Hazus Uninhabitable Residential Building Study

Project Methodology

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Overview

The Hazus Uninhabitable Residential Building Study is an update of an original 1996 ABAG study, entitled *Shaken Awake!,* and a 2003 update called *Preventing the Nightmare,* which utilized building damage data from past California earthquakes to estimate housing loss for 18 plausible Bay Area earthquake scenarios. For this 2017 update, a significant change was made to the methodology for modeling losses. Previously, the model for housing loss was based on broad classifications of Bay Area building types, based on material, number of stories, and age. Based on shaking intensity for each earthquake scenario, a matrix was developed correlating the proportion of buildings that would be red tagged or yellow tagged based on both shaking intensity and building classification. The matrix was developed from a previous study[1] linking the two factors (shaking intensity and building type) with damage, as well as observations of this correlation from the 1989 Loma Prieta and 1994 Northridge earthquakes. For the 2017 study, the approach was changed to utilize Hazus, a nationally applicable, standardized, Geographic Information Systems (GIS)-based methodology and software that contains models for estimating potential losses from earthquakes, floods, tsunamis and hurricanes, developed by the Federal Emergency Management Agency (FEMA). By moving from the previous, proprietary model to Hazus, the study results are more comparable to other regional studies and can be easily replicated in the future, or by others.

Like the 2003 study, the 2017 study focused exclusively on residential building damage and the resulting post-earthquake shelter needs throughout the 9-county Bay Area[2]. However, due to the differences in the modeling tools, rather than categorizing building damage by construction type as in the old model, the new model categorizes residential buildings by three occupancy categories: single family, multifamily, and manufactured/mobile homes. The Hazus model also has the capability to estimate economic loss due to housing damage, which the previous model did not. Additionally, the previous model's results were only available at the county level; by using Hazus, the 2017 study was able to report select findings at the Census Tract level, leading to a much more localized estimate of where building damage is likely to occur.

The 2017 Hazus update also modeled different earthquake shaking scenarios than the previous reports. *Preventing the Nightmare* used earthquake shaking scenarios from the USGS Working Group 2002 study. The scenarios selected for the 2017 study were developed by the USGS in 2013 as part of the ShakeMap program and correspond with the interactive scenario maps utilized by ABAG on the Resilience Program website.

The 2017 study results also includes the scenario utilized for the United States Geological Survey's HayWired project for comparison purposes. The HayWired project analyzes an in-depth look at the consequences of a M 7.0 earthquake on the Hayward fault. However, the Hazus methodology and parameters used by USGS vary from the methodology outlined here, meaning there is no direct comparison of the HayWired results to the results presented here. This project modeled the same scenario used by USGS, but using the ABAG Hazus parameters, to allow the user to compare how the different parameters affect the results and to compare the impacts identified in the HayWired study to potential impacts from the earthquake scenarios

[1] Dunne and Sonnenfield, 1991

[2] ABAG's 9 member counties include: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano and Sonoma Counties.

outlined in this report. A comparison of the HayWired Hazus parameters and the ABAG Hazus parameters can be found in Appendix A. An in-depth look at the earthquake hazards associated with the HayWired earthquake scenario can be found here: https://pubs.usgs.gov/sir/2017/5013/sir20175013ah.pdf. Reports outlining the social, economic, and other consequences of the scenario are expected to be released in 2018.

The following table outlines key differences in earthquake scenario and reporting level between the 2003 *Preventing the Nightmare* study and the 2017 Hazus study.

Table 1: Comparison of scenarios and reporting level between 2003 and 2017 studies

2003 Preventing the Nightmare Earthquake Scenarios	**Reporting Level**	**2017 Hazus Earthquake Scenarios**	**Reporting Level**
Santa Cruz Mountains San Andreas M 6.9	County		
Peninsula-Golden Gate San Andreas M 7.2	County	San Andreas (Peninsula Segment) M 7.2	County
Northern Golden Gate San Andreas M 7.5	County		
Entire Bay Area San Andreas M 7.9	County	San Andreas (All Northern Segments) M 7.8	Census Tract
Northern San Gregorio M 7.3	County	San Gregorio M 7.4	County
Southern Hayward M 6.9	County	Hayward South M 6.8	County
Northern Hayward M 6.6	County		
Northern + Southern Hayward M 7.1	County	Hayward (North & South) M 7.0	Census Tract
		HayWired M 7.0	*Census Tract*
Rodgers Creek M 7.1	County	Rodger's Creek M 7.1	Census Tract
Rodgers Creek-Northern Hayward M 7.2	County		
Southern Maacama M 6.6	County	Maacama M 7.4	County
West Napa M 6.5	County	West Napa M 6.7	Census Tract
Concord-Green Valley M 6.8	County	Concord-Southern Green Valley M 6.8	County
Northern Calaveras M 7.0	County		
Central Calaveras M 6.6	County	Calaveras (Central Segment) M 6.4	County
		Calaveras (All Segments) M 7.0	Census Tract
Mt. Diablo M 6.7	County	Mt. Diablo M 6.7	County
Greenville M 7.2	County	Greenville M 7.0	County
Monte Vista M 6.6	County		
		Berryessa M 7.1	County
		Great Valley – Segment 4b (Gordon Valley) M. 6.8	County
		Great Valley – Segment 5 (Kirby Hills) M 6.7	County

Data Considerations

Data Parameters

Default building inventory data in Hazus, representing the "general building stock," have been developed from census data for residential occupancies, and from Dun & Bradstreet employment data for non-residential occupancies. Hazus differentiates the general building stock into 33 different *Specific Occupancy Classes*, including 11 residential, ten commercial, six industrial, one agricultural, one religious, two education and two government occupancies. The Hazus default inventory database consists of four inter-related data sets, each tabulated at the census tract level for earthquake, and the census block level for flood. The four basic tables are:

- square footage by occupancy, which is used to derive building counts and exposure values
- building count by occupancy
- building exposure value by occupancy
- content exposure value by occupancy (determined as a percent of structure value, by occupancy)

In addition to these occupancy exposure tables, Hazus utilizes "mapping scheme" tables which indicate, by occupancy, the percent distribution of square footage among various structural or *Model Building Types.* These mapping scheme distributions drive which vulnerability functions will be used to estimate damage and loss for each occupancy class.

The Hazus model, as well as data inputs, can be customized where more specificity is available. In this study, data was customized based on advances made by previous studies. The custom Hazus data for the Bay Area that form the basis for this study were developed as part of the scenario modeling effort conducted for the 1906 100-year Earthquake Anniversary Conference.[3] Most of that effort was focused on developing custom mapping schemes; inventory data adjustments were applied in the form of simple escalation factors. A total of 22 custom earthquake mapping schemes were applied at the census tract level across the Bay Area, reflecting differing building age and height patterns, as well as building density; a separate set of schemes are applied to portions of San Francisco and Alameda Counties to reflect urban core areas with concentrations of high-rise construction. For this study, in addition to incorporating the 22 custom mapping schemes, custom parameters were also incorporated into the earthquake shelter module.

Table 2: Summary of Hazus inputs

Definition/Input/Parameter	Value
Hazus execution version	Hazus 3.2
Hazus Study Region Extent	9 ABAG Counties (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano and Sonoma)
Inventory data: building exposure databases (sq. ft., building count, etc.)	Hazus 3.2 default: 2010 census basis for residential, escalated 2006 D&B for commercial

[3] Kircher, et al., 2006

Inventory data: mapping schemes	2006 custom mapping schemes translated to 2010 census geography
Inventory data: $ year of exposure values	Hazus 3.2 default: 2014$
Inventory data: demographics	2010 census
Hazard data: Ground Motion data	USGS ShakeMaps for 17 earthquake scenarios (Hazus.zip data restored to peak values, except for HayWired scenario)
Hazard data: Liquefaction Susceptibility data	USGS regional liquefaction susceptibility (USGS OF00-444, 2000). Manual override of Hazus 3.2 liquefaction susceptibility assignment to census tracts to correct for potential inconsistencies.
Hazard data: Depth to Groundwater	Uniform assumption of 5 feet
Damage Module: Parameters - Fragility curve betas	For all scenarios other than the HayWired scenario, default uncertainties/betas have been utilized. For the HayWired scenario, reduced uncertainties/betas (appropriate for actual events and high quality ShakeMaps) have been used
Shelter Module: Parameters	"ShakeOut" custom parameters utilized. Hand calculations substituted to allow for disaggregation of shelter results by residential occupancy.

