Section 4.5 Earthquake

Earthquake

Earthquakes can be caused by natural shifts in tectonic plates, movement of magma within volcanoes, and the flex and bend of earth's crust. Hawai'i experiences earthquakes regularly, although the majority of them are so small that they can only be detected by seismometers. Most of them occur on or near Hawai'i Island and are related to the island's active volcanoes. Impact statistics below are based on a 100-year statewide probabilistic earthquake.

CHANGES SINCE 2018

+1

Declared Disasters

+50

Events 4.0+ M

COUNTIES MOST VULNERABLE

Kaua'i Honolulu Maui Hawai'i

SOCIALLY VULNERABLE POPULATION

1.66%

Of Total Population

23,547

Persons

HAZARD RANKING

Low Medium High

COMMUNITY LIFELINES

1,369

Total

CLIMATE PROJECTIONS

Melting glaciers and the resulting weight shift may induce seismic activity

During times of drought, pumping groundwater from underground aquafers has been shown to impact patterns of stress loads on the Earth's crust

El Niño cycles in the Pacific trigger seismic responses as the pressure of water changes with sea level fluctuations

489

State Buildings

93

Miles of State Road

SQUARE MILES

3,211

Environmental Resources

14

Hawaiian Home Lands

71

Cultural Resources

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TABLES

FIGURES

[1] *Section Cover Photo: Road damage from the 2018 earthquakes in Leilani Estates, Hawaiʻi Island. Photo by Grace Simoneau/FEMA*

SECTION 4. RISK ASSESSMENT

4.5 EARTHQUAKE

2023 SHMP Update Changes

- Earthquake events that occurred in Hawaiʻi from January 1, 2018, through December 31, 2022, were researched for this 2023 SHMP Update.
- New and updated figures from federal and state agencies are incorporated.
- This section now includes a discussion of how earthquakes impact socially vulnerable populations and community lifelines.
- Six types of cultural resources (archaeology, burial sensitivity area, historic building, historic district, historic object, and historic structure) are added to the vulnerability assessment.

4.5.1 HAZARD PROFILE

Thousands of earthquakes occur every year in the State of Hawaiʻi. Earthquakes in Hawaiʻi are caused by eruptive processes within the active volcanoes or by deep structural adjustments due to the weight of the islands on Earth's underlying crust. Most of these earthquakes are closely related to volcanic processes and are so small they can only be detected by seismometers. Some are strong enough to be felt on one or more of the islands. Some earthquakes are strong enough to cause significant damage and impact residents across the state (U.S. Geological Survey Hawaiian Volcano Observatory n.d.). Additionally, local or distant earthquakes can lead to tsunamis in the State of Hawaiʻi. For details regarding the volcano hazard in Hawaiʻi, refer to Section 4.14. For details regarding the tsunami hazard in the State of Hawaiʻi, refer to Section 4.13.

Hazard Description

Hawaiian earthquakes fall into three main categories: volcanic, tectonic, and mantle:

- Volcanic – Magma movement within, and eruptions from, the presently active volcanoes in the state (Kīlauea, Mauna Loa, Hualālai, Haleakalā, and Kamaʻehuakanaloa) are usually accompanied by hundreds to thousands of small earthquakes that rarely cause significant damage. The small earthquakes are caused by the movement of magma and often occur in shallow swarms, especially after an eruption. These volcanic earthquakes are important for volcano monitoring (U.S. Geological Survey Hawaiian Volcano Observatory n.d.) (U.S. Geological Survey Hawaiian Volcano Observatory n.d.).
- Tectonic – These are earthquakes on major faults within and at the base of the volcanoes. The earthquakes are driven by deformation of the volcano, often by gravity, but also from inflation prior to eruption. While tectonic earthquakes are commonly associated with eruptions, they are not directly caused by the

eruptions, rather, they share a common cause, such as inflation. Tectonic earthquakes may occur at any time and can be damaging (Figure 4.5-1). The largest and most damaging tectonic earthquakes are those that occur right at the base of a volcano, where it sits on preexisting sea floor (U.S. Geological Survey Hawaiian Volcano Observatory n.d.).

- Mantle – This type of earthquake reflects the flexing/bending of the earth's crust and upper mantle, known as the lithosphere, due to the weight of the islands above. This is the most common source of damaging earthquakes north of the Island of Hawaiʻi. This type of earthquake generally occurs more than 12 miles below sea level (U.S. Geological Survey Hawaiian Volcano Observatory n.d.).

Figure 4.5-1. Road Damage from a Tectonic Earthquake in Hawaiʻi County, 2018

Source: Big Island Gazette

Location

The majority of earthquakes in the State of Hawaiʻi occur on and around the County of Hawaiʻi, especially in the southern districts of the island where Kīlauea, Mauna Loa, and Kamaʻehuakanaloa volcanoes are located. These three volcanoes are the most active in the state (U.S. Geological Survey Hawaiian Volcano Observatory n.d.). Most earthquakes are caused by ruptures along geological faults. The County of Hawaiʻi has 12 fault systems: Hilina fault system, Kaʻōiki-Honuʻapo fault system, Kaʻōiki seismic zone, Kahuku fault system, Kealakekua fault system, Kīlauea Volcano, Mauna Kea Volcano, Hualālai Volcano, Koaʻe fault system, Kohala Volcano, Kamaʻehuakanaloa, and Mauna Loa Volcano. Shaking from large-scale events could potentially be felt anywhere in the state, but are most likely to be felt close to the earthquake's epicenter. Where shaking can be felt is discussed in more detail in the Extent subsection below.

National Earthquake Hazard Reduction Program (NEHRP) Soil Classifications

Ground shaking is the primary cause of earthquake damage to buildings and infrastructure. Softer soils amplify ground shaking. One contributor to shaking amplification is the velocity at which the rock or soils transmits shear waves (S-waves). The NEHRP defined five soil types based on their shear-wave velocity (Vs.) that aid in identifying locations that will be significantly impacted by an earthquake. The NEHRP soil classification system ranges from A to E, as noted in Table 4.5-1, where A represents hard rock that reduces ground motions from an earthquake and E represents soft soils that amplify and magnify ground shaking and increase building damage and losses.

Table 4.5-1. NEHRP Soil Classifications

Soil Classification	Description
A	Hard Rock
B	Rock
C	Very dense soil and soft rock
D	Stiff soils
E	Soft soils

Source: (FEMA 2020)

The NEHRP soil classifications have only been determined and spatially-delineated for the Counties of Maui and Hawaiʻi (Table 4.5-2). Approximately 112 square miles (or 9.5%) of the County of Maui is underlain by NEHRP soil Classes D and E, mainly Class D; the County of Hawaiʻi has a similar size area underlain by Class D and E soils (130.1 square miles). Figure 4.5-2 and Figure 4.5-3 show the NEHRP soil classifications for these two counties.

Table 4.5-2. Area of NEHRP Class D and E Soils

County	Area (in square miles)		
	Total Area	Area of NEHRP Class D and E Soils	Area as % of Total Area
County of Kauaʻi	624.3	Unknown	Unknown
City and County of Honolulu	598.6	Unknown	Unknown
County of Maui	1,176.3	111.9	9.5%
County of Hawaiʻi	4,039.6	130.1	3.2%
Total	**6,438.8**	**242**	**3.8%**

Source: AECOM 2008; Tetra Tech 2015

Figure 4.5-2. NEHRP Soil Classification for the County of Maui

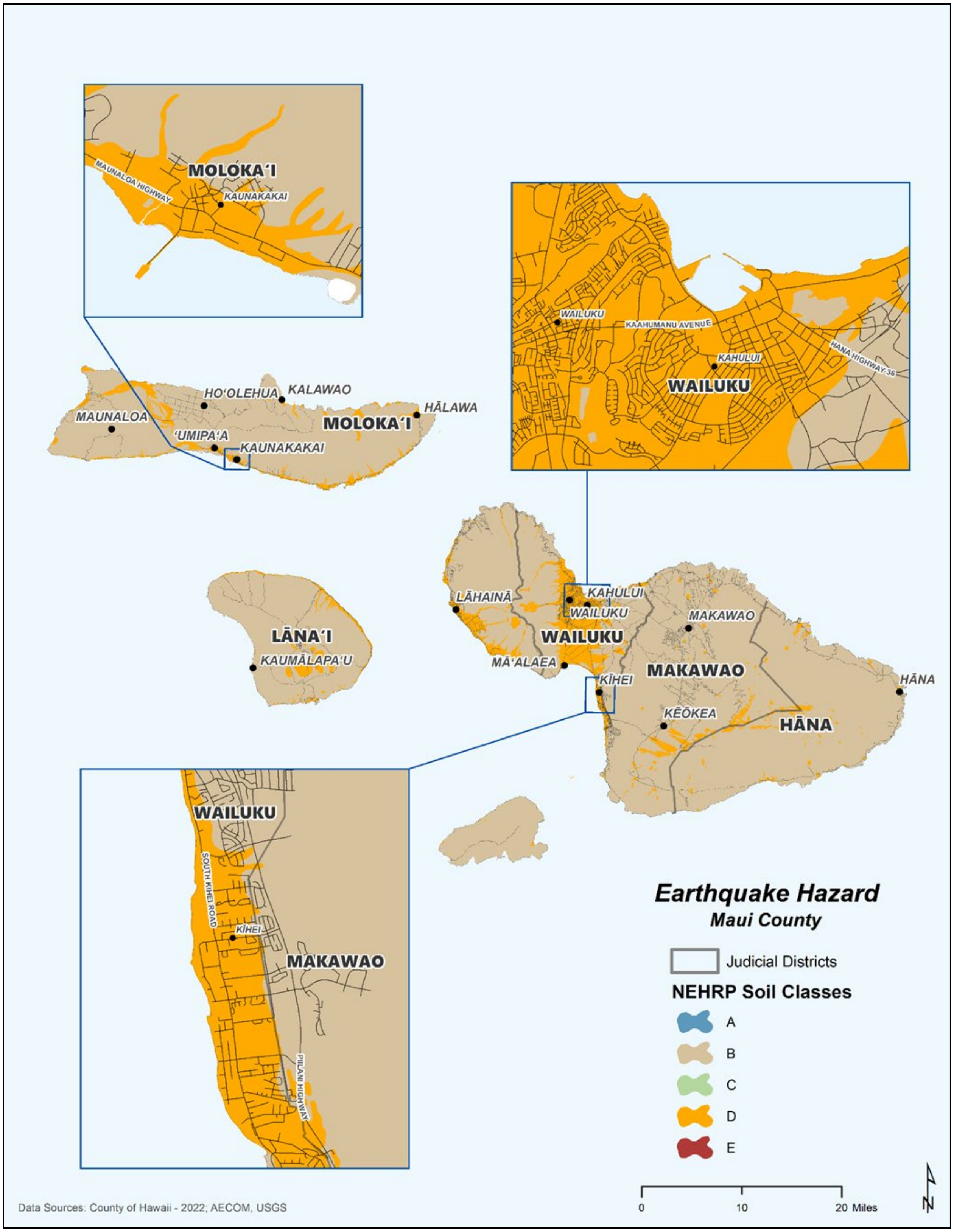
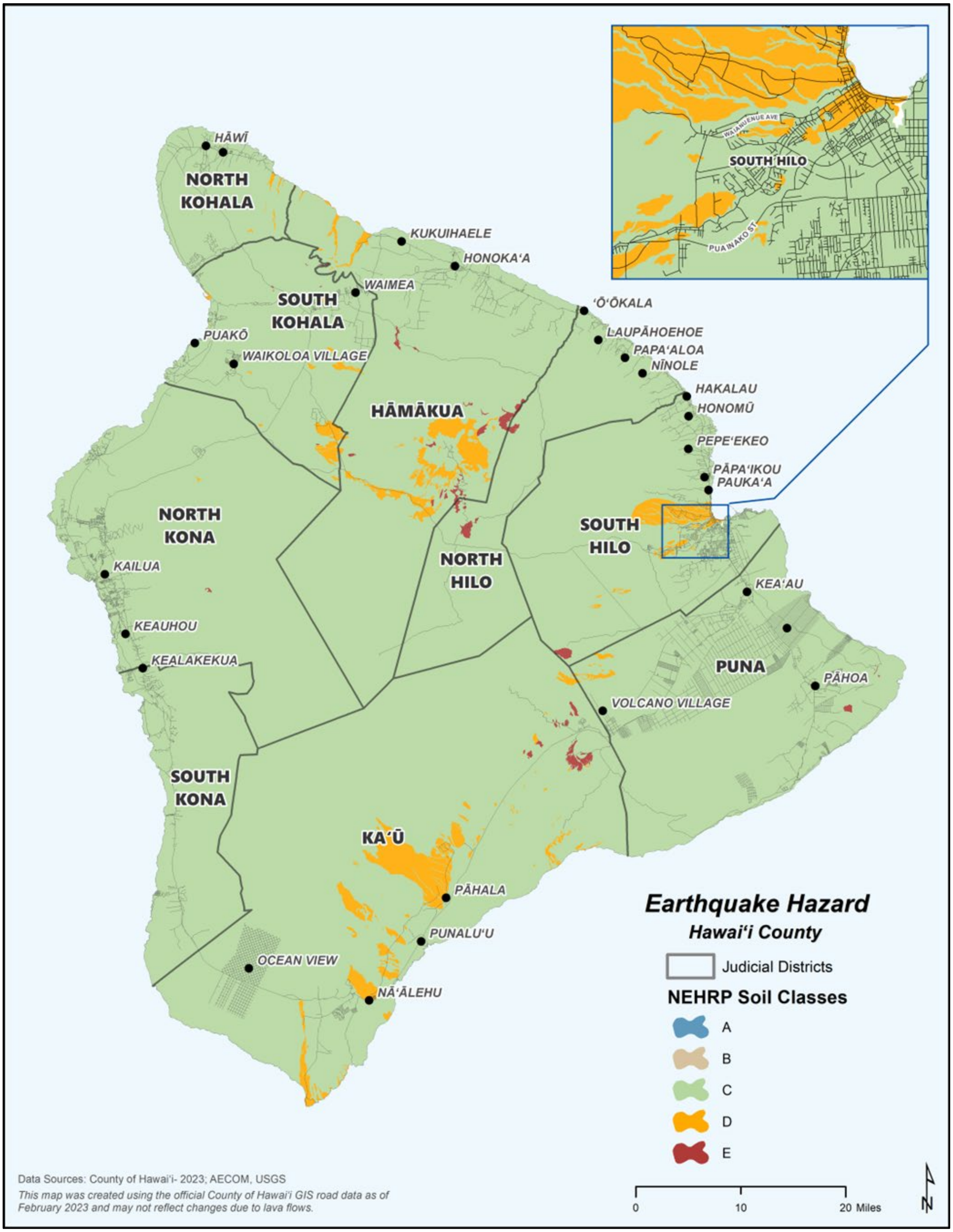


