Section 4.11 Landslide and Rockfall

Landslide and Rockfall

Landslides are generally characterized as the downward and outward movement of soil and/or rocks on a slope such as a hill, cliff, or mountain. Rockfalls are caused by large boulders or rocks that become detached and fall from the side of a slope or cliff. They can be caused by changes in groundwater level, seismic and volcanic activity, and human activities such as road construction and deforestation. Statistics below represent the high landslide susceptibility area.

CHANGES SINCE 2018

+3
Declared Disasters

+8
Landslide Events

COUNTIES MOST VULNERABLE

Kaua'i Honolulu Maui Hawai'i

SOCIALLY VULNERABLE POPULATION

1.04%
Of Total Population

14,823
Persons

HAZARD RANKING

Low Medium High

COMMUNITY LIFELINES

95
Total

Food, Water, Shelter
Greatest

CLIMATE PROJECTIONS

Increased droughts, which may lead to wildfire, may reduce the vegetation on steep slopes, causing landslides and rockfalls

Projected heavier rainfalls may cause an increase in landslides and rockfalls

SQUARE MILES

642
Environmental Resources

119
Hawaiian Home Lands

89
Cultural Resources

357
State Buildings

151
Miles of State Road

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[1] *Section Cover Photo: Landslide covering Pali Highway, Oʻahu. Photo courtesy of Hawaiʻi Department of Transportation*

SECTION 4. RISK ASSESSMENT

4.11 LANDSLIDE AND ROCKFALL

2023 SHMP Update Changes

- Landslide events, including rockfalls and mudslides, that occurred in the State of Hawai'i from January 1, 2018, through December 31, 2022, were researched for the 2023 SHMP Update.
- New and updated figures from federal and state agencies were incorporated.
- This section now includes a discussion of how landslides and rockfalls impact socially vulnerable populations and community lifelines.
- Reefs (both artificial and coral) are now separated out for all hazards in the Environmental Resources analysis and listed along with critical habitat, wetlands, and parks and reserves.
- Six types of cultural resources (archaeology, burial sensitivity area, historic building, historic district, historic object, and historic structure) are added to the vulnerability assessment.

4.11.1 HAZARD PROFILE

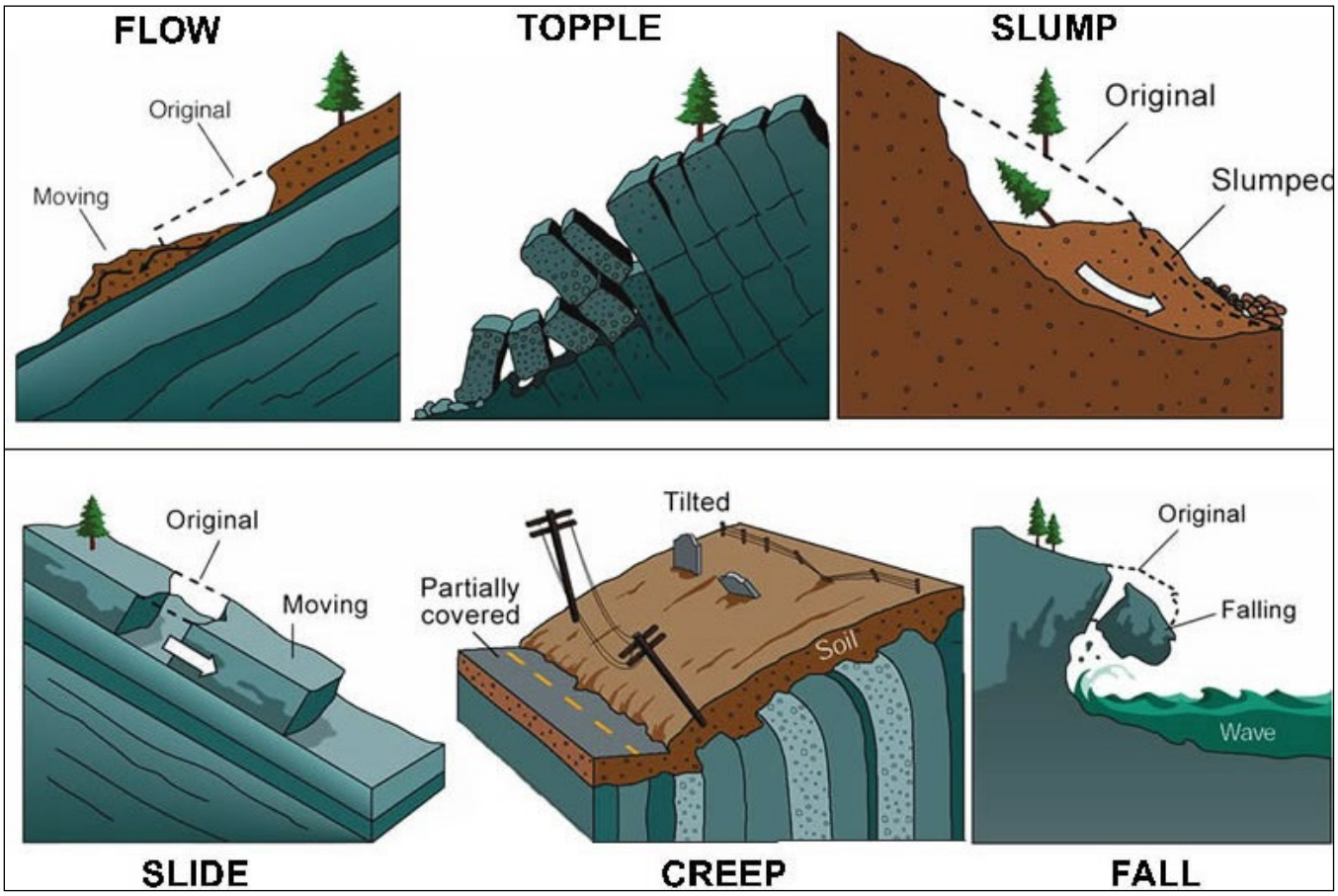
HAZARD DESCRIPTION

Landslide is the broad term that describes the downward and outward movement of soil and/or rock. Landslides may be differentiated by the kinds of materials involved and the type of slope movement. The main types of movements are: flows, topples, slumps, slides, creeps, and falls (USGS 2016). Figure 4.11-1 illustrates the movement mechanisms in graphical form. In addition, avalanches can involve slumps, falls, and flows of soil, rock, and debris. For the purposes of the 2023 SHMP Update, this section focuses on landslides (inclusive of all types of soil/rock movement and debris flow) and rockfalls.

Key Terms

- **Landslide** – The movement of a mass of rock and/or soil down a slope; can also refer to masses of material.
- **Debris Flow** – A form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope; can also refer to masses of material.
- **Rockfall** – The falling of newly detached mass of rock from a cliff or down a very steep slope.

Figure 4.11-1. Types of Landslides



Source: Tara 2017

Many factors cause landslides and rockfalls, but the following are particularly prevalent in the State of Hawai'i: water changes, seismic activity, volcanic activity, and human activity.

