Preparing for the Next Major Southern California Earthquake:
Utilizing HAZUS with Soils Maps and ShakeMaps to Predict Regional Bridge Damage and Closures

by

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To my Father, Mother, and Sister.
As well as my extended family from Greater Los Angeles

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List of Abbreviations

HAZUS	HAZards United States
UCERF3	3rd Uniform California Earthquake Rupture Forecast
M or MM	Magnitude or Moment Magnitude
NEHRP	National Earthquake Hazards Reduction Program
STATSGO	STATe Soil GeOgraphic database
GeoUnit	USGS Geological Units for California
Vs	Shear Wave Velocity at 30M under surface
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PSA0.3	Peak Ground Acceleration at 0.3 seconds
PSA1.0	Peak Ground Acceleration at 1.0 seconds
FHWA	Federal HighWay Authority
FEMA	Federal Emergency Management Agency
SCEC	Southern California Earthquake Center
USGS	United States Geological Service
USDA	United States Department of Agriculture
CGS	California Geological Survey
CDMS	HAZUS Comprehensive Database Management System
.mdb	Microsoft Access Database File
.kml	Kernel Markup Language – Google Earth File
GIS	Geographic information system

Abstract

The San Andreas Faultline is the largest fault in California. On average, this fault has produced a major earthquake every 150 years, the last to strike the southern section was the magnitude 7.9 Fort Tejon earthquake of 1857. Today the Greater LA Area is one of the largest urban agglomerations in the world and the second largest metropolitan region in the U.S. The area is well known for its urban sprawl and expansive highway system. The weak points of any highway system are the bridges and overpasses. Modeling the effects of an earthquake on this infrastructure will help inform emergency planning and speed economic recovery.

Experts have predicted a major earthquake, from magnitude 7.0 to 8.0, will strike the fault within the next 30 years. The goal of this project was to examine enhanced HAZUS hazard datasets to assess potential earthquake damage to highway bridges and how this may correspond to bridge closures. NEHRP soils maps were created by joining shear wave velocity data to STATSGO and Geological Unit data, then classifying each soil unit by the NEHRP class shear wave velocity range. USGS Scenario ShakeMaps at M7.4 and M8.0 were selected near the area of fault section with the highest probability of a great earthquake. Eight scenarios were modeled with this data. Results of this work show that user-supplied datasets for ground motion generally reduce HAZUS bridge damage outputs, that all earthquake scenarios will significantly damage southern California bridge infrastructure, and how relative damage state outputs translate into bridge restrictions and closures.

Chapter 1 Introduction

The San Andreas Fault line runs north and south along most of California and has a history of producing major earthquakes approaching Magnitude (M) 8.0. The last major earthquake on the San Andreas was the 1906 M7.8 San Francisco Earthquake. Before the San Francisco earthquake the fault produced a M7.9 earthquake in 1857 near Fort Tejon, and before that, the southernmost section of the fault near the Salton Sea produced a M7.7 earthquake in 1680 (Jones 2011). Studies suggest that the southern section of the San Andreas Fault will experience a major earthquake sometime in the next 30 years (Fialko 2006; Bird 2009; Jones 2011; Field 2013). Southern California planners have been working on a comprehensive freeway and express system since the 1940's, today it is an interconnected system serving the entire southern California region of 22 million people (Figure 1). Bridges are the weak link in any highway system, and the region has over 9,000 road and highway bridges (Faigin 2015). Even though the system is highly redundant and California has high seismic engineering standards, a major earthquake will cause significant damage to bridges and immediately impair emergency response while leading to days or weeks of economic impacts (Moehle 2003). With over 10.1 million people, Los Angeles County is the most populous county within the Southern San Andreas Fault zone, and much of its infrastructure will be affected by an earthquake in the southern San Andreas Fault (US Census 2016; Porter 2011).

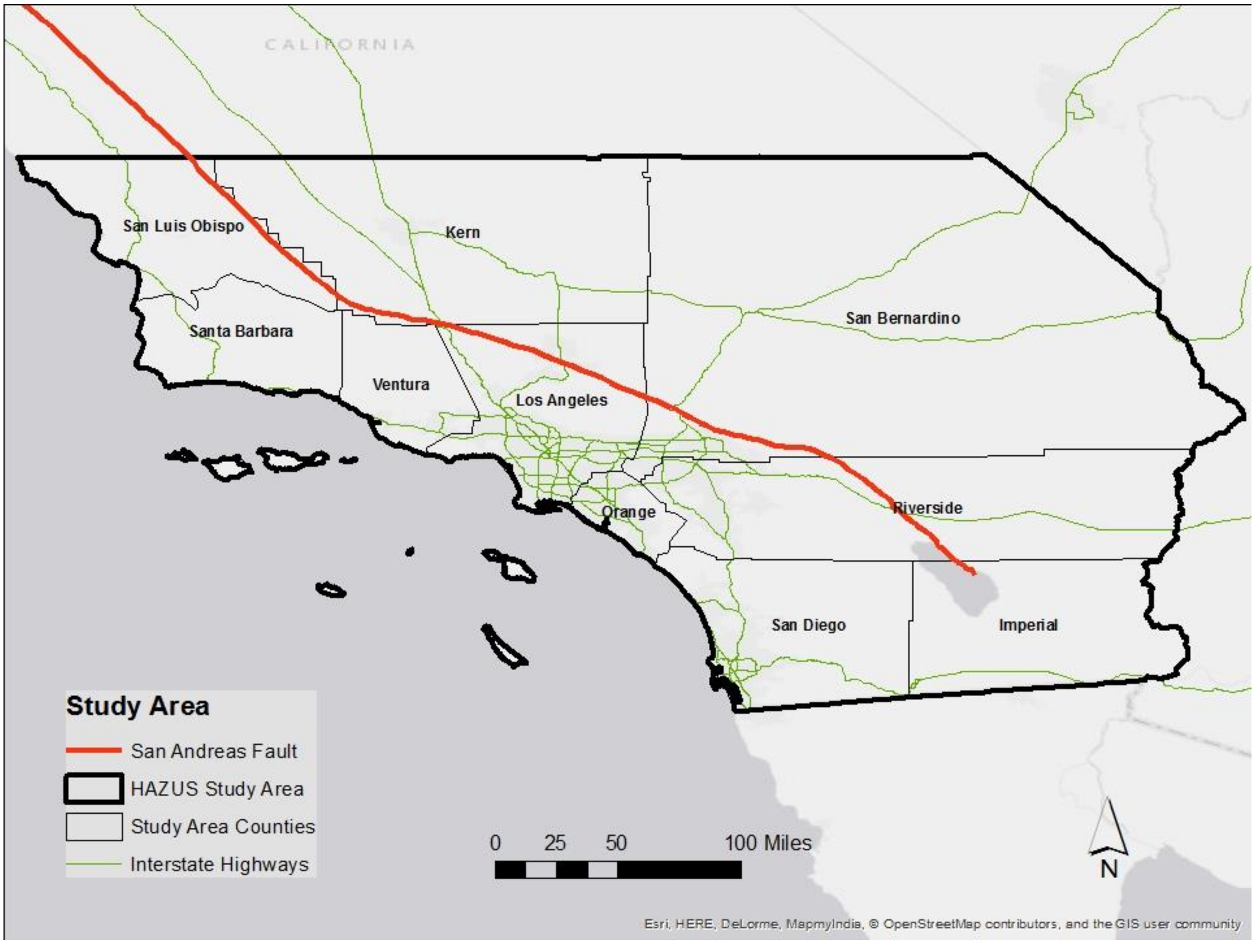

Figure 1 Southern California Study Region Map

The Federal Emergency Management Agency maintains free natural hazards modeling software called HAZUS, which runs on top of ArcMap10.4 and allows users to estimate physical damage, economic and social losses resulting from earthquakes (FEMA 2017). This thesis investigated the effects of a southern San Andreas major earthquake recurrence, with a focus on examining how different datasets determining ground motion will affect damage to bridges. The research examined how to run a custom HAZUS analysis utilizing soils maps and ShakeMaps for enhanced ground motion modeling and how HAZUS damage state probability outputs may be used to identify bridge closures. The project implemented two HAZUS earthquake scenarios, each on the southern San Andreas, with different magnitude values representing a range of ‘major’ earthquake magnitudes. To evaluate model output sensitivity to updated datasets, each earthquake scenario (with event data taken from the selected Scenario ShakeMaps) was run once with default HAZUS data.

1.1. Motivation

Scholars predict another major to great earthquake along the southern San Andreas Fault within the next 30 years (Fialko 2006; Bird 2009; Field 2013). The San Andreas Fault line averages a major earthquake every 150 years and the southern section of the fault is far past this average recurrence frequency (Figure 2). An earthquake is classified as ‘major’ when its magnitude is M7.0-7.9 and ‘great’ at magnitude 8.0 or more. The magnitude scale is logarithmic and not linear, meaning that for every whole number increase in magnitude, the amplitude of ground motion goes up ten times. (Michigan Tech 2017). Modeling a major or great earthquake on infrastructure in a Geographic Information System will help us better understand vulnerabilities and plan appropriate emergency measures to prevent loss of life and economic interruption.

Figure 2 San Andreas Fault Map with Historical Earthquakes and Rupture Sections

Source: whatcausesearthquakes.com

A major earthquake recurrence on the southern San Andreas would affect all southern California and cause significant destruction near the epicenter and along the ruptured section. The section of Fault line with the highest likelihood to rupture at M8.0 or greater lies north of Los Angeles, near the town of Gorman (Figure 3). Gorman is a small town in between Los Angeles and Bakersfield that sits atop the Tejon Pass in the San Gabriel Mountains. Gorman does not have a large population, but the I-5 freeway travels directly past it and is the main North-South freeway artery for all southern California.

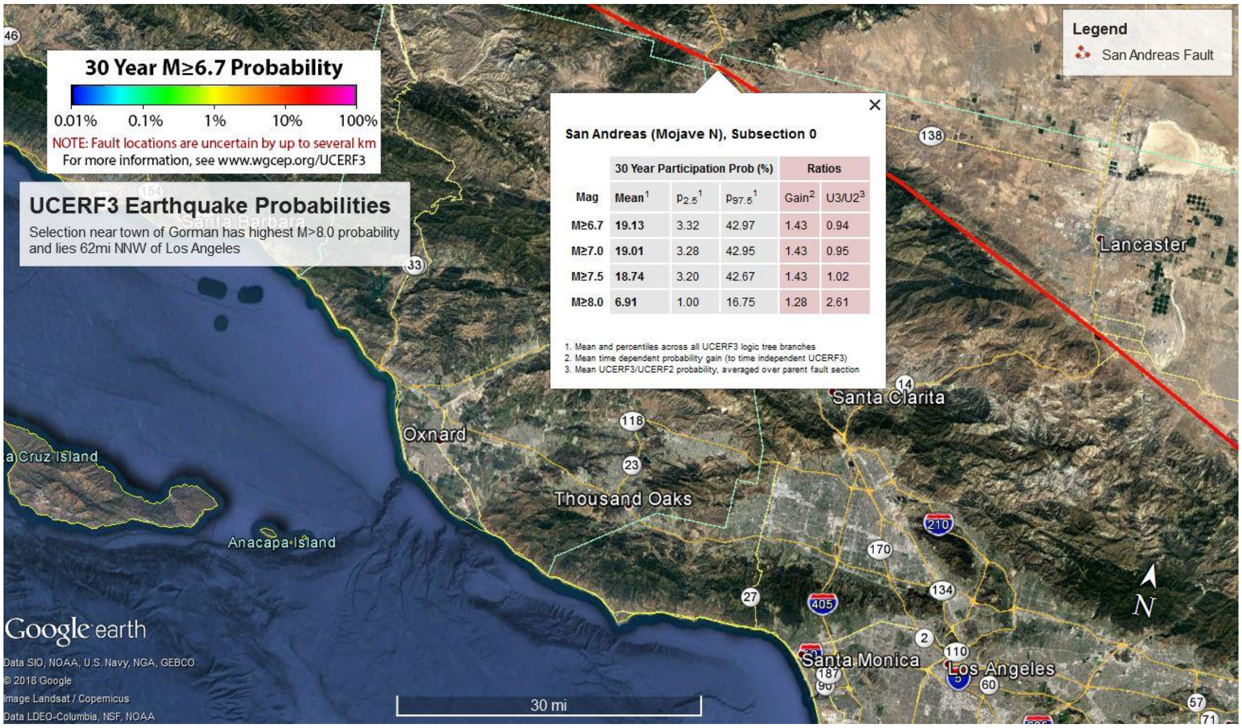

Figure 3 San Andreas Fault and Earthquake Probability Near Gorman, CA

(UCERF3 .kml data from SCEC 2015)

HAZUS is a natural hazards model using sophisticated loss-estimation methods; it was developed by the Federal Emergency Management Agency and National Institute of Building Sciences and released in 2003 (Yeats 2013). HAZUS is used to model natural disasters including earthquakes, runs as a custom application inside ArcGIS10.4, and its software and data are freely available to download from the FEMA website.

HAZUS models ground shaking on highway bridges and provide outputs in terms of relative damage level probabilities (0-1 probability for slight, moderate, extensive, complete damage), total structure loss (with $ repair cost), or percent reduced functionality (% functionality at day 1, 3, 7, 14, 30, and 90) (Kircher 2006). Additional analysis of this data predicted how highway bridge damage outputs could be translated into bridge closures over the road network. A bridge with complete damage or total loss cannot be crossed, but what functionality or traffic capacity will a moderately or extensively damaged bridge provide the road network? While default HAZUS analysis uses only one soils class to determine ground motion, this analysis can be enhanced by adding classified soils maps or ShakeMaps to provide better data for ground motion modeling (FEMA 2015). A HAZUS analysis utilizing local user-supplied data typically provide lower damage estimates (Neighbors. 2013). A major earthquake will affect the entire region, and its unknown to what spatial extent the damages will occur. This project will implement a HAZUS earthquake analysis for all 10 southern California counties using soils maps or ShakeMaps, and employ methods to convert the damage state outputs for highway bridges into thresholds for bridge closures and restrictions.

1.2. Research Goals

The research questions:

- To what degree will a major earthquake on the southern San Andreas Fault damage bridges in southern California?
- How will user-supplied datasets for ground motion effect bridge damage outputs compared to default HAZUS data?
- How might HAZUS bridge damage state outputs correspond to bridge closures and restrictions?

Chapter 2 Background and Related Works

This study area for this project is determined by the 10-county definition of Southern California. This more extensive definition includes the counties of Kern and San Luis Obispo. This definition was decided on due to the spatial distribution of the San Andreas Fault line and the location for the highest probability epicenter located near Gorman, on the edge of Los Angeles and Kern Counties. Also, the predicted lengths of fault rupture and energy released vary greatly between the range of a M7.0 to M8.0 earthquake event predicted in the next thirty years, and the study area needed to account for a low to mid end event magnitude and a maximum event magnitude. There is software other than HAZUS for predicting earthquake losses, such as the open source software SELENA-RiSE (NORSAR/ICG 2010). HAZUS was selected due to its integration with ArcGIS and its comprehensive modeling system and outputs for building damage, economic/social losses and damage to lifeline systems. SELENA-RiSE borrows many of the earthquake hazard algorithms used in HAZUS but currently only outputs losses due to building damage (NORSAR/ICG 2010). NEHRP classified soils maps for input to HAZUS or SELENA define site-specific ground amplifications and must be created by the user based on local knowledge. Studies for classifying NEHRP maps based on soils and geological units are discussed in this chapter. Also discussed in this chapter are studies implementing HAZUS evaluating model sensitivity to input parameters, a HAZUS scenario compared to real-world losses, and a HAZUS scenario for a hypothetical earthquake on the southern San Andreas meant to inform emergency preparedness and disaster mitigation. Finally, the outputs for bridge damage state probabilities are discussed as well as studies that relate these outputs to a Bridge Damage Index used by engineers and corresponding bridge closures which a local transportation agency may impose (Park 2001; Shiraki 2007; Richardson 2015).

2.1. Southern San Andreas Fault and Earthquake Risk

The San Andreas is the dominant fault line across the state of California. In southern California, the San Andreas runs from NE San Luis Obispo County along the San Gabriel, San Bernardino, and San Jacinto mountain ranges, then terminates near the Salton Sea in Imperial County. Earthquake Risk on the Southern San Andreas has been assessed by many researchers and organizations. The first researcher to predict a 30-year timeframe for a major earthquake on the San Andreas was Yuri Fialko from the Scripps Institution of Oceanography at UCSD. In March 2006 he presented a seminal article in *Nature* about slip deficit and strain accumulation on the southern section of the San Andreas Fault. Using synthetic aperture radar data for high-resolution measurements, he found slip deficit on the southern San Andreas to be in the order of 7-10 meters, which is comparable to the maximum co-seismic offset ever documented on the fault (Fialko 2006). Other researchers followed with studies predicting California earthquake likelihood, but the largest is the Working Group on California Earthquake Probabilities, a group of researchers from several Federal and State agencies and many universities who began publishing the Uniform California Earthquake Rupture Forecast reports (Field 2013). Field et al. (2013) produced the UCERF3 Report, detailing rupture probabilities for significant faults throughout the state of California (Figure 4). UCERF3 is a probability model utilizing supercomputers to predict earthquake rates at specific magnitudes along major fault lines. Some of the fault rupture probabilities have decreased compared to UCERF2, the newer model shows a 20% chance of a M6.7 or greater earthquake occurring on the Southern San Andreas Fault within the next 30 years. The UCERF3 report provides the main motivation, background, and basis for this studies' earthquake scenario.

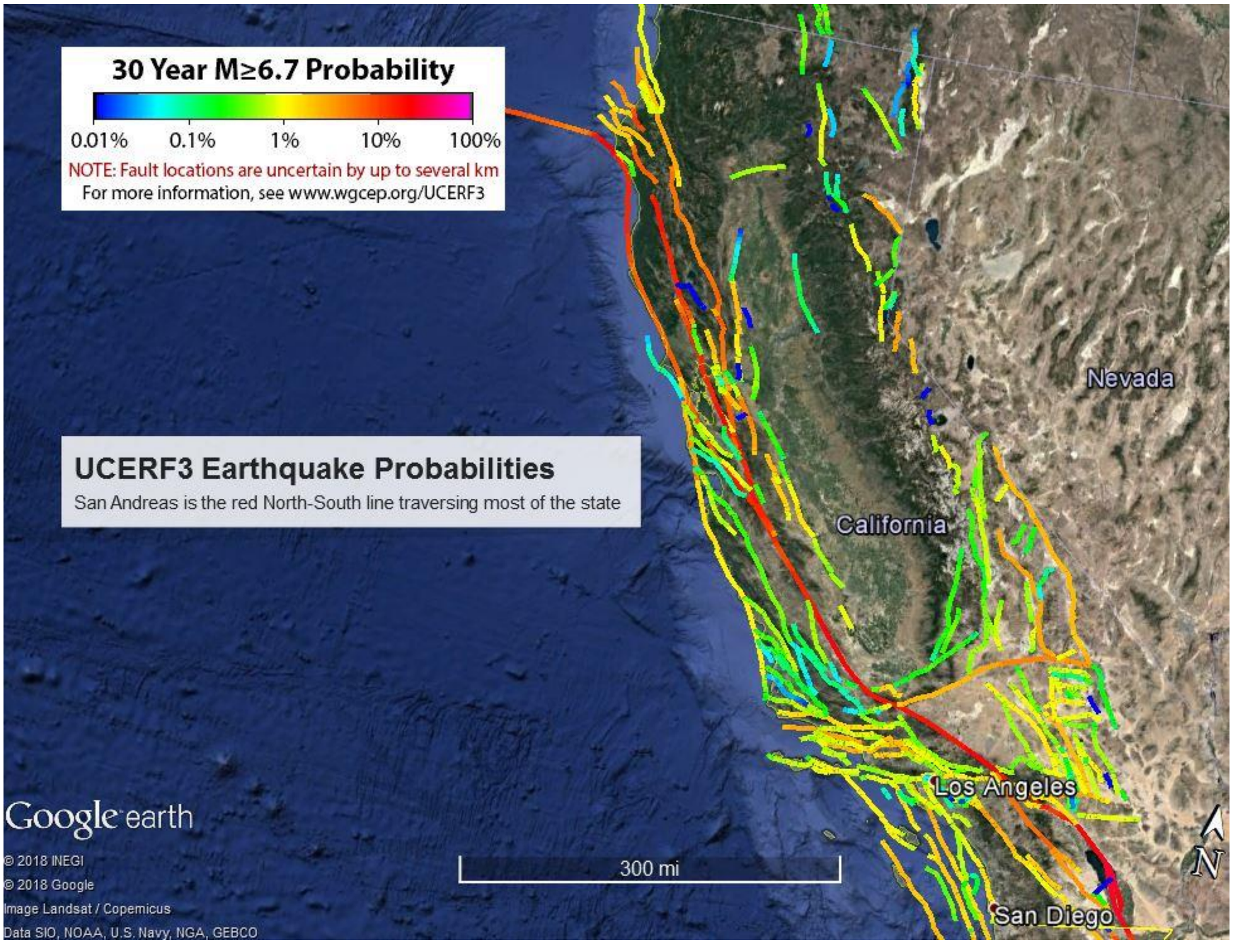

Figure 4 UCERF3 earthquake probabilities for CA by Fault

(.kml data from SCEC)

2.2. Regional Geology and NEHRP Soils Classification

The history of earthquakes and unique geology indicates that the the study region is seismically vulnerable and provides justification for strict earthquake engineering standards. Olsen et al. (2005) utilized the TerraShake model to show that a chain of sedimentary basins between San Bernardino and Los Angeles act as an effective waveguide that channels Long waves (the most destructive earthquake waves) along the southern edge of the San Bernardino and San Gabriel Mountains. They found that this effect can produce unusually high long-period ground motion over the region and produce intense shaking from variations in the waveguide cross section. The Olsen study sheds light on a significant portion of my study areas' lithology, it lends to the importance of using soils maps to make this HAZUS analysis more accurate and provides some assumptions on the general qualities of the Greater Los Angeles areas soil basins.

The National Earthquake Hazards Program (NEHRP) provides the soils classification scheme used in HAZUS modeling software, these soils maps should be custom classified based on local field data from borehole observations. NEHRP soils classes are defined by the shear wave velocity (Vs) values of the soil at 30 meters.

Recently, the use of NEHRP classified soils has been validated for use in HAZUS analyses. Medves (2009) made use of enhanced NEHRP classified soils maps in a HAZUS analysis for his master's thesis at the College of Charleston. He incorporated SSURGO and STATSGO polygon soil data into his analysis by joining shear wave velocity point data from boreholes to soil mapping units, then assigned NEHRP soil classes according to the soil units shear wave velocity values. Soils units with no Vs data were assigned the average values of similar units, then classified for NEHRP values. Thitimakorn et al. (2016) derived NEHRP classified soils maps for Lamphun City, Thailand using shear wave velocity point values derived from multi-channel analysis of surface wave (MASW) data. The Vs values were joined to geological unit polygon data for the area surrounding Lamphun City. NEHRP classifications were assigned to geological units according to the average Vs value. The authors found the alluvium and terrace geologic units surrounding the city to be classified as NEHRP type D and C. These previous analyses provided information and methods for determining NEHRP classifications for soils maps used in this HAZUS analysis.