Figure 4.5-3. NEHRP Soil Classification for the County of Hawai'i



Liquefaction Susceptibility

Liquefaction can be defined as a process by which sediments below the water table temporarily lose strength and behave as a liquid, usually in areas of loosely packed soil. Roads might buckle, bridges and overpasses might crash down, low-rise buildings might sink, but high-rise buildings which are anchored in the underlying rock should be able to survive without collapsing (U.S. Geological Survey n.d.). Areas underlain by NEHRP Class D and E soils are more susceptible to liquefaction. Refer to the figures above for the location of these types of soils in the County of Maui and the County of Hawaiʻi.

In addition, NOAA Coastal Service Center sponsored a project in 2005 to identify areas with the potential for soil liquefaction in the Counties of Maui and Hawaiʻi. The results of the study showed small areas of high liquefaction susceptibility in Maui: the west Maui region (from Lahaina to Nāpili), the south Maui area (from Kīhei to Mākena), and the central Maui region (Kahului and Wailuku) (Wallace 2005)

EXTENT

The severity of an earthquake is classified by magnitude and intensity. Magnitude is a measure of the amount of energy released during an earthquake; each earthquake has a single magnitude. Intensity is a measure of the severity of ground shaking and so varies from place to place.

Ground Motion

One way to express an earthquake's severity is to compare its acceleration to the normal acceleration due to gravity. Peak ground acceleration (PGA) measures the rate of change in motion to the earth's surface and expresses it as a percent of the established rate of acceleration due to gravity (9.8 meters per second squared [m/sec^2]). PGA is expressed as a percent acceleration force of gravity (%g). For example, 100%g PGA in an earthquake (an extremely strong ground motion) means that objects accelerate sideways at the same rate as if they had been dropped from the ceiling. 10%g PGA means that the ground acceleration is 10 percent that of gravity.

Key Terms Simplified

- **PGA** — Peak ground acceleration is motion experienced by a person on the ground during an earthquake.
- **SA** — Spectral acceleration is motion experienced by a building during an earthquake (U.S. Geological Survey 2019).

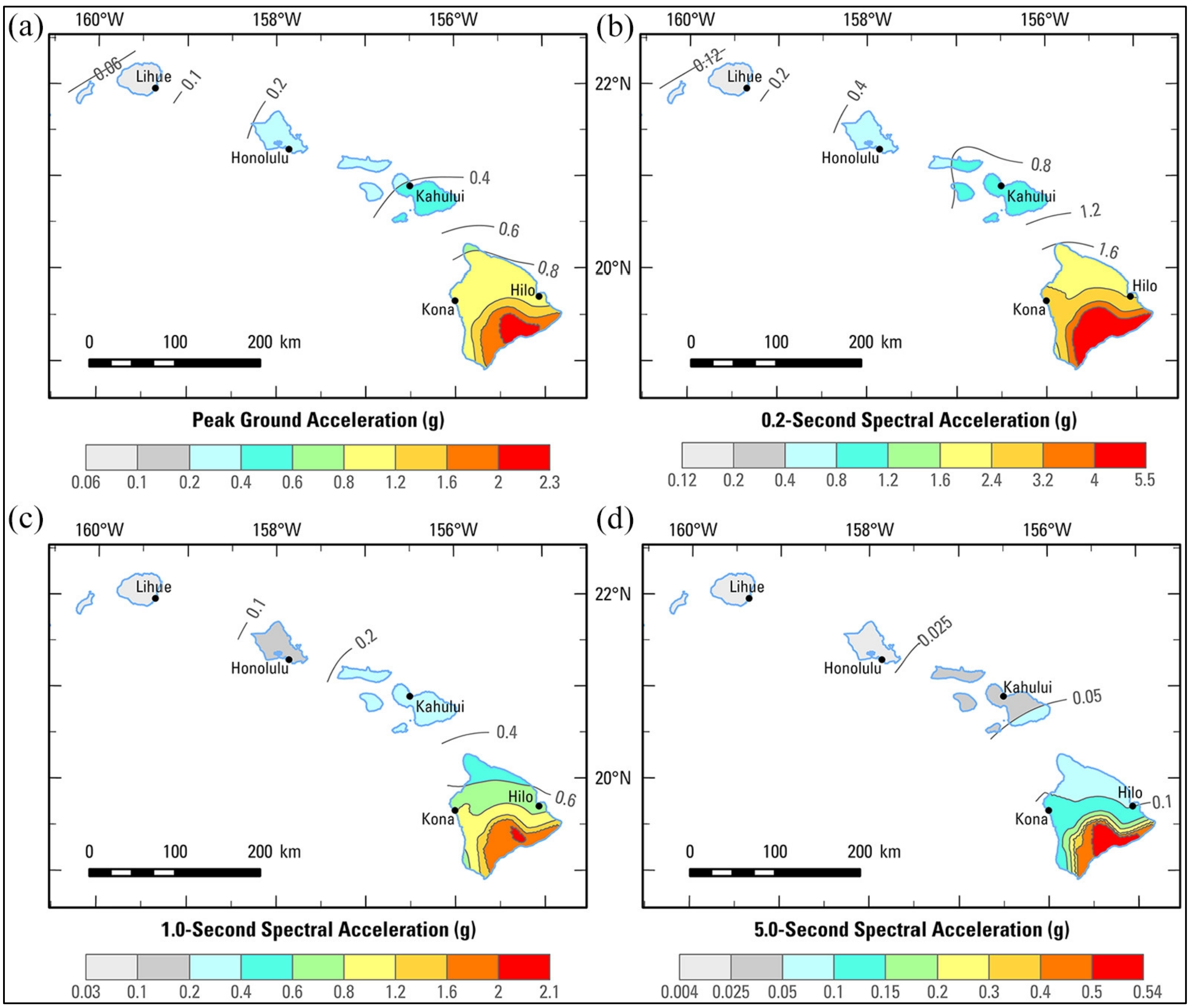
Damage levels experienced in an earthquake vary with the intensity of ground shaking and with the seismic capacity of structures. The following generalized observations provide qualitative statements about the likely extent of damages for earthquakes with various levels of ground shaking (PGA) at a given site:

- Ground motions of 1 to 2%g are widely felt by people; hanging plants and lamps swing strongly, but damage levels, if any, are usually very low.
- Ground motions below 10%g usually cause only slight damage, except in unusually vulnerable facilities.

- Ground motions of 20 to 50%g may cause significant damage in some modern buildings and very high levels of damage (including collapse) in poorly designed buildings.
- Ground motions greater than 50%g may cause higher levels of damage in many buildings, even those designed to resist seismic forces.

According to USGS Earthquake Hazards Program, PGA maps (also known as earthquake hazard maps) are used as planning tools when designing buildings, bridges, highways, and utilities so that they can withstand shaking associated with earthquake events. These maps are also used as planning tools for the development of building codes that establish construction requirements appropriate to preserve public safety. Figure 4.5-4 shows contours of PGA and 0.2, 1, and 5 SA with 2% chance of occurring over the next 50 years.

Figure 4.5-4. 2021 Seismic Hazard Map, PGA, 0.2, 1, and 5 SA with 2% Probability of Exceedance in 50 Years



Source: (Petersen, Shumway and Shiro 2021)

This map was created with data from the USGS to produce uniform probabilistic seismic hazard maps for the United States. The 2% of a 50-year PGA value means that over the next 50 years, there is a 2% probability of this level of ground shaking or higher. The 2% of a 50-year PGA represents a level of ground shaking close to but not the absolute worst-case scenario. The figures show the majority of the state has low levels of seismic hazard, with the Island of Hawaiʻi having intermediate to high levels of seismic hazard.

Magnitude

An earthquake's magnitude is a measure of the energy released at the source of the earthquake. Magnitude is commonly expressed by ratings on the moment magnitude scale (Mw), the most common scale used today (U.S. Geological Survey n.d.). This scale is based on the total moment release of the earthquake (the product of the distance a fault moved, the area of the fault surface, and the strength of the rock). The scale is as follows:

- Great—Mw > 8
- Major—Mw = 7.0 – 7.9
- Strong—Mw = 6.0 – 6.9
- Moderate—Mw = 5.0 – 5.9
- Light—Mw = 4.0 – 4.9
- Minor—Mw = 3.0 – 3.9
- Micro—Mw < 3.0

Intensity

The intensity of an earthquake is based on the observed effects of ground shaking on people, buildings, and natural features, and varies with location. The Modified Mercalli scale expresses intensity of an earthquake; the scale is a subjective measure that describes how strong a shock was felt at a particular location. The Modified Mercalli scale expresses the intensity of an earthquake's effects in a given locality in values ranging from I to XII. Table 4.5-3 summarizes earthquake intensity as expressed by the Modified Mercalli scale and lists damage potential and perceived shaking by PGA factors, compared to the Mercalli scale.

Table 4.5-3. Modified Mercalli Intensity and Peak Ground Acceleration Equivalents

Modified Mercalli Scale	Perceived Shaking	Potential Structure Damage		Estimated PGA (%g)
		Resistant Buildings	Vulnerable Buildings	
I	Not Felt	None	None	Less than 0.17%
II-III	Weak	None	None	0.17% – 1.4%
IV	Light	None	None	1.4% – 3.9%
V	Moderate	Very Light	Light	3.9% – 9.2%
VI	Strong	Light	Moderate	9.2% – 18%
VII	Very Strong	Moderate	Moderate/Heavy	18% – 34%
VIII	Severe	Moderate/Heavy	Heavy	34% – 65%
IX	Violent	Heavy	Very Heavy	65% – 124%
X – XII	Extreme	Very Heavy	Very Heavy	More than124%

Source: (U.S. Geological Survey n.d.)

ShakeMap

The ShakeMap was developed by the USGS and facilitates communication of earthquake information beyond just the magnitude and location. A ShakeMap shows the extent and variation of ground shaking in a region immediately following significant earthquakes.