- **Water** – Intense rainfall, changes in groundwater level, and water level changes along coastlines, earthen dams, and the banks of lakes, reservoirs, and rivers are the primary triggers of landslides and rockfalls. Landslides and flooding are closely related because both can be triggered by precipitation, runoff, and saturation of the ground. They commonly occur simultaneously in a given area (USGS 2016).
- **Seismic Activity** – Earthquakes in landslide-prone areas greatly increase the likelihood that landslides will occur, either due to ground shaking alone or shaking-caused dilation of soil materials. Rockfalls can also occur as a result of earthquakes because the shaking loosens rocks (USGS 2016).
- **Volcanic Activity** – Landslides caused by volcanoes are some of the most devastating types of landslides. Landslides are common on volcanic cones because they are tall, steep, and contain weak rock layers. The ascent of molten rock can further weaken volcanic layers. Volcanic gases and hydrothermal systems in volcanoes also weaken rock by altering minerals to clay (USGS 2016).
- **Human Activity** – Landslides and rockfalls may result directly or indirectly from human activities. Construction activity that undercuts or overloads dangerous slopes or that redirects the flow of surface or groundwater can trigger slope failures.

Landslides

Landslides are mass movements of material, where a distinct zone of weakness separates the slide material from the more stable underlying material (USGS 2016). Several phenomena may be noticeable prior to a landslide. These phenomena include:

- Springs, seeps, or saturated ground in areas that have not typically been wet before
- New cracks or unusual bulges in the ground, street pavements, or sidewalks
- Soil moving away from foundations
- Ancillary structures such as decks and patios tilting and/or moving relative to the main house
- Tilting or cracking of concrete floors and foundations
- Broken water lines and other underground utilities
- Leaning telephone poles, trees, retaining walls, or fences
- Offset fence lines
- Sunken or down-dropped road beds
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content)
- Sudden decrease in creek water levels though rain is still falling or just recently stopped
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb
- A faint rumbling sound that increases in volume is noticeable as the landslide nears
- Unusual sounds, such as trees cracking or boulders knocking together, might indicate moving debris (USGS n.d.)

Debris flows, commonly referred to as mudslides, mudflows, or lahars, are common types of fast-moving landslides and occur in a wide variety of environments. Flows are characterized by deformation distributed throughout a mass of material. Flows typically are distinguished from slides by high water content and distribution of velocities within the flowing material that resembles that of viscous fluids.

Debris flows are a form of rapid mass movement in which loose soils, rocks, and organized matter, combined with air and water, form slurries that flow downslope. Debris flows generally occur during periods of intense rainfall (USGS 2019).

Rockfall

Rockfalls typically result from a combination of rock fracture, erosion, chemical weathering, and the presence of a steep slope. Volcanic rocks in Hawai‘i commonly fracture as they originally form. Subsequently, a variety of processes can cause old or new fractures to grow, such as increases in water pressure in fractures, the wedging action of plant roots, and flexure of the rock. Erosion can undercut slopes and occur by rainfall runoff, stream erosion, or wave action. Wave action occurring during higher sea levels over geologic time can undermine loose, weak rock. Chemical weathering can weaken rock layers and make them more susceptible to failure. These processes can act in tandem. For example, withdrawal of support in a slope by erosion or lava tube collapse can alter the stresses in the slope, cause fractures to open and grow, and concurrently increase the surface area available for chemical weathering.

Rockfalls occur where a source of rock exists above a slope steep enough to allow rapid downslope movement of dislodged rocks by falling, rolling, bouncing, and sliding. Rockfall sources include bedrock outcrops or boulders on steep mountainsides or near the edges of escarpments such as cliffs, bluffs, and terraces (UGS 2019).

LOCATION

The State of Hawai'i has several characteristics that make it susceptible to landslides and rockfalls: steep hillsides, heavy rainfall, a warm climate, lush vegetation, and residential development and other types of construction in upland areas. Areas that may be considered prone to landslides and rockfalls include the following:

- On existing old landslides
- On or at the base of slopes
- In or at the base of minor drainage hollows
- At the base or top of an old fill slope
- At the base or top of a steep cut slope
- Developed hillsides where leach field septic systems are used
- (USGS n.d.)

Heavy or prolonged rainfall is the most common trigger of landslides and rockfalls (USGS n.d.). These slope failure events are particularly common during or immediately after severe rainfall of more than 3 inches in a peak 6-hour period. Figure 4.11-2 illustrates the State of Hawaii's average annual rainfall total in inches from 1920 to 2012. In general, high mean rainfall is found on the windward side of the mountains, and low rainfall prevails in leeward lowlands and on the upper slopes of the highest mountains. High-intensity rainfall events are particularly common in areas of high mean annual rainfall, but they can also occur on the drier leeward sides of the islands.

Sites of wildfire and/or where vegetation has been destroyed on slopes are particularly vulnerable to landslides during and after heavy rain events (CDC 2003). Refer to Section 4.15 (Wildfire) for further discussion on high-risk wildfire areas in the state.

Landslide susceptibility data for the County of Hawai'i was provided by the Pacific Disaster Center (PDC). Figure 4.11-3 through Figure 4.11-6 illustrate the high, moderate, and low landslide susceptibility areas in the Hawaiian Islands. Refer to Section 4.1 (Overview) for more information on the methodology followed to develop this data.

Areas of slope were assigned low, moderate, and high landslide susceptibility categories to align with the slope categories for the County of Hawai'i (refer to Section 4.1 for more details on the methodology). These data are considered suitable for planning purposes only.

For the purposes of the 2023 SHMP Update, the high landslide susceptibility areas were evaluated further in the vulnerability assessment later in this section. Table 4.11-1 shows the high landslide susceptibility area in square miles and the percent of the total area in each county. According to the PDC and USGS, the County of Hawai'i has the largest percent (23.39%) of high landslide susceptibility areas.