2.3. HAZUS-MH Implementation Research

HAZUS has been available to the public for almost fifteen years. There are several studies that address model parameters, ShakeMaps, soil maps, updated datasets, and model sensitivity. A major resource for HAZUS users is the extensive HAZUS User and Technical Manuals that outline how to create hazard scenarios and explain modeling parameters, methodologies, and details for inputs and outputs. FEMA began the HAZUS initiative in 1997 under an agreement with the National Institute of Building Sciences and released HAZUS-MH in 2003 to assist US municipalities or businesses with hazard loss estimation. HAZUS-MH 4.0 uses ArcMap10.4 to map building inventories, soil conditions, faults, critical infrastructure, and lifelines to estimate economic loss, physical damage, and social impacts (Yeats 13). The quality of HAZUS modeling can also be enhanced with the addition of soils maps, ShakeMaps, and the AEBM; which provides analysis for individual buildings as opposed to the general building stock data aggregated at the census block level (FEMA 2015a). Porter et al. (2011) used HAZUS in the Shake Out Scenario to evaluate a hypothetical 7.8 magnitude earthquake striking the Southern San Andreas Fault. Physics-based modeling was used to create shaking intensity and peak ground motion maps. A custom HAZUS analysis utilized 18 special studies to analyze the effects of the hypothetical earthquake on regional infrastructure. The earthquake scenario studied caused 1800 deaths, 53,000 casualties requiring emergency room care, 1600 fires destroying 200 mil ft. of building stock, and a total of 191 billion in economic losses. The study also found widespread damage to highway bridges and major interstates, taking up to seven months to repair. Emergency response activities are also depicted showing activities over time. Using HAZUS to model the effects of the next major earthquake on bridge infrastructure data will assist in regional planning, and emergency response, as well as help mitigate economic losses.

ShakeMap datasets and understanding model outputs for damage states are important to this study. Kircher et al. (2006) focus on building-related methods of HAZUS loss estimation as well as the Advanced Engineering Building Module and the use of ShakeMaps for ground motion data to assess potential damage immediately following an earthquake. The study created a comparison of losses between actual 1994 Northridge Earthquake data and losses generated by HAZUS with ShakeMaps ground motion data collected from the same earthquake. Damage state probabilities and fragility curves are also discussed in detail, these are datasets which HAZUS outputs to assess building and infrastructure damage. This paper provides insights into ShakeMap use in HAZUS and evaluates damage state probability outputs compared to ground truth data. Another sensitivity analysis for HAZUS earthquake model outputs was examined by Neighbors et al. (2013) using a case study in King County, Washington. The research addresses hazard input parameters for earthquake scenarios and how sensitive ground motion and economic loss estimates are to earthquake variables. Primarily concerned with monetary building damages, their results show economic loss scenarios in the study area are more sensitive to changes in earthquake hazard source parameters than changes in site conditions from user-supplied data sets and that changes in source parameters for earthquake intensity influence large variability in building damage. They found that user-supplied datasets can produce lower damage results than default HAZUS data This research provides assumptions on output relationships between scenario variables, and output differences between default data and user-supplied data.

Extracting HAZUS results data and utilizing appropriate highway bridge damage state outputs addressed by Curtis (2016), who implemented a HAZUS transportation analysis in the Dallas/Fort Worth metro area to obtain shelter needs, shelter points, and bridge damage state data for an emergency services location-allocation analysis as her master's thesis at USC. Levels of bridge damage states were used to identify bridge closures used as impediment points for the Location-Allocation analysis.

2.4. Bridge Damage States, Damage Probabilities, and Bridge Closure

Once the enhanced datasets that will used were defined, earthquake scenarios established, analysis run and data extracted, damage states and damage state probabilities that are acceptable for use in a bridge closure analysis also need to be identified. Additionally, damage state levels that qualify for bridge closures in California must be delineated. The California Geological Survey (CGS) released a report in June 2009 detailing HAZUS loss estimation for California Scenario Earthquakes. The CGS reported building and infrastructure to be in moderate damage states when a damage state probability is at least 50% (CGS 2009). Richardson et al. (2015) used the Southern California Planning Model (SCPM) and the Early Post Earthquake Damage Assessment Tool (EPEDAT) to model a hypothetical M7.1 earthquake on the Elysian Park Fault near downtown Los Angeles. While the authors found bridge damage states to be standardized among earthquake models, corresponding bridge functionality for the highway network was highly subjective. They recognize different acceptable risk levels at moderate and severe damage states for bridge closures and suggest different traffic restriction mitigations for maintaining some traffic capacity in a moderate damage state. The importance of this study for my research lies in the methods the authors used to convert relative qualitative damage descriptions ('moderate damage,' 'severe damage') into a corresponding range of engineering

Bridge Damage Index (BDI) values and then thresholds for bridge closure or traffic restriction based on a transportation agencies level of acceptable risk. Shiraki et al. (2007) examine transportation network delay from earthquake damage in Los Angeles and Orange County using simulations with bridge fragility curves to evaluate bridge damage states in terms of bridge damage index. Bridge fragility curves indicating damage as 'at least minor/moderate/major' and 'collapse' were related to BDI values. This research reinforces Richardson et. al. (2015) and relates quantitative bridge damage states to relative states, such as 'Moderate' or 'Extensive. This research is summarized in Table 1 below. Park et al. (2001) provided background on the Bridge Damage Index Method and what index values correspond to in terms of structure damage. The damage index method uses the change in modal strain energy of the pre-damage and post-damage structure to detect, locate, and size damage in a structure. The authors found a strong correlation between predicted BDI and observed damages as well as a significant influence from environmental conditions during wet and dry seasons.

Table 1 Bridge Damage States with corresponding BDI values and Closure Status

Bridge Damage State	Damage State Acceptance Probability	Bridge Damage Index Value	Richardson (2015) CA Closure Status
No Damage	> 0.50	0	Open
At Least Slight Damage	> 0.50	0.1	Open
At Least Moderate Damage	> 0.50	0.3	Restricted
At Least Extensive Damage	> 0.50	0.75	Closed

Chapter 3 Data and Methodology

This chapter outlines the data used and the methodology implemented for this study. This project consisted of a HAZUS earthquake analysis for a 10-county definition of southern California and uses the outputs for highway bridge damage to determine bridge closures and restrictions immediately following the event, as illustrated in Figure 5. Datasets used for this project are discussed first, then the methodology developed in the HAZUS model runs is discussed, followed by the methodology for determining bridge closures and restrictions.

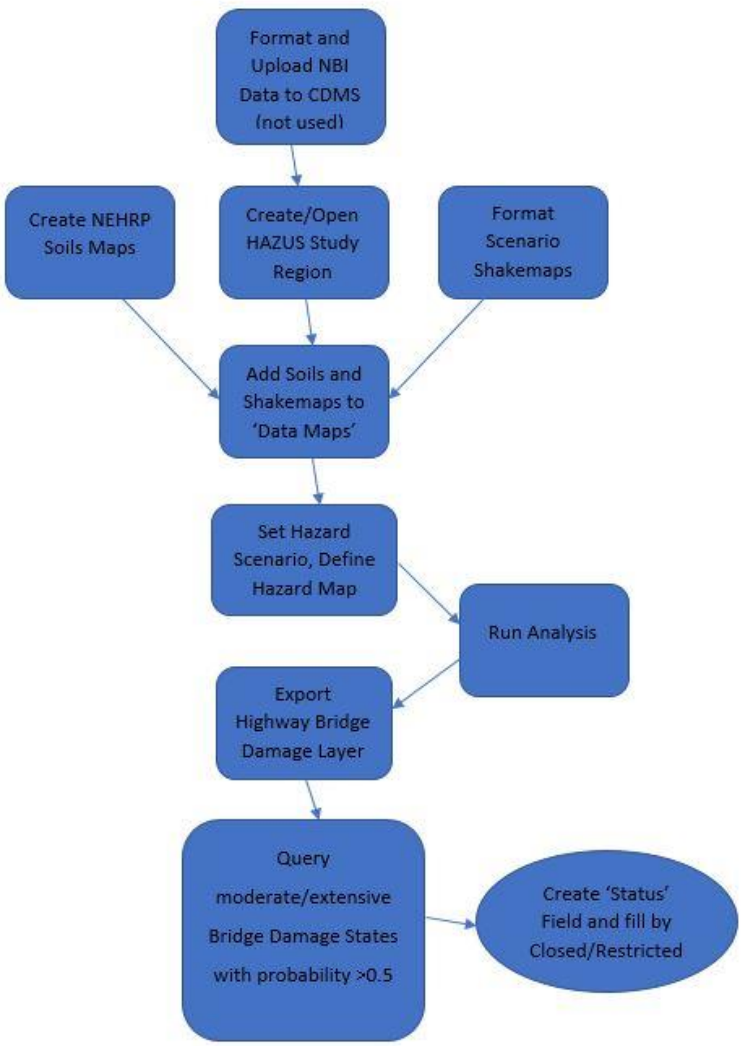

Figure 5 Flowchart of Overall Methodology

3.1. Datasets Used

All data for this project were freely available online and downloaded from various organization or federal government agency websites (SCEC 2015; Soil Survey Staff 2016; Ludington 2005; Young 2015; USGS 2017; FEMA 2017). As mentioned in Chapter 1, HAZUS comes with a preloaded default data inventory mostly based on 2010 census data aggregated at the tract level. Statewide hazard and structural inventory datasets were downloaded from the FEMA website and loaded into the Comprehensive Database Management System (CDMS), which can be defined to create a highly detailed study region for a specific analysis. The statewide database inventory in the CDMS is in Microsoft Access (.mdb) format and can be customized with updated or user-defined datasets uploaded to the statewide inventory through the CDMS or input as Data Maps in the HAZUS hazard scenario setup menu.

Creation of NEHRP classified soils maps through a spatial join between Shear Wave Velocity (Vs) point values to STATSGO, and California Geological Units maps involved careful data pre-processing steps which introduced possible errors as well as assumptions. A detailed explanation of the methods and underlying goals of the spatial join can be found in Medves (2009) and Thitimakorn et al. (2016). I this study, a new field for NEHRP classes was added and filled by the NEHRP class Vs value corresponding to that soil units average Vs value.

Scenario ShakeMaps are hypothetical earthquake scenarios created by USGS seismologists which reflect the characteristics of a specific fault and display rupture length and ground motion data (USGS 2016). Two Scenario ShakeMaps at M8.0 and M7.4 were chosen to represent the likely range of probable values based on UCERF3 forecasts (Field 2013) for a recurrence of a significant earthquake event on the San Andreas.

The 2015 data from the National Bridge Inventory was downloaded from the FHWA website, with 9 fields matched and formatted for upload to the CDMS (FHWA 2015). There were 20 different HAZUS bridge classifications identified in this data using the HAZUS CDMS data dictionary (FEMA 2013). The bridge classification data is 5 years more recent than the default HAZUS bridge inventory and includes all National Highway System bridges in the study area. An overview of these datasets can be found in Table 2 below.

Table 2 Inventory Data, Soil Maps, ShakeMaps, Vs Point Data, and Bridge Point Data

Dataset	Source	Temporal Scale	Spatial Scale
HAZUS Default Inventory	FEMA/HAZUS 2010 native data. Lifelines - Transport systems - Highway - Bridges.	2010	County or region scale
Soils Maps	USDA STATSGO: USGS Geological Units for California:	STATSGO: 2016 GeoUnit: 2005	Statewide CA
ShakeMaps	USGS Earthquake Scenario Map	2017	Regional Extent
Shear Wave Velocity Data	USGS Compilation of Vs 30 values in the US	2015	Regional Point data
National Bridge Inventory	Federal HighWay Authority National Bridge Inventory (Prepared but not used in analysis)	2015	Regional point data

3.1.1. HAZUS Census tract and default inventory data

The HAZUS default data inventory consists of 2010 census data and buildings aggregated at the tract level as well as point or line data for lifelines and Essential Facilities (FEMA 2015). Depending on the modules chosen for an individual analysis, HAZUS uses all of this data to estimate casualties and shelter needs, damage to default structural inventory, and indirect and direct economic impacts. HAZUS does not identify multiple bridges which span over each other, thus stacked bridge data points will be represented as multiple point objects with similar coordinates, yet will be designated according to their HAZUS highway bridge class. (See Appendix A Table 8 for details on HAZUS highway bridge classes).

This project deploys HAZUS, with upgraded ground motion and soils data compared to HAZUS default soil inputs, to model the earthquake scenarios effects on the HAZUS default inventory bridge data. The output data of concern is from the Lifelines Transportation Systems module. Results are provided as point data representing bridges and the discrete probabilistic damage states of no damage, slight damage, moderate damage, extensive damage, and complete damage as well as cumulative damage states of 'at least moderate' and 'at least extensive' (FEMA 2015a). For efficient processing time and to maintain focus on the previously stated research questions, only the necessary modules for analyzing highway bridge damages were selected to illustrate the effects of the chosen earthquake scenarios on the default bridge inventory, and how damage to the bridge data differs between scenarios used in the analysis. Figure 6 illustrates the 9,516 input bridges in the default HAZUS bridge inventory, represented as points.

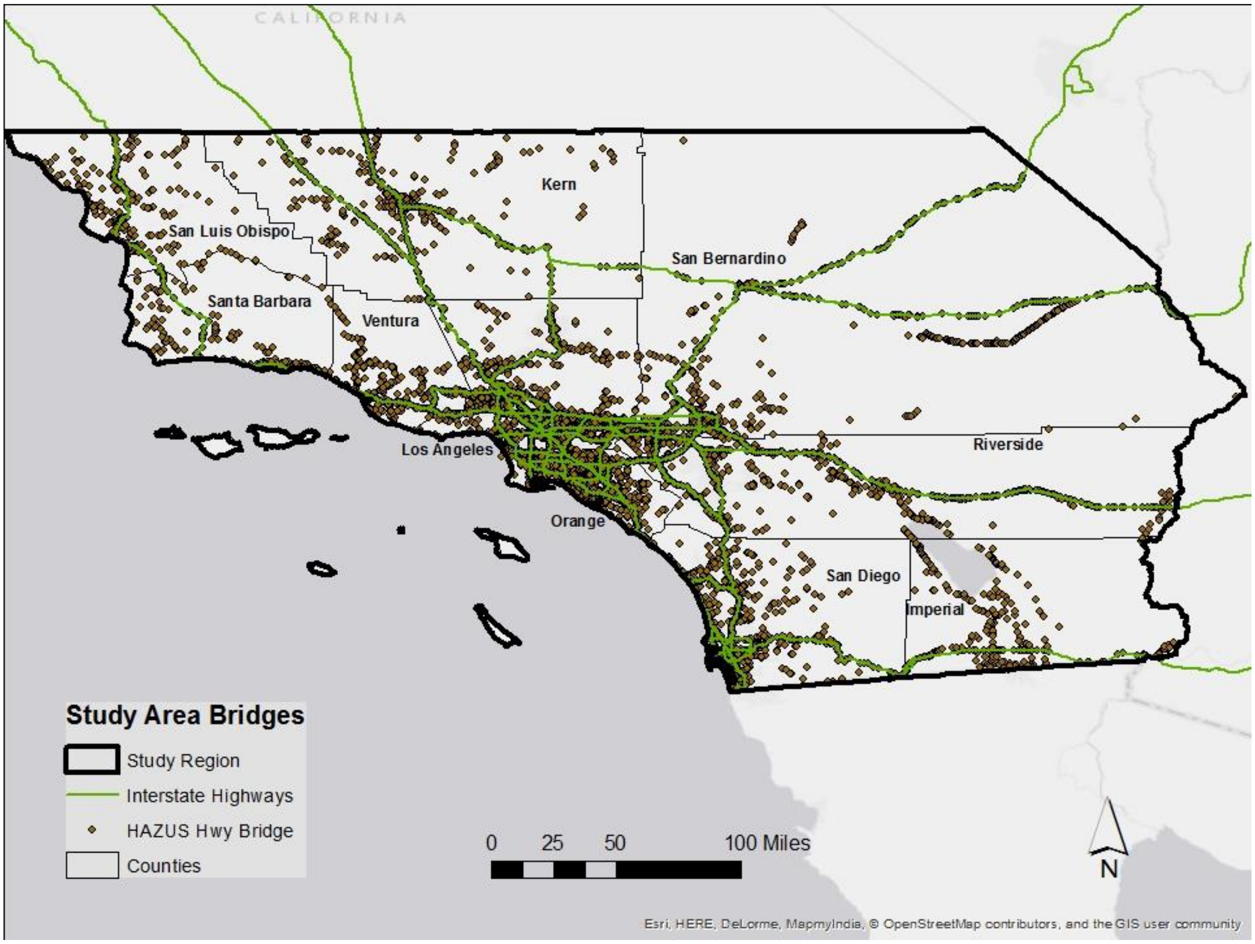

Figure 6 HAZUS Default Highway Bridge Data

3.1.2. Shear Wave Velocity Point Data

NEHRP soils classes are defined by different ranges of shear wave velocities (Vs) in the upper 30M of soil (FEMA 2015b; Medves 2009). In seismic hazard analysis, the Vs at a given location is of interest because it gives an indication of whether the expected shaking in response to specified earthquake event may be high or low. Vs point data was obtained from the USGS Earthquake Hazards Program online data map (Yong 2015). Values from the southern California area were selected and exported in .csv file format. Some values lie to the north outside the study region, these are included so these locations could contribute to overall spatial continuity through spatial joins for soil and geological mapping units which lie in the study area and extend over the northern boundary. The .csv data contains 777 Vs points with latitude and longitude values, Vs values, total depth values, and the survey method used (Figure 7). The latitude and longitude point values were displayed using ArcMap and exported as a shapefile layer for the spatial join to soils and geological mapping unit data.

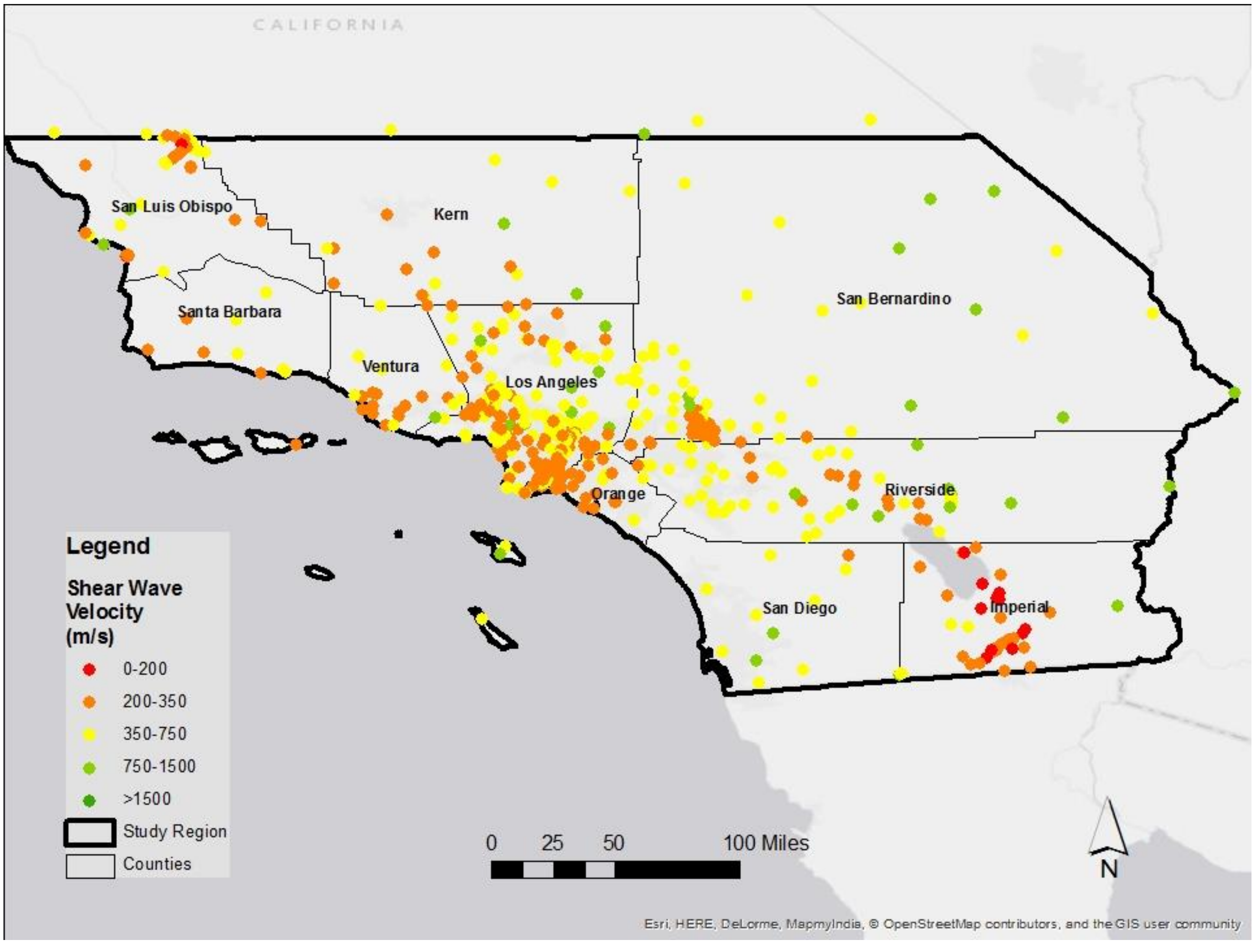

Figure 7 Study Region Shear Wave Velocity (Vs) Points

3.1.3. STATSGO2 Soils Maps

Statewide STATSGO2 soils maps were downloaded from the USDA Web Soil Survey data warehouse (Soil Survey Staff 2017). STATSGO2, the US General Soil Map, was developed by the National Cooperative Soil Survey. It is a broad-based inventory of soils and non-soils areas shown at a scale designed for planning and management over state and multistate areas. The dataset was created by generalizing more detailed soil maps (USDA 2017). For this reason, it was selected for this study region. Soil Taxonomy class names for the dataset are joined to the spatial data within ArcMap using the USDA Soil Data Viewer extension for ArcMap (Figure 8).

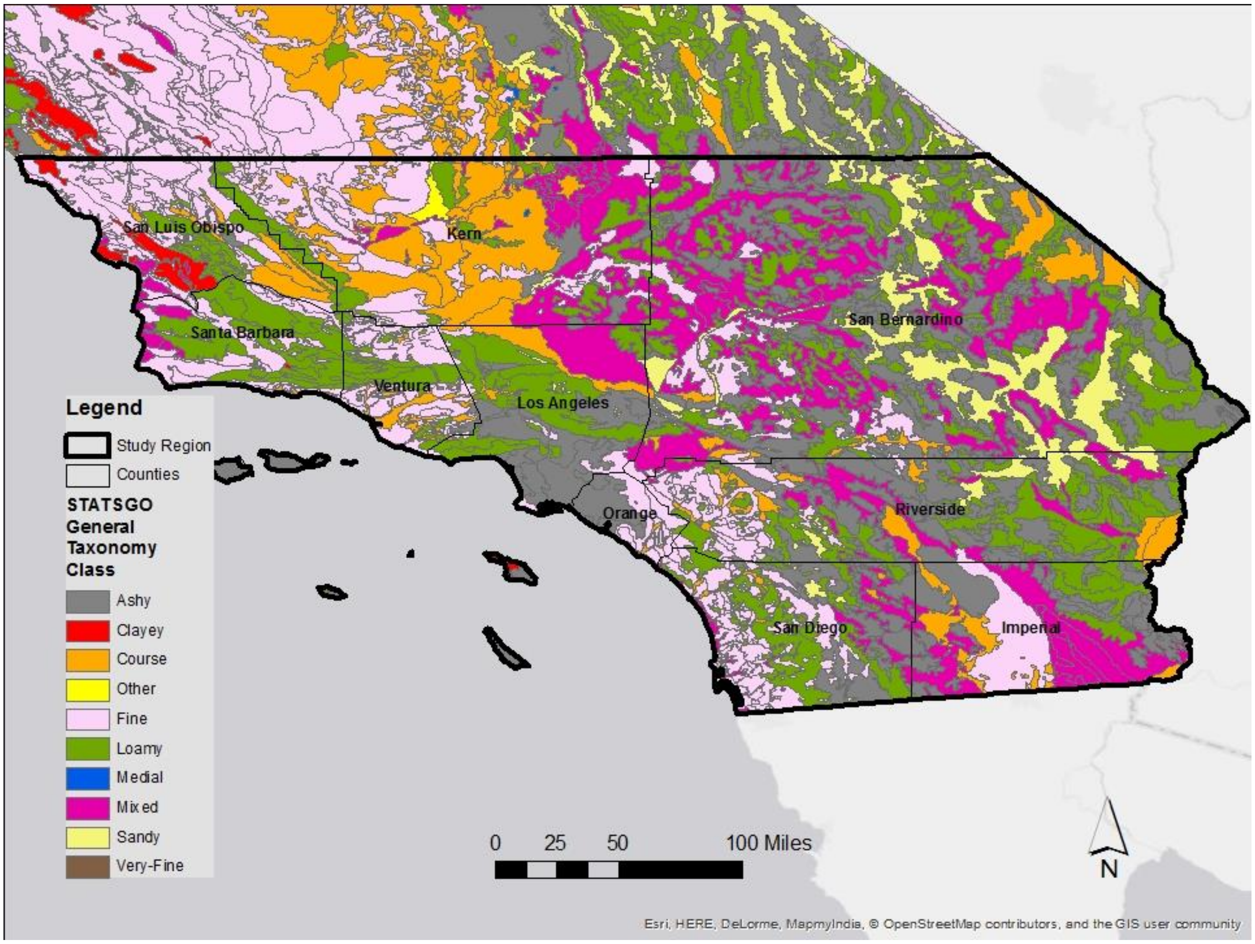

Figure 8 STATSGO2 General Soil Types for California

3.1.4. USGS Geological Unit Map for California

A Geological Units map for the state of California was downloaded from the USGS Mineral Resources online spatial data warehouse. The data was originally organized by Jennings et al. (1977) and updated by Ludington et al. in 2005. Intended to be combined into regional maps to depict age and lithology of map units, this data is aggregated for the state of California and is intended for geographic scales smaller than 1: 500,000. The field 'RockType1' is of main interest for this study area and describes the dominant lithology type in each mapping unit. The dominant lithology for southern California is Alluvium (Figure 9).

