Appendix E

Geotechnical Report

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EXECUTIVE SUMMARY

The citizens of the City of Riverside felt and otherwise experienced few notable earthquakes in the recent past of 1970 through 1994. These have included 1970 Lytle Creek, 1987 Whittier, and 1992 Landers and Big Bear events. The closest and most damaging to the surrounding cities were the magnitude 6.7 Big Bear and 7.6 Landers earthquakes of June 28, 1992. The community of Riverside was spared significant damage during these earthquakes. These earthquakes and the "blind" thrust fault earthquakes associated with the 1987 5.9 magnitude Whittier and 1994 magnitude 6.7 Northridge earthquakes alerted and educated geologists, seismologists and other earthquake specialists to the fact that other faults may present earthquake hazards to the Riverside area with a frequency greater than the "Big One" on the San Andreas fault zone some 30 miles northeast of Riverside. The 1994 Northridge earthquake validated this lesson by causing more damage than any earthquake in California history.

The City is affected by several seismic/geologic hazards, which are to be discussed in the seismic safety portion of the City's Public Safety Element. The most certain and serious of these hazards is ***strong groundshaking*** ("g" forces of 0.05 to 0.43, 5% to 43% the force of gravity, are likely) from either nearby or distant faults. Shallow groundwater and loose alluvial strata, particularly in the western and northern portions of the City, in the presence of this groundshaking can cause ***liquefaction and dynamic compaction*** where the ground loses its ability to fully support structures, causing settlement, and possibly shallow landslides***.*** ***Surface fault rupture*** within the City's sphere of influence, although a rather remote possibility, could occur along a buried fault that trends toward area from the southeast. ***Inundation by floodwaters*** in the event of the failure of the Lake Mathews' dams could result in several feet of water in some portions of the City. While these hazards may have a relatively low probability of occurring in the foreseeable future, they are important and must be factored into long-range planning for the City.

Planning must consider the effects of these hazards on the safety of the City's residents and visitors. This includes effects on the freeways, bridges, and roadways, which would serve as evacuation and emergency response routes into and out of the City. Damage to, or failure of, linear lifeline structures, which pass through or near the City, could have a substantial impact on the potential for fires and on post-earthquake recovery. These include high voltage power lines, high-pressure natural gas lines, and the other utilities serving the residents and businesses within the City. Of potentially greatest importance to post-earthquake disaster response and recovery efforts is the performance of critical facilities such as hospitals, police and fire stations, and educational centers. Each of these facilities has seismic, geologic, location, and structural considerations, which must be analyzed to understand their future performance under various earthquake conditions.

In summary, the City of Riverside has seismic and geologic issues, some of which are potentially more hazardous than other cities in southern California, and some of which are less. This report highlights these potential hazards and indicates where they are most likely to be located. It also provides a compilation of existing data available in the public domain, as well as maps and analysis, which can be applied to an update of the Safety Element of the General Plan. A concerted effort to evaluate the potential impact of these hazards on the citizens, buildings and other structures in the City can yield policies and programs which will help to assure an organized and appropriate response to the next earthquake which impacts the City of Riverside.

1. INTRODUCTION

This document is a technical background report designed to support Cotton/Bridges/Associates, Inc. in preparation of the Safety Element of the City of Riverside General Plan. As such the document contains up-to-date information on the seismic and geologic conditions within and around the City, which will potentially affect the persons and property in the City in the event of a major earthquake in southern California. Discussion is also provided on the buildings and infrastructure most important to the citizens and City personnel in the event these earthquake effects are particularly severe in the City.

The City has experienced both severe to mild earthquake shaking in the historic past, some events occurring within the recent memories of most citizens. Events centered some distance from the City (e.g., Big Bear, Landers, Whittier, Upland, and Lytle Creek) were unsettling but caused only minor local disruptions. The 1992 Landers earthquake main shock occurred approximately 55 miles west of Riverside. Substantial disruption to surrounding communities reminded southern California residents that every several years another area of southern California is vulnerable to a "direct hit". With earthquake prediction still a distant goal, it is important that each City and citizen do what is within its means and power to create policies that will maximize the protection to lives and property.

2. THE GEOLOGIC AND SEISMIC SETTING

The City of Riverside is typical of most southern California cities in that severe local earthquakes (as large as the 6.7 Big Bear and 7.6 Landers earthquakes) may occur within a relatively short distance, for example less than 20 miles (about 32 kilometers [km]). These earthquakes would most likely occur more or less aligned with major strike-slip faults having recognizable surface features (e.g., the Elsinore, San Jacinto and San Andreas faults), but possibly on less well understood faults (e.g., Big Bear) having no, or very subtle, surface expressions. There is no known demonstrated potential for “blind” thrust fault earthquakes in the immediate vicinity of the City. Depending upon the type of source fault, the depth of the energy release, and the magnitude of the earthquake, surface fault rupture may occur causing ground displacements within the near surface geologic and soil formations. Otherwise, there may be coseismic folding and uplift where a localized area is raised with respect to a larger surrounding region, such as regional uplift associated with the 1992 Big Bear earthquake distributed over a large area.

Because of the topography and the nature of the geologic formations present in the City, overall the non-seismic "geologic" hazards are less severe than would be expected in cities with extensive steep hillside terrain. Bedrock landslides and mudslides are not a significant factor. Large-scale subsidence due to fluid withdrawal is also not reported in the area. Dam failure inundation and geotechnical issues are present. Taken together, geologic conditions in the City are somewhat better than average in southern California. The following subsections describe briefly the major seismic and geologic features, which may impact the City.

Also in the following subsections is an overview of the effects in the City of large past earthquakes. This discussion concentrates mainly on the 1987 Whittier Narrows earthquake. The summary of State regulations, which affect seismic safety and earthquake planning, provides a context for later discussions of specific vulnerabilities for City buildings and infrastructure.

2.1. Geologic and Seismic Conditions

2.1.1. Seismic Conditions

2.1.1.1. Earthquakes

Earthquakes generally occur on faults, which are the planar features within the earth. Numerous regional and local faults are capable of producing severe earthquakes, those of magnitude (M) of 6.0 or greater (Figure 1). A computer-generated evaluation of such potential earthquake producing faults was performed considering faults within a radius of 100 km (62 miles) from the center of Riverside are presented in Table 1 (Blake, 2000). This table shows the faults, their maximum potential earthquakes, the likely maximum Modified Mercalli Intensity (MMI; explained on Table 2) and estimated peak horizontal ground acceleration (PGA) near the center of the City using the attenuation relationship of Sadigh et al (1997). Local faults that do not appear in this table (e.g., Rialto-Colton, Casa Loma, Santa Ana thrust) have much less known about their earthquake potential, or they are part of a larger zone, which is evaluated. In either case, the likely upper bounds of their earthquake risk potential are adequately accounted for by the larger, better-studied adjacent faults (e.g., San Jacinto, Cucamonga, Elsinore, San Andreas, Whittier). Regional earthquake epicenters within 100 km (62 miles) of the City center with a magnitude of 4.0 or greater, which occurred through the end of 1995, are also shown on Figure 1.

2.1.1.2. Faults

In cases where earthquakes are large, or hypocenters are shallow, ground rupture can occur along the source fault plane where it intersects the earth's surface. Earthquake shaking is a prime consideration for the City. While the potential for surface fault rupture hazards is considered extremely low, it cannot be fully discounted. “Active” faults (demonstrated offset of Holocene materials [less than 10,000-12,000 years ago] or significant seismic activity) and “potentially active” (Pleistocene [greater than 12,000 but less than 1,600,000 years ago]) faults (as defined by the California Geological Survey -- CGS) must be considered as potential sources for fault rupture. In general, the younger the last movement is on a fault, the higher the potential for future movement on that fault.

Although no active or potentially active fault has been mapped at the surface within the City, one northwest-southeast trending unnamed “Holocene” fault (Figure 2) is projected toward the southwest corner of the sphere boundary (south of Lake Mathews) in the Riverside County Safety Element (2003). In addition to this fault, other minor faults are indicated by the CGS on the State Fault (Jennings, 1994) and Geologic Maps (Santa Ana Map Sheet, Rogers, 1965). A complex set of faults lies south of Lake Mathews, a single fault is west of Lake Mathews near Mockingbird Canyon, and the northwest-southwest trending Elsinore fault zone is indicated approximately 4 miles west of Lake Mathews. In addition, several northwest-southeast trending faults (possibly associated with the San Jacinto fault zone) are shown in the Box Spring Mountains (Figure 1). None of these faults are known to pose a ground rupture threat to the City.

2.1.2. Geologic Conditions

2.1.2.1. Physiography

Physiography (landforms and topography) of the City is controlled by the distribution and character of geologic units, by fault movements, and by climate and erosion. Riverside is within the northern end of the Peninsular Ranges physiographic province, approximately 12 miles south of its intersection with the Transverse Ranges physiographic province. The northwest to southeast trending Santa Ana Mountains (related to the Whittier-Elsinore fault zone and possibly an undocumented Santa Ana Mountains blind thrust) are approximately 15 miles south and southwest of the City, while northwest to southeast trending San Jacinto Mountains (associated with the San Jacinto fault zone) are about 10 miles east and northeast of Riverside.

A series of hills and small mountains, comprised primarily of Cretaceous age crystalline rocks, surrounds the City. These hills and mountains are between the two dominant mountain ranges (San Jacinto and Santa Ana). They include La Loma Hills, Jurupa Mountains, Pedley Hills, La Sierra Hills and others. Within the City, surface elevations range from about 700 feet above mean sea level (amsl) near the Santa Ana River to over 1,400 feet amsl west of La Sierra. The highest point in the immediate vicinity is Arlington Mountain, standing 1,853 feet amsl approximately 1-1/2 miles northwest of Lake Mathews.

Lying between the Santa Ana and San Jacinto Mountain ranges are a series of small valleys separated by small mountains and hills. Generally within the City, ground surfaces slope northwest and have accumulated sediments shed from the mountains along streams and across alluvial fans. The City of Riverside lies along the southern edge of the Santa Ana River valley, just north of the foothills where Lake Mathews is located. This is the point where the Santa Ana River transitions from its north-south path, flowing generally from east to west across the City's northern boundary, before turning southward toward Prado Basin. The Santa Ana River borders the City on the north and northeast, with several small southeast-to-northwest trending tributaries flowing through the City.

The dividing line between hillside and valley topography is taken at the break between greater and less than 15% slope, respectively. Mountains and hills typically have slopes of 15 to 50 percent, with valley and basin areas over have slopes of less than 15%. Within the City most natural slopes are very flat, generally less than 15 percent (800 feet/mile), with some slopes ranging from 15 to 25 percent in eastern and western portions of Riverside (Figure 3). Local slopes may exceed 30 percent in northeastern and western portions of the City.

Many slopes in the sphere of influence are steeper than within the City. Although western part of this area is relatively flat, sloping less than 15 percent, areas around Lake Mathews are much steeper. Slopes along a substantial portion of the area west and south of Lake Mathews exceed 30 percent (Figure 3).

2.1.2.2. Surficial Deposits

2.1.2.2.1 Surficial Mapping

Surficial deposits consist of relatively recent (geologically young) sediments formed by alluvial processes in streams, on alluvial fans/aprons, and primarily by the Santa Ana River and its tributaries. In general, past studies assumed that the uppermost surficial sediments are Holocene (less than 10000-12000 years old) to late Quaternary (less than 100,000 years old) in age, although few deposits have been age-dated by absolute methods (e.g., radiocarbon). Published geologic maps reviewed for this study include the California Department of Water Resources (CDWR, 1970) and US Geological Survey (Morton and Cox, 2001a,b; Morton and Weber, 2001; Morton, 2001; Morton and Gray, 2002; Gray et al, 2002).

The majority of alluvium within and immediately adjacent to the City is divided into three primary units, the younger unit (Qyaa) is associated with more recent deposition by the Santa Ana River and its tributaries, the intermediate unit (Qyfa) concentrated along Magnolia Avenue, and older deposits (Qofa) occupying slightly higher surrounding elevations (Figure 4). The older deposits have been uplifted due broader regional uplift, while the younger sediments were being deposited in the incised river courses around and adjacent to these elevated areas. Nearly 65 percent of the area of the City is underlain by these alluvial deposits (Qyaa, Qyfa and Qofa).

In contrast to the City, a relatively small portion of the sphere of influence contains alluvial deposits. The majority of this area is underlain by crystalline bedrock (Figure 4). Very old alluvial fan deposits (Qvofa) and some minor old alluvium (Qoa, Qvoa, and Qvof) are present on slopes south and southwest of Lake Mathews. Young alluvial deposits (Qyaa) are also present along streams and tributaries flowing into Lake Mathews from the south.

Qyaa, Qyfa, and Qofa deposits (which include overlying soils) consist of predominantly sand, silt, and gravel, with lesser amounts of clay. These deposits are normally unconsolidated and poorly to slightly cemented. Shallow water (less than 30 feet deep) is present in some areas, and the suitability for construction (e.g., slopes, foundation material) may range from acceptable to poor. Liquefaction/dynamic settlement potential is the highest where these Qyaa and Qyfa deposits are mainly sand and silty sand with low density, and are at least partially saturated. High ground shaking intensity (site amplification) potential would be associated with these deposits more so than with otherwise thinner or denser geologic units.

2.1.2.2.2 Subsurface Characteristics

No site-specific reports from the City, which provides subsurface information for the surficial deposits, were made available for this study. Descriptions of subsurface conditions and deposits are summarized from reports and maps published by the California Department of Water Resources and US Geological Survey reports mentioned in the previous section.

Primary subsurface deposits in the Riverside area described by CDWR (1970) and USGS (Morton and Cox, 2001a,b; Morton and Weber, 2001; Morton, 2001; Morton and Gray, 2002; Gray et al, 2002) include recent alluvium and older alluvium. These deposits correspond to younger alluvium (Qyaa), younger alluvial fan deposits (Qyfa), and older alluvial fan deposits (Qofa), respectively.

Quaternary age deposits are present in several areas of the City. These deposits shown on Figure xx consist of older alluvial fan deposits (Qofa), old alluvial valley deposits (Qova), young alluvial fan deposits (Qyfa), younger alluvium (Qyaa), very old alluvial fan deposits (Qvofa), and artificial fill (Qaf). The two most extensive alluvial units are briefly summarized below.

Recent alluvium (Qyfa and Qyaa) is found in stream and riverbeds, washes and other areas with recent sedimentation. They are comprised of relatively unweathered sand, gravel and silt, commonly light yellow, brown or gray. Alluvium consist of rounded fragments derived from erosion of bedrock and reworked older alluvial deposits, as well as mechanical breakdown of larger alluvial fragments during transport. Recent alluvial deposits are up to 150 feet thick (CDWR, 1970).

Along the City's northern border, younger alluvium (Qyaa) consists of gray, unconsolidated, coarse- to fine-grained sand and lesser gravel and silt flanking Santa Ana River channel and its tributaries. It forms terraces slightly elevated above main Santa Ana River channel (Morton and Cox, 2001a,b; Morton and Weber, 2001; Morton, 2001; Morton and Gray, 2002; Gray et al, 2002).

Pleistocene age older alluvial fan deposits (Qofa) cover much of the City, and may also underlie younger alluvium (Qyfa). They are comprised of boulders, gravel, sand, silt, and clay, derived largely from basement rocks in local mountains. These older deposits are distinguishable by their red-brown or brick red color. Typically, thickness of these deposits is less than 500 feet (CDWR, 1970).

Older alluvial fan deposits (Qofa) are the most widely distributed deposits through the northern part of Riverside (Figure 4). These sediments are indurated, to slightly indurated, sandy, reddish-brown alluvial fan deposits. Most of unit is slightly to moderately dissected. Locally, it includes thin, discontinuous surface layer of Holocene alluvial fan material (Morton and Cox, 2001a,b; Morton and Weber, 2001; Morton, 2001; Morton and Gray, 2002; Gray et al, 2002).

The Uniform Building code was updated and revised in 1997. One aspect of the revision was updating the geologic subgrade classification system used to classify soil profiles according to their physical properties. Under the new subgrade classification the upper less dense units (Qyfa and Qyaa) would likely be classified as S_D or $S_{E,}$ which is a stiff to soft soil profile. The lower denser units (Qofa and Qvofa) would likely be classified as S_C or S_D, which is a very dense to stiff soil profile. These classifications will affect seismic coefficients for earthquake design.

2.1.2.3. Bedrock Geology

Cretaceous age crystalline "granitic" bedrock units of the Peninsular Ranges batholith are exposed throughout the City of Riverside. Surface exposures are prevalent in the southern portion of the City and throughout the sphere of influence. Some of these units are formally named, such as Kvt – Val Verde tonalite, present extensively in the eastern 1/3 of Riverside and sphere of influence (see Figure 4). Other "granitic" rock units bear general labels such as Kqd – Quartz-diorite present near the airport, while additional units are undifferentiated (Kgu – undifferentiated granite). Where alluvial deposits are present at the surface, "granitic" bedrock generally underlies these surficial units.

2.1.2.4 Groundwater Depth

The 2003 Riverside County General Plan, Safety Element (Chapter 6) indicates that shallow groundwater is present within the City. But specific groundwater elevation or depth data are not presented in this Plan. Groundwater depths may be discussed in the Natural Hazard Mapping, Analysis and Mitigation Report prepared for the County General Plan, and referenced as Appendix H - Geotechnical Report. Only portions of the text (no Figures, Tables, or Plates) for Appendix H - Geotechnical Report were available for the review conducted for this study.

Available groundwater depth data was limited. No site-specific geotechnical or hydrogeologic studies were provided for this investigation. Data were gathered and reviewed for this study, to support the statements regarding past very shallow water conditions and to assist in quantifying water depths within the City in order to classify areas of the City relative to liquefaction susceptibility potential. Available groundwater data reviewed are discussed below.

2.1.2.4.1 Historical Water Well and Geotechnical Water Level Data

Limited groundwater data was available for this analysis. As noted above, studies prepared for the County of Riverside were not made available for this analysis. One of the most comprehensive historic groundwater investigations of the Riverside area is the California Department of Water Resources (1970) Bulletin No. 104-3, Meeting Water Demands in the Chino-Riverside Area, Appendix A: Water Supply. Groundwater elevation contours from 1960 are presented and compared with groundwater elevations from 1930. Except for the area north of Riverside Drive, between Cedar Avenue and Iowa Avenue, no significant changes were noted.

CDWR (1970) data indicate that 1960 groundwater depths range from approximately 5 feet or less below ground surface (bgs) near the Santa Ana River to about 160 feet bgs in the neighborhood south of Mission Boulevard and west of Iowa Avenue. With the exception of areas noted below, groundwater depth throughout most of the City ranges from 45 to 80 feet bgs. Very shallow groundwater was noted along the Santa Ana River (15 feet or less) and a broad area spanning La Sierra Avenue (10 feet or less).

California Department of Water Resources on-line well records (CDWR website, 2004) were reviewed for water level data within and immediately adjacent to the City. One well, with groundwater level data more recent than the 1970 CDWR report, is located in the NE quarter of section 32, Township 2 South, Range 5 West. It was south of Mountain View Avenue and west of Streeter Avenue. Between January 1955 and December 1984, groundwater depth in this well typically ranged from 46 to 52 feet bgs. These levels are consistent with the 1960 DWR data, indicating that groundwater levels in the Riverside area did not vary substantially during the subsequent decades following CDWR's Bulletin 104 investigation (1970). Therefore, it is concluded that CDWR Bulletin 104 data is valid for this general planning analysis.

Only portions of the text for Appendix H - Geotechnical Report (later titled "Natural Hazard Mapping, Analysis and Mitigation Report") prepared for the Riverside County Safety Element were available for this review. The County Safety Element indicates liquefaction susceptibility areas, dividing them into “shallow” and “deep” groundwater categories (Figure 5). This implies knowledge of shallow groundwater present throughout a large region of the City. Two liquefaction areas delineated on Figure 5 (western and northern sections) coincide with high susceptibility areas indicated on Figure S-3 of the County Safety Element (2003). The western area on Figure 5 also generally corresponds to an area of very shallow groundwater identified from DWR data. In addition, areas of deep water indicated on County Safety Element (2003) Figure S-3 coincide with moderately deep groundwater identified from CDWR data. Therefore, although the original County Safety Element (2003) Appendix H - Geotechnical Report was not available, the results depicted in Figure S-3 in the County Safety Element appear consistent with other data reviewed for this analysis.

The City operates 47 municipal water supply wells (City Financial Statement 1999/2000) across various groundwater basins, with 13.8 percent of water provided by wells in the Riverside Basin. Most water (86.2 percent) is extracted by wells located in the San Bernardino Basin. Water level data from the Riverside basin wells were not available to review for this study. A detailed evaluation of data from all area wells would provide more specific information on water depth distribution, and could be used to refine the level of potential liquefaction hazards across the City with a more detailed zonation.

2.2. Past Earthquake Effects

Several recent earthquakes in southern California have been of a sufficiently high magnitude to be felt in Riverside. (Magnitudes are expressed as M for Richter magnitude, M_L for local magnitude, and M_W for moment magnitude. The specific method of computing each magnitude is unimportant for this report.) None of the following “felt” earthquakes caused injuries and deaths in communities near Riverside; no more than just cosmetic damage to structures occurred in the City. These "felt" earthquakes are the 1971 San Fernando (Mw = 6.5), the 1988 Pasadena (Mw = 4.9), the 1987 Whittier Narrows (M_L = 5.9), the 1989 Sierra Madre (Mw = 5.9), the 1992 Landers (Mw = 7.3) and Big Bear (Mw = 6.2), and the 1994 Northridge (Mw = 6.7) earthquakes. Modified Mercalli Intensity (MMI) values (see Table 2) in Riverside ranged from II to VI.

A list of select historic earthquakes felt in Riverside is provided in Table 3. This list illustrates that Riverside has experience strong ground motion (MMI of VIII to IX) from past local and distant earthquakes. If a major earthquake is generated closer to the City, ground motion could be severe.

