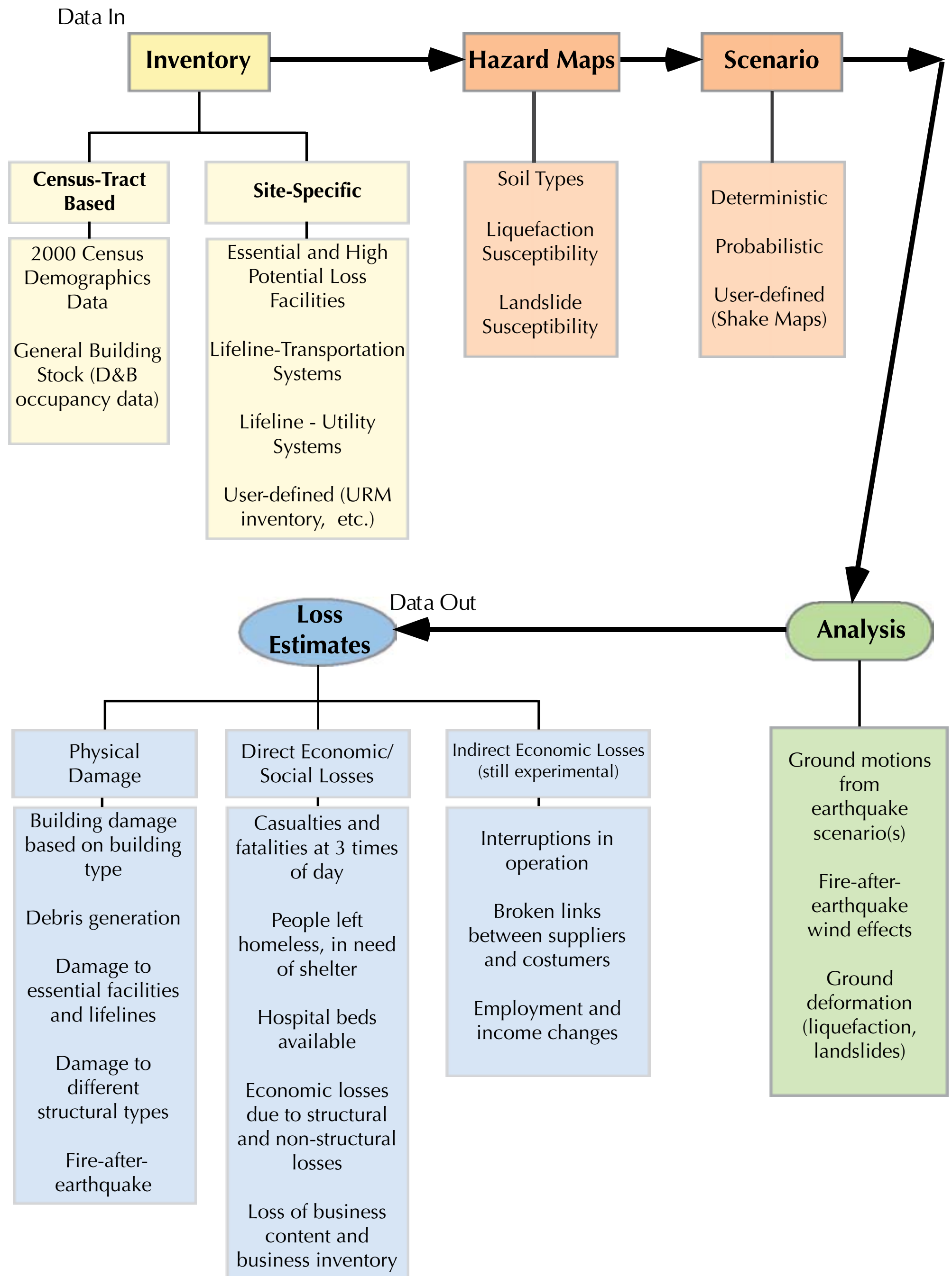
A different concern regarding the analysis is that the 2000 population numbers used are no longer applicable given that this is one of the fastest growing regions in southern California. Specifically, the City estimates that its 2006 population was 84,645, about a 26% increase since the year 2000. This increase in population is associated with a similar increase in housing in the area, consisting of several new large developments. Given this increase, it can reasonably be argued that the results presented here should be increased about 26% to account for the dramatic increase in population and housing. However, since HazUS considers a series of factors, including age and type of construction of the structures housing this population, and most of the casualties and damages are expected to be related preferentially to structures built to older building codes, a blanket 26% increase in the numbers would yield erroneously high loss estimates. For this reason, we chose to report the HazUS results without modification, recognizing that they are approximate and possibly about 10% short of the true numbers.

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

- HazUS is driven by statistics, and thus is most accurate when applied to a region, or a class of buildings or facilities. It is least accurate when considering a particular site, building or facility.
- Losses estimated for lifelines may be less than losses estimated for the general building stock.
- Losses from smaller (less than M 6.0) damaging earthquakes may be overestimated.
- Pilot and calibration studies have not yet provided an adequate test concerning the possible extent and effects of landsliding (although this is not a concern in most of Hesperia).
- The indirect economic loss module is still experimental. While output from pilot studies has generally been credible, this module requires further testing.
- The databases that HazUS draws from to make its estimates are often incomplete or as mentioned above, either do not perfectly match the boundaries of the desired study area, or are no longer representative of current conditions. In the case of Hesperia, the city has grown substantially since the 2000 Census.

1.8.1 Methodology, Terminology and Input Data Used in the Earthquake Loss Estimations for the City of Hesperia

The flow chart in Figure 1-6 illustrates the modules (or components) of a HazUS analysis. The HazUS software uses population data by census tract and general building stock data from Dunn & Bradstreet (DNB). Essential facilities and lifeline inventory are located by latitude and longitude. However, the HazUS inventory data for lifelines and utilities were developed at a national level and where specific data are lacking, statistical estimations are utilized. Specifics about the site-specific inventory data used in the models are discussed further in the paragraphs below. Other site-specific data used include soil types. The user then defines the earthquake scenario to be modeled, including the magnitude of the



Earth Consultants International

Project Number: 2617
Date: February 2010

Generalized Flow Chart Summarizing the HazUS Methodology

Figure 1-6

earthquake, and the location of the epicenter. Once all these data are input, the software calculates the loss estimates for each scenario.

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

<u>Critical Facilities</u>: HazUS breaks critical facilities into two groups: essential facilities and high potential loss (HPL) facilities. Essential facilities provide important services to the community and should be functional after an earthquake. Essential facilities include hospitals, medical clinics, schools, fire stations, police stations and emergency operations facilities. For Hesperia, the HazUS database shows one hospital with a total bed capacity of 83 beds (the Desert Valley Hospital located in Victorville, across the street from Hesperia), 23 schools, four fire stations, one police station and no dedicated emergency operations center (the Council Chambers is used as the EOC in the event of a disaster). Economic losses associated with these facilities are computed as part of the analysis of the general building stock. Data required for the analysis include occupancy classes (current building use) and building structural type, or a combination of essential facilities building type, design level and construction quality factor.

With respect to HPL facilities, the HazUS database shows zero dams in the region, no significant hazardous materials sites, no military installations, and no nuclear power plants. Although there are indeed no dams within the General Plan area, as Plate 3-2 shows, there are three dams near the Hesperia region, and at least two of them have the potential to inundate the low-lying areas along the Mojave River floodplain and Summit Valley if they fail. Similarly, as described in Chapter 5 of this document, there are at least four sites in the Hesperia area that use or produce significant quantities of hazardous materials (this list does not include the Hesperia Fire Lab site, a CERCLIS site that is not actively using or generating hazardous materials). Strong ground shaking during an earthquake could result in the accidental release of some of these compounds, with the potential to impact adjacent areas. For additional information regarding potential earthquake-induced damage to these facilities, refer to Sections 5.1.1 and 5.9 in Chapter 5.

<u>Transportation and Utility Lifelines</u>: HazUS divides the lifeline inventory into two systems: transportation and utility lifelines. The transportation system includes seven components: highways, railways, light rail, bus, ferry, ports, and airports. The utility lifelines include potable water, wastewater, natural gas, crude and refined oil, electric power, and communications. If site-specific lifeline utility data are not provided for these analyses, HazUS performs a statistical calculation based on the population served.

<u>General Building Stock Type and Classification</u>: HazUS provides damage data for buildings based on these structural types:

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

and based on these occupancy (usage) classifications:

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

<u>Building Damage Classification</u>: Loss estimation for the general building stock is averaged for each census tract. Building damage classifications range from slight to complete. As an example, the building damage classification for wood frame buildings is provided below. Wood-frame structures comprise the city's most numerous building type.

<u>Wood, Light Frame:</u>
Slight Structural Damage: Small cracks in the plaster or gypsum-board at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.

Moderate Structural Damage: Large cracks in the plaster or gypsum-board at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.

Extensive Structural Damage: Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of "room-over-garage" or other "soft-story" configurations; small foundations cracks.

Complete Structural Damage: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks.

Incorporation of Historic Building Code Design Functions: Estimates of building damage are provided for "High", "Moderate" and "Low" seismic design criteria. Buildings of newer construction (e.g., post-1973) are best designated by "high," indicating a higher resistance to earthquake damage than buildings classified as “moderate” or “low.” Buildings built after 1940, but before 1973, are best represented by "moderate." If built before about 1940 (i.e., before significant seismic codes were implemented), "low" is most appropriate. According to the 2000 census data, about 0.3% of the housing units in Hesperia date from 1939 and earlier, 12.6% of the housing units were built between 1940 and 1969, and the remaining 87% of the structures (in 2000) were built between 1970 and 2000. More recent data show that between 2000 and 2006, housing in Hesperia increased by about 26%. Therefore, most of the housing stock in Hesperia can be described as in the high seismic design criteria for earthquake resistance.

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

A complete fire-following-earthquake model requires extensive input about the readiness of local fire departments and the types and availability (functionality) of water systems. The fire following earthquake model presented here is simplified. With better understanding of fires that will be garnered after future earthquakes, forecasting capability will undoubtedly improve. For additional information regarding this topic, refer to Section 1.8.4.8 and Chapter 4.

Estimating Casualties: Casualties are estimated based on the assumption that there is a strong correlation between building damage (both structural and non-structural) and the number and severity of casualties. In smaller earthquakes, non-structural damage will most likely control the casualty estimates. In severe earthquakes where there will be a large number of collapses and partial collapses, there will be a proportionately larger number of fatalities. Data regarding earthquake-related injuries are not of the best quality, nor are they available for all building types. Available data often have insufficient information about the type of structure in which the casualties occurred and the casualty-generating mechanism. HazUS casualty estimates are based on the injury classification scale described in Table 1-3.

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

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

Table 1-3: Injury Classification Scale

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

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

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

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

1.8.2 HazUS Scenario Earthquakes for the Hesperia Area

Two specific scenario earthquakes were modeled using the HazUS-HMMH (Multi-Hazard) loss estimation software available from FEMA: an earthquake on the southern San Andreas fault rupturing the San Bernardino and Coachella segments, and an earthquake on the North Frontal Fault Zone. Specifics about each of these earthquake-producing faults are provided in Section 1.5 above, and in Table 1-4 below.

Table 1-4: HazUS Scenario Earthquakes for the City of Hesperia

Fault Source	Magnitude	Description
San Andreas - San Bernardino - Coachella segments	7.7	A large earthquake that ruptures both the San Bernardino and Coachella segments of the San Andreas fault is modeled because of its high probability of occurrence, and closeness to Hesperia.
Frontal Fault Zone	7.2	Low probability but high-risk earthquake event. The HazUS results indicate that this earthquake scenario has the potential to cause significant damage in Hesperia.

1.8.3 Inventory Data Used in the HazUS Loss Estimation Models for Hesperia

As mentioned previously, the population numbers used for the analyses are based on the 2000 Census data and the region encompassed by the census tract boundaries that best cover the Hesperia study area. As shown on Figure 1-5, the area covered in the HazUS analysis extends beyond the city's borders – the region analyzed is about 113 square miles in area and contains 16 census tracts (whereas the city of Hesperia is approximately 75 square miles in area and its Sphere of Influence covers an additional 32 square miles, for a total of about 107 square miles). Population in this region is increasing at a quick pace: the 2000 Census reported a population in the city of 68,442 (Hazus reports a 2000 population in the slightly larger area included in the analyses of 69,074, showing that the outlying areas were only lightly populated), but by 2006, the City estimates that its population had increased to 84,645. Therefore, the Hazus results may be under-representative of current conditions, although most damage is expected to occur in the older sections of town that were included in the analyses.

The HazUS database includes 21,000 buildings in the region, with a total building replacement value (excluding contents) of $3.754 billion. Approximately 99% of the buildings considered in the analysis (and 90% of the building value) are associated with residential housing (Hesperia estimates that in 2006, the number of occupied dwellings in the city is 26,456, for an increase from the 2000 numbers of about 26%, consistent with the 26% increase in population reported earlier). In terms of building construction types found in the region, wood-frame construction makes up approximately 93% of the building inventory. The remainder is distributed between the other general building types. The replacement value for the transportation and utility lifeline systems in the region is estimated at $1.53 billion and $58.1 million, respectively. This inventory includes over 261 kilometers (162 miles) of highways, 18 bridges, and 2,897 kilometers (1,800 miles) of pipes.

The HazUS inventory of unreinforced masonry (URM) buildings includes 16 structures, whereas the 2003 Seismic Safety Commission data indicate that there is only one URM in Hesperia. According to Mr. Regner of the Building and Safety Department (personal communication), there is indeed only one URM structure in Hesperia. Additional URMs could be present in the Sphere of Influence, but not 15 of them. Therefore, the HazUS numbers are over-representative of the URMs in the General Plan area. Since URMs are assigned a "Low" seismic design criteria and are considered likely to collapse or experience significant structural damage during an earthquake, the casualty numbers provided below may include a few victims associated with these non-existent URMs. However, the casualty numbers are primarily related to damaged residential structures, as discussed further in Sections 1.8.4.1 and 1.8.4.2, below.

1.8.4 Estimated Losses Associated with the Earthquake Scenarios

HazUS loss estimations for Hesperia based on the modeled earthquake scenarios are presented concurrently below. These scenarios include an earthquake that ruptures both the San Bernardino and Coachella segments of the San Andreas fault, and an earthquake on the West segment of the North Frontal fault. Of the two earthquake scenarios modeled for the city, the results indicate that a Mw 7.2 earthquake on the North Frontal fault has the potential to cause more damage in Hesperia than a larger, but more distant earthquake on the San Andreas fault.

1.8.4.1 Building Damage

HazUS estimates that between approximately 1,400 and 4,100 buildings will be at least moderately damaged in response to the earthquake scenarios presented herein, with the lower number representative of damage as a result of an earthquake on the San Andreas fault, and the higher number representing damage as a result of an earthquake on the North Frontal fault. These figures represent about 7 and 20%, respectively, of the total number of buildings in the region considered in the analysis. An estimated 80 to 750 buildings will be completely destroyed. Table 1-5 summarizes the expected damage to buildings by general occupancy type, whereas Table 1-6 summarizes the expected damage to buildings in the region, classified by construction type.

The data presented in Tables 1-5 and 1-6 show that most of the buildings damaged will be wood-frame residential structures. A high percentage of manufactured housing is also expected to be damaged. More specifically, the San Andreas fault earthquake scenario has the potential to cause at least slight damage to about 24% of the single-family residential structures in the Hesperia region, and moderate to complete damage to about 4% of the single-family residential stock. The North Frontal fault earthquake scenario has the potential to cause at least slight damage to about 58% of the single-family residential structures, and moderate to complete damage to about 17% of the single-family residential stock.

Table 1-5: Number of Buildings Damaged, by Occupancy Type

Scenario	Occupancy Type	Slight	Moderate	Extensive	Complete	Total
San Andreas	Agriculture	0	0	0	0	0
	Commercial	19	12	3	0	34
	Education	0	0	0	0	0
	Government	0	0	0	0	0
	Industrial	2	1	0	0	3
	Other Residential	380	412	160	22	974
	Religion	1	1	0	0	2
	Single Family	4,017	669	27	59	4,772
	Total	**4,419**	**1,095**	**190**	**81**	**5,785**
North Frontal	Agriculture	0	0	0	0	0
	Commercial	29	26	8	5	68
	Education	0	0	0	0	0
	Government	0	0	0	0	0
	Industrial	4	4	1	1	10
	Other Residential	407	458	195	75	1,135
	Religion	2	1	0	0	3
	Single Family	6,913	2,445	196	660	10,214
	Total	**7,355**	**2,934**	**400**	**741**	**11,430**

Table 1-6: Number of Buildings Damaged, by Construction Type

Scenario	Structure Type	Slight	Moderate	Extensive	Complete	Total
San Andreas	Wood	4,050	661	24	59	4,794
	Steel	9	7	2	0	18
	Concrete	9	5	1	0	15
	Precast	4	3	1	0	8
	Reinforced Masonry	31	22	5	1	59
	Unreinforced Masonry	3	2	0	0	5
	Manufactured Housing	313	395	157	21	886
	Total	**4,419**	**1,094**	**190**	**81**	**5,785**
North Frontal	Wood	6,980	2,435	183	663	10,261
	Steel	11	12	4	2	29
	Concrete	14	10	3	2	29
	Precast	6	8	3	1	18
	Reinforced Masonry	50	53	18	9	130
	Unreinforced Masonry	4	4	2	1	11
	Manufactured Housing	290	412	187	63	952
	Total	**7,355**	**2,934**	**400**	**741**	**11,430**

Multi-family residential structures, including condominiums and apartments, are expected to be impacted in even higher proportions, with the San Andreas fault earthquake scenario causing at least slight damage to about 63% of these structures. The North Frontal fault earthquake scenario would impact about 73% of the multi-family residential structures.

Similarly, the San Andreas fault scenario has the potential to cause moderate to complete damage to about 50% of the manufactured homes (mobile homes), whereas the North Frontal fault earthquake would cause moderate to complete damage to about 55% of these homes.

The commercial and industrial structures in the Hesperia region will also be impacted (Table 1-5), with the San Andreas fault earthquake scenario causing at least slight damage to about 30% and 20%, respectively, of the commercial and industrial buildings in the region. The North Frontal fault earthquake scenario is anticipated to cause at least slight damage to 59%, and 67%, respectively, of the commercial and industrial buildings in Hesperia.