Cost Escalation Modifications

For the 2006 Kircher et al study, the underlying Hazus inventory data (Hazus MR-2, 2006) were based on 2000 Census data for residential construction and 2002 Dun & Bradstreet data for non-residential construction. The custom Bay Area inventory data included both cost escalation factors (default $2005 residential exposure values were increased by 10%, default $2005 non-residential exposure values were increased by 200%) and a non-residential square footage escalation. The non-residential square footage escalation factor would not be appropriate for use with later inventory databases, because the non-residential data were updated and significantly enhanced in a subsequent release of Hazus (Hazus MR-3, 2007). The current Hazus residential inventory data are based on 2010 census data. Non-residential inventory data are based on 2006 Dun & Bradstreet data, with selected occupancies escalated for growth at the time of the Hazus update to 2010 census data (updated Dun & Bradstreet data were not available).

Table 3 provides a comparison of building exposure values (replacement costs) for the 2006 custom data and the current Hazus default data, by Hazus occupancy class, for ABAG's nine Bay Area counties (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano and Sonoma Counties). For a more direct comparison, the custom data set 2005 dollar values have been approximately converted to

2014 dollars, as used by the current Hazus cost model, using national CPI ratios[4]; the CPI ratio used to convert the custom data from 2005 dollars to 2014 dollars is 1.21.

Given that the current Hazus default data represents development as of 2010, we would expect the exposure values to be slightly larger than the 2006 custom data for categories that experienced growth between 2006 and 2010. As shown in **Table 3**, for the ABAG nine county area, the current Hazus default replacement value totals are 1% larger overall than the custom 2006 data, when converted to 2014 dollars. In terms of Hazus *General Occupancy Classes*, the current replacement values for the Residential *General Occupancy Class,* which are the focus of this study, are 7% larger than the 2006 data. The current data for the Commercial and Industrial *General Occupancy Classes* are 21% and 12% less than the 2006 data, which included the 200% escalation factor. In terms of Hazus *Specific Occupancy Classes* for residential construction, the current default database has more residential building exposure value than the 2006 custom database for all classes except for RES3A/Duplexes, for which the typical building size assumed in the underlying cost model was revised in the most recent Hazus update.

The magnitude of the non-residential differences (30% and less for all non-residential *General Occupancies*) do not appear to support the 200% non-residential value escalation used in the prior study. For this reason, and for ease of future replication, the Hazus 3.2 default building inventory data were used as is.

Table 3: Comparison of Nine County Custom Bay Area Building Exposure Value to Current Hazus Default Building Exposure Value*

Occupancy Class	Bay Area Custom Data (2006) Building Exposure Value (2005 $M)	Bay Area Custom Data (2006) Building Exposure Value (2014 $M)	Hazus 3.2 (2016) Building Exposure Value (2014 $M)	Ratio of Hazus 3.2 default to 2006 custom data
All Occupancies	762,606	924,445	934,277	1.01
Hazus General Occupancy Class				
Residential	558,438	676,949	725,197	1.07
Commercial	153,248	185,770	147,324	0.79
Industrial	33,683	40,832	35,751	0.88
Agriculture	1,405	1,703	2,214	1.30
Religion	7,391	8,960	10,469	1.17
Government	2,234	2,829	3,631	1.28
Education	6,106	7,402	9,691	1.31
Hazus Specific Occupancy Class				
RES1 (Single Family Home)	437,667	530,549	539,393	1.02
RES2 (Manuf. Housing)	2,149	2,605	3,100	1.19
RES3A (Multifamily: Duplex)	14,038	17,018	13,399	0.79
RES3B (Multifamily: 3-4 units)	13,286	16,106	20,411	1.27

[4] https://data.bls.gov/cgi-bin/dsrv

RES3C (Multifamily: 5-9 units)	22,274	27,001	30,280	1.12
RES3D (Multifamily: 10-19 units)	16,230	19,674	26,209	1.33
RES3E (Multifamily: 20-49 units)	15,385	18,650	29,246	1.57
RES3F (Multifamily: 50+ units)	21,618	26,206	37,502	1.43
RES4 (Hotel/Motel)	2,502	3,032	5,568	1.84
RES5 (Institutional Housing)	12,775	15,486	18,303	1.18
RES6 (Nursing Home)	514	623	1,786	2.87
COM1 (Retail Trade)	26,931	32,646	18,189	0.56
COM2 (Wholesale Trade)	15,044	18,236	16,316	0.89
COM3 (Personal/Repair Service)	15,387	18,652	14,997	0.80
COM4 (Professional Service)	57,772	70,032	58,921	0.84
COM5 (Bank)	3,835	4,649	4,009	0.86
COM6 (Hospital)	5,256	6,371	5,592	0.88
COM7 (Medical Office/Clinic)	10,225	12,395	10,565	0.85
COM8 (Entertainment/ Recreation)	18,354	22,249	18,225	0.82
COM9 (Theater)	445	540	510	0.94
COM10 (Parking)	-	-	-	-
IND1 (Heavy Industrial)	8,587	10,410	7,662	0.74
IND2 (Light Industrial)	7,866	9,535	7,915	0.83
IND3 (Food/Drugs/Chemical)	6,348	7,695	7,896	1.03
IND4 (Metal/Mineral Processing)	759	920	877	0.95
IND5 (High Tech)	4,919	5,963	5,194	0.87
IND6 (Construction)	5,204	6,309	6,208	0.98
AGR1 (Agriculture)	1,405	1,703	2,214	1.30
REL1 (Church/Non-Profit)	7,391	8,960	10,469	1.17
GOV1 (General Services)	1,926	2,334	2,863	1.23
GOV2 (Emergency Services)	408	495	768	1.55
EDU1 (Grade Schools)	3,617	4,385	7,287	1.66
EDU2 (Colleges/Universities)	2,489	3,017	2,404	0.80

* ABAG's nine Counties include: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano and Sonoma.

Earthquake shelter module parameters

The Hazus shelter module allows users to estimate 1) the number of displaced households (DH) caused by residential building damage and resulting loss of habitability, and 2) the number of people seeking public short-term shelter. The number of DH is derived from the distribution of households in the various residential occupancy types (single family homes, manufactured/mobile homes, and multifamily residential buildings) as distributed across the Hazus building damage states expected to result in potential displacement (*Moderate*, *Extensive* and *Complete* damage states), combined with displacement probabilities referred to as "weighting factors" (WF), given in **Table 4**.

The Hazus model for the number of people seeking publicly-provided, short-term shelter recognizes that only a portion of displaced households will actually utilize public shelter resources. The fraction of DH expected to seek public shelter is determined using population data, weighting factors (WF) and

modification factors (MF), which reflect the shelter-seeking tendencies associated with various income levels, ethnicities, home ownership, and age. For example, households with higher income levels are less likely to seek public shelter.[5] It should be noted, however, that the default values for the age and ownership WFs (AW and OW) are set to zero, effectively removing these factors from consideration under the default Hazus configuration, as shown in **Table 5**. As shown, the default WFs are set such that income has a greater impact on shelter-seeking behavior than ethnicity.

The Hazus shelter model, including the refined parameters utilized in the ABAG analyses, is based on available historic earthquake data. Custom shelter parameters were developed for the 2008 ShakeOut[6] scenario planning effort, based on available population survey data from the UCLA Center for Public Health & Disasters for the 1989 Loma Prieta, 1994 Northridge and other California earthquakes (K. Shoaf, in press), and are included in **Table 4** and **Table 5**. Adjustments included modifying the parameters for the percentage of households seeking shelter based on building damage state (WFs, see **Table 4**) to include some shelter-seeking behavior for occupants of moderately damaged residential structures (normally set to zero in the Hazus default) and modifications to the income and ethnicity factors considered by the model (MFs, see **Table 5**). As noted above, income is assumed to be a more important indicator of shelter-seeking behavior than ethnicity (that is, IW is larger than EW), and those with lower incomes are more likely to seek shelter than those with higher incomes (that is, IM1 > IM2 > IM3).