2.3. Earthquake and Geologic Hazard Regulations

The various regulations governing planning for earthquake and geologic hazards are reflected in City, County, and State requirements. The City General Plan is required under the Section 65300 et seq. of the Government Code and relies on the seismic and geologic information contained in the Seismic Safety and Public Safety Elements for defining areas of the City subject to seismic and geologic hazards. This seismic information should be updated as part of the General Plan process to the extent that new information is available. The City is to use the Public Safety Element and General Plan to assure that geologic and seismic hazards are properly considered and potential problems are mitigated prior to development. The City also uses its Building Code to define specific investigation and mitigation measures, which must be undertaken for certain, projects and certain conditions.

The County of Riverside regulates in much the same way as individual cities, utilizing codes for Building, Zoning, Subdivision, Health and Fire. Seismic and geologic hazard considerations affect sections within these specific codes. The City of Riverside has adopted (Riverside Municipal Code Chapter 16.08.020) The Uniform Building Code for its geology and geotechnical investigation and mitigation standards.

The State has three important seismic and geologic hazard elements, which apply to the City: the California Building Code (CBC, 2001); the Alquist-Priolo Earthquake Fault Zoning Act (APEFZA, 1972, amended in 1994); and the Seismic Hazard Mapping Act (SHMA, 1990). The 1995 CBC is largely equivalent to the Uniform Building Code (UBC; 1997), except that it has a substantial portion specifically rewritten and tailored to be responsive to California earthquake conditions. County or City building codes must adopt the CBC or may develop more stringent codes as appropriate.

The APEFZA (through the California Geological Survey--CGS) specifies the types of faults and specific faults, which are considered sufficiently active and well defined as to constitute a potential hazard to structures from surface faulting or fault creep. Cities are to use the policies and criteria in the exercise of their responsibility to prohibit the location of developments and structures for human occupancy across the trace of active faults. No Alquist-Priolo zones are located within the City

The SHMA requires the CGS to prepare seismic hazard zone maps for liquefaction and seismically induced landslide hazards. The Act also directs, among other things, that cities use the maps in their land use planning and permitting processes. No Seismic Hazard Mapping Act maps have yet been produced for the City due to funding priorities.

3. ANALYSIS OF HAZARDS AFFECTING THE CITY

Potential hazards have been divided into two categories, seismic and geologic (non-seismic). Seismic hazards require an earthquake in order to be activated. The magnitude of this earthquake should be at least 5.0 for most significant effects to be triggered, although lesser magnitude earthquakes have activated hazards and caused damage. Geologic hazards are those, which may be activated with or without an earthquake due to the nature of the geologic materials or the hydrogeologic regime. In the City of Riverside, seismic hazards carry with them the most risk to property and population.

3.1. Seismic Hazards

3.1.1. Overview

For the seismic component of the Public Safety Element, the minimum list of potential hazards, which must be considered, is:

- Ground shaking (earthquake-induced strong ground motion)
- Ground failure (liquefaction and shallow groundwater, and dynamic compaction and consolidation)
- Seismically induced surface (fault) rupture
- Tsunami and seiche
- Seismically induced landslides

Tsunami hazards are not present for the City due to the elevation and distance to the ocean. Seiching in the Lake Mathews or smaller reservoirs (Prenda, Woodcrest, Mockingbird and Harrison), within the City or its sphere of influence, could conceivably cause dam failure. This eventuality is covered in the geologic hazard section for dam failure inundation. Therefore, these hazards are not discussed further in this section. The following subsections discuss the remaining potential hazards in the order of most widespread potential affect within the City.

3.1.2. Ground Shaking (Earthquake Induced Strong Ground Motions)

3.1.2.1. Data

There are local and regional faults (Figures 1 and 2, and Table 1), which will potentially affect the future seismicity of the City and the surrounding region. The effect of an earthquake originating on any given fault will depend primarily upon its distance from the City and the size earthquake (amount of energy release) that the fault is likely to generate. In general, the more distant the fault is and the smaller the potential earthquake, the less the effect. The effect is most often presented as the severity of ground shaking which is presented as the percentage of the force of gravity, which is termed "1 g" for one unit of gravitational force. Therefore, 0.50 g is 50% the force of gravity.

Based on Table 1, the faults which would have the most adverse ground shaking affects on the City for the estimated maximum earthquakes would be the San Jacinto (both San Bernardino and San Jacinto Valley segments), Cucamonga, Chino-Central Avenue (Elsinore), and the San Andreas fault zone (both southern and San Bernardino segments). For critical facilities it may be necessary to consider a larger estimated maximum earthquake on the San Jacinto fault north of the City. Maximum magnitude updates are available from California Geological Survey (e.g., Peterson et al, 1995).

It must be emphasized and understood that the data in Table 1 are taken from a single source (Blake, 2000) for purposes of consistency, utilizing City Hall (latitude 33.982^o, longitude 117.372^o) as the reference point. These values are suitable for general planning purposes, but should not be used for site-specific design. Ground motion for specific project will vary based on numerous factors, including location relative to City Hall, distance from causative fault, directivity of energy release, local geologic conditions, and other technical factors.

Several large historic/pre-instrumental (i.e., before modern seismographs) earthquakes are reported to have occurred within the selected 100-kilometer radius. The epicenter locations of each of these events are considered very uncertain since they are based on damage reports and the felt intensity of shaking. Damage and intensity can be highly affected by local geology and not just distance to the epicenter.

Of some interest, because of damage in the City, is the 1918 event. In April 1918, a Magnitude 6.8 earthquake on the San Jacinto fault caused heavy damage at San Jacinto and Hemet. Property loss was about $200,000. Only one new concrete and one frame building remained standing in the business section of San Jacinto. The dry earth surface was broken up in the San Jacinto fault area southeast of Hemet. An earthquake-induced landslide carried one auto off the road, while many area roads were blocked. Even though the earthquake center was over 30 miles southeast, Riverside experienced a MMI of VII.

3.1.2.2. Generally Expected Effects

The effects of severe groundshaking are not difficult to imagine given the recent earthquakes in southern California. The 1994 Northridge earthquake had a moment magnitude of 6.7 and occurred on a previously unidentified buried thrust fault beneath the San Fernando Valley. It caused significant structural damage, injury, and loss of life in the San Fernando Valley, Simi Valley, Santa Clarita Valley, and the northern Los Angeles Basin. Peak horizontal and vertical ground accelerations exceeded 1 g.

The 1971 San Fernando earthquake (M_m 6.6) was located on a known active reverse fault with surface expression, although the areas of surface rupture (defined by buried groundwater barriers) locations were not expected. The groundshaking lead to MMI values of VII to XI and cause significant damage in areas as far east as Pasadena and south to downtown Los Angeles; peak ground accelerations were as high a 1 g, but mainly less than about 0.5 g in populated areas.

Groundshaking estimates of peak horizontal acceleration in Table 1 account for the effects of the geology to some degree by assuming that the center of the City is a "soil site," that is, bedrock is deep causing some amplification (effective increase) of ground motion as the waves pass from the bedrock through the alluvium. However, it can be expected that local differences in subsurface conditions (e.g., density, water content, grain size, subgrade soil profile classification) will increase the effective shaking above the levels stated in Table 1 and discussed below. This is why site-specific geology, geotechnical, and earthquake engineering studies are mandatory for critical, sensitive, or high-occupancy structures.

Mean peak horizontal ground accelerations for the estimated maximum earthquakes (see Table 1) would be expected to be in the range of 0.048 to 0.277 g, which is within the limits for current structural design (CBC/UBC) for non-critical structures, including most residential, commercial, and industrial buildings. The more conservative one-sigma standard deviation from the mean peak horizontal ground acceleration values for estimated maximum earthquake levels range from 0.071 to 0.433 g for faults of concern. For the closest faults, these accelerations are in the 0.349 to 0.433 g range, which is also within "standard" design in current codes. Experience with the San Fernando and Northridge earthquakes indicates that even higher accelerations are possible (up to 1 g or higher) associated with large earthquakes on nearby reverse or thrust faults, such as a possible Santa Ana Mountains blind thrust fault.

The mean acceleration for the estimated maximum earthquake events would generate site intensities in the range of VI to IX in the City, greater than that likely experienced in Riverside (MMI of VII) during the San Jacinto earthquakes in 1899 and 1918. The higher end of the range (one-sigma values) would likely exceed what was experienced in the moderate to worst damage areas of 1987 Whittier and 1994 Northridge events, and have damage intensity of MMI of IX to X in the City. This damage would be greater in areas where ground failure occurred due to liquefaction, or dynamic consolidation and ground subsidence. These hazards are discussed in the next subsection.

State and Federal agencies, through the California Integrated Seismic Network (CISN), prepared "scenario earthquake" analyses to describe expected ground motion and effects of specific hypothetical large earthquakes generated by the nearby San Jacinto and Elsinore fault zones (see Appendix A). These selected earthquake scenarios are not intended as earthquake predictions, but serve in planning and coordinating emergency response by illustrating locations where earthquake affects may be greatest. Scenarios were developed by, (a) assuming a particular fault or fault segment would rupture over a certain length (using consensus-based information about the fault and its likely earthquake magnitude for planning purposes) and (b) estimating ground motions at all locations in a chosen region surrounding the causative fault. For the San Jacinto and Elsinore fault zones, earthquake magnitudes of 6.7 and 6.8, respectively, were chosen.

In addition to earthquake size, a hypothetical future earthquake location allows a reasonable prediction of assumed earthquake effects, including estimated Modified Mercalli Intensity, Peak Ground Acceleration, Peak Ground Velocity, and Peak Spectral Acceleration for three specific building response periods (see Appendix A). Although these predictions have many limitations, estimates of potential shaking effects from the earthquake scenarios benefit pre-earthquake planning and preparedness. A technical summary of this information, including a series of CISN "ShakeMaps" for the City is provided in Appendix A.

3.1.3. Ground Failure

Ground failure can include an entire suite of affects ranging from simple ground cracking to complex lateral spreading landslides. Failures may be associated with saturated deposits (liquefaction) or unsaturated deposits (densification). The various considerations under these two topics are discussed below.

3.1.3.1. Liquefaction and Shallow Groundwater

3.1.3.1.1. Data

The three key factors, which indicate whether an area is potentially susceptible to liquefaction, are severe groundshaking, shallow groundwater and cohesionless sands. In addition to having ground shaking parameters, quantitative estimates of liquefaction potential require specific data from geotechnical borings and groundwater level information. In the County Public Safety Element, Figure S-3, Liquefaction Areas, delineates areas within the City and adjacent sphere of influence that are susceptible to liquefaction (see Figure 5).

Within the City and adjacent sphere of influence, there are four primary liquefaction areas. These four areas delineated on Figure 5 generally correspond to alluvial deposits Qyaa or Qofa indicated within the City (Figure 6) and shallow high groundwater: (1) along the Santa Ana River (Qyaa), (2) a broad area south and west of the airport (Qofa), (3) a broad area in the western portion of the City (Qofa) spanning La Sierra Avenue, and (4) a smaller area along the City's southern boundary (Qofa).

Data within the City are insufficient to map potential liquefaction conditions with precision. However, the liquefaction hazard map in the 2003 Riverside County General Plan, Chapter 6 – Safety Element (Figure S-3), included herein as Figure 5, provides greater differentiation between level of liquefaction susceptibility. It indicates a substantial part of the City is underlain by areas susceptible to varying degrees of liquefaction, ranging from moderate to very high, while most of the sphere of influence south of the City, except for alluvial filled drainages leading into Lake Mathews, is not susceptible to liquefaction. Primarily "granitic" rocks of the Peninsular Ranges batholith underlie the sphere of influence south of the City.

Although there is some potential for deep liquefaction greater than about 50 below ground surface, liquefaction potential is substantially higher where water has historically been found less than 50 feet deep. Although the Riverside County Safety Element separates potentially liquefiable sediments (Figure S-3) into categories with "shallow groundwater," "deep groundwater," and "no groundwater data," it does not indicate which water depth criteria was used to differentiate between degrees of liquefaction susceptibility indicated. Therefore, susceptibility levels have not been determined with a high degree of precision.

Liquefaction areas shown in Figure 5 are considered to have potential land use constraints. Liquefaction assessments should be made for all important projects. The depth and intensity of study will naturally vary depending on the location, type, and importance of the project. It should be a goal to compile such data as it might exist in City, State, or County files, and to update groundwater depth data so that an ongoing assessment is possible. Due to the lack of available City-specific geologic and engineering properties data, areas of liquefaction potential shown on Figure 5 should be considered approximate. They should be used as general, not absolute, planning guidelines to indicate where assessments are needed for planned structures or possibly for existing critical, essential, and high occupancy facilities.

3.1.3.1.2. Generally Expected Effects

Liquefaction-induced ground failure can involve a complex interaction among seismic, geologic, soil, topographic, and groundwater factors. Failures can include ground fissures, sand boils, ground settlement, loss of bearing strength, buoyancy effects, ground oscillation, flow failure and lateral spread (Bartlett and Youd, 1992). These, in turn, can have effects on surface and subsurface structures. *Ground fissures* may be reflected as linear tensional features which open to widths of a few to several inches, but which may or may not exhibit differential vertical movement. *Sand boils* are built-up sand accumulations often up to three feet across that result from ejected sand and water forced from the subsurface under pressure. *Ground settlement* often occurs as liquefied sand deposits reconsolidate following ejection of the water and sand. A *loss of bearing strength* can cause surface structures to settle, either rather evenly or differentially, causing tilting. *Buoyancy* caused by rapid upward movement of water through sandy soils can cause buried structures to rise (float) when they are founded in the liquefied layer. *Ground oscillation* may not cause permanent ground displacement, but may damage rigid structures beyond the severe ground shaking in a non-liquefied zone. *Flow failure* is found in steeper terrain where liquefied soils near the ground surface flow as a viscous mass down slope similar to a mudflow in rain-saturated soils. *Lateral spread* is a liquefaction-induced landslide of a fairly coherent block of soil and sediment deposits that moves laterally (along the liquefied zone) by gravitational force, sometimes on the order of 10 feet, often toward a topographic low such as a depression or a valley area.

Each of these liquefaction failures can cause damage to surface and subsurface structures, with the severity dependent upon the type and magnitude of failure and the relative location of the structures. For planning purposes it is only possible to designate areas where the likelihood of these failures, as a group, is greatest. In addition, since liquefaction-induced lateral spread failures appear to be more prevalent adjacent to topographic depressions or valley areas, it is possible considering topography to envision locales where these more serious failures have a higher potential.

Considering past earthquake experience from other areas, lateral spreads caused significant damage to critical facilities (i.e., Jensen Filtration Plant, Sylmar Converter Station, Juvenile Hall) during the 1971 San Fernando earthquake, which was totally unexpected. These failures occurred in areas with very low slope gradients; at Juvenile Hall and the Sylmar Converter Station, the average ground surface gradient was 1.5 degrees and the maximum was 3 degrees (O'Rourke, Roth and Hamada, 1992). Lateral spreads in the San Francisco earthquake of 1906 occurred associated with surface gradients of 0.4 to 2.10 percent, or about 0.2 to 1 degree (O'Rourke, Beaujon, and Scawthorn, 1992). In the latter case, the slope of the liquefied subsurface layer may have been as low as zero degrees.

3.1.3.2. Dynamic Consolidation and Subsidence

3.1.3.2.1. Data

Dry- to partially-saturated sediments not susceptible to liquefaction may be susceptible to dynamic consolidation and local ground subsidence. This consolidation or densification occurs in loose cohesionless sediments as the void spaces are diminished due to intense seismic shaking. Hazard maps are not normally created for this condition, and there are no specific data in the City, which allow prediction of the locations or magnitudes of potential consolidation and subsidence.

In general, Qyaa would be the most susceptible to dynamic consolidation effects. Qofa could also be susceptible, but less so due to it’s higher in-place density and some cementation. Areas where artificial fill (Qaf) placed without proper engineering controls and inspections are also susceptible to dynamic consolidation and subsidence.

3.1.3.2.2. Generally Expected Effects

Sections of the City are potentially susceptible to subsidence (Riverside County, 2003, Figure S-7), although no specific areas of documented past subsidence are identified in the City by the Riverside County Safety Element (2003). The County (2003) did not delineate potentially susceptible subsidence within the City’s sphere of influence (see Figure 6).

Due to the heterogeneous nature of the alluvial deposits in the City, the amount of dynamic consolidation and subsidence will not be consistent from location to location. Variations in vertical subsidence may occur within a small area such as an individual lot or beneath an individual structure. This may cause differential settlement of the structure and substantially more damage than if the structure were to settle evenly throughout.

Observations reported in the other areas of southern California suggest that subsidence and building settlement may reach a few feet or more; however, settlements of 5 to 30 centimeters (2 to 12 inches) are not uncommon. The resultant ground failures are manifest as ground cracks with relative vertical displacements as indicated above. When structures overlie these local subsidence areas, ground cracking may be translated through foundations and slabs causing severe structural damage.

If the City is underlain by up to 150 of young alluvium (Qyaa), and we assume approximately 20 to 40 feet is loose, unconsolidated granular alluvium, and consolidation potential ranges from 2 to 6 percent, then dynamic consolidation may range from 5 to 30 inches. In areas overlain by non-engineered fill, these amounts could be greater. An area of artificial fill (Qaf on Figure 4) is located in the eastern portion of the City, north of Century Avenue and along Country Club Drive, east of Alessandro Boulevard. Since this area is subdivided, it is assumed that this fill is engineered and properly compacted. Considering engineered/compacted fill. The cut/fill contact line is a primary location for differential dynamic consolidation that can impact structures.

3.1.4. Fault Rupture

3.1.4.1. Data

No known active or potentially active faults have been mapped within the City boundaries (Figure 2), which would represent locations for potential surface fault rupture. One mapped fault in the sphere of influence parallels Mockingbird Canyon, but no available information on past activity is available. The County (2003) indicates (see County Figure S-2) that an unnamed northwest-southeast trending Holocene fault is projected toward the southern part of the City's sphere of influence (Figure 2). This unnamed fault is shown on Figure 2 and labeled as a County Fault that is zoned for required study.

Unidentified buried faults may exist, underlying the City or sphere of influence. Groundwater investigation by DWR (1970) did not note any faults forming groundwater barriers within the City or sphere of influence. But lack of identified groundwater barriers does not preclude the presence of subsurface faulting.

If movement were to occur on an unidentified buried fault, either vertical or horizontal surface offset or localized uplift could result. With a magnitude of 7or greater, these movements could be very large, possibly 10 feet or more. Ground rupture movements of this magnitude caused very severe damage to structures overlying faults associated with the 7.2 magnitude Landers earthquake in 1992. Earthquakes under magnitude 6 (unless very shallow) may cause no significant offset or uplift.

3.1.4.2. Generally Expected Effects

Fault rupture through a structure will very likely cause irreparable damage and may cause collapse of walls and ceilings. Normal foundations would be dislocated and rendered unusable. Combined with strong ground shaking, this is a very serious hazard. Utilities would likely be severed causing water, natural gas, electrical, storm drain, and sewer system outages. Streets could be passable with some difficulty if fault motion is strike-slip (horizontal). But vertical fault offsets could render streets impassable for emergency traffic, except to high-ground clearance vehicles with 4-wheel drive.

3.1.5. Seismically-induced Landslides

3.1.5.1. Data

A few areas of the City (Figure 7) could be prone to seismically induced landslides and rockfalls. The County of Riverside (Figure S-4) designates some areas in western Riverside with susceptibility to seismically induced landslides and rock falls, ranging from low to locally moderate to high. In addition, some areas in northeastern Riverside are designated with low to locally moderate susceptibility to seismically induced landslides and rockfalls.

3.1.5.2. Generally Expected Effects

Seismically induced landslides and rockfalls are common during large earthquakes. Structures located below this hazard area could be subject to severe damage. Large boulder dislodged from high steep slopes may travel as far as 40 to 80 feet from the slope across adjacent gently sloping surfaces.

A somewhat conservative, yet reasoned approach should be taken with regard to development project evaluation relative to potentially severe ground motion and liquefaction hazards associated with large earthquakes on nearby faults. This somewhat conservative approach based on the available data is in recognition of what geologists have learned through the southern California earthquakes over the past 25 years that is to expect the situation to be worse than sparse data indicate. This is especially true where anomalous shallow groundwater conditions and barriers have been observed or strongly postulated (e.g., San Fernando before 1971).

3.2. Geologic Hazards

3.2.1. Overview

For the geologic component of the Safety Element the minimum list of potential hazards which must be considered are:

- Slope Instability (landslides and mudslides)
- Dam failure inundation
- Subsidence
- Groundwater Depth (also discussed under liquefaction above)

Slope instability under non-earthquake (static) conditions are not considered to be a significant hazard in the City. The slope stability hazard for natural slopes is discussed in the County Safety Element (2003) and delineated on Figures S-4 and S-5. Sections of these maps pertaining to the City are included herein as Figures 8 and 3, respectively. The slope stability hazard within the City is rated as negligible because the topography is very flat to moderately flat, and no bedded sedimentary bedrock is exposed. The Riverside County Seismic Element shows the locations of areas susceptible to seismically induced landslides and rockfall hazards (County, 2003).

Subsidence due to groundwater withdrawal is possible in the City due to substantial pumping. No subsidence within the City was noted in the County Safety Element (2003). Dam failure inundation and shallow groundwater are discussed below.

3.2.2. Dam Failure Inundation and Flooding

<u>3.2.2.1. Data</u>

The past failures (Baldwin Hills and St. Francis) and near-failures (Van Norman) of southern California dams point out the importance of considering dam safety. Dams may fail for seismic or geologic reasons, either of which could lead to the results described in this section. The City lies downstream from several dams and debris basins whose drainages ultimately flow into the Santa Ana River or its tributaries. Inundation hazards range from high to low with distance away from Lake Mathews and other reservoirs, such as Harrison and Mockingbird Reservoirs.

Lake Mathews is the largest reservoir that would affect the City in the event of a dam breach. If Mathews Dike (dam along northern shore) failed catastrophically, floodwaters would travel across an alluvial slope below the dam, and down several small un-named drainages on its way to the City (Figure 8). These floodwaters could inundate broad areas of the City as indicated by the County Safety Element (2003) Figure S-10.