Figure 4.11-2. Average Annual Rainfall in the State of Hawai'i, 1920 to 2012

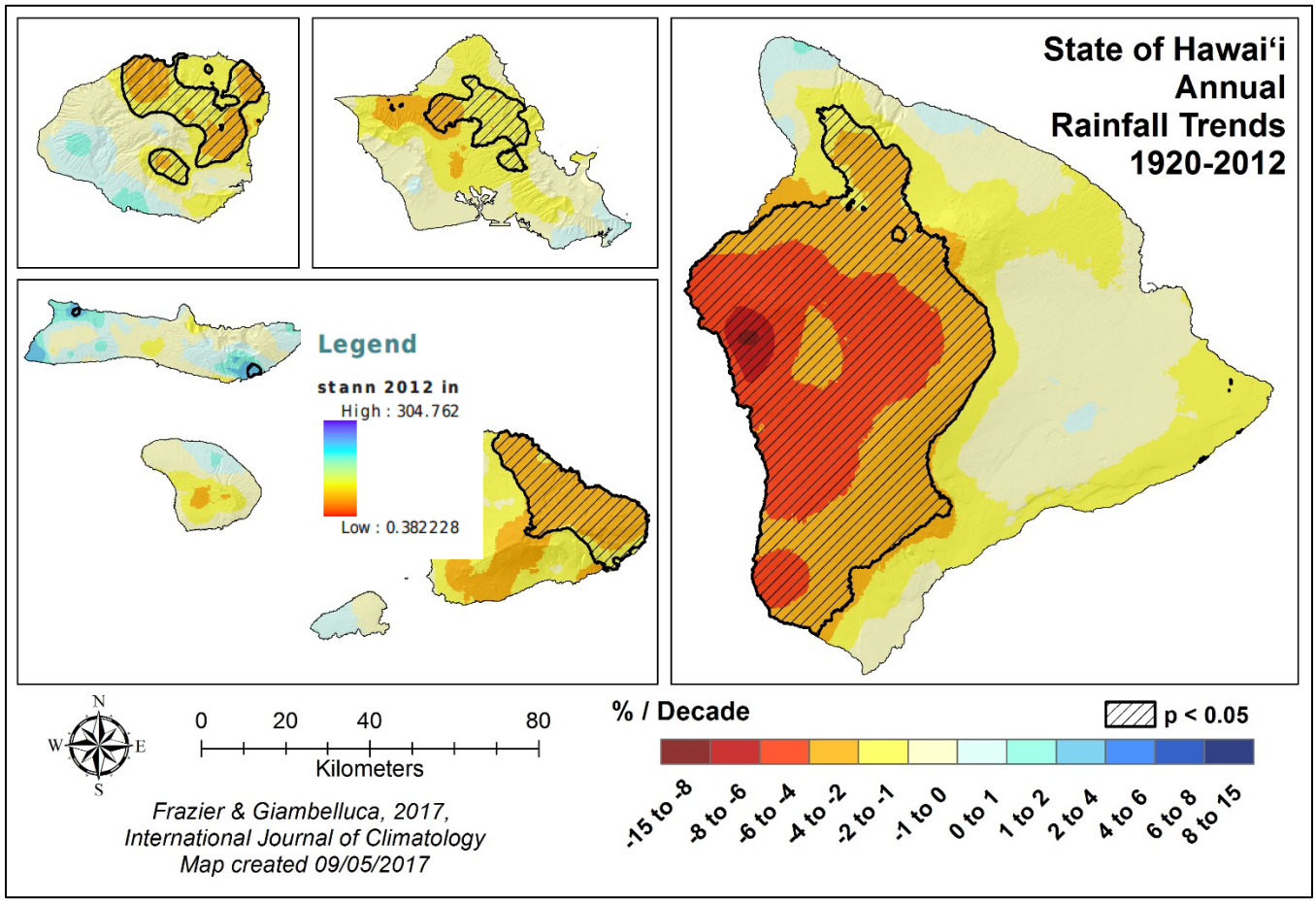