Three types of ShakeMaps are typically generated:

- Probabilistic — A probabilistic seismic hazard map shows the hazard from earthquakes that geologists and seismologists agree could occur. The maps are expressed in terms of probability of exceeding a certain ground motion, such as the 10 percent probability of exceedance in 50 years. This level of ground shaking has been used for designing buildings in high seismic areas.
- Figure 4.5-5 shows the estimated ground motion for the 100-year probabilistic seismic hazard in the State of Hawaiʻi generated by Hazus version 5.1.
- Scenario Maps — Earthquake scenario maps describe the expected ground motions and effects of hypothetical large earthquakes for a region. Maps of these scenarios can be used to support all phases of emergency management.
- Historic/Current Scenario Events — ShakeMaps are generated for historic earthquake events or earthquake events that have recently occurred. Recent events help emergency managers and the public understand where damages are likely and also provide insight to what types of damages would be likely if the event were to occur with today's level of development. Four historic scenarios were chosen for analysis in the 2023 SHMP Update (see Figure 4.5-6 through Figure 4.5-9):
    - Kalapana M7.2 earthquake on November 29, 1975 (Kalapana M7.7 ShakeMap data represents this event)
    - Kaʻū District M7.9 earthquake on April 3, 1868 (Kaʻū M8.0 ShakeMap data represents this event)
    - Lānaʻi M6.8* earthquake on February 20, 1871 (Lānaʻi M7.0 ShakeMap data represents this event)
    - Note: The M6.8 scenario was recommended by subject matter experts at the beginning of the planning process. New analysis by SOEST and USGS revised the Lānaʻi earthquake magnitude to 7.5. The revised scenario may be used in the analysis performed for future updates.
    - Northeast (NE) Maui M6.5 earthquake on January 23, 1938 (NE Maui 7.0 ShakeMap data represents this event)

Figure 4.5-5. PGA for the 100-Year Probabilistic Statewide Scenario

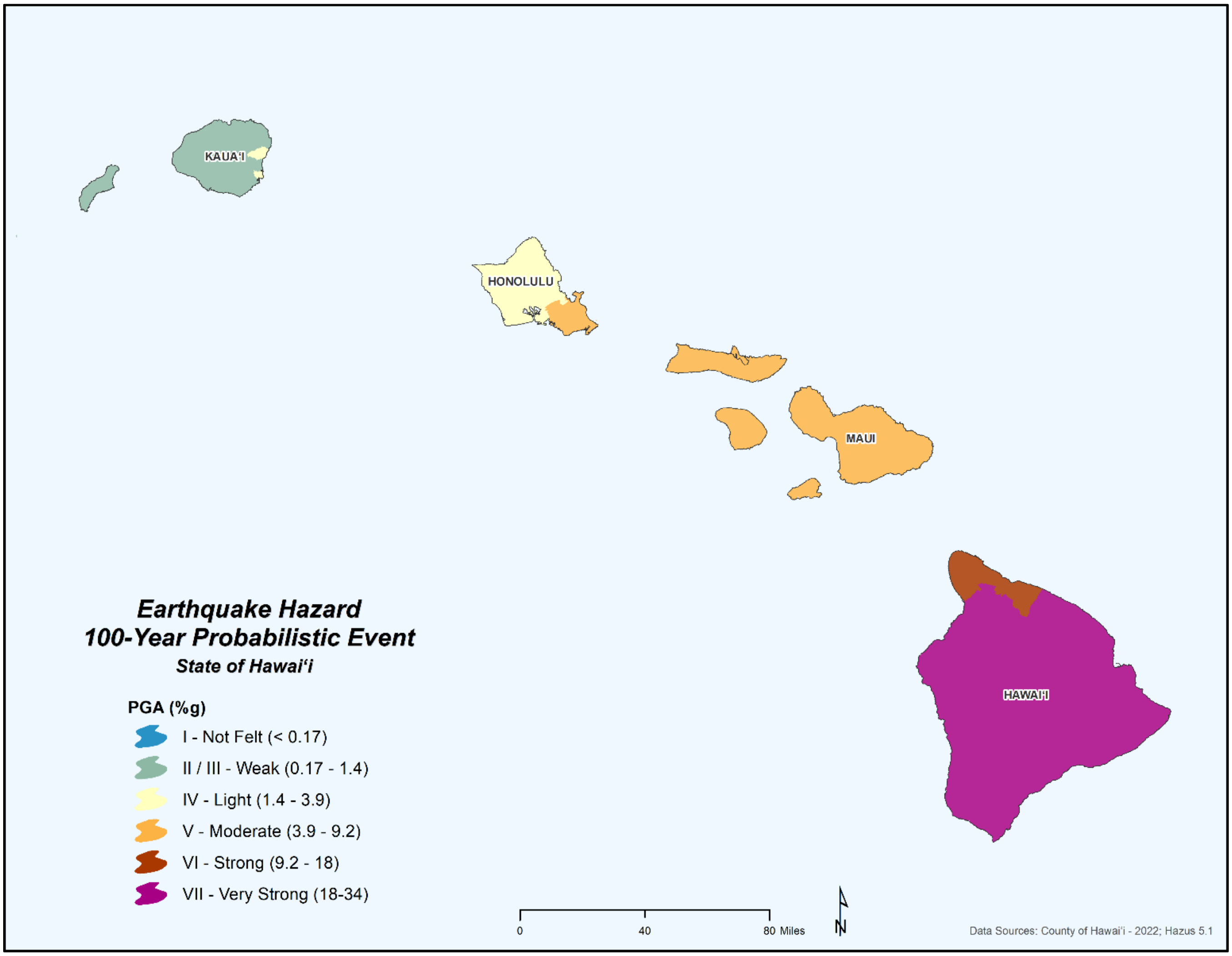


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Figure 4.5-6. Kalapana M7.2 Earthquake Scenario

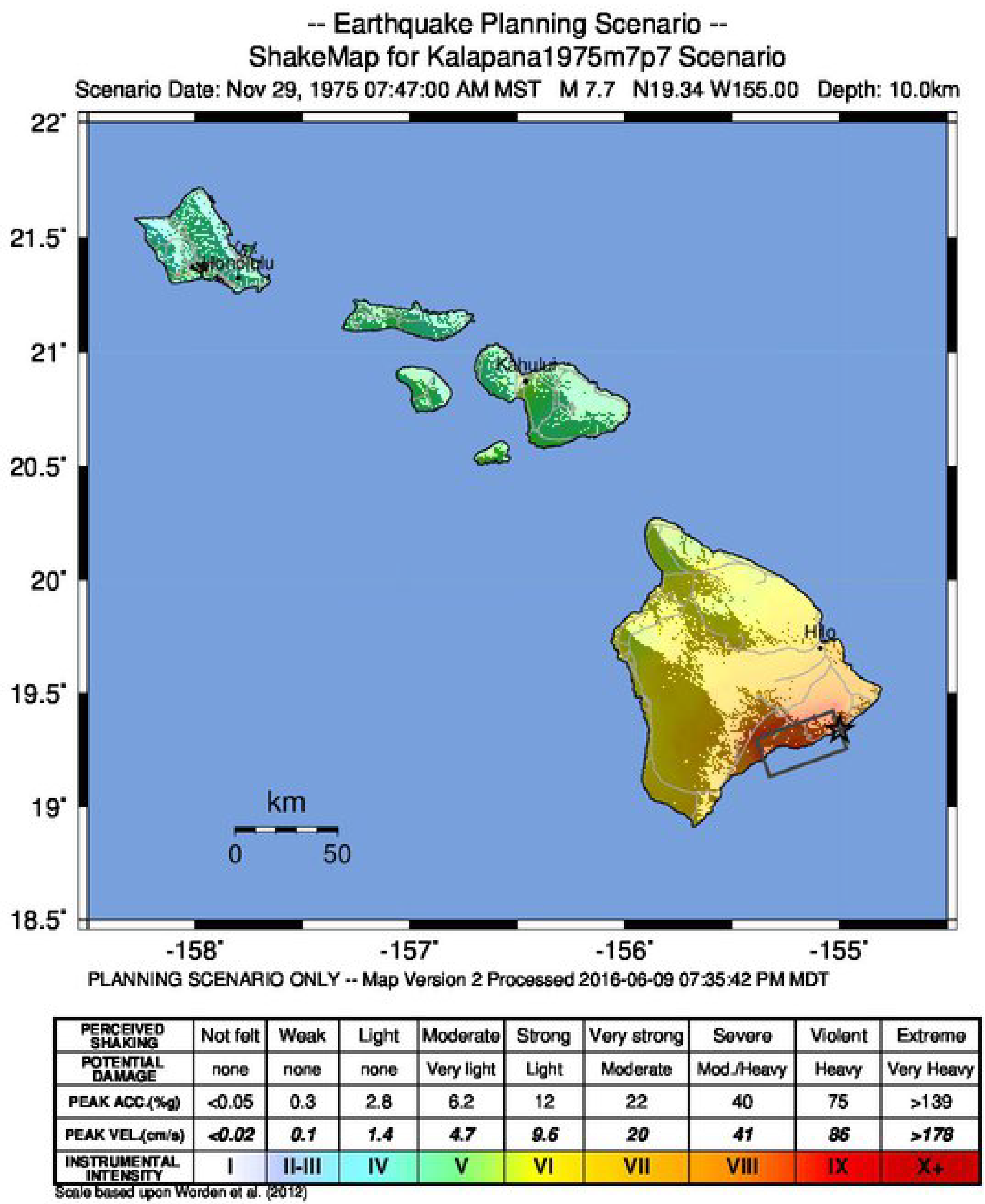


Figure 4.5-7. Ka'ū District M7.9 Earthquake Scenario

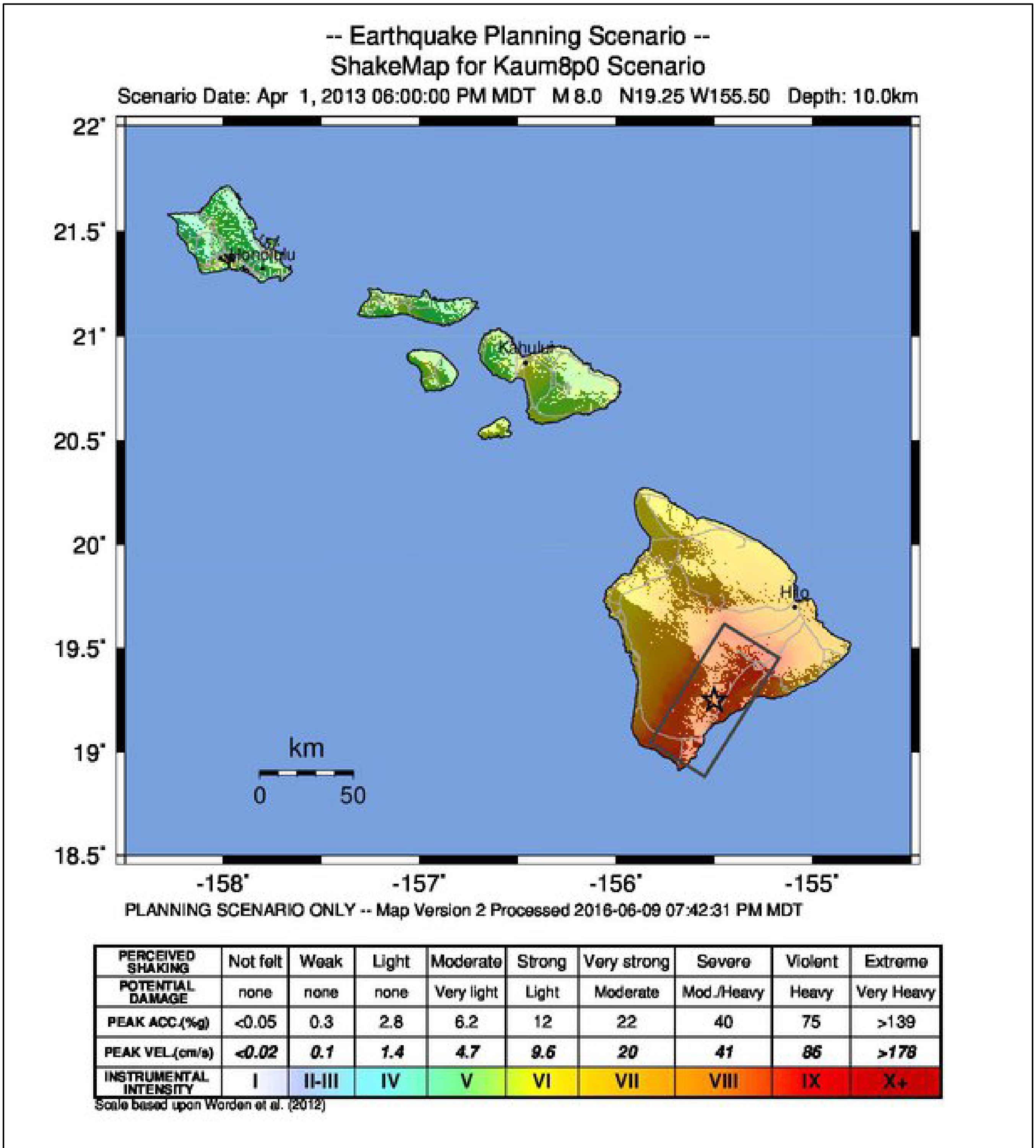
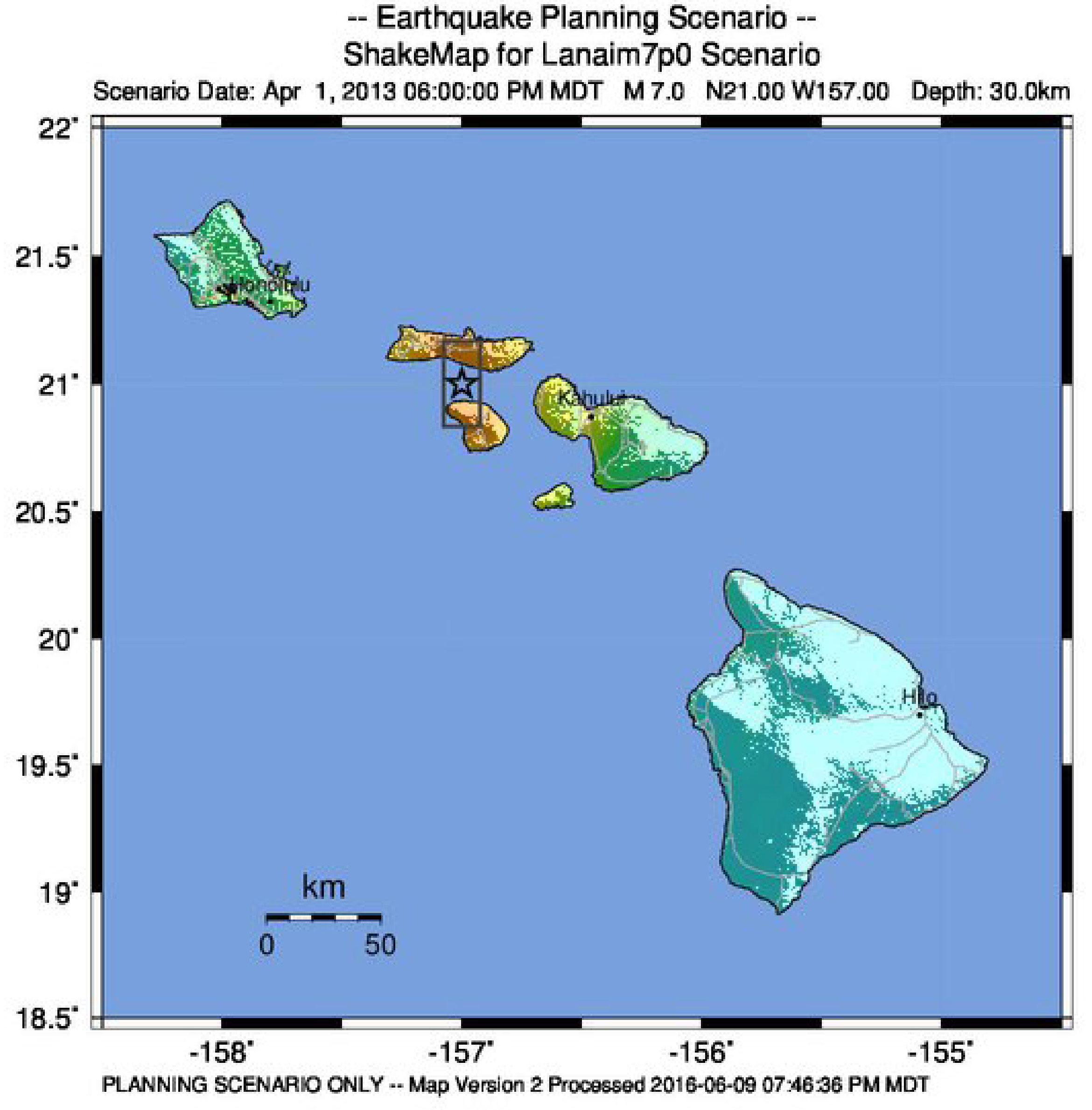


