A Comparison of Two Earthquake Events in the City of Downey: The Puente Hills and Whittier Faults at 7.0 and 6.8 Magnitudes

by

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List of Abbreviations

AEL	Annual Earthquake Loss
AELR	Annual Earthquake Loss Ratio
CDMS	Comprehensive Data Management System
EOC	Emergency Operation Center
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GIS	Geographic information system
GISci	Geographic information science
HAZUS MH	HAZards U.S., Multi-Hazard
HEFRA	Honolulu Essential Facilities Risk Assessment
MH	Manufactured Housing
NEHRP	National Earthquake Hazards Reduction Program
NRCS	Natural Resources Conservation Service
OCEFRA	Orange County Essential Facilities Risk Assessment
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
RM	Reinforced Masonry Manufactured Housing (MH)
SCEC	Southern California Earthquake Center
SSI	Spatial Sciences Institute
UCERF	Uniform California Earthquake Rupture Forecast
URM	Unreinforced Masonry
USC	University of Southern California

USDA	United State Department of Agriculture
USGS	United States Geological Survey

Abstract

Earthquakes have produced losses of over $60 billion since 1971. Of these, California has suffered the highest losses nationally. These losses include building and bridge damage, destruction of building contents and business interruption. The risk factors (as they pertain to loss from earthquake damage) are large stocks of old buildings and bridges; many high-tech and hazardous materials facilities; extensive sewer, water, and natural gas pipelines; earth dams; petroleum pipelines; other critical facilities; and private property. The secondary earthquake hazards (which include liquefaction, ground shaking, amplification, and earthquake-induced landslides) can be just as devastating as the earthquake itself. Damage caused by an earthquake depends on the quality of the buildings' construction, the density of the area, the pattern of intense shaking, and many other factors. Should an earthquake occur in a densely populated area with older buildings, loss of life and damage to infrastructure would be much higher.

This study performs and evaluates two potential earthquake scenarios for the City of Downey utilizing the Federal Emergency Management Agency (FEMA) HAZards U.S., Multi-Hazard (HAZUS) Earthquake Model. According to the Downey General Plan, there is a 50% probability that a major earthquake will occur within the next 30 years along the Whittier-Elsinore Fault, which is 40 miles northeast of Downey. In addition, the Anaheim, Puente Hills, Elysian and Newport-Inglewood Faults are within or near Downey's city limit and those faults are all active or potentially active faults. For this reason, the Whittier and Puente Hills faults with Magnitude (M) 6.8 and 7.0 respectively were chosen to run in the scenarios. HAZUS, which runs on an ArcGIS platform, along with Comprehensive Data Management System (CDMS) was used to ingest updated data, model the earthquakes and create output maps. Essential Facilities data were updated via data provided from the City of Downey Water Work Department into the CDMS. United States Geological Survey (USGS) ShakeMaps were ingested via the

Data tool into HAZUS. Based on the updated data, two earthquake scenarios were modeled and the results were used for mitigation planning.

Chapter 1 Introduction

Earthquakes are the most expensive recurrent hazards in the United States. Many parts of California have the highest probability for earthquake hazard (Figure 1) and produce the highest losses nationally since 1971 (USGS, 2013).

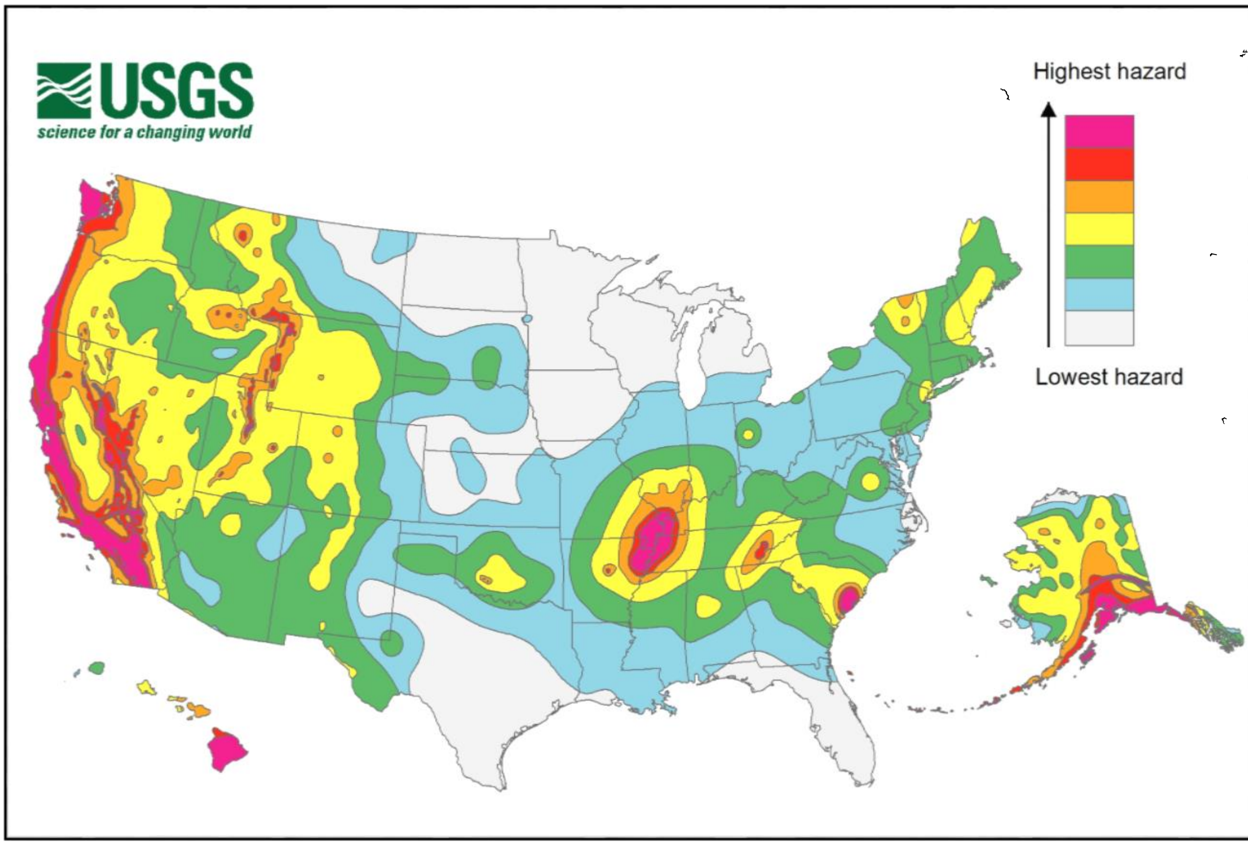

Figure 1: Probability of Earthquake Hazard (Source: USGS)

The risk factors as they pertain to loss from earthquake damage are: (1) large stocks of old buildings and bridges; (2) many high tech and hazardous materials facilities; (3) extensive sewer, water, and natural gas pipelines; (4) earth dams; (5) petroleum pipelines; (6) other critical facilities; and (7) private property (FEMA, 2008). The secondary earthquake hazards (which include liquefaction, ground shaking, amplification, and earthquake-induced landslides) can be just as devastating as the earthquake (Fitzpatrick & Petersen, 2016). Damage caused by an earthquake depends on the quality of the building's construction, the density of the area, the pattern of intense shaking, and many other factors. Due to severe damage during an earthquake prior to 1993, California enhanced its building codes, strengthened the highway structures, and improved emergency management organizations. These changes have reduced the loss of life and damage to buildings. Recent earthquakes in California have provided evidence of how efficient the new building codes are when it comes to construction and retrofitting (Bonowitz, Kornfield, & McNutty, 2016).

The most recent significant earthquake event affecting Los Angeles County was the 1994 Northridge Earthquake (USGS, 2013). This was a moderate but very damaging earthquake with a magnitude of 6.7 that struck the San Fernando Valley. There were thousands of aftershock waves for weeks following the initial quake, causing additional damage. Los Angeles city officials say that more than 200,000 people were living in retrofitted brick buildings when the quake hit. There was not a single death or injury reported from more than 37,000 units in 1,300 strengthened buildings. The structures that were built or strengthened under the new, stricter code experienced limited damage, while those structures that had not been retrofitted suffered greater damage. Approximately 15,000 structures were moderately to severely damaged, leaving thousands of people temporarily homeless. Of the 66,500 buildings that were inspected, nearly 4,000 were severely damaged, and over 11,000 were moderately damaged. There were 57 people killed and more than 1,500 people seriously injured. Thousands of homes and businesses were without electricity; tens of thousands had no gas, and nearly 50,000 had little or no water. Several collapsed bridges and overpasses created commuter havoc on the freeway system. Extensive damage was caused by ground shaking, but earthquake-triggered liquefaction and dozens of fires also caused additional severe damage. This extremely strong ground motion in large portions of Los Angeles County resulted in record economic losses (USGS, 2013). Therefore, to reduce losses in future earthquakes, much work is still needed. There are still older buildings in California that have not been retrofitted. It is up to the owners to do so. Should an earthquake similar to this quake occur in a more densely populated area with older buildings, loss of life and damage would be much higher.

Understanding where future damage is likely to occur can help many to take actions now in order to reduce potential future losses and assist in recovery. For this reason, the City of Downey was chosen to compare earthquake scenarios similar to that of the Northridge earthquake. Many of the buildings in Downey were built before 1993 when building codes were not as strict. Therefore, many of the buildings remain at high risk because retrofitting is not required except under certain conditions and can be expensive. Downey's bridges and roads can be greatly damaged during an earthquake. This is relevant in that many of Downey's residents commute frequently by automobiles and public transportation. According to the Downey General Plan, there is a 50% probability that a major earthquake will occur within the next 30 years along the Whittier-Elsinore Fault, which is 40 miles northeast of Downey. In addition, the Anaheim, Puente Hills, Elysian and Newport-Inglewood Faults are within or near Downey's city limit. Those faults are all active or potentially active faults.

1.1 Motivation

As a Geographic Information System (GIS) professional augmented to the Federal Emergency Management Agency (FEMA) as a liaison, I was tasked to assist with responding to natural disasters. It was here where I was introduced to the HAZards U.S., Multi-Hazard (HAZUS) software, which can model earthquakes and the damage they may cause. After much research and dialogue with Downey's Office of Emergency Management, I discovered the office did not have an up-to-date earthquake assessment. This was because their focus had been on flooding in the past. Downey's flood concerns have been resolved, as much of their work has been done on flood mitigation. However, little has been done on earthquake mitigation. Given the need of the City of Downey - Office of Emergency

Management (OEM), I thought it would be an excellent opportunity to become familiar with the science of earthquake ground motion and the engineering principles behind estimating earthquake impact on the built environment, as well as the potential impact on the human population of the City of Downey. The emergency manager was contacted and asked if an earthquake risk assessment would be useful. The manager agreed and requested an assessment for mitigation planning.

The office emergency manager outlined the criteria for the earthquake risk assessment. They wanted to know what would be the estimated overall loss if an earthquake should occur. They selected earthquakes with a magnitude of 6.8 and 7.0 for the Puente Hills and Whittier faults. The Puente Hills fault is located near the city while the Whittier fault is located just outside of the city. Once the risk assessments are completed through this study, the findings are planned for presentation via a virtual meeting.

1.2 Study Objectives

During the past 20 years, Downey has invested substantially in its essential facilities, enabling it to be more responsive to floods. However, many of the buildings have not been retrofitted to meet the new earthquake code. Essential facilities data (fire and police stations, medical facilities, and schools) for the City of Downey are available through the city and county. This is in addition to those provided with HAZUS. Default data provided with the HAZUS software allows a user to run a simplified (or Level 1) analysis without collecting additional data. However, in many cases, the quality of default national data delivered with the software is less than optimal. The data may originate from agencies other than FEMA, or it was collected for applications other than loss estimation. Accordingly, the accuracy of HAZUS results can be greatly improved with the input of various user supplied data on either the hazard or the affected assets or both (David Adler and Eric Berman, 2003). Such an enhanced analysis is usually referred to as a Level 2 analysis.

This study followed examples of other studies, such as the Orange County Essential Facilities Risk Assessment (OCEFRA) Project Report and the Honolulu Essential Facilities Risk Assessment (HEFRA) Project Report. The OCEFRA Pilot Study examined the risks to the county's essential facilities and general building stock from two different earthquakes, three different floods, and a tsunami affecting the county (ABS, Dewberry, Davis, & MMI, 2009). The project also included an additional task to develop a "Guidelines Document" outlining the approach used throughout the project for enhancing essential facilities data and performing the Level 2 analysis using HAZUS. The HEFRA Study examined the risks to the county's essential facilities and general building stock from earthquakes, hurricane, and floods affecting the Honolulu county (URS, 2010). Unlike the OCEFRA study, the HEFRA study provided an additional risk assessment for high wind using the HAZUS Hurricane Model. The City of Downey assessment examined the risk to the city's essential facilities and general building stock from two difference earthquakes performing the Level 2 analysis using the HAZUS Earthquake Model.

1.3 Scope of Project

This study compared the loss/damage to the essential facilities and building stocks from two Level 2 earthquake scenarios in and nearby the city of Downey. The earthquake events were run in the earthquake model using the user-supplied hazard. Other than the transportation system and utility systems, a second level analysis was conducted by improving the essential facilities, soil, liquefaction and Shakemaps with user-supplied data. The earthquake scenarios were run for a user-defined, arbitrary earthquake for two magnitudes of 6.8 and 7.0 on the Whittier-Elsinore and Puente Hills faults. This project involved several steps:

1. Collect Essential Facilities data
2. Update Essential Facilities data

3. Import Essential Facilities into HAZUS via CDMS
4. Collect General Building Stock data import into HAZUS
5. Collect Earthquake Hazard data from USGS
6. Import ShakeMap into HAZUS
7. Verify Default Transportation and Utility Systems
8. Run Earthquake Model for the Puente Hills fault earthquake scenario
9. Run Earthquake Model for the Whittier fault earthquake scenario
10. Assess the loss estimation results

From these analyses and the resulting assessment, final recommendations were then possible and resultantly made to create a mitigation plan, and how to the assessment could be improved, given further research and data refinement.

Chapter 2 Background

For this project, it was imperative to understand the earthquake and geologic concepts as they relate to the City of Downey. The geology of the terrain upon which the physical city is built is the fundamental base that makes earthquakes possible. Historical earthquakes in California are important to understand as they give insight to the potential impact upon the study area. Ground motion and ground failure (landslides, liquefaction, and amplification) play an important role in determining the potential impacts of an earthquake. The severity of the earthquake depends on soil and slope conditions, proximity to the fault, earthquake magnitude, and the type of earthquake.

2.1 Study Area

The city of Downey is a populated area located with faults within or near the city limits. In 2012, the City of Downey had an estimated population of 112, 200 people, or about 1.1% of the total population of Los Angeles County, California (U.S. Census Bureau, 2012 estimate). According to the Downey General Plan, there is a 79% probability that a major earthquake will occur within the next 30 years along the Whittier-Elsinore Fault. This fault is 40 miles northeast of Downey (Downeyca, 2009). In addition, the Puente Hills Fault, which is active or potentially active, is located within or near the City of Downey (see Figure 2).

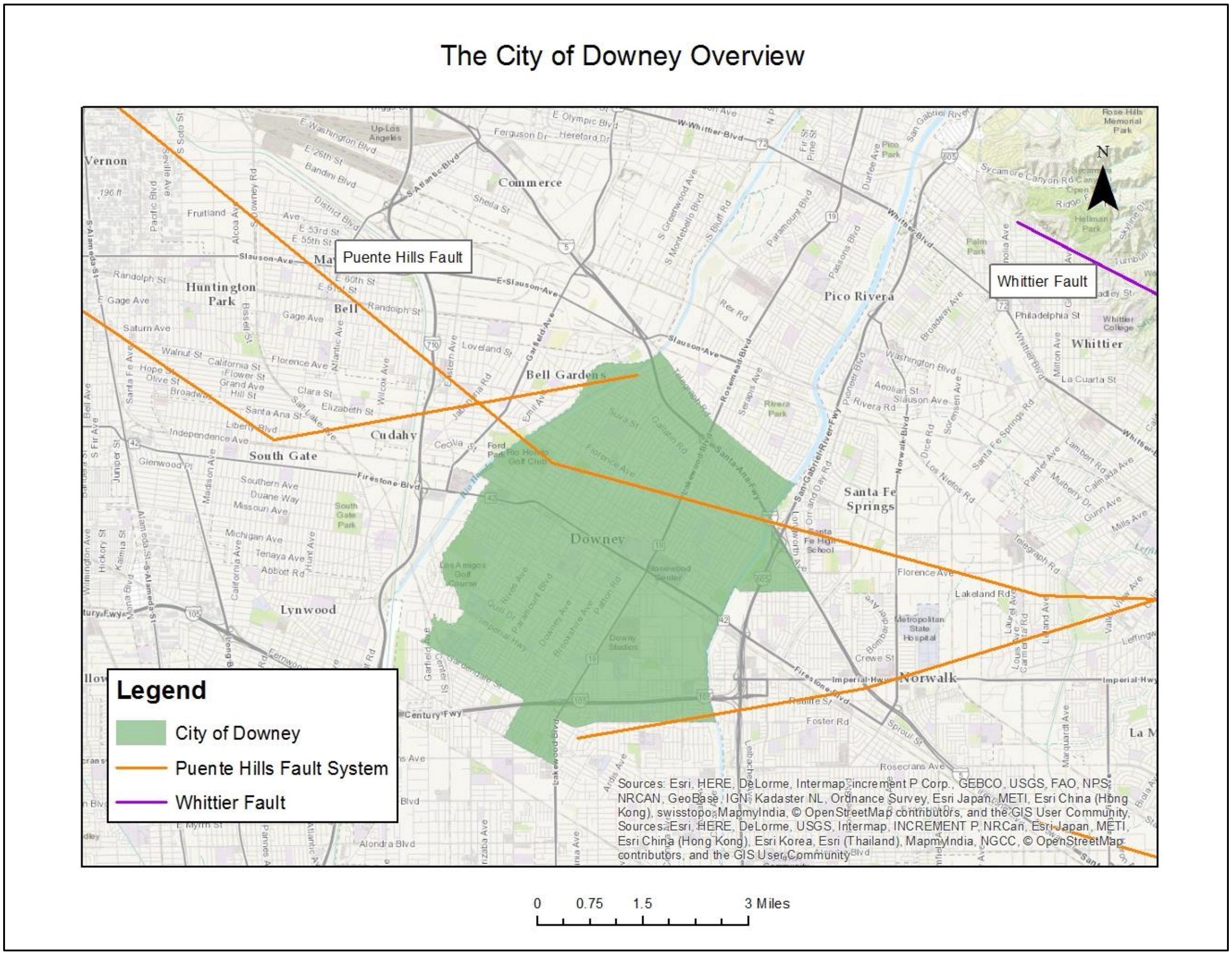

Figure 2: Overview of the City of Downey

Downey is only five miles from Orange County and approximately twelve miles from the Pacific coastline. It is located 13 miles southeast of downtown Los Angeles, which allows it to be affected by the heavy rains of the downtown area. The city is situated between two major rivers. The San Gabriel River is to the east, and the Rio Hondo River is to the west. These rivers serve as flood control channels during heavy rains. They are part of the County Flood Control District with the city being protected by a levee wall with a height of 21 feet (FEMA, 2012). Normally, the river channels are dry and only carry a significant water flow during a major rainstorm. The Rio Hondo River Channel has a capacity to carry 4,200 cubic feet of water per second, and the San Gabriel River Channel is designed to carry 1,900 cubic feet of water per second. North of the city, there are three dams: (1) the Sepulveda; (2) the Whittier Narrows; and (3) the Hansen. According to the City of Downey Emergency Operations Plan (Downeyca, 2009), although the reservoir behind the Whittier Narrows Dam is empty (except during times of heavy runoff) it holds 9.75 million gallons of water and has the potential impact for dam inundation in the City of Downey.

2.2 General Geology and Earthquakes in California

Geological records show that California has a long history of seismic events. The San Andreas Fault is a 400-mile-long fault that runs from the Mexican border to a point offshore, just west of San Francisco. Geologic studies show that over the past 1,400 to 1,500 years, large earthquakes have occurred at about 130-year intervals on the southern San Andreas Fault (USGS, 2013). As the last large earthquake on the Southern San Andreas occurred in 1857, that section of the fault is considered a likely location for an earthquake within the next few decades (USGS, 2013).

San Andreas is only one of many known earthquake faults that traverse Southern California. Some of the better-known faults are the Newport-Inglewood, Whittier, Chatsworth, Elsinore, Hollywood, Los Alamitos, Puente Hills, and Palos Verdes faults. There are a potentially large number of “blind” faults that underlie the surface of Southern California. One such blind fault was involved in the Whittier Narrows earthquake in October 1987. Although the most famous of the faults, the San Andreas, is capable of producing an earthquake with a magnitude of 8+ on the Richter scale, it is located further from the urban area. However, some of the “lesser” faults have the potential to inflict greater damage on the urban core of the Los Angeles Basin because the faults are located closer to or within the urban area. The Uniform California Earthquake Rupture Forecast (UCERF) demonstrates the probability of all-possible, damaging earthquakes over a specified time span (see Figure 3).