1.8.4.2 Casualties

Table 1-7 provides a summary of the casualties estimated for these scenarios. The analysis indicates that the worst time for an earthquake to occur in Hesperia is during maximum residential occupancy, at 2 o'clock in the morning, when most people are at home. This is because, as Tables 1-5 and 1-6 above show, residential wood structures and manufactured housing are expected to experience a large proportion of the overall structural damage. The North Frontal fault earthquake scenario is anticipated to cause the largest number of casualties.

Table 1-7: Estimated Casualties

Type and Time of Scenario			**Level 1:** Medical treatment without hospitalization	**Level 2:** Hospitalization but not life threatening	**Level 3:** Hospitalization and life threatening	**Level 4:** Fatalities due to scenario event
San Andreas	2A.M. (max. residential occupancy)	Residential	30	5	0	0
		Non-Residential	1	0	0	3
		Commute	0	0	0	0
		Total	**31**	**5**	**0**	**0**
	2 P.M. (max educational, industrial, and commercial)	Residential	7	2	0	0
		Non-Residential	15	2	0	1
		Commute	0	0	0	0
		Total	**22**	**4**	**0**	**1**
	5 P.M. (peak commute time)	Residential	12	3	0	0
		Non-Residential	12	2	0	1
		Commute	0	0	0	0
		Total	**24**	**5**	**0**	**1**
North Frontal	2A.M. (max. residential occupancy)	Residential	176	39	3	4
		Non-Residential	2	0	0	0
		Commute	0	0	0	0
		Total	**178**	**39**	**3**	**4**
	2 P.M. (max educational, industrial, and commercial)	Residential	45	10	2	1
		Non-Residential	64	18	2	6
		Commute	0	0	0	0
		Total	**109**	**28**	**4**	**7**
	5 P.M. (peak commute time)	Residential	70	15	1	1
		Non-Residential	53	15	2	5
		Commute	0	0	1	0
		Total	**123**	**30**	**4**	**6**

The second worst time for an earthquake to occur in the region is during the peak commute time, at 5 o'clock in the afternoon. However, a closer review of the data shows that the casualties at this time are not related to commuters, but rather to residential occupancies. That is, at this time there is already a high proportion of individuals (i.e., children and caregivers) at home. The scenarios also show that about 40% to 50% of casualties at this time are expected to occur in the non-residential occupancies, which include commercial, educational, and industrial facilities. Comparison of these data with data in Table 1-5 shows that commercial and industrial facilities combined make up a large percentage of these non-residential casualties, possibly highlighting the structural deficiencies of precast, tilt-up concrete construction typical of many strip malls, shopping centers, warehouses and industrial complexes.

1.8.4.3 Essential Facility Damage

The loss estimation model calculates the total number of hospital beds in Hesperia that will be available after each earthquake scenario. HazUS calculates how many hospital beds will be available for use by patients already in the hospital and those injured by the earthquake on the day of the earthquake, one week after the earthquake, and 30 days (1 month) after the earthquake. The results of the earthquake scenarios are summarized below.

Table 1-8: Hospital Beds Available After the Earthquake Scenario

Scenario	# of beds available on day of earthquake	# of beds available 1 week after earthquake	# of beds available 30 days after earthquake
San Andreas	79	83	83
North Frontal	59	79	81

The regional hospital used in the analysis serves not only the city of Hesperia, but also Victorville, Apple Valley and other nearby communities that would also be impacted by the earthquake scenarios modeled for this study. That, coupled with the estimates of the number of injured people that will require hospitalization after an earthquake on the North Frontal fault (see Table 1-7), suggests that the regional hospital will be unable to meet the demand for medical care, especially immediately after the earthquake. Other hospitals in nearby cities could be expected to help, although given the regional impact that a magnitude 7.2 earthquake is likely to have, it is reasonable to expect that the other nearby hospitals will be similarly overwhelmed. The data suggest that an earthquake on the San Andreas fault, alternatively, will not place severe demands on the hospital, at least not as a result of casualties in Hesperia.

HazUS also estimates the damage to other essential facilities in the city, including schools, fire stations, and police stations. According to the model, an earthquake on the San Andreas fault will not cause significant damage to any of the schools, police stations or fire stations in Hesperia. A maximum magnitude earthquake on the North Frontal fault does have the potential to impact some of the essential facilities in Hesperia. Specifically, the North Frontal fault earthquake is anticipated to cause at least minor damage to 8 of the 23 schools in the area, and to 3 of the 4 fire stations (only 15 of the 23 schools, and 1 of the 4 fire stations are expected to be more than 50% functional the day of the earthquake). Furthermore, one of the fire stations is expected to suffer at least moderate damage.

Similarly, the police station is expected to experience minor damage so that it will not be more than 50% functional the day of the earthquake. This loss of functionality on the day of the earthquake may be in part related to non-structural damage, such as toppled bookshelves and computers, which would prevent these facilities from functioning immediately after the earthquake.

1.8.4.4 Economic Losses

The model estimates that total economic losses in the Hesperia area will range from about $98 million for an earthquake on the San Andreas fault, to nearly $392 million for an earthquake on the North Frontal fault (see Table 1-9 below). These figures include building- and lifeline-related losses based on the region's available inventory, and business interruption losses. Business interruption losses account for 5% to 6% of the losses in the region. The residential occupancies would suffer the most, comprising about 83% of the total loss in either earthquake scenario.

Table 1-9: Estimated Economic Losses

Scenario	Property Damage	Business Interruption	Total
San Andreas	$92.75 million	$5.4 million	$98.15 million
North Frontal	$382.62 million	$9.05 million	$391.67 million

Table 1-10: Building-Related Economic Loss Estimates (in millions of dollars)

		Area	Single-Family	Other Residential	Commercial	Industrial	Others	Total
San Andreas	Income Losses	Wage	0.00	0.02	1.41	0.08	0.04	1.55
		Capital-Related	0.00	0.01	1.21	0.05	0.01	1.28
		Rental	1.22	0.4	0.63	0.02	0.01	2.28
		Relocation	0.13	0.02	0.04	0.00	0.01	0.20
		Subtotal	1.35	0.44	3.29	0.16	0.07	5.31
	Capital Stock Loses	Structural	8.54	1.54	1.71	0.35	0.18	12.32
		Non-Structural	43.32	6.34	4.78	1.25	0.57	56.25
		Content	13.84	1.26	2.37	0.81	0.28	18.56
		Inventory	0.00	0.00	0.12	0.19	0.00	0.32
		Subtotal	65.70	9.14	8.97	2.60	1.03	87.45
		Total	**67.05**	**9.58**	**12.26**	**2.76**	**1.10**	**92.75**
North Frontal	Income Losses	Wage	0.00	0.05	4.60	0.27	0.13	5.04
		Capital-Related	0.00	0.02	3.59	0.17	0.04	3.82
		Rental	7.00	1.92	2.06	0.08	0.04	11.10
		Relocation	0.77	0.06	0.13	0.01	0.02	0.99
		Subtotal	7.77	2.05	10.38	0.53	0.22	20.94
	Capital Stock Loses	Structural	41.54	3.87	6.63	1.24	0.58	53.86
		Non-Structural	179.72	21.47	20.12	5.67	2.08	229.06
		Content	55.71	5.35	11.08	3.91	1.14	77.18
		Inventory	0.00	0.00	0.61	0.94	0.02	1.56
		Subtotal	276.97	30.69	38.44	11.76	3.82	361.67
		Total	**284.74**	**32.73**	**48.82**	**12.29**	**4.04**	**382.62**

Table 1-10 provides a summary of the estimated building-related economic losses anticipated as a result of the two earthquake scenarios considered herein. Table 1-10 shows that a substantial amount of the property damage is due to non-structural losses, that is, cosmetic damage to a structure that does not result in the collapse of the structure and is repairable. This is essentially what building codes are designed to do.

1.8.4.5 Transportation Damage

Damage to transportation systems in Hesperia is based on a generalized inventory of the region, which includes areas outside of the city, since the transportation network extends beyond corporate boundaries. Table 1-11 provides specific information about the damage estimates to specific components of the transportation system. Roadway segments and railroad tracks are assumed to be damaged by ground failure only. Since none of the faults considered in the HazUS analysis extend through Hesperia, damage as a result of ground failure is not considered likely.

Table 1-11: Expected Damage to the Transportation Systems

Scenario	System	Component	Locations/ Segments	With at Least Moderate Damage	With Complete Damage	Functionality >50%		Economic Loss (Millions $)
						After Day 1	*After Day 7*	
San Andreas	Highway	Segments	6	0	0	6	6	2.61
		Bridges	18	0	0	18	18	0.54
		Tunnels	0	0	0	0	0	0.00
	Railways	Segments	20	0	0	20	20	0.03
		Bridges	0	0	0	0	0	0.00
		Tunnels	0	0	0	0	0	0.00
		Facilities	0	0	0	0	0	0.00
	Bus	Facilities	1	0	0	1	1	0.13
	Airport	Facilities	1	0	0	1	1	1.18
		Runways	1	0	0	1	1	0.02
North Central	Highway	Segments	6	0	0	6	6	3.10
		Bridges	18	0	0	18	18	0.58
		Tunnels	0	0	0	0	0	0.00
	Railways	Segments	20	0	0	20	20	0.08
		Bridges	0	0	0	0	0	0.00
		Tunnels	0	0	0	0	0	0.00
		Facilities	0	0	0	0	0	0.00
	Bus	Facilities	1	0	0	1	1	0.4
	Airport	Facilities	1	1	0	1	1	2.38
		Runways	1	0	0	1	1	0.12

The facilities associated with the transportation systems considered herein, however, can be impacted by strong ground shaking. The analyses suggest that the transportation system in Hesperia will not be impacted significantly by either of the earthquake scenarios considered. In fact, all of the components in the transportation system are anticipated to be more than 50% functional on the day of the earthquake in Hesperia. Nevertheless, economic losses due to damage, albeit minor, to the transportation facilities amounts to between $4.5 and $6.7 million, with the lower figure associated with an earthquake on the

San Andreas fault. It is important to remember that these same transportation systems may be significantly impacted in other areas near Hesperia due to surface fault rupture, landsliding, liquefaction and other types of seismically induced ground deformation, which could directly and indirectly have an impact on Hesperia's residents (especially those that commute) and businesses that rely on products shipped on these transportation systems.

1.8.4.6 Utility Systems Damage

The HazUS inventory for the Hesperia region provides a site-specific length of pipelines for potable water, wastewater, natural gas and oil. From this inventory, the model calculates the expected number of leaks and breaks in the system. Table 1-12 summarizes the expected damage to these systems in Hesperia as a result of the earthquake scenarios on the San Andreas and North Frontal faults. The models suggest that the potable water, wastewater and natural gas systems in Hesperia will experience moderate damage as a result of an earthquake on either the San Andreas or North Frontal faults, with dozens of leaks and breaks anticipated in these systems. Where potable water and wastewater pipes occupy the same trench, leaks in both can result in contamination of the potable water supply.

Table 1-13 shows the expected performance of the potable water and electric power systems using empirical relationships based on the number of households served in the area. According to the models, earthquakes on the North Frontal fault has the potential to leave nearly 2,000 households without potable water for one or two days. Given these results, Hesperia residents should be strongly encouraged to store at a minimum, a 2-day supply of drinking water for the entire household (including pets), with a 7-day supply being preferable.

At least 6,000 residents are also expected to be without electricity for the few days after the earthquake. The damage estimates also show that whereas the potable water system may be mostly repaired two days after the earthquake, at least 200 households may be without electric power even a month after the earthquake. This may force many to seek shelter elsewhere, as discussed in the next section.

Table 1-12: Expected Utility System Pipeline Damage (Site Specific)

Scenario	System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks
San Andreas	Potable Water	1,449	58	22
	Wastewater	869	46	18
	Natural Gas	580	49	19
	Oil	0	0	0
North Frontal	Potable Water	1,449	96	71
	Wastewater	869	76	56
	Natural Gas	580	81	60
	Oil	0	0	0

Table 1-13: Expected Performance of Potable Water and Electric Power Services

Scenario	Utility	Number of Households without Service*				
		Day 1	Day 3	Day 7	Day 30	Day 90
San Andreas	Potable Water	0	0	0	0	0
	Electric Power	0	0	0	0	0
North Frontal	Potable Water	1,954	0	0	0	0
	Electric Power	5,918	3,387	1,253	228	9

*Based on Total Number of Households = 22,017

1.8.4.7 *Shelter Requirements*

HazUS estimates that approximately 74 households in Hesperia may be displaced due to the San Andreas fault earthquake modeled for this study (a household contains four people, on average). About 16 people will seek temporary shelter in public shelters (see Table 1-14 below). The rest of the displaced individuals are anticipated to seek shelter with family or friends. An earthquake on the North Frontal fault is anticipated to displace about 780 households, with approximately 200 people seeking temporary shelter. These numbers however, may be low, given the large Hispanic population in Hesperia. Hispanics, especially those of Mexican and Central American ancestry, generally prefer to camp out in parks and other open spaces rather than return to their house soon after an earthquake, even if their house appears to be undamaged. This was observed in the greater Los Angeles area following the 1994 Northridge earthquake, as well as other previous earthquakes in California, such as the 1987 Whittier Narrows and 1989 Loma Prieta earthquakes (Tierney, 1994; Tierney, 1995; Andrews, 1995).

Table 1-14: Estimated Shelter Requirements

Scenario	Displaced Households	People Needing Short-Term Shelter
San Andreas	74	16
North Frontal	783	200

1.8.4.8 *Fire Following Earthquake*

Fires often occur after an earthquake as a result of toppled stoves, sparks caused by downed electrical wires, leaks of flammable materials, and other reasons. The lack of water to fight the fires can then lead to many of these to burn out of control. HazUS uses a Monte Carlo simulation model to estimate the number of ignitions and the amount of burnt area as a result of an earthquake. For the San Andreas fault earthquake scenario ran for Hesperia, HazUS estimates 3 ignitions immediately following an earthquake. The burnt area resulting from these ignitions will vary depending on wind conditions. Normal wind conditions of about 10 miles per hour (mph) are expected to result in burn areas of about 0.04 square miles (0.03% of the region's total area). The model estimate that about 35 people will be displaced by fire, and the value of lost structures will be about $2.1 million. Similarly, an earthquake on the North Frontal fault is estimated to result in 2 ignitions that will burn about 0.04 square miles (0.03% of the region's total area). The model also estimates that about 58 people will be displaced by these fires, with the value of the lost structures amounting to about $3.7 million. If severe wind conditions are present at the time of these earthquakes, the burnt areas can be expected to be significantly larger.

Table 1-15: Fire-Following-Earthquake Losses

Scenario	Number of Ignitions	Population Exposed	Value Exposed (in thousands of $)
San Andreas	3	35	2,077
North Frontal	2	58	3,364

1.8.4.9 Debris Generation

HazUS estimates the amount of debris that will be generated by the scenario earthquakes. The model breaks the debris into two general categories: 1) brick/wood, and 2) concrete/steel. The distinction is made because of the different types of material-handling equipment required to handle the debris. The San Andreas earthquake is estimated to generate a total of 23,000 tons of debris, with brick/wood amounting to about 52% (12,000 tons) of this total. Removing this debris would require approximately 920 truckloads (at 25 tons/truckload). The model estimates that the North Frontal earthquake will generate 49,000 tons of brick and wood, and 50,000 tons of concrete and steel, for a total of 99,000 tons of debris. If the debris tonnage is converted to an estimated number of truckloads, it would require approximately 3,960 truckloads to remove the debris generated by this earthquake.

Table 1-16: Debris Generation (in Thousands of Tons)

Scenario	Brick, Wood & C	Concrete &	Total
San Andreas	12	11	23
North Frontal	49	50	99

1.9 Vulnerability of Structures to Earthquake Hazards

This section assesses the general earthquake vulnerability of structures and facilities common in the Hesperia area. This analysis is based on past earthquake performance of similar types of buildings in the U.S. The effects of design earthquakes on particular structures within the city are beyond the scope of this study.

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

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

1.9.1 Potentially Hazardous Buildings and Structures

Most of the loss of life and injuries due to an earthquake are related to the collapse of hazardous buildings and structures. FEMA (1985) defines a hazardous building as "any inadequately earthquake resistant building, located in a seismically active area, that presents a potential for life loss or serious injury when a damaging earthquake occurs." Building codes have generally been made more stringent following damaging earthquakes.

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

During an earthquake, buildings get thrown from side to side and up and down. Given the same acceleration, heavier buildings are subjected to higher forces than lightweight buildings. Damage occurs when structural members are overloaded, or when differential movements between different parts of the structure strain the structural components. Larger earthquakes and longer shaking duration tend to damage structures more. The level of damage can be predicted only in general terms, since no two buildings undergo the exact same motions, even in the same earthquake. Past earthquakes have shown us, however, that some types of buildings are far more likely to fail than others.

Unreinforced Masonry Buildings – Unreinforced masonry buildings (URMs) are prone to failure due to inadequate anchorage of the masonry walls to the roof and floor diaphragms, lack of steel reinforcing, the limited strength and ductility of the building materials, and sometimes, poor construction workmanship. Furthermore, as these buildings age, the bricks and mortar tend to deteriorate, making the buildings even weaker.

In response to the 1986 URM Law, Hesperia inventoried its URMs. In the year 2003, the City reported to the Seismic Safety Commission (SSC, 2003) that there is only one URM in Hesperia, the old school house, a building that is considered of historical significance, although it has not been designated as such.

Soft-Story Buildings – Of particular concern are soft-story buildings (buildings with a story, generally the first floor, lacking adequate strength or toughness due to too few shear walls). Apartments above glass-fronted stores, and buildings perched atop parking garages are common examples of soft-story buildings. Collapse of a soft story and “pancaking” of the remaining stories killed 16 people at the Northridge Meadows apartments during the 1994 Northridge earthquake (EERI, 1994). There are many other cases of soft-story collapses in past earthquakes. The City of Hesperia should consider conducting an inventory of their soft-stories, and encouraging the structural retrofit of these structures to withstand collapse during an earthquake.