Figure 4.5-8. Lānaʻi M6.8 Earthquake Scenario*

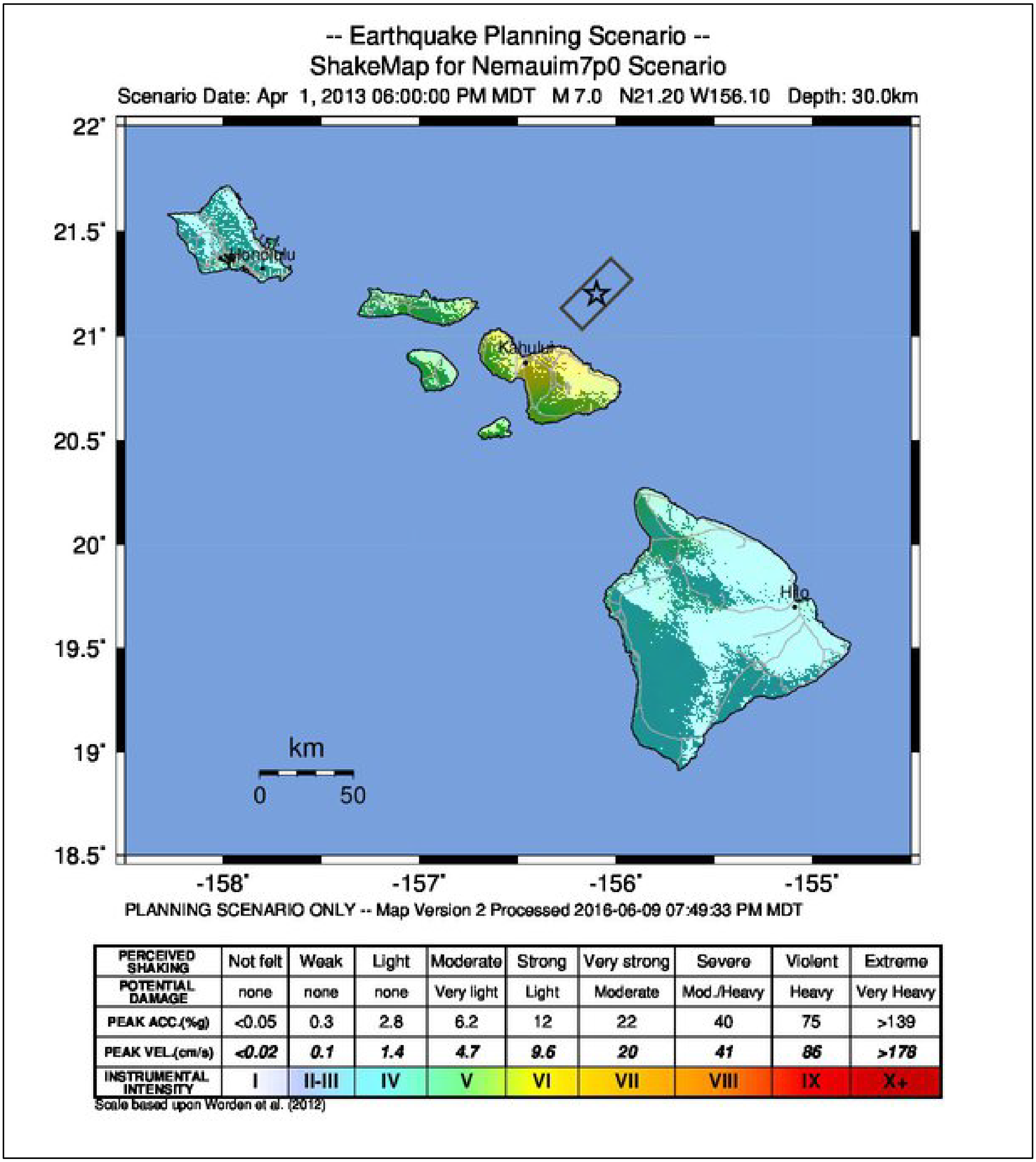


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

*Note: *The M6.8 scenario was recommended by subject matter experts at the beginning of the planning process. New analysis by SOEST and USGS revised the Lānaʻi earthquake magnitude to 7.5. The revised scenario may be used in the analysis for future updates.*

Figure 4.5-9. Northeast (NE) Maui M6.5 Earthquake Scenario



Warning Time

Under the Disaster Relief Act of 1974, the USGS has the federal responsibility to issue alerts for earthquakes, enhance public safety, and reduce losses through effective forecasts and warnings. The USGS currently issues rapid, automatic earthquake information via the internet, email messages, text messages, and social media (U.S. Geological Survey n.d.). Currently, there is no reliable way to predict the day or month that an earthquake will occur at any given location. The ShakeAlert® earthquake early warning system has been developed to monitor for significant earthquakes and issue alerts to warn that strong shaking is expected imminently. The ShakeAlert system is being developed to cover California, Oregon, and Washington. Depending on how far a person is from the earthquake, these potential warning systems could give from a few seconds to a minute's notice that major shaking is about to occur (U.S. Geological Survey 2022). The warning time is very short, but it could allow for someone to get under a desk, step away from a hazardous material they are working with, or shut down a computer system. Currently, no such earthquake early warning system has been developed for Hawaiʻi.

PREVIOUS OCCURRENCES AND LOSSES

During the planning process for this plan update, many sources were researched that provided earthquake information regarding previous occurrences and losses associated with earthquake events throughout the State of Hawaiʻi. The 2018 Plan discussed specific earthquake events that occurred in the State of Hawaiʻi through 2017. For this 2023 SHMP Update, earthquake events were summarized between January 1, 2018, and December 31, 2022. According to the USGS, over 18,000 earthquakes have been recorded in the state between 2018 and 2022. The magnitudes of these events range from 2.5 to 6.9 (U.S. Geological Survey 2022).

Table 4.5-4 includes details regarding earthquake events that occurred in the state between 2018 and 2022 that had a magnitude of 4 or higher. For events prior to 2018, please refer to Appendix E (Hazard Profile Supplement).

Table 4.5-4. Earthquake Events in Hawaiʻi with a Magnitude of 4.0 or Greater, 2018 to 2022

Date(s) of Event	Magnitude	Location (recorded epicenter)	Counties Affected	Description
May – August 2018	0.5 to 6.9	Kīlauea Volcanic Eruption and Earthquakes (DR-4366)	Hawaiʻi	Between May 1 and August 31, there were nearly 42,000 recorded earthquakes, ranging from magnitude 0.5 to magnitude 6.9; of these more than 50 earthquakes of magnitude >= 5 occurred at Kilauea. On May 1, the USGS HVO issued a report that a migration of seismicity and deformation downrift (east) of Puʻu ʻŌʻō indicated that a large area along the East Rift Zone was potentially at risk of new outbreak, possibly in the Lower Puna area. Between May 3 and September 4, Kīlauea erupted, with numerous earthquakes occurring each day. On May 11, FEMA issued a major disaster declaration for the State of Hawaiʻi due to the eruption of Kīlauea. The County of Hawaiʻi was included in this declaration. For details regarding this volcanic eruption, please refer to Section 4.14 (Volcanic Hazards).
February 7, 2019	4.6	86 km SW of Hawaiian Ocean View, Hawaiʻi	Hawaiʻi, Maui, Honolulu	The USGS reported that the earthquake could be felt on Hawaiʻi, Maui, and Oʻahu. The depth, location, and recorded seismic waves of the earthquake suggest a source due to bending of the oceanic plate from the weight of the Hawaiian island chain.

Date(s) of Event	Magnitude	Location (recorded epicenter)	Counties Affected	Description
March 13, 2019	5.5	13 km SSE of Volcano, Hawaiʻi	Hawaiʻi	USGS reported that over 260 people felt the earthquake. The location, depth, and waveforms recorded were consistent with slip along Kīlauea's south flank.
April 13, 2019	5.3	20 km E of Kalaoa, Hawaiʻi	Hawaiʻi, Maui, Honolulu	USGS reported that over 1,000 people felt the earthquake as far away as Oʻahu. Authorities responded to reports of rockfalls along Highways 19 and 11 on Hawaiʻi Island. Three aftershocks were recorded within an hour of the earthquake, including a magnitude 3.0 event. The location and depth of the event suggest it is likely related to flexure or settling of the crust beneath the weight of the island.
April 27, 2019	4.2	15 km SSE of Fern Forest, Hawaiʻi	Hawaiʻi	USGS reported that over 100 people felt the earthquake on Hawaiʻi Island. This earthquake was part of the continuing adjustments beneath the south flank of Kīlauea.
August 12, 2019	4.5	8 km ENE of Pāpaʻikou, Hawaiʻi	Hawaiʻi	USGS reported that the depth, location, and recorded seismic waves of the earthquake suggest a source due to bending of the oceanic plate from the weight of the Hawaiian island chain.
August 22, 2019	4.2	44 km SE of Nāʻālehu, Hawaiʻi	Hawaiʻi	USGS reported that approximately 30 people felt the earthquake off the coast of Kaʻū and that the earthquake was most likely due to bending of the Earth's crust under the weight of Hawaiʻi Island.
November 11, 2019	4.9	18 km SW of Laupāhoehoe, Hawaiʻi	Hawaiʻi, Maui, Honolulu	USGS reported that weak shaking was felt as far away as Oʻahu. Over 1,000 people felt the earthquake. Debris was reported on roadways in the Hāmākua district. The depth, location, and recorded seismic waves suggest a source due to bending of the oceanic plate from the weight of the volcanoes in the Hawaiian island chain.
February 3, 2020	4.2	12 km SSE of Volcano, Hawaiʻi	Hawaiʻi	USGS reported that more than 280 people felt the earthquake. It was likely an aftershock of the 2018 magnitude 6.9 earthquake as the volcano continues to settle.
July 2, 2020	4.6	15 km S of Fern Forest, Hawaiʻi	Hawaiʻi, Maui	USGS reported that nearly 1,200 people felt the earthquake as far away as Maui. It was likely an aftershock of the 2018 magnitude 6.9 earthquake as the volcano continues to settle.
July 3, 2020	4.3	13 km S of Fern Forest, Hawaiʻi	Hawaiʻi, Maui	USGS reported that more than 850 people as far away as Maui reported light shaking. It was likely an aftershock of the 2018 magnitude 6.9 earthquake as the volcano continues to settle.
July 27, 2020	4.7	19 km SE of Nāʻālehu, Hawaiʻi	Hawaiʻi, Maui	USGS reported that more than 600 people as far away as Maui reported light shaking. USGS reported that the depth, location, and recorded seismic waves of the earthquake suggest a source due to bending of the oceanic plate from the weight of the Hawaiian island chain.
August 1, 2020	4.2	8 km ENE of Pāhala, Hawaiʻi	Hawaiʻi	USGS reported that nearly 200 people felt the earthquake that appeared to be part of the seismic swarm under the Pāhala area, which had been going on for over a year.
December 4, 2020	4.1	22 km ENE of Hōnaunau-Nāpōʻopoʻo, Hawaiʻi	Hawaiʻi	USGS reported that more than 80 people felt the earthquake. The event followed an uptick in seismic activity observed at the summit of Kīlauea volcano.
December 12, 2020	4.4	20 km SSE of Waimea, Hawaiʻi	Hawaiʻi, Maui, Honolulu	USGS reported that nearly 700 people felt the earthquake as far away as Oʻahu. Deep earthquakes in this region are most likely caused by the structural adjustment of the Earth's crust due to the heavy load of Mauna Kea.
December 21, 2020	4.4	4 km S of Fern Forest, Hawaii	Hawaiʻi, Maui	USGS reported that more than 450 people felt the earthquake, which hit about an hour after Kīlauea volcano began to erupt.