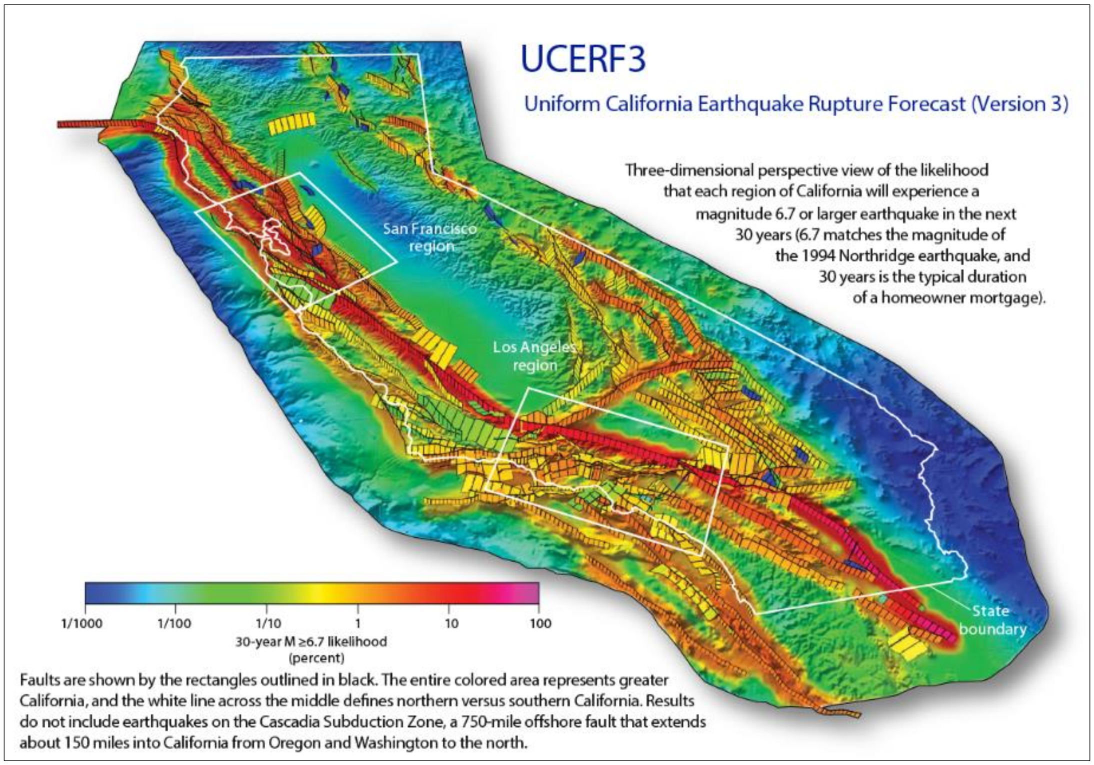

Figure 3: Uniform California Earthquake Rupture Forecast (Version 3) (Source: USGS)

Seismologists believe that a 6.0 earthquake on the Newport-Inglewood fault would result in far more death and destruction than a "great" quake on the San Andreas because the San Andreas is relatively remote from the urban centers of Southern California. Thousands of earthquakes occur in California each year with some causing moderate damage and injuries in small areas. In Southern California alone, over 300 faults may cause damaging earthquakes. Most everyone in Southern California lives within 30 miles of one of these faults. When earthquakes on these faults are in populated areas, the losses can be substantial (Seismic Hazard Zonation Program, 2015).

2.3 Earthquake Hazards

Earthquake hazards include ground motion and ground failure (liquefaction, landslides and surface fault rupture). Essentially, these are the specific hazards associated with earthquakes. The severity of these hazards depends on several factors, including soil and slope conditions, proximity to the fault, earthquake magnitude, and the type of earthquake. Ground motion is the shaking felt on the earth's surface caused by seismic waves generated by the earthquake (Fitzpatrick & Petersen, 2016). It is the primary cause of earthquake damage. The strength of ground motion depends on the magnitude of the earthquake, the type of fault, and distance from the epicenter (David Adler and Eric Berman, 2003).

Ground motion estimates are represented by contour maps and location-specific values of ground shaking demand. For computational efficiency and improved accuracy, earthquake losses are computed using location-specific estimates of ground shaking demand. The analysis has been simplified for general building stock. The spatial distribution of ground motion can be determined using USGS probabilistic ground motion maps (ShakeMaps). When ground motion is based on ShakeMaps location-specific values of ground shaking demand are interpolated between peak ground acceleration (PGA), peak ground velocity (PGV) and spectral acceleration (SA) contours, respectively (David Adler and Eric Berman, 2003). In HAZUS, the user-supplied hazard option requires the user to supply digitized PGA and SA contour maps. Spectral accelerations at 0.3 second and 0.1 second (SA at 0.3 and SA at 1.0) are needed to define the hazard. The damage and losses are computed based on the user-supplied maps. In general, for the general building stock, the analysis has been simplified so that ground motion demand is computed at the centroid of a census tract. However, contour maps are also developed to provide pictorial representations of the variation in ground motion demand within the study region.

As it relates to ground failure, liquefaction, landslides and surface fault rupture must be considered. Liquefaction is a process by which water-saturated sediment temporarily loses strength and acts as a fluid. This causes uneven settlement of the soil which can result in structural damage to infrastructure. To include liquefaction in the analysis, you may supply a liquefaction susceptibility map which shows the susceptibility for each census tract and is based on a soil survey of the area. Based on the liquefaction susceptibility and the peak ground acceleration, a probability of liquefaction is assigned during the analysis. A landslide is a movement of surface material down a slope. To include landslide in the analysis, one may supply a landslide susceptibility map which shows the susceptibility for each census tract. Once landslide susceptibility has been determined, HAZUS provides default values for probability of land-sliding and estimated permanent ground displacement as a function of ground acceleration.

When an earthquake occurs, the fault rupture can extend from its starting point all the way to the ground surface. In the eastern part of the United States, many earthquakes do not show evidence of rupture at the ground surface, however, in the western part of the United States and Alaska surface fault rupture is common. Displacements due to surface fault rupture can measure up to several meters and can cause significant damage to structure. Surface fault rupture can be included by selecting the Ground Failure when the analysis is run.

Downey is primarily affected by flooding, which is of major concern because it promotes liquefaction, and this may result in landslides during an earthquake event (Baumann, 2012). The city has multiple low-lying areas that are prone to flooding (FEMA, 2012). The areas include the locations of Rancho Los Amigos Hospital grounds, Firestone and Lakewood Boulevard, Firestone Boulevard between Paramount Boulevard and Brookshire Avenue, areas south of Telegraph Road and north of the Santa Ana Freeway, and portions of the Glenn Anderson Freeway within the City limits [all according to the Downey Emergency Operations Plan (Downeyca, 2009)]. Almost 55% of the area in the City of Downey has a high concentration of impermeable surfaces that either collect water or concentrate the flow of water in unnatural channels. In addition, elevations in the city range from a high of 145 feet in the northern region of the city to a low of 85 feet in the southern region, with an average elevation of 117 feet, according to the City of Downy Emergency Operations Plan. The terrain of the city is primarily flat and low-lying which has the potential to flood (FEMA, 2012). Earthquake-induced landslides are secondary earthquake hazards (Michael, Irvine, & Slang, 2001). They can destroy the roads, buildings, utilities, and other critical facilities necessary to respond and recover from an earthquake. The City of Downey has a high likelihood of encountering such risks given the soil composition and the varying elevations (Krishna, 2013).

The USDA Natural Resources Conservation Service soil map, which is considered a more detailed soil survey, classified the City of Downey's soil as mostly loam, sandy, silt, and clay, with a small portion of bedrock and organic material (see Figure 4). Loam has a very high percentage of sand and silt, all of which are susceptible to ground failure during an earthquake event (see Figure 5).

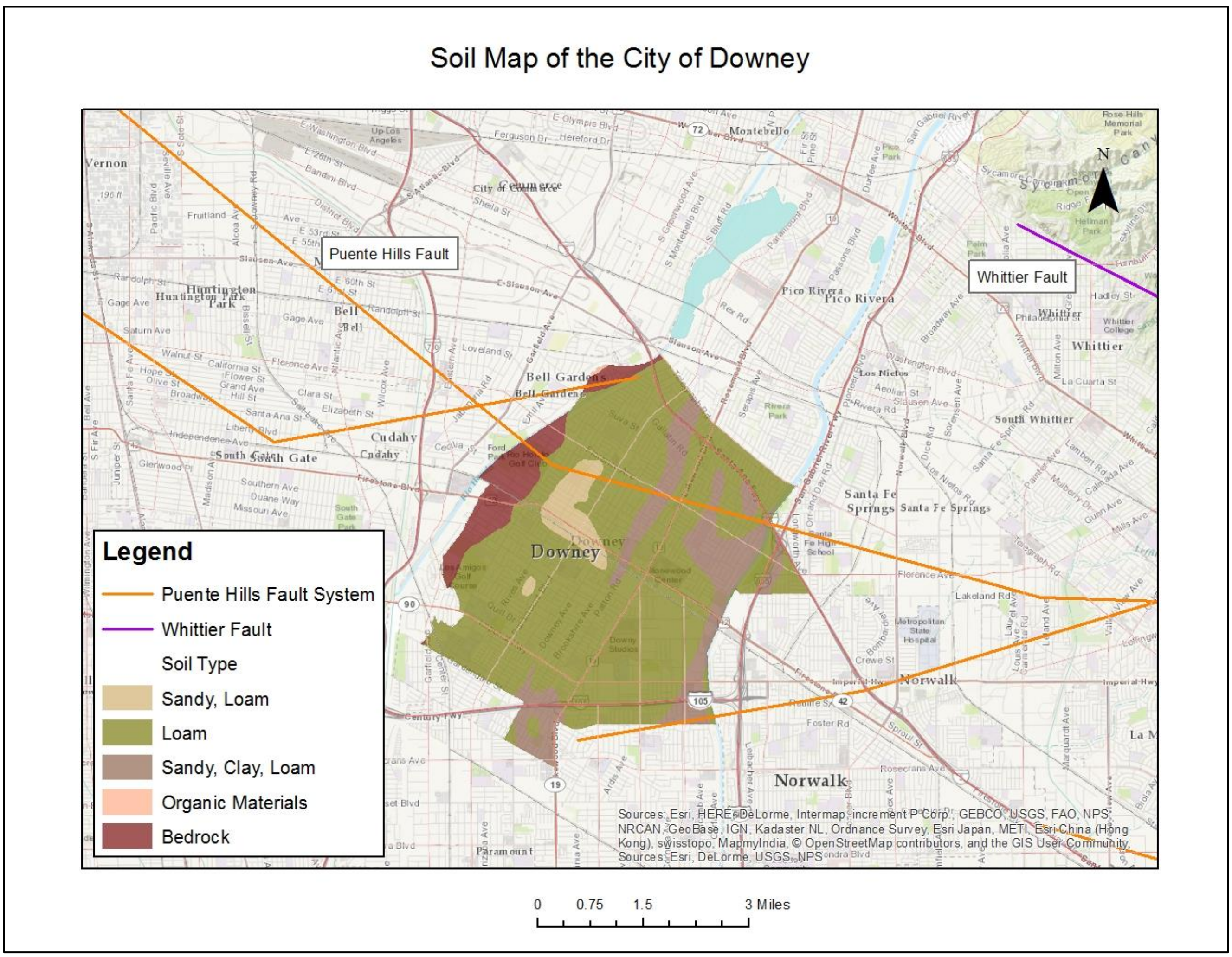

Figure 4: Natural Resources Conservation Service – Soil Map (Source: USDA)

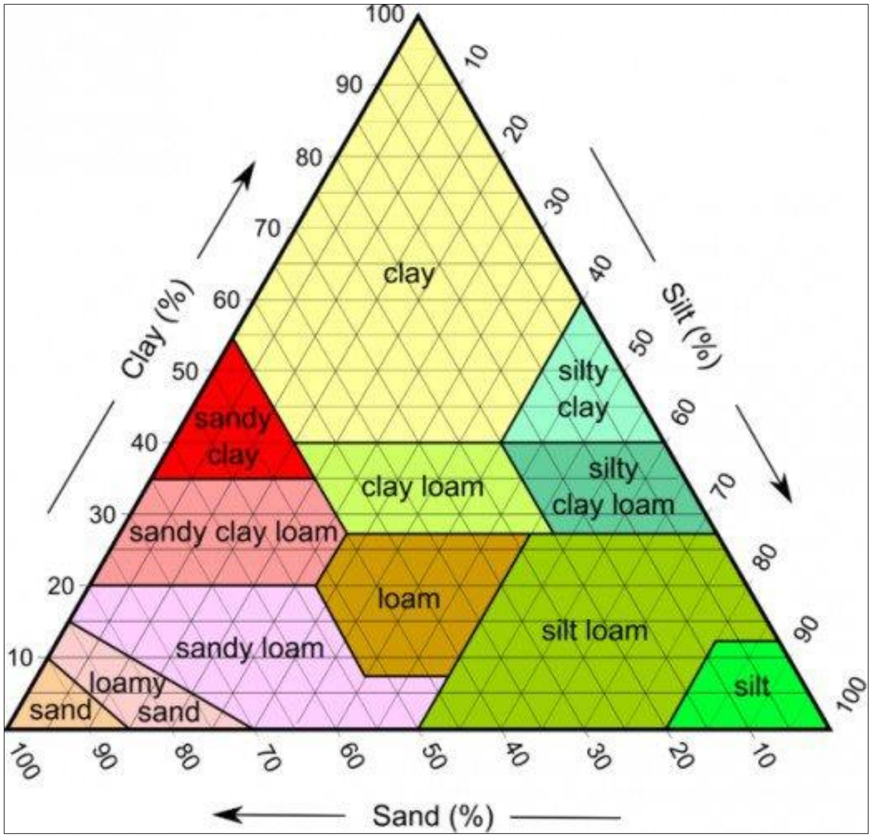

Figure 5: Natural Resource Conversation Service -Types of Soil (Source: USDA)

Soils and soft sedimentary rocks near the earth's surface can modify ground shaking caused by earthquakes. One of these modifications is amplification. Amplification increases the magnitude of the seismic waves generated by the earthquake. The amount of amplification is influenced by the thickness of geologic materials and their physical properties. Buildings and structures built on soft and unconsolidated soils can face greater risk (Bonowitz, Kornfield, & McNutty, 2016).

The likelihood of experiencing liquefaction at a specific location is primarily influenced by the susceptibility of the soil, the amplitude and duration of ground shaking, and the depth of groundwater. Once liquefaction occurs, the ground loses its ability to support structures, can flow down even very gentle slopes, and erupt to the ground surface to form sand boils. Many of these phenomena are accompanied by settlement of the ground surface — usually in uneven patterns that damage buildings, roads, and pipelines. The California Geological Survey has identified areas most vulnerable to liquefaction (see Figure 6); the entire City of Downey is subject to liquefaction (Seismic Hazard Zonation Program, 2015).

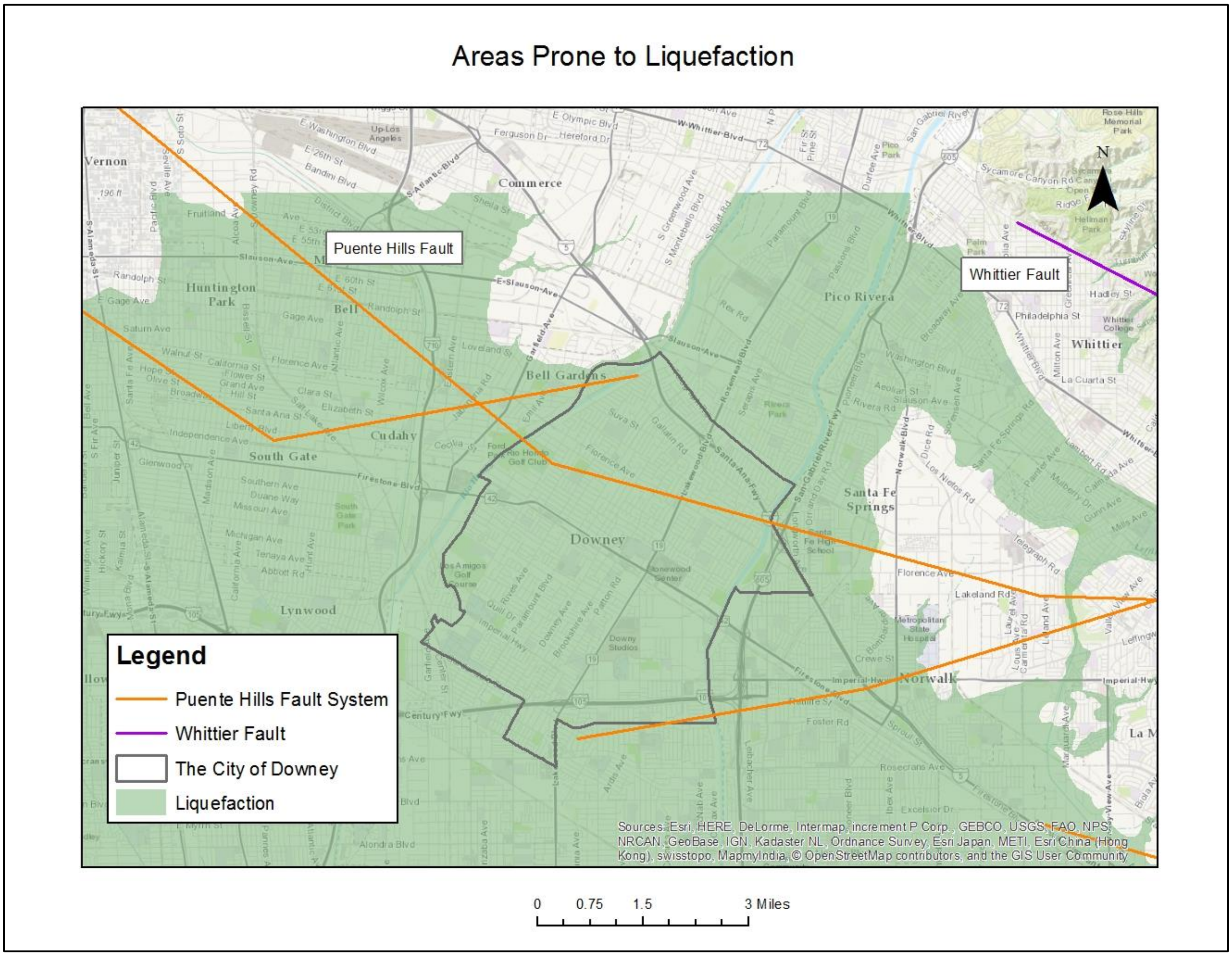

Figure 6: Areas Prone to Liquefaction

For this study, user-supplied USGS ShakeMaps were used. As 4 - 3 HAZUS - MH Technical Manual states in Section 4.1.2.1, the methodology assumes that user-supplied maps reflect soil amplification. Each of these ground failure types are considered in HAZUS and quantified by permanent ground displacement measured in inches (David Adler and Eric Berman, 2003).

2.4 HAZUS

HAZUS is the Federal Emergency Management Agency's (FEMA) nationally applicable software program that estimates potential building and infrastructure losses from earthquakes, riverine and coastal floods, and hurricane winds. HAZUS loss estimates reflect state-of-the-art scientific and engineering knowledge. It can be used to inform decision-making at all levels of government by providing a reasonable basis for developing mitigation, emergency preparedness, and response and recovery plans and policies. HAZUS uses geographic information system software (ArcGIS) to map and display: (1) hazard data; (2) the results of damage and economic loss analyses; and (3) potential effects on area populations. HAZUS analyses also can be run in real time to support response and recovery actions following a disaster event. Other proprietary and research-based earthquake prediction software exists, created and used by government experts at agencies like the Unites States Geological Survey (USGS), or by academic institutions such the Southern California Earthquake Center (USGS, 2017) (SCEC, 2017). However, these are not generally freely available and are most user friendly for Geophysicists and Engineers. Thus, HAZUS was chosen for use in this study, for it's accessibility, ease of use, and comprehensive technical documentation that allows a novice user to thoroughly learn the science behind the earthquake damage modeling tools.

The HAZUS Earthquake Model was first released by FEMA in 1997 as HAZUS97, which was subsequently updated three times. The multi-hazard version of HAZUS -HAZUS-MH - was first released by FEMA in 2004 and its fourth update HAZUS-MH MR4 - became available in October 2009. The HAZUS-MH Earthquake Model estimates earthquake damage and loss to buildings, essential facilities, and transportation and utility lifelines. It also addresses debris generation, fire following earthquake, casualties, and shelter requirements. In 2010, FEMA determined the average Annual

Earthquake Loss (AEL) and average Annual Earthquake Loss Ratio (AELR) risks for all states (see Figure 7). California fell in the top tier of both measurements (FEMA, Earthquake Model , 2010).

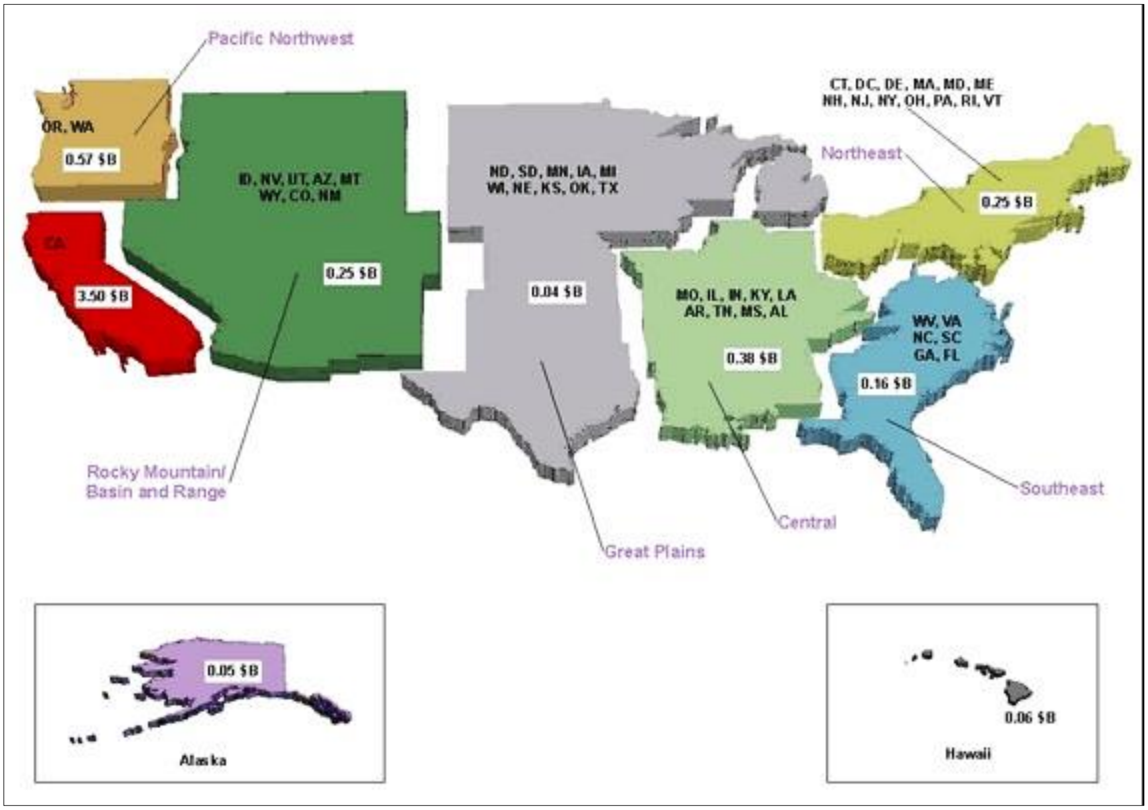

Figure 7: Comparison of U.S. Regional Seismic Risk Annualized Earthquake Loss (Source: FEMA)

The tool created by FEMA and delivered with HAZUS for allowing updates to HAZUS provided inventory with locally produced data is called the Comprehensive Data Management System (CDMS). This tool was developed with the express purpose of allowing users to enhance the analytical outcomes and, therefore, the accuracy of loss estimations generated by HAZUS, by bringing enhanced data into the HAZUS loss estimation process. HAZUS provides three levels of analysis based on the level of effort and expertise employed by the user (Figure 8).