Failure of the Mathews Dam (western side of lake) would send floodwaters down Cajalco Canyon to Temescal Wash (Figure 8). This scenario would bypass most of Riverside and its sphere of influence. Within the sphere of influence, floodwaters would be confined to Cajalco Canyon.

Dam failure at Mockingbird or Harrison Reservoirs could also inundate areas downstream (Figure 10). The areas immediately downstream are classified as a high (Mockingbird) or moderate (Harrison) hazard zones in the County Safety Element (Figure S-10).

Flooding

The Santa Ana River, flowing along Riverside's northern border, represents a potential flood hazard. Sections of the City are within the 100-year flood plain (Figure 10), which could be inundated during a major storm event. In addition, the 2003 County Safety Element (Figure S-9) indicates a small area of the City (northernmost section) within the along the Santa Ana River 500-year flood plain. This area along the Santa Ana River is between the Pomona Freeway (SR-60) and Mission Boulevard (Figure 8). These flood plains represent potential constraints to future development.

3.2.2.2. Generally Expected Effects

A catastrophic failure of Mathews Dike (dam along north shore) would inundate a large section of the City. Extensive damage is expected for structures and facilities located along natural drainage courses in close proximity below the dam. Farther from the dam, flood damage is expected as water spreads across a broad area of the City before reaching the Santa Ana River.

Areas immediately along the natural drainage courses would be the most susceptible to damage from rapidly flowing water, severe erosion, and associated floating debris. Higher areas and those farthest from the channels would suffer more from sheet flow and rising water. Man-made barriers, such as elevated sections of highways or railroads, would locally deflect sheet flow.

Figure 8, covering the City and sphere of influence, are a section of Figure S-10 from the County Safety Element (2003). It illustrates inundation areas resulting from failure of various reservoirs in and around the City. Since other reservoirs are relatively small compared to Lake Mathews, failure of Mathews Dike represents the worst-case inundation scenario.

3.2.3. Shallow Groundwater

3.2.3.1 Data

The data on shallow groundwater are discussed in Section 2.1.2.4 and reviewed in the liquefaction discussion. The concern in this section is the potential to intercept shallow or perched groundwater in subsurface excavations, such a basements, utility trenches, deep foundations, or tunnels. On its liquefaction hazard map (County Figure S-3), the County delineates shallow groundwater within the City. In some areas, groundwater may exist at depths ranging from 10 to 15 feet. In areas where shallow groundwater is indicated on Figure S-3), planning for each project should consider shallow water levels in determining how to best implement construction or exploration programs.

3.2.3.2 Generally Expected Effects

Surface (open cuts and pits) or underground (tunnels, vertical large-diameter borings) excavations can encounter shallow groundwater inflows, which may be perched and local or widespread in extent. This will affect excavation stability, and therefore short- and long-term safety for workers, as well as post-construction stability of structures associated with these excavation areas. The degree of hazard for the City should be determined on a case-by-case basis if projects requiring deep excavations are proposed.

It is important to recognize that shallow groundwater data discussed above are depth estimates based on a "snapshot" in time; shallower historic levels should also be considered for planning purposes. Depths to water of less than 15 feet are considered a high hazard because water may be encountered even in routine project excavations; depths of 15 to 30 feet are considered a moderate hazard because only the more significant excavations for larger project structures would likely extent to these depths. For water greater than 30 feet deep the hazard is considered insignificant, although for some projects (e.g., deep tunnel or a major high-rise building) this will remain a design issue; it is assumed that such structures will be very carefully studied and will have liquefaction as an issue which will call attention to the shallow water depths.

4. POTENTIAL EARTHQUAKE EFFECTS

The hazards discussed above have the potential to cause serious damage, injury and death if the seismic event is large enough to generate short duration high peak ground accelerations, or long duration moderate to high ground accelerations. Examples of the types of structures of concern are linear lifelines (i.e., streets, freeways, pipelines, high voltage lines, utilities lines) and emergency facilities. In particular the 30" diameter high-pressure gas line crossing through the City (Figure 9) could rupture, leading to fires or explosions. Important emergency facilities include medical and care facilities, schools, emergency response centers (City Hall); and fire facilities.

The earthquake effects on structures and facilities will be dependent upon the size and location of the earthquake being considered for specific locations within the City. Table 4, subdivided into Tables 4A, 4B, and 4C, provides a summary of the potential seismic vulnerability of structures and facilities, and the potential geologic and seismic hazards, in or adjacent to the City of Riverside. Discussions are strictly in qualitative and relative terms since no detailed quantitative analysis has been performed. The intent of Table 4 is to highlight potential areas of concern in order to provide a planning tool for the City. The table should be considered in the context of the previous technical discussions and maps.

For purposes of the Table 4 Groundshaking Damage Vulnerability columns, three earthquakes are considered. First is the local estimated maximum event on the San Jacinto fault (San Bernardino or San Jacinto Valley segments) with assumed peak horizontal ground accelerations of 0.403 g to 0.433 g, respectively, and estimated MMI of IX to X. Second is the distant estimated maximum event on the San Andreas fault (southern segment) with an assumed peak horizontal ground acceleration of 0.311 g and an estimated MMI of IX. Third is the local estimate maximum event on the Chino-Central Avenue (Elsinore) fault with an assumed peak horizontal ground acceleration of about 0.295 g and an estimated Modified Mercalli Intensity of IX.

4.1 Lifeline (Linear) Systems

4.1.1 Freeways and Evacuation/Emergency Response Routes

The freeways (Figures 9) are vulnerable to damage from seismic shaking, and associated liquefaction and dynamic consolidation in any of the three earthquakes noted in Table 6. Many freeway bridges/over crossings may have been seismically retrofitted by the State and may have foundations in dense alluvial or bedrock materials with zero to low potential for settlement or liquefaction. Freeway and crossing (over or under) roadbed sections are subject to settlement due to liquefaction and dynamic consolidation, which could cause local disruptions, particularly at the connections with bridges.

Outside the City and sphere of influence, various faults pass beneath major highways. Several traces of the Elsinore fault zone cross I-15 and SH-91 west of the City. Several traces of the San Jacinto fault zone cross sections of I-215 and SR-60 north and east of the City. More important, some traces of the San Jacinto fault zone pass beneath the I-215/I-10 interchange northeast of the City, posing a remote chance for surface rupture or localized uplift, which could damage the structure. Since freeways have proven to be at least temporary weak links in the post-earthquake regional transportation system, they should be avoided where possible. Discussions with Caltrans should be part of earthquake disaster planning.

Primary evacuation and emergency response routes within the City should be roads which will handle maximum traffic and which lead directly to or from areas where less severe damage is predicted. Both northwest-southeast and northeast-southwest roadways will be important. Table 4 considers Van Buren Boulevard and La Sierra Avenue as primary northwest-southeast routes, with Magnolia and Victoria Avenues as northeast-southwest routes, while Arlington Avenue serves as an east-west route.

With few tall structures and no hillside slopes to collapse into the streets, primary evacuation and emergency response routes within the City should remain relatively open and passable. In general, more damage can be expected along La Sierra Avenue and sections of Arlington Avenue where groundwater levels are less than 30 feet deep and liquefaction hazards are identified. Damage from liquefaction and dynamic consolidation could cause local disruptions such as settlement, sinkholes, and severe cracking having inches to a few feet of vertical movement. Lateral spread landslides may be possible adjacent to the Santa Ana River along the north side of the City. Even though slopes are moderately shallow across the City, local areas of very shallow groundwater with down slope “free faces” could be susceptible to lateral spread landslides during longer duration strong shaking.

4.1.2 High Voltage Transmission Line

There are believed to be no high voltage transmission line lies within the City. For future considerations, there is a concern for liquefaction and dynamic settlement beneath the towers, and for strong groundshaking causing swaying. Consultation with Edison Company or the appropriate utility should be done in order to determine the likelihood for damage to future high-voltage transmission lines, and to assess damage to property or persons (e.g., fire) in the City.

4.1.3 High Pressure Natural Gas Lines

A 30-inch diameter high-pressure gas pipeline (Southern California Gas Company) passes through the northwestern portion of the City in a general east-west direction. Where it crosses the Santa Ana River, this area is moderately susceptible to liquefaction and dynamic consolidation. It is possible that these effects could cause disruption of this line in the most severe earthquake events. If this line ruptured, there would be a distinct possibility of fire or explosion if gas entered confined spaces. This possibility is the greatest where the groundwater is less than 30 feet deep, and where there is a greater possibility of lateral spread landslides adjacent to the Santa Ana River. Under these severe conditions gas line disruptions may affect the use of local streets.

4.1.4 Miscellaneous Utilities Services

Liquefaction, dynamic consolidation, and strong groundshaking can affect buried and aboveground utilities, particularly at points-of-connection. These may be at residences or businesses, or at joints, junctions, and valves in the system. In general it can be expected that damage will be more severe due to amplification of ground motions where the groundwater is shallower and sediments are thicker and/or less dense. This would suggest that the northern portion of the City would have generally more frequent instances of damage than the southern portion. It is not possible to predict relative frequency of damage more specifically without knowledge of the age of the various systems and the amount of upgrade that has been done. The older systems are clearly the most vulnerable. The largest short-term threat is from fire caused by natural gas leaks at residences and businesses.

4.2 Medical and Care Facilities

Several medical facilities and hospitals are located throughout the City and surrounding area (Figure 10). Some of these are susceptible to various hazards identified above. Table 4 lists these facilities and summarizes potential hazards. Hospitals in the City are located in an area designated by the County as "Very High" ground shaking risk. They could experience ground motion ranging from 0.30 to 0.40 g (County, 2003).

Some of these facilities are critically important and will be an important source of post-earthquake care for the injured. If located in a zone of liquefaction susceptibility, it is important to understand whether its construction has accounted for geologic and seismic risk, as they are now understood within the City. The hospital owners in conjunction with the City should undertake an evaluation of these factors and conditions. This should include an assessment of the earthquake preparedness of the staff, and the vulnerability of the contents and fixtures. In addition, there may be other dependent care facilities (e.g., convalescent, day care, social services, retirement facilities) or medical centers in the City, which should be identified and evaluated at some level for earthquake safety.

4.3 Schools

Several schools are located throughout the City (Figure 10). Some of these are susceptible to various hazards identified above. Table 4 lists these facilities and summarizes potential hazards. Schools in the City are located in an area designated by the County as "Very High" ground shaking risk. They could experience ground motion ranging from 0.30 to 0.40 g (County, 2003).

The age of construction and relative seismic stability of each individual school is not known. In general, schools located in a zone of liquefaction and dynamic settlement potential would have more damage in a given earthquake than schools outside these areas. Schools located where groundwater is believed to be less than 20 feet deep are the most susceptible to damage. Since schools are often used as evacuation shelters following an earthquake, the southern and eastern locations with shallow "granitic" bedrock will be generally more suitable from a planning viewpoint than the western locations or those adjacent to the Santa Ana River.

4.4 Emergency Response, Police and Fire Facilities

The primary emergency response center is the Riverside City Hall located at 3900 Main Street. It understood that the original facility was constructed in 1924 and may have been subject to more stringent seismic codes in place after the San Fernando earthquake in 1971. Inquiries to the City did not lead to specific geologic or geotechnical data for the City Hall; it is possible that no studies were done. It lies within the area where water is estimated to be deep and liquefaction potential is low. The site lies outside the dam inundation area for the Lake Mathews. Earthquake shaking at the site may exceed the 0.4 g of the current 2001 California Building Code.

City Hall is an important facility if it is intended to be the focal point for of post-earthquake disaster coordination and response. Due to the location in a zone of potential liquefaction susceptibility, the design and construction standards for the building should account for geologic and seismic risk as now understood. The City should undertake an evaluation of these factors and conditions. This should include an assessment of the earthquake preparedness of the staff, and the vulnerability of the contents and fixtures. Depending upon the results of this evaluation, the City may want to consider making a portion of the City Hall disaster response center.

Fire and police facilities are located at various sites across the City (Figure 10). Some of these locations are susceptible to hazards identified above. Table 4 lists these facilities and summarizes potential hazards. Emergency response facilities in the City are located on an area designated by the County as “Very High” ground shaking risk. They could experience ground motion ranging from 0.30 to 0.40 g (County, 2003).

4.5 Potentially Hazardous Buildings

It is beyond the scope of this study to comment on specific non-critical facilities and structures. Generally this includes residences, apartments, businesses, and public facilities such as libraries, agency offices, meeting rooms, motels, hotels, and churches. Many buildings in the City were constructed prior to 1971, before more stringent seismic design codes were enacted based on the San Fernando earthquake and based on later technology studies.

Potentially hazardous buildings consist of: dilapidated structures regardless of age; pre-1971 concrete tilt-up construction; non-ductile concrete frame buildings; multistory buildings with a soft story; buildings with a complex design/floor plan; and homes with unbolted foundations including mobile homes. If present, unreinforced masonry (URMs) buildings are especially hazardous. Also potentially hazardous are non-structural building components (e.g., contents, facades, fixtures) and buildings storing hazardous materials. The City should do whatever it can to educate and persuade City residents, business owners, and owners of buildings within the City that fall into these categories, to perform seismic strengthening and engage in earthquake preparedness programs.

4.6 Land Use and Development

The primary land use constraint identified in the County Safety Plan (2003) is development in locations subject to flooding. Where possible, future development on 100-year or 500-year flood plains should be avoided. Critical emergency facilities and school should not be located in these areas unless proper precautions are taken. In addition, facilities handling or storing hazardous substances should not be permitted within designated flood inundation areas unless proper precautions are taken.

Sites in potential liquefaction prone areas require site-specific geotechnical evaluations and analysis. All recommended engineering design measures included in these studies should be incorporated into building design and construction. When possible, liquefaction hazard areas should be avoided for critical facilities.

Despite these conditions, it is feasible to develop the land (e.g., by raising the site elevation substantially) if the proper use is found, and the proper geologic and geotechnical investigations, analyses, and design considerations are made.

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6 TABLES

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TABLE 1 - Deterministic Site Parameters for Earthquakes Associated With Active Faults Located Within Approximately 100 Kilometers (62 Miles) of the City of Riverside

ABBREVIATED FAULT NAME	APPROXIMATE DISTANCE Miles (Kilometers)	ESTIMATED MAXIMUM EARTHQUAKE		
		MAXIMUM EARTHQUAKE MAGNITUDE (Mw)	MEAN/1-SIGMA VALUES	
			PEAK SITE ACCELERATION (g.)	ESTIMATED SITE INTENSITY[1]
San Jacinto-San Bernardino	6.8 (10.9)	6.7	0.277/0.433	IX/X
San Jacinto-San Jacinto Valley	8.1 (13.1)	6.9	0.266/0.403	IX/X
Cucamonga	14.4 (23.2)	7.0	0.234/0.349	IX/IX
Chino-Central Ave. (Elsinore)	15.3 (24.7)	6.7	0.189/0.295	VIII/IX
San Andreas – Southern	15.4 (24.8)	7.4	0.209/0.311	VIII/IX
San Andreas - San Bernardino	15.4 (24.8)	7.3	0.199/0.297	VIII/IX
Elsinore-Glen Ivy	16.7 (26.8)	6.8	0.144/0.221	VIII/IX
Whittier	17.5 (28.2)	6.8	0.137/0.211	VIII/VIII
San Jose	20.4 (32.8)	6.5	0.125/0.202	VII/VIII
Cleghorn	20.6 (33.2)	6.5	0.096/0.155	VII/VIII
North Frontal Fault Zone (West)	22.1 (35.5)	7.0	0.157/0.234	VIII/IX
Sierra Madre	23.2 (37.3)	7.0	0.149/0.223	VIII/IX
Elsinore-Temecula	23.5 (37.8)	6.8	0.101/0.156	VII/VIII
San Andreas - 1857 Rupture	24.4 (39.3)	7.8	0.173/0.259	VIII/IX
San Andreas – Mojave	24.4 (39.3)	7.1	0.117/0.175	VII/VIII
Elysian Park Thrust	28.1 (45.2)	6.7	0.099/0.155	VII/VIII
San Jacinto-Anza	31.0 (49.9)	7.2	0.096/0.144	VII/VIII
Clamshell-Sawpit	32.4 (52.2)	6.5	0.072/0.116	VI/VII
North Frontal Fault Zone (East)	37.1 (59.7)	6.7	0.070/0.110	VI/VII
Compton Thrust	37.3 (60.0)	6.8	0.075/0.116	VII/VII
Pinto Mountain	37.6 (60.5)	7.0	0.067/0.100	VI/VII
Raymond	38.5 (61.9)	6.5	0.057/0.093	VI/VII
Helendale - S. Lockhardt	39.4 (63.4)	7.1	0.068/0.102	VI/VII
Newport-Inglewood (Offshore)	40.8 (65.6)	6.9	0.056/0.085	VI/VII
Newport-Inglewood (L. A. Basin)	40.9 (65.9)	6.9	0.056/0.085	VI/VII
Verdugo	44.4 (71.5)	6.7	0.055/0.087	VI/VII
Puente Hills (L. A. Segment)	44.6 (71.8)	6.6	0.051/0.081	VI/VII
Elsinore-Julian	46.6 (75.0)	7.1	0.055/0.082	VI/VII
Lenwood-Old Woman Springs	49.5 (79.6)	7.3	0.059/0.089	VI/VII
San Andreas - Coachella	51.9 (83.5)	7.1	0.048/0.072	VI/VI
Palos Verdes	52.2 (84.0)	7.1	0.048/0.071	VI/VI
Landers	56.2 (90.4)	7.3	0.050/0.075	VI/VII
Coronado Bank	58.7 (94.4)	7.4	0.052/0.077	VI/VII

Source: EQFAULT Computer Program (Blake, 2000) 1. Faults producing a Modified Mercalli Intensity [MMI] ≤ V were omitted.

Notes: The estimated maximum earthquake is the largest magnitude (Richter scale) thought possible associated with a given fault or fault zone. Peak site acceleration is the estimated peak horizontal ground acceleration (in percent gravity, abbreviated "g") using the attenuation relationship of Campbell (1993); this represents the expected mean and 1-sigma values. The intensity is the estimated Modified Mercalli Intensity (MMI) at the site, which represents an empirical measure of physical damage to structures and of disturbance to the earth's surface as a result of various magnitude earthquakes at various site distances. The MMI scale ranges from least (I) to most (XII) damage and disturbance. THE DATA IN THIS TABLE ARE TAKEN FROM A SINGLE SOURCE (BLAKE, 2000) FOR PURPOSES OF CONSISTENCY. THE VALUES ARE SUITABLE FOR PLANNING PURPOSES, BUT SHOULD NOT BE USED FOR SITE SPECIFIC DESIGN. OPINIONS ON MAXIMUM MAGNITUDE DIFFER AMONG EXPERTS. PERIODIC UPDATES ARE AVAILABLE FROM THE CALIFORNIA GEOLOGICAL SURVEY.

TABLE 2 - Modified Mercalli Intensity (MMI) Scale: 1931 Abridged Version and 1994 "Modernized" Descriptions

Modified Mercalli Intensity Scale of 1931 (Abridged)[1]		"Modernized" Descriptions of MMI Levels (1994)[2]		Approximate Earthquake Magnitude	Approximate Average Peak Ground Acceleration in G-Force[3, 4]	
Intensity	**Observable Effects**	**Intensity**	**Observable Effects**			
I	Not felt. Marginal and long-period effects of large earthquakes.	I-V	Not included in modernized version.	1 to 2	See Footnote No. 3 for values below	See Footnote No. 4 for values below
II	Felt by persons at rest, on upper floors, or favorably placed.			2 to 3		
III	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.			3 to 4		
IV	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frames creak.			4		
V	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.			4 to 5		
VI	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken, knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visible, or heard to rustle).	VI	Worst effects include some windows broken out; a few instances of fallen plaster or damaged old masonry chimneys on single-family houses; large cracks in interior walls; many small objects overturned and fallen; many items thrown from store shelves; many glassware items or dishes broken; light furniture overturned and moderately heavy furniture displaced. Effects on people not used to define intensities of VI or above.	5 to 6	0.06 to 0.07	0.092 to 0.18

[1] Richter, C.F., *Elementary Seismology. San Francisco CA: W. H. Freeman Co., 1957.*
[2] Dewey, J.W., Dengler, L., Reagor, B.G., and Moley, K., *1995, Spatial variations of intensity in the Northridge earthquake, in The Northridge, California, Earthquake of 17 January 1994, Calif. Div. Mines & Geology Special Publication 116, p. 39-46.*
[3] Bolt, Bruce A. Abridged Modified Mercalli Intensity Scale, *Earthquakes - Newly Revised and Expanded*, Appendix C, W.H. Freeman and Co. 1993, 331 pp.
[4] Wald, Dave, 1999, http://pasadena.wr.usgs.gov/shake/pubs/regress/node3.html, for southern California earthquake events.