Date(s) of Event	Magnitude	Location (recorded epicenter)	Counties Affected	Description
February 2, 2021	4.1	13 km SSE of Fern Forest, Hawaiʻi	Hawaiʻi	USGS reported that more than 350 people on the island of Hawaiʻi felt the earthquake.
March 11, 2021	4.2	17 km NNE of Pāhala, Hawaiʻi	Hawaiʻi, Maui	USGS reported that more than 300 people as far away as Maui felt the earthquake.
March 14, 2021	4.1	12 km SSE of Volcano, Hawaiʻi	Hawaiʻi, Maui	USGS reported that about 180 people as far away as Maui felt the earthquake. The location, depth, and waveforms recorded were consistent with slip along Kīlauea's south flank.
April 3, 2021	4.3	5 km NW of Pāhala, Hawaiʻi	Hawaiʻi, Maui	USGS reported that more than 150 people as far away as Maui felt the earthquake. This quake was part of a swarm of earthquakes reported beneath the northwest flank of Mauna Loa beginning on March 29.
May 23, 2021	4.2	15 km S of Volcano, Hawaiʻi	Hawaiʻi	USGS reported that about 230 people felt the earthquake on Hawaiʻi Island, which was the largest of several quakes that day.
June 2, 2021	4.0	42 km ESE of Nāʻālehu, Hawaiʻi	Hawaiʻi	USGS reported that fewer than 10 people on the island of Hawaiʻi felt the earthquake located about 26 miles offshore, under the Kamaʻehuakanaloa Seamount.
June 18, 2021	4.5	8 km ENE of Pāhala, Hawaiʻi	Hawaiʻi, Maui, Honolulu	USGS reported that nearly 500 people felt the earthquake as far away as Oʻahu. The earthquake was part of an ongoing seismic swarm under the Pāhala area, which started in August 2019.
July 5, 2021	5.2	12 km NNW of Kukuihaele, Hawaii	Hawaiʻi, Maui, Honolulu	USGS reported that more than 1,300 people felt the earthquake as far away as Oʻahu. The earthquake was related to stress from the weight of the island on the underlying ocean crust and mantle.
July 7, 2021	4.2	73 km WNW of Kalaoa, Hawaii	Hawaiʻi, Maui, Honolulu	USGS reported that about 100 people felt the earthquake as far away as Oʻahu. The earthquake was likely due to readjustment of the oceanic plate from the weight of the island chain and posed no significant hazard.
August 18, 2021	4.1	9 km E of Pāhala, Hawaiʻi	Hawaiʻi	USGS reported that more than 40 people on the Island of Hawaiʻi felt the earthquake and was believed to be part of an ongoing seismic swarm under the Pāhala area.
October 5, 2021	4.6	8 km ENE of Pāhala, Hawaiʻi	Hawaiʻi, Maui, Honolulu	USGS reported that more than 250 people felt the earthquake as far away as Oʻahu. The event appeared to be part of the swarm of deep Pāhala earthquakes that had been recorded in the region for months. There were several smaller earthquakes within minutes of the magnitude 4.6 quake.
October 10, 2021	6.2	7 km SSE of Nāʻālehu, Hawaiʻi	Hawaiʻi, Maui, Honolulu, Kauaʻi	USGS reported more than 3,400 people felt the earthquake across the entire state. Strong shaking was felt on the island of Hawaiʻi. The depth, location, and recorded seismic waves of the earthquake suggested a source due to bending of the oceanic plate from the weight of the Hawaiian island chain, a common source for earthquakes in this area.
October 10, 2021	4.3	22 km S of Nāʻālehu, Hawaiʻi	Hawaiʻi, Maui	USGS reported about 20 people felt the earthquake as far away as Maui.
December 24, 2021	4.9	42 km ESE of Nāʻālehu, Hawaiʻi	Hawaiʻi, Maui	USGS reported about 20 people felt the offshore earthquake as far away as Maui. The earthquake was preceded by over 50 small earthquakes on the south rift zone of Kamaʻehuakanaloa over the past two weeks. It is unknown whether it was caused by any volcanic or intrusive activity on Kamaʻehuakanaloa.
January 4, 2022	4.3	8 km E of Pāhala, Hawaiʻi	Hawaiʻi	USGS reported more than 160 people felt the earthquake.

Date(s) of Event	Magnitude	Location (recorded epicenter)	Counties Affected	Description
January 25, 2022	4.7	10 km NNE of Wailua, Hawaii	Maui, Honolulu, Hawaiʻi	USGS reported about 850 people felt the earthquake. The earthquake was located off the coast of Maui at a depth indicative of oceanic plate bending due to the weight of the islands.
January 31, 2022	4.0	8 km ENE of Pāhala, Hawaiʻi	Hawaiʻi	USGS reported more than 30 people felt the earthquake on Hawaiʻi island. It appeared to be part of the ongoing seismic swarm, which has been going on for over a year with more than 10,000 separate quakes.
March 20, 2022	4.5	21 km SSE of Waimea, Hawaiʻi	Hawaiʻi, Maui, Honolulu	USGS reported about 750 people felt the earthquake as far away as Oʻahu. Deep earthquakes in this area are most likely caused by structural adjustments of the Earth's crust due to the heavy load of Mauna Kea.
April 15, 2022	4.3	8 km ENE of Pāhala, Hawaiʻi	Hawaiʻi, Honolulu	USGS reported more than 100 people felt the earthquake on Hawaiʻi and Oʻahu. The earthquake appeared to be part of the ongoing seismic swarm under the Pāhala area.
April 15, 2022	4.6	9 km E of Pāhala, Hawaiʻi	Hawaiʻi, Maui, Honolulu	USGS reported more than 500 people felt the earthquake as far away as Oʻahu. The earthquake appeared to be part of the ongoing seismic swarm under the Pāhala area.
May 21, 2022	4.7	3 km NW of Hōlualoa, Hawaiʻi	Hawaiʻi, Maui, Honolulu	USGS reported more than 1,600 people felt the earthquake as far away as Oʻahu. The earthquake was primarily caused by a lateral slip along a sub-vertical fault.
May 29, 2022	4.0	70 km WSW of Kekaha, Hawaiʻi	Kauaʻi	No reports of shaking were reported as a result of this offshore earthquake.
July 27, 2022	4.3	9 km ENE of Pāhala, Hawaiʻi	Hawaiʻi	USGS reported about 200 people felt the earthquake.
July 27, 2022	4.6	43 km ESE of Nāʻālehu, Hawaiʻi	Hawaiʻi, Maui	USGS reported more than 30 people felt the offshore earthquake. This earthquake was part of the seismic swarm under the Pāhala area, which had been going on since 2019.
August 23, 2022	4.0	9 km E of Pāhala, Hawaiʻi	Hawaiʻi	USGS reported nearly 140 people felt the earthquake. This earthquake was part of the seismic swarm under the Pāhala area.
September 6, 2022	4.0	12 km ENE of Pāhala, Hawaiʻi	Hawaiʻi	USGS reported about 90 people felt the earthquake. This earthquake was part of the seismic swarm under the Pāhala area.
September 8, 2022	4.2	9 km ENE of Pāhala, Hawaiʻi	Hawaiʻi	USGS reported more than 80 people felt the earthquake. This earthquake was part of the seismic swarm under the Pāhala area.
September 27, 2022	4.5	9 km ENE of Pāhala, Hawaiʻi	Hawaiʻi, Maui, Honolulu	USGS reported more than 350 people felt the earthquake as far away as Oʻahu. This earthquake was part of the seismic swarm under the Pāhala area.
October 14, 2022	4.6	8 km S of Pāhala, Hawaiʻi	Hawaiʻi, Maui, Honolulu, Kauaʻi	USGS reported more than 1,000 people across the state felt the earthquakes which caused damage to structures and contents in the Pāhala area. Rocks fell onto Highway 11. USGS scientists said the tremors appear to be related to readjustments along the southeast flank of Mauna Loa, but it was difficult to tell if the earthquakes were magma driven.
October 14, 2022	5.0	7 km SSW of Pāhala, Hawaiʻi	Hawaiʻi, Maui, Honolulu, Kauaʻi	USGS reported more than 1,000 people across the state felt the earthquakes which caused damage to structures and contents in the Pāhala area. Rocks fell onto Highway 11. USGS scientists said the tremors appear to be related to readjustments along the southeast flank of Mauna Loa, but it was difficult to tell if the earthquakes were magma driven.

Date(s) of Event	Magnitude	Location (recorded epicenter)	Counties Affected	Description
October 14, 2022	4.0	9 km SSW of Pāhala, Hawaiʻi	Hawaiʻi, Maui, Honolulu, Kauaʻi	USGS reported more than 1,000 people across the state felt the earthquakes which caused damage to structures and contents in the Pāhala area. Rocks fell onto Highway 11. USGS scientists said the tremors appear to be related to readjustments along the southeast flank of Mauna Loa, but it was difficult to tell if the earthquakes were magma driven.
November 27, 2022	4.2	27 km E of Hōnaunau-Nāpōʻopoʻo, Hawaiʻi	Hawaiʻi, Maui	USGS reported about 50 people felt the earthquake on Hawaiʻi and Maui islands. Swarms of earthquakes continued sporadically when new fissures on Mauna Loa began to spill lava on the caldera floor. For details regarding this volcanic eruption, please refer to Section 4.14 (Volcanic Hazards).
November 29, 2022	4.0	9 km E of Pāhala, Hawaiʻi	Hawaiʻi	USGS reported about 80 people felt the earthquake. Scientists indicated that the earthquake was not related to the eruption of Mauna Loa but was part of the ongoing seismic swarm under the Pāhala area.

Source: FEMA 2022; USGS 2022

Note: With earthquake documentation for Hawaiʻi being so extensive, not all sources have been identified or researched. Additionally, loss and impact information for many events could vary depending on the source. Therefore, the table may not include all events that have occurred in the state (in that time period and magnitude level).

Disaster and Emergency Declarations

The following disaster declarations or emergency proclamations related to earthquake have been issued for Hawaiʻi:

- **Federal disaster (DR) or emergency (EM) declarations, 1955–2022**: 5 events, classified as earthquake, volcanic disruptions, or seismic waves
- **Hawaiʻi state emergency proclamations, 2018–2022**: No events, classified as earthquake
- **USDA agricultural disaster declarations, 2012–2022**: None

Table 4.5-5 lists the earthquake events that have affected the State of Hawaiʻi and were declared a FEMA disaster between 2018 and 2022. For details regarding all declared disasters to date, refer to Section 4.1 (Overview). Refer to Appendix D (Map Atlas), which illustrates the number of earthquake-related federally declared disasters by county since 1955.