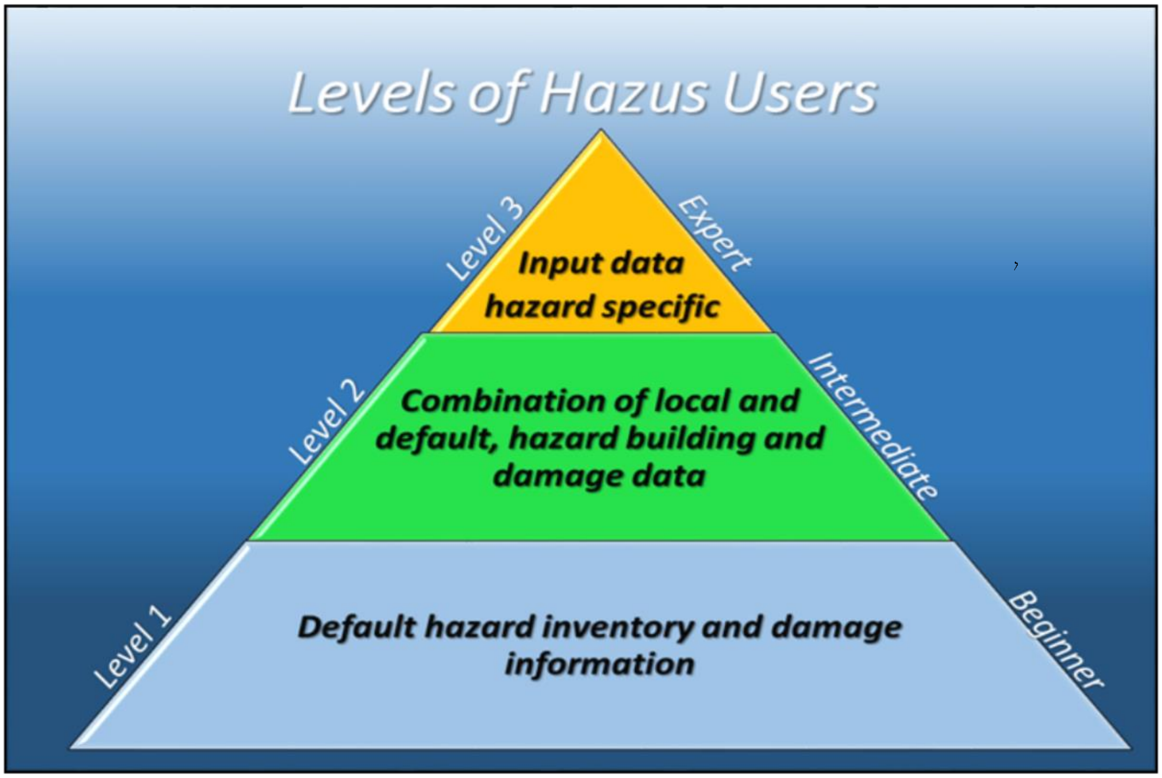

Figure 8: Level of HAZUS Users (Source: FEMA)

For the purpose of this study, a Level 2 earthquake analysis was conducted which included a combination of updated and default data. In HAZUS, a user-defined earthquake scenario was used for the methodology.

Chapter 3 Data and Methodology

This chapter discusses the data used in the project. It discusses the data provided with the HAZUS software, the data provided by the city (which was updated via the CDMS), as well as the ShakeMaps provided by USGS which were incorporated into HAZUS. It also discusses the methodology using HAZUS. The HAZUS earthquake model was run using a user-defined earthquake scenario on two different faults - the Puente Hills and Whittier faults - at two different magnitudes. From this, the results were analyzed and an assessment prepared for mitigation planning.

3.1 Data Used

Within the HAZUS earthquake model, hazards include both primary hazards (earthquake ground motion), and secondary hazards, such as earthquake-induced ground failure. Technical background material, required data formats, and descriptions are also provided in detail in the HAZUS Earthquake Technical Manual Chapter 4 (FEMA, Earthquake Model , 2010).

For regional earthquake risk assessments, ground-shaking hazards (which may impact a broad area) are of significant concern. Modeling of ground failure hazards typically requires detailed site-specific analyses and data. While regional ground failure hazard maps (e.g., liquefaction or landslide susceptibility maps) may be utilized within HAZUS, these hazards may only impact a portion of a given census tract. As a result, interpretation of the results developed at the census tract level should be cautiously used.

For use in estimating regional earthquake losses within HAZUS, three maps delineating patterns of regional ground shaking are required. These include maps of peak ground acceleration (in units of g [where g = the acceleration due to Earth's gravity, equivalent to g-force]), peak ground velocity (in units of inches/second), and Spectral accelerations at both 0.3 and 1.0 second periods (in units of g).

3.1.1. HAZUS census tract base data

The earthquake methodology uses census tracts as the smallest geographic unit. Census tracts are divisions of land that contain 2,500 to 8,000 inhabitants with relatively homogeneous population characteristics, economic status, and living conditions. Each census tract boundary contains aggregated population, demographics, and general building stock values. The City of Downey contains 22 census tracts (see Figure 9), which have a total population of 111,772 people. The geographical size of the region is 12.58 square miles.

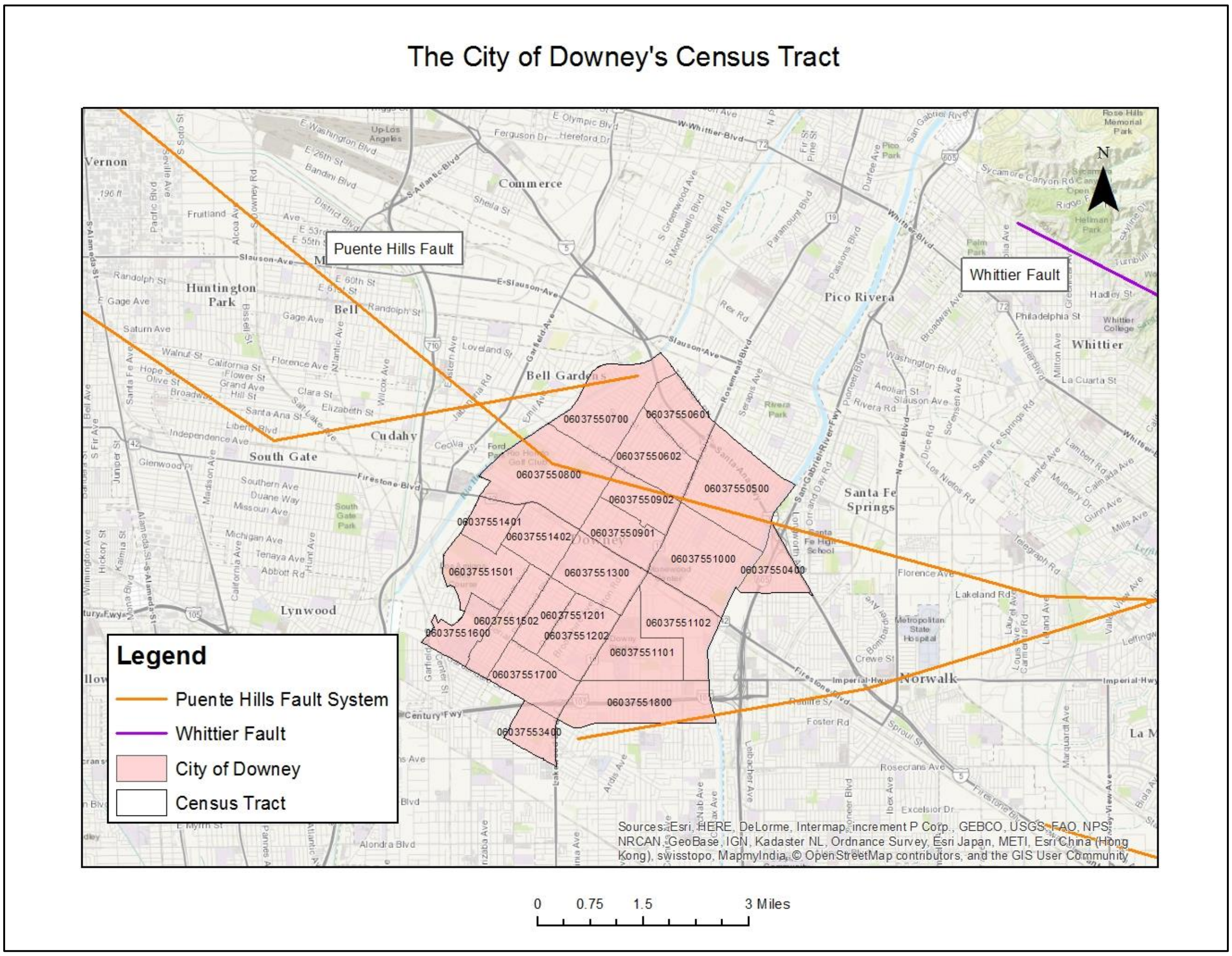

Figure 9: City of Downey by Census Tract

3.1.2. HAZUS inventory data

3.1.2.1. General Building Stock Data

Default building inventory data in HAZUS consists of aggregated data that are summarized at the census tract level for earthquakes. It represents the general building stock described in detail in the HAZUS Earthquake Model technical manuals. Aggregate regional building inventory databases, representing building square footage by HAZUS occupancy class, were developed from census data for residential occupancies and from Dun & Bradstreet employment data for non-residential occupancies.

There are over 33 thousand households and an estimated 25 thousand buildings in the study region with a total building replacement value (excluding contents) of over 9 million dollars. Approximately 92% of the buildings (and 80% of the building value) are associated with residential housing (see Table 1).

Table 1: Study Region (City of Downey) Population and Buildings Value

State	County Name	City of Downey Population	Building Value (millions of dollars)		
			Residential	Non-Residential	Total
California	Los Angeles	111,772	7,658	1,972	9,631

3.1.2.2. Lifeline Inventory (Transportation and Utility Systems)

HAZUS's default databases for lifeline inventory is divided between transportation and utility lifeline systems. For this assessment, the default data were used to complete this study. There are seven (7) transportation systems that include highways, railways, light rail, bus, ports, ferry and airports and six (6) utility systems that include potable water, wastewater, natural gas, crude and refined oil, electric power, and communications. The lifeline inventory data were obtained from the Federal Highway Administration (FHWA) and the Census Bureau's TIGER files.

The total value of the lifeline inventory was over 38 million dollars. This inventory includes over 4,819 kilometers of highways, 23 bridges, and 8,323 kilometers of pipes. This data was not updated but considered for a complete assessment (see Tables 2 and 3).

Table 2: Default Transportation System

System	**Component**	**#Locations/ Segments**	**Replacement value (millions of dollars)**
Highway	Bridges	23	101
	Segments	4,931	36,848
	Tunnels	0	0
		Subtotal	36,959
Railways	Bridges	0	0
	Facilities	0	0
	Segments	594	885
	Tunnels	0	0
		Subtotal	885
Light Rails	Bridges	0	0
	Facilities	1	2
	Segments	99	376
	Tunnels	0	0
		Subtotal	379
Bus	Facilities	0	0
Ferry	Facilities	0	0
Port	Facilities	0	0
Airport	Facilities	0	0
	Runways	0	0
Total		5,648	38,223

Table 3: Default Utility System

System	**Component**	**#Locations/ Segments**	**Replacement value (millions of dollars)**
Potable Water	Distribution Lines	NA	83.20
	Facilities	0	0.00
	Pipelines	0	0.00
		Subtotal	83.20
Waste- Water	Distribution Lines	NA	49.90
	Facilities	0	0.00
	Pipelines	0	0.00
		Subtotal	49.90
Natural Gas	Distribution Lines	NA	33.30
	Facilities	0	0.00
	Pipelines	0	0.00
		Subtotal	33.30
Oil Systems	Facilities	1	0.10
	Pipelines	0	0.00
		Subtotal	0.10
Electrical Power	Facilities		0.00
		Subtotal	0.00
Communication	Facilities	0	0.00
		Subtotal	0.00
Total		1	166.60

3.1.3. User supplied data

3.1.3.1. Essential Facilities Data

The Essential Facilities (EF) are those facilities intended to provide services to the community in the event of a disaster. In HAZUS, essential facilities are classified based on facility function and include Medical Care Facilities, Fire Stations, Police Stations, Emergency Operations Centers, and Schools. The default EF dataset was queried and then updated in the CDMS. The query yielded seventy-seven (77) EFs: 1 Fire Station Facility, 3 Police Stations Facilities, 1 Emergency Operations Center, 2 Medical Care Facilities, and 70 Public and Private Schools (Figures 10 through 15).

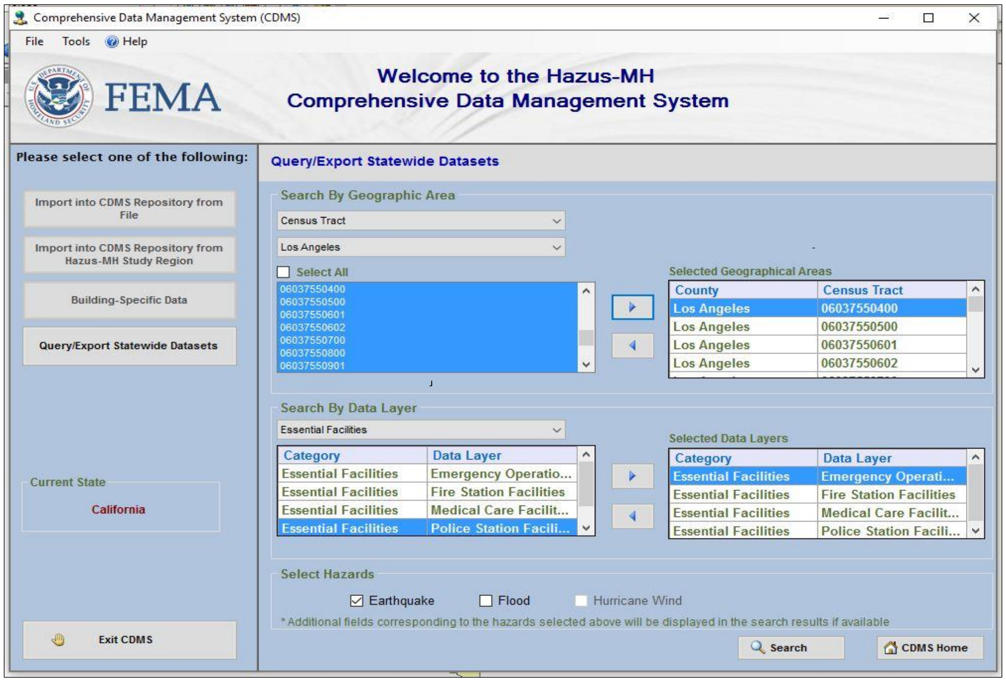

Figure 10: Essential Facilities Query (Source: CDMS)

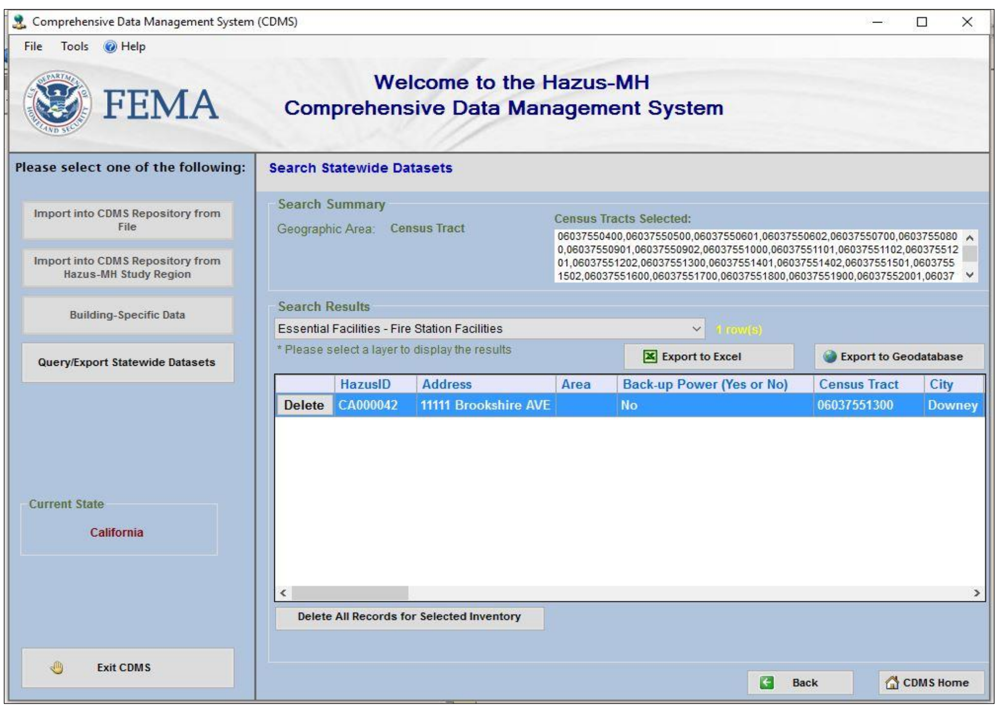

Figure 11: Default Fire Station Facility (Source: CDMS)

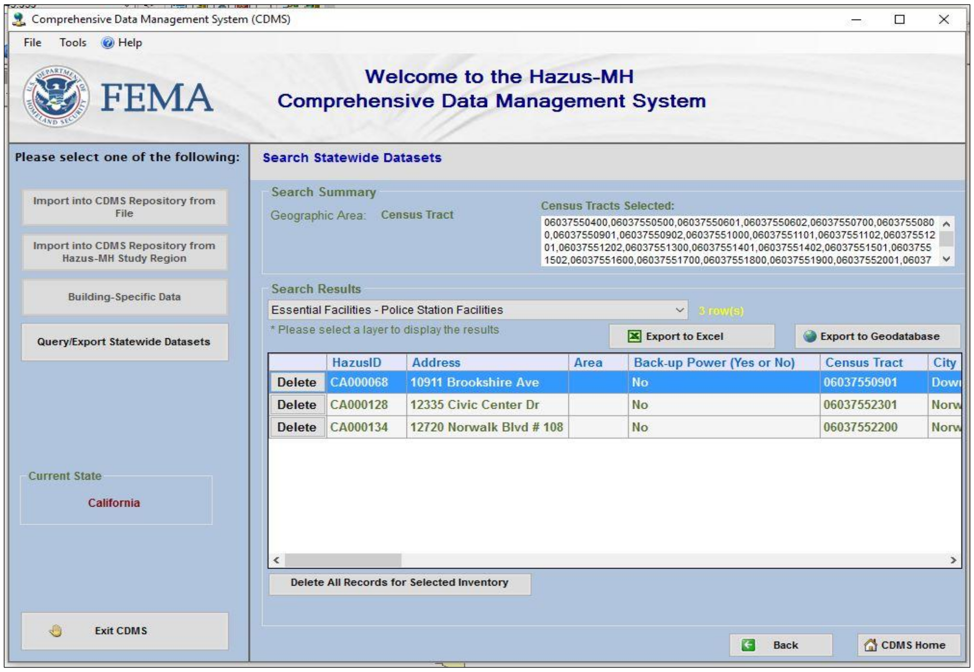

Figure 12: Default Police Station Facilities (Source: CDMS)

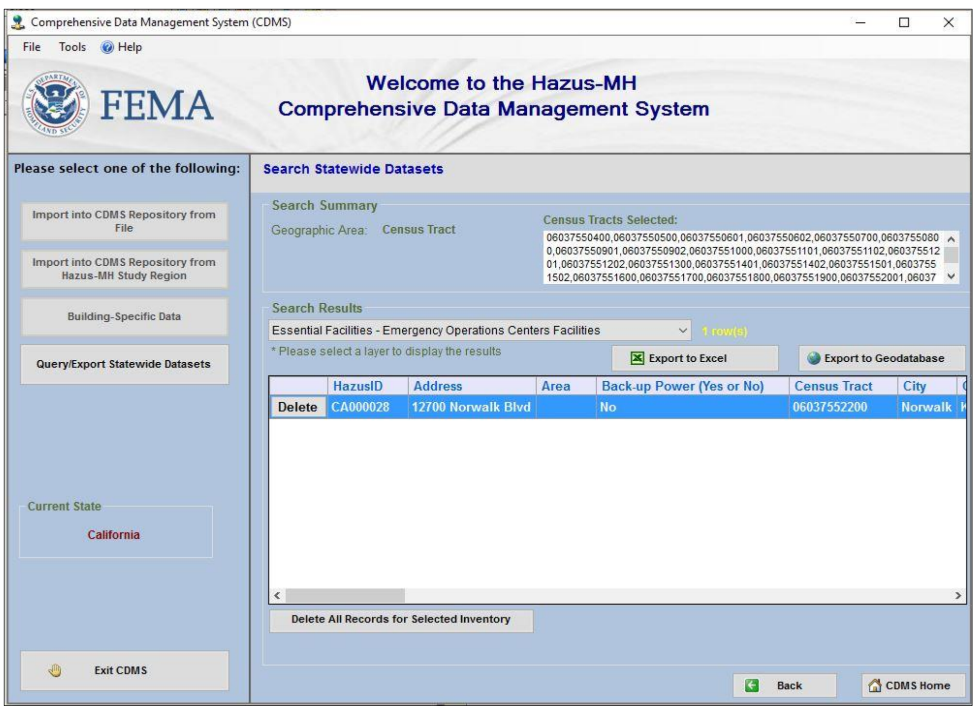

Figure 13: Default Emergency Operation Centers Facility (Source: CDMS)