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

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

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

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

<u>Reinforced Concrete Frame Buildings</u> – Reinforced concrete frame buildings, with or without reinforced infill walls, display low ductility. Earthquakes may cause shear failure (if there are large tie spacings in columns, or insufficient shear strength), column failure (due to inadequate rebar splices, inadequate reinforcing of beam-column joints, or insufficient tie anchorage), hinge deformation (due to lack of continuous beam reinforcement), and

non-structural damage (due to the relatively low stiffness of the frame). A common type of failure observed following the Northridge earthquake was confined column collapse (EERI, 1994), where infilling between columns confined the length of the columns that could move laterally in the earthquake.

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

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

<u>Mobile Homes</u> – Mobile homes are prefabricated housing units that are placed on isolated piers, jackstands, or masonry block foundations (usually without any positive anchorage). Floors and roofs of mobile homes are usually plywood, and outside surfaces are covered with sheet metal. Mobile homes typically do not perform well in earthquakes. Severe damage occurs when they fall off their supports, severing utility lines and piercing the floor with jackstands.

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

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

<u>Building Shape</u> – A building's vertical and/or horizontal shape can also be important. Simple, symmetric buildings generally perform better than non-symmetric buildings. During an earthquake, non-symmetric buildings tend to twist as well as shake. Wings on a building tend to act independently during an earthquake, resulting in differential

movements and cracking. The geometry of the lateral load-resisting systems also matters. For example, buildings with one or two walls made mostly of glass, while the remaining walls are made of concrete or brick, are at risk. Asymmetry in the placement of bracing systems that provide a building with earthquake resistance can result in twisting or differential motions.

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

1.9.2 Essential Facilities

Essential facilities are those parts of a community's infrastructure that must remain operational after an earthquake. Buildings that house essential services include schools, hospitals, fire and police stations, emergency operation centers, and communication centers. Plate 1-4 shows the locations of the city's fire stations, police station, schools, and other essential facilities. A vulnerability assessment for these facilities involves comparing their locations to potentially hazardous areas identified in the city, including areas underlain by active and potentially active faults (Plate 1-2), liquefaction-susceptible areas (Plate 1-3), potential flood areas due to either storm events (Plate 3-1) or dam failure inundation (Plate 3-2), and sites that generate, use or store hazardous materials (Plate 5-1).

High-risk facilities, if severely damaged, may result in a disaster far beyond the facilities themselves. Examples include power plants, dams and flood control structures, and industrial plants that use or store explosives, toxic materials or petroleum products.

High-occupancy facilities have the potential of resulting in a large number of casualties or crowd-control problems. This category includes high-rise buildings, large assembly facilities, and large multifamily residential complexes.

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

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

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

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

NOTES:

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

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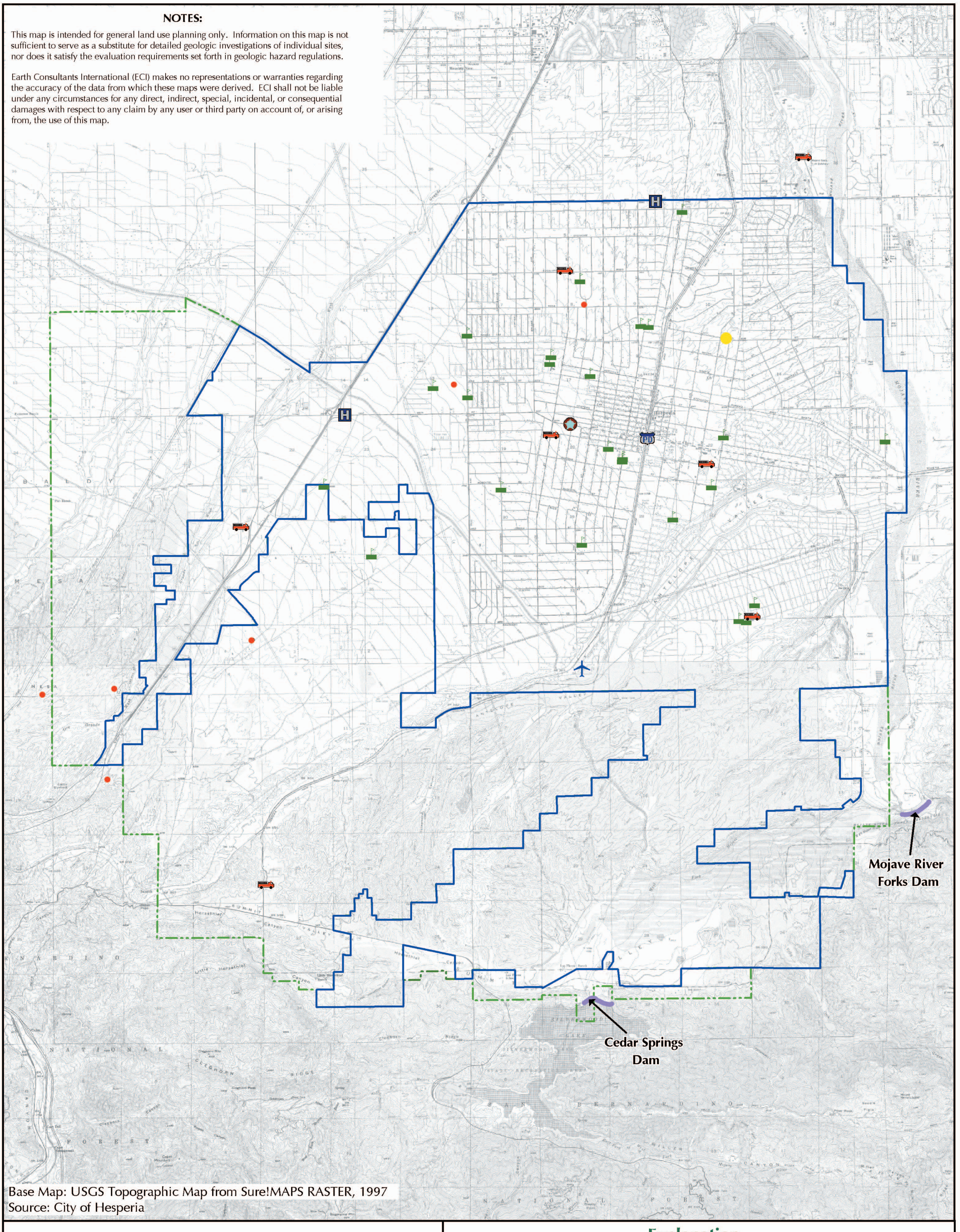

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Source: City of Hesperia

N
W E
S

0 7000 14000 Feet

0 2000 4000 Meters

Scale: 1:84,000

Explanation

- City Hall
- Fire Station
- Emergency Operations Center
- Hospital
- Police Station
- Schools
- Reservoir
- Hazardous Materials Drop Off Site
- Dam
- Airport
- Hesperia City Limit
- Hesperia Sphere of Influence

Earth Consultants International

Project Number: 2617
Date: February 2010

Critical Facilities Map

in and near Hesperia, California

Plate 1-4

- Patients, visitors, and medical, nursing, technical and support staff within and immediately outside the facility should be protected during an earthquake. Emergency utility systems in the facility should remain operational after an earthquake.
- Occupants should be able to evacuate the facility safely after an earthquake.
- Rescue and emergency workers should be able to enter the facility immediately after an earthquake and should encounter only minimum interference and danger.
- The facility should be available for its planned disaster response role after an earthquake.

1.9.3 Lifelines

Lifelines are those services that are critical to the health, safety and functioning of the community. They are particularly essential for emergency response and recovery after an earthquake. Furthermore, certain critical facilities designed to remain functional during and immediately after an earthquake may be able to provide only limited services if the lifelines they depend on are disrupted. Lifeline systems include water, sewage, electrical power, communication, transportation (highways, bridges, railroads, and airports), natural gas, and liquid fuel systems. The improved performance of lifelines in the 1994 Northridge earthquake, relative to the 1971 San Fernando earthquake, shows that the seismic codes upgraded and implemented after 1971 have been effective. Nevertheless, the impact of the Northridge earthquake on lifeline systems was widespread and illustrates the continued need to study earthquake impacts, to upgrade substandard elements in the systems, to provide redundancy in systems, to improve emergency response plans, and to provide adequate planning, budgeting and financing for seismic safety. Some of the lifelines in the city of Hesperia are shown in Plate 1-5. This plate, however, does not show all of the utility pipes that extend through the city, as there are so many that showing them would make the graphic unusable.

Water supply facilities, such as dams, reservoirs, pumping stations, water treatment plants, and distribution lines are especially critical after an earthquake, not only for drinking water, but to fight fires. Possible failure of reservoirs during an earthquake is discussed further in Chapter 3.

Some of the observations and lessons learned from the Northridge earthquake are summarized below (from Savage, 1995; Lund, 1996).

- Several electrical transmission towers were damaged or totally collapsed. Collapse was generally due to foundation distress in towers that were located near ridge tops where amplification of ground motion may have occurred. One collapse was the result of a seismically induced slope failure at the base of the tower.
- Damage to above ground water tanks typically occurred where piping and joints were rigidly connected to the tank, due to differential movement between the tank and the piping. Older steel tanks not seismically designed under current standards buckled at the bottom (called "elephant's foot"), in the shell, and on the roof. Modern steel and concrete tanks generally performed well.

NOTES:

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

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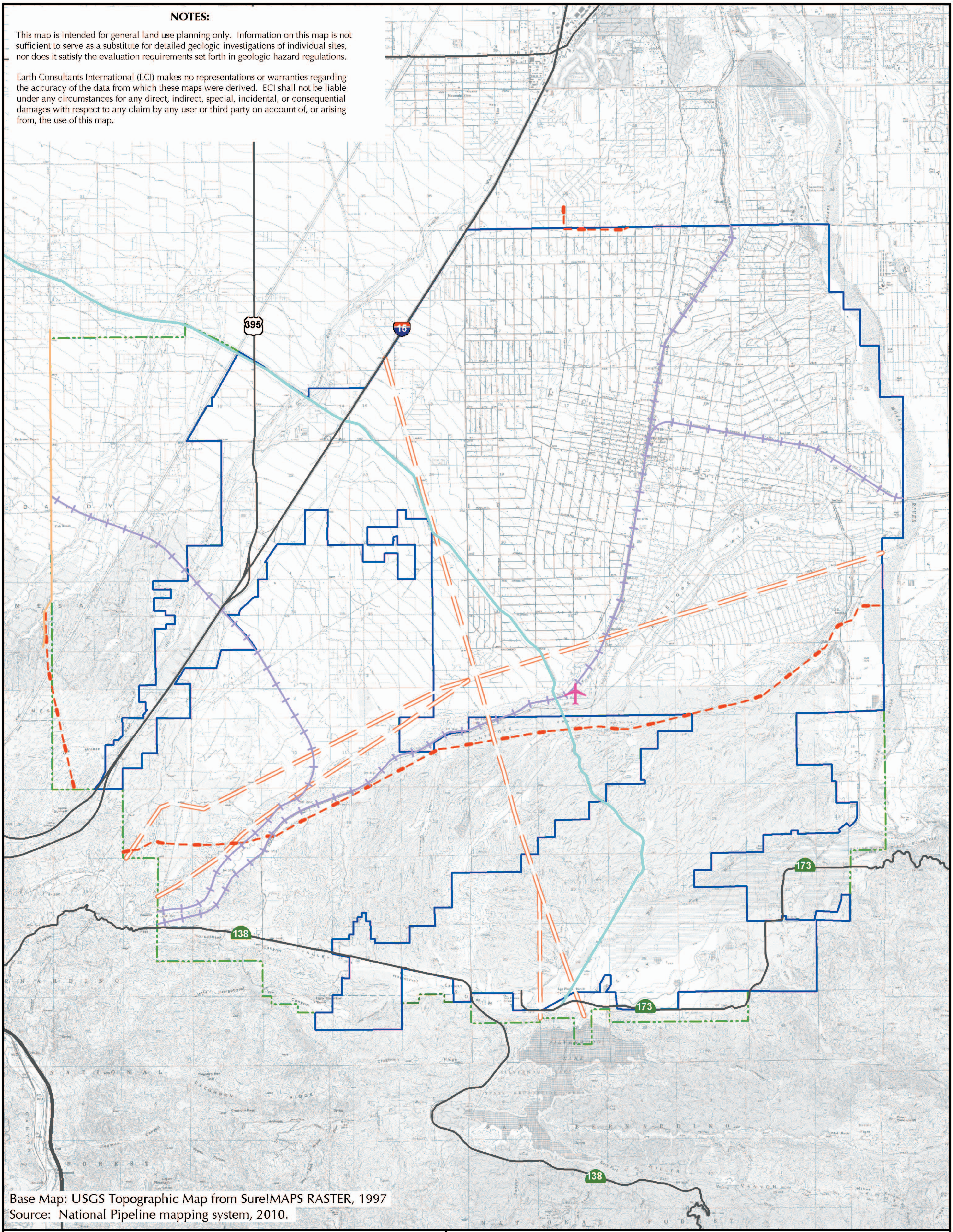


Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Source: National Pipeline mapping system, 2010.

N
W E
S

0 7000 14000 Feet

0 2000 4000 Meters

Scale: 1:84,000

Explanation

- California Aqueduct
- Railroad
- Power line
- Major Road
- Airport
- Approximate Location of Gas Transmission Pipeline
- Approximate Location of Hazardous Liquid Pipeline
- Hesperia City Limit
- Hesperia Sphere of Influence

HESPERIA

Earth Consultants International

Project Number: 2617
Date: February 2010

Major Utility and Lifelines Map

Hesperia, California

Plate 1-5

- The most vulnerable components of pipeline distribution systems were older threaded joints, cast iron valves, cast iron pipes with rigid joints, and older steel pipes weakened by corrosion. In the case of broken water lines, the loss of fire suppression water forced fire departments to utilize water from swimming pools and tanker trucks.
- Significant damage occurred in water treatment plants due to sloshing in large water basins.
- A number of facilities did not have an emergency power supply or did not have enough power supply capacity to provide their essential services.
- Lifelines within critical structures, such as hospitals and fire stations, may be vulnerable. For instance, rooftop mechanical and electrical equipment is not generally designed for seismic forces. During the Northridge quake, rooftop equipment failed causing malfunctions in other systems.
- A 70-year old crude oil pipeline leaked from a cracked weld, spreading oil for 12 miles down the Santa Clara River.

The above list is by no means a complete summary of the earthquake damage, but it does highlight some of the issues pertinent to the Hesperia area. All lifeline providers should make an evaluation of the seismic vulnerability within their systems a priority. The evaluation should include a plan to fund and schedule the needed seismic mitigation.

1.10 Reducing Earthquake Hazards in the City of Hesperia

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

Prioritizing rehabilitation and strengthening projects requires that the City consider where its resources would be better spent to reduce earthquake hazards in the existing development, and how the proposed mitigation programs can be implemented so as not to cause undue hardship on the community. Rehabilitation programs should target, on a priority basis, potentially hazardous buildings, critical facilities, and high-risk lifeline utilities. The City can best address rehabilitation issues. However, the hazard evaluation is intended to define the scope of the problem.

Recent earthquakes, with their relatively low loss of life, have demonstrated that the best mitigation technique in earthquake hazard reduction is the constant improvement of building codes with the incorporation of the lessons learned from past earthquakes. The most recent building codes (UBC 1997; CBC 2001; IBC, 2006; CBC, 2007) are prime examples of how incorporating past experience can further reduce the devastating effects of an earthquake. However, while new building codes reduce the hazard, increases in population leading to building in vulnerable areas and the aging of the existing building stock work toward increasing the earthquake hazard in a given region.

1.10.1 Building Code Impacts on the City of Hesperia

To mitigate for seismic shaking in new construction, recent building codes use amplification factors to account for the impacts that soft sediments and proximity to earthquake sources have on ground motion. Three main effects are considered: 1) soft soils, 2) proximity to earthquake sources (referred to as near-source factors), and 3) the seismic characteristics of the nearby earthquake sources (seismic source type).

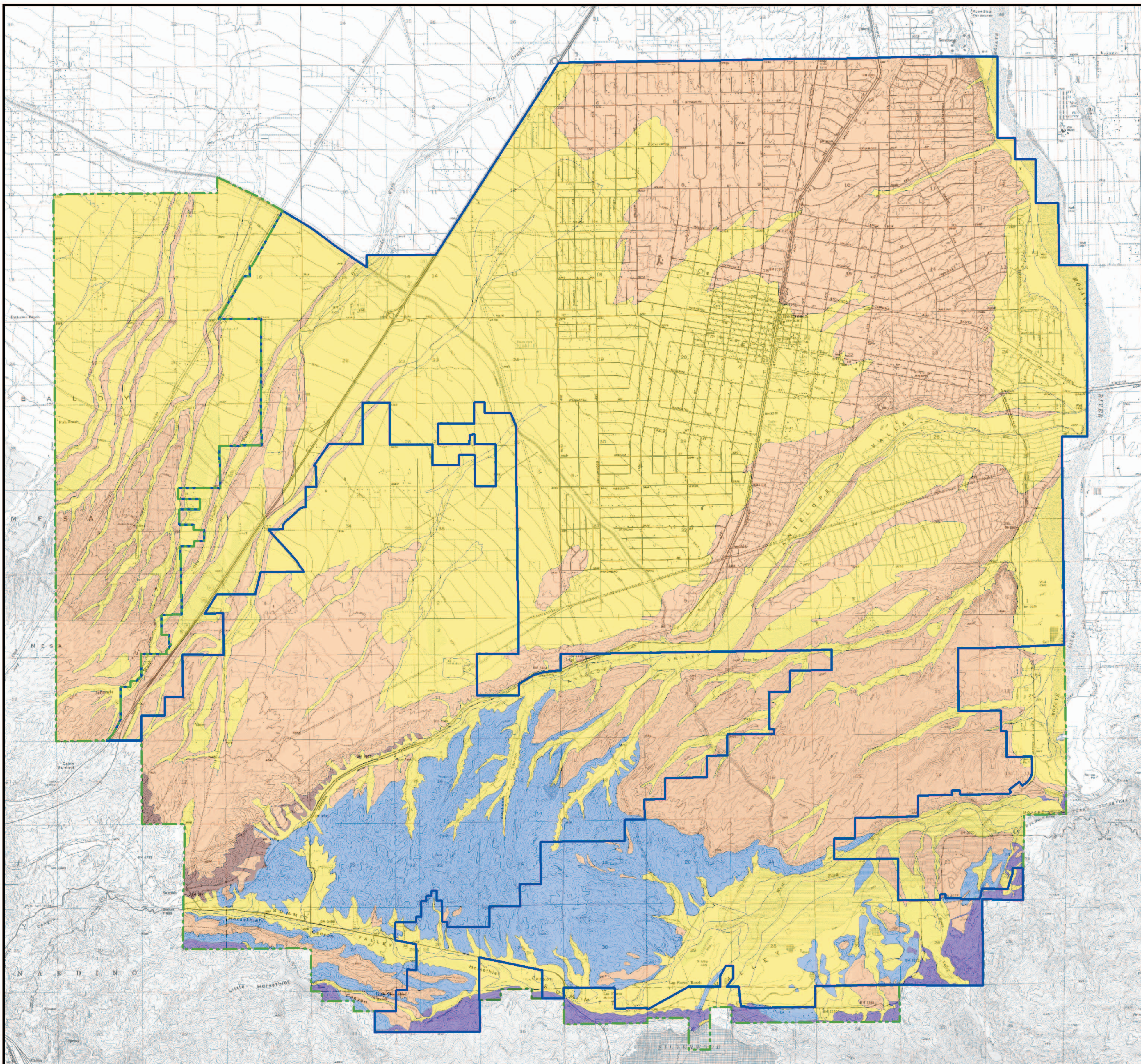
Soft-Soil Effects: The soft soil amplification factors were developed from observations made after the 1985 Mexico City, 1989 Loma Prieta and other earthquakes that showed the amplifying impact that underlying soil materials have on ground shaking. The ground-shaking basis for code design includes six soil types based on the average soil properties for the top 100 feet of the soil profile (see Table 1-17 and Plate 1-6).