Table 4.5-5. Earthquake-Related Federal Declarations (2018 to 2022)

Year	Event Type	Date Declared	Federal	Counties Affected
2018	Kīlauea Volcanic Eruption and Earthquakes	May 11, 2018	DR-4366	Hawaiʻi

Source: FEMA 2022

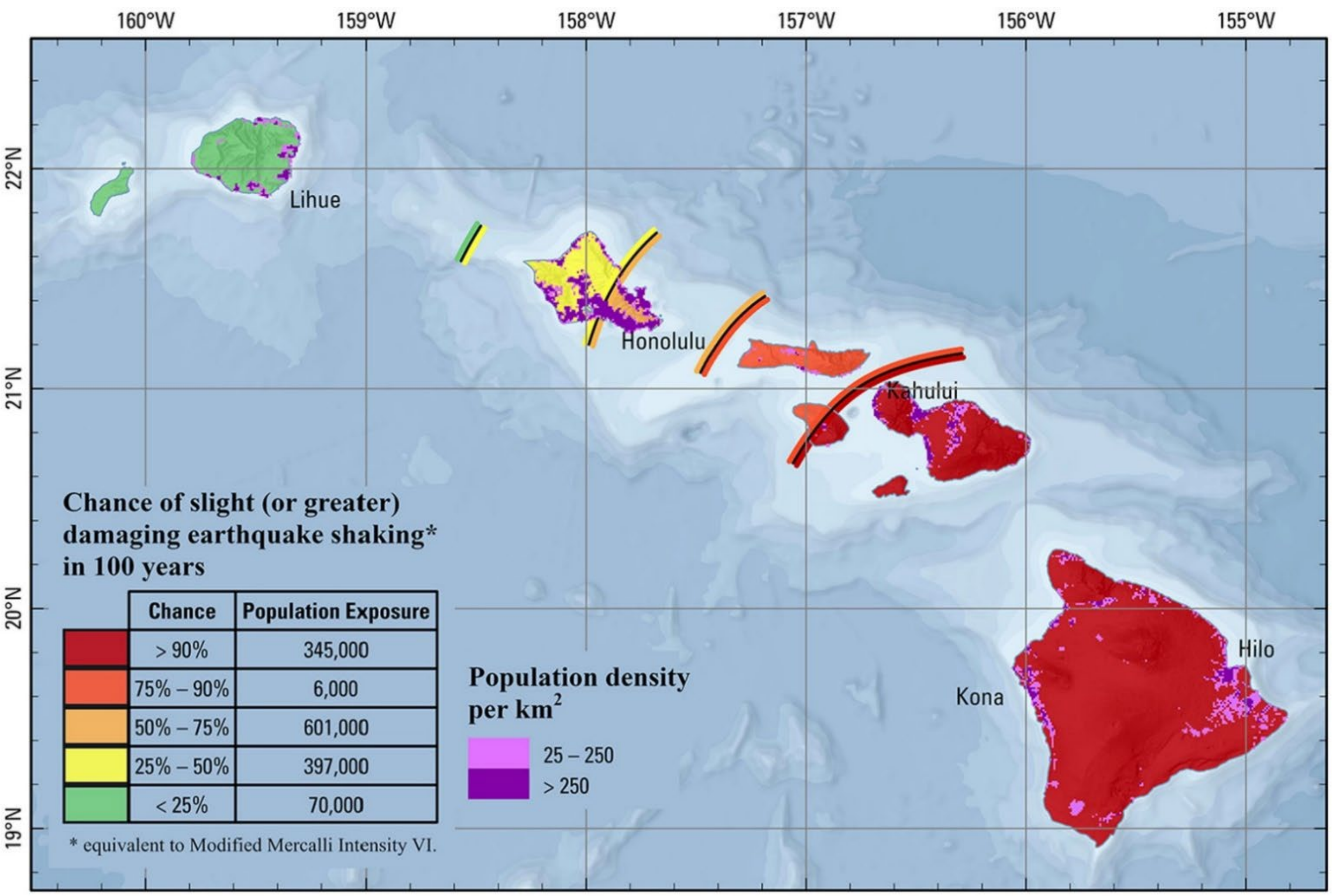
PROBABILITY OF FUTURE HAZARD EVENTS

Overall Probability

For the purpose of this 2023 SHMP Update, the probability of future occurrences is defined by the number of events over a specified period of time. Between 1950 and 2022, there have been 9,302 earthquakes, magnitude

3 (often felt but causes minor damage) and greater (refer to Table 4.5-3 for a description of magnitude and intensity), with epicenters in or near the State of Hawaiʻi. Based on this historic data, the state may experience an average of 129 earthquakes, magnitude 3 or greater, each year. As for earthquakes categorized as strong to severe, between 1950 and 2022, there have been 11 earthquakes, magnitude 6 and greater, with epicenters in or near the State of Hawaiʻi. Based on this historic data, the state has an estimated 15 percent annual chance of a strong or greater strength earthquake occurring. Figure 4.5-10 shows the probability of over 100 years of the state experiencing an earthquake with at least minor damage.

Figure 4.5-10. Chance of Minor or Greater Damaging Earthquake Shaking Within 100 Years



(Petersen, Shumway and Shiro 2021)

An updated ground shaking model published in 2021 indicates that there is a 90 percent chance that the 345,000 people on the islands of Hawaiʻi and Maui could experience damaging levels of shaking during the next 100 years. A lower but significant chance of damaging shaking is expected across Oʻahu; within the southeastern portion of the island near Honolulu there is a greater than 50 percent chance of damaging shaking occurring during this period.

Climate Change Impacts

The potential impacts of global climate change on earthquake probability are still being studied. Some scientists feel that melting glaciers could induce tectonic activity. As ice melts and water runs off, tremendous amounts of weight are shifted on the Earth's crust. As newly freed crust returns to its original, pre-glacier shape, it could cause seismic plates to slip and stimulate volcanic activity. Additionally, changes in the Earth's crust from periods of drought can be significant. Similarly, pumping of groundwater from underground aquafers for human use, which is exacerbated during times of drought, has been shown to impact patterns of stress loads by "unweighting" the Earth's crust (NASA 2019). A University College London study reported that El Niño cycles in the Pacific Ocean over the past 40 years have triggered a regular seismic response as the pressure of water changes with sea level fluctuations. The eastern Pacific experiences more earthquakes in the months after the cycle lowers sea levels in the area by a few centimeters, which flexes the plates beneath (Pearce 2012). These climate change impacts could affect the entire state.

Secondary impacts of earthquakes could be magnified by climate change. Earthquakes can cause large and sometimes disastrous landslides. Any steep slope is vulnerable to slope failure. Rising air temperatures can facilitate soil breakdown, allowing more water to penetrate soils and affect the rates of erosion, sediment control, and the likelihood of landslides. Climate change may also increase the probability of more frequent, intense rainstorms. This can result in greater erosion, higher sediment transport in rivers and streams, and a higher probability of landslides, primarily as a result of higher soil content (University of Washington 2014). Refer to Section 4.11 (Landslide and Rockfall) for details regarding climate change impacts on landslides.

Another secondary impact of an earthquake is dam failure. Earthen dams are highly susceptible to seismic events. The most common type of earthquake-induced dam failure is slumping or settlement of earth-fill dams where the fill has not been properly compacted. If the slumping occurs when the dam is full, then overtopping of the dam, with rapid erosion leading to dam failure is possible. Changes in weather patterns and increases in rainfall can lead to dams being full more often, increasing the risk of failure during an earthquake. Refer to Section 4.10 (Infrastructure Failure) for details regarding climate change impacts on dam failure.

4.5.2 VULNERABILITY ASSESSMENT

ShakeMap data prepared by the USGS and probabilistic earthquake data in Hazus version 5.1 were used to assess the earthquake hazard. The evaluation of the historic events utilizing the current environment provides an understanding of potential loss if the events were to happen today.

- The Kalapana 1975 magnitude 7.7 scenario with an epicenter approximately 26 miles south-southeast of Hilo. This scenario represents the Kalapana magnitude 7.2 earthquake on November 29, 1975.
- The Kaʻū magnitude 8.0 scenario with an epicenter approximately 4 miles northwest of Pāhala. This scenario represents the Kaʻū District magnitude 7.9 earthquake on April 3, 1868.
- The Lānaʻi magnitude 7.0* scenario with an epicenter approximately 13 miles north-northwest of *Lānaʻi* City. This scenario represents the Lānaʻi magnitude 6.8 earthquake on February 20, 1871.
- * Note: The M6.8 scenario (Lānaʻi M7.0 ShakeMap data) was recommended by subject matter experts at the beginning of the planning process. New analysis by SOEST and USGS revised the Lānaʻi earthquake magnitude to 7.5. The revised scenario may be used in the analysis performed for future updates.

- The NE Maui magnitude 7.0 scenario with an epicenter approximately 31 miles northeast of Kahului. This scenario represents the Maui magnitude 6.5 earthquake on January 23, 1938.
- The standard Hazus 100-year probabilistic event.

Assessment of State Vulnerability and Potential Losses

This section discusses statewide vulnerability of exposed state assets (state buildings and state roads), community lifelines and critical facilities to the earthquake hazard.

State Assets

The total replacement cost value of state buildings is an estimated $26 billion; all of which are exposed to an earthquake event. Table 4.5-6 summarizes these values by county. The potential damage estimated to state buildings associated with the 100-year probabilistic earthquake event is approximately $358 million, which represents approximately 1.4% of the inventory's total replacement cost value. The County of Hawai'i has the greatest estimated potential loss (7.2%) to state buildings.

Table 4.5-6. State Buildings Exposure and Potential Losses to the 100-year Probabilistic Earthquake Event

County	Total Value	Estimated Potential Loss	
		Value	Percent of Total
County of Kaua'i	$990,850,824	$2,061	<1%
City and County of Honolulu	$17,393,945,915	$18,380,927	0.1%
County of Maui	$3,097,491,689	$5,277,466	0.2%
County of Hawai'i	$4,638,567,141	$335,122,218	7.2%
Total	**$26,120,855,568**	**$358,782,672**	**1.4%**

Source: State of Hawaii Risk Management Office 2017; United States Geological Survey 2013; FEMA Hazus v5.1 2022

The estimated potential state building loss to the Ka'ū M8.0 and the Lāna'i M7.0 scenarios are summarized in Table 4.5-7, and results for the Kalapana M7.7 and the NE Maui M7.0 scenarios are summarized in Table 4.5-8 by county. The results by state agency for the 100-year probabilistic earthquake event and the four historic scenario events are included in Appendix F (State Profile and Risk Assessment Supplement).

Table 4.5-7. State Buildings Exposure and Potential Losses to the Ka'ū M8.0 and Lāna'i M7.0 Earthquake Event Scenarios

County	Total Value	Estimated Potential Loss			
		Ka'ū M8.0		Lāna'i M7.0	
		Value	Percent of Total	Value	Percent of Total
County of Kaua'i	$990,850,824	$0	0.0%	$0	0.0%
City and County of Honolulu	$17,393,945,915	$3,892,689	0.02%	$2,067,123	<1%
County of Maui	$3,097,491,689	$772,179	0.02%	$37,395,087	1.2%
County of Hawai'i	$4,638,567,141	$143,537,454	3.1%	$23,550	<1%
Total	**$26,120,855,568**	**$148,202,322**	**0.57%**	**$39,485,760**	**0.15%**

Source: State of Hawaii Risk Management Office 2017; USGS 2013; FEMA Hazus v5.1 2022

Table 4.5-8. State Buildings Exposure and Potential Losses to the Kalapana M7.7 and NE Maui M7.0 Earthquake Event Scenarios

County	Total Value	Estimated Potential Loss			
		Kalapana M7.7		NE Maui M7.0	
		Value	Percent of Total	Value	Percent of Total
County of Kauaʻi	$990,850,824	$0	0.0%	$0	0.0%
City and County of Honolulu	$17,393,945,915	$2,607,370	0.0%	$743,785	0.0%
County of Maui	$3,097,491,689	$361,115	0.0%	$3,897,232	0.1%
County of Hawaiʻi	$4,638,567,141	$112,266,079	2.4%	$47,651	0.0%
Total	**$26,120,855,568**	**$115,234,564**	**0.4%**	**$4,688,669**	**0.0%**

Source: State of Hawaii Risk Management Office 2017; United States Geological Survey 2013; FEMA Hazus v5.1 2022

Of the four historic scenarios evaluated, the Kaʻū M8.0 scenario has the greatest potential state building loss at approximately $148 million (see Table 4.5-7). The County of Hawaiʻi has the greatest estimated potential state building loss equating to $143.5 million (3.1%) of the four counties.

State roads can be damaged by moderate to significant earthquake shaking. Roads that are on soft ground or on embankments can experience extensive cracking, ripped apart, settlement and sloughing. This can result in a disruption of transportation systems, which limits post-disaster emergency response.

Table 4.5-9 shows the length of state roads located on the vulnerable NEHRP Class D and E soils for the Counties of Hawaiʻi and Maui. The County of Maui has the greatest number of miles (80.4 miles) located on NEHRP Class D and E soils. The County of Hawaiʻi has a total of 12.6 miles on Class D and E soils. A complete list of state roads exposed is included in Appendix F.

Table 4.5-9. State Road Exposure to NEHRP Class D and E Soils by County

County	Length (in miles)						
	Total Length of State Roads	NEHRP Class D Area	Exposed Length as % of Total	NEHRP Class E Area	Exposed Length as % of Total	NEHRP Class D and E Area	Exposed Length as % of Total
County of Kauaʻi	103.7	-	-	-	-	-	-
City and County of Honolulu	374.9	-	-	-	-	-	-
County of Maui	245.9	80.4	32.70%	0	0.00%	80.4	32.70%
County of Hawaiʻi	379.2	12.6	3.32%	0.17	0.04%	12.7	3.35%
Total	**1,103.70**	**93**	**8.43%**	**0.17**	**0.02%**	**93.1**	**8.44%**

Source: State of Hawaii Department of Transportation 2022; AECOM 2008; United States Geological Survey
Notes: The County of Kauaʻi and the City and County of Honolulu do not have spatially-delineated NEHRP soils available for this analysis.