VII	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.	VII	Worst effects include significant damage to unreinforced masonry buildings, including cracks in bearing walls and 'out-of-plane' movement or fall of upper walls and parapets; many old masonry chimneys fallen or broken at the roofline on single-family homes; some masonry fences fallen or destroyed; heavy furniture overturned.	6	0.10 to 0.15	0.018 to 0.34
VIII	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.	VIII	Worst effects include considerable damage to old, unreinforced masonry buildings, with partial collapse; many cases where wood-frame houses are moved on their foundation if not anchored and braced; damage to wood-frame apartment buildings having open first-stories, with some cases of apartments being destroyed; significant damage to reinforced, lined, masonry chimneys on single-family homes, and widespread damage to old masonry chimneys; structural damage to some reinforced-concrete structures built when a seismic code was in effect; very heavy furniture moved conspicuously or overturned.	6 to 7	0.25 to 0.30	0.34 to 0.65
IX	General panic. Masonry D destroyed; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.	IX	Worst effects include multiple cases of structural damage to reinforced-concrete buildings and parking structures built when a seismic code was in effect, with some cases of partial or complete collapse; collapse of elevated freeway sections; widespread damage to unreinforced masonry buildings (e.g., old brick buildings), with total collapse; widespread incidence of wood-frame houses shifted off foundations where not securely anchored and braced; widespread destruction of wood-frame apartment buildings having large open areas in their first stories; widespread collapse of masonry (brick, block or stone) chimneys, whether reinforced or not, on single-family homes; furniture and	7	0.50 to 0.55	0.65 to 1.24

			building contents generally overturned and thrown across room.			
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks to canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.	X-XII	As originally defined and as modified in 1931, these intensity levels described earthquake effects that involve permanent changes in the shape of the ground (fault rupture, landsliding, liquefaction, etc.). Nowadays, however, Intensities X, XI and XII are increasingly regarded as approximately the same level of shaking as Intensity IX. The many phenomena originally associated with intensities X and above are apparently related less to the level of ground shaking than to the presence of ground conditions susceptible to spectacular failure, or to the ease with which seismic faulting of different style and depth can propagate to the ground surface.	7 to 8	More than 0.60	More than 1.24
XI	Rails bent greatly. Underground pipelines completely out of service.			8		
XII	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.			8 or greater		

Compiled by Wilson Geosciences Inc., 2003

TABLE 3 - Historic Earthquakes in the Riverside Area (Within 100 Kilometers of City Hall) from 1800 through 2000 (Blake, 2000) [1]

NORTH LATITUDE	WEST LONGITUDE	DATE	TIME (UTC) H M Sec	DEPTH (km) [2]	EARTHQUAKE MAGNITUDE	SITE ACCELERATION (g)	SITE MODIFIED MERCALLI INTENSITY	APPROXIMATE DISTANCE MILES [km]	PROBABLE FAULT OR GEOGRAPHIC AREA [3,4]
34.0000	117.5000	12/16/1858	10 0 0.0	0.0	7.00	0.291	IX	7.4 (11.9)	Mira Loma?[5]
34.0000	117.2500	07/23/1923	7 30 26.0	0.0	6.25	0.210	VIII	7.1 (11.4)	S. Jacinto
34.3000	117.5000	07/22/1899	20 32 0.0	0.0	6.50	0.084	VII	23.1 (37.2)	S. Jacinto
34.3700	117.6500	12/08/1812	15 0 0.0	0.0	7.00	0.084	VII	31.1 (50.1)	S. Andreas
34.1000	117.3000	07/15/1905	20 41 0.0	0.0	5.30	0.086	VII	9.1 (14.7)	S. Andreas
33.7500	117.0000	04/21/1918	22 32 25.0	0.0	6.80	0.088	VII	26.7 (42.9)	S. Jacinto
33.9000	117.2000	12/19/1880	0 0 0.0	0.0	6.00	0.119	VII	11.4 (18.3)	S. Jacinto
34.3000	117.6000	07/30/1894	5 12 0.0	0.0	6.00	0.049	VI	25.5 (41.1)	S. Andreas
34.2030	116.8270	06/28/1992	15 05 30.7	5.0	6.70	0.059	VI	34.7 (55.9)	Big Bear
34.2000	117.4000	07/22/1899	0 46 0.0	0.0	5.50	0.060	VI	15.1 (24.3)	S. Jacinto
34.2000	117.1000	09/20/1907	1 54 0.0	0.0	6.00	0.060	VI	21.7 (34.8)	Big Bear ?
34.2010	116.4360	06/28/1992	11 57 34.1	1.0	7.60	0.064	VI	55.6 (89.5)	Landers
33.7000	117.4000	05/15/1910	15 47 0.0	0.0	6.00	0.068	VI	19.5 (31.4)	Elsinore
33.8000	117.0000	12/25/1899	12 25 0.0	0.0	6.40	0.072	VI	24.8 (39.9)	S. Jacinto
34.0610	118.0790	10/01/1987	14 42 20.0	9.5	5.90	0.024	V	40.8 (65.7)	PHT
34.2670	116.9670	08/29/1943	34 51 3.0	0.0	5.50	0.025	V	30.4 (48.9)	Big Bear ?
33.9330	116.3830	12/04/1948	23 43 17.0	0.0	6.50	0.026	V	56.8 (91.3)	S. Andreas
33.7000	117.4000	05/13/1910	6 20 0.0	0.0	5.00	0.029	V	19.5 (31.4)	S. Jacinto
33.7000	117.4000	04/11/1910	7 57 0.0	0.0	5.00	0.029	V	19.5 (31.4)	S. Jacinto
34.1400	117.7000	02/28/1990	23 43 36.6	5.0	5.20	0.030	V	21.7 (34.9)	Upland
33.8000	117.6000	04/22/1918	21 15 0.0	0.0	5.00	0.032	V	18.1 (29.1)	Elsinore ?
34.1000	118.1000	07/11/1855	4 15 0.0	0.0	6.30	0.033	V	42.4 (68.3)	PHT ?
33.6170	117.9670	03/11/1933	1 54 7.8	0.0	6.30	0.033	V	42.4 (68.2)	NI
34.2700	117.5400	09/12/1970	14 30 53.0	8.0	5.40	0.035	V	22.1 (35.5)	S. Jacinto
33.6990	117.5110	05/31/1938	8 34 55.4	10.0	5.50	0.041	V	21.1 (33.9)	Elsinore ?

1. Shading in the rows indicates recent earthquakes with reasonably accurate locations and magnitude data. Site acceleration and Modified Mercalli Intensity values are estimated based on the stated earthquake magnitude and epicenter distance using the attenuation relationship of Sadigh, et al, (1997). 2. A depth of 0.0 indicates the depth is not known. 3. S. Andreas = San Andreas fault; S. Jacinto = San Jacinto fault; Elsinore = Elsinore fault; NI = Newport-Inglewood fault; PHT = Puente Hills Thrust fault. 4. Mira Loma, Big Bear, Landers, Upland refer to geographic areas associated with the earthquake location (columns 1 and 2). 5. The California Geological Survey data base indicated this earthquake was magnitude 6.0 located at 34.200/117.400, which is between the San Andreas and San Jacinto faults near Cajon Creek. This suggests a MMI of about VII and site acceleration of about 0.07.

TABLE 4 - A Summary of the Potential Geologic/Seismic Hazards and the Vulnerabilities of Structures and Facilities in the City

STRUCTURE OR FACILITY OF CONCERN	GROUNDSHAKING DAMAGE VULNERABILITY			LIQUEFACTION POTENTIAL	DYNAMIC CONSOLIDATION POTENTIAL	SURFACE FAULT RUPTURE POTENTIAL	DAM INUNDATION HAZARD LEVEL	RELATIVE DEPTH TO GROUND-WATER	COMMENTS
	Local SJ	Distant SA	Local CCE						
Lifeline (Linear) Structures									
Freeways/Bridges									
SR-60/SR-91 Interchange	MV	MV	MV	M	M-H	NV	NV	Shallow	Groundshaking, liquefaction and roadbed settlement critical concern.
SR-60/I-215 Interchange	MV	V	V	L	M	NV	NV	Deep	Groundshaking and roadbed settlement concern.
I-15/SR-91 Interchange	MV	MV	V	H	M-H	NV	H	Shallow	Groundshaking, liquefaction and roadbed settlement critical concern.
SR-60/Santa Ana River	MV	MV	V	VH	M-H	NV	NV	Shallow	Groundshaking, liquefaction and roadbed settlement critical concern.
Evacuation/Emergency Response Routes									
Van Buren/Santa Ana River	MV	MV	V	H VH	M-H	NV	NV	Shallow	Groundshaking, liquefaction and roadbed settlement most critical concern along Van Buren, crossing the Santa Ana River and past the airport and extending south to the City boundary.
La Sierra Avenue	MV	MV	MV	H VH	M-H	NV	NV	Shallow	Groundshaking, liquefaction and roadbed settlement some concern northeast of La Sierra Avenue, extending southward from Arlington past SR-91.
Arlington Avenue	MV	MV	V	M-VH	M-H	NV	M	Shallow to Deep	Groundshaking, liquefaction and roadbed settlement critical concern. M to H probability near La Sierra and south of airport, H to VH near Magnolia.
Natural Gas Pipelines									
High Pressure Natural Gas Transmission Pipelines	MV	MV	V	M-H	M	NV	M	Moderate	Moderate to high concern for liquefaction and settlement or buoyancy effects where pipeline crosses liquefaction prone areas.
Aqueducts and Water Transmission Pipelines									
Various	MV	MV	V	M-VH	L-H	NV	L-VH	Shallow to	Moderate to high concern for liquefaction and settlement or

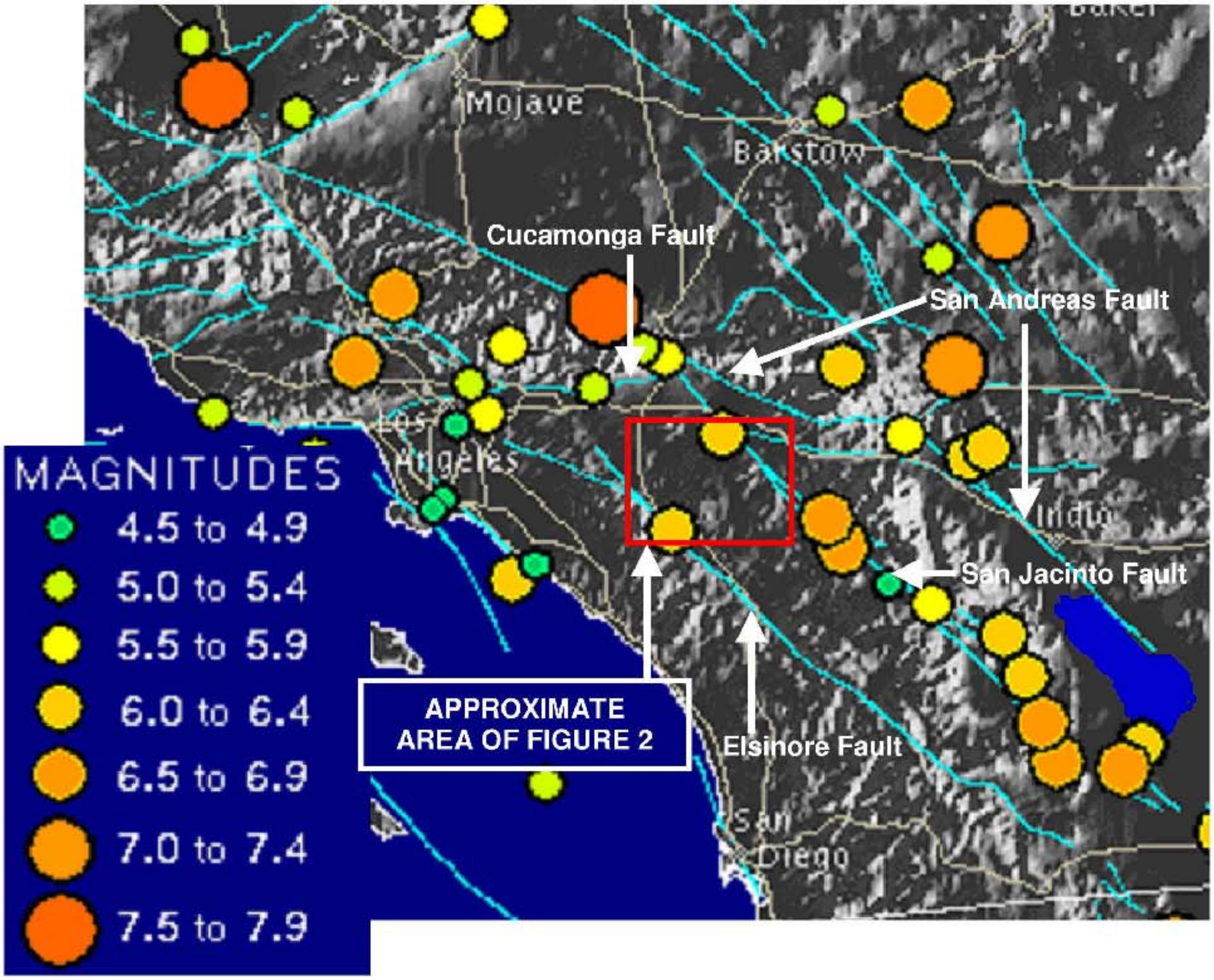
STRUCTURE OR FACILITY OF CONCERN	GROUNDSHAKING DAMAGE VULNERABILITY			LIQUEFACTION POTENTIAL	DYNAMIC CONSOLIDATION POTENTIAL	SURFACE FAULT RUPTURE POTENTIAL	DAM INUNDATION HAZARD LEVEL	RELATIVE DEPTH TO GROUND-WATER	COMMENTS
	Local SJ	Distant SA	Local CCE						
Aqueducts and Transmission Pipelines								Deep	buoyancy effects where pipeline crosses liquefaction prone areas.
Miscellaneous Utility Lines									
Gas, Water, Electrical, Sewer Feeder Lines and Connections	LV-MV	LV-MV	LV-MV	L-H	L-H	NV	L-H	Shallow to Deep	Groundshaking, liquefaction, and dynamic consolidation effects mainly causing disruptions adjacent to residences or businesses.
Critical and Important Facilities									
Fire Station									
Fire Station No. 1 @ 3420 Mission Inn Avenue	MV	MV	V	M-H	M	NV	M	Moderate	Primary concern, strong groundshaking. Moderate to high potential for liquefaction/ dynamic consolidation to cause subsidence and differential settlement.
Fire Station No. 2 @ 9449 Andrew Street	V	MV	V	M-H	M-H	NV	H	Shallow	Groundshaking, liquefaction and settlement a critical concern at facility and surrounding vicinity.
Fire Station No. 3 @ 6395 Riverside Ave.	MV	MV	V	M	M	NV	M	Moderate	Groundshaking, liquefaction and settlement concern at site and surrounding vicinity.
Fire Station No. 4 @ 3510 Cranford Ave.	MV	V	V	L	M	NV	NV	Deep	Strong to severe ground motion a concern at site and surrounding vicinity.
Fire Station No. 5 @ 6963 Streeter Ave.	LV-V	LV-V	V	M	M	NV	M	Shallow	Liquefaction and settlement a concern at west and critical concern at east ends of facility.
Fire Station No. 6 @ 2293 Main Street	MV	V	V	M	M	NV	NV	Moderate	Strong to severe ground motion a concern at site and surrounding vicinity.
Fire Station No. 7 @ 10191 Cypress Ave.	V	MV	V	L	L	NV	NV	NV	Groundshaking, a concern at facility and surrounding vicinity.
Fire Station No. 8 @ 11076 Hole Ave.	V	MV	MV	H	M-H	NV	NV	Shallow	Groundshaking, liquefaction and settlement a concern at site and surrounding vicinity.

STRUCTURE OR FACILITY OF CONCERN	GROUNDSHAKING DAMAGE VULNERABILITY			LIQUEFACTION POTENTIAL	DYNAMIC CONSOLIDATION POTENTIAL	SURFACE FAULT RUPTURE POTENTIAL	DAM INUNDATION HAZARD LEVEL	RELATIVE DEPTH TO GROUND-WATER	COMMENTS
	Local SJ	Distant SA	Local CCE						
Fire Station No. 9 @ 6674 Alessandro Blvd	MV	V	V	NV	L	NV	NV	NV	Strong to severe ground motion a concern at site and surrounding vicinity.
Fire Station No. 10 @ 2590 Jefferson St.	LV-V	LV-V	V	M	M	NV	M	Moderate	Strong ground motion a concern at site and surrounding vicinity.
Fire Station No. 11 @ 19595 Orange Terrace Parkway	MV	V	V	NV	L	NV	NV	NV	Strong to severe ground motion a concern at site and surrounding vicinity.
Fire Station No. 12 @ 10692 Indiana Ave.	V	MV	MV	H	M-H	NV	H	Shallow	Groundshaking, liquefaction and settlement a concern at site and vicinity.
Fire Station No. 13 @ 22250 Eucalyptus Ave.	MV	V	V	NV	L	NV	NV	NV	Strong to severe ground motion a concern at site and surrounding vicinity.
City Hall									
City Hall 3900 Main Street @ Main Street and 9th Street	MV	MV	V	M-H	M	NV	M	Moderate	Primary concern for damage from strong groundshaking. Moderate to high potential for liquefaction/ dynamic consolidation to cause subsidence and differential settlement.
Riverside Police									
Police Headquarters 4102 Orange Street	MV	MV	V	M-H	M	NV	M	Moderate	Primary concern for damage from strong groundshaking. Moderate to high potential for liquefaction/ dynamic consolidation to cause subsidence and differential settlement.
Field Operations 8181 Lincoln Avenue	V	MV	V	H-VH	H	NV	M-H	Shallow	Liquefaction and settlement a most critical concern at site and surrounding vicinity.
Other Municipal									
Riverside County	MV	V	V	M	M	NV	NV	Moderate	Strong to severe ground motion a

STRUCTURE OR FACILITY OF CONCERN	GROUNDSHAKING DAMAGE VULNERABILITY			LIQUEFACTION POTENTIAL	DYNAMIC CONSOLIDATION POTENTIAL	SURFACE FAULT RUPTURE POTENTIAL	DAM INUNDATION HAZARD LEVEL	RELATIVE DEPTH TO GROUND-WATER	COMMENTS
	Local SJ	Distant SA	Local CCE						
Administration 1080 Lemon Street									concern at site and surrounding vicinity.
Riverside County Administration 1939 9th Street	MV	V	V	L	M	NV	M	Deep	Strong to severe ground motion a concern at site and surrounding vicinity.
Riverside Courthouse 4050 Main Street	MV	MV	V	M-H	M-H	NV	M	Moderate	Groundshaking, liquefaction and settlement a critical concern at site and surrounding vicinity.
Riverside Central Library 3581 Mission Inn Avenue	MV	V	V	M	M	NV	M	Moderate	Groundshaking, liquefaction and settlement a concern at site and surrounding vicinity.
Hospital									
Parkview Community Hospital 3865 Jackson Street	V	MV	V	M-H	M-H	NV	H	Shallow	Groundshaking, liquefaction and settlement a critical concern at facility and surrounding vicinity.
Riverside Community Hospital 4445 Magnolia Avenue	V	MV	MV	M-H	M-H	NV	H	Shallow	Groundshaking, liquefaction and settlement a critical concern at facility and surrounding vicinity.
Kaiser Foundation Hospital 10800 Magnolia Avenue	V	MV	V	H	M-H	NV	H	Shallow	Groundshaking, liquefaction and settlement a critical concern at facility and surrounding vicinity.
Schools									
La Sierra University 4700 Pierce Street	MV	MV	MV	VH	H	NV	H	Shallow	Groundshaking, liquefaction and settlement a most critical concern at site and surrounding vicinity.
Riverside Community College 4800 Magnolia Avenue	MV	MV	V	M	M	NV	M	Moderate	Groundshaking, liquefaction and settlement concern at site and surrounding vicinity.

STRUCTURE OR FACILITY OF CONCERN	GROUNDSHAKING DAMAGE VULNERABILITY			LIQUEFACTION POTENTIAL	DYNAMIC CONSOLIDATION POTENTIAL	SURFACE FAULT RUPTURE POTENTIAL	DAM INUNDATION HAZARD LEVEL	RELATIVE DEPTH TO GROUND-WATER	COMMENTS
	Local SJ	Distant SA	Local CCE						
University of California-Riverside 900 University Avenue	MV	V	V	L	M	NV	NV	Deep	Strong ground motion a concern at site and surrounding vicinity.
California Baptist University 8432 Magnolia Avenue	V	MV	V	H-VH	H	NV	M-H	Shallow	Liquefaction and settlement a most critical concern at site and surrounding vicinity.
Other Transportation Centers									
Riverside Municipal Airport 6951 Flight Road	LV-V	LV-V	V	L-H	L-M	NV	M	Shallow	Liquefaction and settlement a concern at west and critical concern at east ends of facility.
Metrolink Station 10901 Indiana Avenue	V	MV	MV	H	M-H	NV	H	Shallow	Groundshaking, liquefaction and settlement a concern at station and along tracks in vicinity.