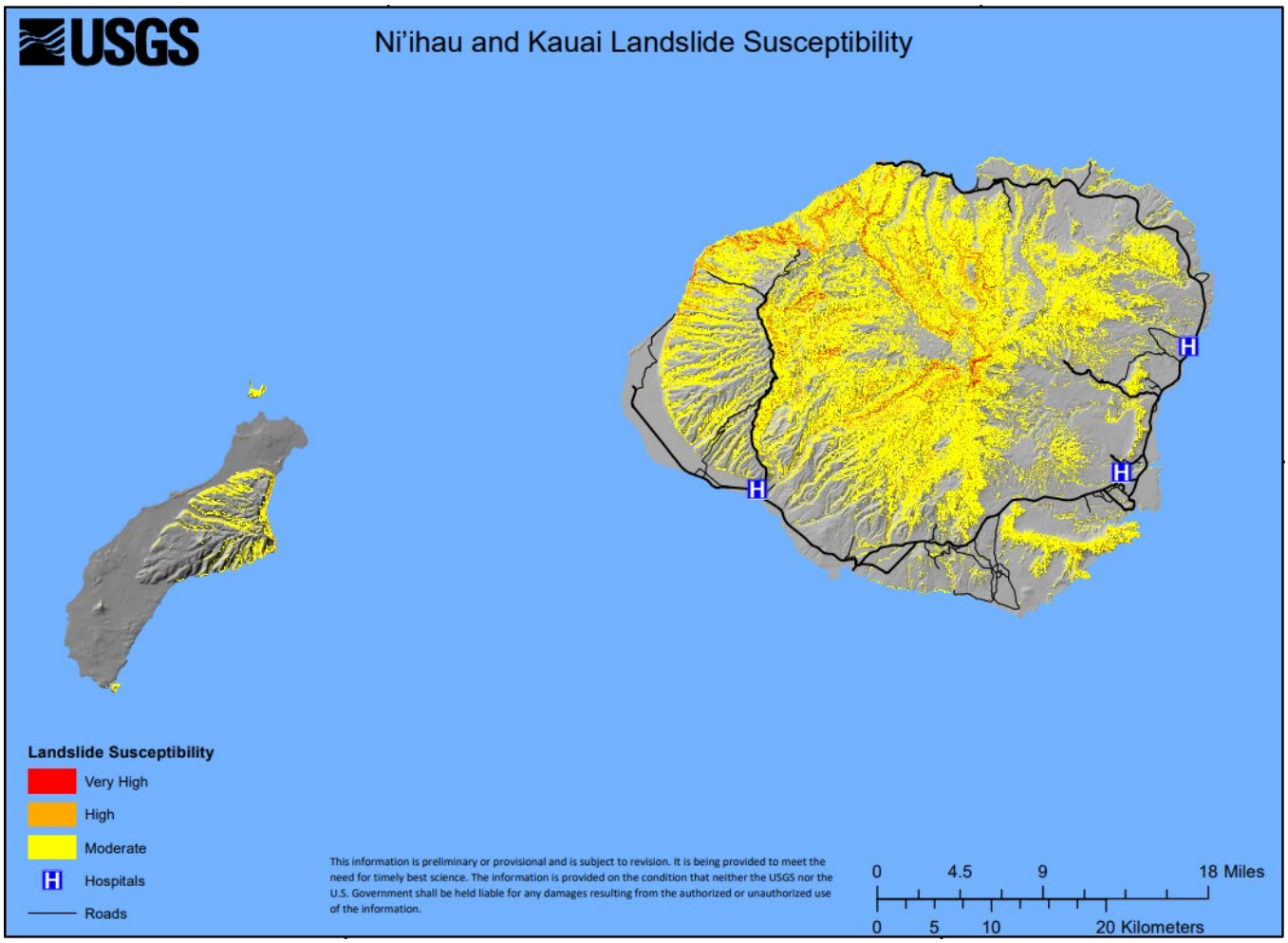
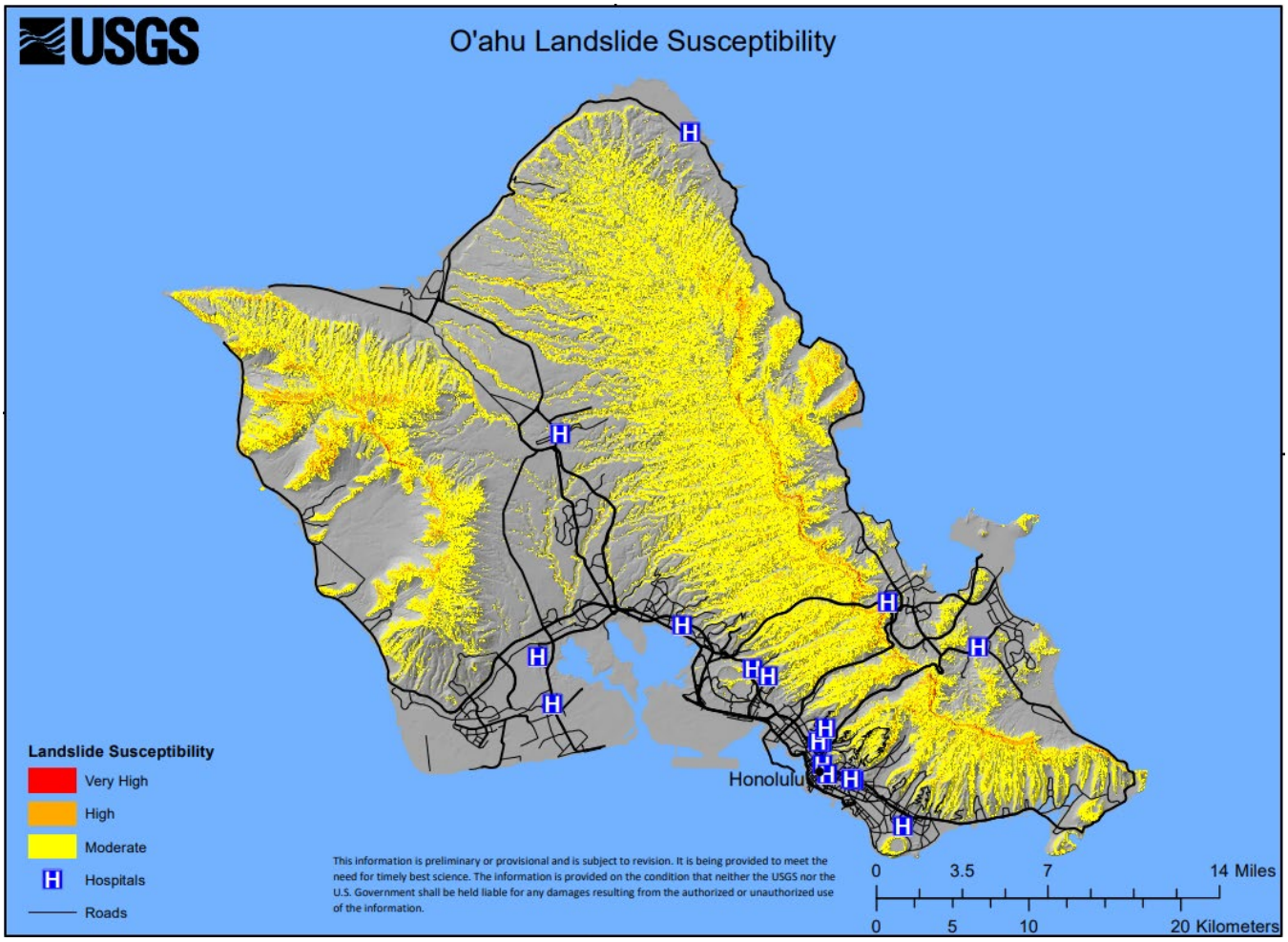