Table 1-17: Site Class Definitions (Based on Soil Profile Types) (from CBC, 2007)

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

From Table 1613.5.2 of the 2007 California Building Code
Psf = pounds per square foot

Given the youthful, unconsolidated nature of the alluvial sediments underlying most of the city, a large portion of the Hesperia area can be designated as having a site class type E profile. Denser soils more characteristic of the class type D profile are also present throughout, in areas underlain by older sedimentary deposits. Denser soil profiles, described as rock or hard rock occur in the southern, less-developed portions of the city and its Sphere of Influence (see Plate 1-6). Mapping of these soil types in the General Plan area is based on published descriptions of the geologic units that occur in the area (see



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0 7000 14000 Feet

0 2000 4000 Meters

Scale: 1:84,000

N W E S

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D	Stiff soil profile	600 to 1,200	15 to 50	1,000 to 2,000
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	Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index PI > 20 2. Moisture Content w>= 40%, and 3. Undrained shear strength < 500 psf			
F	Any profile containing soil having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays, where the thickness of this section is more than 10 feet. 3. Very high plasticity clays (more than 25 feet of clay with plasticity index PI > 75). 4. Very thick soft/medium stiff clays (thickness of the soil > 120 feet).			

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Sources: Based on data from Morton and Miller, 2003 and Table 1613.5.2 of the 2007 California Building Code
psf = pounds per square foot

HESPERIA

Earth Consultants International

Project Number: 2617
Date: February 2010

Engineering Soil Types in
Hesperia, California
(In Accordance with 2007 California Building Code)

Plate 1-6

Plate 2-2). Site-specific studies designed to characterize the shear wave velocity and undrained shear strength of the soil column need to be conducted to confirm which site class is most applicable in the design analysis for a specific project.

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

Seismic Source Type*:* Near-source factors also include a classification of seismic sources based on slip rate and maximum magnitude potential. These parameters are used in the classification of three seismic source types (A, B and C) summarized on Table 1-18.

Table 1-18: Seismic Source Type

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

Type A faults are highly active and capable of producing large magnitude events. Most segments of the San Andreas fault, for example, are classified as Type A. The Type A slip rate (>5 mm/yr) is common only to tectonic plate boundary faults. Type C seismic sources are considered not capable of producing large magnitude events such that their potential ground shaking effects can be ignored. Type B sources include most of the active faults in California and include all faults that are neither Type A nor C. Type A faults near Hesperia include the San Andreas and San Jacinto faults. Type B faults in the region include the

Cleghorn, Cucamonga, Helendale-South Lockhart, Lenwood-Lockhart-Old Woman Springs, North Frontal and Sierra Madre faults (Cao et al., 2003).

To establish near-source factors for any proposed project in the city of Hesperia, the first step is to identify and locate the known active faults in the region. The International Conference of Building Officials (ICBO) has provided an Atlas of the location of known faults for California to accompany the 1997 UBC, although this map is now dated, and consultants should refer to more recent sources as well. The rules for measuring distance from a fault are provided by the 1997 UBC. The criteria for determining distance to vertical or near-vertical strike-slip faults, such as the San Andreas or San Jacinto faults, are relatively straightforward. However, the distance to thrust faults and blind thrust faults, such as the Cucamonga and North Frontal fault, is assumed as 0 for anywhere above the dipping fault plane to a depth of 10 kilometers. This greatly increases the areal extent of high ground shaking parameters, but is warranted based on observations of ground shaking at Northridge.

Summary: Seismic codes have been undergoing their most significant changes in history. These improvements are a result of experience in recent earthquakes, as well as extensive research under the National Earthquake Hazard Reduction Program (NEHRP). Inclusion of soil and near-field effects in the most recent building codes represents a meaningful and impactive change put forth by the geoscience community. Seismic codes will continue to improve with new versions of the building code, and as new data are obtained from both past and future earthquakes.

1.10.2 Retrofit and Strengthening of Existing Structures

Building codes are generally not retroactive, and past earthquakes have shown that many types of structures are potentially hazardous. Structures built before the lessons learned from the 1971 Sylmar earthquake are particularly susceptible to damage during an earthquake, including unreinforced masonry (URM) structures, pre-cast tilt-up concrete buildings, soft-story structures, unreinforced concrete buildings, as well as pre-1952 single-family structures. Other potentially hazardous buildings include irregular-shaped structures and mobile homes. Therefore, while the earthquake hazard mitigation improvements associated with the current building codes address new construction, the retrofit and strengthening of existing structures requires the adoption of ordinances.

Potentially hazardous buildings, such as pre-1971 concrete tilt-up structures and soft-story buildings should be inventoried. Potentially hazardous buildings can be identified and inventoried following the recommendations set forth in publications such as "Rapid Visual Screening of Buildings for Potential Seismic Hazards: Handbook and Supporting Documentation" and "A Handbook for Seismic Evaluation of Existing Buildings and Supporting Documentation", both prepared by the Applied Technology Council in Redwood City, California, and supplied by the Federal Emergency Management Agency (FEMA publications 154 and 155, and 175 and 178, respectively).

The building inventory phase of a seismic hazard mitigation program should accurately record the potentially hazardous buildings in an area. To do so, a GIS system is invaluable. The database should include information such as the location of the buildings, the date and type of construction, construction materials and type of structural framing system, structural conditions, number of floors, floor area, occupancy and relevant characteristics of the occupants (such as whether the building houses predominantly senior citizens, dependent care or handicapped residents, etc.), and information on structural elements or other characteristics of the building that may pose a threat to life.

Once buildings are identified as potentially hazardous, a second, more thorough analysis may be conducted. This step may be carried out by local officials, such as the City's Building and Safety Department, or building owners may be required to submit a review by a certified structural engineer that has conducted an assessment of the structural and non-structural elements and general condition of the building, and has reviewed the building's construction documents (if available). The nonstructural elements should include the architectural, electrical and mechanical systems of the structure. Cornices, parapets, chimneys and other overhanging projections should be addressed too, especially in areas with high pedestrian traffic, as these may pose a significant threat to passersby, and to individuals who, in fear, may step out of the building during an earthquake. State of repair of buildings should also be noted, including cracks, rot, corrosion, and lack of maintenance, as these conditions may decrease the seismic strength of a structure. Occupancy should be noted as this factor is very useful in prioritizing the buildings to be abated for seismic hazards.

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

With the inventory and analysis phases complete, a retrofit program can be implemented. Although retrofit buildings may still incur severe damage during an earthquake, the mitigation results in a substantial reduction of casualties by preventing collapse. The societal and economic implications of rehabilitating existing buildings are discussed in many publications, including "Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings – A Handbook and Supporting Report," and "Typical Costs for Seismic Rehabilitation of Existing Buildings: Summary and Supporting Documentation," (FEMA Publications 174 and 173, and 156 and 157, respectively). Another appropriate source is the publication prepared by Building Technology, Inc. entitled "Financial Incentives for Seismic Rehabilitation of Hazardous Buildings – An Agenda for Action" (Report and Appendices).

The City of Hesperia should set a list of priorities by which strengthening of the buildings identified as hazardous will be established and conducted. Currently, there are no Federal or State mandated criteria established to determine the required structural seismic resistance capacity of structures. Retrofitting to meet the most current CBC standards may be cost-prohibitive, and therefore, not feasible. The City may develop its own set of criteria, however, this task should be carried out following a comprehensive development and review process that involves experienced structural engineers, building officials, insurance representatives, and legal authorities. Selection of the criteria by which the structural seismic resistance capacity of structures will be measured may follow a review of the performance during an earthquake of similar types of buildings that had been retrofit prior to the seismic event. Upgrading potentially hazardous buildings to, for example, 1973 standards may prove inefficient if past examples show that similar buildings retrofit to 1973 construction codes performed poorly during a particular earthquake, and had to be demolished anyway. Issues to be addressed include justification for strengthening a building to a performance level less than the current code requirements, the potential liabilities and limitations on liability, and the acceptable damage to the structure after strengthening (FEMA, 1985).

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

1.11 Summary and Recommendations

Since it is not possible to prevent an earthquake from occurring, local governments, emergency relief organizations, and residents are advised to take action and develop and implement policies and programs aimed at reducing the effects of earthquakes. Individuals should also exercise prudent planning to provide for themselves and their families in the aftermath of an earthquake.

<u>Earthquake Sources:</u>

- There are no known earthquake sources within the Hesperia General Plan area. However, Hesperia is close to the North Frontal, Cleghorn, and San Andreas faults (within 15 km or 9 miles). Therefore, proposed new developments in Hesperia should incorporate near-source factors in the design of the structures. Specifically, near-source factors need to be used if the proposed structure is located within 10 km of a Type A fault (the San Andreas fault), or within 5 km of any of the Type B faults (Cleghorn or North Frontal faults).

- A number of historic earthquakes have caused strong ground shaking in Hesperia. Strong ground shaking due to future earthquakes on nearby regional sources should be expected and designed for.

<u>Design Earthquake Scenarios:</u>

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

- The North Frontal, San Andreas, and Cleghorn faults have the potential to generate earthquakes that would be felt strongly in the Hesperia region. Unfortunately, we cannot predict when a fault will break causing an earthquake, but we can anticipate the size of the resulting earthquake and estimate the level of damage that the earthquake would generate in the region. The North Frontal fault is though capable of generating an earthquake of magnitude 7.2. The San Andreas fault is thought capable of generating an earthquake of magnitude between 7.4 and 8.0, depending on how many segments of the fault rupture together during a single event. The Cleghorn fault is thought capable of generating a magnitude 6.5 earthquake. With the exception of the Cleghorn, most other faults within 100 km (62 miles) of the city can generate earthquakes as large or larger than the M_w 6.7 Northridge earthquake, the single most-expensive earthquake yet to impact the United States.

- The loss estimation analyses conducted for this study indicate that the North Frontal fault has the potential to be the worst-case scenario for Hesperia, causing moderate to significant damage in the city. Although capable of generating a larger magnitude earthquake, the San Andreas fault is not expected to cause as much damage in Hesperia.

<u>Fault Rupture and Secondary Earthquake Effects:</u>

- A few potentially active faults have been mapped near the southern boundary of the General Plan area, but no Alquist-Priolo Earthquake Fault Zones have not been defined within the Hesperia area. These faults are potentially active because they have not been studied in sufficient detail to determine their recency of activity and relationship to other nearby faults that have been shown to the active. Specifically, some of the north- to north-east trending faults near the city's southeastern boundary may be carrying some of the slip from the North Frontal fault. These and the east-west trending faults along the study area's southern boundary could also move, albeit slightly, in response to an earthquake on a nearby fault such as the San Andreas fault. As a result, if a critical facility (either high-risk or high-occupancy) is proposed across the trace of any of these faults, geological studies to evaluate its recency of activity and future surface fault rupture potential should be conducted as a condition of approval prior to development. These studies should be conducted to the level of detail required by California Geological Survey for fault studies under the purview of the Alquist-Priolo Act. If these studies determine that the fault trace of concern is active, structural setbacks or other measures designed to mitigate the potential for future surface fault rupture should be implemented.

- The California Geological Survey (CGS) has not conducted mapping in the Hesperia area under the Seismic Hazards Mapping Act. This report presents a liquefaction susceptibility map that was prepared using a similar but simpler form of the method used by the California Geological Survey (geotechnical data providing density of the near-surface sediments were not reviewed). Studies in accordance with the guidelines prepared by the CGS should be conducted in those areas identified as susceptible to liquefaction, at least until sufficient studies have conclusively shown whether or not the sediments are indeed susceptible to liquefaction. Currently, shallow ground water levels (less than 30 feet from the ground surface) are known to occur in the Mojave River floodplain, especially near the recharge outlets and reclaimed water discharge locations. Increased dependence on imported water could lead to decreased pumping for ground water, which could result in an even higher groundwater table in the floodplain. Groundwater levels in the areas elevated above the Mojave River channel are reportedly in the hundreds of feet, so an increase in water levels in these areas due to decreased pumping rates is not anticipated to result in liquefaction susceptibility. Development in the floodplain should be discouraged given the potential for storm-induced or dam-failure flooding, liquefaction, and other environmental concerns associated with the protection of riparian vegetation and fauna. However, in the event that infrastructure or other projects are proposed in this area, liquefaction evaluation studies following the guidelines established by the CGS should be conducted and if liquefaction is found to be a hazard, mitigation measures should be implemented.

- Given that most of the developed area in Hesperia has low relief, the hazard of seismically induced slope failure in the General Plan area is low. However, slope damage in the San Bernardino Mountains and foothills to the south could impact the highways and roads that provide access to Hesperia, with substantial impacts to Hesperia residents and businesses.

- Some parts of Hesperia may be susceptible to seismically induced settlement given the youthfulness and unconsolidated nature of the alluvial deposits that underlie the region. Geotechnical studies to evaluate this potential hazard should be conducted in areas underlain by Holocene sediments where developments are proposed. If the sediments are found to be susceptible to this hazard, mitigation measures designed to reduce settlement should be incorporated into the design.

<u>Earthquake Hazard Reduction</u>:

- Most of the loss of life and injuries that occur during an earthquake are related to the collapse of hazardous buildings and structures, or from non-structural components, including contents, in those buildings. The HazUS analyses conducted for this study indicate that a large percentage of the single-family, wood-frame structures in Hesperia are anticipated to experience at least slight damage during an earthquake. The total losses expected as a result of any of these earthquakes are in the millions of dollars.

- The HazUS results indicate that dozens of people could be injured if and when an earthquake strikes the region during the night, when a large portion of the population is at home. A lesser, but still significant number of casualties is associated with damage to commercial and industrial facilities.

- The regional hospital may not be able to meet the demand for medical care in the aftermath of an earthquake in the area. An inventory of regional hospitals should be conducted in advance of the next earthquake to identify alternate medical care providers. Ultimately, more hospitals should be planned and built in this area to accommodate the large increase in population that this region has experienced in the last decade, and the increase in population expected in the decades to come.

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

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

- The eastern and southern portions of Hesperia are subject to near-source design factors because the city is located near three active fault systems (North Frontal fault to the east, San Andreas and Cleghorn faults to the south).

- While the earthquake hazard mitigation improvements associated with the latest building code address new construction, the retrofit and strengthening of existing structures requires the adoption of ordinances. The City of Hesperia should consider the implementation of a mandatory ordinance aimed at retrofitting older wood-frame residential buildings, pre-cast concrete buildings, and soft-story structures, among others. Although retrofitted buildings may still incur severe damage during an earthquake, their mitigation results in a substantial reduction of casualties by preventing collapse.

- Adoption of new building codes does not mitigate local secondary earthquake hazards such as liquefaction and ground failure. Therefore, these issues are best mitigated at the local level. Avoiding areas susceptible to earthquake-induced liquefaction or settlement is generally not feasible. The best alternative for the City is to require "special studies" within these zones for new construction, as well as for significant redevelopment, and require implementation of the engineering recommendations for mitigation.

- Effective management of seismic hazards in Hesperia includes technical review of consulting reports submitted to the City. For projects in areas susceptible to liquefaction, the City should consider following the State law that requires that the reviewer be a licensed engineering geologist and/or civil engineer having competence in the evaluation and mitigation of seismic hazards (CCR Title 14, Section 3724). Because of the interrelated nature of geology, seismology, and engineering, most projects will benefit from review by both the geologist and civil engineer. The California Geological Survey has published guidelines to assist reviewers in evaluating site-investigation reports (CDMG, 1997; CGS, 2008).

- The HazUS analyses suggest that the potable water, wastewater and electric systems in Hesperia will be slightly to moderately damaged by an earthquake on the North Frontal fault. The City and its lifeline service providers should consider retrofitting the existing pipelines, replacing the older lines first.

CHAPTER 2: GEOLOGIC HAZARDS

2.1 Physiographic Setting

Hesperia lies across the boundary of two very distinct geomorphic provinces, each having a unique landscape formed by geologic, topographic, and climatic processes. The very southern edge of the city encroaches into the Transverse Ranges Province, a region whose characteristic features are a series of east-west trending ranges that include the San Gabriel and San Bernardino Mountains. The ranges are called "transverse" because they lie at an oblique angle to the prominent northwesterly grain of the southern California landscape, a trend that is aligned with the San Andreas fault. The Transverse Ranges are being intensely compressed by active tectonic forces, therefore they are some of the fastest rising (and fastest eroding) mountains in the world.