As noted above, the custom shelter model parameters developed for the ShakeOut scenario utilized survey data from the M6.9 1989 Loma Prieta and M6.7 1994 Northridge earthquakes. In those two events, approximately 22% and 16% of the population surveyed, respectively, were displaced from their homes. Further, the number of survey respondents staying in a formal shelter was small. The net impact of the custom ShakeOut parameters (relative to the Hazus default parameters) is to significantly increase the estimated number of displaced households, and decrease slightly the number of people seeking short-term shelter. Given that the historic event data is for events of Magnitude less than 7, the resulting shelter population estimates may not adequately reflect the broader regional impact expected in the larger scenario events being modeled here. Accordingly, the short-term shelter estimates could be considered lower-bound estimates.

Table 4: Hazus Shelter Module: Weighting Factors for the Household Displacement Model - Default Values and Custom Values Developed for the 2008 ShakeOut Scenario

Parameter	Residence Type/Hazus Damage State	Hazus Default Value	ShakeOut Custom Value
W_{SFM}	Single family home/Moderate damage state	0.0	0.2
W_{SFE}	Single family home/Extensive damage state	0.0	0.4
W_{SFC}	Single family home/Complete damage state	1.0	1.0
W_{MFM}	Multifamily residence/Moderate damage state	0.0	0.4
W_{MFE}	Multifamily residence/Extensive damage state	0.9	0.65
W_{MFC}	Multifamily residence/Complete damage state	1.0	1.0

[5] For additional details, refer to chapter 14 of the Hazus Technical Manual; FEMA, 2012
[6] https://pubs.usgs.gov/of/2008/1150/

Table 5: Hazus Shelter Module: Weighting/Modification Factors for the Short-Term Shelter Model - Default Values and Custom Values Developed for the 2008 ShakeOut Scenario

Model Parameter	Weighting Factor (WF)/Modification Factor (MF) Description	Hazus Default value	ShakeOut Custom Value
AW	Age WF	0	No change
EW	Ethnicity WF	0.27	No change
IW	Income WF	0.73	No change
OW	Ownership WF	0	No change
AM_1	Age MF: Percent of population under 16 years old	0.4	No change
AM_2	Age MF: percent of population between 16 and 65 years old	0.4	No change
AM_3	Age MF: percent of population over 65 years old	0.4	No change
EM_1	Ethnicity MF: White households	0.24	0.1
EM_2	Ethnicity MF: Black households	0.48	0.2
EM_3	Ethnicity MF: Hispanic households	0.47	0.2
EM_4	Ethnicity MF: Asian households	0.26	0.1
EM_5	Ethnicity MF: Native American households	0.26	0.1
IM_1	Income MF: household income < $10,000	0.62	0.3
IM_2	Income MF: $10,000 < household income < $15,000	0.42	0.3
IM_3	Income MF: $15,000 < household income < $25,000	0.29	0.14
IM_4	Income MF: $25,000 < household income < $35,000	0.22	0.08
IM_5	Income MF: household income > $35,000	0.13	0.05
OM_1	Ownership MF: percent of households that are owner occupied	0.4	No Change
OM_2	Ownership MF: percent of households that are renter occupied	0.4	No Change

Earthquake Module Methodology and Results

Hazus results of interest to ABAG include estimates of displaced households and short-term shelter loads (results of the Hazus Shelter module, discussed in more detail below), estimates of uninhabitable buildings (manually derived from building damage state probability distributions) and estimates of residential building damage in dollars (a direct output from the Hazus General Building Stock module).

Displaced Households

The Hazus *Displaced Households* (*DH*) *model* associates predicted building damage state probability distributions for residential occupancies with demographic data on housing units. According to the Hazus Technical Manual, the DH model consists of three basic equations, as follows:

1) $\%SF = W_{SFM} \times \%SFM + W_{SFE} \times \%SFE + W_{SFC} \times \%SFC$

2) $\%MF = W_{MFM} \times \%MFM + W_{MFE} \times \%MFE + W_{MFC} \times \%MFC$

3) $\#DH = (\#SFU \times \%SF + \#MFU \times \%MF) * \frac{\#HH}{(\#SFU + \#MFU)}$

Where,

- %SF = the percent of single family housing units considered uninhabitable
- %MF = the percent of multifamily housing units considered uninhabitable
- W_{SFM}, W_{SFE}, W_{SFC}, W_{MFM}, W_{MFE} and W_{MFC} are the residence type/damage state weighting factors given in **Table 4** above
- %SFM, %SFE and %SFC are the damage state probabilities for Moderate, Extensive and Complete structural damage, respectively, for the single family residential occupancy class (Hazus RES1), i.e., the probability that for each census tract, single family homes will experience Moderate/Extensive/Complete structural damage.
- %MFM, %MFE and %MFC are the damage state probabilities for Moderate, Extensive and Complete structural damage, respectively, for multifamily residential occupancies (Hazus RES3A-RES3F inclusive, see **Table 3** for occupancy class definitions).
- #DH = total number of displaced households in the census tract
- #SFU = total number of single family housing units (tabulated by census tract in the Hazus demographics table as Owner-Occupied Single Household Units, Renter-Occupied Single Household Units and Vacant Single Household Units)
- #MFU = total number of multifamily housing units (tabulated by census tract in the Hazus demographics table as Owner-Occupied Multi-Household Units, Renter-Occupied Multi-Household Units and Vacant Multi-Household Units)
- #HH = total number of households in the census tract (also tabulated in the Hazus demographics table).

The final term in the #DH equation ($\frac{\#HH}{(\#SFU + \#MFU)}$) is essentially an occupancy rate, converting the estimated number of uninhabitable housing units to households.

It should be noted that the DH method, as documented, neglects to mention manufactured housing/mobile homes (Hazus Occupancy Class RES2), for which both housing unit data and damage state probability data are specifically available. Further, results of the Hazus DH model are tabulated as a single estimate of all displaced households by census tract, with no interim results provided (i.e., results for displaced single vs. multifamily housing units are not available). Because results were desired by individual Hazus occupancy, an attempt was made to "reverse-engineer" the results to allow for disaggregation by residential occupancy class. Unfortunately, the Hazus displaced household results were not able to be replicated except for a few census tracts that have a single occupancy type (i.e., all single family or all multifamily). This could mean that the method as documented in the manual is incomplete or does not precisely match what is coded into the software, or that there is an error in the code. Hand calculations of the displaced household estimates are lower than the final Hazus result, generally on the order of 10%. Because the individual occupancy results were needed, it was decided to utilize the hand-calculated results, ensuring consistency with the documented methodology, and explicitly including manufactured housing/mobile homes.

Short-term Shelter

The Hazus short-term shelter (STS) model combines the results of the displaced household model with additional demographic data on income and ethnicity (data on age and ownership could also be considered, but are omitted in both the default and custom ShakeOut parameter sets, see **Table 5**).

According to the Hazus Technical Manual, the STS model consists of two basic equations (modified here to omit the factors for age and ownership), as follows:

1) $\#STS = \sum_{i=1}^{5} \quad \sum_{j=1}^{5} (\alpha_{i,j} * (\frac{\#DH * POP}{\#HH}) * HI_j * HE_j)$

2) $\alpha_{i,j} = (IW * IM_i) + (EW * EM_j)$

Where,

- #STS = total number of people who require short-term shelter
- POP = total population in the census tract
- HIi = percentage of population in the census tract in the ith income class
- HEj = percentage of population in the census tract in the jth ethnicity class
- αi,j = aggregated census tract weighting factor
- IW and EW are income and ethnicity weighting factors (see **Table 5**)
- IMi and EMj are modification factors for various income and ethnicity categories (see also **Table 5**)

Similar to the DH model, the results of the Hazus STS model are tabulated as a single estimate of shelter populations by census tract, with no interim results provided. Unlike the DH model, Hazus calculations for STS were replicable, allowing for occupancy-specific hand-calculations of STS from our hand-calculated DH that are fully consistent with the programmed Hazus approach.

Uninhabitable Buildings

While not a standard Hazus output, the number of uninhabitable residential buildings can readily be calculated from the census tract building count damage state distributions (i.e., the number of buildings of each residential occupancy class expected to be in the *Moderate*, *Extensive* or *Complete* damage state, by

census tract), multiplied by the shelter module weighting factors (W_{SFM}, W_{SFE}, W_{SFC}, W_{MFM}, W_{MFE} and W_{MFC} given in **Table 4**).