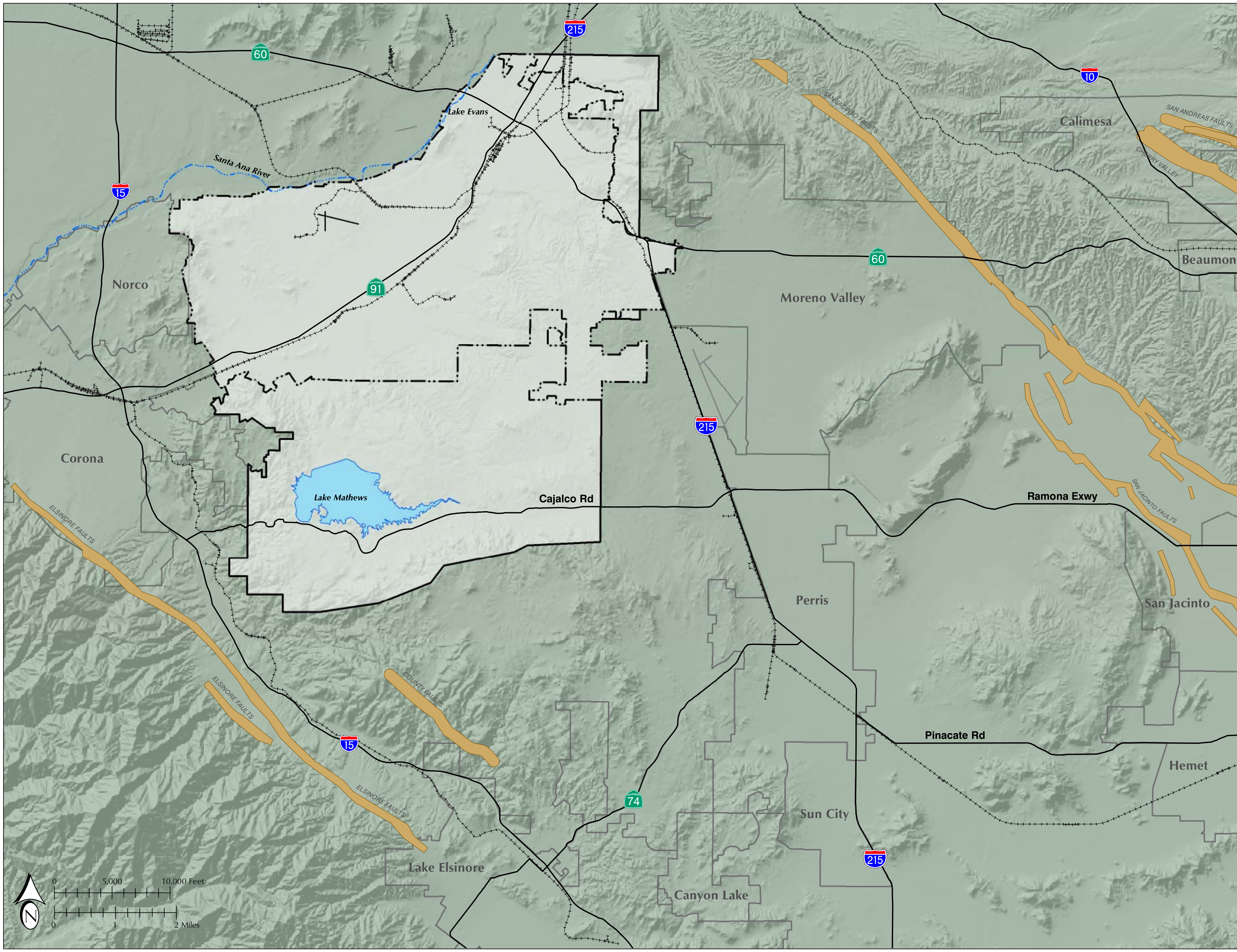
VULNERABILITY: LV = Least, V = Vulnerable, MV = Most, NV = None Apparent. **HAZARD POTENTIAL:** L = Least, M = Medium, H = High, VH = Very High, NV = None Apparent. **SJ** = San Jacinto fault. **SA** = San Andreas fault. **CCE** = Chino-Central Avenue (Elsinore) fault.



Source: SCEC, 2004

Scale Unknown

Figure 1
REGIONAL FAULTS AND HISTORIC SEISMICITY FOR THE SOUTHERN CALIFORNIA REGION



LEGEND

FAULT ZONE

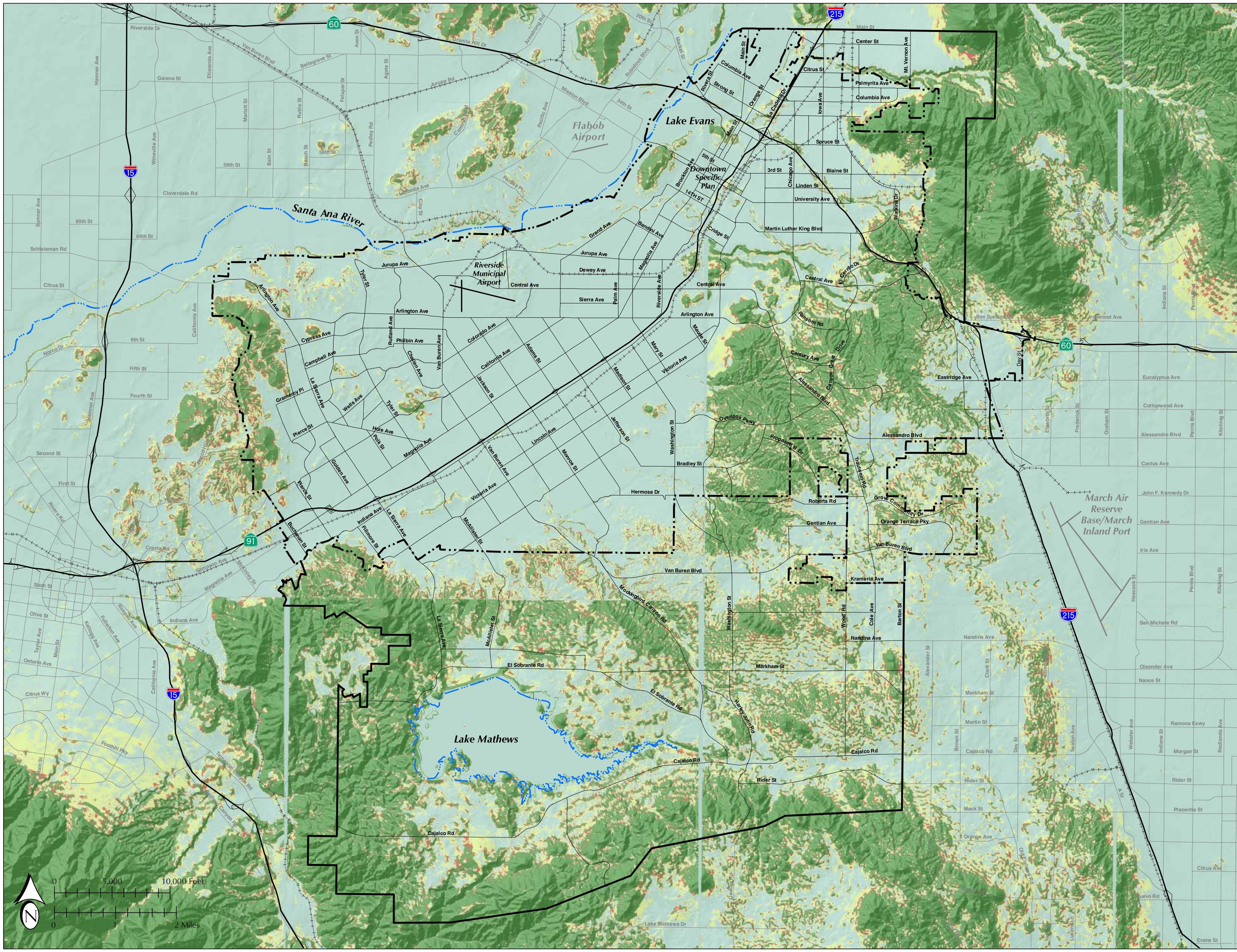
RIVERSIDE CITY BOUNDARY

RIVERSIDE SPHERE OF INFLUENCE

SOURCE: CENSUS 2000 TIGER/LINE® DATA AND RIVERSIDE COUNTY, 2004.

Figure 2

FAULT ZONES

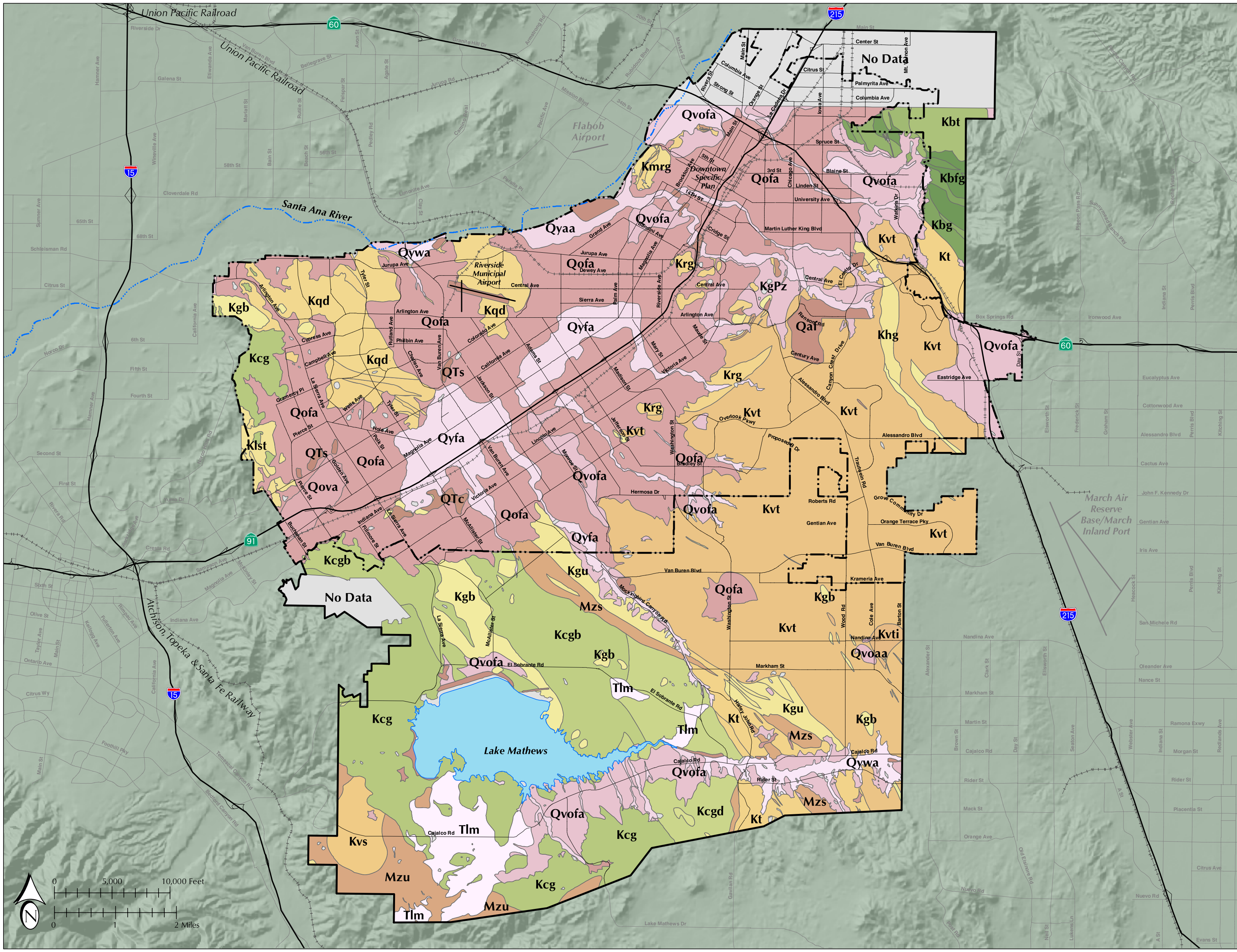


LEGEND

- LESS THAN 15%
- 15 - 25%
- 25 - 30%
- 30 AND GREATER
- Water Features
- RIVERSIDE CITY BOUNDARY
- RIVERSIDE SPHERE OF INFLUENCE

Source: Digital Elevation Model, U.S. Geological Survey (USGS), GIS 2000.

Figure 3
AREAS UNDERLAIN BY STEEP SLOPE



LEGEND

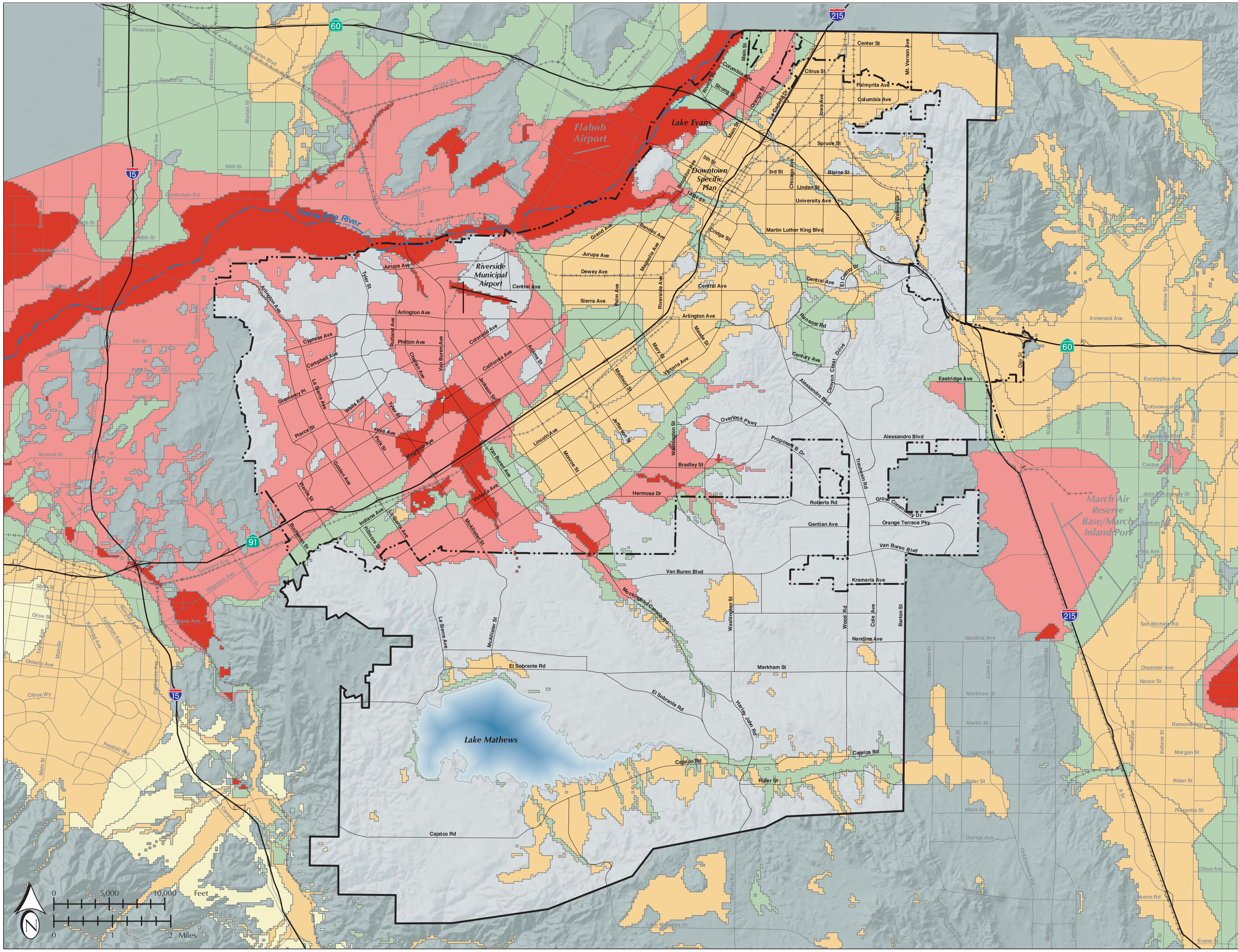
Soil Type

Kbfg	Biotite Granodiorite and Tonalite
Kbft	Biotite-Hornblend Tonalite
Kbg	Porphyritic Granodiorite
Kbhg	Heterogeneous Porphyritic Granodiorite
Kbhg1	Layerd Heterogeneous Porphyritic
Kbht	Heterogeneous Biotite Tonalite
Kbt	Biotite Tonalite
Kcg	Monzogranite
Kcgb	Granodiorite and Gabbro, Undifferentiated
Kcgd	Granodiorite
Kct	Tonalite
Kcto	Tourmalinized Monzogranite and Granodiorite
Kg	Granitic Dikes (Cretaceous)
KgPz	Mixed Metamorphic Rocks and Granitic Rocks
Kgb	Gabbro
Kgd	Granodiorite, Undifferentiated (Cretaceous)
Kgu	Granite, Undifferentiated (Cretaceous)
Khg	Heterogeneous Granitic Rocks (Cretaceous)
Klst	La Sierra Tonalite
Kmhg	Mount Hole Granodiorite (Cretaceous)
Kmrg	Granite of Mount Rubidoux
Kp	Granitic Pegmatite Dikes
Kqd	Quartz Diorite (Cretaceous)
Krg	Granite of the Riverside Area (Cretaceous)
Kt	Tonalite, undifferentiated (Cretaceous)
Ktd	Tonalite Dikes of Mount Rubidoux
Kvs	Intermixed Estelle Mountain Volcanics of Herzig (1991) and Mesozoic Sedimentary Rocks (Mesozoic)
Kvt	Val Verde Tonalite
Kvt?	Val Verde Tonalite
Kvti	Inclusion-Rich Tonalite
Mzs	Schist
Mzu	Mesozoic Granitic Rocks, Undivided
Pzc	Point of Zero Charge
Pzms	Marble and Schist, Undifferentiated
Pzq	Impure Quartzite
Pzs	Biotite Schist
QTc	Conglomerate Sedimentary Rocks of Riverside West 7.5' Quadrangle
QTs	Unnamed late Cenozoic Sedimentary Rocks in Riverside and Corona Areas
Qaf	Artificial Fill
Qoa	Old Axial Channel Deposites (Late to Middle Pleistocene)
Qoaa	Old Axial Channel Deposits, Arenaceous
Qofa	Old Alluvial Fan Deposits, Arenaceous
Qova	Old Alluvial Valley Deposits, Arenaceous
Qvoa	Very Old Alluvial-Valley Deposits
Qvoaa	Very Old Axial Channel Deposits, Arenaceous
Qvofa	Very Old Alluvial Fan Deposits, Arenaceous
Qwa	Wash Deposits, Arenaceous
Qyaa	Young Axial Channel Deposits, Arenaceous
Qyfa	Young Alluvial Fan Deposits, Arenaceous
Qywa	Young Wash Deposits, Arenaceous
Tlm	Lake Mathews Formation (Miocene)

Riverside City Boundary
Riverside Sphere of Influence

Source: California Division of Mines and Geology, and U.S. Air Force

Figure 4
GEOLOGIC MAP



LEGEND

- Very low
- Low
- Moderate
- High
- Very High

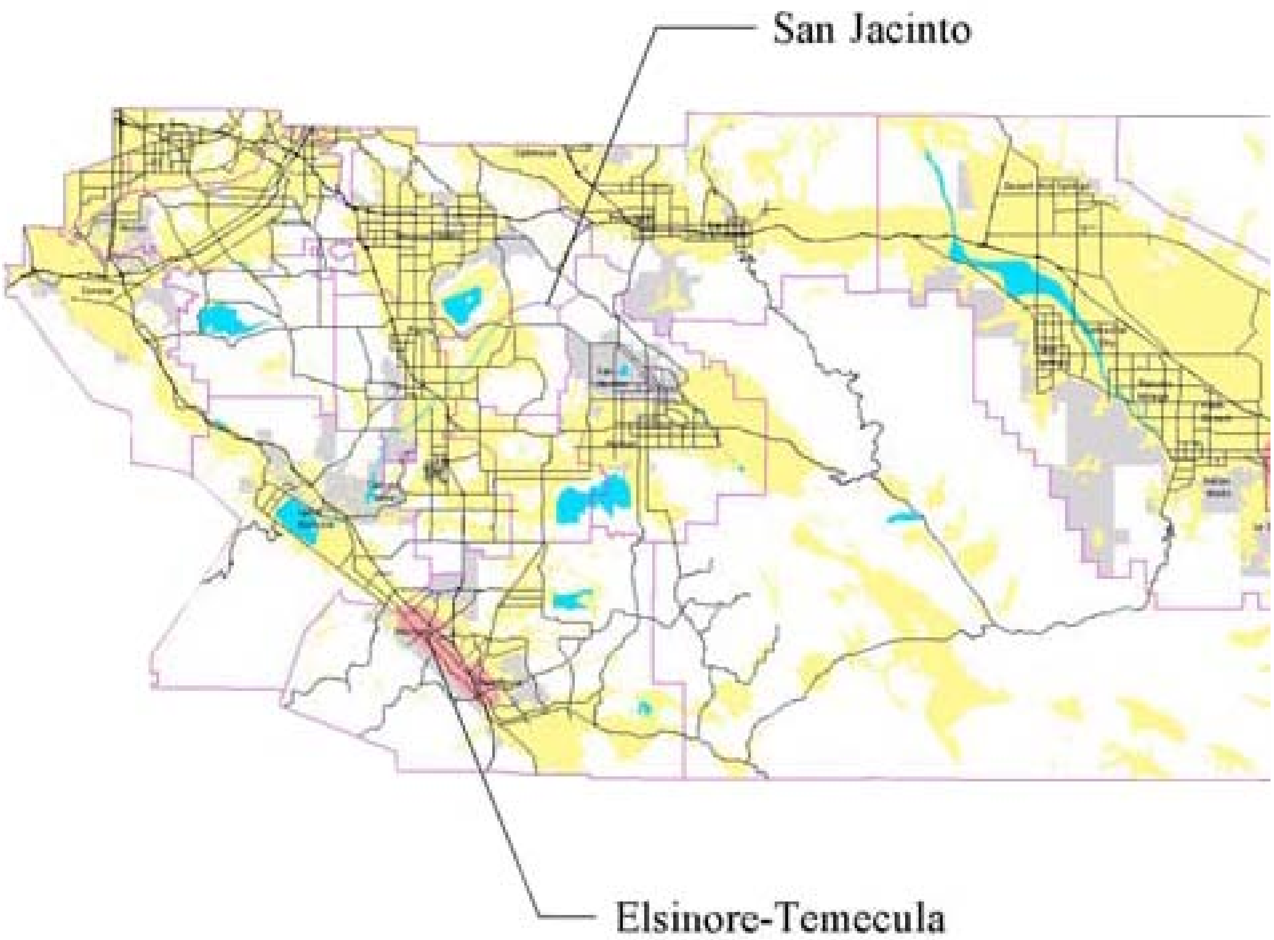
RIVERSIDE CITY BOUNDARY

RIVERSIDE SPHERE OF INFLUENCE

SOURCE: CITY OF RIVERSIDE AND RIVERSIDE COUNTY.

Figure 5

GENERALIZED LIQUEFACTION



Source: Earth Consultants International.