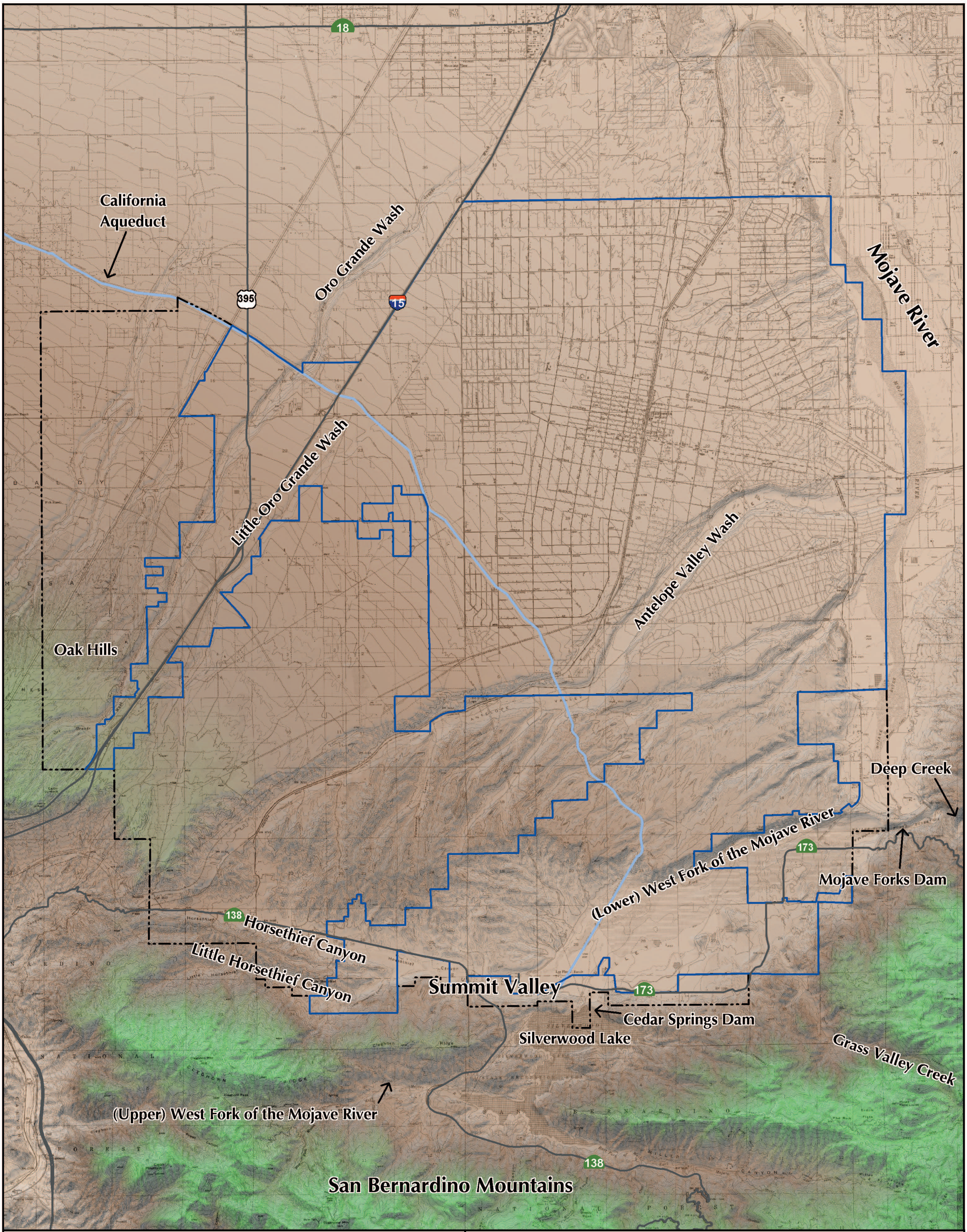
North of the mountains, the greater part of Hesperia lies within the Mojave Desert Province, an arid region of alluvial fans, desert plains, dry lakebeds, and scattered mountain ranges. This province covers a large portion of eastern California, stretching from the southern end of the Sierra Nevada Mountains to the Colorado River. Faults in the Mojave Desert Province have a predominant northwesterly trend; however, some faults with a trend more aligned with the Transverse Ranges are also present. The east-west trending Garlock fault defines the northern boundary of the province, whereas the northwest-trending San Andreas fault roughly defines its western boundary.

The central and northern parts of the city lie upon a moderately to gently sloping alluvial fan. Ranging in elevation from about 4,200 feet at the top of the fan to about 2,900 feet at the Mojave River, the lower reaches of the fan are the most densely populated. The southern part of the city, which encompasses low foothills and a broad valley (Summit Valley area), is very sparsely populated. The southernmost boundary of the city encroaches onto the base of the rugged San Bernardino Mountains, with parts of the city lying inside the National Forest. Farther south, the mountains rise to an elevation of more than 6,000 feet. One of the most prominent features in Hesperia is the Mojave River, a wide floodplain that defines the city's eastern boundary. Nearly every drainage channel in the region eventually reaches the river, making it the largest drainage system in the Mojave Desert, and one of the largest in southern California (Plate 2-1).

Hesperia is located within the high desert portion of the Inland Empire, an area that is rapidly changing. In fact, this region, which includes San Bernardino and Riverside counties, has the fastest growing populations in all of California. Hesperia is no exception, with its current population of approximately 84,000 residents expected to double by the year 2025. Development on the alluvial fan is expanding westward and into the upper reaches of the fan. Widely scattered semi-rural development is present in Summit Valley and the foothills, however large-scale master planned developments have been proposed for the Summit Valley area. Future developments and the associated infrastructure will be increasingly impacted by geologic hazards, such as flooding and slope stability, unless coordinated mitigation measures are developed on both a regional and site-specific basis.

2.2 Geologic Setting

The physical features described above reflect geologic and climatic processes that have affected this region in the last few million years. The most striking feature is the dramatic contrast between



N
W E
S

0 7000 14000 Feet

0 2000 4000 Meters

Scale: 1:84,000

Explanation

Elevation Shading (meters)

500 1000 1500 2000

Hesperia City Limit

Hesperia Sphere of Influence

Base Map: USGS 30-meter Digital Elevation Model.

Earth Consultants International

Project Number: 2617
Date: February 2010

Physiographic Map of Hesperia, California and Surrounding Areas

Plate 2-1

the Mojave Desert and the adjacent mountains – a direct result of movement along faults that have both elevated and down-dropped great blocks of the Earth's crust. As a result, the mountain ranges that form the backdrop to Hesperia are composed of rocks that have been sheared and intensely fractured under the strain of tectonic movement. Along the base of the mountains, multiple generations of overlapping alluvial fans have a range of ages coincident with the rise of the mountains. Hesperia is underlain by the informally named Victorville Fan (Morton and Miller, 2003) and is composed of sediments ranging in age from early Pleistocene to Holocene (approximately 1 million years to less than 10,000 years old). Because the Victorville Fan was constructed with sediments shed primarily from the San Gabriel Mountains, their composition reflects that of the rocks eroded by the various streams that entered the valley from the south.

Within the eastern and southwestern parts of the city, older, highly dissected fan surfaces are widespread. In the eastern part of the foothills, south of Antelope Valley Wash, the deeply channeled fan surface forms a broad plateau. In Summit Valley, remnants of the older fans can only be found in isolated areas, generally capping low ridges. In the central to northwestern parts of the city, younger fan sediments blanket the eroded surface of the older deposits. Deposition is still ongoing, with the youngest alluvium filling drainage channels and the Mojave River floodplain. At depth, this sequence of alluvial sediments is underlain by crystalline bedrock similar to that exposed in the San Bernardino Mountains to the south.

The physiography and geologic history of the Hesperia area are important in that they control to a great extent the geologic hazards, as well as the natural resources, within the city. For example, the city receives great quantities of runoff from the nearby mountains during storms, leading to flooding problems within the developed areas. Regional tectonic subsidence along the valley floor, concurrent with uplift of the adjacent mountains, is responsible to a great extent for the rapid deposition of poorly consolidated alluvium that is susceptible to consolidation and/or collapse. On the other hand, the deep alluvium-filled basin, which is bounded by relatively impermeable rock and faults, provides a natural underground reservoir (aquifer) for ground water, the city's source of all its domestic water.

2.3 Geologic Units and Their Engineering Properties

The geologic units in Hesperia consist mainly of water-laid sand, silt, and gravel. The various alluvial units and their estimated ages have been categorized by researchers primarily by noting the degree of soil development on the fan surface, stratigraphic position, degree of stream incision, relative uplift, and other physical characteristics. Most of these units do not have formal names, but they have been labeled with symbols that emphasize their age and mode of deposition. A few older sedimentary units in the region have been given formal names, and the oldest rock units, exposed in the San Bernardino Mountains, are named primarily for their texture and mineral composition. The general distribution of geologic units that are exposed at the surface is shown on the Geologic Map (Plates 2-2 and 2-2a). In the section that follows, the characteristics of each unit are discussed using the nomenclature and descriptions published by Morton and Miller (2003). The units are described in the following pages, from youngest to oldest.

2.3.1 Artificial Fill

There are many deposits of man-made fill throughout the city, including, most notably, man-made fills associated with roadway, bridge, and railway embankments; levees; and graded developments. These deposits vary widely in size, age, and composition, and

NOTES:

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

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

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

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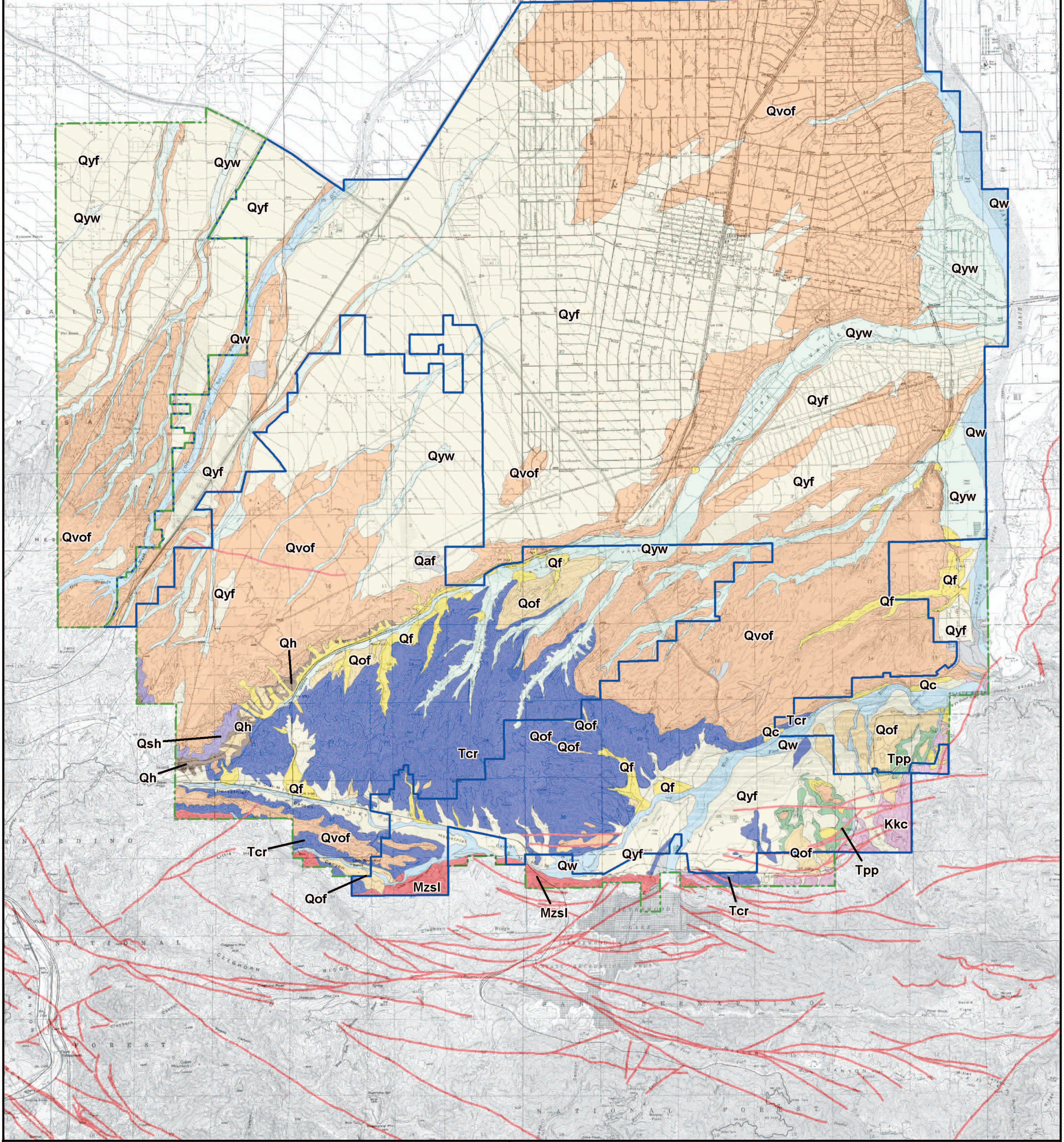

N
W E
S

0 7000 14000 Feet

0 2000 4000 Meters

Scale: 1:84,000

For Geologic Unit Descriptions See Plate 2-2b

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Source: Morton and Miller, 2003

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Date: February 2010

Geologic Map

Hesperia, California

Plate 2-2a

Symbols

Fault	Fault; solid where location known, dashed where approximate, dotted where concealed. (for more information refer to Plate 1-2)
Geologic Contact	Geologic Contact
Hesperia City Boundary	Hesperia City Boundary
Hesperia Sphere of Influence	Hesperia Sphere of Influence

Geologic Unit Descriptions

Cenozoic	Quaternary	Holocene	Qaf	Artificial Fill- Not all fill areas are shown
Cenozoic	Quaternary	Holocene	Qf	Very Young Alluvial Fan Deposits- Unconsolidated silt, sand, and gravel on active and recently active fans
Cenozoic	Quaternary	Holocene	Qw	Very Young Wash Deposits- Unconsolidated sand, gravel, cobbles, and boulders in active washes
Cenozoic	Quaternary	Holocene	Qc	Very Young Colluvium- Unconsolidated silt and sand in drainage swales and on toes of natural slopes
Cenozoic	Quaternary	Holocene / Pleistocene	Qyf	Young Alluvial Fan Deposits- Unconsolidated to slightly consolidated silt and sand; locally with gravel
Cenozoic	Quaternary	Holocene / Pleistocene	Qyw	Young Wash Deposits- Unconsolidated to slightly consolidated silt, sand, and cobbles in the marginal parts of active and recently active washes
Cenozoic	Quaternary	Pleistocene	Qof	Old Alluvial Fan Deposits- Moderate to well consolidated silt, sand, and gravel
Cenozoic	Quaternary	Pleistocene	Qvof	Very Old Alluvial Fan Deposits- Well consolidated sand with minor gravel
Cenozoic	Quaternary	Pleistocene	Qsh	Shoemaker Gravel- Conglomerate and sandstone
Cenozoic	Quaternary	Pleistocene	Qh	Harold Formation- Sandstone and conglomeratic sandstone, with minor conglomerate
Cenozoic	Tertiary	Pliocene	Tpp	Phelan Peak Deposits- Claystone and siltstone
Cenozoic	Tertiary	Miocene	Tcr	Crowder Formation- Sandstone, pebbly sandstone, and conglomerate
Mesozoic	Triassic - Cretaceous		Kkc	Monzogranite of Kinley Creek- Quartz-rich muscovite-biotite monzogranite
Mesozoic			Mzsl	Mixed granitic rocks of Silverwood Lake- Biotite granodiorite and monzogranite; hornblende-biotite quartz monzonite, quartz monzodiorite, and tonalite; hornblende monzonite

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Explanation for Geologic Map

Plate 2-2b

although some may cover a significant area, due to the scale of Plate 2-2, most are not shown on the Geologic Map.

2.3.2 Very Young Sediments: Alluvial Fan, Wash, and Colluvium Deposits (Map Symbols Qf, Qw, and Qc)

Very young alluvial fan deposits (Qf) are present chiefly as small fans emanating from canyons and channels tributary to the upper reaches of Antelope Valley Wash, the West Fork of the Mojave River, and Horsethief Canyon. These sediments are unconsolidated to slightly compacted, lack soil development, are undissected, and generally consist of poorly bedded silt, sand, and gravel.

Very young wash deposits (Qw) consist of unconsolidated sand and gravel lining active drainage courses, including Oro Grande Wash, Horsethief Creek, West Fork of the Mojave River, and the Mojave River floodplain (Figure 2-1). Although too small to show on Plate 2-2, nearly all of the drainages west of the Mojave River have narrow, active channels that are filled with young, recently deposited sediments. North of the foothills, these sediments consist primarily of fine- to very coarse-grained sand with a lesser amount of gravel and pebbles. These deposits have no soil development on the surface, and may be reworked or buried by new sediment during winter storms. The upper reaches of the drainages, especially near the mountains may contain large boulders deposited during flash floods.

Figure 2-1: Very Young Wash Deposits in Horsethief Creek.
These sediments consist primarily of unconsolidated sand, gravel, and small boulders.

Modern colluvium (Qc) is similar in character to the Qf deposits. In hillside areas, colluvium is commonly present lining drainage swales and along the toes of natural slopes, where it has accumulated from a combination of slope wash and in-place weathering of the underlying units. Colluvial deposits are typically massive, unconsolidated, and may contain organic material.

2.3.3 Young Sediments: Alluvial Fan and Wash Deposits (Map Symbols Qyf and Qyw)

Young alluvial fan deposits (Qyf) of middle to late Holocene age form a veneer of relatively uniform silt and sand with scattered gravel over much of the central part of the city. Near the mountains, above the Mojave Forks Dam, these deposits may contain cobbles and boulders. The surface of this unit is slightly to moderately dissected by stream channels resulting in low amplitude ridges and swales.

Young wash deposits (Qyw) include unconsolidated to slightly consolidated silt, sand, and cobbles lining well-developed drainage channels and in localized areas along the west side of the Mojave River. These units differ from those described in Section 2.3.2 in that they are typically elevated above, and incised by, the active channel containing the modern wash sediments (Qw). Young wash deposits are typically of low density and have very little soil development. Most are Holocene in age (i.e., were deposited in the past 11,000 years), although the oldest sediments in this group date back to the latest Pleistocene (a little more 11,000 years ago).