Earthquake Results

Population and housing impact estimates have been provided at the census tract level for single family homes (Hazus occupancy class RES1), manufactured housing/mobile homes (RES2), and multifamily residences (RES3A – RES3F) for six significant earthquake scenarios; for the remaining 11 scenarios, the results are reported in summary form at the County level. **Table 6** provides a regional summary of the Hazus-estimated impacts across ABAG's nine counties for each of the 17 scenarios (listed alphabetically), and identifies the six scenarios with census tract level reporting of results.

Table 7 provides county level results for the eleven scenarios with county level reporting. **Table 8** provides more detailed results, by occupancy class and county, for the six scenarios (listed alphabetically) with census tract level reporting.

Table 6: Summary of Hazus-Estimated Impacts for Selected USGS Earthquake Scenarios, including effects of Liquefaction, for Nine Bay Area Counties

Scenario Earthquake	Displaced Households (# Households)	Short-Term Shelter Loads (# People)	Uninhabitable Residential Buildings (# Buildings)	Residential Building Damage ($Billion)	Reporting Level
Berryessa M7.1	9,100	2,500	3,300	1.4	County
Calaveras (all segments) M7.0	68,700	19,100	25,500	11.0	Census Tract
Calaveras (central segment) M6.4	14,600	4,300	5,500	2.6	County
Concord – Southern Green Valley M6.8	40,200	11,300	16,700	6.8	County
Great Valley – Segment 4b (Gordon Valley) M6.8	20,600	5,900	10,100	3.7	County
Great Valley – Segment 5 (Kirby Hills) M6.7	18,200	5,400	8,200	3.3	County
Greenville M7.0	26,100	7,300	9,700	4.6	County
Hayward (North & South) M7.0	145,000	42,000	55,100	20.9	Census Tract
Hayward South M6.8	115,700	33,300	41,800	16.2	County
HayWired M7.0	*172,800*	*51,300*	*62,500*	*25.7*	*Census Tract*
Maacama M7.4	8,800	2,300	3,800	1.4	County
Mount Diablo M6.7	45,900	12,000	18,200	8.0	County
Rodger's Creek M7.1	42,800	11,500	16,600	6.1	Census Tract
San Andreas (all Northern segments) M7.8	198,700	51,600	68,900	28.4	Census Tract
San Andreas (Peninsula Segment) M7.2	121,100	31,100	40,500	17.1	County
San Gregorio M7.4	87,300	22,200	24,300	10.8	County
West Napa M6.7	19,600	5,600	8,900	3.3	Census Tract

Table 7: Summary of Hazus-Estimated Impacts at the County Level for Eleven USGS Earthquake Scenarios, including the effects of Liquefaction, for Nine Bay Area Counties

Scenario	County	Displaced Households (# Households)	Short-term Shelter Loads (# People)	Uninhabitable Buildings (# Buildings)	Building Damage ($Million)
Berryessa M7.1	Alameda	1,800	500	500	173
	Contra Costa	800	200	400	203
	Marin	300	100	100	77
	Napa	900	300	600	188
	San Francisco	2,800	700	400	191
	San Mateo	200	0	100	39
	Santa Clara	300	100	100	39
	Solano	1,200	400	600	294
	Sonoma	800	200	500	200
	Total	**9,100**	**2,500**	**3,300**	**1,403**
Calaveras (Central Segment) M6.4	Alameda	2,100	600	900	500
	Contra Costa	200	0	100	96
	Marin	0	0	0	10
	Napa	0	0	0	2
	San Francisco	900	200	200	80
	San Mateo	600	100	200	133
	Santa Clara	10,800	3,400	4,100	1,787
	Solano	0	0	0	8
	Sonoma	0	0	0	5
	Total	**14,600**	**4,300**	**5,500**	**2,621**
Concord – Southern Green Valley M6.8	Alameda	10,800	3,200	3,400	1,408
	Contra Costa	14,800	4,100	7,500	3,008
	Marin	600	100	300	140
	Napa	1,200	400	700	229
	San Francisco	5,300	1,300	1,100	480
	San Mateo	1,200	300	400	234
	Santa Clara	1,800	500	500	211
	Solano	3,900	1,200	2,400	916
	Sonoma	600	200	400	143
	Total	**40,200**	**11,300**	**16,700**	**6,770**
Great Valley – Segment 4b (Gordon Valley) M6.8	Alameda	3,200	1,000	900	377
	Contra Costa	2,200	700	1,000	536
	Marin	500	100	200	112
	Napa	1,100	300	700	234
	San Francisco	3,100	700	600	254
	San Mateo	400	100	100	75
	Santa Clara	200	0	100	26
	Solano	9,200	2,800	6,000	1,916
	Sonoma	700	200	500	170
	Total	**20,600**	**5,900**	**10,100**	**3,698**
Great Valley – Segment 5 (Kirby Hills) M6.7	Alameda	3,900	1,100	1,200	533
	Contra Costa	5,800	1,900	3,300	1,332
	Marin	200	0	100	55
	Napa	300	100	200	72

Scenario	County	Displaced Households (# Households)	Short-term Shelter Loads (# People)	Uninhabitable Buildings (# Buildings)	Building Damage ($Million)
	San Francisco	2,500	600	500	208
	San Mateo	400	100	100	91
	Santa Clara	1,100	300	300	137
	Solano	3,800	1,200	2,300	823
	Sonoma	200	100	200	58
	Total	**18,200**	**5,400**	**8,200**	**3,309**
Greenville M7.0	Alameda	8,600	2,600	3,500	1,545
	Contra Costa	5,000	1,400	2,700	1,381
	Marin	300	100	100	63
	Napa	100	0	100	22
	San Francisco	4,000	900	700	335
	San Mateo	1,200	300	400	225
	Santa Clara	6,300	1,800	1,800	845
	Solano	500	200	300	138
	Sonoma	100	0	100	24
	Total	**26,100**	**7,300**	**9,700**	**4,577**
Hayward South M6.8	Alameda	65,900	20,200	27,400	9,626
	Contra Costa	5,100	1,400	2,400	1,232
	Marin	900	200	400	201
	Napa	100	0	100	27
	San Francisco	18,100	4,200	3,100	1,530
	San Mateo	4,600	1,200	1,700	854
	Santa Clara	20,200	5,900	6,300	2,593
	Solano	600	200	300	140
	Sonoma	200	0	100	43
	Total	**115,700**	**33,300**	**41,800**	**16,245**
Maacama M7.4	Alameda	1,000	300	300	89
	Contra Costa	400	100	200	81
	Marin	300	100	100	72
	Napa	500	100	400	91
	San Francisco	2,100	500	300	139
	San Mateo	200	0	0	27
	Santa Clara	200	0	0	17
	Solano	300	100	100	68
	Sonoma	3,800	1,100	2,400	793
	Total	**8,800**	**2,300**	**3,800**	**1,377**
Mount Diablo M6.7	Alameda	14,600	4,300	5,700	2,353
	Contra Costa	15,100	3,800	8,400	3,666
	Marin	500	100	200	114
	Napa	200	0	100	33
	San Francisco	9,100	2,100	1,500	710
	San Mateo	1,600	400	500	310
	Santa Clara	3,700	1,000	1,200	555
	Solano	900	300	500	212
	Sonoma	200	0	100	36
	Total	**45,900**	**12,000**	**18,200**	**7,988**
	Alameda	13,700	4,000	4,600	1,813

Scenario	County	Displaced Households (# Households)	Short-term Shelter Loads (# People)	Uninhabitable Buildings (# Buildings)	Building Damage ($Million)
San Andreas (Peninsula Segment) M7.2	Contra Costa	1,900	600	800	442
	Marin	2,300	600	1,000	483
	Napa	100	0	100	24
	San Francisco	44,500	10,600	11,800	4,768
	San Mateo	29,500	7,600	13,100	5,521
	Santa Clara	28,400	7,500	8,700	3,884
	Solano	300	100	200	79
	Sonoma	400	100	200	88
	Total	**121,100**	**31,100**	**40,500**	**17,102**
San Gregorio M7.4	Alameda	13,600	3,900	3,800	1,514
	Contra Costa	2,200	700	800	431
	Marin	2,600	700	1,100	506
	Napa	200	0	100	27
	San Francisco	39,400	9,200	8,700	3,943
	San Mateo	15,800	4,100	6,400	2,803
	Santa Clara	12,600	3,300	3,000	1,399
	Solano	500	200	200	96
	Sonoma	400	100	200	89
	Total	**87,300**	**22,200**	**24,300**	**10,807**