Areas with Documented Subsidence

Susceptible Areas

Stream, River, Canal or Ditch

Cities

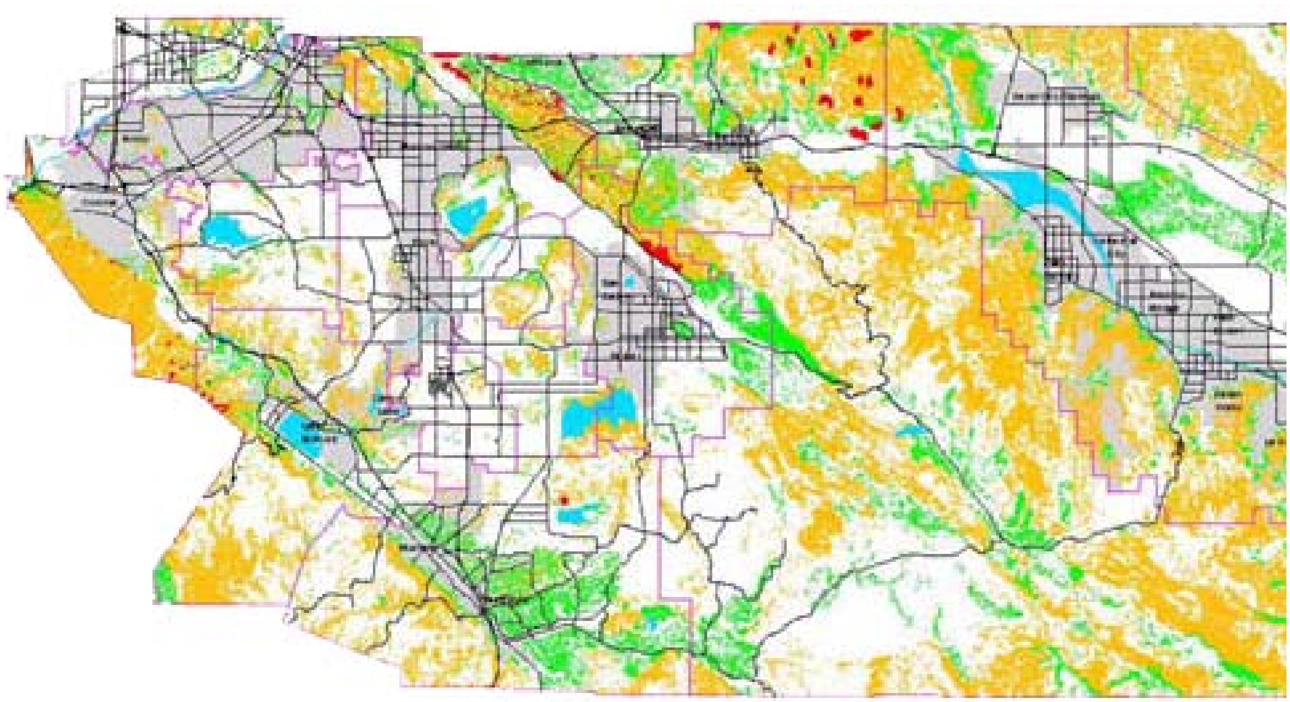
Area Plan Boundaries

Major Roads and Highways

N

Scale: 1:65,000 Feet

Figure 6
DOCUMENTED
SUBSIDENCE AREAS



Source: Earth Consultants International.

Existing Landslides

High susceptibility to seismically Induced landslides and rockfalls.

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

Cities

Area Plan Boundaries

Major Roads and Highways

N

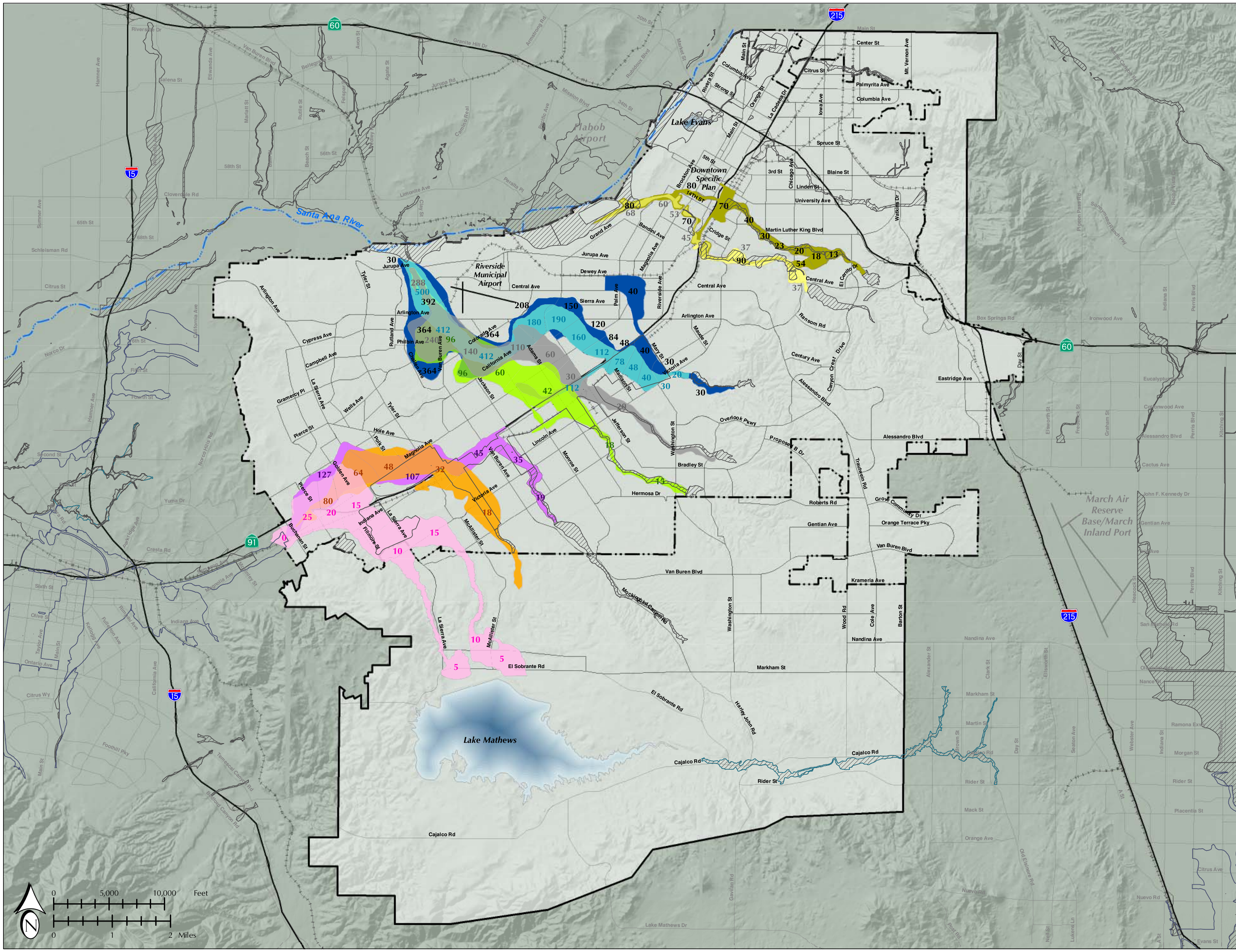
Scale: 1:65,000 Feet

GENERAL PLAN 2025

CITY OF RIVERSIDE

Figure 7

EARTHQUAKE INDUCED SLOPE STABILITY



LEGEND

FLOOD HAZARD AREAS

- 100-YEAR FLOOD ZONE
- 500-YEAR FLOOD ZONE

DAM INUNDATION AREAS

- 37 SYCAMORE CANYON DAM
- 90 BOX SPRINGS DAM
- 20 PRENDA DAM
- 15 WOODCREST DAM
- 30 MARY ST DAM
- 40 ALESSANDRO DAM
- 10 CAJALCO DAM
- 32 HARRISON DAM
- 45 MOCKINGBIRD CANYON DAM

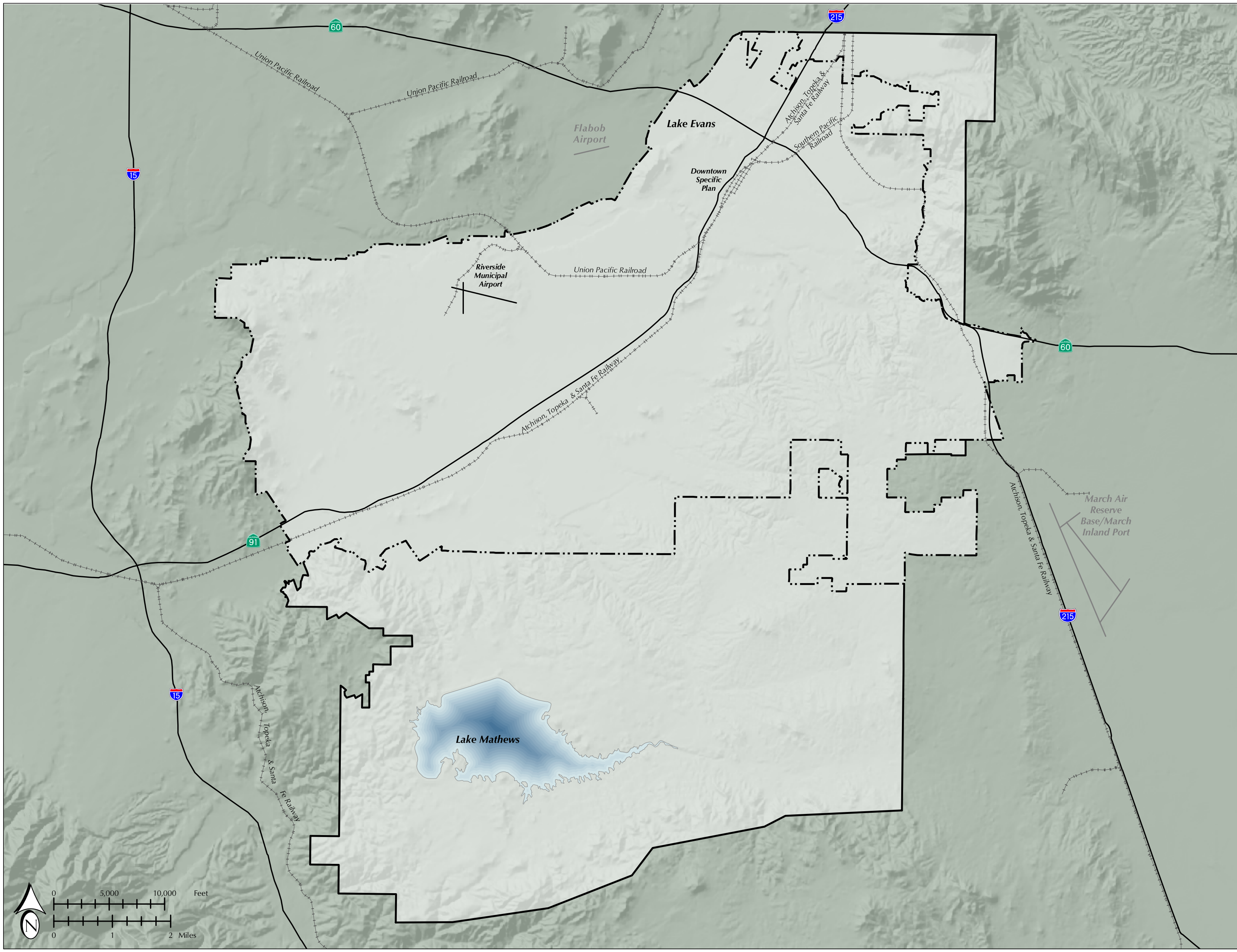
NUMBERS REPRESENT ESTIMATED TIME IN MINUTES FROM DAM FAILURE TO ARRIVAL OF FIRST WATER.*

- RIVERSIDE CITY BOUNDARY
- RIVERSIDE SPHERE OF INFLUENCE

SOURCE: FEMA FLOOD CONTROL MAPS (DATE?); RIVERSIDE COUNTY FLOOD CONTROL DISTRICT, 2004.

Figure 8

DAM FAILURE INUNDATION AND FLOOD ZONES

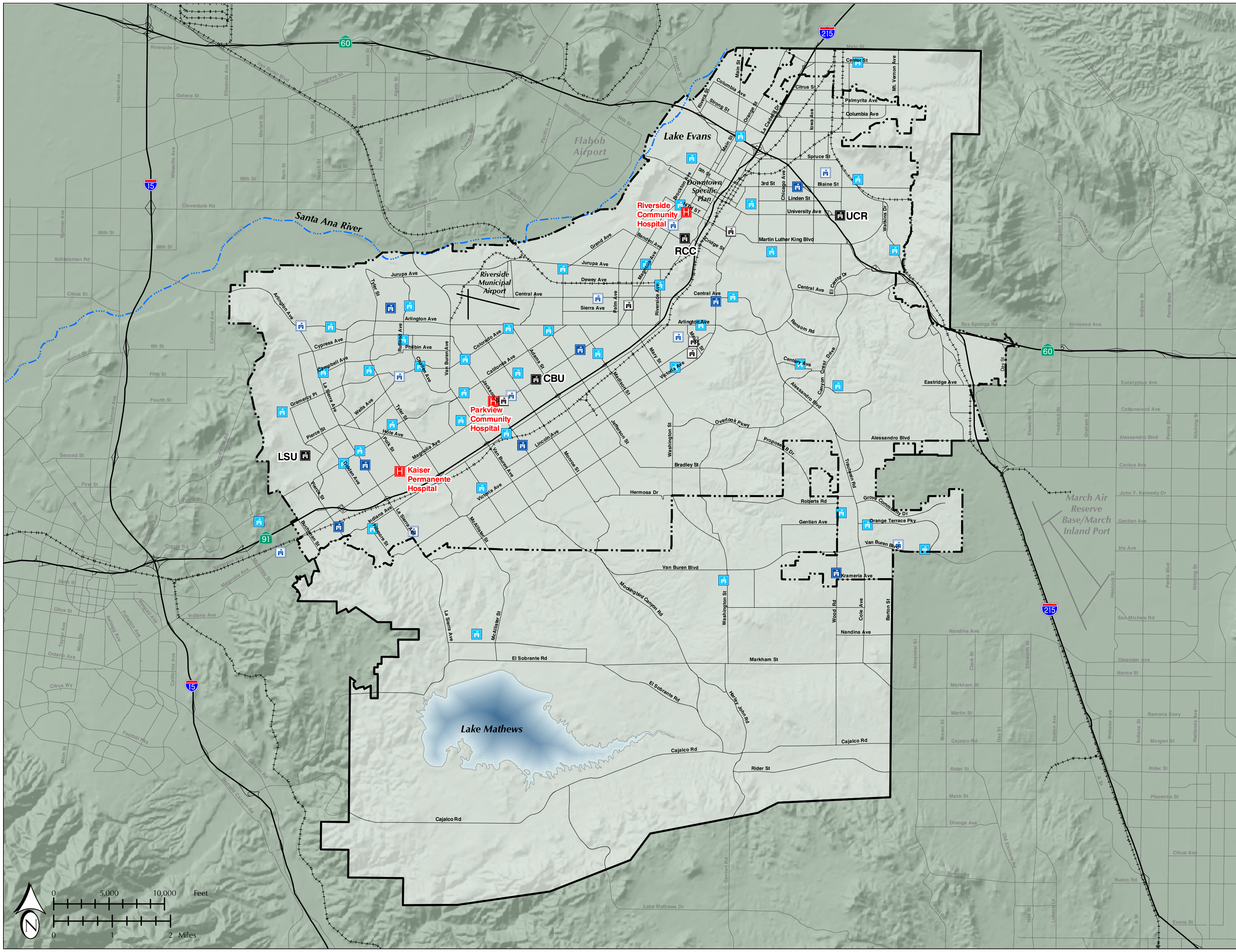


LEGEND

- MAJOR HIGHWAYS
- RAILROADS
- RIVERSIDE CITY BOUNDARY
- RIVERSIDE SPHERE OF INFLUENCE

SOURCE: CITY OF RIVERSIDE, CENSUS TIGER/LINE DATA, 2000.

Figure 9
MAJOR RAIL AND HIGHWAY FACILITIES

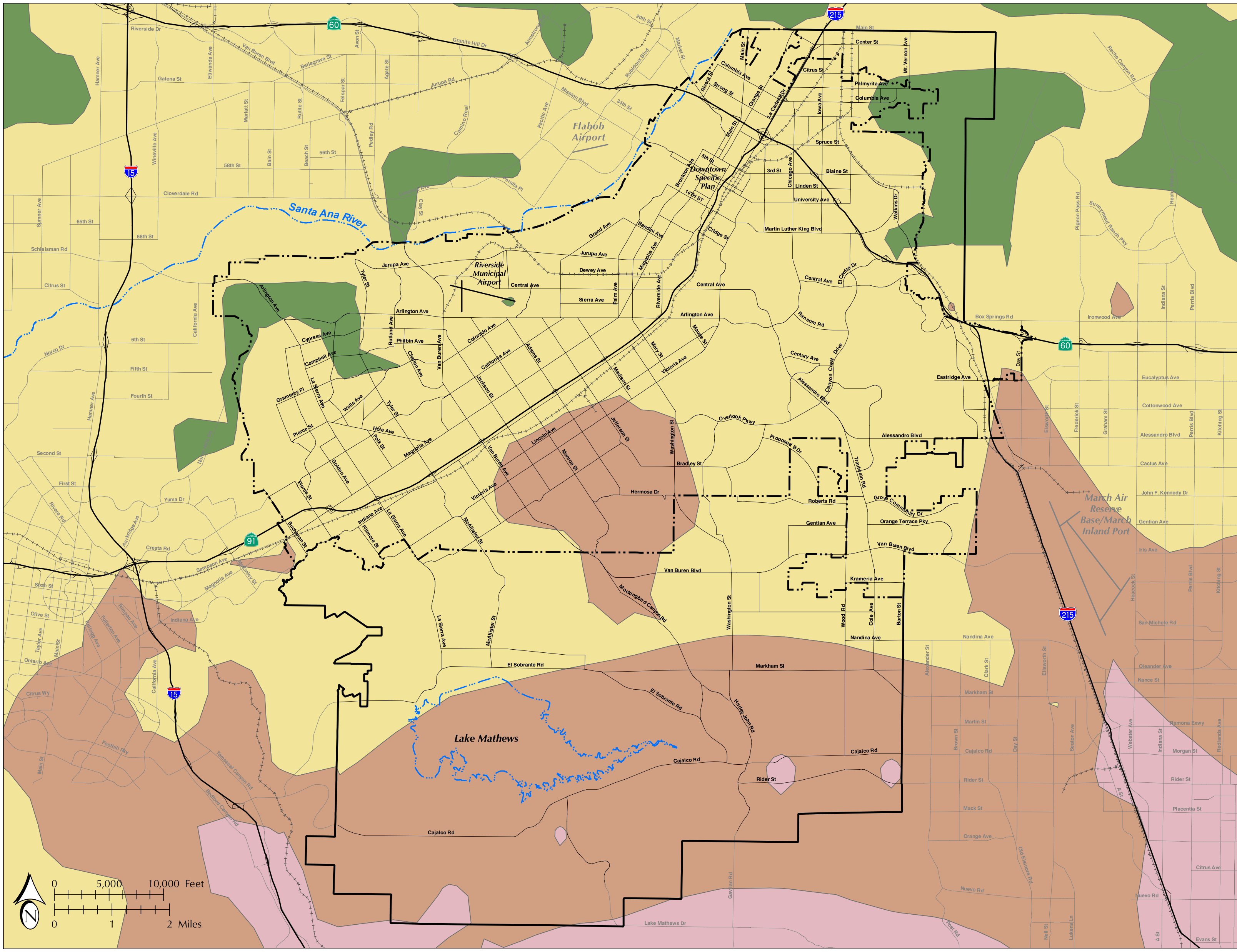


LEGEND

- HOSPITAL
- ELEMENTARY SCHOOL
- MIDDLE SCHOOL
- HIGH SCHOOL
- OTHER SCHOOL
- COLLEGE/UNIVERSITY
- RIVERSIDE CITY BOUNDARY
- RIVERSIDE SPHERE OF INFLUENCE

Source: City of Riverside,
Alvord Unified School District,
Riverside Unified School District,

Figure 10
SCHOOL AND HOSPITAL LOCATIONS



LEGEND

ELSINORE PEAK GROUND ACCELERATION (PGA)

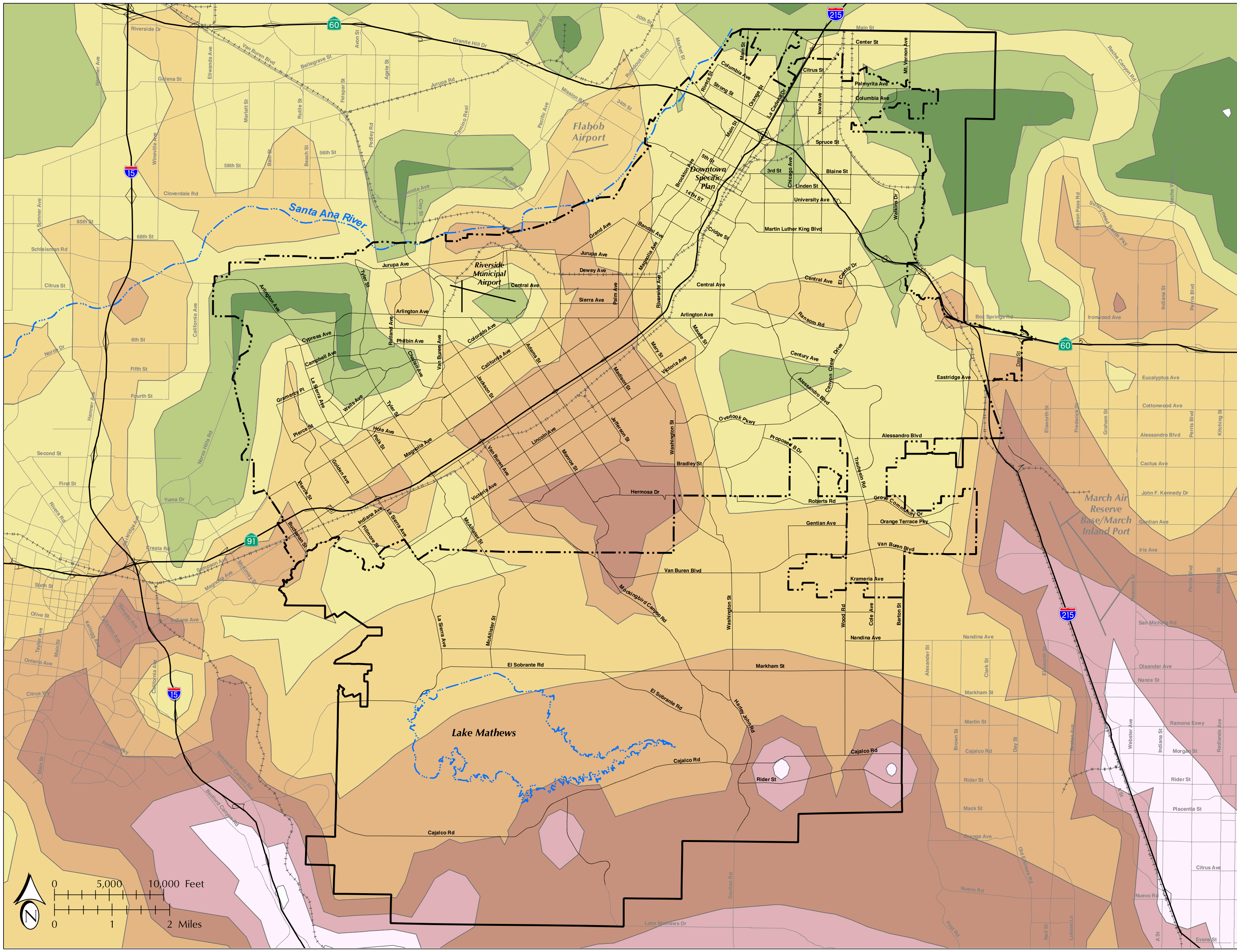
- 0.08
- 0.12
- 0.16
- 0.2

- RIVERSIDE CITY BOUNDARY
- RIVERSIDE SPHERE OF INFLUENCE

SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY

Figure A-E1

PEAK GROUND ACCELERATION- ELSINORE FAULT ZONE



LEGEND

ELSINORE MODIFIED MERCALLI INTENSITIES (MMI)