Figure 4.11-3. Landslide Susceptibility in the County of Kaua‘i



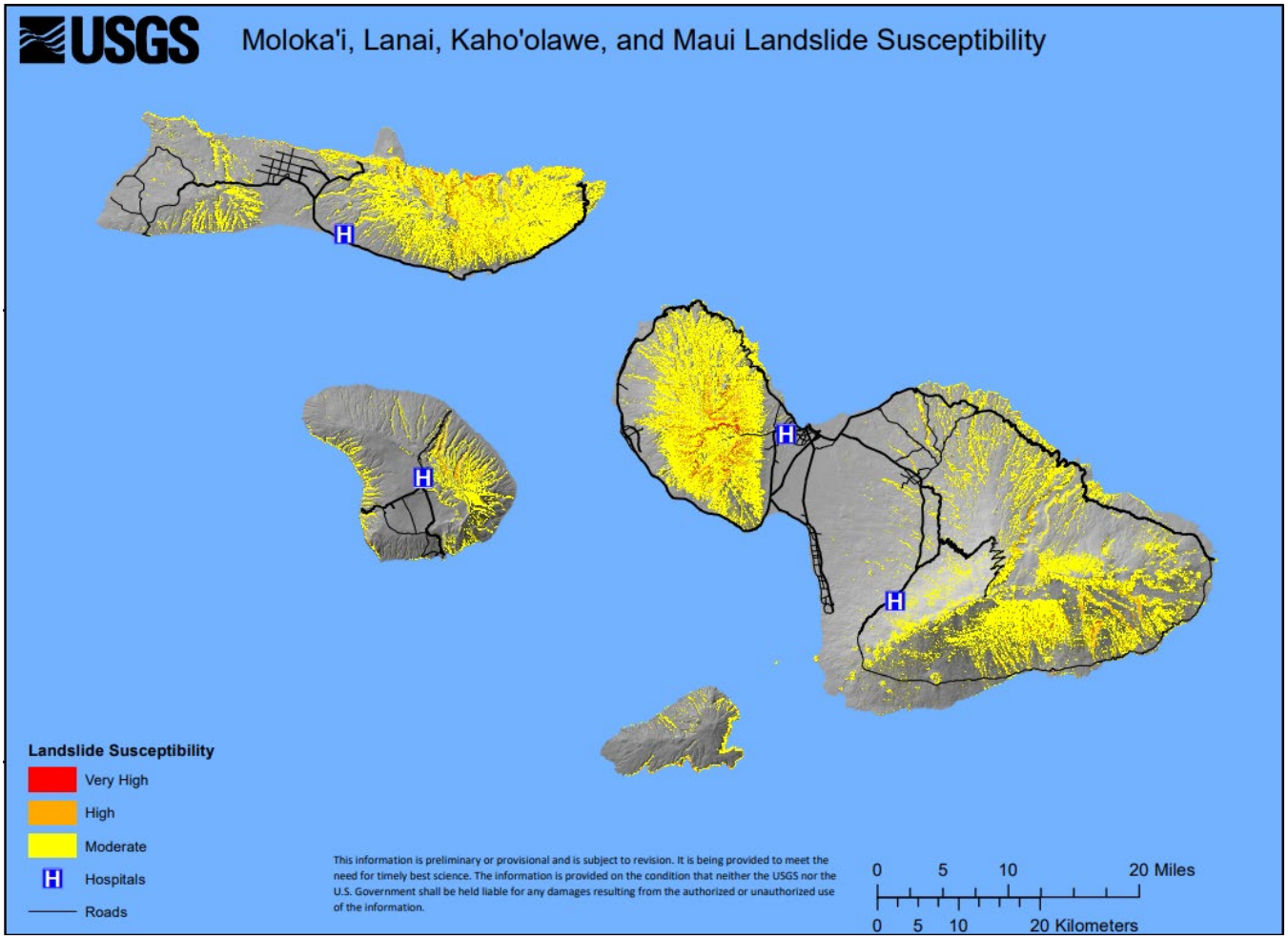
Source: USGS 2018

Figure 4.11-4. Landslide Hazard Areas in the City and County of Honolulu



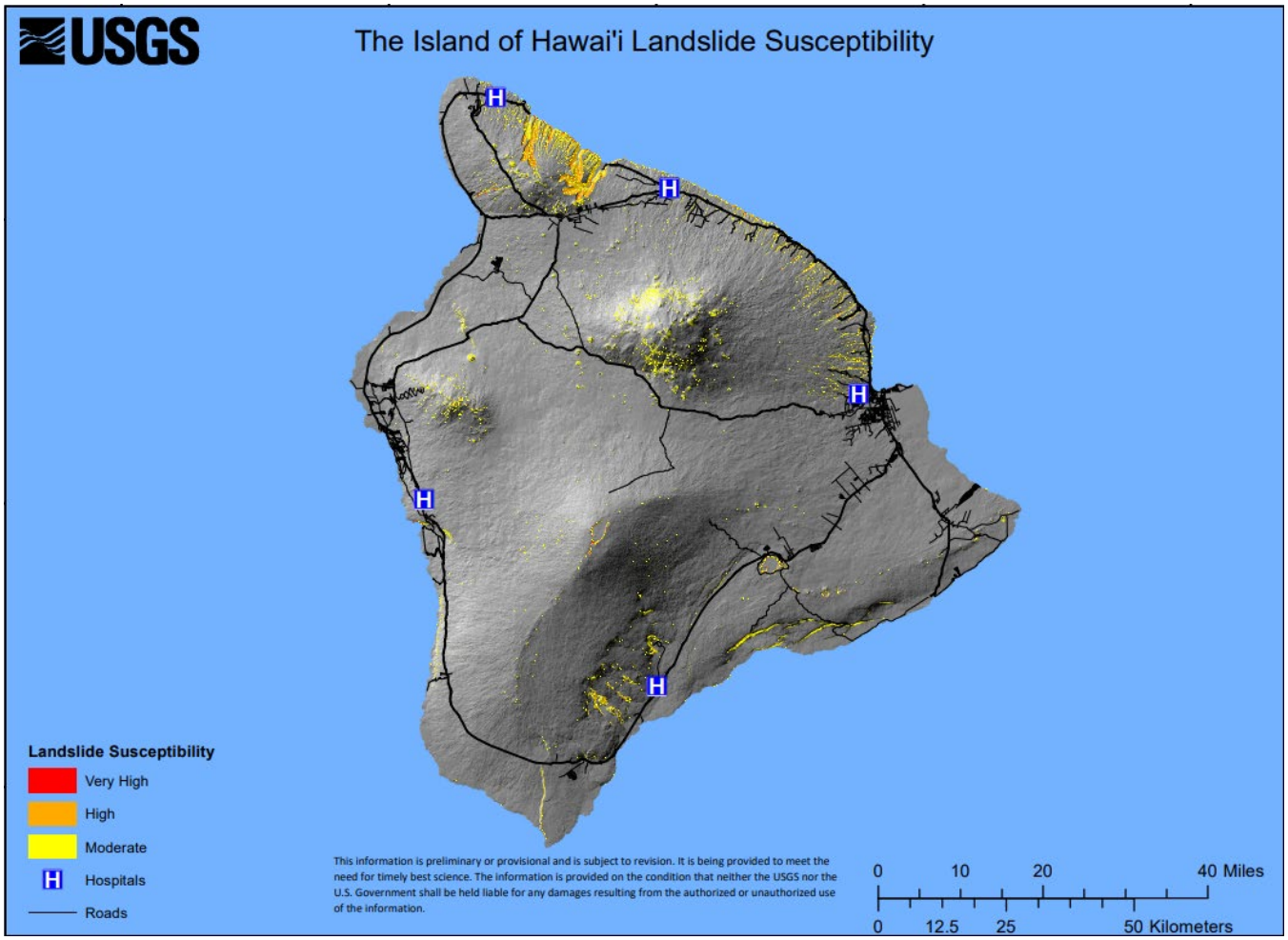
Source: USGS 2018

Figure 4.11-5. Landslide Hazard Areas in the County of Maui



Source: USGS 2018

Figure 4.11-6. Landslide Hazard Areas in the County of Hawai'i



Source: USGS 2018

Table 4.11-1. Total High Landslide Susceptibility Area by County

County	Total Area	High Landslide Susceptibility Area	High Susceptibility as Percent (%) of Total Area
County of Kaua'i	624.2914	69	11.05%
City and County of Honolulu	598.5707	54.9	9.17%
County of Maui	1,176.28	82.5	7.01%
County of Hawai'i	4,039.64	944.9	23.39%
Total	**6,438.78**	**1,151**	**17.88%**

Source: Pacific Disaster Center 2017; United States Geological Survey 2016

The following provides details, by county, of where landslides typically occur.

- **County of Kaua'i** – Debris avalanches and slides typically occur on the western side or northern side of the County of Kaua'i. Landslides also occur frequently near road cuts. Significant historical landslides have occurred along the highways and coastal roads. High-risk areas include portions of Kaumuali'i Highway (State Highway 50) near Kalāheo and Lawa'i, portions of Kūhiō Highway (State Highway 56) between Hā'ena and Hanalei (see Figure 4.11-7), and portions of Kuamoo Road (State Highway 580) near Kapa'a (County of Kaua'i 2021).
- **City and County of Honolulu** – Several key contributors to debris flows exist in the City and County of Honolulu: steep hillsides, heavy rainfall, and residential development in upland areas. Significant events that have impacted the eastern part of the Honolulu District and in the Kuli'ou'ou and Haha'ione valleys. Additionally, 66 highways sites were identified as having high risk of rockfall. The affected highways include Pali Highway, Kalaniana'ole Highway, Kamehameha Highway, and Farrington Highway (City and County of Honolulu Plan 2020).
- **County of Maui** – There is a high risk of landslides from earthquakes in the County of Maui caused by the volcanic activity in the County of Hawai'i. Landslides, debris flows, and rockfalls occur along coastal highways in the county, especially where highways are along mountain slopes (County of Maui 2020).
- **County of Hawai'i** – Several areas along the Hāmākua Coast on the island of Hawai'i are chronic problem areas for landslides, particularly during periods of heavy rainfall (see Figure 4.11-8). Also, the three major gulches of Maulua, Laupāhoehoe and Ka'awali'i are areas prone to rockfalls (County of Hawai'i 2020).

EXTENT

Landslides and rockfalls are natural events that can vary widely in extent, from a single rock tumbling down a hillside to a major landslide or mudflow that covers several acres. Landslide severity is directly related to the results of an event.

Debris flows exhibit a broad range of characteristics. The consistency of debris flow ranges from watery mud to wet rocky debris. Debris flows can carry large items such as boulders, trees, and cars, and they can cause extensive damage. Debris flows from multiple sources can combine in channels, greatly increasing their destructive power. As they flow down hills and through channels, they grow in volume with the addition of water, sand, mud, boulders, trees, and other materials. When the flows reach flatter ground, the debris spreads over a broad area, locally accumulating in thick deposits that can wreak havoc in developed areas. Once started, debris flows can travel even over gently sloping ground. The most hazardous areas are valley bottoms, stream channels, areas near outlets of valleys, and slopes for buildings and roads (USGS 2016a).

Warning Time

Landslides exhibit a wide range of speeds—from a slow creep of inches per year to many feet per second, depending on slope angle, material, and water content. As a result of the range of speeds, the amount of warning time ranges widely.