Table 8: Summary of Hazus-Estimated Impacts Disaggregated by Residential Occupancy Class for Six USGS Earthquake Scenarios, including effects of Liquefaction, for Nine Bay Area Counties

(DH = Number of displaced households; STS = short-term shelter loads, number of people; UninB = number of uninhabitable residential buildings; BD$M = residential building damage in $million; CC = Contra Costa; SF = San Francisco)

Scenario	County	Single Family Homes (Hazus RES1)				Manufactured Homes (Hazus RES2)				Multifamily Residences (Hazus RES3A-RES3F)				Residential Total			
		DH	**STS**	**UninB**	**BD$M**	**DH**	**STS**	**UninB**	**BD$M**	**DH**	**STS**	**UniB**	**BD$M**	**DH**	**STS**	**UninB**	**BD$M**
Calaveras M7.0	Alameda	5,900	1,600	6,100	2,730	700	200	700	20	15,500	4,600	2,200	1,000	22,100	6,300	9,000	3,760
	CC	3,200	800	3,400	1,800	300	100	400	10	4,800	1,200	600	380	8,300	2,000	4,400	2,200
	Marin	100	0	100	80	0	0	0	0	300	100	0	30	400	100	200	100
	Napa	0	0	0	20	0	0	0	0	100	0	0	0	100	0	100	20
	SF	500	100	500	240	0	0	0	0	10,100	2,400	1,100	590	10,600	2,500	1,700	830
	San Mateo	600	200	700	380	100	0	100	0	2,100	600	200	150	2,800	700	1,000	540
	Santa Clara	4,600	1,500	4,800	2,450	1,700	600	1,800	60	17,500	5,200	2,100	890	23,800	7,300	8,700	3,410
	Solano	100	0	200	110	100	0	100	0	300	100	100	30	500	200	300	140
	Sonoma	0	0	0	20	0	0	0	0	100	0	0	10	100	0	100	30
	Total	**15,000**	**4,200**	**15,800**	**7,830**	**2,900**	**900**	**3,100**	**90**	**50,800**	**14,200**	**6,300**	**3,080**	**68,700**	**19,100**	**25,500**	**11,030**
Hayward M7.0	Alameda	20,800	6,100	22,000	7,200	2,000	600	2,200	90	52,700	16,400	8,000	3,890	75,500	23,100	32,200	11,180
	CC	4,800	1,400	5,100	2,060	600	200	600	20	8,300	2,700	1,500	640	13,700	4,300	7,200	2,730
	Marin	900	200	900	470	200	0	200	10	1,900	600	300	160	3,000	800	1,400	630
	Napa	100	0	100	70	100	0	100	0	300	100	0	20	500	100	300	100
	SF	1,100	300	1,200	510	0	0	0	0	21,100	4,800	2,500	1,360	22,200	5,100	3,700	1,870
	San Mateo	1,200	300	1,300	680	100	0	100	0	3,700	1,000	400	270	5,000	1,300	1,800	960
	Santa Clara	3,400	1,000	3,600	1,930	1,400	400	1,500	50	17,800	5,100	2,000	900	22,600	6,500	7,100	2,880
	Solano	400	100	500	230	200	0	200	10	900	300	200	70	1,500	500	800	310
	Sonoma	200	100	300	180	200	100	200	10	500	100	100	40	1,000	300	600	220

	Total	**32,900**	**9,500**	**35,000**	**13,330**	**4,800**	**1,300**	**5,100**	**190**	**107,200**	**31,100**	**15,000**	**7,350**	**145,000**	**42,000**	**55,100**	**20,880**
HayWired M7.0	Alameda	21,500	6,400	22,700	8,070	4,200	1,300	4,600	210	67,500	21,300	9,900	5,250	93,300	29,000	37,200	13,540
	CC	5,700	1,600	6,000	3,220	1,500	500	1,600	60	16,800	4,900	2,600	1,530	24,000	7,000	10,200	4,820
	Marin	100	0	100	190	100	0	100	0	400	100	100	50	600	200	300	240
	Napa	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	20
	SF	500	100	600	480	0	0	0	0	13,300	3,200	1,600	780	13,900	3,300	2,200	1,270
	San Mateo	1,700	400	1,800	1,190	200	100	200	10	5,300	1,400	600	400	7,200	1,900	2,600	1,600
	Santa Clara	3,400	1,000	3,500	2,780	3,000	900	3,100	90	26,900	7,900	3,100	1,170	33,300	9,700	9,700	4,030
	Solano	100	0	100	120	100	0	100	0	300	100	100	40	500	200	300	160
	Sonoma	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	20
	Total	**33,000**	**9,500**	**34,800**	**16,080**	**9,100**	**2,800**	**9,700**	**370**	**130,500**	**38,900**	**18,000**	**9,220**	**172,800**	**51,300**	**62,500**	**25,700**
Rodgers Creek M7.1	Alameda	800	200	800	420	100	0	100	0	6,000	1,800	900	310	6,900	2,000	1,900	740
	CC	700	200	800	490	200	100	200	10	1,900	600	300	140	2,900	900	1,300	640
	Marin	900	200	1,000	480	200	0	200	10	1,900	600	300	160	3,000	800	1,500	650
	Napa	200	100	200	110	200	0	200	10	400	100	100	30	700	200	400	140
	SF	500	100	600	260	0	0	0	0	11,900	2,800	1,300	710	12,500	2,900	1,900	980
	San Mateo	200	0	200	150	0	0	0	0	900	200	100	60	1,100	300	300	210
	Santa Clara	0	0	0	70	100	0	100	0	1,100	300	100	50	1,300	300	200	120
	Solano	400	100	400	230	100	0	200	10	1,000	300	200	80	1,500	500	800	310
	Sonoma	4,600	1,200	4,900	1,720	2,200	600	2,500	90	6,100	1,800	1,000	490	12,900	3,600	8,300	2,300
	Total	**8,300**	**2,100**	**8,900**	**3,930**	**3,100**	**700**	**3,500**	**130**	**31,200**	**8,500**	**4,300**	**2,030**	**42,800**	**11,500**	**16,600**	**6,090**
Scenario	**County**	**Single Family Homes (Hazus RES1)**				**Manufactured Homes (Hazus RES2)**				**Multifamily Residences (Hazus RES3A-RES3F)**				**Residential Total**			
		DH	**STS**	**UninB**	**BD$M**	**DH**	**STS**	**UninB**	**BD$M**	**DH**	**STS**	**UniB**	**BD$M**	**DH**	**STS**	**UninB**	**BD$M**
Sa	Alameda	4,500	1,300	4,700	1,930	500	200	600	20	20,400	6,000	3,000	1,270	25,400	7,500	8,300	3,220

	CC	700	200	700	490	200	100	200	10	2,800	900	500	190	3,600	1,100	1,400	690
	Marin	1,800	400	2,200	900	300	100	300	10	4,100	1,100	600	350	6,200	1,500	3,100	1,260
	Napa	0	0	100	40	100	0	100	0	200	100	0	10	300	100	200	60
	SF	8,100	2,200	8,800	2,730	100	0	100	0	61,400	14,300	9,400	5,300	69,600	16,500	18,300	8,030
	San Mateo	14,400	3,700	15,000	5,360	1,000	300	1,100	50	26,800	7,000	3,100	2,490	42,200	11,000	19,300	7,900
	Santa Clara	7,900	2,100	8,300	3,970	2,900	800	3,100	110	36,400	9,800	4,100	2,250	47,200	12,700	15,500	6,330
	Solano	100	0	200	100	100	0	100	0	500	200	100	40	700	200	400	150
	Sonoma	1,000	200	1,200	550	800	200	900	30	1,800	500	300	130	3,500	1,000	2,400	710
	Total	**38,500**	**10,100**	**41,200**	**16,070**	**6,000**	**1,700**	**6,500**	**230**	**154,400**	**39,900**	**21,100**	**12,030**	**198,700**	**51,600**	**68,900**	**28,350**
West Napa M6.7	Alameda	400	100	400	260	100	0	100	0	3,100	900	500	160	3,500	1,000	1,000	430
	CC	600	100	600	430	200	100	200	10	1,600	500	300	120	2,400	700	1,100	560
	Marin	200	0	200	140	100	0	100	0	500	100	100	40	700	200	300	180
	Napa	1,400	400	1,500	530	800	200	800	30	1,800	600	300	140	3,900	1,200	2,700	690
	SF	200	100	200	120	0	0	0	0	3,700	800	500	210	3,900	900	800	340
	San Mateo	100	0	100	70	0	0	0	0	400	100	0	30	400	100	100	100
	Santa Clara	0	0	0	40	100	0	100	0	200	0	0	10	300	100	100	60
	Solano	1,200	400	1,300	520	300	100	400	20	1,800	600	400	150	3,300	1,100	2,000	680
	Sonoma	300	100	400	230	300	100	300	10	600	200	100	50	1,200	300	800	290
	Total	**4,400**	**1,200**	**4,700**	**2,340**	**1,900**	**500**	**2,000**	**70**	**13,700**	**3,800**	**2,200**	**910**	**19,600**	**5,600**	**8,900**	**3,330**