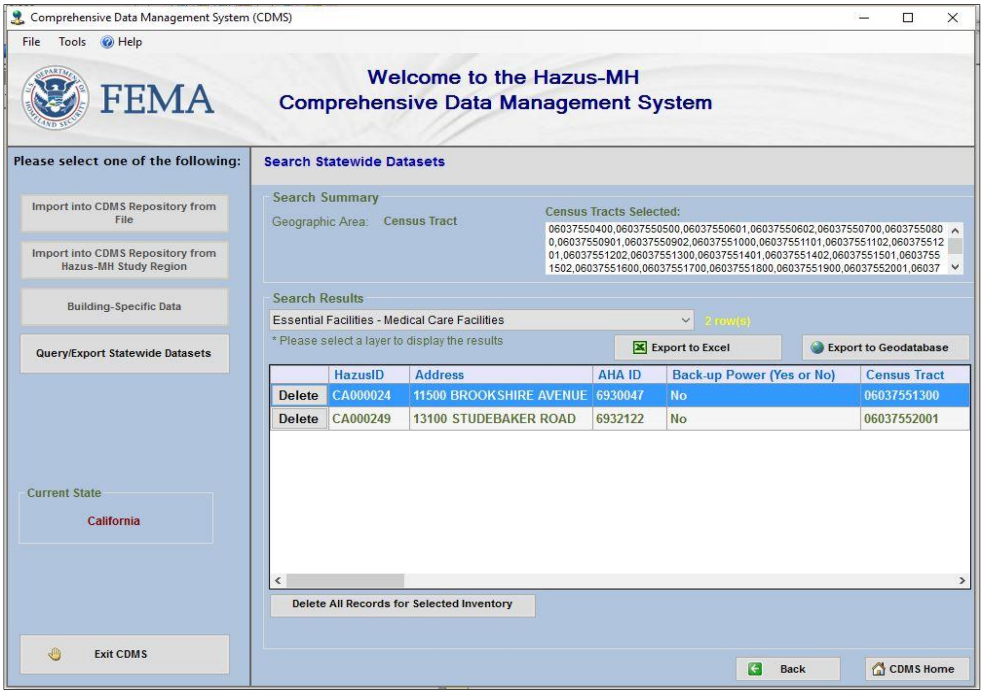

Figure 14: Default Medical Care Facilities (Source: CDMS)

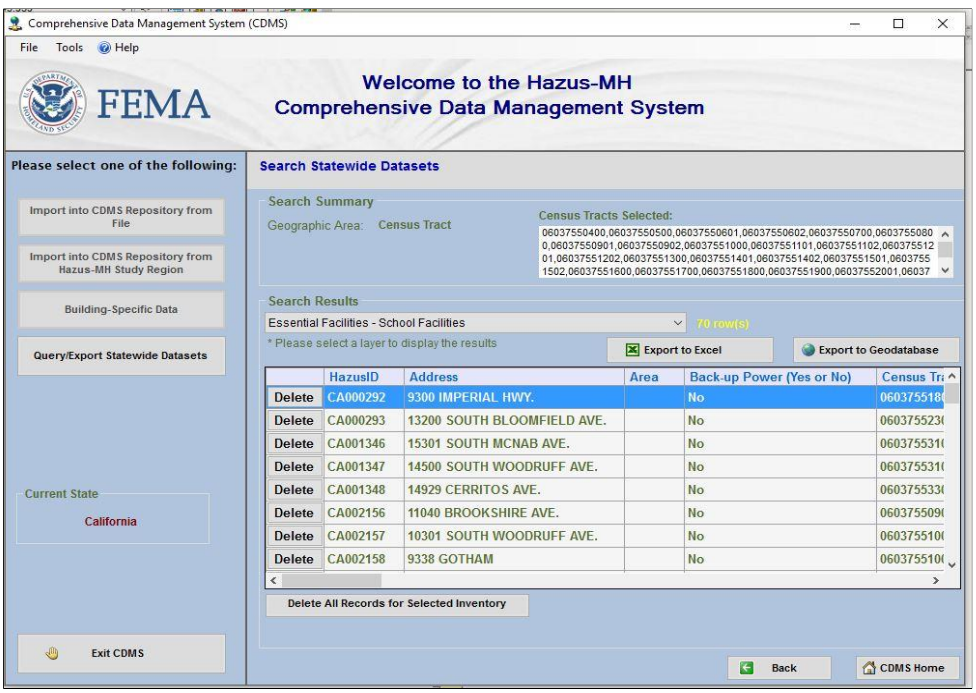

Figure 15: Default School Facilities (Source: CDMS)

3.1.3.2. Upgraded Essential Facilities Data for use in HAZUS

The EF dataset was updated to increase accuracy with the city's data acquired from the City of Downey's Water Work Department. The data was ingested into the CDMS repository and then transferred into the study area dataset (David Adler and Eric Berman, 2003). There were an additional 41 Essential Facilities added to the dataset: 5 x Fire Station Facilities; 1 x Police Stations Facilities; 15 x Emergency Operations Center/Medical Care Facilities; and 20 x Public and Private Schools (see Figure 16).

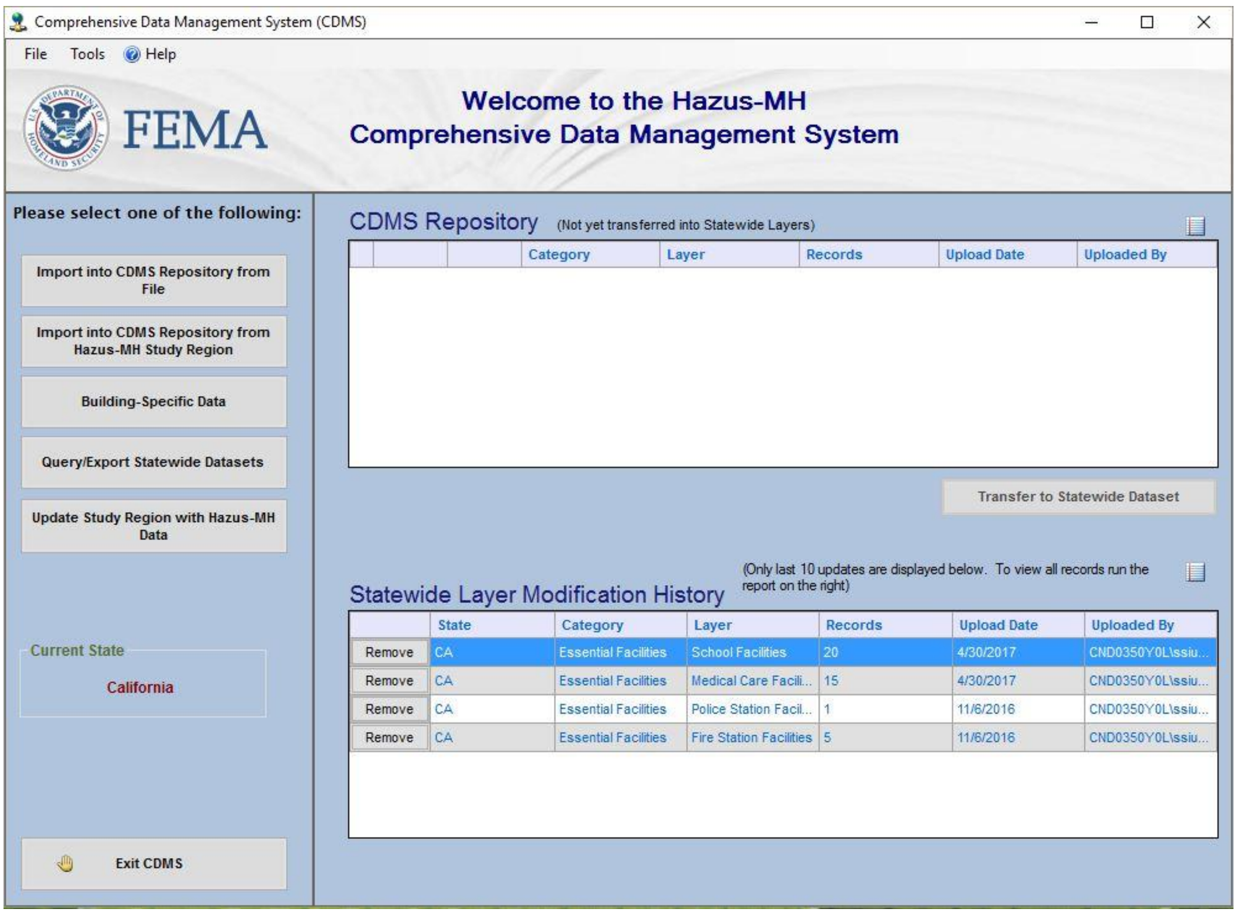

Figure 16: Updated Essential Facilities Data (Source: CDMS)

3.1.3.3. USGS ShakeMaps

The ShakeMaps were obtained from the U.S. Geological Survey (USGS). The maps facilitate communication of earthquake information beyond just magnitude and location. By rapidly mapping out earthquake ground motions, ShakeMaps portray the distribution and severity of shaking.

ShakeMap soil types are based on the National Earthquake Hazards Reduction Program (NEHRP), which define five soil types (USGS, 2016). In HAZUS, the default classified soil type is type D, which includes some Quaternary muds, sands, gravels, silts, and mud. A significant amplification of shaking by these soils is generally expected

This information is critical for gauging the extent of the areas affected, determining which areas are potentially hardest hit, and allowing for rapid estimation of losses. The ShakeMaps take advantage of any high-quality recorded ground motions and any available macro seismic intensity data to provide ground-truth constraints on shaking. Thus, ShakeMaps portray the best possible description of shaking by employing a combination of recorded and estimated shaking values (Worden & Wald, 2016). The ShakeMaps (from both Puente Hills and Whittier) were imported into HAZUS via the Data Map tool to enhance the area (see Figure 17).

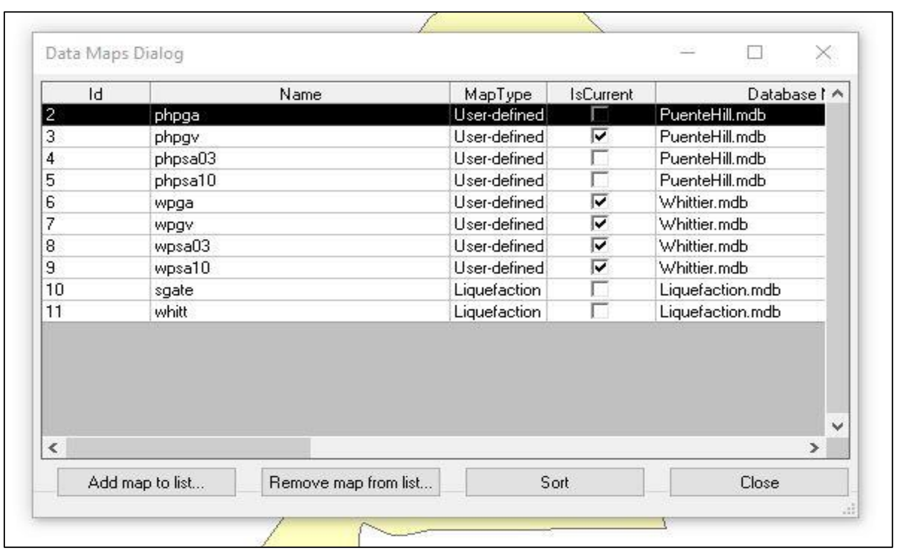

Figure 17: ShakeMaps ingested into HAZUS

3.2 Methodology

The City of Downey earthquake risk assessments were conducted using HAZUS (FEMA F. E., 2009). HAZUS study regions for Downey was created by extracting the census tracts designated for City of Downey (FEMA, Earthquake Model , 2010). The data provided by the City of Downey's Public Works Office was ingested into CDMS to enhance the essential facilities database and improve general building stock data (Downeyca, 2009). The USGS ShakeMap was converted to HAZUS compatible geodatabase format so it could be incorporated into HAZUS as "user supplied hazard" data for scenario analysis. For information on how this is done, see Appendix J of the technical manual (FEMA, HAZUS-MH Overview, 2016). All analyses were conducted utilizing default damage functions, default restoration functions, and default parameter settings (see Figure 18).

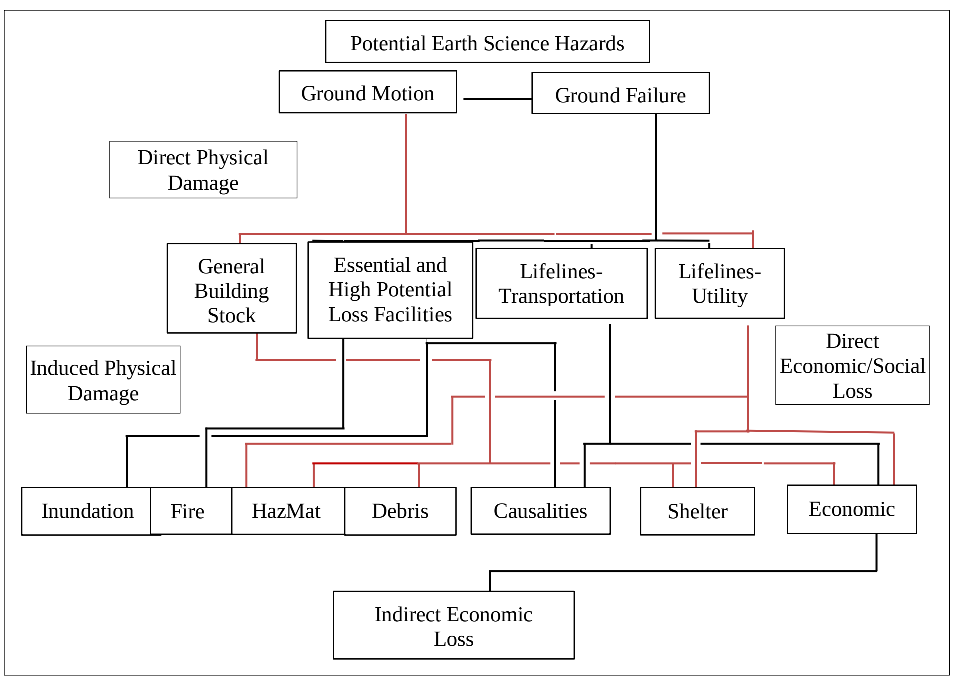

Figure 18: Flow of Methodology

For completeness, the HAZUS analysis modules for transportation and utility systems were included in the analyses. However, these assessments used existing HAZUS default data. HAZUS results from these modules are not included in this report.

3.2.1. Earthquake Scenario Selection Process

Two earthquake scenarios were selected for the risk assessment by the City of Downey - Office of Emergency Management. The office emergency manager selected earthquakes with a magnitude of M6.8 and M7.0 for the two faults. The Whitter and Puente Hills faults were selected for the scenarios.

3.2.2. Whittier Earthquake Scenario 1:

The Whittier Fault is a fault located in eastern Los Angeles County. It is one of the two upper branches of the Elsinore Fault Zone; the Chino Fault is the second. The Whittier Fault is a 40 km (25 mile) right-lateral strike-slip fault that runs along the Chino Hills range between the cities of Chino Hills and Whittier. A strike-slip fault is a fault that moves laterally, or side to side (see Figure 18).

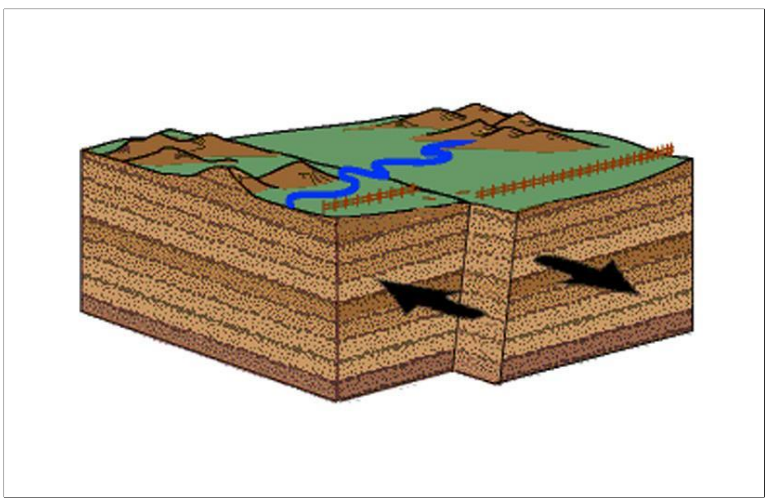

Figure 18: Strike-slip fault (Source: USGS)

The fault has a slip rate of 2.5 to 3.0 millimeters (0.098 to 0.118 in) per year. It is estimated that this fault could generate a quake of MW6.0–7.2 on the moment magnitude scale. For that reason, the USGS

Scenario ShakeMap for M6.8 earthquakes on the Whittier Fault was chosen to simulate ground motion for the scenario (see Figure 19).

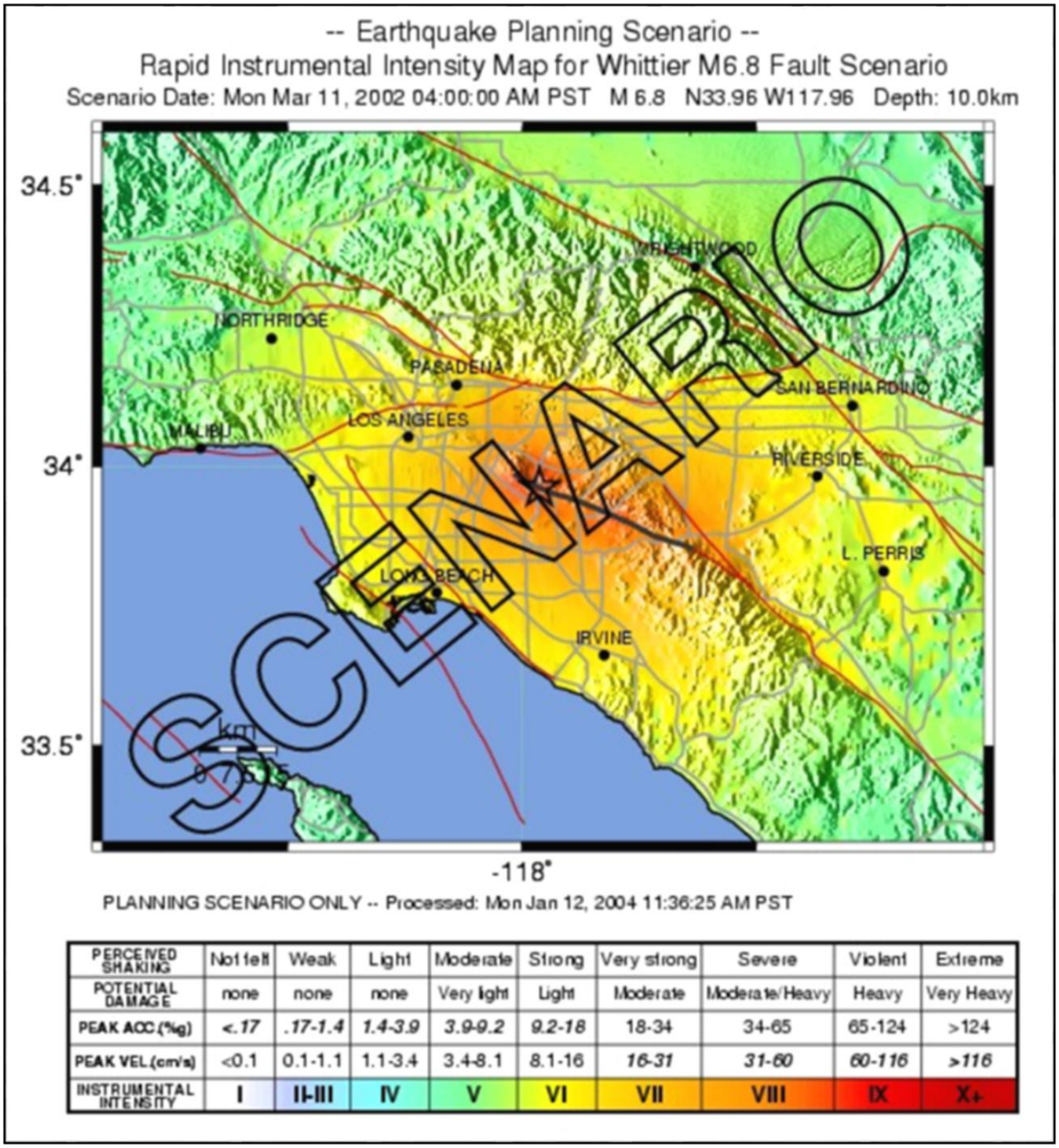

Figure 19: USGS ShakeMap of Whittier fault (Source: USGS)

3.2.3. Puente Hills Earthquake Scenario 2:

The Puente Hills fault is a fault located in the Los Angeles Basin and discovered in 1999. The thrust fault runs about 40 km (25 mile) in three sections from the Puente Hills region in the southeast to the south of Griffith Park in the northwest. A thrust fault is a break in the Earth's crust across which there has been relative movement, in which rocks of lower stratigraphic position are pushed up and over higher strata. Thrust faults are the result of compressional forces (see Figure 20).