Community Lifelines and Critical Facilities

All critical facilities in the State of Hawaiʻi are exposed to the earthquake hazard. Community lifelines and critical facilities need to remain in operation during and after a disaster event to provide essential services. To remain in operation, these facilities may depend on electrical power. Maintaining electrical power generation and distribution is essential; however, substations and switchyards are vulnerable to strong ground shaking. As part of the *Makani Pahili 2017 Temporary Emergency Power County Workshop Report*, the HI-EMA and county emergency managers developed a list of county and state critical facilities and essential services that require emergency power during response operations and a methodology to prioritize temporary emergency power in each county. These critical facilities are included in the Hazus analysis for the 2023 SHMP Update.

Table 4.5-10 and Table 4.5-11 summarize the estimated potential losses to critical facilities as a result of the 100-year probabilistic earthquake event by county and category. The County of Hawaiʻi has the greatest estimated loss ($436.5 million or 6.4% of the total value of critical facilities in the county). The greatest loss is to the Safety and Security category ($258 million), followed by Food, Water and Shelter ($146 million).

Refer to Appendix F, which lists the estimated potential loss to community lifelines and critical facilities for the four historic earthquake scenarios evaluated.

Table 4.5-10. Estimated Potential Losses to Community Lifelines and Critical Facilities to the 100-year Probabilistic Earthquake Event, by County

County	Total Replacement Cost Value	Estimated Potential Loss	
		Replacement Cost Value	Percent (%) of Total
County of Kauaʻi	$3,420,500,143	$5,165	0.0%
City and County of Honolulu	$22,973,873,078	$21,580,249	0.1%
County of Maui	$28,244,157,982	$71,346,221	0.3%
County of Hawaiʻi	$6,773,572,388	$436,545,861	6.4%
Total	**$61,412,103,591**	**$529,477,495**	**0.9%**

Source: Hawai'i Emergency Management Agency 2017; FEMA Hazus v5.1

Table 4.5-11. Community Lifelines and Critical Facilities Potential Losses to the 100-year Probabilistic Earthquake Event, by Category

Category	Total Number of Facilities	Total Replacement Cost Value	Estimated Potential Loss	
			Replacement Cost Value	Percent (%) of Total
Communications	188	$776,797,683	$7,095,329	0.9%
Energy	89	$3,093,949,530	$13,479,748	0.4%
Food, Water, Shelter	345	$11,847,189,588	$146,012,563	1.2%
Hazardous Material	12	$436,474,800	$10,142,360	2.3%
Health and Medical	193	$4,606,713,364	$72,129,550	1.6%
Safety and Security	486	$38,164,188,232	$258,089,610	0.7%
Transportation	56	$2,039,091,600	$14,024,179	0.7%
Additional Critical Facilities	106	$447,698,794	$8,504,156	1.9%
Total	**1,475**	**$61,412,103,591**	**$529,477,495**	**0.9%**

Source: Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020; FEMA Hazus v5.1

Fires may also follow earthquakes, often occurring in developed areas. They may be caused by broken power lines or leaking combustibles that find a source of ignition. Response may be affected due to losses incurred to critical facilities and services, including communication service, isolated or damaged equipment, water supply access and other competing emergency demands on available facilities and resources.

ASSESSMENT OF LOCAL VULNERABILITY AND POTENTIAL LOSSES

This section provides a summary of vulnerability and potential losses to socially vulnerable and total populations, general building stock, and environmental resources and cultural assets by county.

The local HMPs were reviewed to integrate risk assessment results into the 2023 SHMP Update; a summary of information available is below.

- **County of Kauaʻi** – The County used magnitude, the Mercalli intensity scale, peak ground acceleration, the National Earthquake Hazard Reduction Program's soil maps, and two USGS earthquake mapping programs—ShakeMap and the National Seismic Hazard Map—to identify areas of peak seismic hazard (with additional mapping in Appendix L). The plan found that 34,695 buildings, with a replacement value of $20.4 billion, are at risk, as well as the entirety of the county population. There are over 663 critical facilities at risk from earthquakes in the County. The County HMP also included a list of residents who are most vulnerable to seismic hazards, including residents living below the poverty line and residents over the age of 65 (County of Kauaʻi 2020).
- **City and County of Honolulu** – The City and County HMP included a discussion of soil conditions and historic building design criteria to assess property risk on the island. The HMP includes an Average Annualized Loss estimate for the City and County of $21 million (City and County of Honolulu 2020).
- **County of Maui** – The County used magnitude, the Mercalli intensity scale, peak ground acceleration, the National Earthquake Hazard Reduction Program's soil maps, and the USGS to identify areas of peak seismic hazard. The HMP utilized HAZUS to conduct an inventory of potential residential losses, with nearly $54 billion residential property assets exposed to earthquakes. The County HMP also included a list of residents who are most vulnerable to seismic hazards, including single parent and dependent households, residents living below the poverty line, residents without adequate communication infrastructure and/or limited English proficiency, residents living in properties built prior to the 1950s, and residents with limited mobility (County of Maui 2020).
- **County of Hawaiʻi** – The County used magnitude, the Mercalli intensity scale, peak ground acceleration, the National Earthquake Hazard Reduction Program's soil maps, and two USGS earthquake mapping programs—ShakeMap and the National Seismic Hazard Map—to identify areas of peak seismic hazard. The risks to property from earthquakes in Hawaiʻi are the highest in the nation, with all structures in the plan area—82,796 buildings—at risk, as well as the entirety of the county population. There are over 52 critical facilities at risk from earthquakes in the County. The County HMP also included a list of residents who are most vulnerable to seismic hazards, including those on seismically sensitive soils, residents living below the poverty line, and residents over the age of 65 (County of Hawaiʻi 2020).

Socially Vulnerable and Total Populations

The degree of exposure is dependent on many factors, including the age and type of construction people live in, the soil types their homes are located on, and the intensity of the earthquake. Whether directly or indirectly impacted, residents may be faced with business closures, road closures that could isolate population, and loss of function of critical facilities and utilities.

Overall, the County of Kauaʻi lies in an area of reduced seismic risk. However, if a severe earthquake affects the City and County of Honolulu, the Counties of Kauaʻi, Hawaiʻi, and Maui would be impacted severely in the receipt of goods, services, and finances since many systems rely on the ports and harbors or institutions on the island of Oʻahu.

Table 4.5-12 displays the estimated population residing on the NEHRP Class D and E soils. Nearly 50% of the population in the County of Maui are located on Class D and E soils. As noted earlier, NEHRP soils are only delineated for the Counties of Maui and Hawaiʻi. This analysis does not include the number of tourists and visitors in the state whose lodgings may be located on NEHRP Class D and E soils. Therefore, this estimate may be underestimating exposure and vulnerability.

Table 4.5-12. 2020 U.S. Census Population Located on the NEHRP Class D and E Soils by County

County	Total Population	Total Population Located in Hazard Area	Population Exposed as Percent (%) of Total Population	Socially Vulnerable Population Located in Hazard Area	Socially Vulnerable Population Exposed as Percent (%) of Total Population
County of Kauaʻi	71,949	-	-	-	-
City and County of Honolulu	979,682	-	-	-	-
County of Maui	167,093	80,507	48%	2,764	1.65%
County of Hawaiʻi	201,350	6,681	3%	20,783	10.32%
Total	**1,420,074**	**87,188**	**6%**	**23,547**	**1.66%**

Source: *U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018; AECOM 2008; United States Geological Survey*
Note: *The County of Kauaʻi and the City and County of Honolulu do not have spatially-delineated NEHRP soils available for this analysis.*

While all people located in the NEHRP Class D and E Soils areas are considered exposed and potentially vulnerable, socially vulnerable populations include the very young, the elderly, and those experiencing poverty. These socially vulnerable populations are most susceptible based on many factors, including their physical and financial ability to react or respond during a hazard and the ability to be self-sustaining for prolonged periods of time after an incident because of limited ability to stockpile supplies. Socially vulnerable populations may live in structures that do not conform to seismic building codes; therefore, homes will sustain more damage during an event. In the County of Hawaiʻi, more than 10 percent of the population exposed to the earthquake hazard is considered socially vulnerable.

Residents may be displaced or require temporary to long-term sheltering because of an earthquake event. The number of people requiring shelter is generally less than the number displaced, as some displaced persons use hotels or stay with family or friends following a disaster event. Estimated shelter requirements as a result of the 100-year probabilistic event and the four historic scenario events were calculated using Hazus; results of these analyses are summarized in Table 4.5-13 and Table 4.5-14.

Table 4.5-13. Estimated Shelter Requirements for the 100-year Probabilistic Event

County	100-year Probabilistic Event	
	Displaced Households	Short-Term Sheltering Needs
County of Kauaʻi	0	0

County	100-year Probabilistic Event	
	Displaced Households	Short-Term Sheltering Needs
City and County of Honolulu	216	131
County of Maui	54	29
County of Hawaiʻi	1,488	1,083
Total	**1,758**	**1,244**

FEMA Hazus v5.1

Table 4.5-14. Estimated Shelter Requirements for the Kaʻū, Lānaʻi Kalapana and NE Maui Scenarios

County	Kaʻū M8.0		Lānaʻi M7.0		Kalapana 1975 M7.7		NE Maui M7.0	
	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs	Displaced Households	Short-Term Sheltering Needs
County of Kauaʻi	0	0	0	0	0	0	0	0
City and County of Honolulu	0	0	0	0	0	0	0	0
County of Maui	0	0	9	6	0	0	0	0
County of Hawaiʻi	124	93	0	0	55	41	0	0
Total	**124**	**93**	**9**	**6**	**55**	**41**	**0**	**0**

Source: United States Geological Survey 2013, FEMA Hazus v5.1

Hazus version 5.1 estimates the number of people that may potentially be injured and/or killed by an earthquake depending on the time of day the event occurs. These estimates are provided for three times of day (2:00 a.m., 2:00 p.m., and 5:00 p.m.), representing the periods of the day that different sectors of the community are at their peak. The 2:00 a.m. estimate considers the residential occupancy at its maximum; the 2:00 p.m. estimate considers the educational, commercial, and industrial sector at their maximum; and the 5:00 p.m. estimate represents peak commuter time. Table 4.5-15 and Table 4.5-16 summarize the injuries and casualties estimated for the 100-year probabilistic event and the four earthquake scenarios.

Table 4.5-15. Estimated Injuries and Casualties for 100-year Probabilistic Event

Level of Severity	100-year Probabilistic Event		
	2 a.m.	2 p.m.	5 p.m.
Injuries	370	659	458
Hospitalization	73	171	113
Casualties	11	37	23

Source: FEMA Hazus v5.1

Table 4.5-16. Estimated Injuries and Casualties for Kaʻū, Lānaʻi Kalapana and NE Maui Scenarios

Level of Severity	Kaʻū M8.0			Lānaʻi M7.0			Kalapana 1975 M7.7			NE Maui M7.0		
	2 a.m.	2 p.m.	5 p.m.	2 a.m.	2 p.m.	5 p.m.	2 a.m.	2 p.m.	5 p.m.	2 a.m.	2 p.m.	5 p.m.
Injuries	25	59	40	8	19	10	18	32	23	1	3	2
Hospitalization	2	9	5	1	3	1	2	3	2	0	0	0
Casualties	0	1	1	0	0	0	0	0	0	0	0	0

Source: FEMA Hazus v5.1

Land Use Districts

Table 4.5-17 shows the area of NEHRP Class D and E soils in the combined state land use district in the County of Maui and the County of Hawaiʻi; refer to Appendix F (State Profile and Risk Assessment Supplement) for results by County. Agricultural District lands have the most square miles of Class D and E soils, as these soil types frequently overlap with floodplain areas, which are commonly highly productive agricultural lands. Nearly 7 percent of the Urban District Land in these two counties have Class D or E soils. Urban Districts are those areas that are most likely to be developed. NEHRP soils are used in the International Building Code (IBC) to classify sites, with Class A and E corresponding to the best and poorest soil conditions, respectively. The State of Hawaiʻi adopted the 2018 IBC on April 20, 2021, and included seismic designs required for buildings in the state based on NEHRP soil classifications (State of Hawaiʻi Department of Accounting and General Services 2023). Counties in the state have adopted or are in the process of adopting the 2018 IBC (see Section 5 for more information).