Flood Module Methodology and Results

The flood-related portions of the current Hazus loss estimation project were focused on testing the Hazus flood methodology for riverine flooding and coastal sea level rise in one Bay Area county to determine the relative magnitude of loss for each hazard type, assess data storage and processing demands, and identify considerations for further regional assessment.

To both assess the applicability of the Hazus flood results to ABAG's resilience planning efforts and to better assess the resources required for analyses, the current study has focused on one County (Alameda County, selected in conjunction with the San Francisco Bay Conservation and Development Commission, BCDC), and has assessed flood damage for a Hazus default 100-year flood, as well as under three Sea Level Rise (SLR) scenarios, using SLR depth grid data provided by ABAG's partners. Hazus flood analyses have significantly larger data storage and processing demands than Hazus earthquake analyses. Flood analyses are conducted at the census block level (vs. the census tract level used in the Hazus earthquake model), require raster data processing capabilities, and are typically executed on a county or sub-county level, rather than on a regional level. The eventual assessment of flood damage to ABAG's nine county area would likely require separate analyses for each of the counties. This section summarizes the results of Hazus Flood test runs conducted for Alameda County:

- A Hazus default ("Level 1") riverine flooding scenario for the 100-year flood
- Three "future conditions" scenarios reflecting potential Sea Level Rise (SLR) of three, four and six feet.

Hazus Flood Mapping Schemes

It should be noted that the custom Hazus earthquake mapping schemes utilized in the earthquake analyses are not applicable for flood; Hazus flood mapping schemes consider only foundation types (pile, pier, solid wall, basement, crawl space, fill or slab) and first flood heights for pre-FIRM (built before community entry into the National Flood Insurance Program) and post-FIRM construction (built after community entry into the NFIP). Default flood mapping schemes utilized in the current assessment are provided in

Table 9 for riverine hazard areas and **Table 10** for coastal hazard areas. Any customization of the mapping schemes for future analyses will require information on prevalence of foundation types and associated first floor heights for pre- and post-FIRM construction.

In the Hazus default database, each census block has an associated FIRM entry date, derived from FEMA's Community Status information[7]. The Hazus default FIRM entry dates for each populated census block in Alameda County are shown in **Figure 1**, and **Figure 2** identifies which census blocks are considered riverine vs. coastal hazard areas. These default assignments can be reviewed and modified, as needed. As shown in **Figure 2**, these assignments may need adjustment, given that a small area in the northeastern part of the County has been identified as "coastal."

[7] https://www.fema.gov/national-flood-insurance-program-community-status-book

Table 9: Hazus Default Flood Mapping Schemes for Alameda County Census Blocks in Riverine Hazard Areas

Foundation Type	Pre-FIRM distribution (% of construction)	Pre-FIRM First Floor Height (feet)	Post-FIRM distribution (% of construction)	Post-FIRM First Floor Height (feet)
Basement	13	4	13	4
Crawl Space	45	3	45	4
Fill	0	2	0	2
Pier	0	5	0	6
Pile	0	7	0	8
Slab	42	1	42	1
Solid Wall	0	7	0	8

Table 10: Hazus Default Flood Mapping Schemes for Alameda County Census Blocks in Coastal Hazard Areas

Foundation Type	Pre-FIRM distribution (% of construction)	Pre-FIRM First Floor Height (feet)	Post-FIRM distribution (% of construction): Coastal A Zone	Post-FIRM First Floor Height (feet): Coastal A Zone	Post-FIRM distribution (% of construction): Coastal V Zone	Post-FIRM First Floor Height (feet): Coastal V Zone
Basement	2	4	0	4	0	4
Crawl Space	46	3	55	4	10	4
Fill	0	2	0	2	0	2
Pier	7	5	5	6	25	8
Pile	7	7	20	8	60	8
Slab	37	1	20	1	5	1
Solid Wall	1	7	0	8	0	8