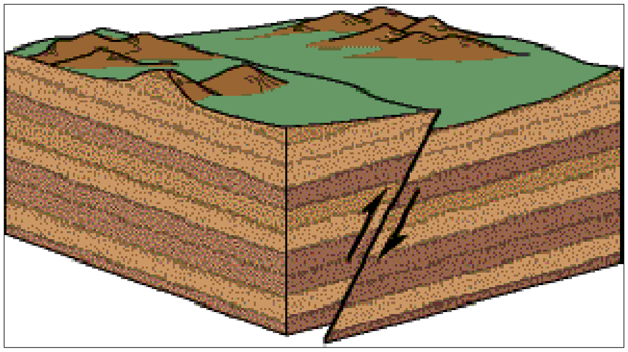

Figure 20: Thrust Fault (Source: USGS)

Large earthquakes on the fault are relatively infrequent, but computer modeling has indicated that a major event could have a substantial impact in the Los Angeles area. This fault is believed to be responsible for the moderate Whittier Narrows earthquake in 1987 that caused considerable damage and deaths, as well as another light event that took place in 2010. For this reason, the USGS Scenario ShakeMap for a M7.0 earthquake on the Puente Hills fault was chosen to simulate ground motion for the scenario (see Figure 21).

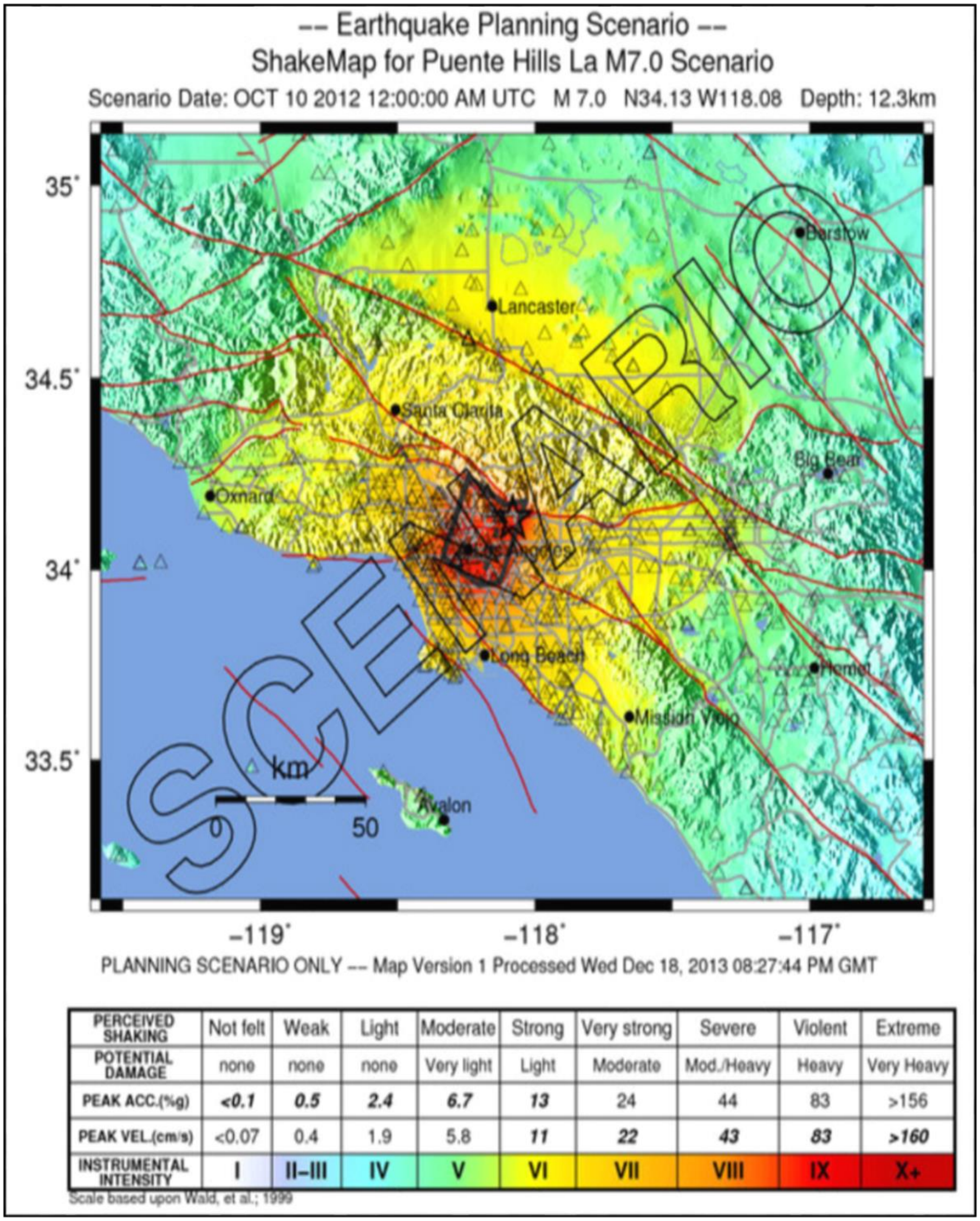

Figure 21: USGS ShakeMap of Puente Hills (Source: USGS)

3.3 Summary

HAZUS, which runs on the ArcGIS platform along with CDMS, was used to ingest updated data, model the earthquakes, and create output maps. Essential Facilities data was updated via data provided by the City of Downey Water Work Department into the CDMS. Detailed soil, liquefaction, and ShakeMaps were ingested via the Data tool into HAZUS.   Based on the updated data, two earthquake scenarios were run in the earthquake model. The results are discussed in the next chapter. These results are then used to make recommendations for future proactive planning in preparation for possible earthquake events. The conclusions and recommendations are provided in Chapter 5.

Chapter 4 Results

HAZUS is one of several earthquake damage prediction algorithms & software. These systems model ground motion (or ground failure), provide advanced engineering model outputs, show inundation from dams and exposure related to that inundation, track fire following earthquakes, and provide reports of estimated casualties as a result of earthquake events. Others used by experts include USGS or SCEC, however not freely available like HAZUS. They all produce similar outputs which include reports, tables, and a number of maps.

HAZUS scenarios were run to estimate damage due to earthquakes occurring on both the Puente Hills and the Wittier faults, as described in detail in Chapter 3. A comparison of the results indicates that the Puente Hills M7.0 earthquake would have a greater impact on the City of Downey area than the Whittier M6.8 earthquake. The Puente Hills fault is a thrust fault located near and within the city limits and the estimated magnitude is slightly higher, while the Whittier fault is a strike-slip fault located approximately 5 miles from the City's boundaries. Thrust faults are routinely considered to be more destructive than strike-slip faults.

4.1 Puente Hills Scenario Results

4.1.1. Building Damage

The HAZUS earthquake model calculates direct physical damages. These include damages to both structural and nonstructural building components reported as damage state probability, counts, and losses. This section reports on the damages estimated in the HAZUS earthquake scenarios run as part of this thesis work. Additional highly detailed explanations about the program outputs are provided in the HAZUS-MH technical manuals. For example, a generalized description of the conditions that would exist for each building type based on its damaged state are found in the technical manuals. The in-depth explanations provided in the technical manuals can be freely accessed online from the HAZUS website, and could assist the decision makers and others in effectively making better earthquake preparation plans for their communities (David Adler and Eric Berman 2003).

For the Puente Hills scenario, HAZUS estimated that about 3,244 buildings would be at least moderately damaged. This is over 13.00 % of the buildings in the region. An estimated 104 buildings would be damaged beyond repair. About 1700 single-family homes are estimated to suffer moderate damage, 174 Other Residential buildings which include mobile home, multi family dwelling, temporary lodging, and institutional dormitory, and nursing home are estimated to suffer extensive to complete, while damage to commercial structure would dominate (see Table 4).

Table 4: Estimated Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	7	0.07	10	0.07	6	0.23	3	0.55	1	0.97
Commercial	314	3.35	483	3.67	487	18.33	214	43.94	53	51.03
Education	18	0.19	20	0.15	11	0.41	4	0.89	1	0.87
Government	8	0.08	9	0.07	7	0.27	4	0.79	1	1.00
Industrial	63	0.67	105	0.80	120	4.53	58	11.82	16	15.67
Other Residential	472	5.04	637	4.84	308	11.61	174	35.66	27	26.24
Religion	31	0.34	43	0.33	32	1.21	15	3.15	4	4.19
Single Family	8,459	90.26	11,859	90.08	1,683	63.40	16	3.20	0	0.02
Total	**9,372**		**13,165**		**2,654**		**487**		**104**	

Based on the building, about 1800 wood buildings are estimated to suffer moderate damage. Steel, concrete and manufactured housing (MH) buildings would possibly experience extensive and complete damage (see Table 5).

Table 5: Estimated Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	8,900	94.97	12516	95	1,794	67.58	41	8.49	5	4.57
Steel	51	0.55	97	0.7	191	7.21	104	21.36	24	23.18
Concrete	97	1.04	149	1.1	113	4.27	61	12.47	21	20.52
Precast	62	0.66	123	0.9	156	5.87	49	10.14	13	12.25
RM*	246	2.63	227	1.7	194	7.30	69	14.19	14	13.37
URM*	14	0.15	36	0.2	53	1.98	25	5.19	7	6.88
MH*	1	1	17	0.1	153	5.78	137	28.15	20	19.23
Total	9,372		13,165		2,654		487		104	

*Reinforced Masonry (RM), Unreinforced Masonry (URM), and Manufactured Housing (MH)

Building damage can be described in terms of the nature and extent of damage exhibited by its components (beams, columns, walls, ceilings, piping, HVAC equipment, etc.). Damage is described by five damage states: none, slight, moderate, extensive or complete: None – No Damage; Slight - Small plaster or gypsum board cracks at corners of door and window openings and wall, ceiling intersections, and small cracks in masonry chimneys and masonry veneer; Moderate - Large plaster or gypsum-board cracks at corners of door and window openings, small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels, large cracks in brick chimneys, toppling of tall masonry chimneys; Extensive - Large diagonal cracks across shear wall panels or large cracks at plywood joints, permanent lateral movement of floors and roof, toppling of most brick chimneys, cracks in foundations, splitting of wood sill plates and/or slippage of structure over foundations, partial collapse of room-over-garage or other soft-story configurations, small foundations cracks; Complete - Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or the failure of the lateral load resisting system, some structures may slip and fall off the foundations, large foundation cracks (David Adler and Eric Berman, 2003).

4.1.2. Essential Facilities Damage

Before the earthquake, the region had 222 hospital beds available for use. On the day of the predicted earthquake, the model estimates that only eight hospital beds (4%) would be available for use by patients already in the hospital and those injured by the earthquake. After one week, 8% of the beds are estimated to be back in service. By 30 days, 31% are estimated to be operational (see Table 6).

Table 6: Estimated Damage to Essential Facilities

Classification	Total	# Facilities		
		At Least Moderate Damage> 50%	Complete Damage> 50%	With Functionality > 50% on day 1
Hospitals	19	18	0	1
Schools	86	0	0	27
EOCs	0	0	0	0
PoliceStations	1	0	0	0
FireStations	5	0	0	1

Essential facility outputs include restoration time to 100 percent functionality. The damage state shown in Table 6 reflects schools suffering moderate or greater damage, estimated facility damage based upon the number of facilities that may experience greater than 50 percent likelihood of at least moderate damage, complete damage, and various states of functionality. In contrast to the general building stock, where damage probabilities are calculated for groups of buildings, for essential facilities the damage probabilities are estimated for each individual facility. As with the general building stock, the damage states are none, slight, moderate, extensive and complete. Both structural and nonstructural damage is considered. Damage state probabilities are estimated for health care facilities, police and fire stations, emergency operation centers and schools. In addition, loss of beds and facility functionality are computed as a function of time for health care facilities. In this context, functionality is defined as the range of which the facility can operate. Figures 22-27 provide estimates of the peak ground velocity

(PGV) experienced by the essential facilities examined in the study. The higher the velocity, the higher the degree of shaking experienced. For example, essential facilitates such as fire stations located closer to the fault line experience a greater degree of ground shaking and, thus, more damage (Figure 22). These included fire stations 3 and 4. Only fire station 1 experienced minor shaking, however, fire stations 2 and 5 still suffered damage. The types of soil the buildings were built on may not have an influence as to the degree of damage, given that all the soil types in the City of Downey are susceptible to earthquake activity.

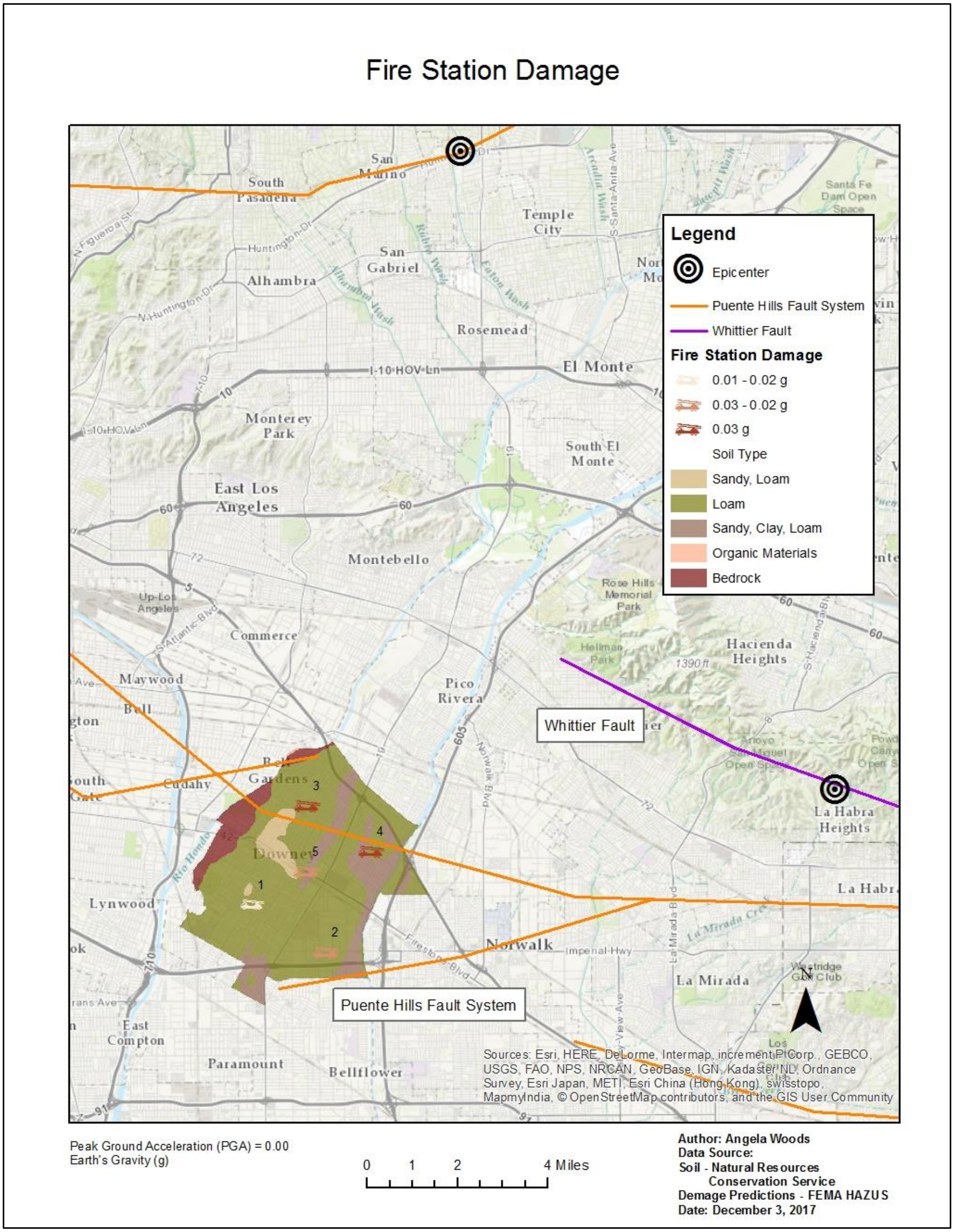

Figure 22: Estimated Moderate Damage to Fire Stations

Table 7: Fire Station of the City of Downey

Fire Station				
Name	Address	City	State	Zip code
Downey Fire Department - Station 1	12222 Paramount Blvd.	Downey	CA	90242
Downey Fire Department - Station 2	9556 Imperial Highway	Downey	CA	90242
Downey Fire Department - Station 3	9900 Paramount Blvd.	Downey	CA	90240
Downey Fire Department - Station 4	9349 Florence Ave.	Downey	CA	90240
Downey Fire Department - Station 5	11111 Brookshire Ave	Downey	CA	90241

The fire stations 3 and 4 are located closest to the fault line and should be considered first for retrofitting. Fire station 1 should be considered last; it sustained the least amount of damage (see Table 7).

Medical facilities numbered 1, 4, 7, 13 and 15 located closer to the fault line experience a greater degree of ground shaking and, thus, more damage (Figure 23). Medical facilities numbered 8 and 9 suffered the least amount of damage. The types of soil the buildings were built on may not have an influence as to the degree of damage, given that all the soil types in the City of Downey are susceptible to earthquake activity.

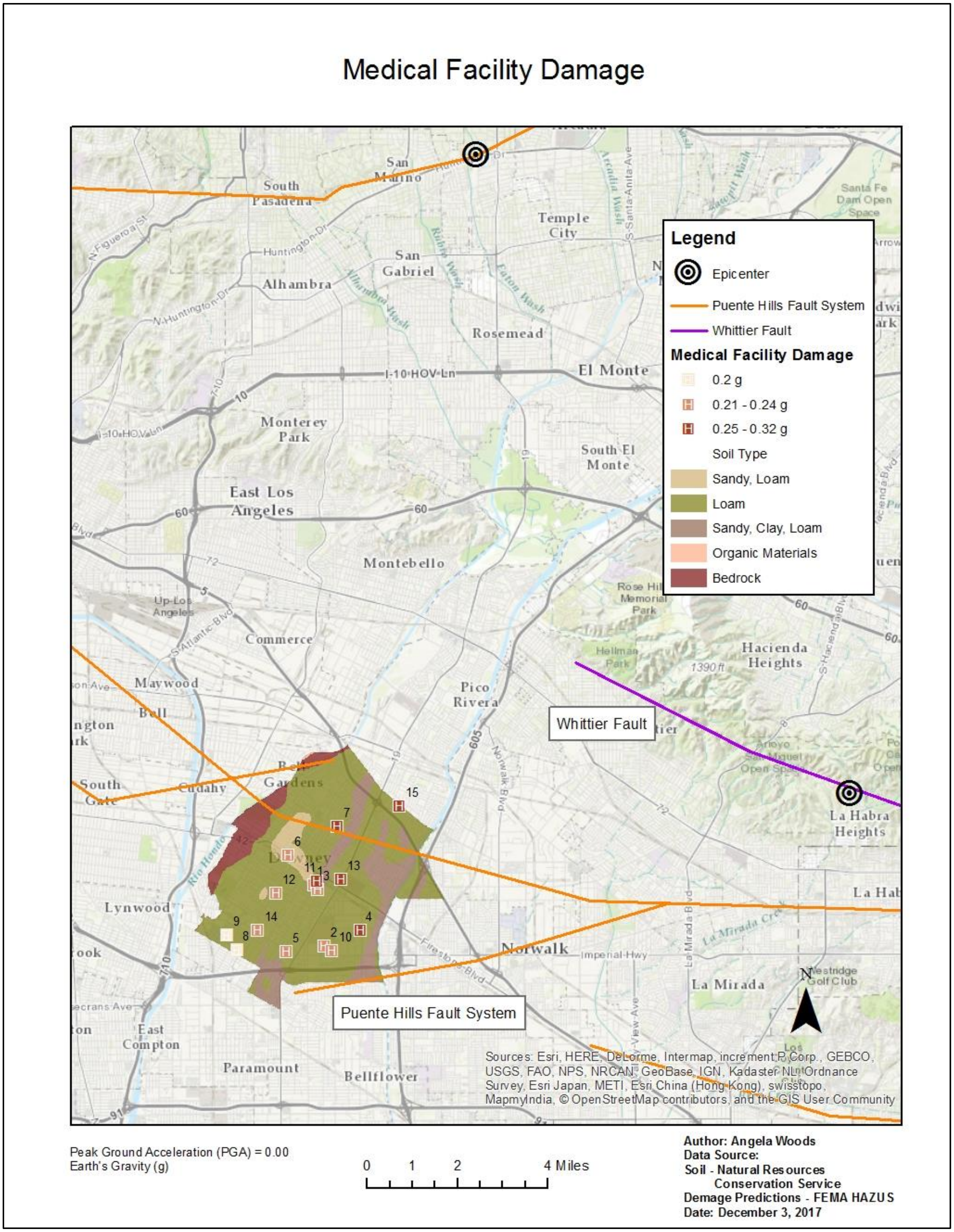

Figure 23: Estimated Moderate Damage to Medical Facilities

Table 8: Medical Facilities in the City of Downey

Medical Facility					
ID	Name	Address	City	State	Zip
1	Downey Regional Medical Center	11525 Brookshire Ave	Downey	CA	90241
2	Kaiser Permanente Medical Center	9333 Imperial Highway	Downey	CA	90242
3	PIH Health Hospital	11500 Brookshire Ave.	Downey	CA	90241
4	Downey Family Health Care Center	12113 Woodruff Ave	Downey	CA	90241
5	Prima Vida Medical Clinic	8706 Imperial Highway	Downey	CA	90242
6	Santo Tomas Medical Clinic	7862 Firestone Blvd	Downey	CA	90241
7	Talbert Medical	8311 Florence Ave	Downey	CA	90240
8	Downey Care Center	13007 Paramount Blvd	Downey	CA	90242
9	Rancho Faculty Medical	12841 Dahlia Ave	Downey	CA	90239
10	Kaiser Downey Urgent Care	9449 Imperial Hwy	Downey	CA	90242
11	Pioneer Medical Group	11411 Brookshire Ave	Downey	CA	90241
12	AME Medical Group - Urgent Care	11942 Paramount Blvd	Downey	CA	90242
13	Downey Urgent Care	11003 Lakewood Blvd	Downey	CA	90241
14	Life Medical Home Care Services	8051 Imperial Hwy	Downey	CA	90242
15	Brookfield Healthcare Center	9300 Telegraph Rd	Downey	CA	90240

Medical facilities numbered 1, 4, 7, 13 and 15 were the closest to the fault line and suffered the most damage; therefore, those facilities should be considered first for retrofitting. Medical facilities numbered 8 and 9 should be considered last for retrofitting because they suffered the least amount of damage (see Table 8).