How and where these young and very young deposits were laid down have a significant bearing on the properties of these materials. At the base of the mountains and hills, the alluvium is coarse grained, poorly sorted, often has organic debris, and was typically deposited rapidly. As a result, the major engineering issues affecting these geologically young deposits are: 1) compressibility, which occurs when additional loads are applied, and 2) collapse (hydroconsolidation) upon introduction of irrigation water if the deposit is dry. Being unconsolidated, the sandy alluvium is also highly susceptible to erosion. Colluvium filling swales on slopes with gradients steeper than about 27 degrees (50-percent slope) may form mudflows if the sediment becomes saturated. Boulders in the alluvium near the base of slopes and in active channels may be a hindrance to earthwork and foundation construction. Alluvium and colluvium are suitable for use as fill, once organic materials and oversized rocks are removed, however they typically require the addition of water to achieve compaction. The alluvial deposits have moderate to high permeability, except where silt layers may retard the downward percolation of water. The potential for expansive soils is generally low, except where floodplain deposits of silt and clay are exposed.

2.3.4 Older Alluvial Fan Deposits (Map Symbols Qof and Qvof)

Older alluvial fan deposits (Qof) are late to middle Pleistocene in age (about 11,000 to 500,000 years old), and consist of moderately to well-consolidated silt, sand and gravel. Near the base of the mountains, these deposits may contain boulders. In Hesperia, these deposits occur as scattered erosional remnants in Summit Valley and in the upper reaches of Antelope Valley Wash, where they are typically elevated above and are more dissected than the Qyf deposits.

Very old alluvial fan deposits (Qvof) are early to middle Pleistocene in age (about 500,000 to 1 million years old), and consist primarily of medium to coarse sand, with a lesser amount of gravel. These medium to dark reddish brown sediments are moderately to well consolidated and have a deeply dissected surface with drainage channels as much as 100 feet deep. This unit is crudely bedded and has a well-developed soil at the surface. These deposits are widespread, covering large areas in the western and eastern parts of the city.

Older alluvium is generally more consolidated than young alluvium, and therefore may provide better structural support. Clayey soils that develop on the fan surface, however, may be expansive. Slope stability is generally only a problem where slopes have become oversteepened, typically by stream erosion.

Figure 2-2: Eastern Part of Summit Valley.
The elevated plateau on the top-left side of the photo is underlain by very old alluvial fan sediments. Most of the valley floor is covered with young alluvial fan sediments, with very young wash deposits of Horsethief Creek in the foreground. The mountains on the right side of the photo are comprised of ancient granitic rocks.

2.3.5 Sedimentary Rocks (Map Symbols Qsh, Qh, Tpp and Tcr)

The Pleistocene-age Shoemaker Gravel (Qsh) has been exposed by erosion in the Cajon Pass area, where it underlies the very old fan deposits. This unit consists of pale grayish brown, moderately well consolidated conglomerate and sandstone. Bedding is crudely defined locally by large conglomeratic lenses, but its appearance overall is generally massive. Clasts range in size from pebble to boulder, and are rounded to well-rounded. The contact with the underlying Harold Formation (Qh) is gradational.

The Harold Formation is similar in appearance to the Shoemaker Gravel, but finer grained. This tan to light brown unit consists of sandstone, conglomeratic sandstone, and minor conglomerate. Bedding consists of relatively thin beds and lenses. This unit is well consolidated, friable, and contains discontinuous carbonate-cemented layers.

Pliocene-age (1 million to 10 million years old) claystone and siltstone of the Phelan Peak deposits are present as isolated patches in the southeast corner of the city. This unit is orangish brown, moderately well to very well consolidated, and contains carbonate-cemented layers, as well as argillic (clay-rich) old soils (paleosols).

The western part of the foothills is underlain by Miocene-age (10 to 26 million years old) sandstone, pebbly sandstone, and conglomerate of the Crowder Formation (Figure 2-3). Pinkish-tan, pale gray, and pale brown in color, this unit has massive to planar bedding and large-scale cross-bedding.

Figure 2-3: Western Part of Summit Valley.
Pinkish-colored foothills are underlain by sandstone, pebbly sandstone, and conglomerate of the Crowder Formation. Highway 138 bridge across Horsethief Creek is on the left.

Most of the sedimentary rocks in the Hesperia area are granular and poorly bedded. These characteristics are generally favorable for gross slope stability, as the units are permeable and do not have well-developed potential slip planes. Conversely, they are highly susceptible to erosion and surficial failures on natural slopes as well as graded slopes made from these materials. The exception is the Phelan Peak siltstone and claystone. This unit may be susceptible to gross instability if clay-rich beds are undermined by stream erosion or grading. These rock types are more likely to have low permeability and moderate to high expansion characteristics.

2.3.6 Crystalline Rocks of the San Bernardino Mountains (Map Symbols Kkc and MzSl)

Crystalline rocks of the San Bernardino Mountains are only exposed along the southern boundary of the city, near Silverwood Lake. Elsewhere in the city they have been buried by younger sedimentary deposits. East of the lake, the rocks consist of a Cretaceous-age (65 to 135 million years old) granitic rock named the Monzogranite of Kinley Creek (Kkc). This quartz-rich, medium-grained rock underlies a large area of the mountains between Lake Arrowhead and Hesperia. West of the lake there is mix of rock types that are also variable in age and texture. This unit is referred to as Mixed Granitic Rocks of Silverwood Lake (MzSl) and are thought to have an age range spanning the Triasssic through Cretaceous periods (about 65 to 225 million years old). These rocks are very weathered, and form rounded, bouldery outcrops on slopes within the city.

These bedrock units have similar engineering properties. They are very hard where not highly weathered, and tend to form steep, rugged slopes and deep canyons. They are typically non-water bearing, except where extensively jointed and fractured. Accordingly, these materials have low to moderately low permeabilities, except where joints, shears and foliation surfaces provide avenues for water to move in and around the rock mass. Unweathered rock cannot be excavated easily; blasting is typically required.

Because these rocks are brittle and have been subjected to millions of years of tectonic activity, they are typically very fractured, locally crushed, and sheared. These deformation features, along with the inherent jointing present in granitic rocks, locally serve as planes of weakness along which slope instability can occur. Large prehistoric landslides have been mapped in these units, however these mapped slides are outside of the city limits.

2.4 Geologic Hazards in the Hesperia Area

Geologic hazards are generally defined as surficial earth processes that have the potential to cause loss or harm to the community or the environment. The basic elements involved in the assessment of geologic hazards are climate, geology, soils, topography, and land use. The types of geologic hazards effecting Hesperia are discussed in the following sections.

2.4.1 Landslides and Slope Instability

A significant portion of the city encompasses hillside terrain. This includes the foothills between Antelope Valley Wash and Summit Valley, as well as the base of the San Bernardino Mountains. At present these areas are sparsely occupied; however, large-scale development has been proposed for parts of Summit Valley and the adjacent foothills. In other parts of the city, deeply incised drainage channels, some ranging up to 100 feet in depth, have been locally developed, including the channel margins, sides and bottoms (Figure 2-4).

Consequently, slope instability remains a significant hazard in the areas of Hesperia mentioned above, particularly in winters characterized by heavy and persistent rainfall, or during winters following hillside wildfires. Although a slope failure tends to affect a relatively small area (as compared to an earthquake or major flood), and is generally a problem for only a short period of time, the dollar loss can be high. Insurance policies typically do not cover land slippage, and this can add to the anguish of the affected property owners.

Figure 2-4: Upper Reach of Oro Grande Wash, One of the Deepest Drainage Channels in Hesperia. Side slopes in the canyon are formed from very old alluvial fan sediments.

Large landslides are present in the San Bernardino Mountains, however these are outside of the city limits. Nevertheless, the foothills, washes, and mountains within and adjacent to Hesperia have steep slopes along which slope failures can occur during or after periods of intense rainfall or in response to strong seismic shaking (see Plate 1-3, Chapter 1). Areas of high topographic relief, such as steep canyon walls, are most likely to be impacted by rockfalls, rockslides, and soil slips, and to a lesser degree, large landslides. In the Summit Valley area, the older surficial sediments and sedimentary rocks that occur in the shallow subsurface are generally granular in texture (sands and gravels), and massive to poorly bedded. These types of deposits are typically more stable than sediments that consist of thinly bedded silt and clay, since well-developed bedding planes provide surfaces along which landslides can occur. Nevertheless, even thick or poorly bedded sedimentary deposits can have localized well-developed clay beds that become planes of slippage when undermined.

2.4.1.1 *Types of Slope Failures*

Slope failures occur in a variety of forms, and there is usually a distinction made between gross failures (sometimes also referred to as "global" failures) and surficial failures. Gross failures include deep-seated or relatively thick slide masses, such as landslides, whereas surficial failures can range from minor soil slips to destructive mud or debris flows. Failures can occur on natural or man-made slopes. For man-made slopes, most failures occur on older slopes, many of which were built at slope gradients steeper than those allowed by today's grading codes. Although infrequent, failures can also occur on newer, graded slopes, generally due to poor engineering or poor construction. Furthermore, slope failures often occur as elements of interrelated natural hazards in which one event triggers a secondary event, such earthquake-induced landsliding, fire-flood sequences, or storm-induced mudflows.

- **Gross Instability**

Landslides **–** Landslides are movements of relatively large landmasses, either as nearly intact bedrock blocks, or as jumbled mixes of bedrock blocks, fragments, debris, and soils. Landslide materials are commonly porous and very weathered in the upper portions and along the margins of the slide. They may also have open fractures and joints. The head of the slide may have a graben (pull-apart area) that has been filled with soil, bedrock blocks and fragments.

From an engineering perspective, landslides are generally unstable (may be subject to reactivation), and may be compressible, especially around the margins, which are typically highly disturbed and broken. The headscarp area above the landslide mass is also unstable, since it is typically oversteepened, cracked, and subject to additional failures. The type of movement is generally described as follows:

- Translational - slippage on a relatively planar, dipping layer.
- Rotational - circular-shaped failure plane.
- Wedge - movement of a wedge-shaped block from between intersecting planes of weakness, such as fractures, faults and bedding.

The potential for slope failure is dependent on many factors and their interrelationships. Some of the most important factors include slope height, slope steepness, shear strength and orientation of weak layers in the underlying geologic unit, as well as pore water pressures. Joints and shears, which weaken the rock fabric, allow penetration of water leading to deeper weathering of the rock along with increasing the pore pressures, increasing the plasticity of weak clays, and increasing the weight of the landmass. For engineering of earth materials, these factors are combined in calculations to determine if a slope meets a minimum safety standard. The generally accepted standard is a factor of safety of 1.5 or greater (where 1.0 is equilibrium, and less than 1.0 is failure). Natural slopes, graded slopes, or graded/natural slope combinations must meet these minimum engineering standards where they impact planned homes, subdivisions, or other types of developments. Slopes adjacent to areas where the risk of economic losses from landsliding is small, such as parks and roadways, are often allowed, at the discretion of the local reviewing agency, a lesser factor of safety.

- **Surficial Instability**

Surficial failures are too small to map at the scale used in Plate 2-2, however they are common in hillside areas, typically occurring in drainage swales and in the thick colluvial sediments and deeply weathered bedrock near the base of steep slopes. Soil slips are generally widespread throughout the mountains during winters of particularly heavy and/or prolonged rainfall.

Slope Creep – Slope creep in general involves deformation and movement of the outer soil or rock materials in the face of the slope due to the forces of gravity overcoming the shear strength of the material. Movement is imperceptibly slow and relatively continuous on moderate to steep slopes. Creep occurs most often in soils that develop on fine-grained bedrock units. Rock creep is a similar process, and involves permanent deformation of the outer few feet of the rock face resulting in folding and fracturing. Rock creep is most common in highly fractured, fine-grained rock units, such as Phelan Peak Deposits (claystone and siltstone), but can also occur in igneous rocks, such as those present along the southern edge of the Hesperia General Plan area..

Creep also occurs in graded fill slopes. This is thought to be related to the alternate wetting and drying of slopes constructed with fine-grained, expansive soils. The repeated expansion and contraction of the soils at the slope face leads to loosening and fracturing of the soils, thereby leaving the soils susceptible to creep. While soil creep is not catastrophic, it can cause damage to structures and improvements located at the tops of slopes.

- Natural slope creep and creep of graded fill slopes are not a widespread hazard in Hesperia, since most soils in this area are coarse-grained and non-expansive.

Soil Slip **–** This type of failure is generated by strong winter storms, and is widespread in steeper slope areas, particularly after winters with prolonged and/or heavy rainfall. Failure occurs on canyon sideslopes, and in soils that have accumulated in swales, gullies and ravines. Slope steepness has a strong influence on the development of soil slips, with most slips occurring on slopes having gradients between about 27 and 56 degrees (Campbell, 1975).

- Slopes susceptible to soil slip are common in the foothills and mountains surrounding Summit Valley. Steep slopes are also present locally along incised drainage channels, particularly in the eastern part of Summit Valley, and intermittently along the Mojave River (Figure 2-5).

Figure 2-5: Soil Slippage on Steep Bluffs along the West Fork of the Mojave River in Summit Valley. Slippage has resulted in a small debris flow at the base of the slope.

Earth Flow – This type of slope failure is a persistent, slow-moving, lobe-shaped slump that typically comes to rest on the slope not far below the failure point. Earth flows commonly form in fine-grained soils (clay, silt and fine sand), and are mobilized by an increase in pore water pressure caused by infiltration of water during and after winter rains. Earth flows occur on moderate to steep slopes, typically in the range of about 15 to 35 degrees (Keefer and Johnson, 1983).

- Within Hesperia, this type of failure is likely to be rare, due to the granular nature of most geologic units.

Debris Flow – This type of failure can be the most dangerous and destructive of all types of slope failure. A debris flow (also called mudflow, mudslide, and debris avalanche) is a rapidly moving slurry of water, mud, rock, vegetation and debris. Larger debris flows are capable of moving trees, large boulders, and even cars. This type of failure is especially dangerous as it can move at speeds as fast as 40 feet per second, is capable of crushing buildings, and can strike with very little warning. As with soil slips, the development of debris flows is strongly tied to exceptional storm periods of prolonged rainfall. Failure typically occurs during an intense rainfall event, following saturation of the soil by previous rains.

A debris flow most commonly originates as a soil slip in the rounded, soil-filled "hollow" at the head of a drainage swale or ravine. The rigid soil mass is deformed into a viscous fluid that moves down the drainage, incorporating into the flow additional soil and vegetation scoured from the channel. Debris flows also occur on canyon walls, often in soil-filled swales that do not have topographic expression. The velocity of the flow depends on the viscosity, slope gradient, height of the slope, roughness and gradient of the channel, and the baffling effects of vegetation. Even relatively small amounts of debris can cause damage from inundation and/or as a result of crashing into a structure (Ellen and Fleming, 1987; Reneau and Dietrich, 1987). Recognition of this hazard led FEMA to modify its National Flood Insurance Program to include inundation by "mudslides."

Watersheds that have been recently burned typically yield greater amounts of soil and debris than those that have not burned. Erosion rates during the first year after a fire are estimated to be 15 to 35 times greater than normal, and peak discharge rates range from 2 to 35 times higher. These rates drop abruptly in the second year, and return to normal after about 5 years (Tan, 1998). In addition, debris flows in burned areas can develop in response to small storms and do not require a long period of antecedent rainfall. These kinds of flows are common in small gullies and ravines during the first rains after a burn, and can become catastrophic when a severe burn is followed by an intense storm season (Wells, 1987).

- Areas of Hesperia that are most susceptible to debris flow are those properties at the base of moderate to steep slopes, or at the mouths of small to large drainages.

Rockfalls – Rockfalls are free-falling to tumbling masses of bedrock that have broken off steep canyon walls or cliffs. The debris from repeated rockfalls typically collects at the base of extremely steep slopes in cone-shaped accumulations of angular rock fragments called talus. Rockfalls can happen wherever fractured rock slopes are oversteepened by stream erosion or man's activities.

Granitic rock commonly weathers into large, rounded boulders that perch precariously on slopes, posing a rock fall hazard to areas adjacent to and below these slopes. Rock falls can occur suddenly and without warning, but are more likely to occur in response to earthquake-induced ground shaking, during periods of intense rainfall, or as a result of man's activities, such as grading and blasting.

- This hazard is largely restricted to the southern edge of the General Plan area, where outcrops of granitic rock are present (Figure 2-6).

Figure 2-6: Rounded Granitic Boulders on the South Side of Summit Valley.
Boulders like these can become dislodged during earthquakes or intense rainfall and roll down on properties below without warning.

2.4.1.2 Susceptibility to Slope Failure

Developments that encroach upon the edge of natural slopes may be impacted by slope failures. Even if a slope failure does not reach the adjacent property, the visual impact will generally cause alarm to homeowners. The city's natural hillsides, illustrated by steepness in Plate 2-3, are vulnerable to the types of slope instability mentioned above, especially surficial failures. Table 2-1 below summarizes the geologic conditions in various parts of the city that provide the environment for slope instability to occur. These conditions usually include such factors as terrain steepness, rock or soil type, condition of the rock (such as degree of fracturing and weathering), internal structures within the rock (such as bedding, foliation, faults) and the prior occurrence of slope failures. Catalysts that ultimately allow slope failures to occur in vulnerable terrain are most often water (as a result of heavy and prolonged rainfall, intense irrigation over a long period of time, or leaks from broken water mains), erosion and undercutting by streams, man-made alterations to the slope, and seismic shaking. The summary in Table 2-1 was derived from the Geologic Map (Plate 2-2), the Seismic Hazards Map (Plate 1-3) and the Slope Distribution Map (Plate 2-3).

Table 2-1: General Slope Instability Potential within Hesperia

Area	Existing Geologic Conditions	Types of Potential Slope Instability
Base of the San Bernardino Mountains (southern edge of General Plan area)	Moderate to very steep natural slopes, many in excess of 26 degrees. Fractured, sheared, faulted, and locally crushed bedrock; existing rockslides and talus slopes; soils and loose debris at the toes of slopes and in drainage courses. Locally, small to large boulders weathered out on slope faces.	***Most Common***: Rockfalls and rockslides, falling boulders, soil slips, and surficial landslides on steep slopes; small to large debris and mudflows in canyons; sedimentation at the mouths of canyons. ***Less Common:*** Large, deep-seated landslides.
Foothills north of Summit Valley	Moderate to steep natural slopes; most sloping at between 10 and 26 degrees; locally steeper than 40 degrees. **Western Part:** Crudely bedded sandstone and gravelly sandstone of the Crowder Formation; young surficial deposits in drainage swales and at the base of the slopes. **Eastern Part:** Very old alluvium consisting of moderately well consolidated silt, sand, and gravel; young surficial deposits in drainage swales and at the base of slopes; oversteepened, raveling slopes adjacent to the West Fork of the Mojave River.	***Most Common:*** Surficial soil slips; erosion and slumping of oversteepened slopes; small to moderate debris/mudflows; sedimentation at the base of the hills. ***Less Common:*** Large, deep-seated landslides; large debris flows.
Antelope Valley Wash and other deeply incised drainge channels	Poorly consolidated to well consolidated granular sediments, primarily sand and gravel; undefined to crudely defined bedding; raveling slopes; erosion gullies in channel banks, loose soil and debris at the toes of slopes and in channels.	***Most Common*** Erosion and slumping of channel walls; soil slips, sedimentation aprons and small to moderate debris flows from incised tributary channels during heavy rains. ***Least Common*** Large, deep-seated landslides; large debris flows.