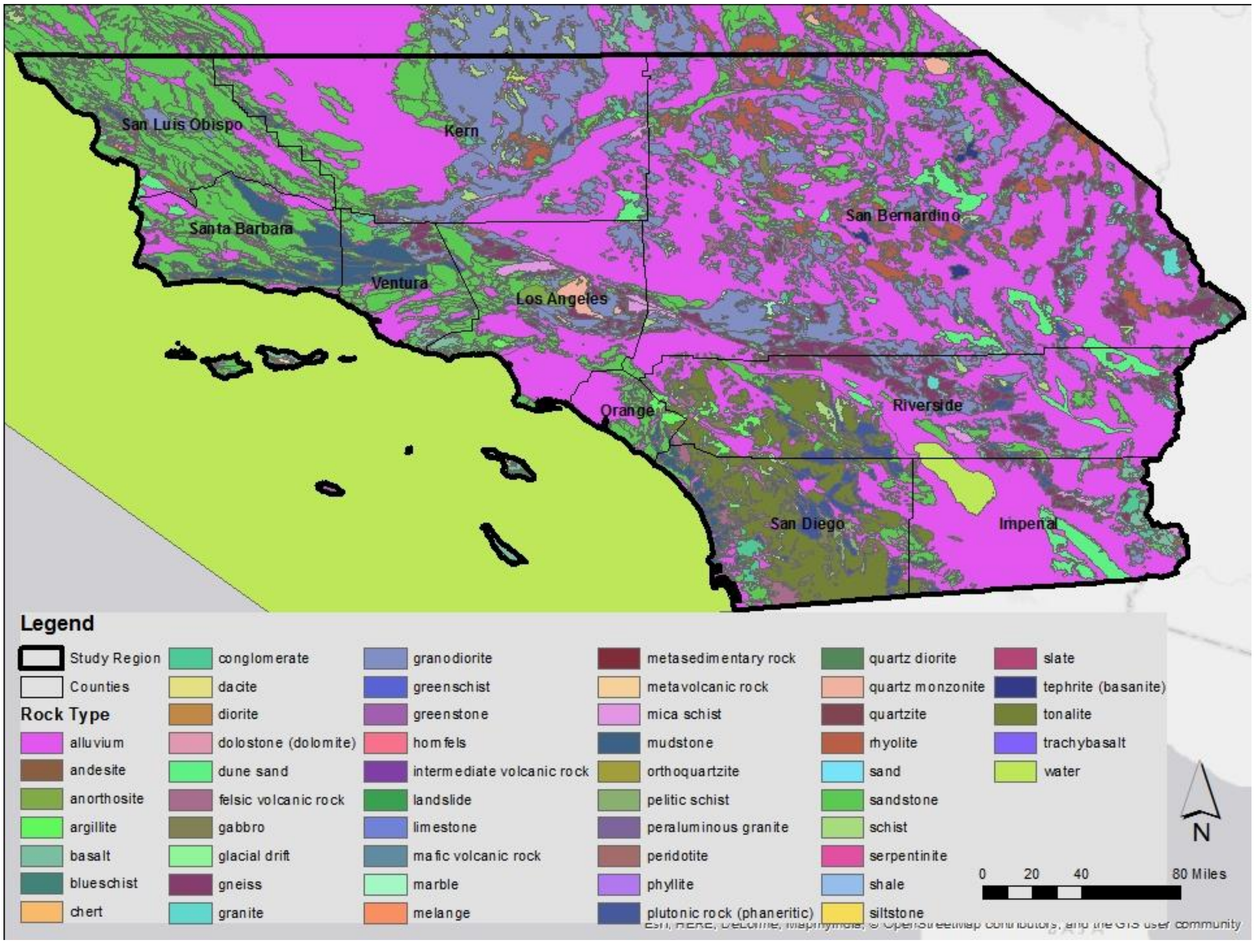

Figure 9 USGS Geological Units for California by Dominant Lithology

3.1.5. Custom NEHRP classified Soils Maps

Mapping unit polygons represent distinct soil or lithology classes. Vs data points were joined by spatial location to the mapping units they overlay. NEHRP classes of the mapping units were then determined by the mapping units' average Vs values and queried by a range of Vs values in NEHRP classes; these layers included a NEHRP Class field added and filled by class type. NEHRP classes range from Class A (highest Vs values and lowest amplification) to

Class E (lowest Vs values and highest amplification). Table 3 below displays the Vs range for each class and general lithology characteristics typical of that class. Average Vs point value data joined to STATSGO soil units or USGS GeoUnits serves as the ground truth Vs value for any individual mapping unit.

Table 3 NEHRP Classes by Vs Values (Definitions from USGS Earthquake Hazards Program)

NEHRP Soil Type	Shear Wave Velocity (Vs)	Generalized Lithology Definition
A	Vs > 1500 m/sec	Includes unweathered intrusive igneous rock. Soil types A and B do not contribute greatly to shaking amplification.
B	1500 m/sec > Vs > 750 m/sec	Includes volcanics, most Mesozoic bedrock, and some Franciscan bedrock.
C	750 m/sec > Vs > 350 m/sec	Includes some Quaternary sands, sandstones and mudstones, some Upper Tertiary sandstones, mudstones and limestone, some Lower Tertiary mudstones and sandstones, and Franciscan melange and serpentinite.
D	350 m/sec > Vs > 200 m/sec	Includes some Quaternary muds, sands, gravels, silts, and mud. Significant amplification of shaking by these soils is generally expected.
E	200 m/sec > Vs	Includes water-saturated mud and artificial fill. The strongest amplification of shaking due is expected for this soil type.

Mapping units with no data joined to them in either STATSGO or GeoUnit maps were assigned the average Vs value of all similar STATSGO taxonomy classes or GeoUnit rocktype1 classifications and given the appropriate NEHRP class category according to the average class value (Table 4 and Table 5). Soil taxonomy and rocktype1 classes with no Vs data were assigned NEHRP classes based on general lithology from the Geologic Map Unit Classification 6.1 guide (USGS Staff 2002) or soil class characteristics from the USDA Soil Taxonomy guide (USDA 1999) and similar rock domains while using the descriptions in Figure 10 as a guide.

Table 4 STATSGO Class Averages

Grouped Taxonomy Classes	Vs Avg	NEHRP Class	# Objects	# Vs Points
No Tax Name	584.2	C	407	374
Clayey-Skeletal	447.3	C	9	3
Coarse-Loamy	394.2	C	142	76
Fine-Loamy	410.9	C	228	70
Fine-Silty	403.3	C	7	3
Fine	496.9	C	112	97
Loamy-Skeletal	587.1	C	135	16
Loamy-Skeletal	616.3	C	162	61
Medial-Skeletal	ND	C	1	0
Mixed	461.5	C	110	54
Sandy-Skeletal	403.2	C	30	5
Sandy-Skeletal	451.5	C	10	3
Torriorthents	ND	C	3	0

*ND = No Data

Table 5 Geo Units Class Averages

RockType1	Avg Vs	NEHRP Class	# Objects	# Vs Points
Alluvium	401	C	401	442
Andesite	ND	B	13	0
Anorthosite	ND	C	8	0
Argillite	469.5	C	56	4
Basalt	634.6	C	198	4
Conglomerate	439	C	149	1
Dune Sand	285.3	D	33	2
Felsic Volcanic Rock	ND	B	89	0
Gabbro	533.5	C	111	2
Glacial Drift	ND	C	3	0
Gneiss	521	C	389	12
Granite	ND	C	73	0
Granodiorite	692.6	C	587	23
Greenstone	ND	C	27	0
Int. Volcanic Rock	ND	B	12	0
Landslide	ND	C	6	0
Limestone	ND	C	104	0
Marble	ND	C	22	0
Melange	ND	C	1	0
Metavolcanic Rock	ND	C	1	0
Mica Schist	401	C	33	2
Mudstone	580.5	C	146	3
Orthoquartzite	ND	C	2	0
Pelitic Schist	501	C	10	1
Peridotite	ND	C	1	0
Plutonic Rock	579.8	C	177	7
Quartz Diorite	756	B	2	1
Quartz Monozite	927	B	11	1
Rhyolite	589	C	489	4
Sandstone	458.3	C	1249	36
Schist	893	B	224	2
Serpentinite	505	C	43	1
Siltstone	ND	C	1	0
Tephrite (basinite)	ND	B	6	0
Tolanite	654.7	C	120	12
Water	636.3	C	174	5

ND = No Data

A significant portion of the study region was classified as other than NEHRP Class D (the default HAZUS soils class for the study area). Type B and C NEHRP soils were identified throughout the study area, each class has higher Vs values than Class D, which attributes lower shaking amplifications to these soils and a lower hazard level. These results for the NERHP classifications for both STATSGO and GeoUnit maps (Figure 10 and Figure 11) confirm the Neighbors et al. (2013) finding that hazard maps with local user-defined data decrease HAZUS loss outputs due to the default soil class for HAZUS models being set as Class D.

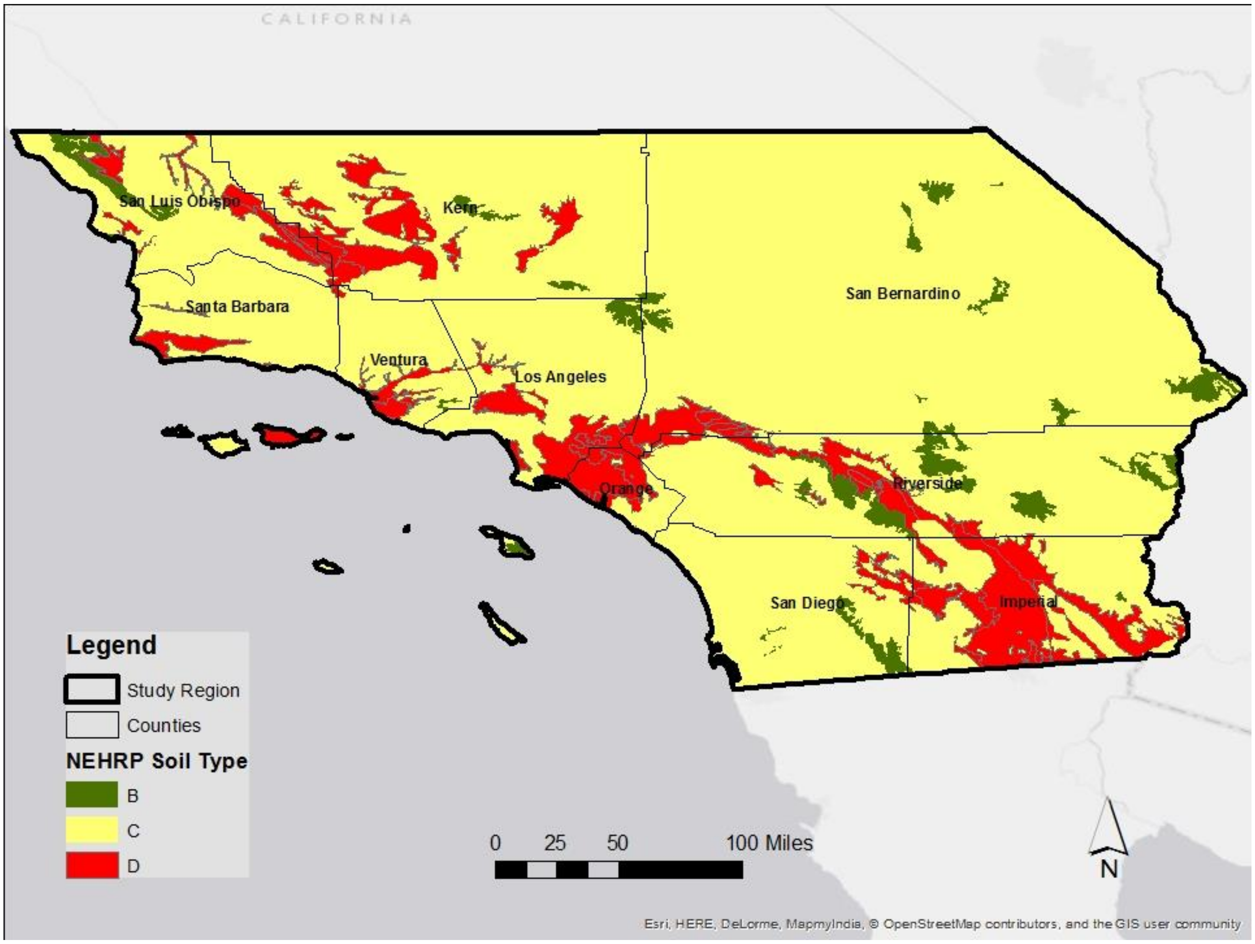

Figure 10 STATSGO NEHRP Soil Class by Type

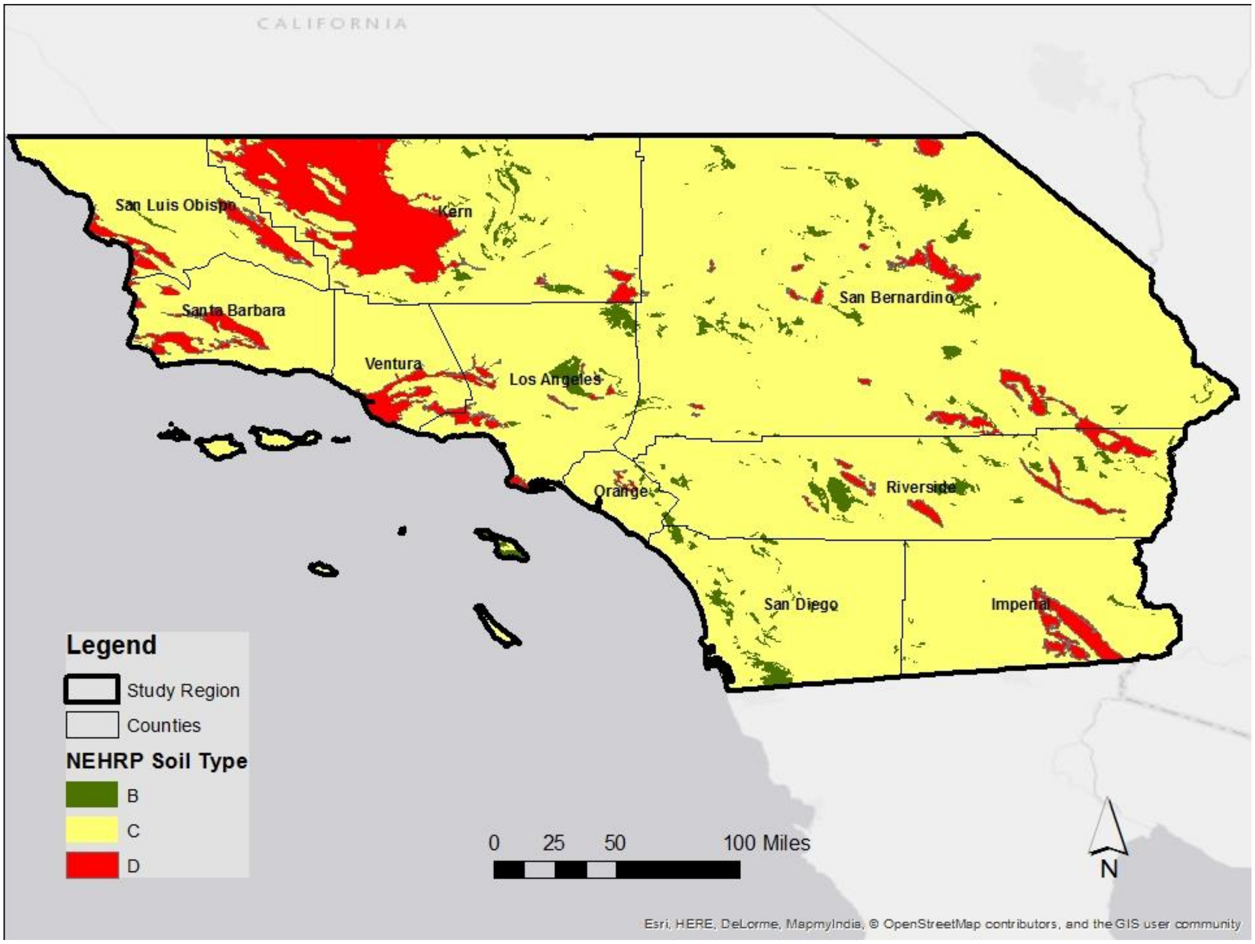

Figure 11 USGS CA Geological Units by NEHRP Class Type

Once all soil and geological units were NEHRP classified the datasets were formatted for upload to the HAZUS hazard scenario data maps according to Appendix K in the HAZUS User Manual (FEMA 2015a).

3.1.6. USGS Scenario ShakeMaps

Scenario ShakeMaps are hypothetical earthquake scenarios created by the USGS that adhere to the known characteristics of a specific fault and display rupture length and ground motion data as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Spectral Acceleration at 0.3 seconds (SA0.3), and Spectral Acceleration at 1.0 seconds (SA1.0) (USGS 2016). ShakeMap datasets account for all necessary ground motion data needed for HAZUS analysis. Epicenter, rupture length, depth, moment magnitude, and fault type data compiled by USGS scientists are incorporated into this HAZUS scenario event data, removing significant uncertainty and user-input mistakes regarding the hazard event. Two Scenario ShakeMaps were selected and downloaded from the online USGS Earthquake Scenario Map (USGS 2017) to represent a range of predicted magnitudes from UCERF3 for the area around Gorman, CA. One M8.0 ShakeMap and one M7.4 ShakeMap with both epicenters a few miles apart on the southern San Andreas Fault Carrizo Section which was identified as having the highest probability of a M8.0 or greater event, shown below in Figure 12 and Figure 13. The event parameters from these ShakeMaps, such as latitude and longitude location of the epicenter, fault section, and magnitude were used to define the two earthquake scenarios for the other datasets tested in this study. These ShakeMaps from the USGS Scenario Map were downloaded as shapefiles in HAZUS format and were transferred to a .mdb HAZUS compatible database format for upload to the hazard data maps.