Schools located closer to the fault line experience a greater degree of ground shaking, thus more damage. These include schools numbered 7, 8, 10, 11, 15, and 17. Schools 1, 2, 4, 5, 9 and 20 experience minor shaking but still suffered damage (Figure 24). The types of soil the buildings were built on may not have an influence as to the degree of damage, given that all the soil types in the City of Downey are susceptible to earthquake activity.

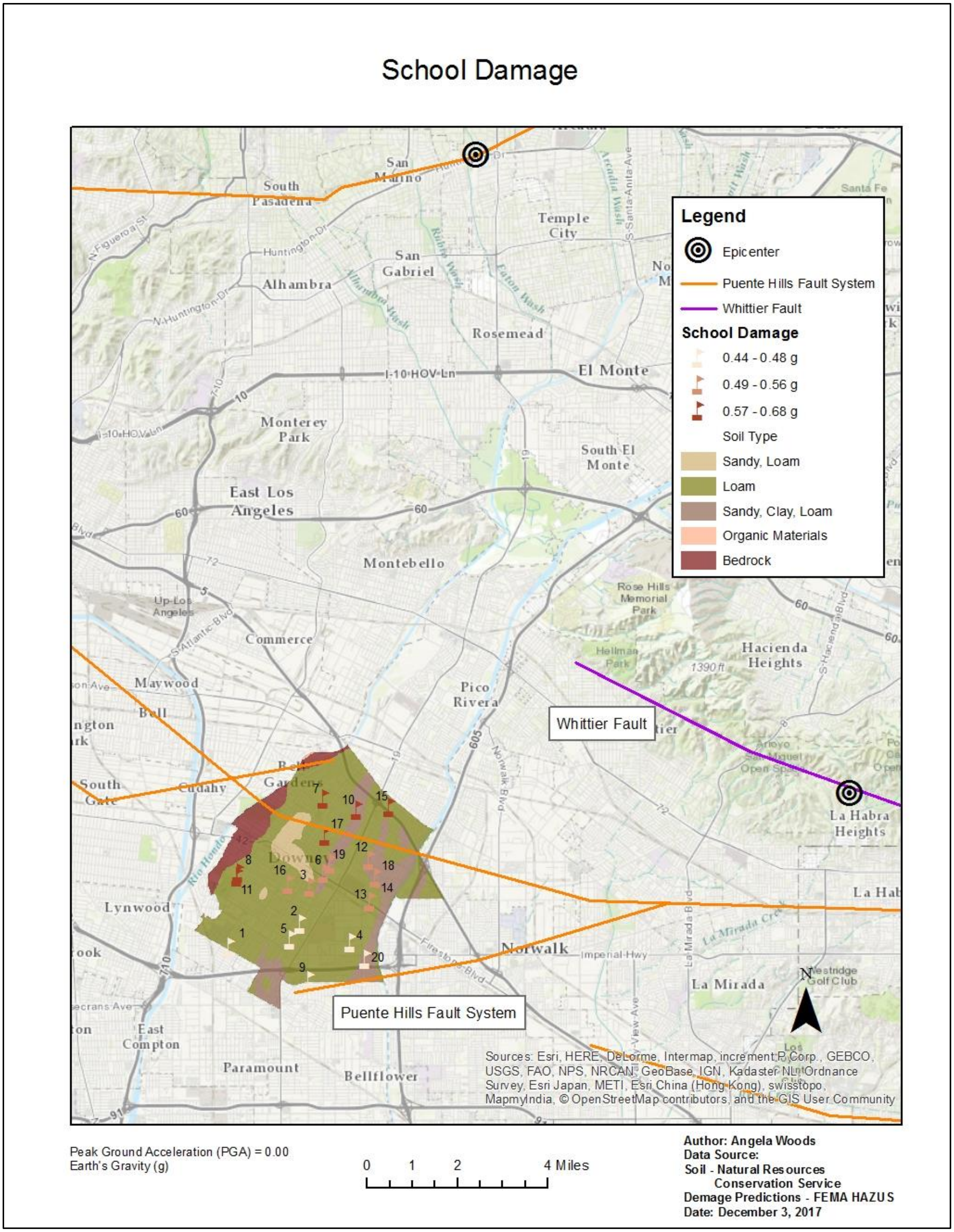

Figure 24: Estimated Moderate Damage to School Facilities

Table 9: Schools in the City of Downey

Schools					
ID	Name	Address	City	State	Zip
1	St. Pius X - St. Matthias Academy	7851 Gardendale St	Downey	CA	90242
2	Alameda Elementary School	8613 Alameda St	Downey	CA	90242
3	Downey Unified School District	11627 Brookshire Ave	Downey	CA	90241
4	A L Gauldin Elementary School	9724 Spry St	Downey	CA	90242
5	Sussman Middle School	12500 Birchdale Ave	Downey	CA	90242
6	Downey High School	11040 Brookshire Ave	Downey	CA	90241
7	Griffiths Middle School	9633 Tweedy Ln	Downey	CA	90240
8	Stauffer Middle School	11985 Old River School Rd	Downey	CA	90242
9	Carpenter Elementary School	9439 Foster Rd	Downey	CA	90241
10	Gallatin Elementary School	9513 Brookshire Ave	Downey	CA	90240
11	Old River Elementary School	11995 Old River School Rd	Downey	CA	90242
12	Doty Middle School	10301 Woodruff Ave	Downey	CA	90241
13	Kirkwood Christian Schools	11115 Pangborn Ave	Downey	CA	90241
14	St Raymond School	12320 Paramount Blvd	Downey	CA	90242
15	Unsworth Elementary School	9001 Lindsey Ave	Downey	CA	90240
16	Warren High School	8141 De Palma St	Downey	CA	90241
17	Our Lady of Perpetual Help School	10441 Downey Ave	Downey	CA	90241
18	Rio San Gabriel Elementary	9338 Gotham St	Downey	CA	90241
19	Kirkwood Christian Schools	10822 Brookshire Ave	Downey	CA	90241
20	Calvary Chapel Christian School	12808 Woodruff Ave	Downey	CA	90242

The schools closest to the fault line and suffered the most damage should be considered first for retrofitting. These include schools numbered 7, 8, 10, 11, 15, and 17.   Schools 1, 2, 4, 5, 9 and 20 suffered minor damage and should be retrofitted last (see Table 9).

The Downey Police Department is estimated to experience ground shaking and, thus, causing extensive damaged (Figure 25). This is to be expected given the station’s foundation is built on sand, clay and loam which are all susceptible to earthquake activity. The police station should be considered in the group of the first to be retrofitted.

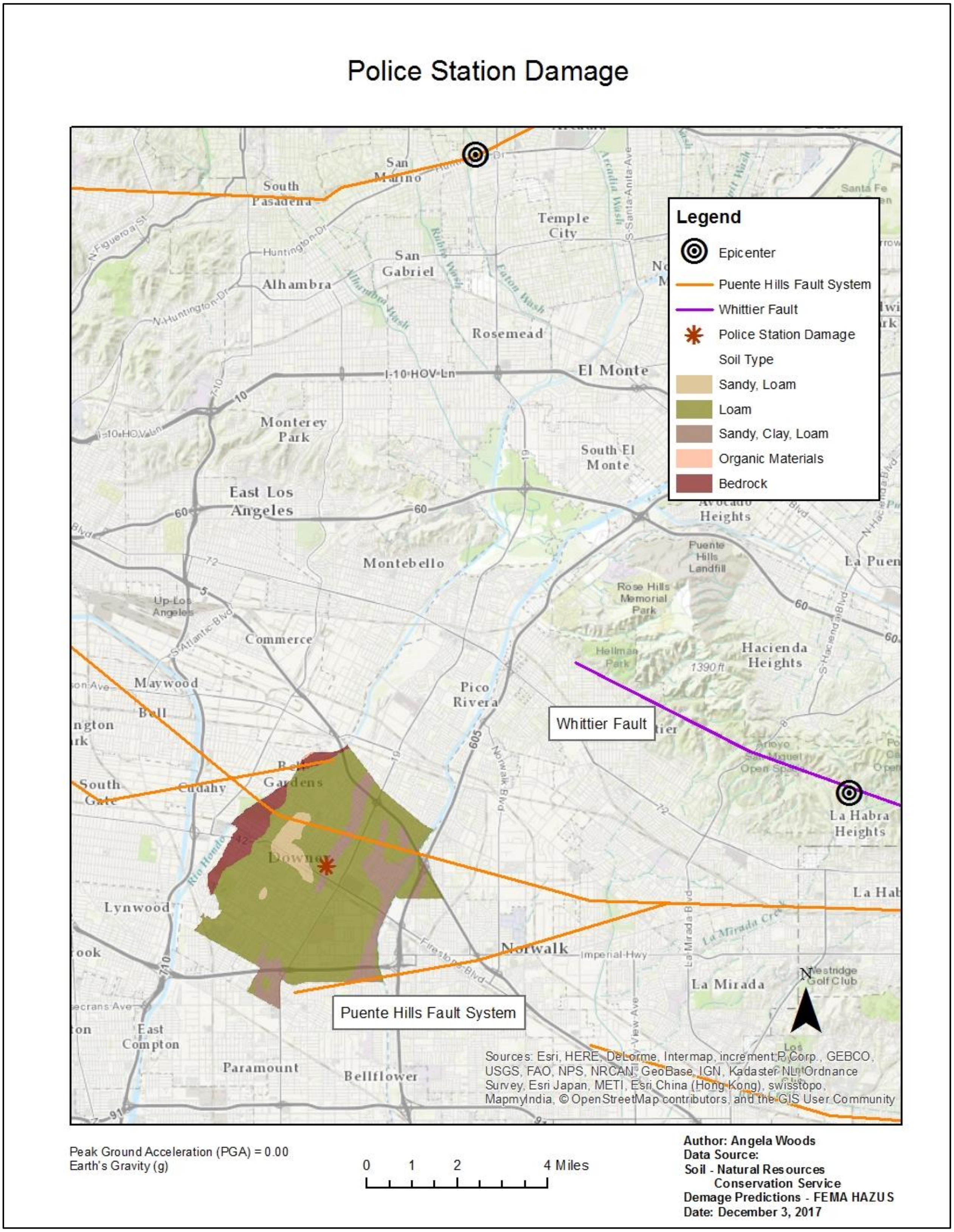

Figure 25: Estimated Moderate Damage to Police Station

4.1.3. Debris Generation

HAZUS estimates the amount of debris that will be generated by a given earthquake. The model breaks the debris into two general categories: (1) wood and masonry structures and (2) estimates of steel and concrete debris. This information is provided in order to recognize that different types of debris requires different types of material handling equipment and, thus, different post-disaster response actions.

The model estimates that 0.16 million tons of debris will be generated as a result of the Puente Hills event. Of the total amount, brick or wood comprises 29% of the total with the remainder being reinforced concrete or steel. If the debris tonnage is converted into an estimated number of truckloads, it will require 6,440 truckloads, assuming at 25 tons/truck, to remove the debris generated by the earthquake.

4.1.4. Post-Disaster Shelter Requirements

HAZUS estimates a percentage of households that are expected to be displaced from their homes due to a particular earthquake and the number of displaced people that will require accommodations in temporary public shelters (Figure 26).

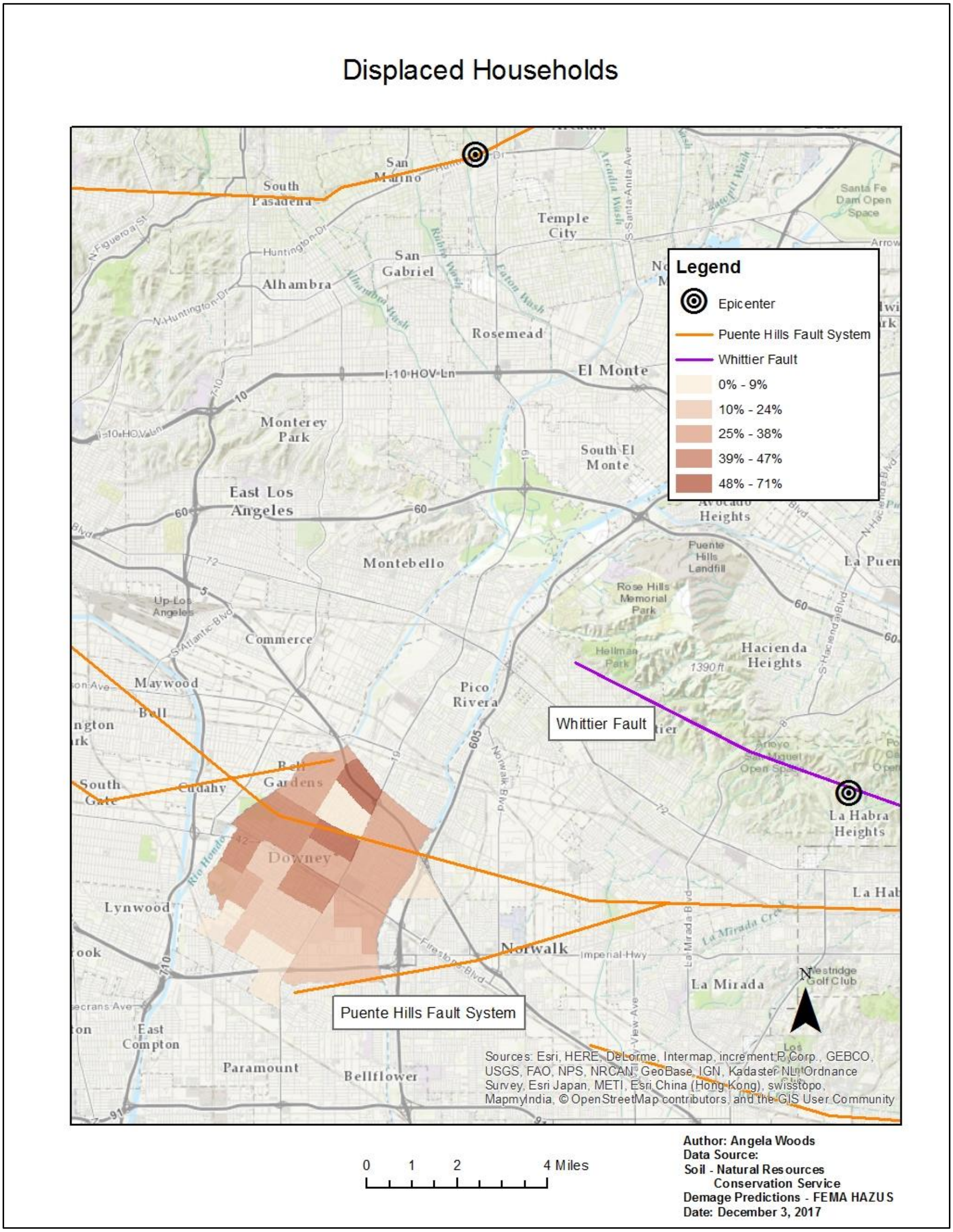

Figure 26: Displaced Households

The model estimates 602 households to be displaced due to the predicted earthquake. Of these, 499 people (out of a total population of 111,772) will seek temporary shelter in public shelters.

4.1.5. Casualties

HAZUS estimates the number of people that will be injured and killed by a given earthquake (David Adler and Eric Berman, 2003). The casualties are broken down into four severity levels that describe the extent of the injuries. The levels are defined as follows:

(1) Severity Level 1: Injuries will require medical attention, but hospitalization is not needed.

(2) Severity Level 2: Injuries will require hospitalization but are not considered life-threatening.

(3) Severity Level 3: Injuries will require hospitalization and can become life-threatening if not promptly treated.

(4) Severity Level 4: Victims are killed by the earthquake.

The casualty estimates are provided for three times of day: 2:00 AM, 2:00 PM and 5:00 PM. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum. The 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum. The 5:00 PM represents peak commute time (see Table 10). The greatest casualties in one single area occurred in the commercial area with the exception of the 2:00 AM timeframe. The total amount at all levels is 270 with the major at level 1 at 201. The greatest casualties in all areas at all levels is 464 with the major at level 1 at 348. These casualties include areas in commercial, commuting, educational, hotels, industrial, other residential, and single family during the 2:00 PM timeframe.

Table 10: Casualty Estimates According to Severity Levels

		Level 1	Level 2	Level 3	Level 4
2AM	Commercial	3	1	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	0	0	0	0
	Industrial	6	1	0	0
	Other-Residential	54	11	2	3
	Single Family	38	2	0	0
	Total	101	15	2	3
2PM	Commercial	201	48	7	14
	Commuting	0	0	1	0
	Educational	88	21	3	6
	Hotels	0	0	0	0
	Industrial	41	9	1	2
	Other-Residential	11	2	0	1
	Single Family	8	1	0	0
	Total	348	81	12	23
5PM	Commercial	142	33	5	10
	Commuting	6	7	13	2
	Educational	10	2	0	1
	Hotels	0	0	0	0
	Industrial	26	6	1	2
	Other-Residential	21	4	1	1
	Single Family	14	1	0	0
	Total	219	53	20	16

4.1.6. Economic Loss

The HAZUS earthquake model can generate a great deal of information about the economic impacts of an earthquake on a community (David Adler and Eric Berman, 2003). Direct economic losses include building losses reported for the general building stock. This is information about buildings aggregated to the census tract level and can be reported for both structural and nonstructural building components, the contents of those buildings (such as furnishings), and business inventory in structures (such as commercial facilities).

Finally, the HAZUS earthquake model can also calculate business interruption impacts. These can include wage and income losses, rental and relocation costs, and business cost. Business costs are defined as repair and replacement cost, contents and business inventory damages. HAZUS can additionally generate lifeline estimates, reported in terms of the cost of repairs to lifelines. Lifelines are defined as the transportation and utility systems. These systems include highways, railways, light rails, bus, ports, airports, ferries, electric, gas, potable water, wastewater, oil and communication. The estimates are based on the following considerations:

- For components of the 13 lifeline systems: damage probabilities, cost of repair or replacement and estimated functionality for various times following earthquake
- For all pipeline systems: the estimated number of leaks and breaks
- For potable water and electric power systems: estimate of service outages

This information provides calculations of economic impacts to transportation networks and utility networks that are considered lifelines within the earthquake model. These vital components of a community are necessary to be available to the community in order for that community to return to its economic status of that prior to the earthquake.

The HAZUS earthquake model can also calculate indirect economic losses. These longer-term impacts are vital to helping community planners understand what is going to be needed in order to bring a community back to its former state, or at least a state that has improved beyond the conditions that exist following the earthquake hazard. The total economic loss estimated for a Puente Hills M7.0 earthquake is 800 million dollars, which includes building and lifeline-related losses, as well as the indirect economic losses based on the region's available inventory (Figure 27). Census tracts 06037550800 and 06037550901 will suffer the highest total losses (as considered below):

Dollar losses associated with general building stock:

- Structural and nonstructural cost of repair or replacement
- Loss of contents
- Business inventory loss
- Relocation costs
- Business income loss
- Employee wage loss
- Loss of rental income

Lifeline – related losses:

- For components of the 13 lifeline systems: damage probabilities, cost of repair or replacement and estimated functionality for various times following earthquake
- For all pipeline systems: the estimated number of leaks and breaks
- For potable water and electric power systems: estimate of service outages

Indirect economic impact

- Long-term economic effects on the region based on a synthetic economy
- Long-term economic effects on the region

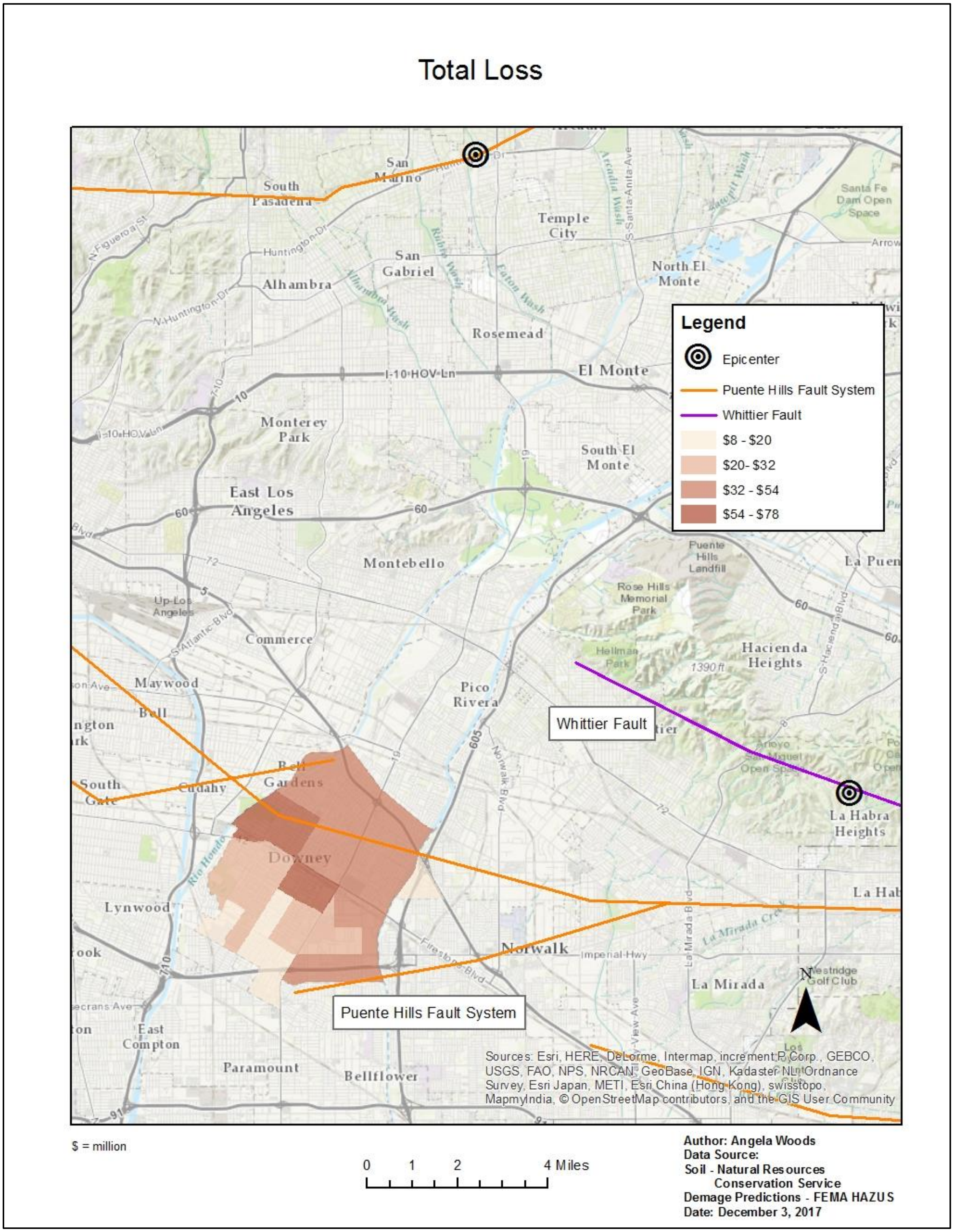

Figure 27: Total Economic Loss (US Million $)

4.2 Whittier Scenario Results

4.2.1. Building Damage

HAZUS estimates that about 960 buildings will be at least moderately damaged. This is over 4% of the buildings in the region. An estimated one building will be damaged beyond repair. Table 11 below summarizes the estimated damage by general occupancy for the buildings in the region. Table 12 below summarizes the estimated damage by general building type.