2.4.1.3 Mitigation of Slope Instability in Future Development

Careful land management in hillside areas can reduce the risk of economic and social losses from slope failures. This generally includes land use zoning to restrict development in unstable areas, grading codes for earthwork construction, geologic and soil engineering investigation and review, construction of drainage structures, and where warranted, placement of warning systems. Other important factors are risk assessments (including susceptibility maps), a concerned local government, and an educated public.

NOTES:

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

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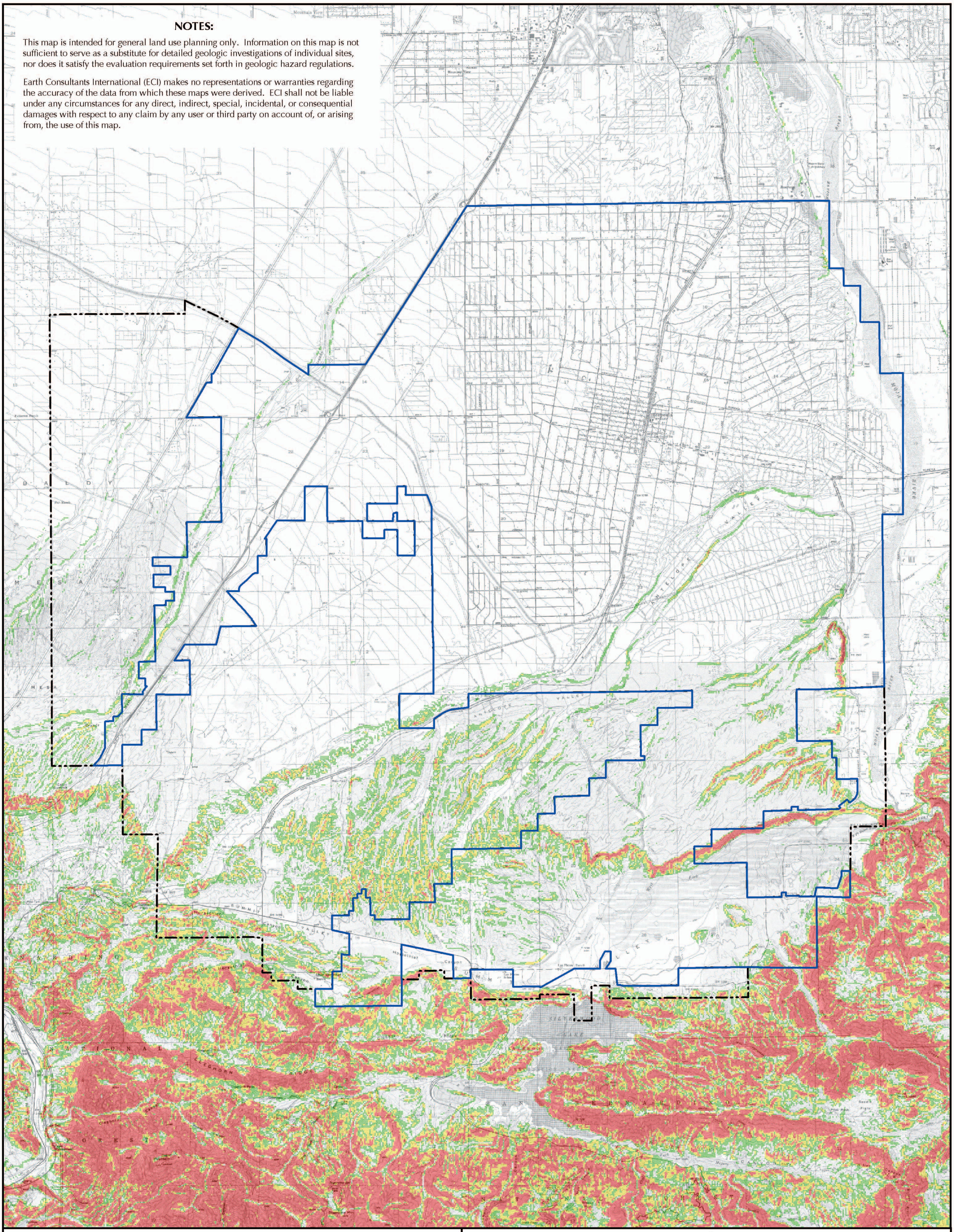

N
W E
S

0 7000 14000 Feet

0 2000 4000 Meters

Scale: 1:84,000

Explanation

Slope (in percent)

- 0 to 19
- 20 to 29
- 30 to 39
- 40 and greater
- Hesperia City Limit
- Hesperia Sphere of Influence

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Source: Derived from USGS 30m Digital Elevation Model

Earth Consultants International

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Date: February 2010

Slope Distribution Map

Hesperia, California

Plate 2-3

The Municipal Code for the city of Hesperia includes standards and guidelines for construction in hillside areas (Title 16: Development Code, Chapter 16.40: Hillside Development Regulations). The intent of this Chapter is to: 1) protect and preserve existing landforms, drainage patterns, natural ridgelines and rock outcroppings, scenic vistas, and native vegetation as much as possible; 2) discourage mass grading and terracing; 3) encourage variety in design; 4) provide safe traffic circulation in hillside areas; and 5) mitigate slope instability, erosion, and sedimentation by requiring soils reports, and where necessary, engineered drainage facilities. The Code defines hillside areas as those with a slope of 20 percent or greater (illustrated by the colored areas on Plate 2-3, the Slope Distribution Map). Further, slopes are classified in the Code (according to steepness), in order to define areas of maximum development density, areas to remain natural, and grading standards. Plate 2-3 generally illustrates slope gradients that correspond to the slope classes in Hesperia's Development Code.

For unincorporated areas, the San Bernardino County Development Code provides similar standards and guidelines for growth and development, in addition to providing a basis for county-wide planning and construction of public facilities such as flood control. The Code addresses zoning, permitting, grading, and investigation requirements for areas subject to potential geologic problems, including slope stability.

The Oak Hills Community Plan, prepared to establish clear guidelines for the future development in the unincorporated area within Hesperia's Sphere of Influence known as Oak Hills, contains land use policies to augment those set forth in the General Plans of Hesperia and San Bernardino County. Chapter 1 of the Community Plan Policies provides additional criteria for hillside development where slope gradients exceed 15 percent.

Soils reports for hillside areas, as required by Development Codes, should include a geotechnical evaluation of any slopes that may impact the future use of the property, as well as any impact to adjacent properties. This includes existing slopes that are to remain natural, and any proposed graded slopes. This type of investigation typically includes borings to collect geologic data and soil samples, laboratory testing to determine soil strength parameters, and engineering calculations. Numerous soil-engineering methods are available for stabilizing slopes that pose a threat to development. These methods include designed buttresses (replacing the weak portion of the slope with engineered fill); reducing the height of the slope; designing the slope at a flatter gradient; and adding reinforcements such as soil cement or layers of geogrid (a tough polymeric net-like material that is placed between the horizontal layers of fill). Most slope stabilization methods include a subdrain system to prevent excessive ground water (typically landscape water) from building up within the slope area. If it is not feasible to mitigate the slope stability hazard, building setbacks are typically imposed.

Temporary slope stability is also a concern, especially where earthwork construction is taking place next to existing improvements. Temporary slopes are those made for slope stabilization backcuts, fill keys, alluvial removals, retaining walls, and underground utility lines. The risk of slope failure is higher in temporary slopes because they are generally cut at a much steeper gradient. In general, temporary slopes should not be cut steeper than 1:1 (horizontal:vertical), and depending on actual field conditions, flatter gradients may be necessary. The potential for slope failure can also be reduced by cutting and filling large excavations in segments, and not leaving temporary excavations open for long periods of time. The stability of large temporary slopes should be analyzed prior to construction, and mitigation measures provided as needed.

For debris flows, assessment of this hazard for individual sites should focus on structures located or planned in vulnerable positions. This generally includes canyon areas; at the toes of steep, natural slopes; and at the mouth of small to large drainage channels. Mitigation of soil slips, earth-flows, and debris flows is usually directed at containment (debris basins), or diversion (impact walls, deflection walls, diversion channels, and debris fences). A system of baffles may be added upstream to slow the velocity of a potential debris flow. Other methods include removal of the source material, placing subdrains in the source area to prevent pore water pressure buildup, or avoidance by restricting building to areas outside of the potential debris flow path.

There are numerous methods for mitigating rock falls. Choosing the best method depends on the geological conditions (i.e., slope height, steepness, fracture spacing, bedding orientation), safety, type and cost of construction repair, and aesthetics. A commonly used method is to regrade the slope. This ranges from locally trimming hazardous overhangs, to completely reconfiguring the slope to a more stable condition, possibly with the addition of benches to catch small rocks. Another group of methods focuses on holding the fractured rock in place by draping the slope with wire mesh, or by installing tensioned rock bolts, tie-back walls, or even retaining walls. A third type of mitigation includes catchment devices at the toe of the slope, such as ditches, walls, or combinations of both. Designing the width of the catchment structure requires analysis of how the rock will fall. For instance, the slope gradient and roughness of the slope determines if rocks will fall, bounce, or roll to the bottom (Wyllie and Norrish, 1996).

2.4.1.4 Mitigation of Slope Instability in Existing Development

There are a number of options for management of potential slope instability where development has already taken place. Implementation of these options should reduce the hazard to an acceptable level, including reducing or eliminating the potential for loss of life or injury, and reducing economic loss to tolerable levels. Mitigation measures may include:

- Protecting existing development and population where appropriate by physical controls such as improved drainage, slope-geometry modification, protective barriers, and retaining structures;
- Posting warning signs in areas of potential slope instability;
- Encouraging homeowners to install landscaping consisting primarily of drought-resistant, preferably native vegetation that helps stabilize the hillsides;
- Incorporating recommendations for potential slope instability into geologic and soil engineering reports for building additions and new grading; and
- Providing public education on slope stability, including the importance of maintaining drainage devices and avoiding heavy irrigation. U.S. Geological Survey Fact Sheet FS-071-00 (May, 2000) and California Geological Survey Note 33 (March, 2004) provide

public information on landslide and mudslide hazards. Both of these are available on the World Wide Web (see Appendix A).

2.4.2 Compressible Soils

Compressible soils are typically geologically young (Holocene age) unconsolidated sediments of low density that may compress under the weight of proposed fill embankments and structures. Geologic units that are generally susceptible to this hazard include young alluvium, the upper weathered part of older alluvium, colluvium/slope wash that collects near the base of natural slopes, and slope failure debris. The settlement potential and the rate of settlement in these sediments can vary greatly, depending on the soil characteristics (texture and grain size), natural moisture and density, thickness of the compressible layer(s), the weight of the proposed load, the rate at which the load is applied, and drainage.

- The portion of Hesperia where compressible soils are most likely to occur is where young alluvial fan and wash deposits are present. This would generally include the floor of Summit Valley, the Mojave River bed, and the central part of the alluvial fan, as well as the bottoms of active and recently active stream channels. Compressible soils are also commonly found in hillside areas, typically in canyon bottoms, swales, and at the base of natural slopes. Deep fill embankments, generally those in excess of about 60 feet deep, will also compress under their own weight.

2.4.2.1 Mitigation of Compressible Soils

When development is planned within areas that contain potentially compressible soils, a geotechnical soil analysis is required to identify the presence of this hazard. The analysis should consider the characteristics of the soil column in that specific area, and also the load of any proposed fills and structures that are planned, the type of structure (i.e. a road, pipeline, or building), and the local groundwater conditions. Removal and recompaction of the near-surface soils is generally the minimum that is required. Deeper removals may be needed for heavier loads, or for structures that are sensitive to minor settlement. Based on the location-specific data and analyses, partial removal and recompaction of the compressible soils is often performed, followed by settlement monitoring for a number of months after additional fill has been placed, but before buildings or infrastructure are constructed. Similar methods are used for deep fills. In cases where it is not feasible to remove the compressible soils, buildings can be supported on specially engineered foundations that may include deep caissons or piles.

2.4.3 Collapsible Soils

Hydroconsolidation or soil collapse typically occurs in recently deposited, Holocene-age soils that accumulated in an arid or semi-arid environment. Soils prone to collapse are commonly associated with wind-deposited sands and silts, and alluvial fan and debris flow sediments deposited during flash floods. These soils are typically dry and contain minute pores and voids. The soil particles may be partially supported by clay, silt or carbonate bonds. When saturated, collapsible soils undergo a rearrangement of their grains and a loss of cementation, resulting in substantial and rapid settlement under relatively light loads. An increase in surface water infiltration, such as from irrigation, or a rise in the groundwater table, combined with the weight of a building or structure, can initiate rapid settlement and cause foundations and walls to crack. Typically, differential settlement of structures occurs when landscaping is heavily irrigated in close proximity to the structure's foundation.

- The young and very young alluvial sediments in the Hesperia area may be susceptible to this hazard due to the granular nature of the soils, rapid deposition in the alluvial fan environment, and generally dry condition of the upper soils. These soil types are present primarily in the low-lying portions of the city.

2.4.3.1 Mitigation of Collapsible Soils

The potential for soils to collapse should be evaluated on a site-specific basis as part of the geotechnical studies for development. If the soils are determined to be collapsible, the hazard can be mitigated by several different measures or combination of measures, including excavation and recompaction, or pre-saturation and pre-loading of the susceptible soils in place to induce collapse prior to construction. After construction, infiltration of water into the subsurface soils should be minimized by proper surface drainage design, which directs excess runoff to catch basins and storm drains.

2.4.4 Expansive Soils

Fine-grained soils, such as silts and clays, may contain variable amounts of expansive clay minerals. These minerals can undergo significant volumetric changes as a result of changes in moisture content. The upward pressures induced by the swelling of expansive soils can have significant harmful effects upon structures and other surface improvements.

- The valley and canyon areas of Hesperia are underlain by sediments that are largely composed of granular soils (silty sand, sand, gravel). Such units typically have a low expansion potential, although pockets of fine-grained expansive soils are not uncommon within these units. Sediments within the floodplain of the Mojave River may locally contain fine-grained (silts and clays) sediments, and these deposits may be moderately to highly expansive. Argillic soil profiles (due to weathering of the surface) that have developed on the older fan deposits are commonly clay-rich and probably fall in the moderately expansive range.

- Granitic and metamorphic basement rocks underlying the mountains generally have low expansion characteristics, however faults and shear zones within these rocks may contain clays with expansive minerals. In some cases, engineered fills may be expansive and cause damage to improvements if such soils are incorporated into the fill near the finished surface.

2.4.4.1 Mitigation of Expansive Soils

The best defense against this hazard in new developments is to avoid placing expansive soils near the surface. If this is unavoidable, building areas with expansive soils are typically "presaturated" to a moisture content and depth specified by the soil engineer, thereby "pre-swelling" the soil prior to constructing the structural foundation or hardscape. This method is often used in conjunction with stronger foundations that can resist small ground movements without cracking. Good surface drainage control is essential for all types of improvements, both new and old. Property owners should be educated about the importance of maintaining relatively constant moisture levels in their landscaping.

Excessive watering or alternating wetting and drying can result in distress to improvements and structures.

2.4.5 Ground Subsidence

Ground subsidence is the gradual settling or sinking of the ground surface with little or no horizontal movement. Most ground subsidence is man-induced. In the areas of southern California where ground subsidence has been reported (such as the San Joaquin Valley, Coachella Valley, and Wilmington), this phenomenon is usually associated with the extraction of ground water, oil, or gas from below the surface in sediment-filled valleys and floodplains. Less commonly, ground subsidence can also occur as a response to natural forces such as earthquake movements.

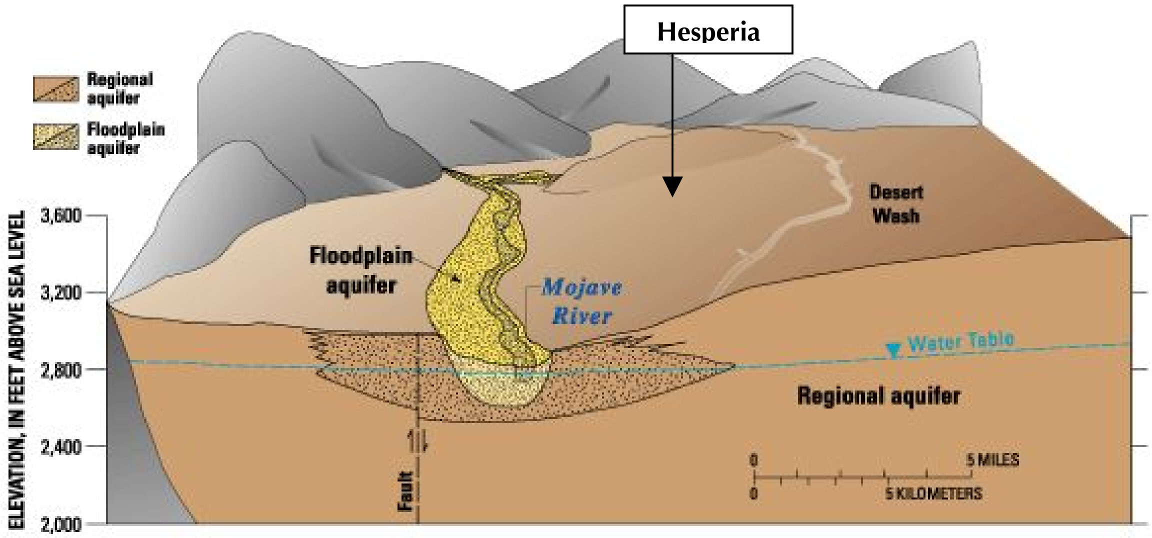
Ground-surface effects related to regional subsidence can include earth fissures, sinkholes or depressions, and disruption of surface drainage. Damage is generally restricted to structures sensitive to slight changes in elevations, such as canals, levees, underground pipelines, and drainage courses; however, significant subsidence can result in damage to wells, buildings, roads, railroads, and other improvements. Subsidence due to the overdraft of ground water supplies can also result in the permanent loss of aquifer storage capacity. Subsidence has largely been brought under control in affected areas by careful management of local water supplies, including reducing pumping of local wells, importing water, and use of artificial recharge (Johnson, 1998; Stewart et al., 1998).