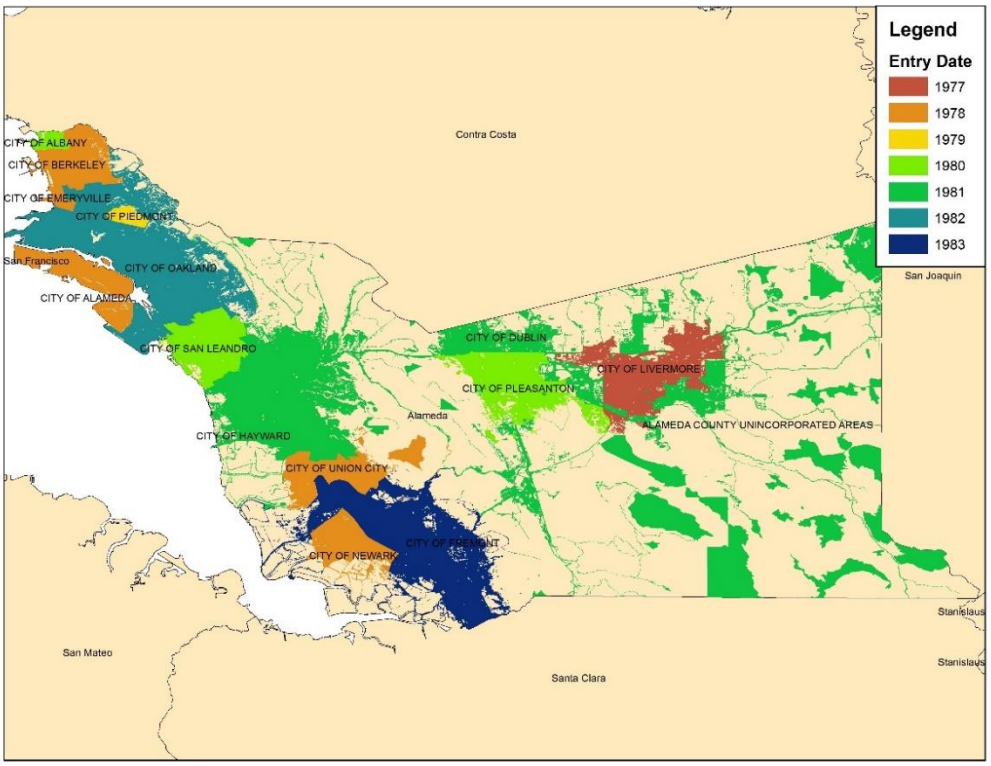

Figure 1: FIRM Entry Dates for Alameda County Census Blocks

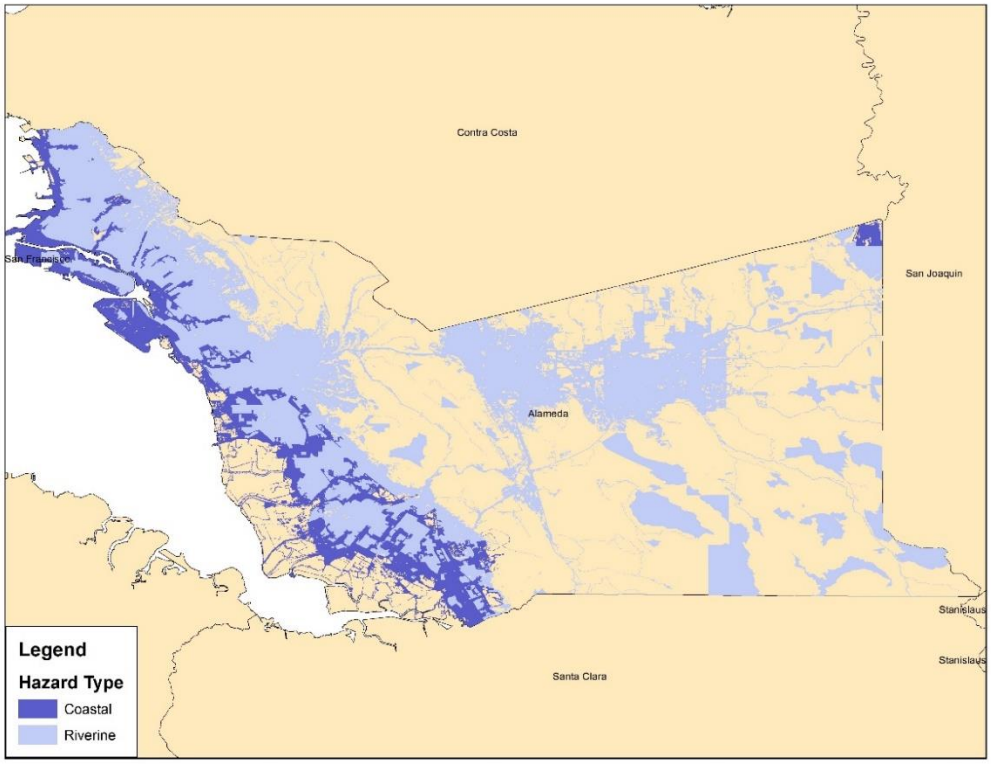

Figure 2: Hazard Types for Alameda County Census Blocks

Flood Shelter Module

The Hazus Flood Shelter module shares some similarities to the Hazus Earthquake Shelter module, but diverges from it in significant ways. While the earthquake model determines population displacement from physical damage to residential buildings, the Hazus flood model considers displacement to be a function of physical access to flooded areas; the default threshold at which ingress/egress to residential areas is restricted is 0.5 feet. At that depth and above, occupants are considered at least temporarily displaced. From the Hazus Flood Technical Manual (FEMA, 2012):

> *"The controlling factor is physical access into the area where the property is located. This is a function of the depth of water and the ability to travel into the area either on foot or by vehicle. For short-term sheltering estimations the user will need to determine at what depth of flooding will access to the area be obstructed. This depth typically would vary somewhere between 6" (typical curb height) and 12" (where vehicles will begin to float). Any residential unit located in the area where flood depth, defined as di, equals or exceeds that depth will be displaced from their home."*

The Flood model's determination of short-term shelter loads from displaced households is similar to that utilized in the earthquake model, although with different weighting and modification factors, as shown in **Table 11**. While no custom model parameters similar to the ShakeOut earthquake scenario custom parameters are available for flood, during initial model development, the Hazus Flood Model developers did suggest alternate income modification factors for use in communities where more than 60% of households had income greater than $35,000 (0.46, 0.36, 0.12, 0.05 and 0.01 for IM1, IM2, IM3, IM4 and IM5, respectively). These alternate factors could be tested in future analyses.

Table 11: Hazus Flood Shelter Module: Weighting/Modification Factors for Earthquake & Flood

Model Parameter	Weighting Factor (WF)/ Modification Factor (MF) Description	Hazus Earthquake Default Value	ShakeOut Custom Value	Hazus Flood Default Value
AW	Age WF	0	No change	0.2
EW	Ethnicity WF	0.27	No change	0
IW	Income WF	0.73	No change	0.8
OW	Ownership WF	0	No change	0
AM_1	Age MF: Percent of population < 16 years old	0.4	No change	0.05
AM_2	Age MF: Percent of population 16-65 years old	0.4	No change	0.2
AM_3	Age MF: Percent of population > 65 years old	0.4	No change	0.5
EM_1	Ethnicity MF: White households	0.24	0.1	N/A
EM_2	Ethnicity MF: Black households	0.48	0.2	N/A
EM_3	Ethnicity MF: Hispanic households	0.47	0.2	N/A
EM_4	Ethnicity MF: Asian households	0.26	0.1	N/A
EM_5	Ethnicity MF: Native American Households	0.26	0.1	N/A
IM_1	Income MF: household income < $10,000	0.62	0.3	0.4
IM_2	Income MF: $10,000 < household income <$15,000	0.42	0.3	0.3
IM_3	Income MF: $15,000 < household income < $25,000	0.29	0.14	0.15
IM_4	Income MF: $25,000 < household income < $35,000	0.22	0.08	0.1

IM_5	Income MF: household income > $35,000	0.13	0.05	0.05
OM_1	Ownership MF: % of households owner occupied	0.4	No change	N/A
OM_2	Ownership MF: % of households renter occupied	0.4	No change	N/A

Hazus Level 1 Flood Analysis – 100-year Flood Hazard

Hazus 3.2 was used to develop a flood depth grid for the 1-percent annual chance (100-year) riverine flood in Alameda County, using the Hazus 3.2 built-in, basic (i.e., "Level 1") flood depth estimation methodology. The Hazus 3.2 flood hazard assessment methodology uses available information and local river and floodplain characteristics, such as frequency, discharge and ground elevation to estimate flood elevation, and ultimately flood depth. Digital elevation model (DEM) data with 30-meter (1 arc-second) resolution, available from the USGS' National Elevation Dataset[8] have been utilized in the current assessment.

It should be noted that the flood depth grid generated by Hazus 3.2 ***is not*** equivalent to regulatory floodplain data contained in FEMA's Digital Flood Insurance Rate Maps (DFIRMs), which are the result of extensive, detailed engineering study. The Hazus-generated flood depth grid is a hypothetical representation of a potential flooding scenario, intended for non-regulatory uses. Further, it should also be noted that the DEM data used in the default analysis do not reflect the presence of channels and levees. A more detailed assessment would utilize higher resolution DEM data, such as 10 meter (1/3 arc-second) resolution data or LIDAR-based DEM data, and/or would require GIS-based revisions to the DEM to better reflect local flood control structures. Given that the Hazus 3.2 Level 1 approach does not consider the presence of levees, Hazus 3.2 loss and damage estimates produced for areas with levees should be considered "worst-case" flood losses, reflecting potential flood damage that could occur in the event that the levees fail. The Hazus-estimated 100-year riverine flood depths across Alameda County are provided in **Figure 3**.

[8] http://nationalmap.gov/elevation.html

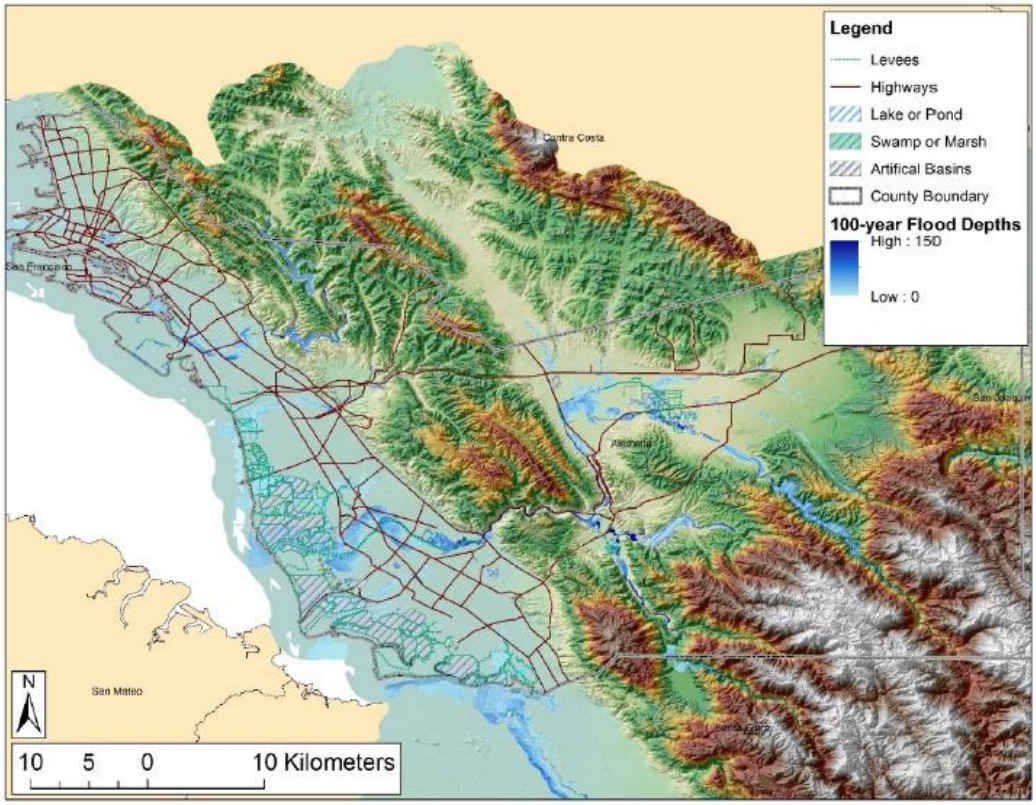

Figure 3: Hazus-Estimated Flood Depths in Alameda County for a 1-percent Annual Chance (100-year) Flood