Figure 4.11-7. Landslide Covering Prince Kūhiō Highway on Kaua'i, 2018

Source: Hawai'i Department of Transportation

Figure 4.11-8. Landslide on Hawaiʻi Island, 2018

Source: Hawai'i Emergency Management Agency

The warning time for landslides depends on the geology, the vegetation, and the amount of predicted precipitation for an area. The current standard operating procedure is to monitor situations on a case-by-case basis and respond after the event has occurred (Wieczorek and Snyder 2009). Generally accepted warning signs for landslide activity include:

- Springs, seeps, or saturated ground in areas that have not typically been wet before
- New cracks or unusual bulges in the ground, street pavements, or sidewalks
- Soil moving away from foundations
- Ancillary structures such as decks and patios tilting and/or moving relative to the main house
- Tilting or cracking of concrete floors and foundations
- Broken water lines and other underground utilities
- Leaning telephone poles, trees, retaining walls, or fences
- Offset fence lines
- Sunken or down-dropped road beds
- Rapid increase in creek water levels, possibly accompanied by increased turbidity (soil content)
- Sudden decrease in creek water levels though rain is still falling or just recently stopped
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb
- A faint rumbling sound that increases in volume is noticeable as the landslide nears
- Unusual sounds, such as trees cracking or boulders knocking together, might indicate moving debris (USGS n.d.)

Real-time data on rainfall, soil water content and soil water pressure can be combined with numerical modeling to assist with the development of real-time debris flow warning systems. The following findings may assist with predicting landslides:

- Seasonal variation in soil moisture affects the susceptibility of a hillside to landslides
- Wetness of the soil before a storm that triggers landslides affect the rainfall threshold for an area
- Low moisture content of hillsides in the dry season allows the hillsides to tolerate much greater amounts of rainfall before sliding than during the wet season
- Soil does not have to be completely saturated with water for landslides to occur
- Positive pore-water pressure (which contributes to the initiation of landslides) occurs at select locations on a hillside only briefly (hours) a few times per year during heavy rainfall
- Measurement of soil water content and water suction or pressure in hillside soils gives a more accurate estimate of slope stability than rainfall or soil water content measurements alone (USGS 2018)

Previous Occurrences and Losses

Many sources provided information regarding previous occurrences and losses associated with landslide and rockfall events throughout the State of Hawai‘i. The 2018 SHMP discussed specific landslide and rockfall events that occurred in the state through 2017. For the 2023 SHMP Update, events for all hazards assessed were summarized between January 1, 2018, and December 31, 2022.

Disaster and Emergency Declarations

Table 4.11-2 lists landslide events that were included in federal disaster declarations.

- **Federal disaster (DR) or emergency (EM) declarations, 1955 – 2022**: 9 events, classified as landslide, mudslide, or combination of both
- **USDA agricultural disaster declarations, 2012 – 2022**: 1 event classified as landslide
- **Hawai'i state emergency proclamations, 2018 – 2022**: 6 events classified as landslide, flood, heavy rains, or combination

Table 4.11-2. Landslide and Mudslide-Related Federal Declarations, 2018 to 2022

Event Type	Date Declared	Declaration	Counties Affected
Severe Storms, Flooding, Landslides, and Mudslides	May 8, 2018	DR-4364-HI	Honolulu, Kaua'i
Severe Storms, Flooding, and Landslides	May 13, 2021	DR-4604-HI	Maui
Severe Storms, Flooding, and Landslides	February 15, 2022	DR-4639-HI	Honolulu, Maui

Source: FEMA 2023

Table 4.11-3 lists major landslide and rockfall events that occurred in the state between 2018 and 2022. For events prior to 2018, please refer to Appendix E (Hazard Profile Supplement).

Table 4.11-3. Landslide Events in the State of Hawai'i, 2018 to 2022

Date(s) of Event	Event Type and Federal Disaster Declaration (if applicable)	Counties Affected	Description
February 22, 2018 – February 23, 2018	Debris Flow	Kaua'i	With an upper trough west of the islands and a surface trough over the state, heavy showers, including thunderstorms, formed across the local area. Heavy snow also fell over the summits of Mauna Loa and Mauna Kea on the Big Island of Hawai'i. The cost of any damages was not available. There were no reports of serious injuries. A debris flow occurred on the southbound lane of Kūhiō Highway in northern Kaua'i between Waikoko Beach and Waipa Farmers Market. A debris flow occurred near Wainiha in northern Kaua'i along Kūhiō Highway. When county workers tried to clear the debris, a larger flow occurred, which then closed both lanes of the highway.
March 15, 2018	Debris Flow	Kaua'i	An area of low pressure west of Hawai'i produced heavy showers and thunderstorms. The precipitation led to flash flooding over portions of Kaua'i and Maui. There were no reports of significant injuries. The cost of any damages was not available. A debris flow covered part of Kūhiō Highway near Lumahai in northern Kaua'i.

Date(s) of Event	Event Type and Federal Disaster Declaration (if applicable)	Counties Affected	Description
April 13, 2018 – April 14, 2018	Debris Flow (FEMA-DR-4365)	Honolulu and Kaua'i	A developing upper low northwest of the state, in combination with tropical moisture, induced periods of heavy showers and thunderstorms, and generated historic flash flooding conditions over the Garden Isle of Kaua'i. An apparent 24-hour rainfall total of 49.69 inches, ending at 1245 HST April 15, was recorded at an automated rain gauge in Waipa, Kaua'i, about a mile west of Hanalei. The deluge, mainly over northern Kaua'i but also affecting East Oahu, damaged or destroyed farms and various structures, including 532 homes; downed trees and power lines; flooded homes, businesses and vehicles; and closed and damaged numerous roadways with water and debris flows, with highway and road repairs estimated at $35 million. There were apparently no significant injuries, but material losses will be extremely exorbitant, with public property damages alone estimated at $19.7 million. Hawaii's state legislature already approved, as of April 25, $100 million in relief aid for flood-ravaged communities on Kaua'i and Oahu. (The aid package was later increased to $125 million.). Mudslide (debris flow) caused a partial road blockage at Kalanianaole Highway and Keolu Drive near Kailua on the windward side of Oahu. Three landslides (debris flows) closed Kūhiō Highway between Wainiha and Waikoko in northern Kaua'i.
September 12, 2018	Debris Flow	Maui	As Tropical Storm Olivia approached the islands from the east-northeast and then made a double landfall in Maui County on September 12, it brought gusty winds and heavy precipitation. Most of its effects were concentrated over Maui, Molokai, and Oahu. The system downed trees, caused power outages and debris flows, and generated flash flooding. The costs of damages had not yet been assessed. There were no reports of serious injuries. Hana Highway closed in both directions one mile west of Keanae on Maui due to a debris flow from heavy rain.
December 25, 2019	Debris Flow	Honolulu	A cold front with good upper-level support pushed its way through the island chain around the Christmas holiday, bringing periods of heavy precipitation, isolated thunderstorms, and strong to high winds. The weather system caused a flash flood and felled trees and power poles, especially on the Garden Isle of Kaua'i. No significant injuries were reported. On Oahu, a rock slide occurred along Pali Highway near the tunnel, closing the Kailua-bound lanes for a time starting at Waokanaka Street.
January 11, 2020	Debris Flow	Hawai'i	With plenty of moisture near the surface and unstable conditions aloft, heavy rainfall and isolated thunderstorms developed across much of the state. Flash flooding occurred on the Big Island of Hawai'i, as well. No serious injuries were reported. The costs of any damages were not available. Hawai'i Police and the Department of Transportation reported a landslide on Highway 19 at the Laupāhoehoe Gulch in the Hāmākua District on the Big Island of Hawai'i.