Hesperia is located above the southern end of the Mojave River Groundwater Basin. With an area covering 1,400 square miles and an estimated storage capacity of nearly five million acre-feet (an acre-foot equals about 326 thousand gallons), this basin is one of the largest groundwater reservoirs in southern California (Schlumberger, 2004). The basin consists of two interconnected aquifers, one underlying the Mojave River floodplain, and a larger, regional aquifer within the alluvial fan sediments (Figure 2-7). Natural recharge to the basin comes primarily from the Mojave River (more than 80 percent), with the remainder coming from runoff that infiltrates the upper reaches of tributary washes. Water extraction from the basin has been ongoing for decades, at rates exceeding the natural replenishment, leading to an overdraft condition in the basin. In fact, regional groundwater levels in the basin have dropped more than 100 feet between the 1950s and 1990s, and approximately 30 feet in the last 20 years alone (Carollo Engineers, 2005).

Because surface water is scarce, the high desert communities, including Hesperia, have relied almost entirely on ground water from the Mojave Basin for their domestic supply since the early 1900s. The thick alluvial deposits comprising the aquifer may be susceptible to compaction (with resulting subsidence at the surface) should rapid ground water withdrawal occur beneath the area in response to the water needs of a growing population. Recognizing the potential for declining water levels to induce or renew land subsidence, the United States Geological Survey (USGS), in cooperation with the Mojave Water Agency (MWA), have conducted geologic and hydrologic studies of the basin, including the detection and measurement of subsidence. Three areas within the Mojave Basin showed minor subsidence (01.5 to 0.3 feet) during the study period of 1992-1999, although the subsidence could not be tied definitively to groundwater levels, due to insufficient groundwater data. However, during the time that measurements were recorded, groundwater levels in these areas were at or below historically low levels. The closest subsidence area to Hesperia was northwest of Adelanto, approximately 16 miles from the city.

- To date, subsidence has not been detected within Hesperia.

Figure 2-7: Aquifers Underlying Hesperia, shown in the diagram below, are currently the City's sole source of domestic water.



Source: US Geological Survey, Fact Sheet 122-01, dated November 2001.

2.4.5.1 *Mitigation of Ground Subsidence*

Prevention of subsidence requires a regional approach to groundwater conservation and recharge. The Mojave Basin has been managed by the MWA since the agency's inception in 1960. The primary goal of the MWA is to insure a low-cost, sustainable supply of quality water for the future. To that end, the agency, in conjunction with the U.S. Geological Survey (USGS), has implemented programs with the following elements, all of which will result either directly or indirectly in the prevention of ground subsidence:

- Better understand the basin's geology, hydrology, and hydraulic control. Several different types of tests, including geophysical surveys, surface water measurements, ground water level measurements, water quality sampling, meteorological measurements, and well production tests, need to be conducted to adequately characterize the basin.
- Increase the use of imported water. Since July 1994, imported water has been released to the Mojave River southeast of Hesperia, near Rock Springs Road. The imported water supply is crucial to the area's survival, since residents have been using more water than is replaced naturally. The MWA is entitled to 75,800 acre-feet of State Water Project (SWP) water per year via the California Aqueduct, however the amount that is actually available each year is variable, depending on for instance, if the state has a wet or dry year, or if there are multiple dry years.

This variability is expected to increase as users compete for the available supply. To help alleviate this, programs continue to be developed to allow transfers of allotments between water contractors in order to maximize storage of SWP water supplies when they are available (Schlumberger, 2004).

- Increase the use of wastewater. Currently the Mojave Basin receives treated wastewater from several mountain communities. This water is discharged to the Mojave River in the Hesperia area. Within the Mojave Basin, the Victor Valley Wastewater Reclamation Authority provides collection and treatment of wastewater for a number of high desert cities, including Hesperia. The reclaimed water is discharged directly into the Mojave River channel or into percolation ponds. Additional wastewater treatment facilities are currently being planned.
- Continue to develop artificial recharge programs. Studies by the USGS show that artificial recharge can significantly reduce the decline in water levels. In 2002, the MWA conducted a pilot recharge project by constructing four percolation ponds at the Oro Grande Wash and pumping water into the basins to test the recharge capabilities of the aquifer. The results of this study will be used in the design and construction of permanent recharge facilities in the basin. In addition, the Mojave River Pipeline will bring SWP water to spreading basins where it can percolate down to the aquifer. Eventually this pipeline is expected to deliver up to 45,000 acre-feet per year to local communities (www.mojavewater.org). SWP water is also released periodically from Silverwood Lake into the West Fork of the Mojave River.
- Determine the safe yields of the groundwater basins, so that available supplies can be balanced with extraction.
- Monitor the groundwater levels and basin conditions. The MWA has developed a 2,000-foot deep monitoring well in the Oro Grande Wash near Hesperia. This is in addition to approximately 140 shallower monitoring wells that have been installed in the basin since the 1990s (www.mojavewater.org).
- Continue to monitor land subsidence.
- Reduce long-term water demand with specific programs of water conservation.
- Encourage water conservation through public education and water conservation programs.
- Compile and archive collected data for future analysis, as needed.

All of Hesperia's water currently comes from underground sources local to the area. The Hesperia Water District, which supplies water to users within the current city boundary, maintains 13 active wells, all of which are located on the alluvial fan north of the foothills. The district also has eleven aboveground storage reservoirs with a total capacity of 49.5 million gallons (Carollo Engineers, 2005). Hesperia has numerous ongoing and planned improvements to their water distribution infrastructure, including additional wells and reservoirs, new pipelines, replacement of old leaking pipelines, and the addition of alternative energy sources (such as generators) in the case of power failures.

The city has prepared or is in the process of preparing various studies that set forth their goals and actions for water management in the next couple of decades. These include the

Urban Water Management Plan (Carollo Engineers, 2005), the Water Master Plan that is based on land uses within various parts of the city, and a Water Reuse Master Plan to optimize the use of recycled water.

Hesperia has already implemented several water conservation programs including retrofitting older homes with water-saving fixtures or devices, and providing public information on water conservation, landscaping, and resource management. Information on these programs is available at City Hall, the City's website, schools, community events, and with the purchase of new homes. The City also has tiered pricing to encourage conservation and has adopted ordinances that prohibit wasting of water. In order to cope with water shortages, the City has developed a three-stage rationing plan that includes both voluntary and mandatory measures. A severe water shortage contingency plan can be implemented during drought conditions, or during an emergency situation such as an earthquake or loss of electrical power.

The City currently does not utilize recycled water, primarily because it does not have the necessary infrastructure in place. However, new housing developments are required to install dual water systems, so that when recycled water mains are installed, these developments will have a distribution system already available for this recycled water. Future plans also being considered are additional water treatment plants and conveyance routes. Excess recycled water not used by future customers would be used instead to recharge the groundwater basin.

According to the Hesperia's Urban Water Management Plan, the City currently has water supply capabilities to meet daily demands as well as future demands into the year 2030 (Carollo, 2005). However, this will require aggressive water management by the City, the use of recycled water, the continued development for new water sources, and the implementation and enforcement of stringent water conservation measures, especially during droughts.

2.4.6 Erosion

Erosion, runoff, and sedimentation are influenced by several factors, including climate, topography, soil and rock types, and vegetation. The topographic relief between the desert and the adjacent mountains makes erosion and sedimentation an important issue for communities built on alluvial fans and within hillside areas. The fractured condition of the bedrock forming the mountains, combined with rapid geologic uplift and infrequent but powerful winter storms leads to high erosion rates. Further, erosion can increase significantly when mountain slopes are denuded by wildfires, such as those that occurred in the local mountains in 2003. Winter storms that follow a season of mountain wildfires can transport great volumes of sediment onto the low-lying areas below.

Natural erosion processes are often accelerated through man's activities – whether they are agricultural or land development. Development often increases the potential for erosion and sedimentation by removing protective vegetation, altering natural drainage patterns, and constructing cut and fill slopes that may be more susceptible to erosion than the natural condition. Developments also reduce the surface area available for infiltration, leading to increased flooding and sedimentation downstream of the project.

- Near-surface sediments in Hesperia are generally sandy and highly susceptible to erosion, particularly the younger, unconsolidated materials. Erodible deposits are widespread, covering nearly all the General Plan area, with the exception of the southern edge, where rock of the San Bernardino Mountains is exposed.

2.4.6.1 Mitigation of Erosion

Erosion will have an impact on those portions of Hesperia located above and below natural and man-made slopes. Hilltop homes or structures above natural slopes should not be permitted at the head of steep drainage channels or gullies without protective measures against headward erosion of the gully. Structures placed near the base of slopes and/or near the mouths of small canyons, swales, washes, and gullies will need protection from sedimentation. Developments in the valley that are adjacent to natural drainage channels should be adequately set back from eroding channel banks, or modification of the channel to reduce erosion should be included in the project design.

Mitigation of erosion and sedimentation typically includes structures to slow down stream velocity, such as check dams and drop structures, devices to collect and channel the flow, catchment basins, and elevating structures above the toes of the slopes. Diversion dikes, interceptor ditches, swales, and slope down-drains are commonly lined with asphalt or concrete, however ditches can also be lined with gravel, rock, decorative stone, or grass.

There are many options for protecting manufactured slopes from erosion, such as terracing slopes to minimize the velocity attained by runoff, the addition of berms and v-ditches, and installing adequate storm drainage structures. Other measures include establishing protective vegetation, and placing mulches, rock facings (either cemented on non-cemented), gabions (rock-filled galvanized wire cages), or building blocks with open spaces for plantings on the slope face. All slopes within developed areas should be protected from concentrated water flow over the tops of the slopes by the use of berms or walls. All ridge-top building pads should be engineered to direct drainage away from slopes.

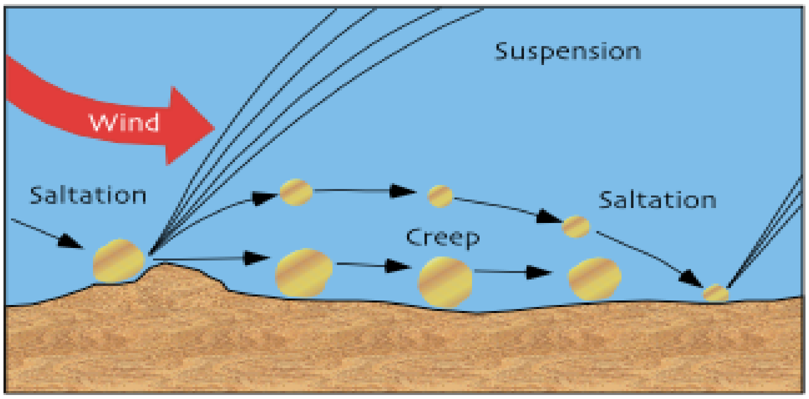
Temporary erosion control measures must be provided during the construction phase of a development, as required by local building codes and ordinances, as well as State and Federal stormwater pollution regulations (National Pollutant Discharge Elimination System – NPDES, see Chapter 5). In addition, permanent erosion control and clean water runoff measures are required for new developments. These measures might include desilting basins, percolation areas to cleanse runoff from the development, proper care of drainage control devices, appropriate irrigation practices, and rodent control. Erosion control devices should be field-checked following periods of heavy rainfall to assure they are performing as designed and have not become blocked by debris.

2.4.7 Wind-Blown Sand

Wind erosion is a serious environmental problem attracting the attention of many across the globe. It is a common phenomenon occurring mostly in flat, bare areas; where dry, sandy soils are present; or anywhere the topsoil is loose, dry, and finely granulated. Wind erosion damages land and natural vegetation by removing soil from one place and depositing it in another. It causes soil loss, dryness and deterioration of soil structure, nutrient and productivity losses, air pollution, and sediment transport and deposition.

Soil movement is initiated as a result of wind forces exerted against the surface of the ground. For each specific soil type and surface condition, there is a minimum velocity required to move soil particles. This is called the threshold velocity. Once this velocity is reached, the quantity of soil moved is dependent upon the particle size, the cloddiness of the particles, and the wind velocity itself. Suspension, saltation, and surface creep are the three types of soil movement that occur during wind erosion (Figure 2-8). While soil can be blown away at virtually any height, the majority (over 93 percent) of soil movement takes place at or within one meter (3 feet) of the ground surface.

Figure 2-8: Wind-Induced Soil Movement



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

- Hesperia is affected by strong gusts of wind associated with the Cajon Pass, as well as climatic differences between the high desert, the mountains, and the inland valleys south of the pass. Combined with the sandy surface soils that are common in Hesperia, the wind poses an environmental, and often destructive, hazard. The presence of dust particles in the air is also the source of several major health problems. Atmospheric dust causes respiratory discomfort, and may carry pathogens that cause eye infections and skin disorders. Dust storms also reduce highway and air traffic visibility.

2.4.7.1 Mitigation of Wind-Blown Sand

Mitigation measures that have been used and are used in windy areas include hedges and other barriers to wind. Increased development in the Hesperia area has the positive side-effect of significantly reducing the local sand available to be picked up and transported by the wind. This is due to the increasing amount of hardscape (asphalt and concrete) and vegetation (such as grass and ornamental plants) in the area, covering the soil and isolating it from the wind. During grading and construction stages, however there is the potential for increased amounts of soils available for transport. Therefore, water is typically sprayed at construction sites to reduce dust in the air by weighting down the soil. To further decrease the potential for air-born dust, earthwork construction should be curtailed on very windy days.

2.5 Summary of Issues

The Hesperia area is highly diverse geologically. This diversity is strongly related to the youthful (in geologic terms) seismic setting of the area, which includes the ongoing uplift of the San Bernardino Mountains to the south as a result of tectonic movement along the San Andreas fault and its broad zone of subsidiary faults. This, along with the effects of climate, has resulted in a landscape that is complex in geologic processes and hazards. As the City's population grows in the next few years, new development will be needed to meet the demand for homes. When meeting this demand, it is imperative to manage land uses in a responsible way, as development disrupts natural processes, often leading to negative impacts on the environment as well as on the development and adjacent projects. The impacts of land development can be minimized, however, if both site-specific and regional planning elements are recognized and considered, the project incorporates knowledge gained from scientific research in developing and implementing a design appropriate to the area, and protective measures are constructed and maintained for the lifetime of the project.

Most of Hesperia is situated on an older alluvial fan surface that has well-established, deeply incised drainage channels. In contrast, the southern part of the city contains low foothills and a broad, sediment-filled valley. The southernmost boundary encroaches onto the base of the San Bernardino Mountains, a range of mountains that not only forms a dramatic backdrop to the city, but also greatly influences its climate, geology, and hydrology. These elements combine in various ways to create geologic hazards, as well as benefits (such as Mojave River aquifers) to the community. Hazards that have the greatest impact on Hesperia are summarized below.

Slope instability is a potential hazard where development has encroached into the foothills and washes. This may take the form of small landslides, but is more likely to consist of surficial failures and erosion of the sandy geologic materials. Such failures typically occur during exceptional and/or prolonged rainfall events, and may manifest as mud or debris flows. Rockfall is a hazard near the base of the mountains where bedrock forms bouldery outcrops. Rockfall is more likely to occur as a result of earthquake-induced ground shaking, posing a threat to structures and passing motorists.

Potentially compressible and/or collapsible soils underlie a significant part of the city, typically on parts of the alluvial fan, in Summit Valley, and within washes and canyon bottoms. These are generally young sediments of low density with variable amounts of organic materials. Under the added weight of fill embankments or buildings, these sediments will settle, causing distress to improvements.

Although not prevalent, some of the geologic units in the Hesperia area, including both surficial soils and bedrock, may have fine-grained components locally that are moderate to highly expansive. These materials may be present at the surface or exposed by grading activities. Man-made fills can also be expansive, depending on the soils used to construct them.

Regional ground subsidence from groundwater withdrawal is a potential hazard that the City of Hesperia can proactively help to prevent by supporting the proper management of the groundwater supplies, creating water conservation programs, encouraging water recycling, and through public education. With the expected increase in population, one of the most serious challenges ahead is the potential overdraft of the aquifers underlying the Mojave Basin, with a resultant negative impact on the region's environmental quality.

Because of the topographic relief in and around Hesperia, erosion and sedimentation are inherently significant elements of the natural setting. Land development can have adverse impacts on these elements by altering natural processes, topography, and protective vegetation, in addition to reducing the area of natural infiltration. This in turn can lead to damage from increased flooding, erosion, and sedimentation in other areas, typically downstream. Erosion and sedimentation are also important considerations on a site-specific basis, with respect to developments adjacent to slopes and drainage channels. These issues are not only critical during the design of a project, but also during construction and during the long-term maintenance of the developed site.

Strong winds are also inherent to the Hesperia area, due to the tunneling effect of air through the Cajon Pass, as well as climatic differences between the desert, the mountains, and the inland valleys. Wind is also an important agent of erosion that can damage land and vegetation. In this region, where surface sediments are predominantly dry and granular, wind-blown sand and dust can impact surface improvements, air quality (creating health hazards), and visibility.

Losses resulting from geologic hazards are generally not covered by insurance policies, causing additional hardship on property owners. The potential for damage can be greatly reduced by:

- Strict adherence to grading ordinances – many of which have been developed as a result of past disasters.
- Sound land planning and project design that avoids severely hazardous areas.
- Detailed, site-specific geotechnical investigations, followed by geotechnical oversight during grading and during construction of foundations and underground infrastructures.
- Effective geotechnical and design review of projects performed by qualified, California-registered engineering geologists, soil engineers, and design engineers.
- Public education that focuses on reducing losses from geologic hazards, including the importance of proper irrigation practices, in addition to the care and maintenance of slopes and drainage devices.