Table 11: Esitmated Building Damage by Occupancy

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	15,206	93	7642	91	407	45.06	1	2.53	0	0.92
Steel	216	1.31	145	1 7,	96	10.66	11	18.89	0	32.73
Concrete	227	1.38	144	1.71	64	7.04	7	12.90	0	13.44
Precast	175	1 07	136	1.61	82	9.09	9	15.76	0	9.57
RM	495	3.02	167	1.99	80	8.91	8	13.28	0	4.04
URM	48	0.30	52	0.62	31	3.42	3	5.93	0	10.45
MH	44	0.27	123	1.47	143	15.82	18	30.72	0	28.85
Total	16,412		8,409		903		57		1	

Table 12: Estimated Building Damage by Building Type (All Design Levels)

	None		Slight		Moderate		Extensive		Complete	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Agriculture	14	0.08	8	0.10	3	0.38	1	0.91	0	2.06
Commercial	799	4.87	496	5.89	233	25.82	23	40.42	0	38.57
Education	33	0.20	16	0.19	5	0.53	0	0.64	0	0.36
Government	18	0.11	8	0.09	3	0.37	0	0.61	0	0.59
Industrial	167	1.02	118	1.40	68	7.58	8	14.83	0	20.51
Other Residential	863	5.26	534	6.34	200	22.13	22	37.64	0	34.43
Religion	70	0.43	39	0.46	15	1.72	2	2.88	0	3.47
Single Family	14,448	88.03	7,192	85.53	374	41.47	1	2.06	0	0.00
Total	16,412		8,409		903		57		1	

*Note: Reinforced Masonry, URM Unreinforced Masonry, and MH Manufactured Housing

4.2.2. Essential Facilities Damage

Before the predicted earthquake, the region had 222 hospital beds available for use. On the day of the predicted earthquake, the model estimates that only 72 hospital beds (32%) would be available for use by patients already in the hospital and those injured by the earthquake. After one week, 64% of the beds would be back in service. By 30 days, 96% would be operational (see Table 13).

Table 13: Estimated Damage to Essential Facilities

Classification	Total	# Facilities		
		At Least Moderate Damage> 50%	Complete Damage> 50%	With Functionality > 50% on day 1
Hospitals	19	18	0	1
Schools	86	0	0	27
EOCs	0	0	0	0
PoliceStations	1	0	0	0
FireStations	5	0	0	1

Essential facility outputs include restoration time to 100 percent functionality; information expressed as damage state as shown in this example, which reflects schools suffering moderate or greater damages; and estimated facility damages based upon the number of facilities that are showing at least moderate damages greater than 50 percent likelihood, complete damages, and various states of functionality. Explanations for these estimates are also provided in the technical manuals. The peak ground acceleration experienced by essential facilities such that they experience moderate damage is shown in Figure 28 through 32.

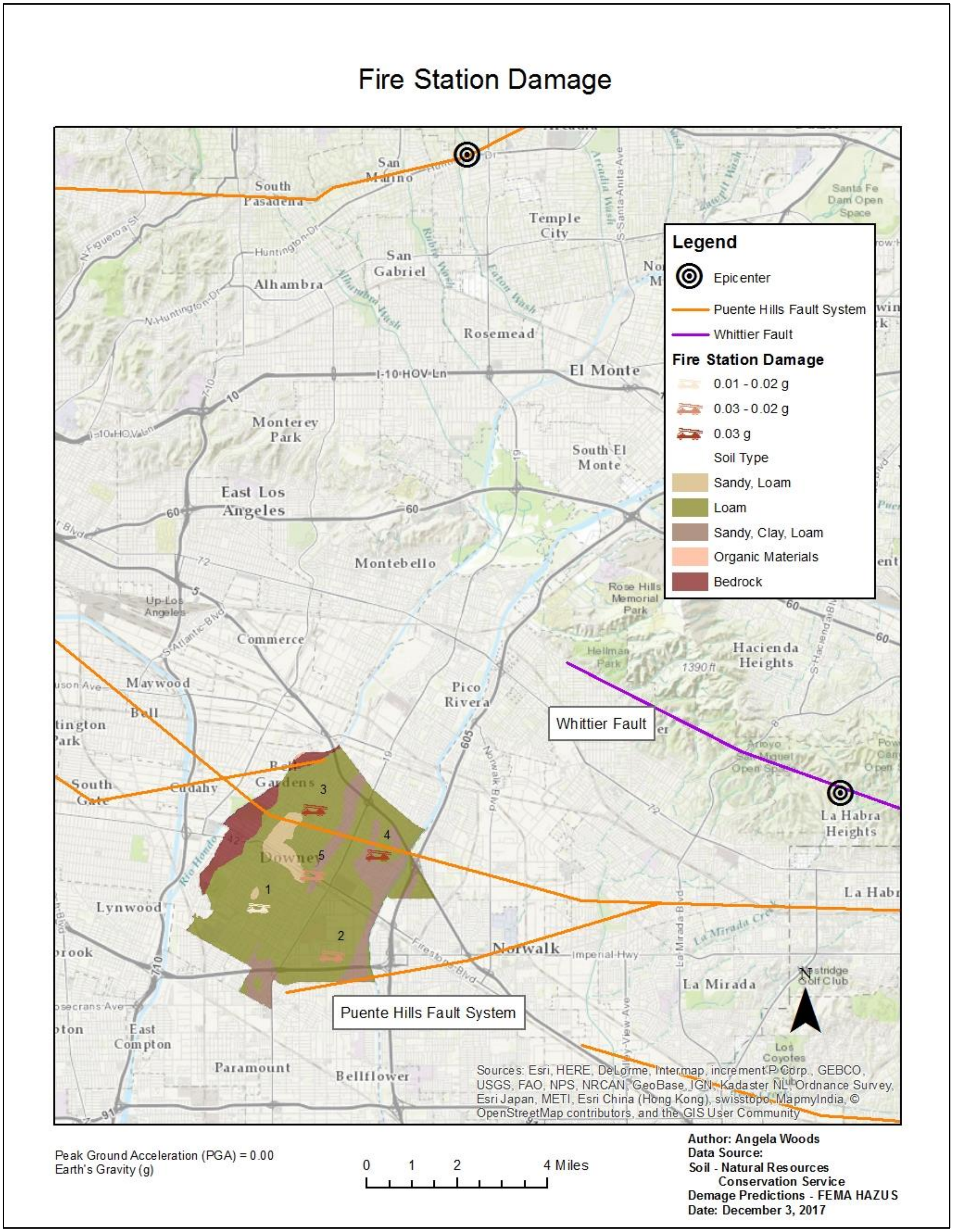

Figure 28: Estimated Moderate Damage to Fire Stations

As detailed earlier, the fault line is located north-east of the city. The fire stations located closest to the fault line experience a greater degree of ground shaking and, thus, more damage. These included fire stations 3 and 4. Only fire station 1 experienced minor shaking, however fire stations 2 and 5 still suffered damage (see Table 14). The types of soil the buildings were built on may not have an influence as to the degree of damage, given that all the soil types in the City of Downey are susceptible to earthquake activity. Only one facility experienced minor shaking, but still suffered damage.

Table 14: Fire Station of the City of Downey

Fire Station				
Name	Address	City	State	Zip code
Downey Fire Department - Station 1	12222 Paramount Blvd.	Downey	CA	90242
Downey Fire Department - Station 2	9556 Imperial Highway	Downey	CA	90242
Downey Fire Department - Station 3	9900 Paramount Blvd.	Downey	CA	90240
Downey Fire Department - Station 4	9349 Florence Ave.	Downey	CA	90240
Downey Fire Department - Station 5	11111 Brookshire Ave	Downey	CA	90241

The fire stations 3 and 4 are located closest to the fault line and should be considered first for retrofitting. Fire station 1 should be considered last as it sustained the least amount of damage.

Medical facilities located closer to the fault line experience a greater degree of ground shaking and, thus, more damage. The facility numbered 6, 7 and 15 were the closest to the fault line and suffered the most damage. Facilities numbered 3, 9, 11, 12, 13 and 14 suffered moderate damage (Figure 29). The types of soil the buildings were built on may not have an influence as to the degree of damage, given that all the soil types in the City of Downey are susceptible to earthquake activity.

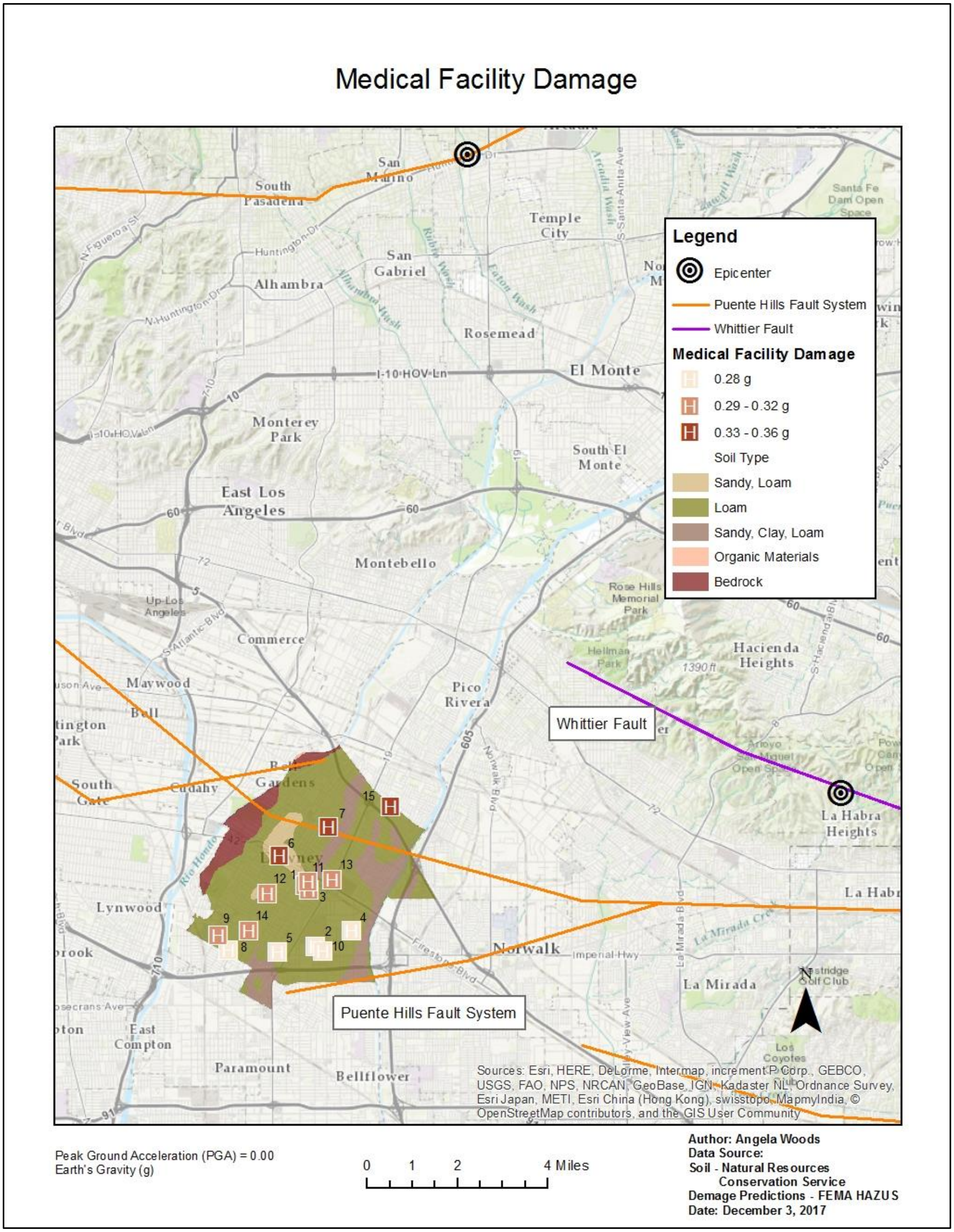

Figure 29: Estimated Moderate Damage to Medical Facilities

Table 15: Medical Facility of the City of Downey

Medical Facility					
ID	Name	Address	City	State	Zip
1	Downey Regional Medical Center	11525 Brookshire Ave	Downey	CA	90241
2	Kaiser Permanente Medical Center	9333 Imperial Highway	Downey	CA	90242
3	PIH Health Hospital	11500 Brookshire Ave.	Downey	CA	90241
4	Downey Family Health Care Center	12113 Woodruff Ave	Downey	CA	90241
5	Prima Vida Medical Clinic	8706 Imperial Highway	Downey	CA	90242
6	Santo Tomas Medical Clinic	7862 Firestone Blvd	Downey	CA	90241
7	Talbert Medical	8311 Florence Ave	Downey	CA	90240
8	Downey Care Center	13007 Paramount Blvd	Downey	CA	90242
9	Rancho Faculty Medical	12841 Dahlia Ave	Downey	CA	90239
10	Kaiser Downey Urgent Care	9449 Imperial Hwy	Downey	CA	90242
11	Pioneer Medical Group	11411 Brookshire Ave	Downey	CA	90241
12	AME Medical Group - Urgent Care	11942 Paramount Blvd	Downey	CA	90242
13	Downey Urgent Care	11003 Lakewood Blvd	Downey	CA	90241
14	Life Medical Home Care Services	8051 Imperial Hwy	Downey	CA	90242
15	Brookfield Healthcare Center	9300 Telegraph Rd	Downey	CA	90240

The medical facilities experience a greater degree of 6, 7, and 15 should be first to be retrofitted. The medical facilities 2, 4, 5, 8, and 10 should be retrofitted last (see Table 15).

School facilities located in the north, north-west region experience a greater degree of ground shaking and, thus, more damage. These facilities include 6, 7, 8, 10, 11, 15, and 19. School facilities 2, 3, 12, 13, 14 16, and 18 experience moderate damage. Seven facilities 1, 4, 5, 9 and 20 experience minor shaking, but still suffered damage (Figure 30).

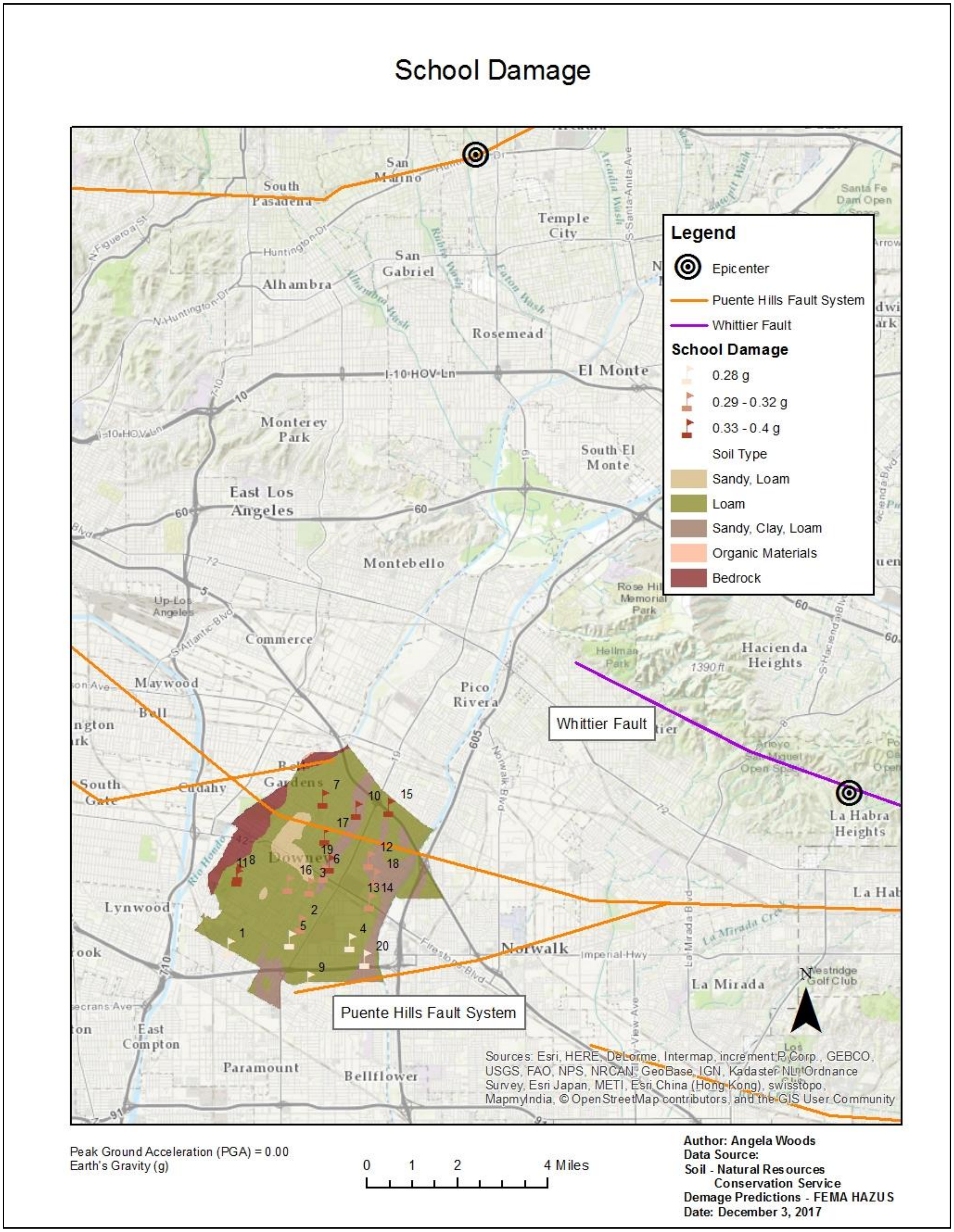

Figure 30: Estimated Moderate Damage to School Facilities

Table 16: Schools of the City of Downey

Schools					
ID	Name	Address	City	State	Zip
1	St. Pius X - St. Matthias Academy	7851 Gardendale St	Downey	CA	90242
2	Alameda Elementary School	8613 Alameda St	Downey	CA	90242
3	Downey Unified School District	11627 Brookshire Ave	Downey	CA	90241
4	A L Gauldin Elementary School	9724 Spry St	Downey	CA	90242
5	Sussman Middle School	12500 Birchdale Ave	Downey	CA	90242
6	Downey High School	11040 Brookshire Ave	Downey	CA	90241
7	Griffiths Middle School	9633 Tweedy Ln	Downey	CA	90240
8	Stauffer Middle School	11985 Old River School Rd	Downey	CA	90242
9	Carpenter Elementary School	9439 Foster Rd	Downey	CA	90241
10	Gallatin Elementary School	9513 Brookshire Ave	Downey	CA	90240
11	Old River Elementary School	11995 Old River School Rd	Downey	CA	90242
12	Doty Middle School	10301 Woodruff Ave	Downey	CA	90241
13	Kirkwood Christian Schools	11115 Pangborn Ave	Downey	CA	90241
14	St Raymond School	12320 Paramount Blvd	Downey	CA	90242
15	Unsworth Elementary School	9001 Lindsey Ave	Downey	CA	90240
16	Warren High School	8141 De Palma St	Downey	CA	90241
17	Our Lady of Perpetual Help School	10441 Downey Ave	Downey	CA	90241
18	Rio San Gabriel Elementary	9338 Gotham St	Downey	CA	90241
19	Kirkwood Christian Schools	10822 Brookshire Ave	Downey	CA	90241
20	Calvary Chapel Christian School	12808 Woodruff Ave	Downey	CA	90242

School facilities numbered 6, 7, 8, 10, 11, 15, and 19 should be considered first for retrofitting. School facilities 2, 3, 12, 13, 14 16, and 18 experience moderate damage and should be considered next for retrofitting. The seven facilities numbered 1, 4, 5, 9 and 20 suffered minor damage and should be considered last for retrofitting (see Table 16).