Table 4.5-17. State Land Use Districts on NEHRP Class D and E Soils

Land Use District	Total (square miles)	Square Miles NEHRP Class D and E Soils	Percent (%) of Total Area
Agricultural	2,973.6	118.50	3.99%
Conservation	3,202.9	110.50	3.45%
Rural	16.3	3.30	20.20%
Urban	319.1	21.90	6.86%
Total	**6,511.95**	**254.20**	**3.90%**

Source: AECOM 2008; United States Geological Survey; State Land Use Commission, Hawaii Statewide GIS Program 2021; Honolulu County GIS 2022
Notes: The County of Kauaʻi and the City and County of Honolulu do not have spatially-delineated NEHRP soils available for this analysis.

General Building Stock and Economy

Similar to the analyses presented earlier, the general building stock data was overlaid with the earthquake hazard area to assess vulnerability. The total replacement cost value of general building stock is an estimated $372 billion, all of which are exposed to an earthquake event. Table 4.5-18 summarizes these values by county. The potential damage estimated to general building stock as a result of a 100-year probabilistic earthquake event is approximately $3.1 billion statewide. The County of Hawaiʻi may experience the greatest damages ($2.65 billion or 4.5% of their total general building stock inventory replacement cost).

Table 4.5-18. General Building Stock Exposure and Potential Losses to the 100-year Probabilistic Earthquake Event

County	Total Replacement Cost Value	Estimated Potential Loss	
		Replacement Cost Value	Percent (%) of Total
County of Kaua'i	$24,246,497,228	$616,228	0.0%
City and County of Honolulu	$239,152,051,766	$339,206,046	0.1%
County of Maui	$50,796,693,140	$128,472,802	0.3%
County of Hawai'i	$58,395,349,136	$2,654,461,478	4.5%
Total	**$372,590,591,270**	**$3,122,756,555**	**0.8%**

Source: NIYAM IT 2022; United States Army Corps of Engineers 2022; FEMA Hazus v5.1

Of the four historic scenarios evaluated, the Ka'ū M8.0 scenario would result in the greatest estimated potential building loss, approximately $372 million in damages statewide (see Table 4.5-19). The County of Hawai'i is estimated to experience the greatest loss, followed by the City and County of Honolulu and County of Maui, respectively. The estimated potential building losses resulting from all four historic scenarios are summarized in Table 4.5-19 and Table 4.5-20 by county.

Table 4.5-19. General Building Stock Exposure and Potential Losses to the Ka'ū M8.0 and Lāna'i M7.0 Earthquake Event Scenarios

County	Total Replacement Cost Value	Estimated Potential Loss			
		Ka'ū M8.0		Lāna'i M7.0	
		Value	Percent of Total	Value	Percent of Total
County of Kaua'i	$24,246,497,228	$0	<1%	$0	<1%
City and County of Honolulu	$239,152,051,766	$20,447,622	<1%	$14,617,141	<1%
County of Maui	$50,796,693,140	$10,970,739	<1%	$144,614,004	0.3%
County of Hawai'i	$58,395,349,136	$524,483,419	1.0%	$182,916	<1%
Total	**$372,590,591,270**	**$555,901,780**	**0.1%**	**$159,414,061**	**<1%**

Source: NIYAM IT 2022; United States Army Corps of Engineers 2022; USGS 2013; FEMA Hazus v5.1

Table 4.5-20. General Building Stock Exposure and Potential Losses to the Kalapana M7.7 and NE Maui M7.0 Earthquake Event Scenarios

County	Total Replacement Cost Value	Estimated Potential Loss			
		Kalapana M7.7		NE Maui M7.0	
		Value	Percent of Total	Value	Percent of Total
County of Kaua'i	$24,246,497,228	$0	0.0%	$0	0.0%
City and County of Honolulu	$239,152,051,766	$13,686,577	<1%	$4,067,819	<1%
County of Maui	$50,796,693,140	$4,985,259	<1%	$55,064,967	0.1%
County of Hawai'i	$58,395,349,136	$324,284,927	0.6%	$904,868	<1%
Total	**$372,590,591,270**	**$342,956,763**	**0.1%**	**$60,037,654**	**<1%**

Source: NIYAM IT 2022; United States Army Corps of Engineers 2022; USGS 2013; FEMA Hazus v5.1

Earthquakes have the potential to impact economies at both the local and regional scale. Losses can include structural and non-structural damage to buildings, loss of business function, damage to inventory, relocation costs, wage loss, and rental loss caused by the repair and replacement of buildings. Table 4.5-21 summarizes the estimated potential economic loss as calculated by Hazus for the four historic earthquake scenarios evaluated.

Table 4.5-21. Estimated Potential Economic Losses for the State of Hawaiʻi (Millions of Dollars) for the Kaʻū, Lānaʻi Kalapana and NE Maui Scenarios

	Kalapana 1975 M7.7	Kaʻū M8.0	Lānaʻi M7.0	NE Maui M7.0
Income Losses				
Wage	$21.8	$31.4	$5.3	$2.1
Capital-Related	$16.8	$23.8	$4.5	$1.8
Rental	$15.2	$21.7	$4.4	$1.6
Relocation	$28.5	$42.7	$7.7	$2.0
Subtotal	**$82.2**	**$119.6**	**$21.9**	**$7.5**
Capital Stock Losses				
Structural	$52.7	$79.2	$22.5	$4.2
Non-Structural	$193.9	$296.2	$94.5	$35.4
Content	$96.3	$141.1	$42.5	$20.5
Inventory	$1.7	$2.4	$0.4	$0.5
Subtotal	**$344.7**	**$518.9**	**$159.9**	**$60.6**
Total	**$426.9**	**$638.5**	**$181.7**	**$68.1**

Source: FEMA Hazus v5.1

Roads that cross earthquake-prone soils have the potential to be significantly damaged during an earthquake, potentially impacting commodity flows. Access to major roads is crucial to life and safety after a disaster as well as to response and recovery. Further, water and sewer infrastructure would likely suffer considerable damage in the event of an earthquake.

Due to its location and isolation, the state faces unique challenges in addressing disaster debris. With limited landfill capacity, advanced planning for large amounts of debris is critical. The Hazus earthquake model estimates volume of debris that may be generated as a result of an earthquake event to enable the state to prepare for and efficiently manage debris removal and disposal. Debris estimates are divided into two categories: (1) reinforced concrete and steel that require special equipment to break up before transport, and (2) brick, wood, and other debris that can be loaded directly onto trucks with bulldozers (FEMA 2022). Table 4.5-22 summarizes the estimated debris generated by the 100-year probabilistic event and the four earthquake scenarios in Hazus 5.1.

Table 4.5-22. Estimated Debris Generated for each Earthquake Scenario

Scenario	Debris Type	
	Brick/Wood (tons)	Concrete/ Steel (tons)
100-year Probabilistic Event	309,935	571,270
Kalapana 1975 M7.7	25,812	40,545
Kaʻū M8.0	42,639	65,229
Lānaʻi M7.0	9,083	11,256
NE Maui M7.0	3,484	2,474

Source: FEMA Hazus 5.1

Environmental Resources

Earthquakes can lead to numerous, widespread, and devastating environmental impacts. Hazardous materials releases can occur during an earthquake from fixed facilities or transportation-related incidents. During an earthquake, structures storing these materials could rupture and leak into the surrounding area or an adjacent waterway, having a disastrous effect on the environment. Facilities holding hazardous materials are of concern because of possible isolation of neighborhoods surrounding them. Transportation corridors can be disrupted during an earthquake, leading to the release of materials to the surrounding environment. Table 4.5-23 summarizes environmental resources on NEHRP D or E soils.

Table 4.5-23. Environmental Resources Located on NEHRP Class D or E Soils

	Statewide		
Environmental Resource	**Total Square Miles of Resources**	**Square Miles in High-Risk Area**	**Percent (%) of Total Resource Area**
Critical Habitat [a]	950.6	703.4	74.0%
Wetlands	3,636.7	199.1	5.5%
Parks and Reserves	2,777.7	2,308.1	83.1%
Reefs [b]	54.8	0.3	0.6%
Total [c]	**7,419.8**	**3,211.0**	**43.3%**

Source: Hawai'i Wildfire Management Organization, Division of Forestry and Wildlife; U.S. Fish and Wildlife Service, Pacific Islands Office, 2022, U.S. Fish and Wildlife Service 2021; 2017, Hawai'i State Department of Land and Natural Resources, Division of Forestry and Wildlife 2022, NOAA raster nautical charts 2020, State of Hawai'i Department of Land and Natural Resources, Division of State Parks 2021

Notes:

a. *Critical area mileage includes the combined area of coverage of individual critical habitat areas.*
b. *Reefs include artificial and coral reefs.*
c. *Total square miles includes environmental assets within 3 nautical miles of each county and may be over-reported as some environmental asset areas may overlap.*

Additional environmental impacts may include but are not limited to:

- Induced flooding or landslides
- Poor water quality
- Damage to vegetation
- Breakage in sewage or toxic material containments

Cultural Assets

Consistent with Native Hawaiian culture, Hawaiian Home Lands include areas from mauka to makai (from the mountain to the sea). The population and structures located on Hawaiian Home Lands are more vulnerable to earthquake events if located on NEHRP Class D and E soils (see Table 4.5-24). The County of Maui has 6.4% of its Hawaiian Home Lands on this type of soil. Table 4.5-25 summarizes cultural resources located on NEHRP Class D and E soils.

Table 4.5-24. Hawaiian Home Lands on NEHRP Class D and E Soils

County	Area (in square miles)						
	Total Area of Hawaiian Home Lands	NEHRP Class D Area	Percent (%) of Total	NEHRP Class E Area	Percent (%) of Total	Total NEHRP Class D and E Area	Percent (%) of Total
County of Kauaʻi	32.1	-	-	-	-	-	-
City and County of Honolulu	10.6	-	-	-	-	-	-
County of Maui	102.6	6.6	6.4%	0.0	0.0%	6.6	6.4%
County of Hawaiʻi	191.5	5.1	2.7%	2.6	1.3%	7.7	4.0%
Total	**336.7**	**11.7**	**3.5%**	**2.6**	**0.8%**	**14.3**	**4.2%**

Source: *Hawaii State Department of Hawaiian Homelands 2021; AECOM 2008; United States Geological Survey*
Note: *The County of Kauaʻi and the City and County of Honolulu do not have spatially-delineated NEHRP soils available for this analysis.*

Table 4.5-25. Cultural Resources Located on NEHRP Class D or E Soils, Statewide

Cultural Resource Site Type	Area (in square miles)						
	Total Square Miles	Cultural Resources in NEHRP Class D Area	Percent (%) of Total	Cultural Resources in NEHRP Class E Area	Percent (%) of Total	Cultural Resources in NEHRP Class D and E Area	Percent (%) of Total
Archaeology	90.9	9.8	10.8%	0.6	0.7%	10.4	11.5%
Burial Sensitivity Area	2.1	0.1	7.1%	0.0	0.0%	0.1	7.1%
Historic Building	2.7	0.2	8.1%	0.0	0.0%	0.2	8.1%
Historic District	849.4	58.1	6.8%	1.6	0.2%	59.7	7.0%
Historic Object	9.6	0.0	0.5%	0.0	0.0%	0.0	0.5%
Historic Structure	20.7	0.0	0.2%	0.0	0.0%	0.0	0.2%
Total	**975.4**	**68.4**	**7.0%**	**2.2**	**0.2%**	**70.6**	**7.2%**

Future Changes that May Impact State Vulnerability

Understanding future changes that impact vulnerability in the state can assist in planning for future development and ensuring that appropriate mitigation, planning, and preparedness measures are in place. The State of Hawaiʻi considered the following factors to examine potential conditions that may affect hazard vulnerability:

- Potential or projected development
- Projected changes in population
- Other identified conditions as relevant and appropriate, including the impacts of climate change

NEHRP Class D and E soil areas were overlain on areas that may experience significant changes in development or redevelopment in future years (see Table 4.5-26 below; refer to Section 3 for more information on projected development areas). Because only the County of Hawaiʻi and the County of Maui have this data available, the analysis was only conducted using Maui Development Project Areas and Enterprise Zones in these counties. About 22% of the area in the Maui Development Projects are in the hazard area and 9% of Enterprise Zone areas have Class D or E soils. Generally, new development will be more resistant to damage from earthquake events than older construction as building code seismic design standards have improved over time and modern codes, such as the IBC, include provisions for classifying soils.

Table 4.5-26. Maui Development Projects and Enterprise Zones Located in NEHRP Class D or E Soils

County	Area (square miles)					
	Maui Development Projects (Total Area)	Total Area Exposed to Hazard	Hazard Area as % of Total Area	Enterprise Zones (Total Area)	Total Area Exposed to Hazard	Hazard Area as % of Total Area
County of Maui	27.6	6	21.7%	1,059.8	94.7	8.9%
County of Hawai'i	0	0	0	1,274.9	45.4	3.6%
Total	**27.6**	**6**	**21.7%**	**2,334.7**	**140.1**	**6.0%**

Source: Maui County Planning Department 2016; Community Economic Development Program, Department of Business, Economic Development & Tourism, County Planning Departments 2021; AECOM 2008; United States Geological Survey

Note: NEHRP soil classification has not been conducted in the County of Kaua'i or in the City and County of Honolulu