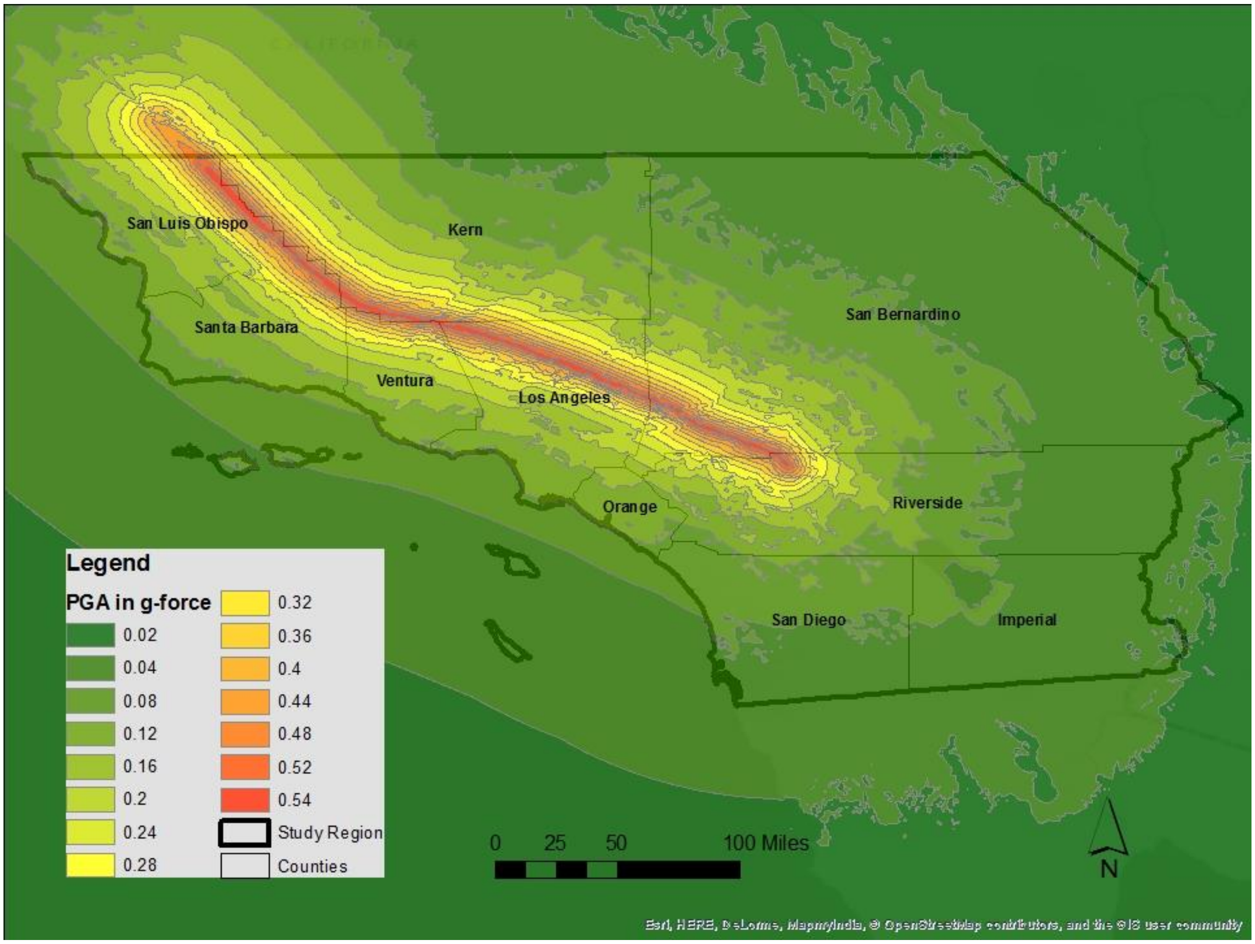

Figure 12 M8.0 Scenario ShakeMap Peak Ground Acceleration in G-Force

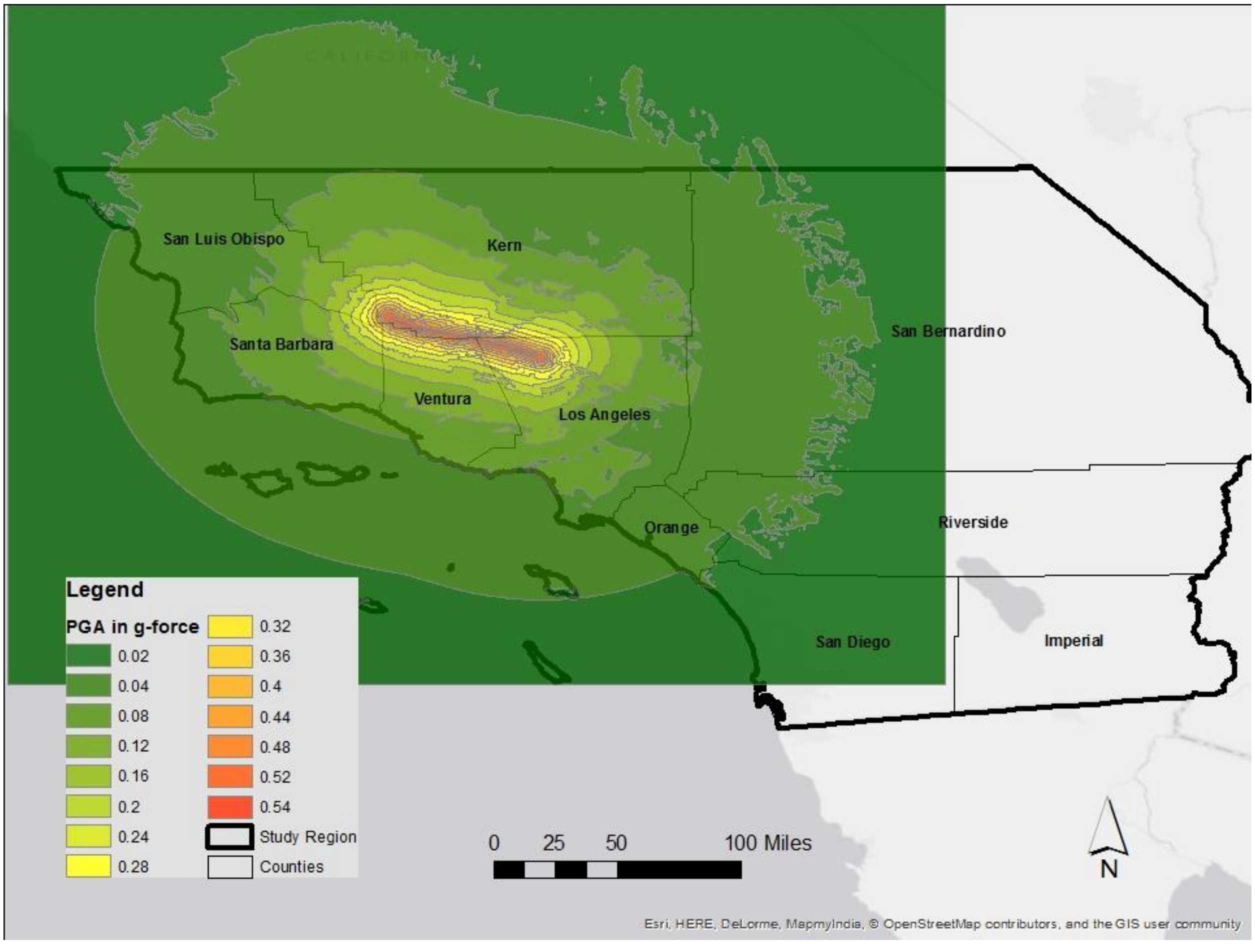

Figure 13 M7.4 Scenario ShakeMap Peak Ground Acceleration in G-Force

3.1.7. FHWA National Bridge Inventory

Prepared, but not used in this analysis due to current technical problems with the HAZUS CDMS. 2015 NBI data is updated bridge point data downloaded from the Federal High Way Authorities' National Bridge Inventory website. Highway bridge data is part of the HAZUS Transport Systems module and must be uploaded through the CDMS before the study region, and hazard scenario parameters are established. This data was intended to replace the default HAZUS bridge data in the statewide dataset, which is based on older 2010 NBI data. HAZUS bridge class designations were determined by querying and compositing several NBI fields, 20 different HAZUS bridge classes were identified for the study region (Figure 14) and 9 other NBI fields were identified for field matching in the CDMS. One deficiency in user-supplied NBI data is that replacement costs for bridge points are not a field in the NBI dataset but are defined in HAZUS default data. However, uploading this data into the CDMS exposed a field mismatch in the CDMS and made this dataset inaccessible for analysis runs until the HAZUS development team can fix the problem in the next version of HAZUS/CDMS.

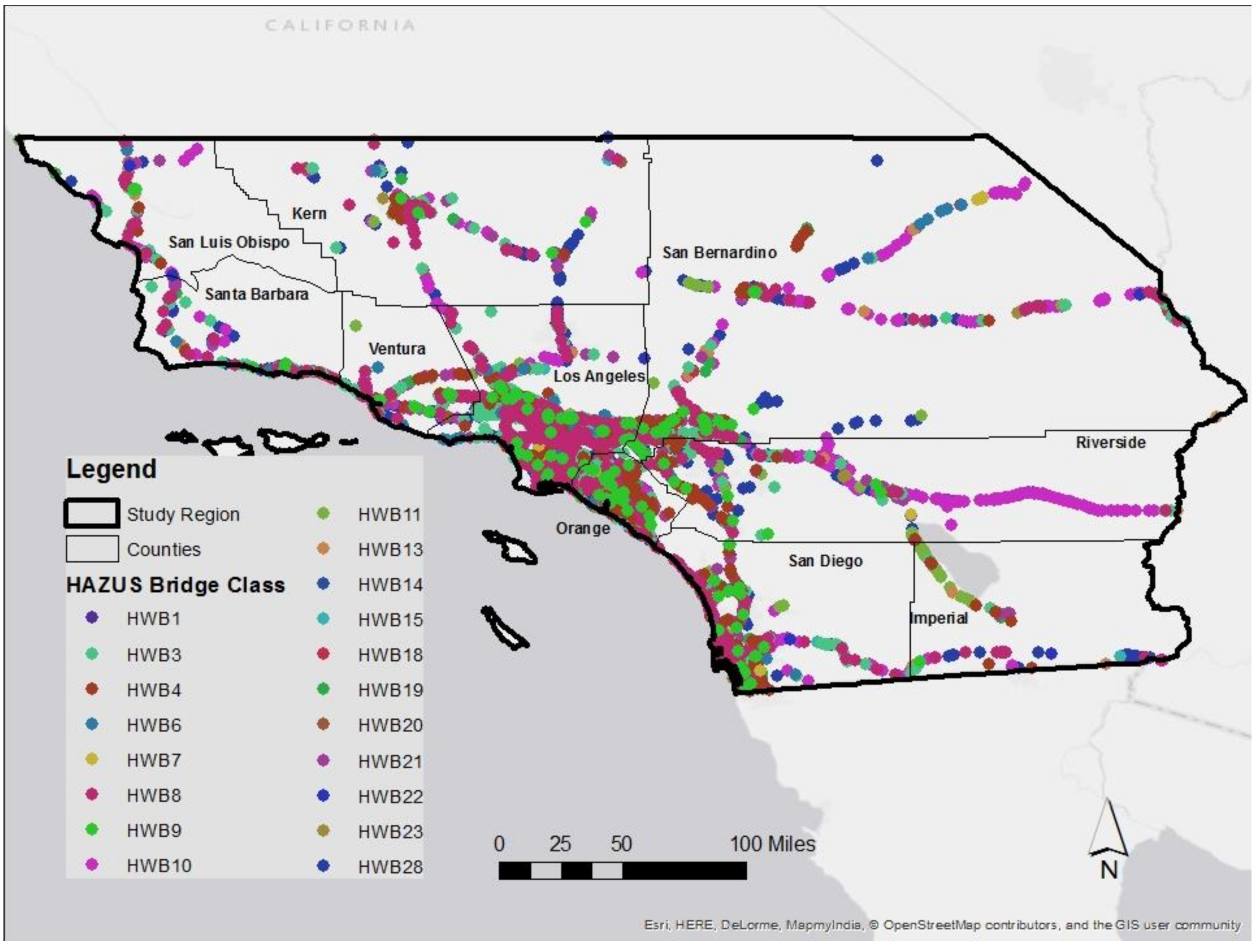

Figure 14 2015 National Bridge Inventory National Highway System Bridges by HAZUS Bridge Class. Please see Appendix A for HWB definition table

3.2. HAZUS Earthquake Modeling using Soils Maps and ShakeMaps

HAZUS default data defaults all soils as in its inventory as NEHRP type D. Adding a regional soils map to the analysis dataset will classify the various soils that the building and infrastructure inventory overlays as one of five NEHRP soils classes designated as soil type A thru E (fig 10). Different soil types transfer earthquake wave energy with varying intensity, with soft-soils (class E) providing the greatest amplification. Classifying NEHRP types within established soils units will lead to more accurate regional analysis when compared to the default soil type 'D.' ShakeMaps provide historical or probable snapshots of earthquake ground motion parameters and allow HAZUS to use these values to more accurately predict ground shaking. Neighbors 2013 identified generally lower earthquake damage and ground motion output values when using user-supplied data (Neighbors et al. 2013). Using soils and ShakeMaps in the current HAZUS analysis will remove some model uncertainty with respect to ground motion and soil amplification and provide more accurate bridge damage outputs from my infrastructure data.

3.2.1. Setting up HAZUS and loading User Supplied Datasets

Setting up HAZUS for analysis first involves downloading a state-specific dataset from the FEMA website, unpacking it and designating the database path in the CDMS options menu. Upon opening HAZUS, the user is asked to create or import a study area. The hazard mode (Earthquake in this project) was selected, and the analysis aggregation scale was set to 'County' level, then individual counties for southern California were selected, the study region was then generated from the statewide data and saved to be used for multiple run scenarios.

User-supplied data is uploaded to HAZUS through the 'Data Maps' option in the hazard setup menu or through CDMS upload to the statewide dataset. NEHRP classified soil maps and PGA, PGV, PSA0.3, and PSA1.0 data from Scenario ShakeMaps are input into 'Data Maps' in the HAZUS Hazard drop-down menu. Once imported to the Data Maps menu, soils maps are selected for the current hazard scenario by opening the scenario wizard and selecting 'Define Data Maps' option and setting the soils drop-down menu to the desired map previously uploaded to the Data Maps table. The software then applies this map to the study region and updates inventory tables to reflect the soil type the inventory data overlays. Scenario ShakeMap data are constructed by USGS for hypothetical earthquake events and are intended for planning purposes only. Scenario ShakeMap data is input into a study region scenario through the scenario setup wizard in the Hazard drop-down menu. A deterministic User-Defined scenario must be selected to input the Data Maps established for the ShakeMap defined PGA, PGV, PSA0.3, and PSA1.0 contour maps. These maps account for all ground motion data to be calculated by the software, which makes soil map data unnecessary (FEMA 2015b).

3.2.2. Setting Hazard Event Scenarios and Running Analysis

UCERF3 earthquake probabilities data for California was used to reference the fault section with the highest probability for a great (M>8.0) earthquake in southern California. This data showed the San Andreas-Carrizo fault section with an epicenter near Gorman, CA to have the highest probability of a M8.0 or greater earthquake in all southern California. Setting the hazard event scenarios for this project involved using the Scenario setup wizard to create two deterministic User-Defined scenarios using ShakeMap datasets to define the hazards, two deterministic Source scenarios using STATSGO and GeoUnit based NEHRP classified soils maps, and two Source scenarios using only default HAZUS data and no user-supplied soils maps or ShakeMaps. Two USGS ShakeMaps at M8.0 and M7.4 were selected from the USGS website. The M8.0 ShakeMap has an epicenter in Gorman, CA and the M7.4 ShakeMap has epicenter a short distance to the east in the town of Fraser Park, Ca. For accurate comparison, the event parameters for magnitude, epicenter location, and source fault of these two ShakeMaps were used to define the same event parameters for the Source scenarios. Once the hazard scenarios were input, the relevant HAZUS analysis modules to use in the model were selected, and the analysis run. With only the Transportation-Highway Bridges analysis selected (7 modules needed to analyze the data), each scenario for southern California only took several minutes for HAZUS to process. Uploaded ShakeMaps data in the user-defined scenarios took several minutes of processing time. Uploading a soils map in the define hazards wizard took at least an hour of processing time for HAZUS and often crashed before applying the soil map NEHRP values to inventory datasets. Uploading soils maps was the most problematic, as after the wizard was done processing, the maps would show as 'current' in the 'display current hazard' window, but the inventory data was not updated. After uploading it is necessary to check the Inventory-Transportation Systems drop-down menu to confirm that the study region bridge inventory soil class has been updated to the soil map and does not display only the default HAZUS value of class 'D'.

3.2.3. Exporting HAZUS Output Data

Once HAZUS had finished an analysis, individual output layers must be called to ArcMap from the 'Results' tab Transportation Systems option. Bridge damage state probability data were mapped from the results tab and exported as layer files to into a created file geodatabase. One result layer for highway bridge damage will contain all damage state probabilities in its attribute table. The damage state probabilities of 'Exceeding Moderate,' 'Exceeding Extensive,' and 'Complete' damages are the fields of interest to this projects bridge closure analysis.

3.3. Bridge Closure Analysis

For this project, HAZUS was used to output predicted bridge damage state probabilities for each scenario (2) and dataset (4) modeled. Damage state probabilities are output as attribute table fields in the results point data for bridges. These indicate the 0.0 to 1 probability that an individual bridge will be in a discrete slight/moderate/extensive/complete damage state, as well as cumulative damage states labeled as at least slight/moderate/extensive. HAZUS leaves the significance threshold for damage state probabilities are open to user interpretation. To assess regional bridge closures and restrictions, this research relied on previous studies significance thresholds for reporting damage states, then used bridges meeting the stated damage state probability threshold as actual damage states corresponding to closure and restriction criteria suggested by Richardson et al. (2015).

3.3.1. Bridge Damage States to California Bridge Closures

Relative damage state probabilities, such as ‘moderate’ and ‘extensive’ are how HAZUS and similar earthquake models output structural damage for building and lifelines like bridges. Other research has used different levels of probability as thresholds for accepting that a structure will reach this damage state for reporting losses. Kircher et al. (2006) discusses median demand parameters for ground shaking and the effect on damage state variability. When comparing predicted HAZUS building losses using ShakeMaps to actual data from the Northridge earthquake the number of buildings with extensive or complete damage, the accepted probability thresholds were not explicitly stated but might be implied in a an example fragility curve table at 50%. Barbat et al. (2008) examined predicted earthquake building losses in Barcelona and identified probabilities in the 30-40% range as significant for severe damage states. Curtis (2016) used a 20% probability threshold for moderate bridge damage states while using HAZUS for transportation network analysis. The California Geological Survey in its June 2009 Project Report on HAZUS Loss Estimation for California Earthquakes (CGS 2009) Reported moderate bridge damage at 50% or greater damage state probabilities. Per the CGS report, this analysis will use a 50% probability threshold for identifying ‘at least moderate’ and ‘at least extensive’ damage to bridges for means of identifying bridge closures and restrictions.

The Bridge Damage Index (BDI) method is how seismic engineers assess specific bridge damage during field inspections (Park 2001; Shiraki 2007). Actual bridge closures and restrictions are dependent on the relative rules and acceptable risk policies of transportation departments in each state. Since earthquakes are common events in California, the bridge infrastructure was constructed with high seismic risk considerations and the state DOT is more liberal than other states when determining the minimum BDI for full bridge closure (Richardson 2015). Levels of closure and restriction are important for emergency response and economic recovery, as even though the southern California road network is highly redundant, closing a bridge that could handle restricted traffic in the hours, days, or weeks after this event will affect access to casualties and shelter points as well as have significant indirect economic impact. Richardson et al. suggests that for states like California, management strategies for moderately damaged bridges can maintain limited levels of traffic capacity and allow restricted access, while severe or extensive damage states would still pose an unacceptable risk and be closed to all traffic. Its accepted that slightly damaged bridges will remain open with minimal risk and return to full functionality days after the earthquake event. The bridge closure threshold for Richardson et al. was set at 0.75 BDI, which corresponds to the ‘severe/extensive’ damage state. Traffic restrictions begin at 0.33 BDI, which corresponds to ‘moderate’ damage states. For the current analysis, Bridges with probabilities of 0.5 or greater for at least moderate or extensive damage states were assigned corresponding traffic restrictions and closures by adding an attribute field indicating C (closed) or R (restricted). The query for at least moderate damage excluded bridges that also met probability requirements for at least extensive damage.

Chapter 4 Results

This chapter is divided into three parts. The first section provides a summary of the final results from the bridge closure analysis. The second section provides results from each of the eight HAZUS runs as well as a map for each run with outputs displayed for bridge damage probabilities exceeding at least moderate damage states. The final section examines the eight runs in terms of bridge closures and restrictions derived from the cumulative damage state probabilities.

4.1. Final Results Summary

ArcMap layers were exported from HAZUS results according to each of the two earthquake scenarios and the soils or ShakeMap dataset used in the analysis. Due to the rather high levels of minimum damage states and probability thresholds required for analysis a small percent of the total bridge inventory was identified for closures or restrictions in either scenario. In general, those bridges closest to the fault rupture zone returned the highest probabilities for damage to exceed moderate or extensive and therefore be closed or restricted. However, all 8 hazard scenario runs derived restricted bridges and 6 of 8 runs derived closed bridges. These results are provided in detail in Table 6 at the end of section 4.3

As expected, the model runs using default data generally produced higher damage states due to higher soil amplifications from the default HAZUS soil class of NEHRP type D. The one unexpected exception is the M8.0 Scenario ShakeMap which produced several times the number of bridge closures and restrictions over a much larger spatial extent as the M8.0 default data run.

4.2. Bridge Damage Probabilities to Exceed At Least Moderate Damage

The results in the sub-sections below indicate the range of probability a bridge point will sustain at least moderate damage. These probability levels were chosen to illustrate bridges that could be damaged by the scenario but did not meet the 50% or greater probability requirement to be included in the bridge restrictions and closures analysis. Bridges not meeting the significant probability requirement are displayed with ranges of 15-49.9% probability of at least moderate damage. Only those bridge points in red indicate bridges with at least moderate damage probabilities of 50% or greater and were determined to be restricted or closed based on the probability for at least extensive damage also to be 50% or greater.

Describing the effects of each scenario on the whole dataset of 9,516 bridge points can be challenging even with maps. The sum of predicted economic losses for the whole bridge inventory is reported as well as the number of bridges that exceed 15% probability of at least moderate damage. These values are summarized in Table 6 at the end of this section.

4.2.1. M7.4 Scenario ShakeMap

The M7.4 Scenario ShakeMap run results (Figure 15) produced 43 bridges with greater than 15% probability of at least moderate damage. HAZUS predicts a total bridge economic loss of $13,991,710.

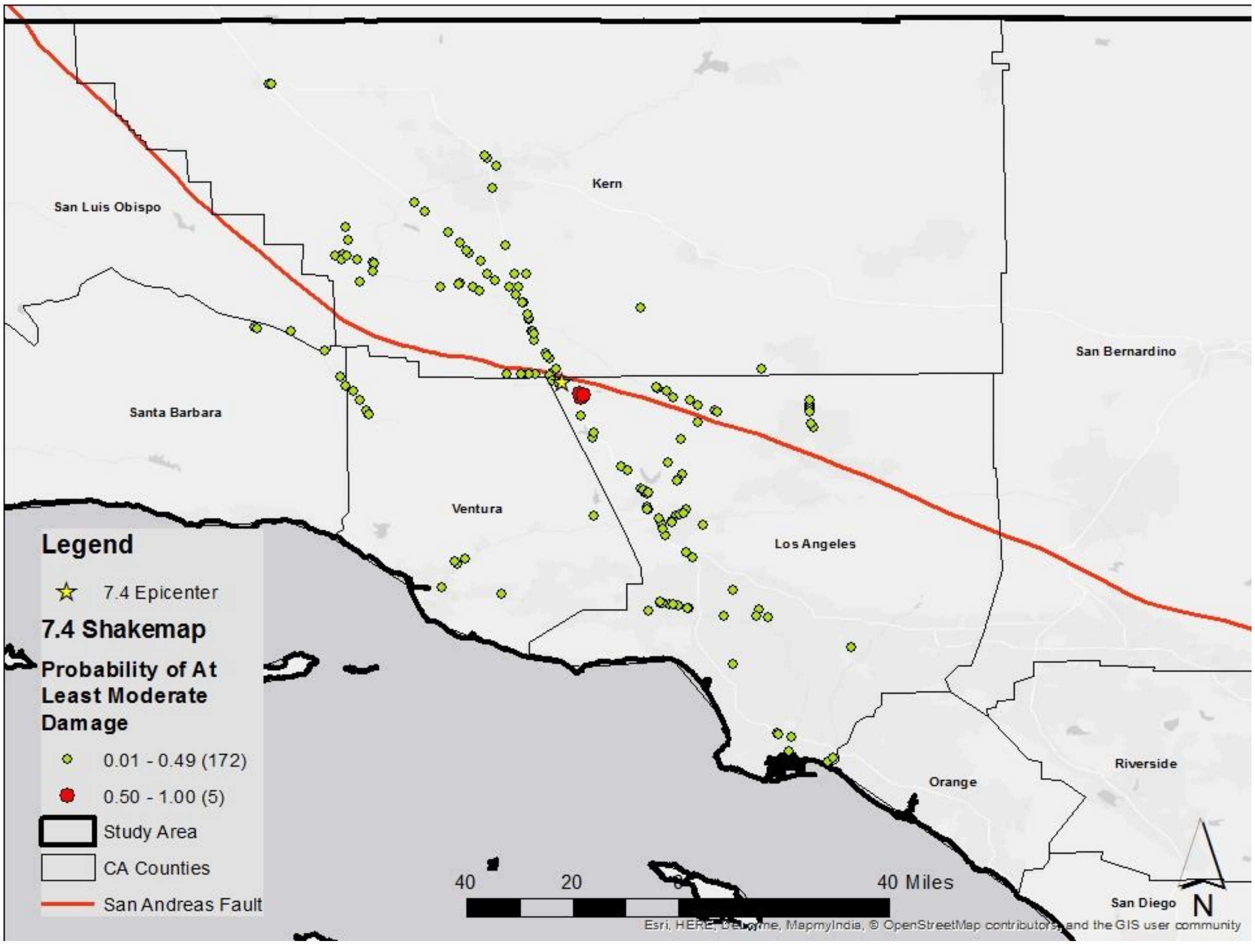

Figure 15 M7.4 ShakeMap At Least Moderate Bridge Damage Probabilities

(Point Counts in Parenthesis)

4.2.2. M7.4 NEHRP STATSGO Data Map

The M7.4 STATSGO run results (Figure 16) produced 32 bridges with greater than 15% probability of at least moderate damage. HAZUS predicts total bridge damage related economic loss of $13,971,880.