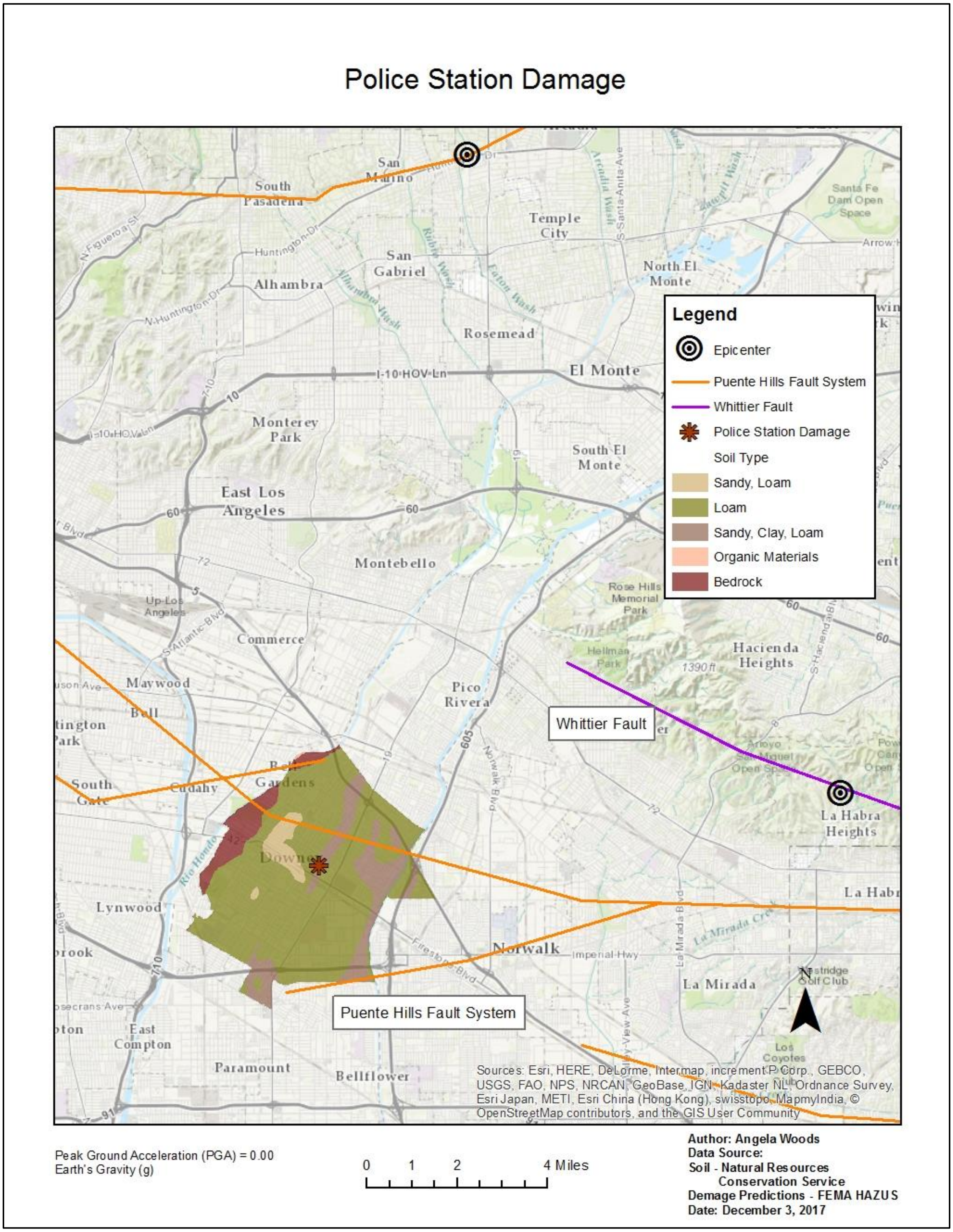

Figure 31: Estimated Moderate Damage to Police Station

The Downey Police Department is estimated to experience ground shaking thus, causing extensive Damaged (Figure 31). The station should be retrofitted.

4.2.3. Debris Generation

The HAZUS model estimated that 0.03 million tons of debris will be generated. Of the total amount, brick or wood Brick/Wood comprises 45% of the total with the remainder being reinforced concrete or steel. If the debris tonnage is converted into an estimated number of truckloads, it will require 1,360 truckloads at 25 (@25 tons/truck) to remove the debris generated by this the earthquake.

4.2.4. Shelter Requirement

HAZUS estimates the number of households that are expected to be displaced from their homes due to an earthquake and the number of displaced people that will require accommodations in temporary public shelters (Figure 32). The model estimates that 53 households might to be displaced due to the predicted earthquake. Of these, 45 people (out of a total population of 111,772) will seek temporary shelter in public shelters.

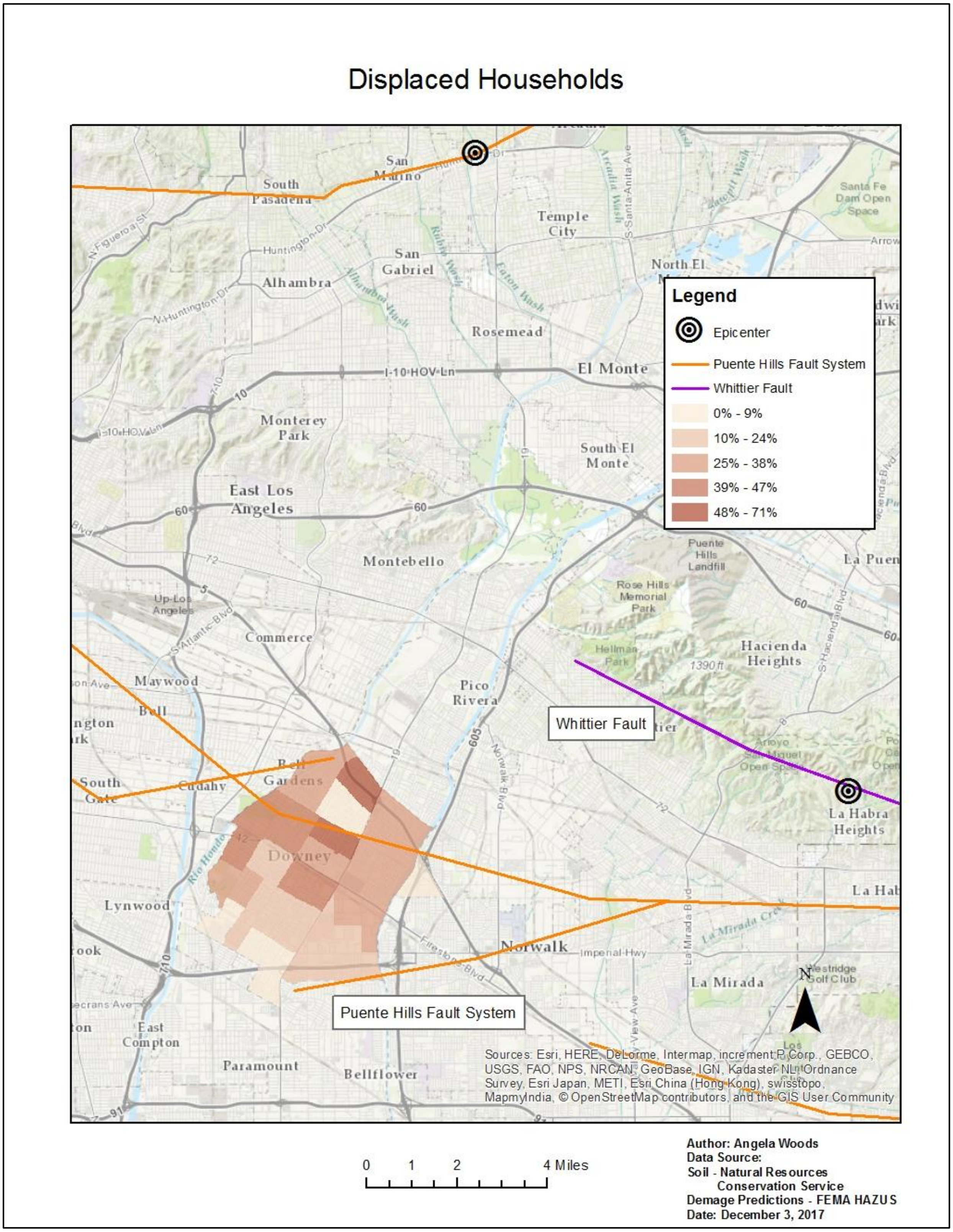

Figure 32: Displaced Household

4.2.5. Casualties

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

(5) Severity Level 1: Injuries will require medical attention, but hospitalization is not needed.

(6) Severity Level 2: Injuries will require hospitalization but are not considered life-threatening.

(7) Severity Level 3: Injuries will require hospitalization and can become life-threatening if not promptly treated.

(8) Severity Level 4: Victims are killed by the earthquake.

The casualty estimates are provided for three times of day: 2:00 AM, 2:00 PM and 5:00 PM. These times represent the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum. The 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum. The 5:00 PM represents peak commute time (see Table 17).

The greatest casualties in one single area occurred in the commercial area with the exception of the 2:00 AM timeframe. The total amount at all levels is 52 with the major at level 1 at 48. The greatest casualties in all areas at all levels is 119 with the major at level 1 at 110. These casualties include areas in commercial, commuting, educational, hotels, industrial, other residential/single family during the 2:00 PM timeframe.

Table 17: Casualty Estimates

		Level 1	Level 2	Level 3	Level 4
2AM	Commercial	3	0	0	0
	Commuting	0	0	0	0
	Educational	0	0	0	0
	Hotels	0	0	0	0
	Industrial	1	1	0	0
	Other-Residential	11	1	0	3
	Single Family	16	0	0	0
	Total	28	1	0	0
2PM	Commercial	26	3	0	0
	Commuting	0	0	0	0
	Educational	10	1	0	0
	Hotels	0	0	0	0
	Industrial	6	1	0	0
	Other-Residential	2	0	0	0
	Single Family	3	0	0	0
	Total	48	4	0	0
5PM	Commercial	19	2	0	0
	Commuting	0	1	1	0
	Educational	1	0	0	0
	Hotels	0	0	0	0
	Industrial	4	0	0	0
	Other-Residential	4	0	0	0
	Single Family	6	0	0	0
	Total	34	3	1	0

4.2.6. Economic Loss

Direct economic losses include building losses reported for the general building stock. This is information about buildings aggregated to the census tract level and can be reported for both structural and nonstructural building components, the contents of those buildings (such as furnishings), and business inventory in structures (such as commercial facilities).

Finally, the HAZUS earthquake model can also calculate business interruption impacts. These can include wage and income losses, rental and relocation costs, and business costs. Business costs are defined as repair and replacement costs for contents and business inventory damages. HAZUS can additionally generate lifeline estimates, reported in terms of the cost of repairs to lifelines. Lifelines are defined as the transportation and utility systems. These systems include highways, railways, light rails, bus, ports, airports, ferries, electric, gas, potable water, wastewater, oil and communication. The estimates are based on the following considerations:

- For components of the 13 lifeline systems: damage probabilities, cost of repair or replacement and estimated functionality for various times following earthquake
- For all pipeline systems: the estimated number of leaks and breaks
- For potable water and electric power systems: the estimate of service outages

This information provides calculations of economic impacts to transportation networks and utility networks that are considered lifelines within the earthquake model. These vital components of a community are necessary to be available to the community in order for that community to return to its economic status of that prior to the earthquake.

The HAZUS earthquake model can also calculate indirect economic losses. These longer-term impacts are vital to helping community planners understand what is going to be needed in order to bring a community back to its former state, or at least a state that has improved beyond the conditions that exist following the earthquake hazard. The total economic loss estimated for the Whittier earthquake is approximately 300 million dollars (see Figure 33), which includes building and lifeline-related losses, as well as the indirect economic losses. Census tracts 06037550500, 06037551000, 06037550400 and 06037551300 will suffer the highest total losses. In the total losses, the following are considered:

Dollar losses associated with general building stock:

- Structural and nonstructural cost of repair or replacement
- Loss of contents
- Business inventory loss
- Relocation costs
- Business income loss
- Employee wage loss
- Loss of rental income

Lifeline – related losses:

- For components of the 13 lifeline systems: damage probabilities, cost of repair or replacement and estimated functionality for various times following earthquake
- For all pipeline systems: the estimated number of leaks and breaks
- For potable water and electric power systems: estimate of service outages

  Indirect economic impact

- Long-term economic effects on the region based on a synthetic economy
- Long-term economic effects on the region

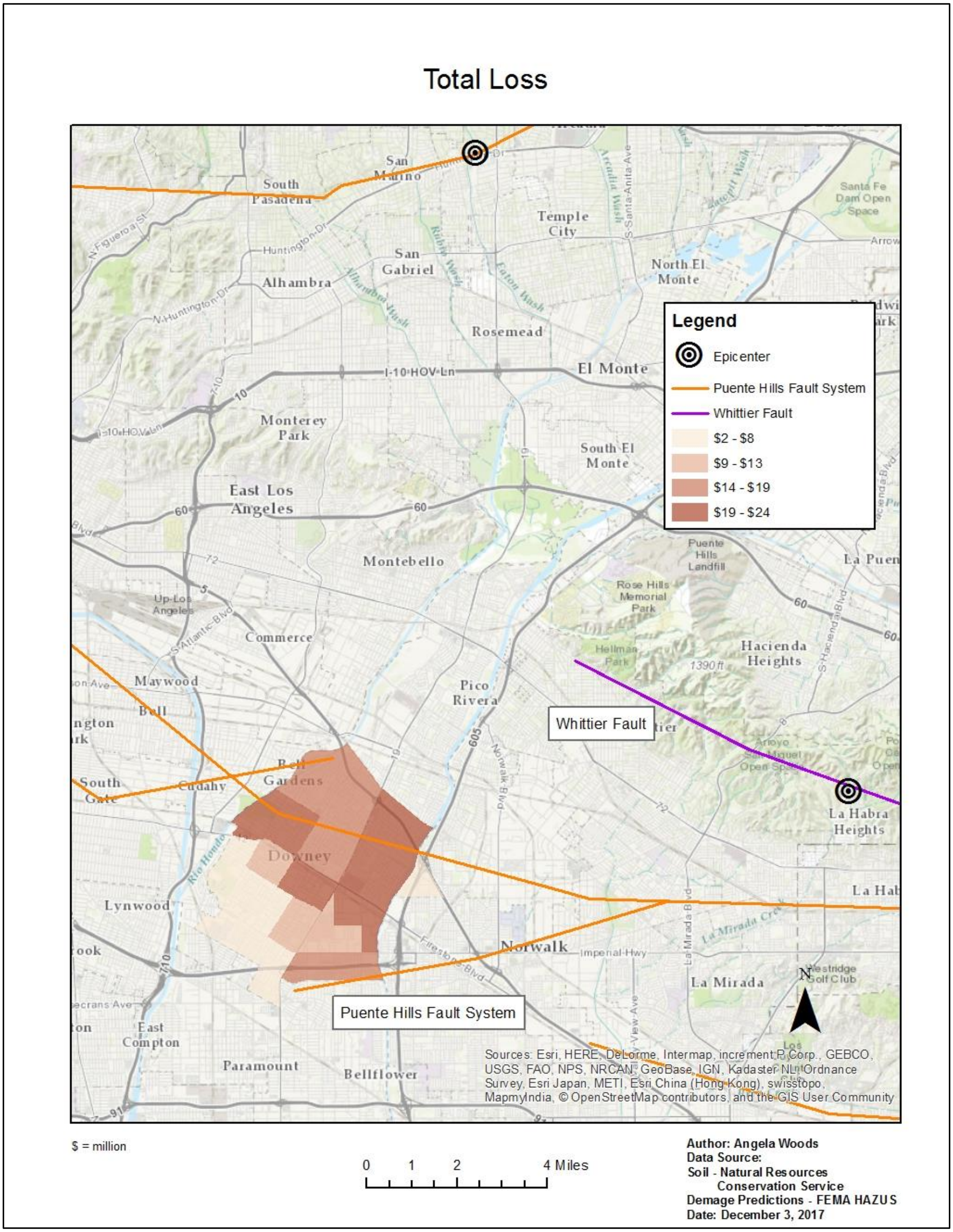

Figure 33: Total Economic Loss (US Million $)

Chapter 5 Conclusions

The results from running the earthquake model provided by HAZUS showed that there is potential for moderate damage from an earthquake on both the Whittier and Puente Hills faults. Although there are limitations when running the earthquake model, the results can provide enough information to frame a mitigation plan. The mitigation plan can be better refined if future research is conducted while the recommendation is being offered for consideration.

5.1 Implication of these results

After running HAZUS, the model showed that the damage from a Whittier 6.8 and Puente Hills 7.0 magnitude earthquake could have a significant impact on residential homes, other residential homes, and commercial structures. Other residential homes include mobile homes, apartments/condominiums, hotel/motel, institutional dormitory, and nursing home. The Puente Hills 7.0 magnitude earthquake had a greater predicted impact on the City of Downey area than the Whittier 6.8 magnitude earthquake. HAZUS estimates that, out of residential homes, 90% will be slightly damaged, 60% will be moderately damaged, and 3% will be extensively damaged. If the predicted outcome holds true, it is necessary to retrofit the city's building stock to meet the current earthquake code to mitigate loss. Given that much of the building stock in Downey does not meet the earthquake-prone code and retrofitting the building stock is expensive, it would be helpful if the city can provide an incentive for companies and a grant for consumers to offset the cost to retrofit the building stock. In both the Puente Hills and Whittier earthquake scenarios the essential facilities suffered over 50% of heavy to moderate damage combined. The following table list the essential facilities that should be considered first for retrofitting (see Table 18).

Table 18: Essential Facility to be considered first for Retrofitting

Fire Station					
ID	Name	Address	City	State	Zip
3	Downey Fire Department - Station 3	9900 Paramount Blvd.	Downey	CA	90240
4	Downey Fire Department - Station 4	9349 Florence Ave.	Downey	CA	90240
Medical Facility					
6	Santo Tomas Medical Clinic	7862 Firestone Blvd	Downey	CA	90241
7	Talbert Medical	8311 Florence Ave	Downey	CA	90240
13	Downey Urgent Care	11003 Lakewood Blvd	Downey	CA	90241
15	Brookfield Healthcare Center	9300 Telegraph Rd	Downey	CA	90240
School Facility					
7	Griffiths Middle School	9633 Tweedy Ln	Downey	CA	90240
8	Stauffer Middle School	11985 Old River School Rd	Downey	CA	90242
10	Gallatin Elementary School	9513 Brookshire Ave	Downey	CA	90240
11	Old River Elementary School	11995 Old River School Rd	Downey	CA	90242
12	Doty Middle School	10301 Woodruff Ave	Downey	CA	90241
13	Kirkwood Christian Schools	11115 Pangborn Ave	Downey	CA	90241
14	St Raymond School	12320 Paramount Blvd	Downey	CA	90242
15	Unsworth Elementary School	9001 Lindsey Ave	Downey	CA	90240
17	Our Lady of Perpetual Help School	10441 Downey Ave	Downey	CA	90241
19	Kirkwood Christian Schools	10822 Brookshire Ave	Downey	CA	90241
Police Department Station					
1	Police Department Station	10911 Brookshire Ave	Downey	CA	90241

During an earthquake, the Whittier 6.8 earthquake, out of a total population of 111,772, the model estimates 53 households to be displaced, and 45 people will seek temporary shelter in public shelters. From the Puente Hills 7.0 earthquake, the model estimates 602 households to be displaced, of these, 499 people will seek temporary shelter in public shelters.

HAZUS estimates the number of people that will be injured and killed by the earthquake. While there are only 146 predicted injuries throughout the various times of the day due to the Whittier 6.8 earthquake. There are a predicted 851 injured and 42 killed throughout various times of the day from the Puente Hills 7.0 earthquake. The time of day is a big factor. If the earthquake were to hit in the early morning or late at night while many people are at home and not commuting, the number of injured and killed people is estimated to be lower. If the earthquake were to hit during rush hour while people are commuting, then the likelihood of the number of people that are injured and/or killed increases. This is why it is imperative to have roads and rail systems that can withstand earthquakes.

In transportation, roads are a crucial component and are vital in built-up areas that rely on a dense road network. As part of the road network, bridges are critical as well and are extremely vulnerable to earthquake activity. Major earthquakes during the past 40 years have revealed the vulnerability of highway bridges to seismic loads. If the outcome holds true when running the earthquake model in HAZUS, many of the bridges in the city of Downey were predicted to be slightly or moderately damaged, making the bridges inoperative. The need for the development of effective bridge seismic design criteria and retrofitting techniques are necessary to help mitigate both direct and indirect loss.

5.2 Limitations

HAZUS-MH provides users with valuable information that can be used to reduce damage to a community from an earthquake. HAZUS provides this information in the form of maps, reports, charts, graphs, and tables. For user convenience, reports generated in HAZUS can be saved in various file formats. One loss estimation that is unique to earthquake models is casualties. These are all advantages that HAZUS offers, however, it is important to keep in mind that all outputs generated in HAZUS-MH are estimations. In order to get insight, it is necessary to have excellent data that will give one a more accurate estimate of what may occur.

For this project, many of the limitations revolved around HAZUS and the data used in the model. In some cases, accurate data was not available and needed to be collected and/or created which, in both cases, can be very time consuming. Although HAZUS provides "canned" data at the national level, much of it is quite basic and often out-of-date; it essentially just provides one with a start. It is best to seek and obtain state, county or local level data to get more accuracy in the outcome. In doing so, the data still needs to be prepared in order to be ingested into HAZUS via the HAZUS database CDMS. Again, this process is time consuming. Detailed data for all modules were not collected; as a consequence, the predictive results were limited.

5.3 Future Research

In order to have a more accurate study, there are several recommendations to refine this study:

(1) Collect and update the building stock data. The data can be collected from the county and city government, which would provide a more accurate dataset. This data could then put into the correct format and ingested into the HAZUS provided database.

(2) Collect and update the transportation and utility system data. Again, the data can be collected from a local source to include the government and the private sector. One can collect the data themselves. However, this option is more time consuming. Once the data is collected and put into the correct format, it can be ingested into HAZUS's database.

(3) Update soil data within HAZUS. Although ShakeMaps were used to simulate ground shake, the soil was based on the NEHRP soil type. It used soil type D for the entire Downey. The USDA Natural Resources Conservation Service soil data is considered a more detailed soil survey. There were five soil types for Downey to include bedrock. Ultimately, this generic consideration of the soils type could have affected the overall results.

(4) Develop seismic design criteria and retrofitting techniques for the road network.

(5) Develop seismic design criteria and retrofitting techniques for the building stock.

In researching and completing the above tasks, it could provide more accurate information for the study. With a more accurate study, it could enhance the management budget plan, as well as provide guidance in terms of resource allocation. It could also provide a priority list for retrofitting the city-owned roads, bridges and buildings. Ultimately, this would enhance the city mitigation plan.

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