Coastal Flood Analyses – Sea Level Rise of 36, 48 and 77 inches

Hazus 3.2 was used to analyze damage and loss resulting from projected sea level rise. An ArcGIS geodatabase containing inundation raster data (depth grids) and various other data for Alameda County, developed by AECOM, was provided by BCDC. The inundation raster data were described as follows (AECOM, 2017):

> *These rasters contain extent and depth of land-only inundation (in feet) of the Alameda County bayside shoreline under various sea level rise scenarios. The sea level rise scenarios are described in terms of inches above the current conditions mean higher high water (MHHW) tidal datum. These scenarios include: 12", 24", 36", 48", 52", 66", 77", 84", 96" and 108" of water level above MHHW.*

Inundation raster data for the 36", 48" and 77" scenarios were imported into Hazus 3.2 as "user data," and building damage and shelter impacts were estimated. Each SLR scenario modeled represents several approximate "SLR + storm surge" scenarios, as indicated in

Table 12 below.

The Hazus flood model is intended to model temporary inundation conditions (i.e., storm surge, or rise and retreat flooding) rather than permanent inundation. Accordingly, the current Hazus loss and damage estimates for SLR do not reflect permanent loss of use, and should be considered lower bound (and more representative of the larger storm surge variants for each scenario listed in

Table 12).

Table 12: Alameda County Sea Level Rise Scenario Definitions (AECOM, 2017)

SLR Scenario	Approximate SLR + Storm Surge Scenarios
MHHW + 36" SLR	0" SLR + 50-year storm surge 6" SLR + 25-year storm surge 12" SLR + 5-year storm surge 18" SLR + 2-year storm surge 24" SLR + 1-year storm surge
MHHW + 48" SLR	6" SLR + 100-year storm surge 12" SLR + 50-year storm surge 18" SLR + 10-year storm surge 24" SLR + 5-year storm surge 30" SLR + 2-year storm surge
MHHW + 77" SLR	36" SLR + 100-year storm surge 42" SLR + 50-year storm surge 48" SLR + 10-year storm surge 52" SLR + 5-year storm surge 60" SLR + 1-year storm surge

Flood Results

An overview of the county-wide Hazus-estimated economic loss results in the four flooding scenarios is provided in **Table 13** for all occupancy classes, while **Table 14** provides the same information for residential occupancies only. **Table 15** provides population displacement and shelter estimates, and **Table 16** provides a breakdown of estimated residential building damage (building count by percent damage range) in the flooded census blocks for each scenario. As noted above, the Hazus flood model is intended to model temporary inundation conditions rather than permanent inundation. Accordingly, the current Hazus loss and damage estimates for SLR do not reflect permanent loss of use, and should be considered lower bound**.** **Table 16** allows some perspective on the magnitude of permanent loss of use; in each SLR scenario, all damaged residential buildings in the inundation areas (not just those with substantial damage) could be considered lost.

Table 13: Hazus-Estimated Direct Economic Losses for All Occupancy Classes for Four Flooding Scenarios in Alameda County (in $Million)

Flood Scenario	Building Damage	Contents Damage	Inventory Loss	Building Damage-Related Income Losses	Total Direct Economic Loss
Riverine: 100-yr flood (Hazus default)	1,650	1,512	31	15	3,208
Coastal: SLR 36 inches	329	510	35	4	877

Coastal: SLR 48 inches	598	838	50	7	1,493
Coastal: SLR 77 inches	2,371	2,923	130	26	5,450

Table 14: Hazus-Estimated Direct Economic Losses for Residential Occupancy Classes for Four Flooding Scenarios in Alameda County (in $Million)

Flood Scenario	Building Damage	Contents Damage	Building Damage-Related Income Losses	Total Direct Economic Loss
Riverine: 100-yr flood (Hazus default)	1,397	799	15	2,202
Coastal: SLR 36 inches	193	123	1	317
Coastal: SLR 48 inches	388	245	1	635
Coastal: SLR 77 inches	1,725	1,098	4	2,827

Table 15: Hazus Displacement and Shelter Estimates for Four Flooding Scenarios in Alameda County

Flood Scenario	Displaced Households	Displaced People	Short-term Shelter Loads (# People)
Riverine: 100-yr flood (Hazus default)	33,700	101,100	95,100
Coastal: SLR 36 inches	3,000	9,100	8,100
Coastal: SLR 48 inches	7,500	22,500	20,600
Coastal: SLR 77 inches	27,000	81,000	77,100

Table 16: Hazus Residential Building Damage Estimates for Four Flooding Scenarios in Alameda County (Number of Buildings by Percent Damage)

Flood Scenario	1-10%	11-20%	21-30%	31-40%	41-50%	Substantial Damage	Total # Damaged Buildings
Riverine: 100-yr flood (Hazus default)	4,600	5,700	2,200	1,600	800	850	15,750
Coastal: SLR 36 inches	0	450	120	50	40	260	920
Coastal: SLR 48 inches	0	1,100	270	130	90	530	2,120
Coastal: SLR 77 inches	20	4,600	1,100	590	410	2,600	9,320

Appendix A – HayWired and ABAG Hazus Methodology Comparison

	USGS HayWired Scenario	ABAG HayWired Scenario
Hazus execution version	Hazus 2.1	Hazus 3.2
Hazus Study Region Extent	17 Bay Area Counties (Alameda, Contra Costa, Marin, Merced, Monterey, Napa, Sacramento, San Benito, San Francisco, San Joaquin, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Stanislaus and Yolo)	9 ABAG Counties (Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano and Sonoma)
Inventory data: building exposure databases (sq. ft., building count, etc.)	Hazus MR-2 default: 2000 census basis for residential, 2002 D&B for commercial (2006)	Hazus 3.2 default: 2010 census basis for residential, escalated 2006 D&B for commercial (2016)
Inventory data: mapping schemes	Custom schemes developed for the 100th Anniversary Earthquake Conference commemorating the 1906 San Francisco Earthquake (2006)	2006 custom mapping schemes translated to 2010 census geography (2017)
Inventory data: $ year of exposure values	2005$	2014$
Inventory data: Cost escalation factors	10% for residential, 200% for commercial	None
Inventory data: demographics	2000 census	2010 census
Hazard data: Ground Motion data	HayWired M7.0 ShakeMap (2014)	HayWired M7.0 ShakeMap (2014)
Hazard data: Liquefaction Susceptibility data	USGS regional liquefaction susceptibility (USGS OF00-444, 2000) [Covers 9 ABAG Counties only]	USGS regional liquefaction susceptibility (USGS OF00-444, 2000) [Covers 9 ABAG Counties only]
Hazard data: Depth to Groundwater	Uniform assumption of 5 feet (also assessed with adjusted depth in Western San Mateo County).	Uniform assumption of 5 feet
Damage Model: Parameters - Fragility curve betas	Reduced uncertainty (appropriate for actual events and high quality ShakeMaps)	Reduced uncertainty (appropriate for actual events and high quality ShakeMaps)
Shelter Model: Parameters	Both default & ShakeOut custom parameters utilized.	Default & ShakeOut parameters reviewed; ShakeOut parameters selected. Hand calculations substituted to allow for disaggregation by residential occupancy.
Shelter Module Result: Displaced Households (ShakeOut parameters, 9 county area only)	152,400	196,700
Shelter Module Result: Short-term Shelter Population (ShakeOut parameters, 9 county area only)	47,900	58,600

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