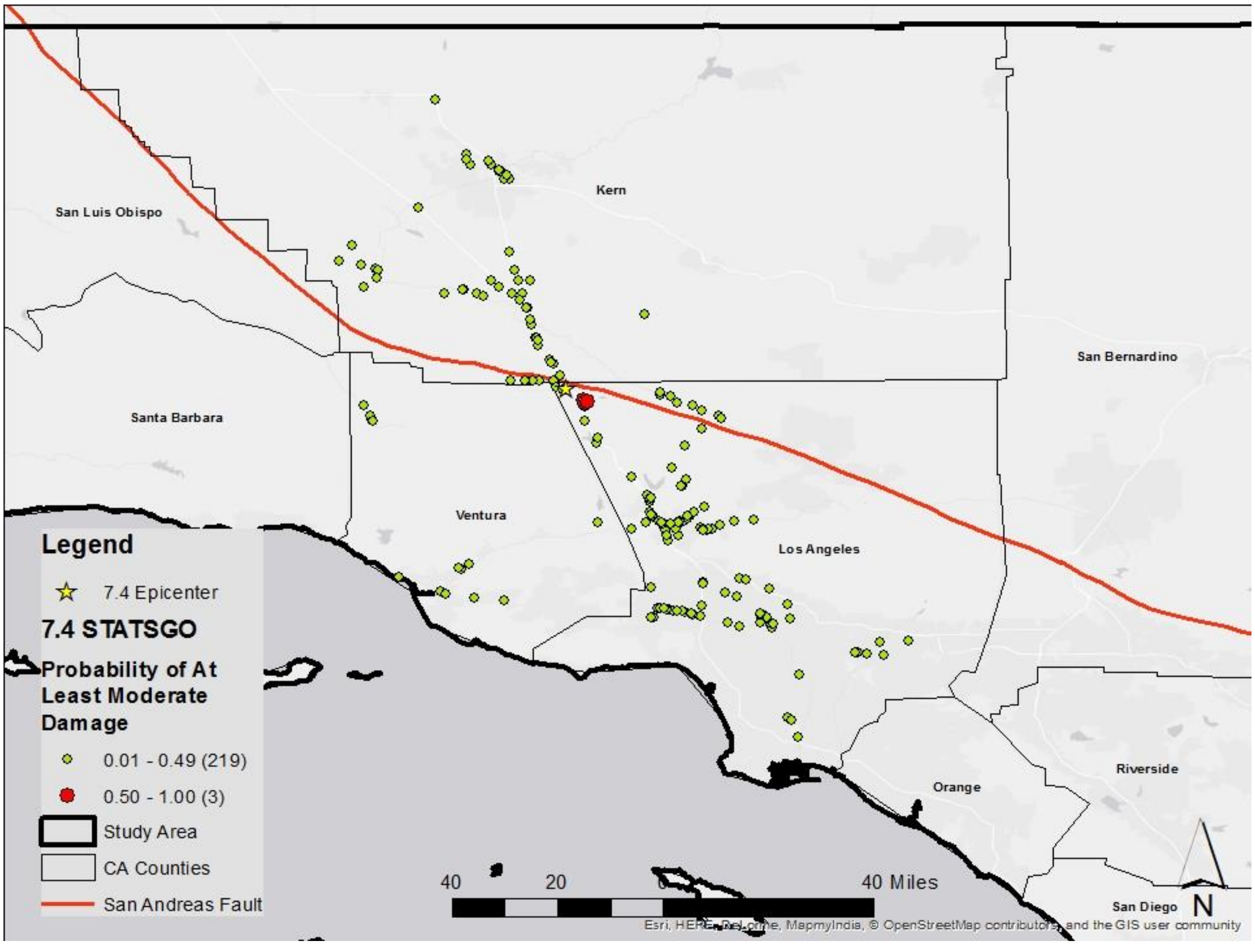

Figure 16 M7.4 STATSGO At Least Moderate Bridge Damage Probabilities

(Point Counts in Parenthesis)

4.2.3. M7.4 NEHRP GeoUnit Data Map

The M7.4 Geological Units run results (Figure 17) produced 32 bridges with greater than 15% probability of at least moderate damage. HAZUS predicts total bridge damage related economic loss of $10,545,840.

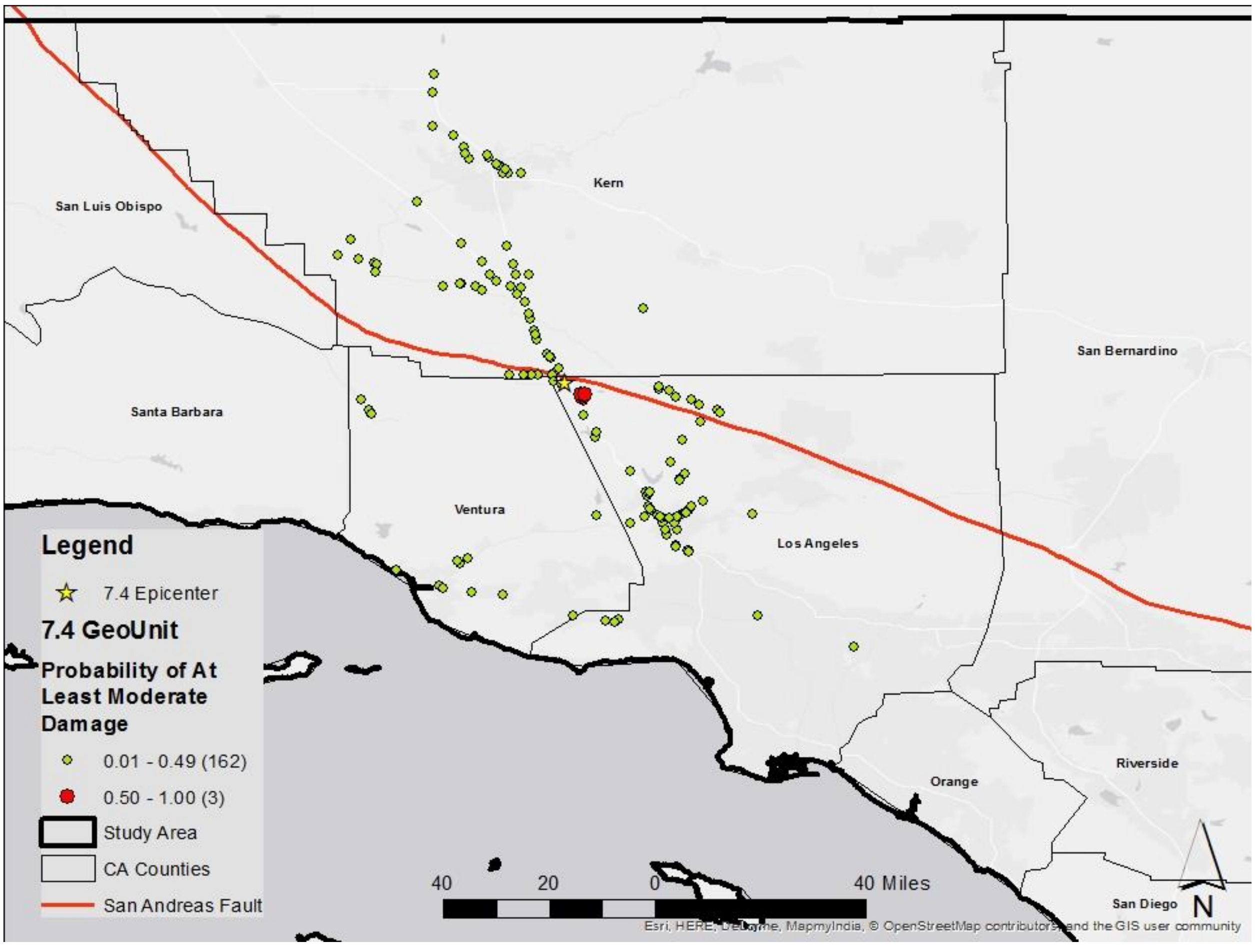

Figure 17 M7.4 Geologic Units At Least Moderate Bridge Damage Probabilities

(Point Counts in Parenthesis)

4.2.4. M7.4 No User-Supplied Data

The M7.4 Default data run results (Figure 18) produced 50 bridges with greater than 15% probability of at least moderate damage. HAZUS predicts total bridge damage related economic loss of $20,189,830.

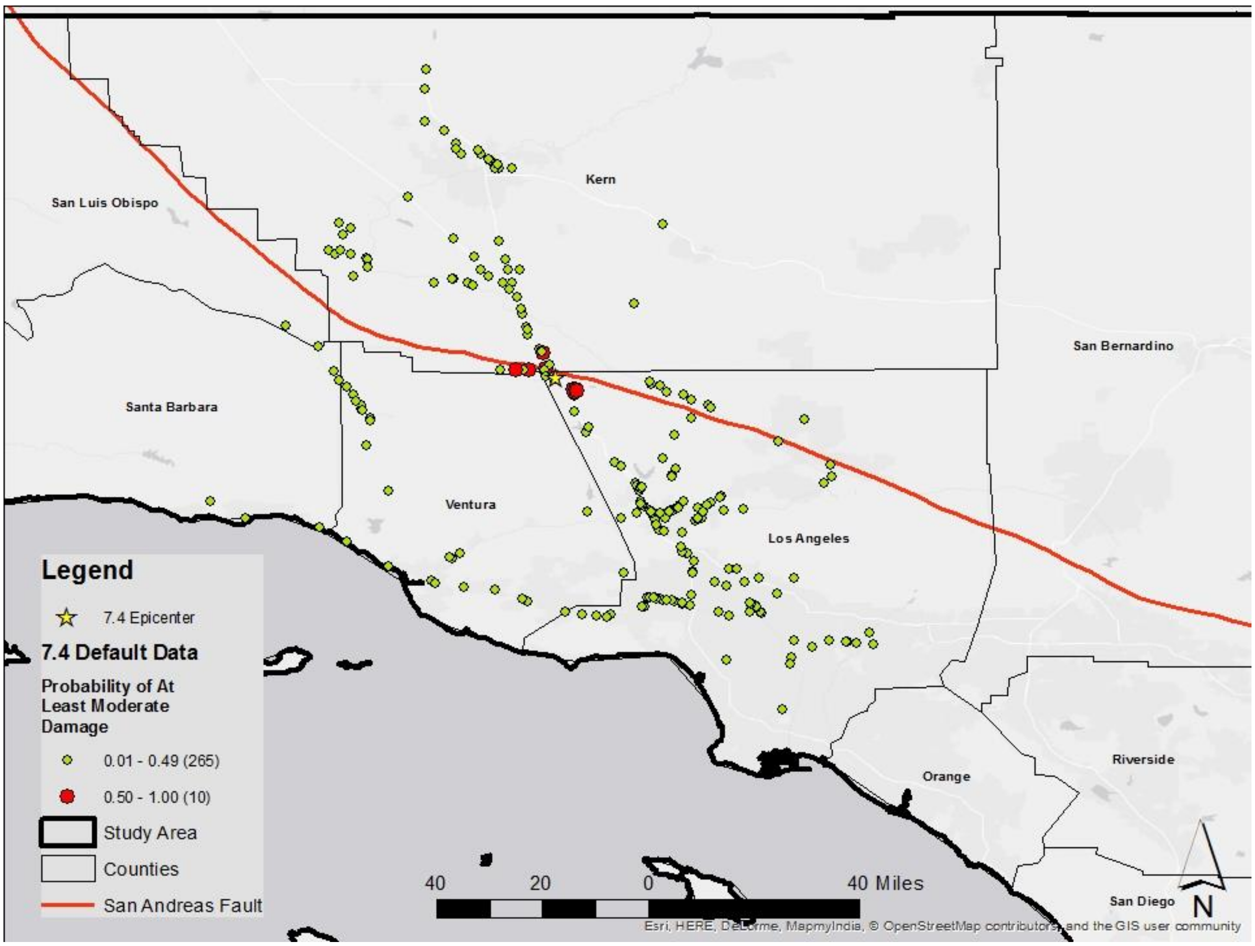

Figure 18 M7.4 Default Data At Least Moderate Bridge Damage Probabilities

(Point Counts in Parenthesis)

4.2.5. M8.0 Scenario ShakeMap

The M8.0 Scenario ShakeMap results (Figure19) produced 707 bridges with greater than 15% probability of at least moderate damage. HAZUS predicts total bridge damage related economic loss of $284,880,410.

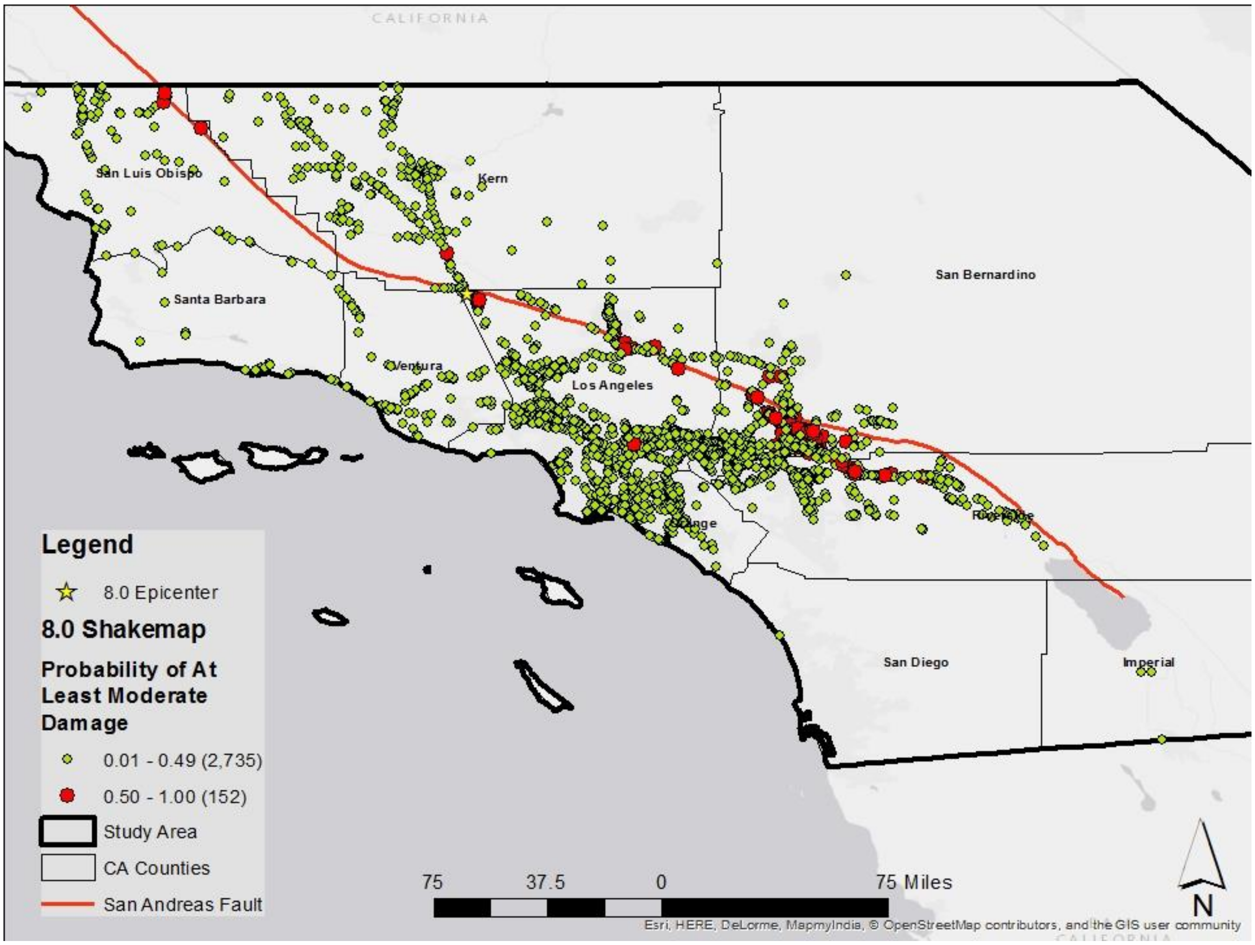

Figure 19 M8.0 ShakeMap At Least Moderate Bridge Damage Probabilities

(Point Counts in Parenthesis)

4.2.6. M8.0 NEHRP STATSGO Data Map

The M8.0 STATSGO run results (Figure 20) produced 85 bridges with greater than 15% probability of at least moderate damage. HAZUS predicts total bridge damage related economic loss of $56,776,890.

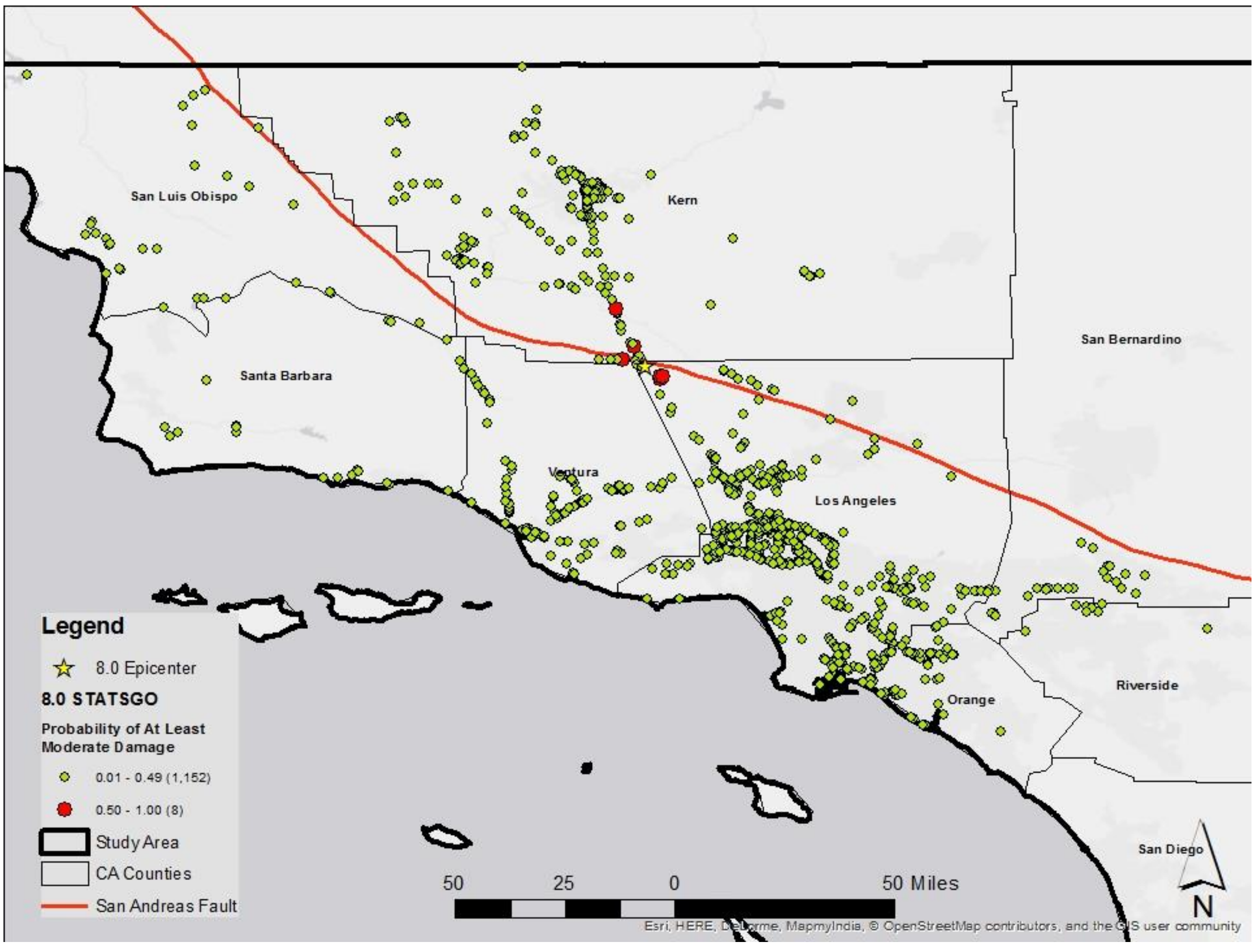

Figure 20 M8.0 STATSGO At Least Moderate Bridge Damage Probabilities

(Point Counts in Parenthesis)

4.2.7. M8.0 NEHRP GeoUnit Data Map

The M8.0 Geological Units run results (Figure 21) produced 74 bridges with greater than 15% probability of at least moderate damage. HAZUS predicts total bridge damage related economic loss of $33,805,660.

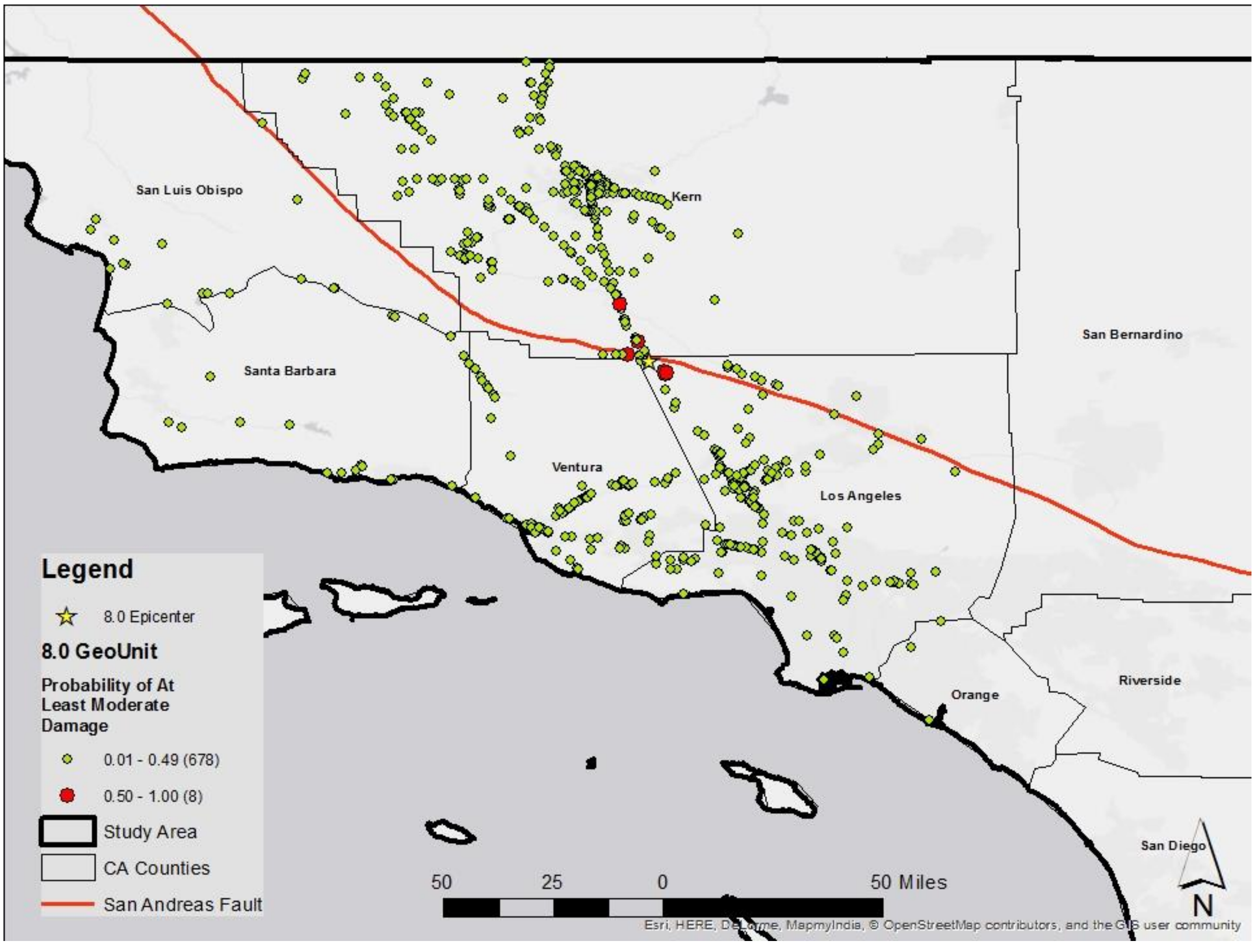

Figure 21 M8.0 Geo Unit At Least Moderate Bridge Damage Probabilities

(Point Counts in Parenthesis)

4.2.8. M8.0 No User-Supplied Data

The M8.0 default data run results (Figure 22) produced 102 bridges with greater than 15% probability of at least moderate damage. HAZUS predicts total bridge damage related economic loss of $80,541,180.