Date(s) of Event	Event Type and Federal Disaster Declaration (if applicable)	Counties Affected	Description
March 06, 2021 – March 12, 2021	Debris Flow (DR-4604-HI)	Hawai'i, Honolulu, Kaua'i, Maui	A slow-moving surface trough, heading east to west, and an upper disturbance triggered heavy showers and isolated thunderstorms that caused flash flooding in some instances. Damages occurred to public and private property, including roads and bridges washed out. Nine homes were destroyed, 44 suffered major damage, and 55 suffered minor damage. No significant injuries were reported. In Kaua'i County, rocks and soil caused the closure of one lane of Kūhiō Highway at mile marker 4.5, near Waikoko on Kaua'i's north shore. Both lanes of Kūhiō Highway were impacted at Hanalei Hill approaching Hanalei Bridge. Kūhiō Highway was reopened for two-way traffic in mid-October after emergency construction was completed. Approximately $3.9 million in property damages occurred. In Maui County, Hana Highway was closed between mile post 10 and mile post 13, about 2 miles west-northwest of Keanae in windward East Maui. The closure was caused by large boulders blocking the roadway. In the County of Hawai'i, one lane of Highway 19 in windward Big Island near Hakalau, and the Hakalau Bridge, was closed due to debris on the roadway. In Honolulu County Kalanianaole Highway was closed between Hanauma Bay and the Halona Blowhole due to debris on the roadway on the island of Oahu, there was a partial closure of Kamehameha Highway near Waimea Bay on Oahu's North Shore (see Figure 4.11-9), and a small section of the Pali Highway, in the Kaneohe-bound lane, was blocked by debris from the nearby steep terrain.
December 05, 2021 – December 10, 2021	Debris Flow (DR-4639-HI)	Honolulu, Kalawao, Maui	Torrential rains triggered a landslide in Palolo Valley. The National Weather Service confirms the area received over 9 inches of rain in a 24-hour period. The slow-moving weather system dumped more than 20 inches of rain on areas of Hawai'i, at as much as 3 inches an hour. It caused widespread flooding, power outages, landslides, and damage.

Sources: NOAA NCEI 2022; FEMA 2023

Figure 4.11-9. A Mudslide Coats Kamehameha Highway on O'ahu, 2021

Source: Craig T. Kojima/Associated Press

PROBABILITY OF FUTURE HAZARD EVENTS

Overall Probability

As discussed in detail earlier, landslides and rockfalls are commonly related to precipitation (e.g., tropical cyclone events, heavy rain on saturated ground), earthquakes, volcanic activity, and human activity. Therefore, landslide and rockfall event frequency is often related to the frequency of these other events. Refer to Section 4.6 (Earthquakes), Section 4.11 (Hurricane), and Section 4.14 (Volcanic Hazards) for details regarding the probability of future hazard events for each of these hazards.

Climate Change Impacts

Climate change may impact storm patterns and increase the probability of more frequent, intense storms with varying duration. Climate projections for the State of Hawai‘i indicate an overall decline in rainfall; however, the state is expected to experience an increase in heavy rain events potentially causing an increase in landslides and rockfalls. Warming temperatures may increase the occurrence and duration of droughts, which could increase the probability of wildfire, reducing the vegetation that helps to support steep slopes. All these factors may increase the probability of landslide occurrences.

Each county in the state has topography susceptible to increased landslides and rockfalls from climate change impacts. Increased drought and wildfires may especially impact the leeward side of each island which will be more likely to experience landslides during extreme precipitation events after a wildfire has altered the landscape. However, landslides triggered by the increase of extreme precipitation can happen in any sloped area. Landslide impacts resulting from severe rain events may be minor with small rocks and mud coating a roadway, to a major slope failure covering an entire highway for weeks or months as was experience on Kaua‘i in 2018 after the extreme rain event. The frequency of these climate change impacts on the landslide hazard is directly related to the frequency of increased wildfire and extreme precipitation events.

4.11.2 VULNERABILITY ASSESSMENT

A statewide assessment was conducted based on landslide susceptibility data from two sources. For the County of Hawai‘i, landslide susceptibility data was provided by the Pacific Disaster Center (PDC). The data are based on topographic slope, geology, and soil moisture as described in Section 4.1. For the Counties of Kaua‘i, Maui, and the City and County of Honolulu, landslide susceptibility data were not available; therefore, the topographic slope was calculated using a USGS 10-meter DEM (USGS 2016). Slopes were assigned to landslide susceptibility categories consistent with the slope categories used by the County of Hawai‘i:

- Low—slope less than 20 degrees
- Moderate—slope of 20 to 40 degrees
- High—slope greater than 40 degrees

Landslide Hazard Area

High Landslide Susceptibility Hazard Area – To assess vulnerability to the landslide hazard, the high landslide susceptibility areas were used.

A qualitative discussion of the relationship between slope angles and rockfall impacts is included below.

Assessment of State Vulnerability and Potential Losses

This section discusses vulnerability of state assets (state buildings and roads) and critical facilities in areas exposed to high landslide susceptibility. Assets located in the moderate landslide susceptibility area are presented in Appendix F (State Profile and Risk Assessment Supplement).

State Assets

There are 357 state buildings located in high landslide susceptibility areas statewide. Almost all of the state buildings exposed are located in the County of Hawai'i (353 buildings with a replacement cost value of $2.032 billion). The remaining four buildings are located in the City and County of Honolulu. The vast majority of the buildings exposed in the County Hawai'i are occupied by the Department of Education (67.1%). Table 4.11-4 summarizes the state buildings located in the high landslide susceptibility areas by county. Table 4.11-5 summarizes the state buildings located in the high landslide susceptibility areas by agency.

Table 4.11-4. State Buildings Located in High Landslide Susceptibility Areas by County

County	High Landslide Susceptibility	
	Number of State Buildings in Hazard Area	Total Replacement Cost Value of State Buildings in Hazard Area
County of Kaua'i	0	$0
City and County of Honolulu	4	$11,561,110
County of Maui	0	$0
County of Hawai'i	353	$2,032,000,622
Total	**357**	**$2,043,561,732**

Source: Pacific Disaster Center 2017; United States Geological Survey 2016; State of Hawai'i Risk Management Office 2017

Table 4.11-5. State Buildings Located in High Landslide Susceptibility Areas by Agency

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent of Total Buildings	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Dept of Accounting & General Services	66	$953,963,738	14	21.21%	$9,484,078	0.99%
Dept of Agriculture	70	$147,607,399	12	17.14%	$11,531,395	7.81%
Dept of Attorney General	15	$108,425,480	0	0.00%	$0	0.00%
Dept of Budget & Finance	16	$28,968,679	1	6.25%	$466,382	1.61%
Dept of Business, Economic Development and Tourism	25	$645,480,379	0	0.00%	$0	0.00%