- 5.4
- 5.6
- 5.8
- 6
- 6.2
- 6.4
- 6.6
- 6.8

RIVERSIDE CITY BOUNDARY

RIVERSIDE SPHERE OF INFLUENCE

SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY

Figure A-E2

MODIFIED MERCALLI INTENSITY-ELSINORE FAULT ZONE

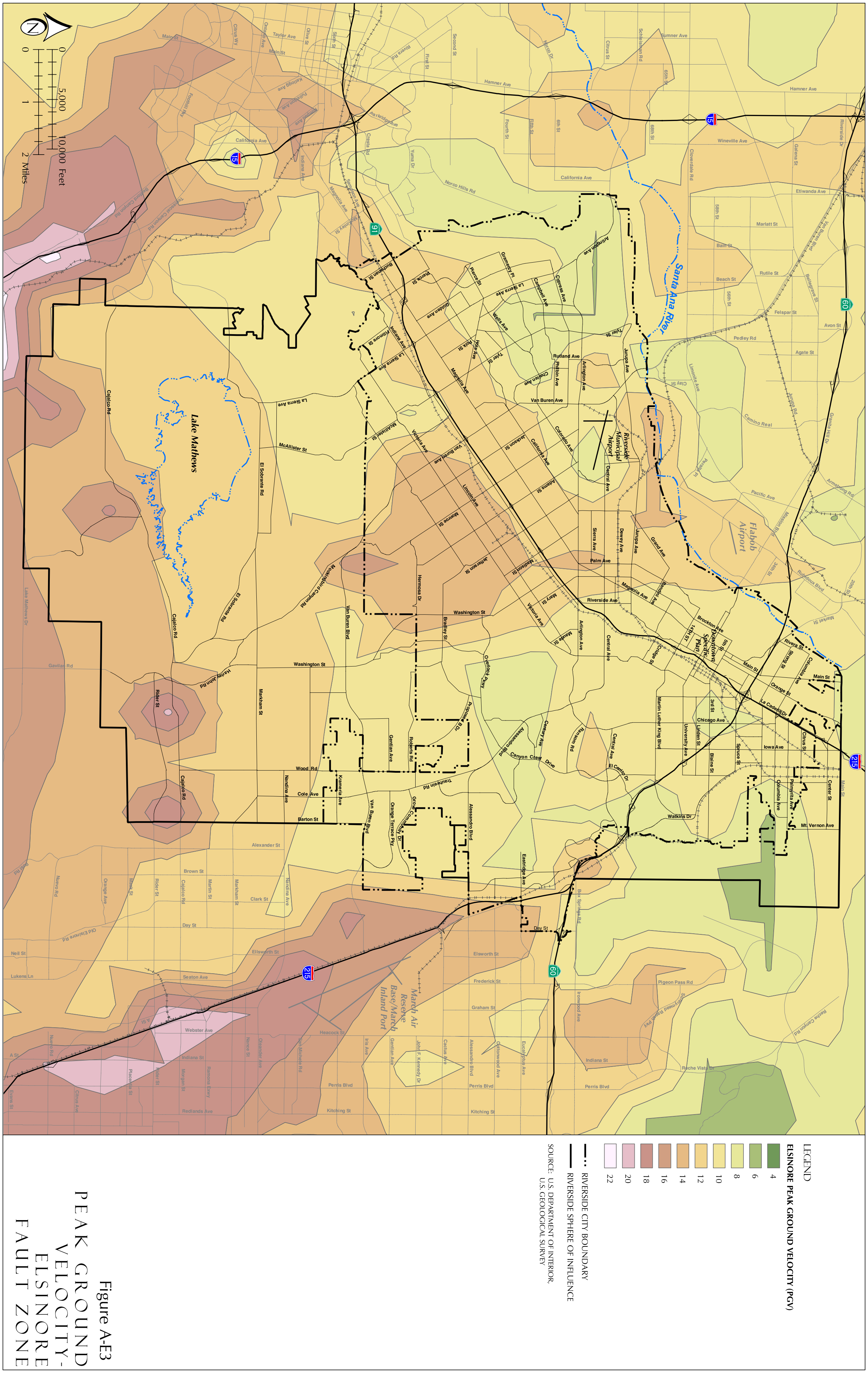
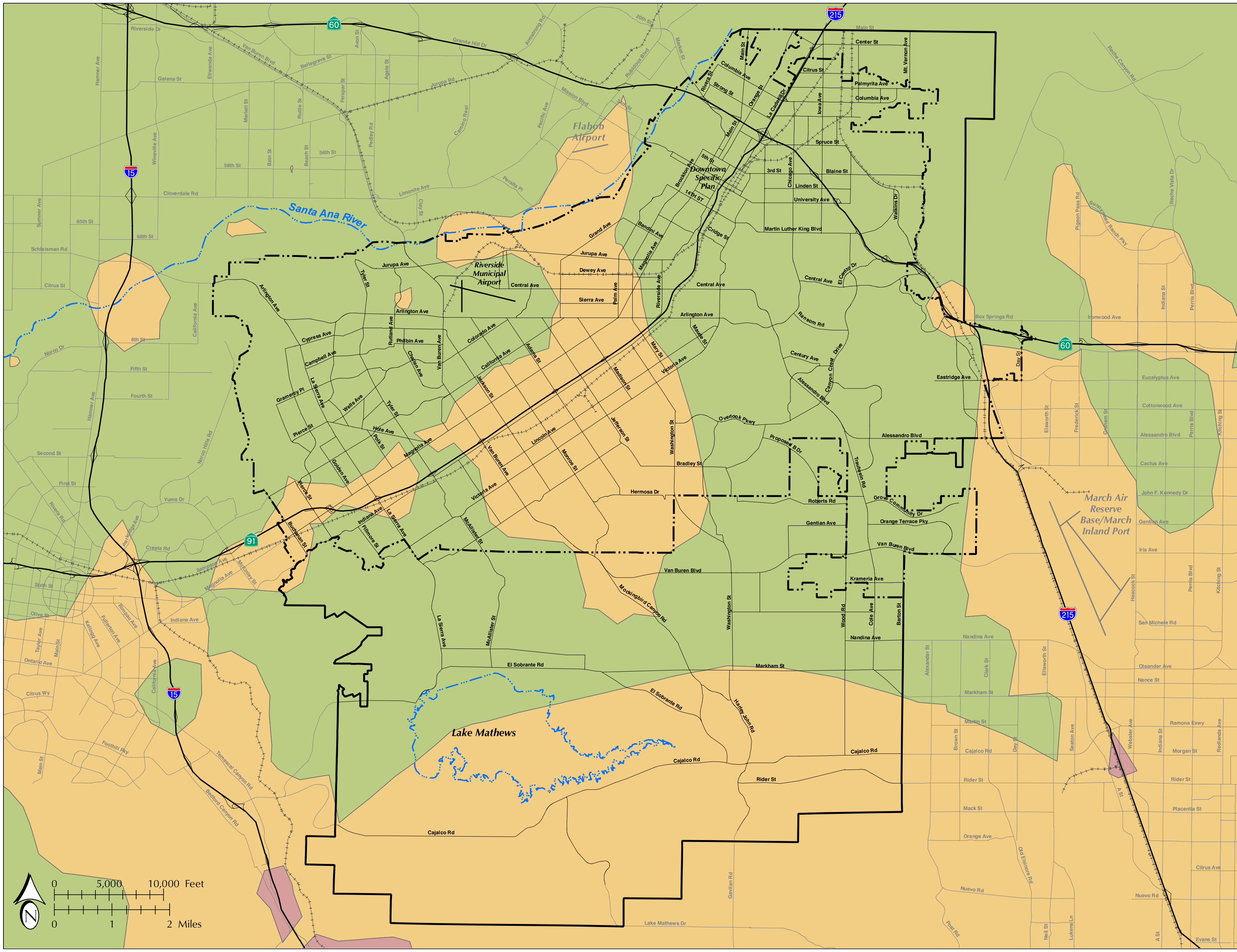


Figure A-E3

PEAK GROUND VELOCITY-ELSINORE FAULT ZONE



LEGEND

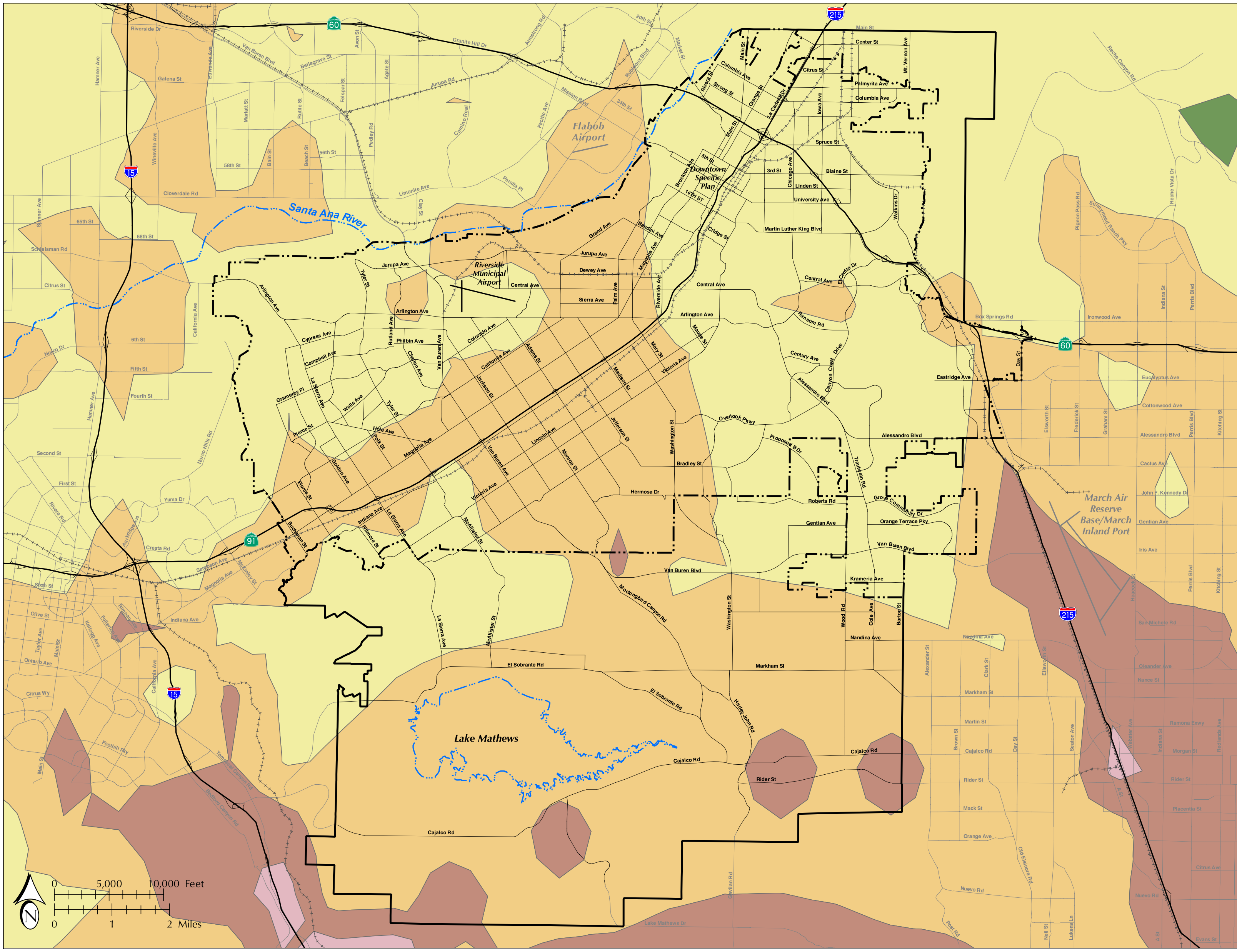
ELSINORE PEAK SPECTRAL ACCELERATION (PSA30)

- 0.04
- 0.08
- 0.12
- RIVERSIDE CITY BOUNDARY
- RIVERSIDE SPHERE OF INFLUENCE

SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY

Figure A-E4

PEAK SPECTRAL ACCELERATION FOR A 3 SECOND PERIOD-ELSINORE FAULT ZONE



LEGEND

ELSINORE PEAK SPECTRAL ACCELERATION (PSA10)

- 0.06
- 0.08
- 0.12
- 0.16
- 0.2
- RIVERSIDE CITY BOUNDARY
- RIVERSIDE SPHERE OF INFLUENCE

SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY

Figure A-E5

PEAK SPECTRAL ACCELERATION FOR A 1 SECOND PERIOD-ELSINORE FAULT ZONE

LEGEND

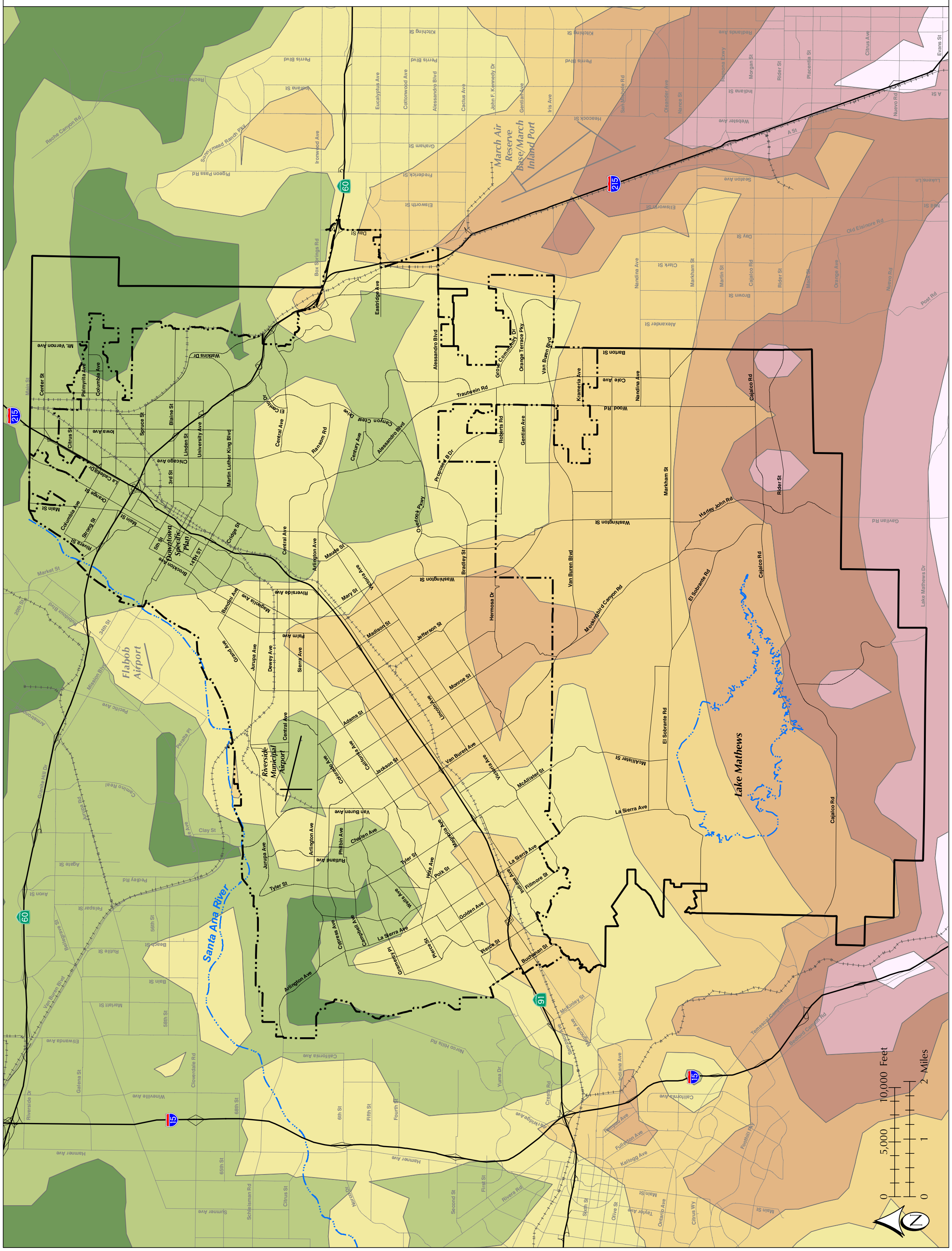
ELSINORE PEAK SPECTRAL ACCELERATION (PSA03)

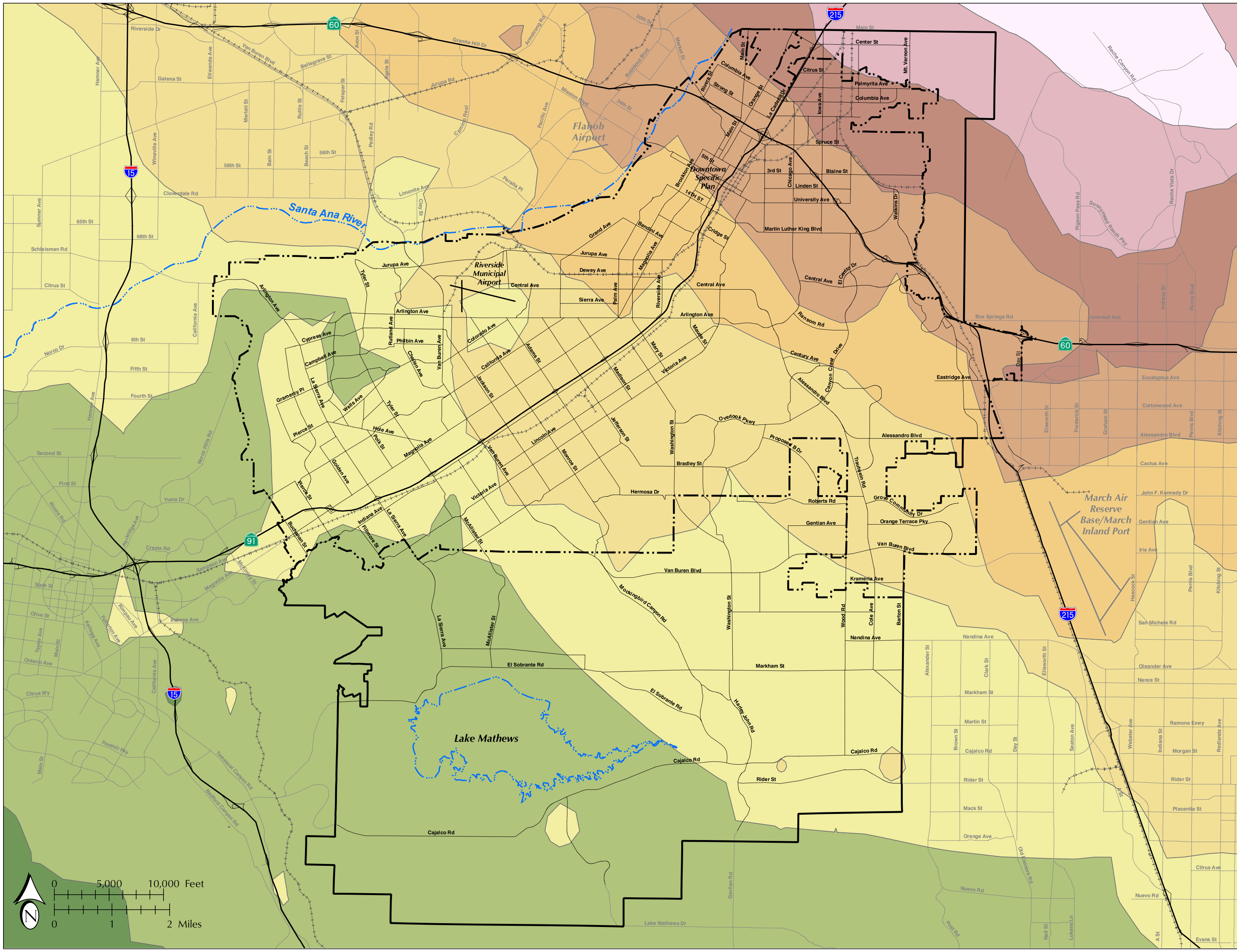
- 0.2
- 0.24
- 0.28
- 0.32
- 0.36
- 0.4
- 0.44
- 0.48
- RIVERSIDE CITY BOUNDARY
- RIVERSIDE SPHERE OF INFLUENCE

SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY

Figure A-E6

PEAK SPECTRAL ACCELERATION FOR A 0.3 SECOND PERIOD-ELSINORE FAULT ZONE





LEGEND

SAN JACINTO PEAK GROUND ACCELERATION (PGA)

- 0.08
- 0.12
- 0.16
- 0.2
- 0.24
- 0.28
- 0.32
- 0.36
- 0.4

RIVERSIDE CITY BOUNDARY

RIVERSIDE SPHERE OF INFLUENCE

SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY

Figure A-SJ1

PEAK GROUND ACCELERATION-SAN JACINTO FAULT ZONE

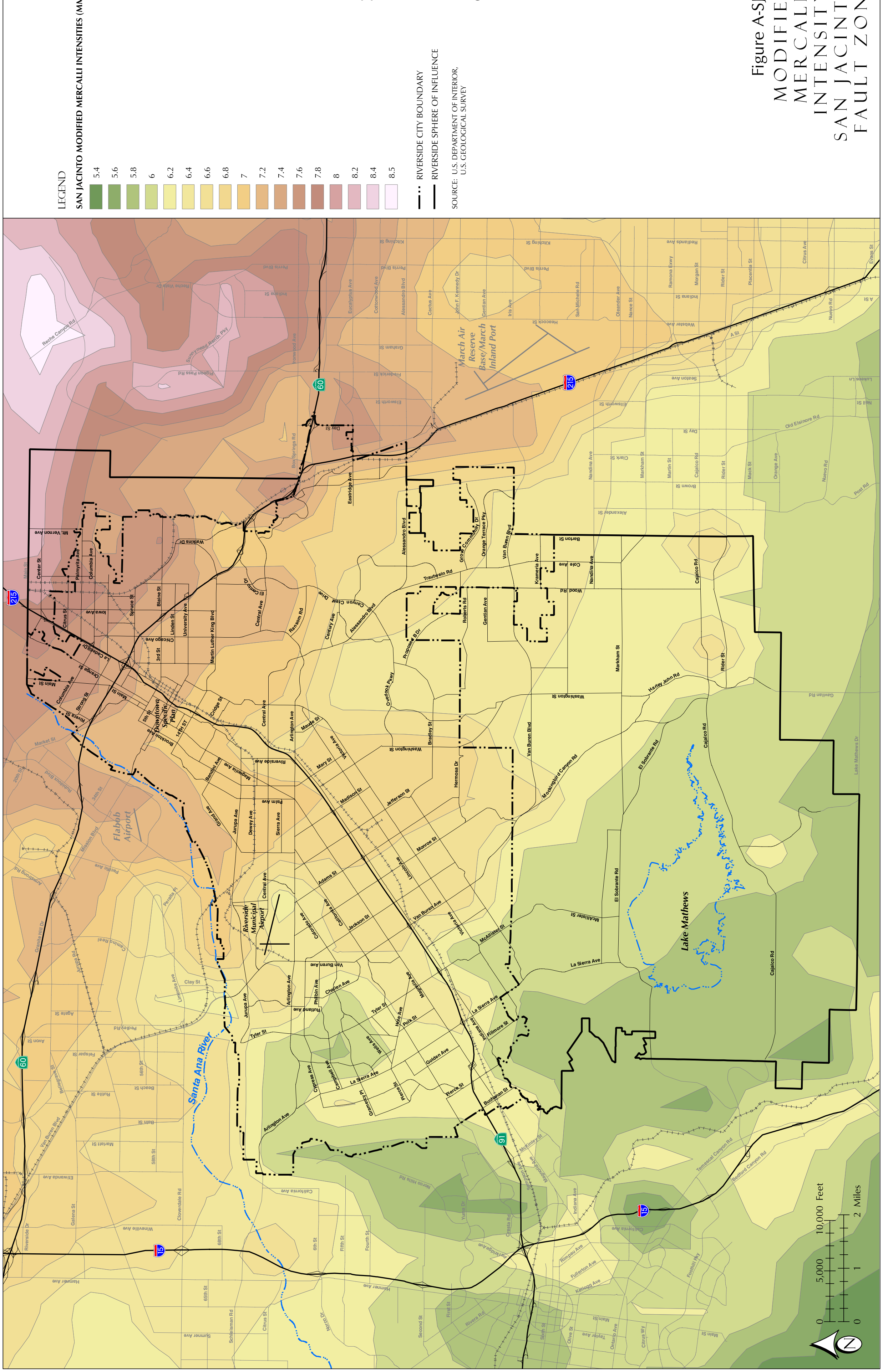
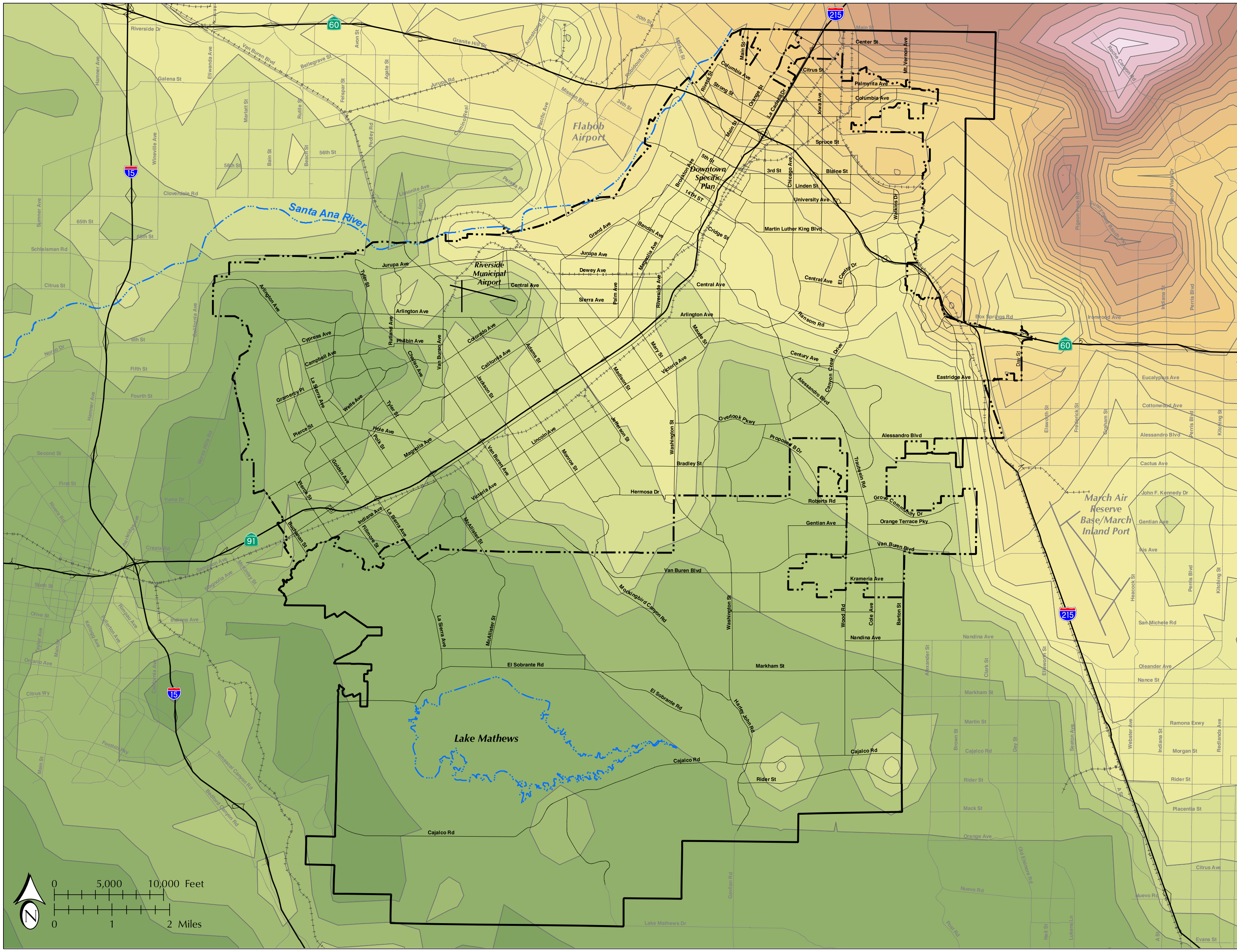


Figure A-SJ2
MODIFIED MERCALLI INTENSITY-SAN JACINTO FAULT ZONE
LEGEND
SAN JACINTO MODIFIED MERCALLI INTENSITIES (MMI)
5.4
5.6
5.8
6
6.2
6.4
6.6
6.8
7
7.2
7.4
7.6
7.8
8
8.2
8.4
8.5
RIVERSIDE CITY BOUNDARY
RIVERSIDE SPHERE OF INFLUENCE
SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY
0 5,000 10,000 Feet
0 1 2 Miles
N
Lake Mathews
Santa Ana River
March Air Reserve Base/March Inland Port
Riverside Municipal Airport
Flabob Airport
Downtown Specific Plan



LEGEND

SAN JACINTO PEAK GROUND VELOCITY (PGV)

6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
65

RIVERSIDE CITY BOUNDARY

RIVERSIDE SPHERE OF INFLUENCE

SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY

Figure A-SJ3

PEAK GROUND VELOCITY-
SAN JACINTO FAULT ZONE

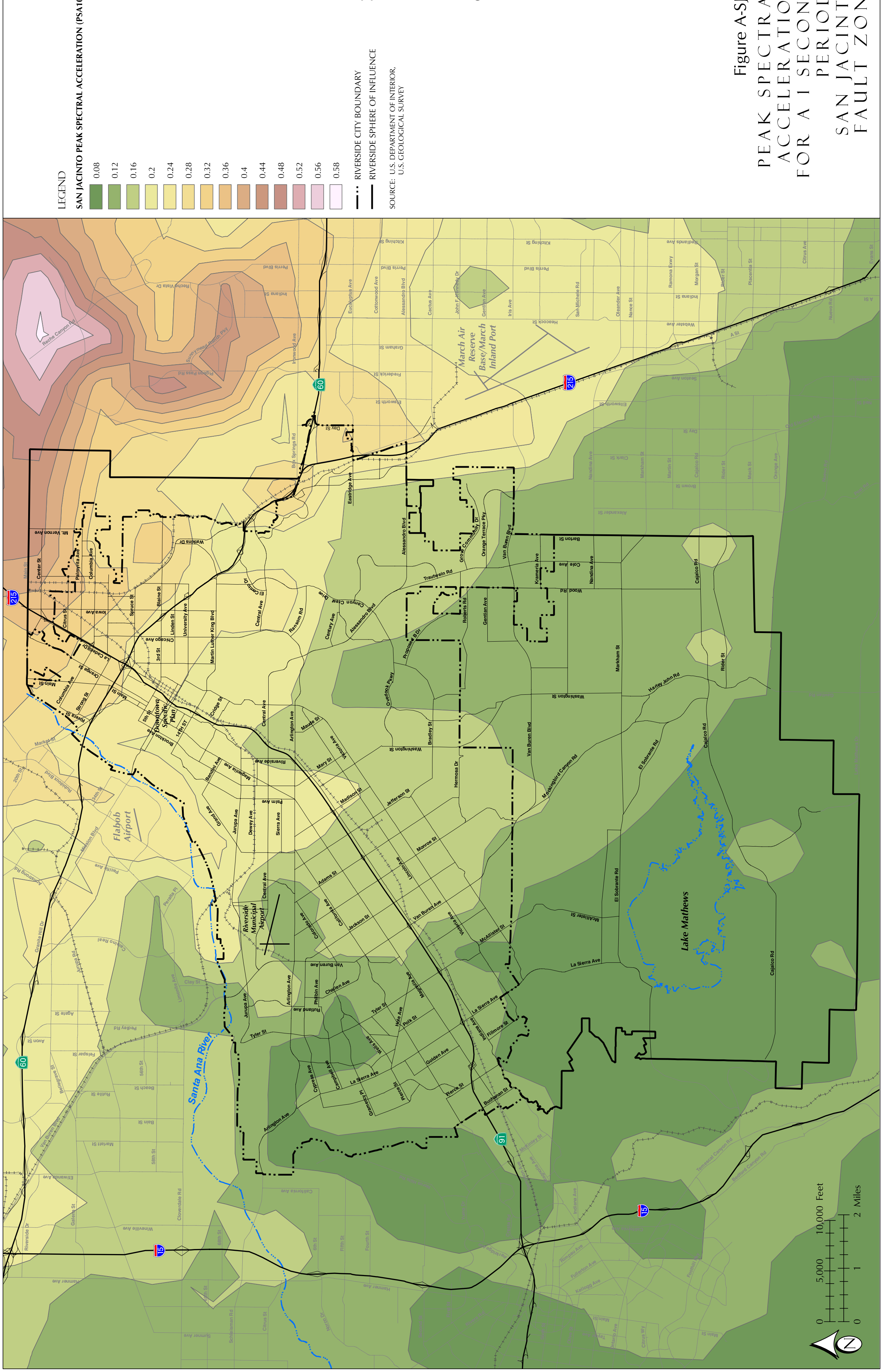
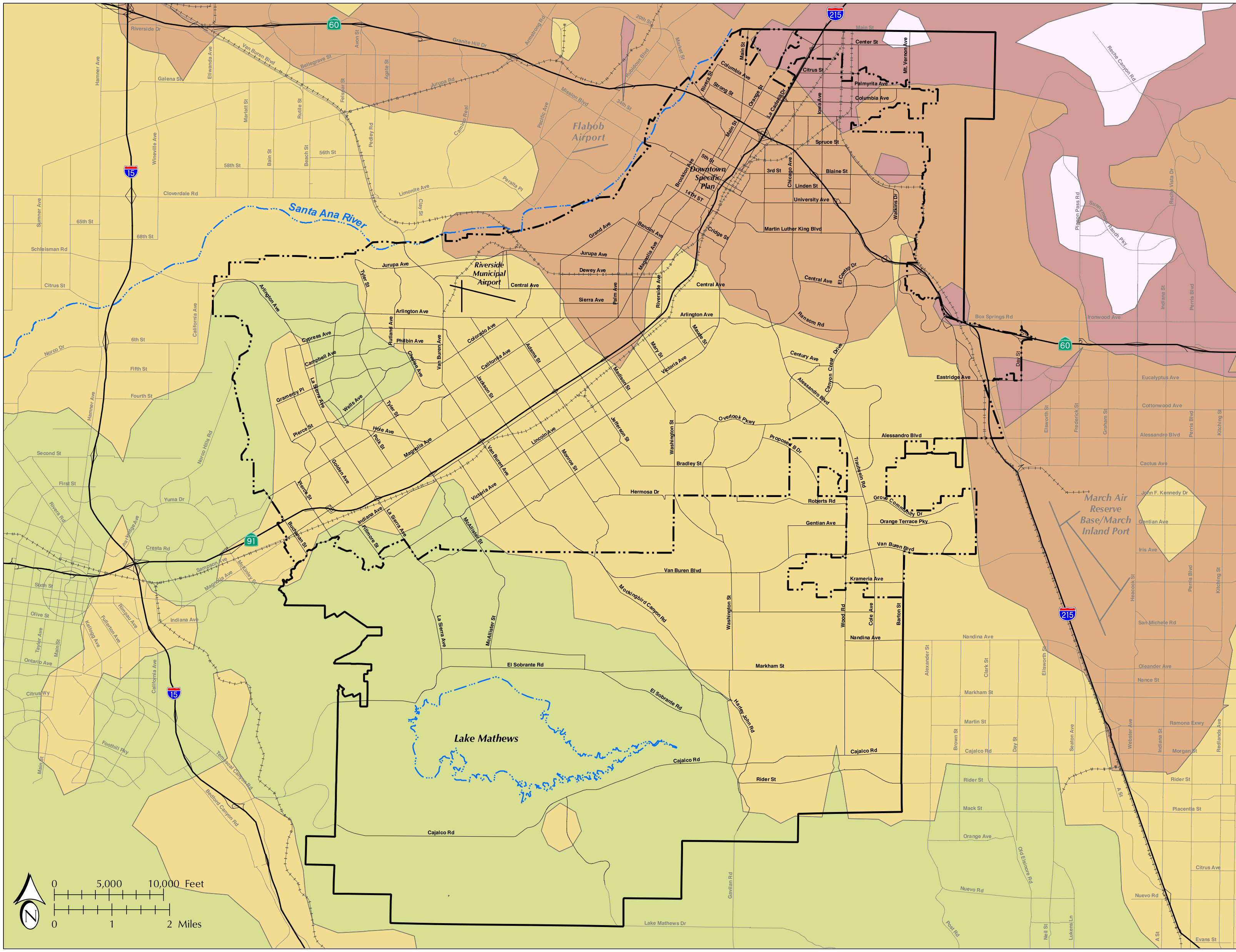


Figure A-SJ5
PEAK SPECTRAL ACCELERATION FOR A 1 SECOND PERIOD- SAN JACINTO FAULT ZONE



LEGEND

SAN JACINTO PEER STUDENTS ASSOCIATION (PSA30)

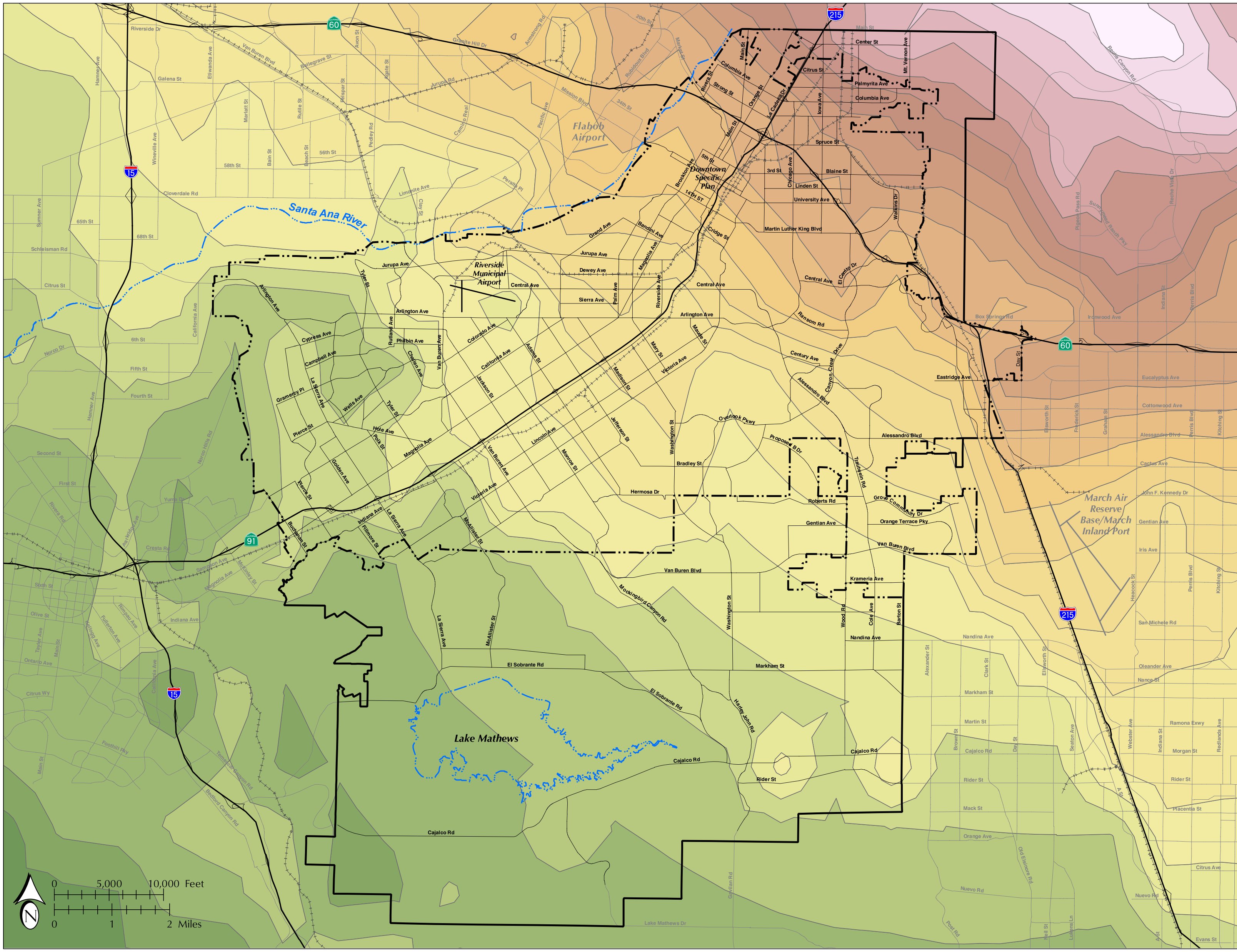
- 0.02
- 0.04
- 0.08
- 0.12
- 0.16
- 0.18

- RIVERSIDE CITY BOUNDARY
- RIVERSIDE SPHERE OF INFLUENCE

SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY

Figure A-SJ5

PEAK SPECTRAL ACCELERATION FOR A 3 SECOND PERIOD- SAN JACINTO FAULT ZONE



LEGEND

SAN JACINTO PEAK SPECTRAL ACCELERATION (PSA03)

- 0.2
- 0.24
- 0.28
- 0.32
- 0.36
- 0.4
- 0.44
- 0.48
- 0.52
- 0.56
- 0.6
- 0.64
- 0.68
- 0.72
- 0.76
- 0.8
- 0.84
- 0.88
- 0.92
- 0.96
- 1
- 1.04
- 1.08

RIVERSIDE CITY BOUNDARY

RIVERSIDE SPHERE OF INFLUENCE

SOURCE: U.S. DEPARTMENT OF INTERIOR, U.S. GEOLOGICAL SURVEY

Figure A-SJ6

PEAK SPECTRAL ACCELERATION FOR A 0.3 SECOND PERIOD- SAN JACINTO FAULT ZONE

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