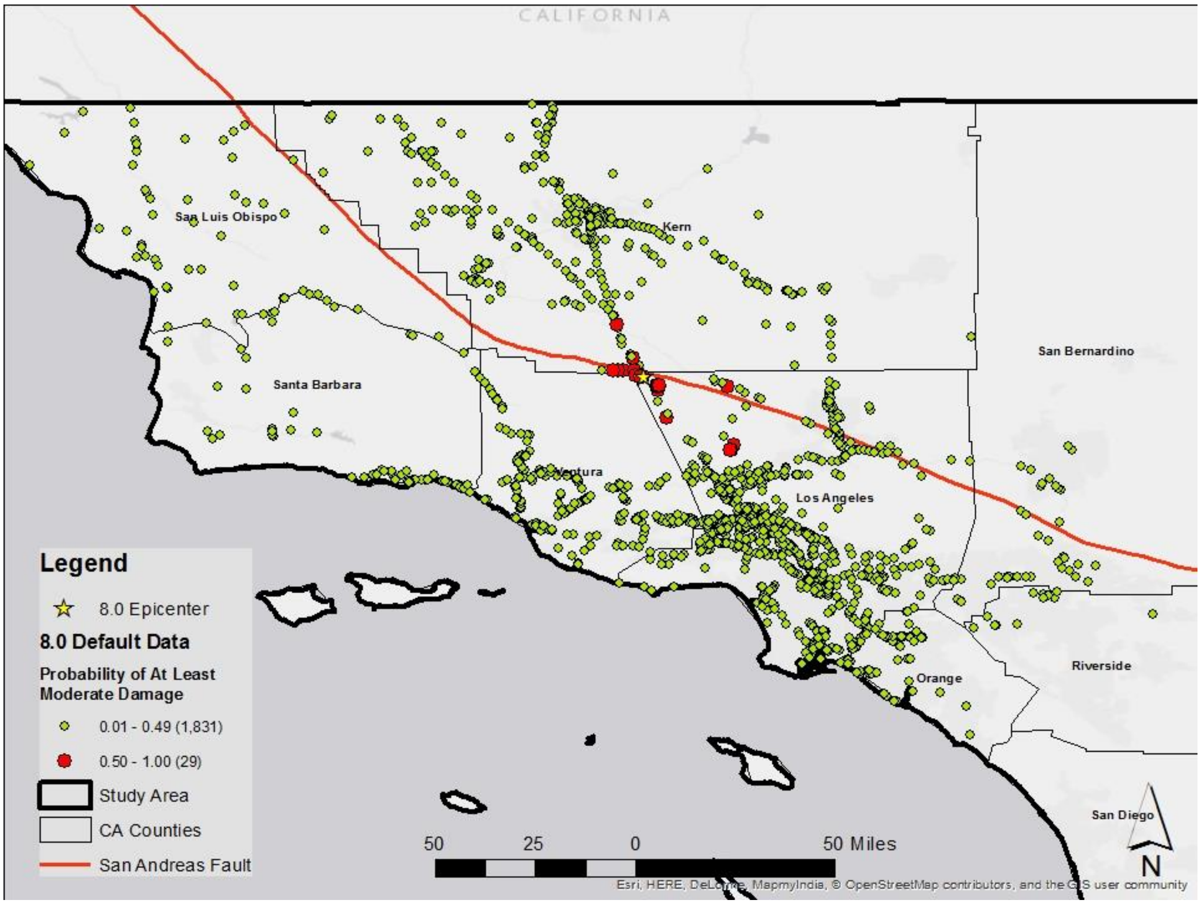

Figure 22 M8.0 Default Data At Least Moderate Bridge Damage Probabilities

(Point Counts in Parenthesis)

Table 6 Economic Losses and >15% Probability of At Least Moderate Damage

Bridges	Sum of Economic Losses	# with > 15% prob of At Least Moderate Damage
M7.4 GeoUnit	$10,545,840	32
M7.4 STATSGO	$13,971,880	32
M7.4 ShakeMap	$13,991,710	43
M7.4 Default Data	$20,189,830	50
8.0 GeoUnit	$33,805,660	74
M8.0 STATSGO	$56,776,890	85
M8.0 ShakeMap	$284,880,410	707
M8.0 Default Data	$80,541,180	102

4.3. Bridge Restrictions and Closures Analysis Results

This map series depicts bridge restrictions and closures derived from damage state probabilities according to Richardson et al. (2015). These are determined by greater than 50% probability of at least moderate damage for restrictions and greater than 50% probability of at least extensive damage for full closure. A number of either restrictions or closures is reported, this data is displayed in Figure 23 through Figure 30 below, and is summarized in Table 7 at the end of this section.

4.3.1. Regional Bridge Closures

The M7.4 ShakeMap run, returned four restrictions and one closure, all just south of the epicenter at the junction of Interstate 5 and Hwy 138 (Figure 23).

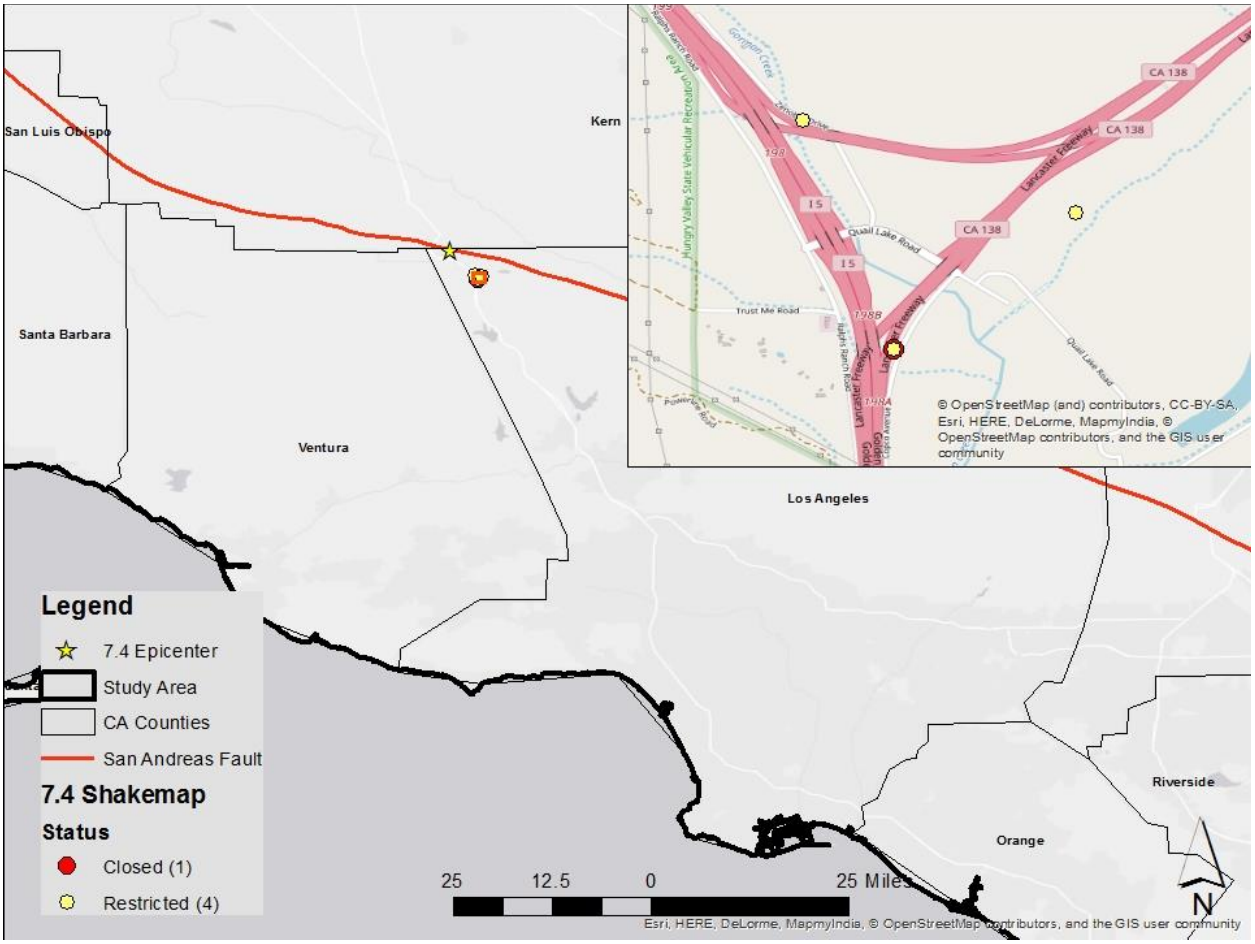

Figure 23 M7.4 ShakeMap Restrictions and Closures

(Point Counts in Parenthesis)

The M7.4 STATSGO run, returned three restrictions and no closures, all just south of the epicenter at the junction of Interstate 5 and Hwy 138 (Figure 24).

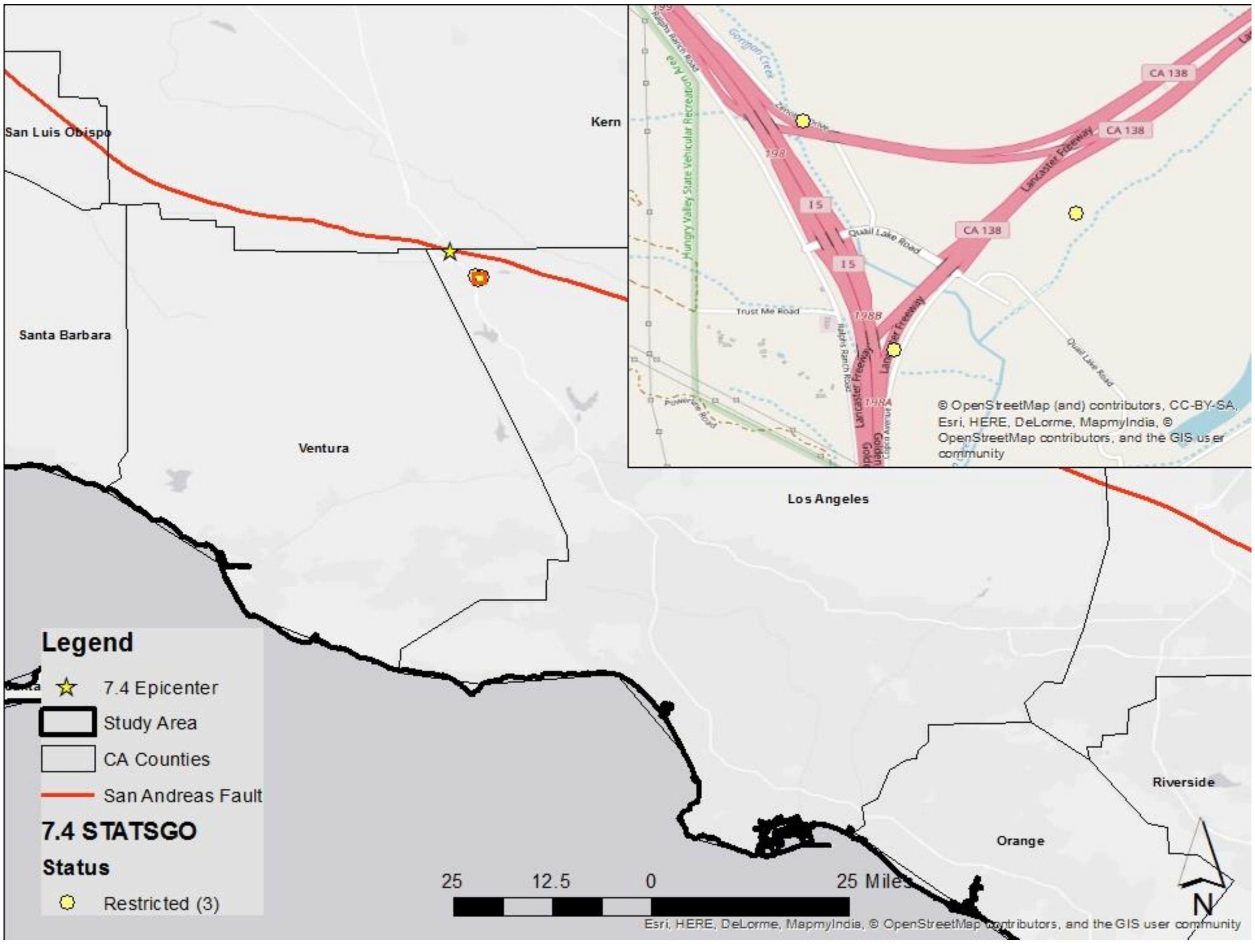

Figure 24 M7.4 STATSGO Restrictions and Closures

(Point Counts in Parenthesis)

The M7.4 Geological Unit run, returned three restrictions and no closures, all just south of the epicenter at the junction of Interstate 5 and Hwy 138 (Figure 25).

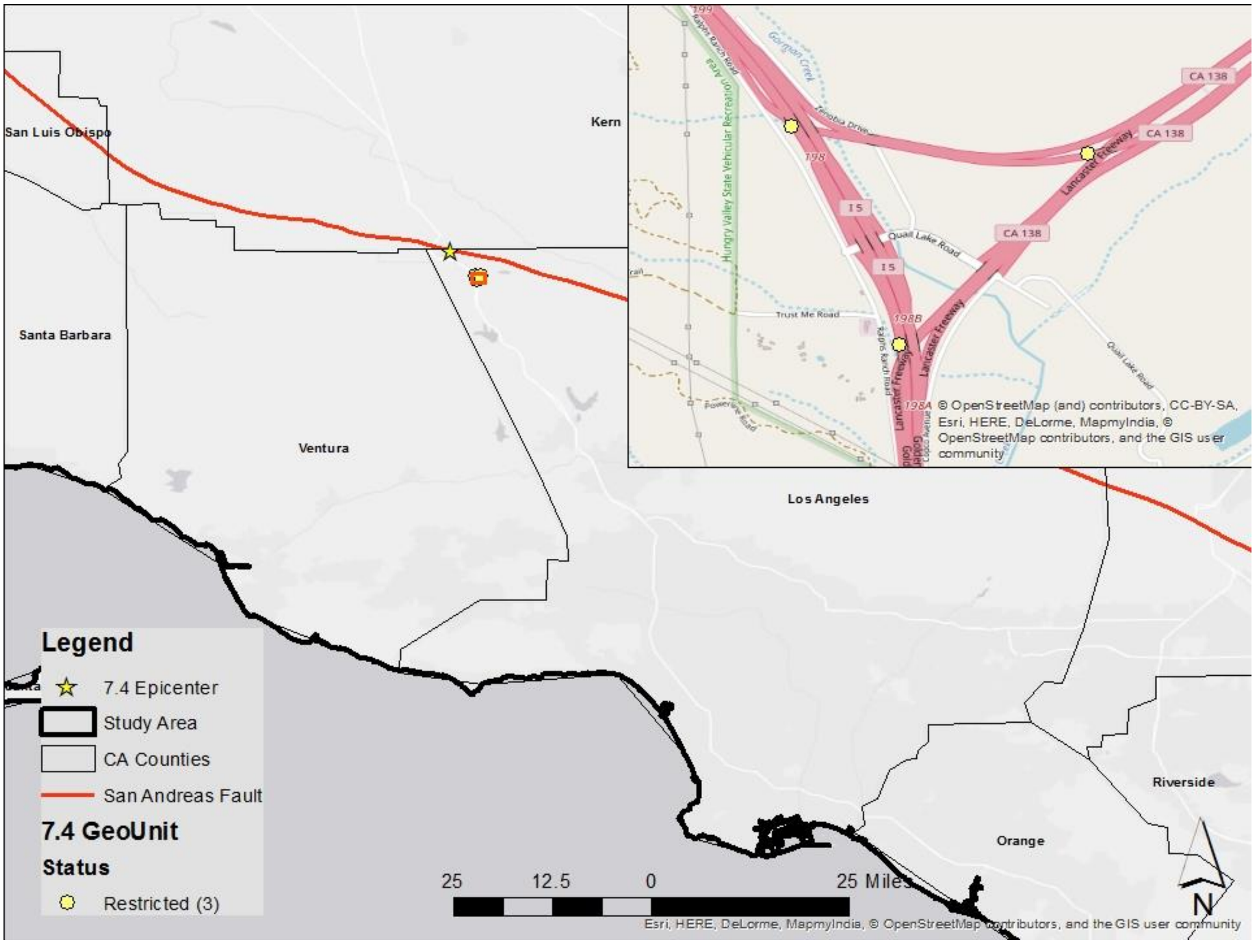

Figure 25 M7.4 Geological Unit Restrictions and Closures

(Point Counts in Parenthesis)

The M7.4 Default data run, returned seven restrictions and three closures, several south of the epicenter at the junction of Interstate 5 and Hwy 138, and several north of Gorman on the I-5 and Fraser Mountain Park Rd (Figure 26).

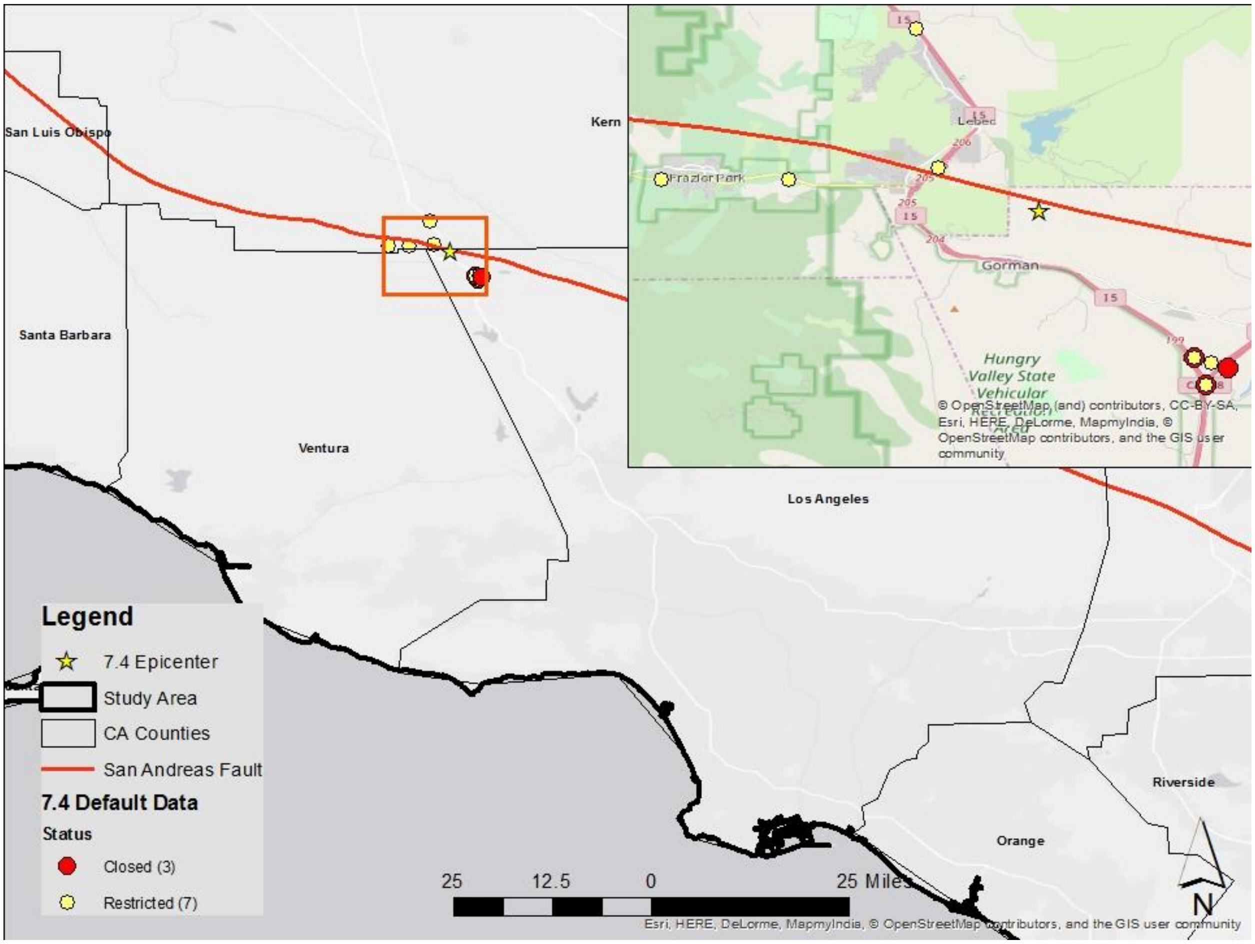

Figure 26 M7.4 Default Data Restrictions and Closures

(Point Counts in Parenthesis)

The M8.0 ShakeMap run, returned one hundred two restrictions and forty-nine closures (Figure 27). Mostly along the faultline of the southern San Andreas with a large cluster near the city of San Bernardino, one outlier restriction on the I-10 westbound on ramp from Baldwin Ave in Rosemead, CA, a cluster near the Gorman epicenter, and one closure and three restrictions in San Luis Obispo County. The M8.0 ShakeMap modeled far more extensive damage than the other scenarios and it is important to note that closures were produced at chokepoints on the I-5, I-15, and I-10, cutting off or greatly restricting both main North-South arteries and the East-West artery into southern California. Potentially reducing access for emergency response to the North and East of the region.

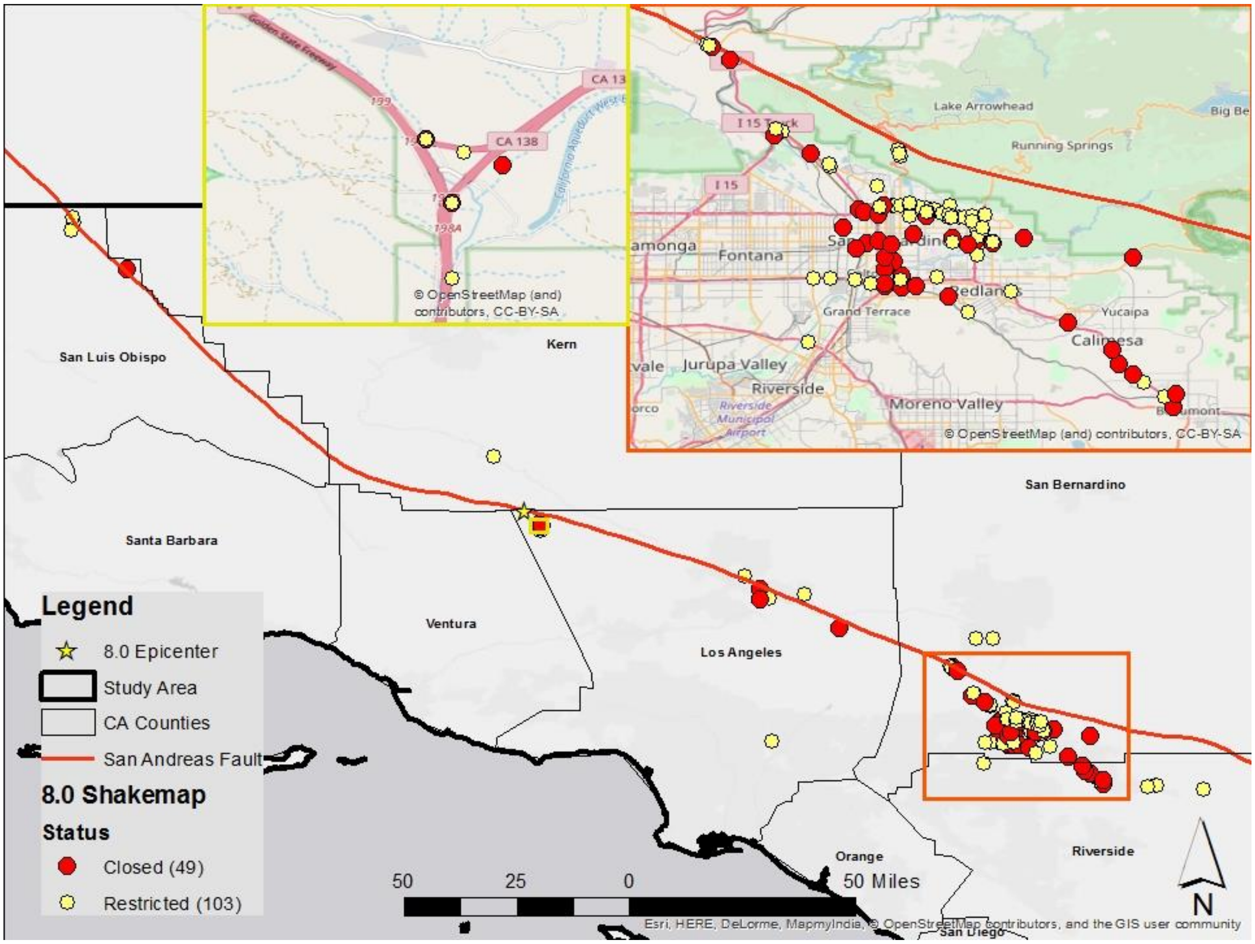

Figure 27 M8.0 ShakeMap Restrictions and Closures

(Point Counts in Parenthesis)

The M8.0 STATSGO run, returned seven restrictions and one closure, all around the epicenter near Gorman, Fraser Park, and Lebec (Figure 28).

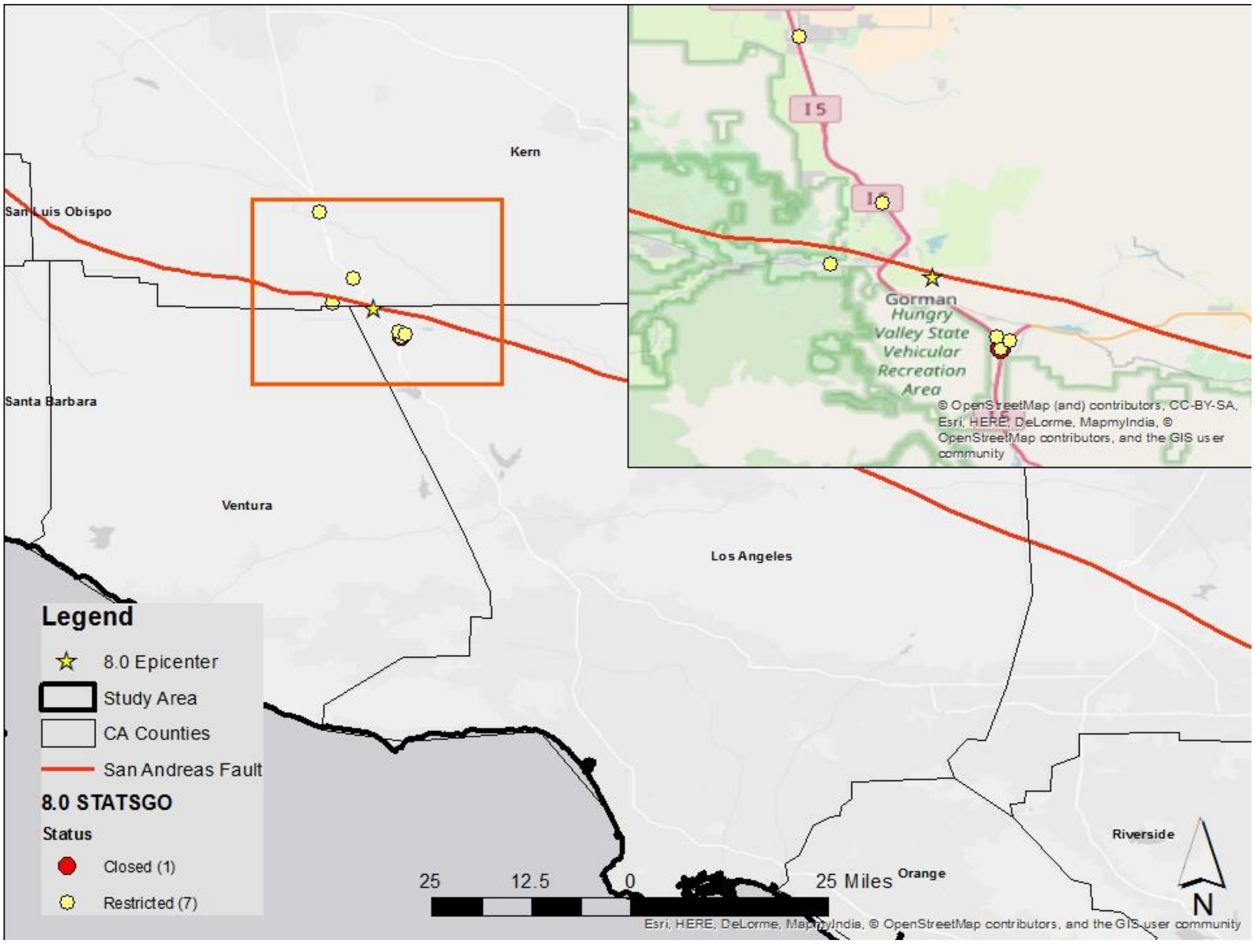

Figure 28 M8.0 STATSGO Restrictions and Closures

(Point Counts in Parenthesis)

The M8.0 Geological Units run, returned seven restrictions and one closure, similar to the STATSGO run, all around the epicenter near Gorman, Fraser Park, and Lebec (Figure 29).

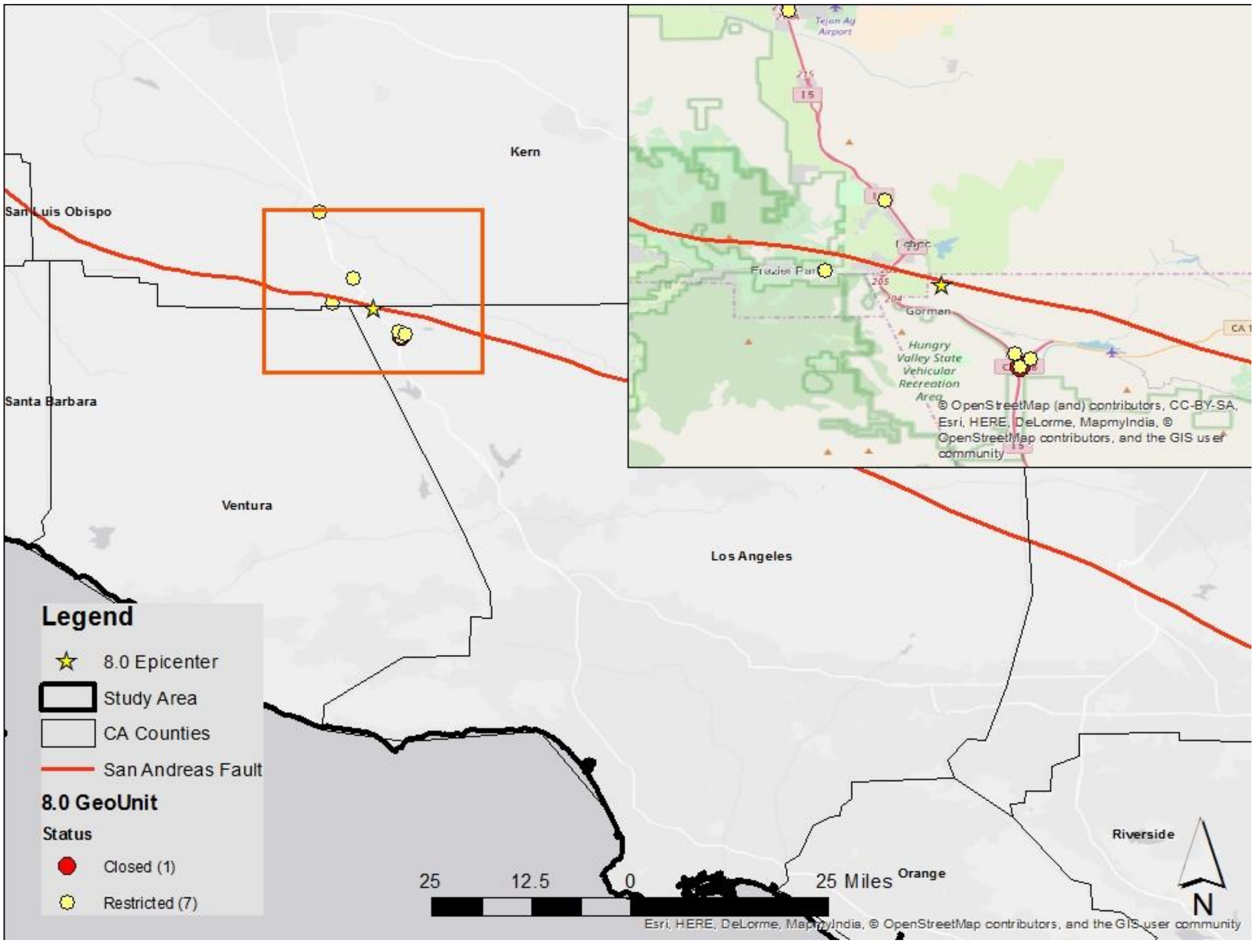

Figure 29 M8.0 GeoUnit Restrictions and Closures

(Point Counts in Parenthesis)

The M8.0 default data run, returned seven closures and twenty-two restrictions, around the epicenter near Gorman, Fraser Park and Lebec as well as east of east of Castaic Lake on San Francisquito Rd (Figure 30).

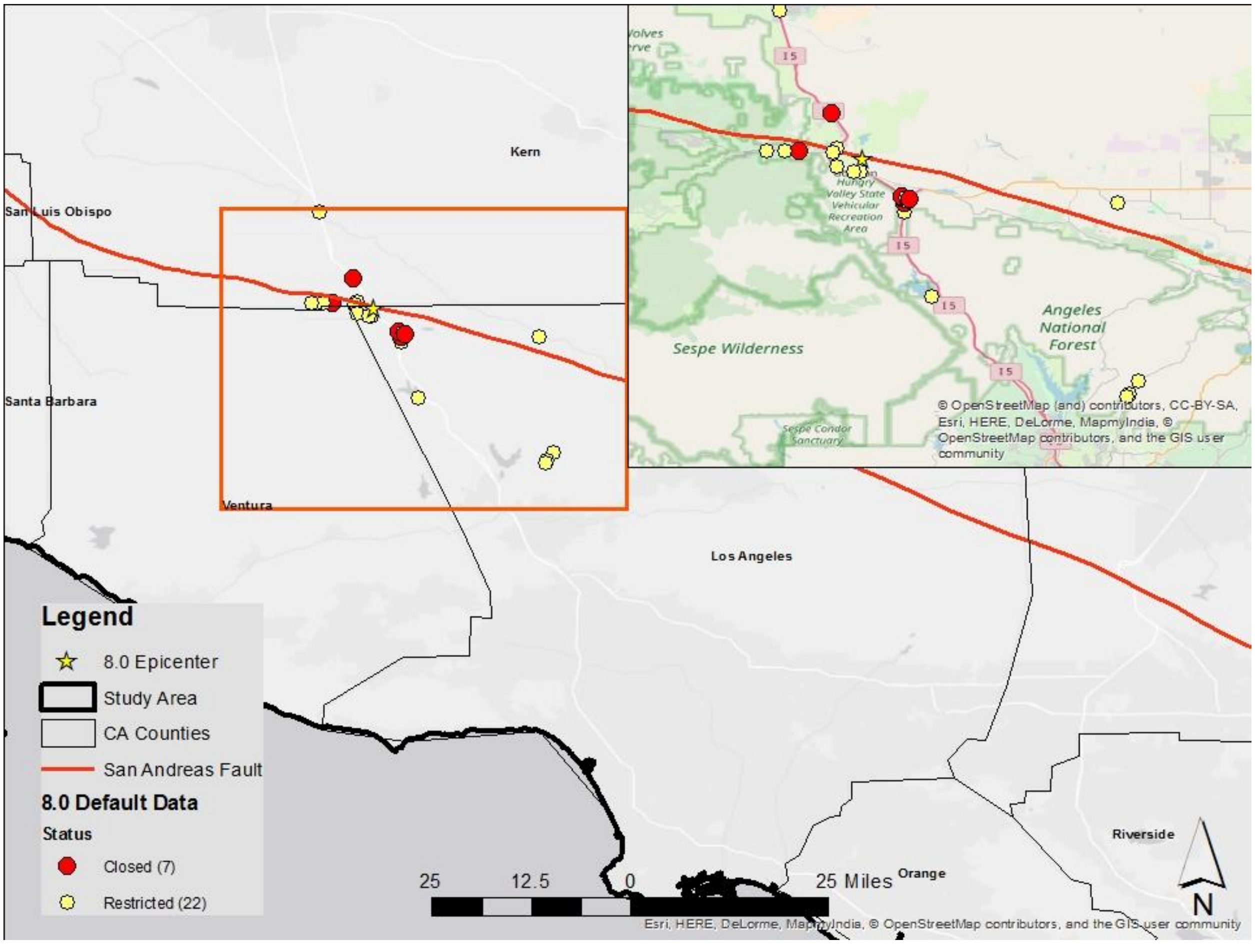

Figure 30 M8.0 Default Data Restrictions and Closures

(Point Counts in Parenthesis)

Table 7 below summarizes the number of restrictions and closures for each model run. For the M7.4 earthquke scenairos, the model run with HAZUS default data produced the greatest number of closures and restrictions. This was followed by the M7.4 ShakeMap, then the GeoUnit and STATSGO soil maps which produced the same restricted bridges. The M8.0 earthquake scenario runs returned a greater difference of closures and restrictions between them.

The M8.0 GeoUnit and STATSGO runs produced the same number of restrictions and fewer closures than the M7.4 defaut data run. The M8.0 ShakeMap run returned the greatest number of closures and restrictions over a larger spatial extent compared to the default data or either soil map run. The individual bridges identified for closures or restrictions are summarized in Appendix A.

Table 7 HAZUS Scenario Runs and Number of Bridges Restricted or Closed

Bridges	M7.4 GeoUnit	M7.4 STATSGO	M7.4 ShakeMap	M7.4 Default Data	M8.0 GeoUnit	M8.0 STATSGO	M8.0 ShakeMap	M8.0 Default Data
# Restricted	3	3	4	7	7	7	103	22
# Closed	0	0	1	3	1	1	49	7

4.4. Summary

Except for the M8.0 ShakeMap run, the default data runs generally displayed higher damage state probabilities and greater numbers of closures and restrictions. The reason for the difference in the M8.0 ShakeMap runs may be due to the default HAZUS calculations for ground motion data in the Source Scenario compared to a User-defined Scenario. When entering ShakeMap datasets into a User-Defined Scenario HAZUS will use the values and spatial extents defined by those datasets, including the rupture lengths. Defining a Source Scenario involves selecting the desired fault section, in this case the San Andreas Carrizo section, then selecting an epicenter along that segment from which HAZUS will calculate equal distances of rupture length from the epicenter that follow the contours of the faultline. If the line segment for the fault section reaches its endpoint, HAZUS will stop the rupture length at the endpoint (FEMA 2015b). The sections of the San Andreas are connected on the HAZUS Source fault map and large rupture lengths from one section should continue into adjacent sections, as this would reflect the actual continuity of the fault. But the difference between the spatial extent of damages from the User-Defined (ShakeMaps data) and Source (soil map and default data) Scenarios can be explained by the rupture lengths of the M8.0 Source scenarios being contained within the endpoints of the San Andreas Carrizo fault section. This difference in damage is not observed between the M7.4 runs because the rupture length from that magnitude is much shorter and did not exceed the endpoints of the Carrizo section. It is not known if or why shortened rupture lengths are intended by HAZUS programmers in Source scenarios for large continuous faults like the San Andreas, but this should be important to note for users intending to model great earthquakes with large rupture lengths using Source Scenario fault selection. Arbitrary scenarios will apply the full rupture length predicted from the magnitude level, but only as a straight line with a user-defined orientation value measured in degrees from north. (FEMA 2015b).

Damage probability returns between GeoUnit and STATSGO soil maps were similar, with STATSGO producing slightly higher values, probably due to more NEHRP type D soils located along the rupture line of the fault and in the Los Angeles Basin. Both ShakeMap runs produced higher damage probability returns than runs using either a STATSGO or GeoUnit NEHRP classified soil map. Three bridges south of Gorman, CA at the Interstate 5 junction to highway 138 were closed or restricted in every single run and were identified as the bridges of greatest importance in this study. These had the HighwayBridgeId CA20662, CA20668, and CA20674.

Chapter 5 Conclusion

HAZUS showed there is potential for significant closures and restrictions from any scenario tested. The HAZUS runs also showed significant output differences between different user supplied datasets and default HAZUS data. This study shows the degree to which the earthquake scenarios could damage bridge infrastructure and how the different datasets used can change these outputs. This research also investigated significant damage state probabilities and how different cumulative damage states may translate into bridge restrictions and closures.

The first research question asked to what degree will a major earthquake damage southern California bridges. This was answered using the studies two earthquake scenarios to represent the range of magnitudes for a major to great earthquake. Different instances of bridge damage for each scenario were evaluated with default HAZUS data as well as user-supplied soils maps and ShakeMaps. Bridges reaching a cumulative damage state of 'at least moderate' or 'at least extensive' were identified at the 50% or greater damage state probability level.

The second research question asked how different user-supplied datasets for ground motion will change bridge damage outputs compared to default HAZUS data. This was evaluated by each scenario runs; number of bridges in the dataset with greater than 15% probability of at least moderate damage, the total bridge damage related economic loss, and the total number of bridges determined to be closed or restricted.

The final research question posed how relative damage state outputs returned by HAZUS could correspond to bridge closures and restrictions. This was examined using a damage state acceptance criterion of at least 50% per the reporting limits of the California Geological Survey Project Report: HAZUS Loss Estimation for CA Scenario Earthquakes (CGS 2009).

Correspondence thresholds for relative damage states to closures and restrictions were set using the research of Richardson et al. (2015).

Overall HAZUS showed itself to be particularly useful for assisting planners in limiting economic losses and informing emergency preparedness. Implications for the study are discussed below, followed by limitations of the implemented methodology and the possibilities for future research.

5.1. Implications

Running HAZUS with either earthquake scenario and any user-supplied dataset showed that damage to highway bridge infrastructure could be significant, even with the high seismic engineering standards of California bridges. The degree and spatial extent to which the earthquake scenarios could damage southern California bridge infrastructure varies between scenarios and between soil, ShakeMap, and default datasets. The dataset used can change the outputs for either scenario, and it was unexpected that the M8.0 ShakeMap exceeded the damage estimates of the M8.0 default data run as this was not the case in the M7.4 scenario runs. The default data run for the M7.4 scenario estimated higher damage state probabilities than the other three runs because all soils are left at NEHRP Type D. HAZUS developers likely left the default soils to Type D so the software will output more liberal estimates of damages to avoid liability and not promote a false sense of security for users performing analysis with default datasets by outputting an underestimation of damages. The M7.4 scenario runs are in line with the findings from Neighbors (2013) that user-supplied hazard maps will return decreased damage values compared to the default data. Even the M7.4 ShakeMap estimated lower values for ground motions and damages compared to the default HAZUS values. The M8.0 ShakeMap run may have been a more accurate assessment of damages than the M8.0 soil maps and default data runs due to rupture lengths with those datasets possibly being cut short by endpoints of the fault section in the Source scenarios.

The NEHRP soil classification methodology was applied by other researchers to the scale of an average sized city and not to regional scale. Ground truth Vs data is intended to inform local site conditions and the averages of many Vs points over large mapping units, such as some alluvium units in the CA Geological Units map, may have skewed the Vs values for those units creating less variability than a larger scale map such as SSURGO might have made.

ShakeMaps, in general, showed greater damage returns than soil maps, the M7.4 Default data run had the largest and most expansive damage returns of that scenario, while the M8.0 ShakeMap run covered a much larger geographic area than the M8.0 Default data run and had the largest number of bridges damaged. As stated in the results summary, this is most likely due to the User-Defined ShakeMap hazard scenario that implements a longer rupture length than the Carrizo fault segment selected in the Source scenario used for the other datasets. The Source scenarios were selected to mimic the contour of the San Andres fault and rupture line used by the ShakeMaps in the User-Defined scenarios. There is no other option for selecting particular faults in a deterministic scenario and the user cannot select multiple connected fault segments in an effort to define a more expansive fault hazard. This difference between User-Defined ShakeMap scenarios and Source scenarios suggests Scenario ShakeMaps, if available for the fault the user desires to model, are a better source for regional ground motion data.

Bridge closure and restrictions classifications were based on identified relationships to BDI and bridge damage states established in Richardson (2015) and Shiraki (2009). The criteria for significant probability of a damage state could be lowered to include a larger set of at least moderately and at least extensively damaged bridges in the closures analysis, but these damage state probabilities would be more likely not to reach the cumulative damage states mentioned.

Several of the bridges at the junction of the I-5 and state highway138 were closed or restricted in every scenario run. These are inconveniently located in mountainous terrain that would be difficult to bypass and may create a significant impediment for emergency responders and supplies attempting to reach the Greater Los Angeles region from central and northern California. The M8.0 scenario ShakeMap also produced this chokepoint effect on the I-5 as well as on the I-15 and I-10, restricting arteries to the north and east of the regions most populated areas. Appendix A contains a table for each scenario run, listing individual bridge restrictions and closures.

5.2. Limitations

Some soil data units had no Vs data from any similar unit to average NEHRP classes to. These were assigned values by me (not a geologist or soils scientist) according to class classification guides. Generalized soil classifications based on soil taxa or geologic lithography are not recommended due to differing compaction and other site-specific criteria (Medves 2009).

The default NBI highway bridge inventory was used in this analysis. Compared to the 2015 dataset I downloaded and cut to the study area, there are about three hundred bridges built after 2010 omitted from the study area. Newer bridges may have less wear and stress, and be built to higher current seismic standards, but a more complete data set may have informed model returns better. The CDMS upload functionality for highway bridges was not working during this study, the 2015 data prepared for HAZUS threw upload errors in the HAZUS CDMS likely due to mislabeled CDMS data matching field for statewide census tracts.

As mentioned above there may be differences in PGA distributions and rupture lengths between User-defined Scenario (ShakeMaps) and Source Fault scenarios (Soil Maps) using default HAZUS calculations for rupture length constrained by the endpoints of a fault section.

5.3. Future Research

HAZUS development plans to fix the highway bridge CDMS upload issue in the next version of HAZUS set to be released sometime in 2018. Future research should incorporate the latest 2015 NBI datasets for analysis, the FHWA updates the NBI every five years.

A significant number of Vs points in the USGS Vs dataset used in this study are located along the 605 freeway in Los Angeles. (Most of these were averaged into the alluvium GeoUnit that covers much of LA.) A large geographic scale study focused on the bridges and segments of the 605 using SSURGO soils units may be very informative.

There is a large database of Scenario ShakeMaps that could be used to compare HAZUS outputs to ShakeMaps generated from historical events, this could inform variability or sensitivity between the datasets.

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APPENDIX A TABLES

Table 8 HAZUS Highway Bridge Types (FEMA 2015b)

CLASS	NBI Class	State	Year Built	# Spans	Length of Max.Span (meter)	Length less than 20 m	Design	Description
HWB1	All	Non-CA	< 1990		> 150	N/A	Conventional	Major Bridge - Length > 150m
HWB1	All	CA	< 1975		> 150	N/A	Conventional	Major Bridge - Length > 150m
HWB2	All	Non-CA	>= 1990		> 150	N/A	Seismic	Major Bridge - Length > 150m
HWB2	All	CA	>= 1975		> 150	N/A	Seismic	Major Bridge - Length > 150m
HWB3	All	Non-CA	< 1990	1		N/A	Conventional	Single Span
HWB3	All	CA	< 1975	1		N/A	Conventional	Single Span
HWB4	All	Non-CA	>= 1990	1		N/A	Seismic	Single Span
HWB4	All	CA	>= 1975	1		N/A	Seismic	Single Span
HWB5	101-106	Non-CA	< 1990			N/A	Conventional	Multi-Col. Bent Simple Support - Concrete
HWB6	101-106	CA	< 1975			N/A	Conventional	Multi-Col. Bent Simple Support-Concrete
HWB7	101-106	Non-CA	>= 1990			N/A	Seismic	Multi-Col. Bent Simple Support-Concrete
HWB7	101-106	CA	>= 1975			N/A	Seismic	Multi-Col. Bent Simple Support-Concrete
HWB8	205-206	CA	< 1975			N/A	Conventional	Single Col. Box Girder -Continuous Concrete
HWB9	205-206	CA	>= 1975			N/A	Seismic	Single Col. Box Girder -Continuous Concrete
HWB10	201-		<			N/A		Continuous Concrete

CLASS	NBI Class	State	Year Built	# Spans	Length of Max.Span (meter)	Length less than 20 m	Design	Description
	206	Non-CA	1990				Conventional	
HWB10	201-206	CA	< 1975			N/A	Conventional	Continuous Concrete
HWB11	201-206	Non-CA	>= 1990			N/A	Seismic	Continuous Concrete
HWB11	201-206	CA	>= 1975			N/A	Seismic	Continuous Concrete
HWB12	301-306	Non-CA	< 1990			No	Conventional	Multi-Col. Bent Simple Support -Steel
HWB13	301-306	CA	< 1975			No	Conventional	Multi-Col. Bent Simple Support- Steel
HWB14	301-306	Non-CA	>= 1990			N/A	Seismic	Multi-Col. Bent Simple Support Steel
HWB14	301-306	CA	>= 1975			N/A	Seismic	Multi-Col. Bent Simple Support- Steel
HWB15	402-410	Non-CA	< 1990			No	Conventional	Continuous Steel
HWB15	402-410	CA	< 1975			No	Conventional	Continuous Steel
HWB16	402-410	Non-CA	>= 1990			N/A	Seismic	Continuous Steel
HWB16	402-410	CA	>= 1975			N/A	Seismic Continuous Steel	
HWB17	501-506	Non-CA	< 1990			N/A	Conventional	Multi-Col. Bent SimpleSupport - Prestressed Concrete
HWB18	501-506	CA	< 1975			N/A	Conventional	Multi-Col. Bent SimpleSupport - Prestressed Concrete
HWB19	501-506	Non-CA	>= 1990			N/A	Seismic	Multi-Col. Bent SimpleSupport - Prestressed Concrete
HWB19	501-506	CA	>= 1975			N/A	Seismic	Multi-Col. Bent SimpleSupport - Prestressed Concrete
HWB20	605-606	CA	< 1975			N/A	Conventional	Single Col. Box Girder -Prestressed Continuous Concrete

CLASS	NBI Class	State	Year Built	# Spans	Length of Max.Span (meter)	Length less than 20 m	Design	Description
HWB21	605-606	CA	>= 1975			N/A	Seismic	Single Col. Box Girder -Prestressed Continuous Concrete
HWB22	601-607	Non-CA	< 1990			N/A	Conventional	Continuous Concrete
HWB22	601-607	CA	< 1975			N/A	Conventional	Continuous Concrete
HWB23	601-607	Non-CA	>= 1990			N/A	Seismic	Continuous Concrete
HWB23	601-607	CA	>= 1975			N/A	Seismic	Continuous Concrete
HWB24	301-306	Non-CA	< 1990			Yes	Conventional	Multi-Col. Bent Simple Support - Steel
HWB25	301-306	CA	< 1975			Yes	Conventional	Multi-Col. Bent Simple Support - Steel
HWB26	402-410	Non-CA	< 1990			Yes	Conventional	Continuous Steel
HWB27	402-410	CA	< 1975			Yes	Conventional	Continuous Steel
HWB28								All other bridges that are not classified

Table 9 M8.0 ShakeMap Bridge Closures

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA020662	HWB10	INTERSTATE 5 SB	0.71	0.58	856.19	C
CA020668	HWB10	ROUTE 5 SB	0.68	0.55	768.38	C
CA020674	HWB10	S5-E138 CONNECTOR	0.71	0.58	517.16	C
CA022964	HWB10	AVENUE S	0.68	0.55	423.18	C
CA025533	HWB11	GREENSPOT ROAD	0.65	0.52	1,194.72	C
CA016483	HWB13	MOONSTONE BEACH DR	0.85	0.76	261.28	C
CA022704	HWB13	PEARBLOSSOM HWY	0.77	0.67	644.13	C
CA024060	HWB13	HIGHLAND AVE	0.88	0.81	2,914.82	C
CA024084	HWB13	N215-E10 RAMP CONN	0.62	0.50	906.24	C
CA024087	HWB13	INTERSTATE 215 SB	0.62	0.50	1,627.02	C
CA024090	HWB13	INTERSTATE 215 NB	0.62	0.50	1,160.74	C
CA024574	HWB13	STATE ROUTE 138	0.74	0.63	1,397.45	C
CA025101	HWB13	WATERMAN AVE	0.78	0.68	633.15	C
CA025102	HWB13	WATERMAN AVE	0.70	0.58	1,112.33	C
CA025103	HWB13	E FIFTH ST	0.92	0.86	573.23	C
CA025116	HWB13	MT VERNON AVE	0.73	0.62	1,104.95	C
CA025121	HWB13	MT. VERNON AVE	0.80	0.70	514.64	C
CA025317	HWB13	NINTH ST	0.89	0.83	1,243.89	C
CA025326	HWB13	RIALTO AVE	0.72	0.61	773.98	C
CA025447	HWB13	CENTRAL AVE	0.73	0.62	799.06	C
CA025494	HWB13	ORANGE ST	0.88	0.80	298.21	C
CA027074	HWB13	ROUTE 60	0.74	0.63	377.42	C
CA023972	HWB15	STATE ROUTE 38	0.66	0.66	408.64	C
CA024005	HWB15	ROUTE 66 (5TH ST)	0.51	0.51	561.97	C
CA024071	HWB18	ORANGE SHOW ROAD	0.70	0.58	1,433.81	C
CA024078	HWB18	INTERSTATE 215 SB	0.62	0.50	826.18	C
CA024080	HWB18	INTERSTATE 215 NB	0.62	0.50	1,209.04	C
CA024331	HWB18	16TH STREET	0.67	0.55	596.56	C
CA024529	HWB18	STATE ROUTE 259 SB	0.81	0.71	558.04	C
CA024531	HWB18	STATE ROUTE 259 NB	0.81	0.71	558.04	C

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA024652	HWB18	INTERSTATE 15 SB	0.76	0.66	819.13	C
CA024653	HWB18	INTERSTATE 15 NB	0.76	0.66	819.13	C
CA025117	HWB18	WATERMAN AVE	0.66	0.55	641.81	C
CA025146	HWB18	ANDERSON ST	0.66	0.54	688.37	C
CA025158	HWB18	BASE LINE ROAD	0.74	0.63	1,077.87	C
CA025159	HWB18	BARTON RD	0.82	0.73	1,545.07	C
CA025312	HWB18	G ST	0.83	0.74	1,045.64	C
CA027454	HWB18	CHERRY VALLEY BLVD	0.62	0.50	749.18	C
CA027456	HWB18	SINGLETON ROAD	0.64	0.52	569.88	C
CA027458	HWB18	SANDALWOOD DRIVE O	0.62	0.50	671.77	C
CA024541	HWB22	W30-S259 CONNECTOR	0.73	0.61	2,564.30	C
CA025343	HWB27	SECOND STREET	0.65	0.65	321.10	C
CA025186	HWB28	5TH ST	0.72	0.61	174.87	C
CA025353	HWB28	DEL ROSA AV	0.66	0.55	181.07	C
CA025443	HWB28	ALABAMA ST	0.70	0.59	355.44	C
CA022771	HWB6	VALYERMO RD	0.83	0.74	398.69	C
CA024181	HWB6	LITTLE LEAGUE DR	0.82	0.72	416.91	C
CA025164	HWB6	CAJON BLVD	0.62	0.50	101.95	C
CA028070	HWB6	14TH ST	0.62	0.50	129.58	C
CA016163	HWB10	STATE ROUTE 46	0.60	0.46	172.45	R
CA018491	HWB10	INTERSTATE 5	0.52	0.38	181.67	R
CA018492	HWB10	INTERSTATE 5	0.57	0.44	234.26	R
CA018493	HWB10		0.57	0.44	148.07	R
CA020664	HWB10	INTERSTATE 5 NB	0.60	0.47	592.32	R
CA020670	HWB10	ROUTE 5 NB	0.59	0.46	554.33	R
CA020673	HWB10	RAMP/CONNECTOR 138	0.52	0.39	490.87	R
CA023494	HWB10	BARREL SPRINGS RD	0.54	0.41	328.33	R
CA024069	HWB10	INTERSTATE 10 WB	0.56	0.43	651.66	R
CA024070	HWB10	INTERSTATE 10 EB	0.56	0.43	651.66	R
CA024150	HWB10	INTERSTATE 215	0.59	0.46	254.03	R
CA024151	HWB10	INTERSTATE 215	0.59	0.46	254.03	R
CA024163	HWB10	DEVORE ROAD	0.52	0.39	524.92	R
CA024246	HWB10	INTERSTATE RTE 10	0.51	0.38	1,637.55	R

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA024270	HWB10	INTERSTATE 10 WB	0.56	0.43	552.67	R
CA024272	HWB10	INTERSTATE 10 EB	0.56	0.43	552.67	R
CA024315	HWB10	INTERSTATE RTE 10	0.50	0.37	1,329.38	R
CA024543	HWB10	E STREET OC	0.51	0.38	855.52	R
CA024545	HWB10	ARROWHEAD AVE	0.52	0.39	940.70	R
CA024547	HWB10	MT VIEW AVE OC	0.54	0.41	552.99	R
CA024549	HWB10	MT VIEW AVE OC	0.54	0.41	552.99	R
CA024551	HWB10	SIERRA WAY OC	0.54	0.41	1,004.49	R
CA024555	HWB10	STATE ROUTE 18	0.54	0.41	1,112.59	R
CA025493	HWB10	BOULDER AVE	0.59	0.46	241.34	R
CA025526	HWB10	KENDALL DR	0.52	0.39	90.97	R
CA025530	HWB10	BOULDER AVE	0.62	0.49	304.61	R
CA027038	HWB10	INTERSTATE 10	0.51	0.38	814.71	R
CA027272	HWB10	INTERSTATE 10	0.59	0.46	267.61	R
CA027398	HWB10	INTERSTATE 10	0.51	0.38	696.40	R
CA016372	HWB11	PALO PRIETO RD	0.60	0.47	195.33	R
CA024953	HWB11	STATE ROUTE 30 WB	0.54	0.41	149.06	R
CA024955	HWB11	STATE ROUTE 30 EB	0.54	0.41	140.50	R
CA024973	HWB11	STATE ROUTE 30 WB	0.62	0.49	342.97	R
CA024974	HWB11	STATE ROUTE 30 EB	0.62	0.49	362.03	R
CA016654	HWB13	WHEELER RIDGE RD	0.54	0.42	412.42	R
CA024055	HWB13	INTERSTATE RTE 10	0.57	0.45	808.55	R
CA024056	HWB13	INTERSTATE RTE 10	0.57	0.45	862.69	R
CA024405	HWB13	N15-N395 CONNECTOR	0.61	0.49	434.42	R
CA024519	HWB13	STATE ROUTE 18	0.53	0.41	245.77	R
CA024520	HWB13	STATE ROUTE 18	0.53	0.41	471.55	R
CA024594	HWB13	STATE ROUTE 18	0.57	0.45	202.12	R
CA024595	HWB13	STATE ROUTE 18	0.53	0.41	177.83	R
CA024175	HWB18	PEPPER AVE	0.53	0.41	456.43	R
CA024185	HWB18	RIVERSIDE AVE	0.53	0.41	844.82	R
CA025137	HWB18	MT VERNON AVE	0.57	0.45	318.79	R
CA025325	HWB18	SAN TIMOTEO CYN RD	0.54	0.42	317.15	R

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA025379	HWB18	MAPLE AVE	0.52	0.40	224.39	R
CA027337	HWB18	STATE ROUTE 60	0.59	0.47	476.67	R
CA027452	HWB18	BROOKSIDE AVE	0.56	0.44	454.68	R
CA027483	HWB18	SAN TIMOTEO CANYON	0.53	0.41	486.16	R
CA027540	HWB18	STATE ROUTE 111	0.52	0.40	273.41	R
CA027541	HWB18	STATE ROUTE 111	0.52	0.40	273.41	R
CA025538	HWB19	WATERMAN AVENUE	0.53	0.32	383.19	R
CA021741	HWB22	ROUTE 14 SB	0.52	0.39	551.91	R
CA021743	HWB22	ROUTE 14 NB	0.52	0.39	551.91	R
CA022963	HWB22	AVENUE T	0.63	0.50	435.55	R
CA024590	HWB22	INTERSTATE 15 NB	0.56	0.43	959.60	R
CA024596	HWB22	VALENCIA AV OC	0.54	0.41	1,071.89	R
CA024602	HWB22	STATE ROUTE 30 WB	0.59	0.46	505.05	R
CA024604	HWB22	STATE ROUTE 30 EB	0.59	0.46	505.05	R
CA024606	HWB22	STATE ROUTE 30 WB	0.60	0.47	489.28	R
CA024608	HWB22	STATE ROUTE 30 EB	0.60	0.47	489.28	R
CA024853	HWB23	STATE ROUTE 30 WB	0.51	0.38	825.98	R
CA024854	HWB23	STATE ROUTE 30 EB	0.51	0.38	804.28	R
CA024951	HWB23	STATE ROUTE 138	0.54	0.41	367.45	R
CA024952	HWB23	STATE ROUTE 138	0.62	0.49	594.76	R
CA024969	HWB23	STATE ROUTE 30 WB	0.60	0.46	680.15	R
CA024972	HWB23	STATE ROUTE 30 EB	0.60	0.46	839.59	R
CA024979	HWB23	CENTRAL AVENUE	0.57	0.44	612.01	R
CA024981	HWB23	PALM AVENUE	0.58	0.45	1,294.43	R
CA024983	HWB23	BASELINE ROAD	0.57	0.44	1,117.44	R
CA024985	HWB23	STATE ROUTE 30 WB	0.57	0.44	748.34	R
CA024986	HWB23	STATE ROUTE 30 EB	0.57	0.44	794.26	R
CA024992	HWB23	STATE ROUTE 330	0.59	0.46	889.44	R
CA024998	HWB23	ORANGE STREET	0.57	0.44	672.40	R
CA025009	HWB23	STATE ROUTE 330	0.57	0.44	587.69	R

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA025011	HWB23	E30-N330 CONNECTOR	0.57	0.44	721.86	R
CA016371	HWB28	CHOLAME VALLEY RD	0.59	0.47	60.77	R
CA025203	HWB28	HIGHLAND AV	0.50	0.38	86.07	R
CA025356	HWB28	PUMALO ST	0.50	0.38	47.89	R
CA025373	HWB28	THIRD ST	0.62	0.50	101.33	R
CA025490	HWB28	40TH ST	0.61	0.49	831.16	R
CA025524	HWB28	LYNNWOOD DR	0.50	0.38	60.69	R
CA025531	HWB28	HIGHLAND AVE	0.50	0.38	96.24	R
CA024537	HWB3	STATE ROUTE 259	0.55	0.43	373.26	R
CA024539	HWB3	STATE ROUTE 259	0.55	0.43	373.26	R
CA024553	HWB3	STATE ROUTE 30	0.50	0.38	186.24	R
CA024554	HWB3	STATE ROUTE 30	0.50	0.38	186.24	R
CA024598	HWB3	STATE ROUTE 30 WB	0.50	0.38	281.62	R
CA024600	HWB3	STATE ROUTE 30 EB	0.50	0.38	289.45	R
CA025107	HWB3	ORANGE ST	0.50	0.38	51.19	R
CA025143	HWB3	30TH STREET	0.61	0.49	513.56	R
CA025384	HWB3	GILBERT ST	0.58	0.46	141.70	R
CA025444	HWB3	21ST ST	0.53	0.41	122.96	R
CA025448	HWB3	LYNWOOD DR	0.50	0.38	115.65	R
CA027263	HWB3	INTERSTATE RTE 10	0.53	0.41	1,402.42	R
CA024975	HWB4	STATE ROUTE 30 WB	0.51	0.39	254.05	R
CA024977	HWB4	STATE ROUTE 30 EB	0.51	0.39	273.10	R
CA024994	HWB4	HIGHLAND AVENUE	0.50	0.38	562.03	R
CA025007	HWB4	S330-E30 CONNECTOR	0.50	0.38	190.89	R
CA025106	HWB4	BASELINE ROAD	0.55	0.43	180.36	R
CA025498	HWB4	HIGHLAND AVE	0.51	0.39	579.42	R
CA019362	HWB6	I 10 WB	0.56	0.44	612.38	R

Table 10 M8.0 Default Data Bridge Closures

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA017090	HWB10	FRAZIER MTN ROAD	0.64	0.51	248.21	C
CA020662	HWB10	INTERSTATE 5 SB	0.74	0.62	928.70	C
CA020664	HWB10	INTERSTATE 5 NB	0.64	0.51	652.96	C
CA020668	HWB10	ROUTE 5 SB	0.74	0.62	883.01	C
CA020670	HWB10	ROUTE 5 NB	0.66	0.53	650.76	C
CA020674	HWB10	S5-E138 CONNECTOR	0.74	0.62	557.45	C
CA016748	HWB13	LEBEC RD	0.73	0.63	914.68	C
CA016569	HWB10	INTERSTATE 5	0.59	0.46	761.10	R
CA017091	HWB10	FRAZIER MTN ROAD	0.55	0.42	322.62	R
CA017092	HWB10	FRAZIER MTN ROAD	0.62	0.48	375.08	R
CA018491	HWB10	INTERSTATE 5	0.52	0.39	184.44	R
CA018492	HWB10	INTERSTATE 5	0.57	0.44	237.58	R
CA018493	HWB10		0.57	0.44	150.04	R
CA020623	HWB10	INTERSTATE 5	0.52	0.39	243.43	R
CA020624	HWB10	INTERSTATE 5	0.52	0.39	243.43	R
CA020625	HWB10	INTERSTATE 5	0.55	0.42	345.48	R
CA020626	HWB10	INTERSTATE 5	0.55	0.42	345.48	R
CA020627	HWB10	TEJON PASS OC	0.52	0.39	390.24	R
CA020666	HWB10	INTERSTATE 5	0.51	0.38	506.86	R
CA020667	HWB10	INTERSTATE 5	0.51	0.38	506.86	R
CA020672	HWB10	RAMP/CONNECTOR 138	0.52	0.39	699.44	R
CA020673	HWB10	RAMP/CONNECTOR 138	0.59	0.46	585.61	R
CA022965	HWB10	LANCASTER RD	0.53	0.39	268.47	R
CA016654	HWB13	WHEELER RIDGE RD	0.56	0.44	433.79	R
CA018490	HWB13		0.55	0.43	661.65	R
CA023607	HWB28	PEACE VALLEY RD	0.50	0.38	57.72	R
CA022730	HWB6	SAN FRCSQUTO CA RD	0.59	0.46	33.87	R
CA022731	HWB6	SAN FRCSQUTO CA RD	0.55	0.43	51.07	R
CA022732	HWB6	SAN FRCSQUTO CA RD	0.54	0.42	49.97	R

Table 11 M8.0 STATSGO Bridge Closures

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA020662	HWB10	INTERSTATE 5 SB	0.63	0.50	716.13	C
CA017090	HWB10	FRAZIER MTN ROAD	0.52	0.39	194.55	R
CA020664	HWB10	INTERSTATE 5 NB	0.52	0.39	479.34	R
CA020668	HWB10	ROUTE 5 SB	0.63	0.50	684.93	R
CA020670	HWB10	ROUTE 5 NB	0.54	0.41	486.24	R
CA020674	HWB10	S5-E138 CONNECTOR	0.63	0.50	432.40	R
CA016654	HWB13	WHEELER RIDGE RD	0.56	0.44	433.79	R
CA016748	HWB13	LEBEC RD	0.56	0.43	619.37	R

Table 12 M8.0 GeoUnit Bridge Closures

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA020662	HWB10	INTERSTATE 5 SB	0.63	0.50	716.13	C
CA017090	HWB10	FRAZIER MTN ROAD	0.52	0.39	194.55	R
CA020664	HWB10	INTERSTATE 5 NB	0.52	0.39	479.34	R
CA020668	HWB10	ROUTE 5 SB	0.63	0.50	684.93	R
CA020670	HWB10	ROUTE 5 NB	0.54	0.41	486.24	R
CA020674	HWB10	S5-E138 CONNECTOR	0.63	0.50	432.40	R
CA016654	HWB13	WHEELER RIDGE RD	0.56	0.44	433.79	R
CA016748	HWB13	LEBEC RD	0.56	0.43	619.37	R

Table 13 M7.4 ShakeMap Bridge Closures

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA020662	HWB10	INTERSTATE 5 SB	0.65	0.52	742.44	C
CA020664	HWB10	INTERSTATE 5 NB	0.53	0.40	500.20	R
CA020668	HWB10	ROUTE 5 SB	0.62	0.48	661.52	R
CA020670	HWB10	ROUTE 5 NB	0.53	0.40	467.36	R
CA020674	HWB10	S5-E138 CONNECTOR	0.58	0.45	382.33	R

Table 14 M7.4 STATSGO Bridge Closures

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA020662	HWB10	INTERSTATE 5 SB	0.51	0.38	518.94	R
CA020668	HWB10	ROUTE 5 SB	0.51	0.38	506.80	R
CA020674	HWB10	S5-E138 CONNECTOR	0.51	0.38	319.95	R

Table 15 7.4 GeoUnit Bridge Closures

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA020662	HWB10	INTERSTATE 5 SB	0.51	0.38	518.94	R
CA020668	HWB10	ROUTE 5 SB	0.51	0.38	506.80	R
CA020674	HWB10	S5-E138 CONNECTOR	0.51	0.38	319.95	R

Table 16 M7.4 Default Data Bridge Closures

Highway BridgeID	HAZUS Bridge Class	Name	PDs Exceed Moderate	PDs Exceed Extensive	Econ Loss Thou	Status
CA020662	HWB10	INTERSTATE 5 SB	0.67	0.55	790.86	C
CA020668	HWB10	ROUTE 5 SB	0.67	0.54	747.47	C
CA020674	HWB10	S5-E138 CONNECTOR	0.67	0.54	471.89	C
CA016569	HWB10	INTERSTATE 5	0.51	0.38	624.27	R
CA017090	HWB10	FRAZIER MTN ROAD	0.56	0.42	211.56	R
CA017092	HWB10	FRAZIER MTN ROAD	0.53	0.40	309.42	R
CA020664	HWB10	INTERSTATE 5 NB	0.56	0.43	538.82	R
CA020670	HWB10	ROUTE 5 NB	0.58	0.45	537.08	R
CA020673	HWB10	RAMP/CONNECTOR 138	0.51	0.38	474.26	R
CA016748	HWB13	LEBEC RD	0.62	0.50	711.88	R