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent of Total Buildings	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Dept of Commerce & Consumer Affairs	2	$40,197,360	0	0.00%	$0	0.00%
Dept of Defense	69	$267,352,836	4	5.80%	$12,857,832	4.81%
Dept of Education	4,090	$10,598,205,739	258	6.31%	$1,719,366,025	16.22%
Dept of Hawaiian Home Lands	12	$110,427,352	2	16.67%	$2,281,602	2.07%
Dept of Health	44	$387,068,440	2	4.55%	$1,220,303	0.32%
Dept of Human Resources Development	1	$5,973,872	0	0.00%	$0	0.00%
Dept of Human Services	130	$480,212,294	5	3.85%	$8,619,142	1.79%
Dept of Labor and Industrial Relations	22	$90,076,209	2	9.09%	$5,459,152	6.06%
Dept of Land and Natural Resources	90	$101,441,821	0	0.00%	$0	0.00%
Dept of Public Safety	154	$440,774,415	14	9.09%	$33,842,195	7.68%
Dept of Taxation	1	$7,174,162	0	0.00%	$0	0.00%
Dept of Transportation	68	$2,935,208,214	2	2.94%	$1,363,600	0.05%
Hawai'i State Ethics Commission	1	$984,533	0	0.00%	$0	0.00%
Hawai'i Health Systems Corporation	106	$1,230,852,871	21	19.81%	$171,901,454	13.97%
Hawai'i Housing Finance & Development Corporation	86	$360,851,671	0	0.00%	$0	0.00%
Hawai'i Public Housing Authority	273	$982,981,701	3	1.10%	$8,864,400	0.90%
Hawai'i State Legislature	2	$48,555,381	0	0.00%	$0	0.00%
Hawai'i State Public Library System	53	$525,584,082	4	7.55%	$15,073,630	2.87%
Judiciary	41	$534,877,354	5	12.20%	$7,614,067	1.42%
Legislative Reference Bureau	1	$2,996,162	0	0.00%	$0	0.00%
Office of Hawaiian Affairs	11	$54,125,645	0	0.00%	$0	0.00%
Office of the Auditor	2	$1,921,180	0	0.00%	$0	0.00%
Office of the Governor	1	$2,996,162	0	0.00%	$0	0.00%
Office of the Lieutenant Governor	2	$4,588,849	0	0.00%	$0	0.00%
Office of the Ombudsman	1	$1,818,060	0	0.00%	$0	0.00%
Research Corporation of the University of Hawai'i	3	$4,189,026	0	0.00%	$0	0.00%
University of Hawai'i	637	$5,014,974,503	8	1.26%	$33,616,475	0.67%
Total	**6,095**	**$26,120,855,568**	**357**	**5.86%**	**$2,043,561,731**	**7.82%**

Source: *Pacific Disaster Center 2017; United States Geological Survey 2016; State of Hawai'i Risk Management Office 2017*

The state has jurisdiction over many roads and highways in all four counties; many of these thoroughfares are adjacent to slopes subject to rockfall and landslide events. A Rockfall Hazard Rating System (Publication No. FWHA SA-93-057, November 1993) allows transportation agencies to evaluate and rate the risk of rockfall sites and may be used to prioritize construction funds. Both preliminary and detailed rating methodologies exist. The preliminary rockfall rating subjectively groups hazard conditions into three classes (A, B, and C) based on historic rockfall activity and the probability of falling rocks reaching roadway pavement (U.S. DOT 1993). The detailed rating is based on the following factors:

- Slope height
- Ditch effectiveness
- Average vehicle risk, derived from Average Daily Traffic (ADT)
- Percentage of decision sight distance

- Roadway width
- Structural condition, Case One slopes (movement along discontinuities)
- Rock friction
- Structural condition, Case Two slopes (differential erosion or over-steepening leads to rockfall)
- Erosion rate
- Expected volume of a rockfall event
- Climate and the presence of water on slope
- Rockfall history

The City and County of Honolulu implemented a study to evaluate potential rockfall sites along 79 state highways and roadways and develop a rockfall hazard management system for the State of Hawai‘i using a rockfall hazard rating. Overall, 66 highway sites were identified as having a high risk to rockfall (State of Hawai'i 2018).

The State of Hawai‘i Department of Transportation mitigates landslides near roadways by erecting metal meshes around the edge of cliffs. The meshes prevent rocks and other debris from sliding or falling onto the roadways. Since the identification of high-risk sites along highways and roads in the City and County of Honolulu, many have been mitigated, including a site along the Diamond Head State Monument trail, completed in December 2017.

Due to the County of Kaua‘i’s mountainous terrain, few roads connect the island. Many roads are under the jurisdiction of the State of Hawai‘i Department of Transportation (e.g., Kūhiō Highway and Kaumuali‘i Highway). The roads are connected by bridges, with few areas for roadway bypass or alternate routes (County of Kaua'i 2020). Impacts on main roadways in the county from natural hazard events can have devastating impacts on residents and visitors. Roadway closures due to a landslide or rockfall, as demonstrated by the April 2018 event, can isolate communities; prevent residents from getting to work; and cut off access for emergency response.

The County of Maui has a history of recurring landslides, debris flows, and rockfalls. Many of these events have occurred along coastal highways that are against mountain slopes (State of Hawai'i 2018). The Kīholo Bay and Mahukona Earthquakes of October 15, 2006, resulted in several landslides and rockfalls at various locations on the Island of Maui, including along Pi‘ilani Highway (State Highway 30). As is the case on other islands, road closures on Maui due to a landslide can isolate communities. In some cases, it can take years to fully repair a roadway and reopen (County of Kaua'i 2020).

The County of Hawai‘i has the greatest state road exposure to landslide hazards in the state. Owing to the lack of redundancy in the road network there, the closure of roads due to landslides will significantly hamper emergency response and potentially isolate communities. Table 4.11-6 shows the length of state roads in high landslide susceptibility areas by county and confirms that the County of Hawai‘i has, by far, the greatest number of exposed miles of any county in the state (147.1 miles out of 150.63 miles). A complete list of state roads located in the high landslide susceptibility areas is included in Appendix F.

Community Lifelines and Critical Facilities

There are 78 community lifelines in high landslide susceptibility areas in the state and 17 additional critical facilities (see Table 4.11-7). The County of Hawai‘i has the greatest number such facilities. Table 4.11-8 summarizes the exposed critical facilities by category. The majority of these facilities are categorized as Food, Water, and Shelter.

Table 4.11-6. State Roads Located in High Landslide Susceptibility Areas by County

County	Length (in miles)		
	Total Length	Length in the Hazard Area	Length in the Hazard Area as Percent (%) of Total Length
County of Kaua'i	103.7	0.23	0.22%
City and County of Honolulu	374.9	1.8	0.48%
County of Maui	245.9	1.5	0.61%
County of Hawai'i	379.2	147.1	38.79%
Total	**1,103.70**	**150.63**	**13.65%**

Source: Pacific Disaster Center 2017; United States Geological Survey 2016; State of Hawai'i Risk Management Office 2017

Table 4.11-7. Community Lifelines and Critical Facilities Located in High Landslide Susceptibility Areas, by County

County	Community Lifeline Categories								Additional Critical Facilities
	Communications	Energy	Food, Water, Shelter	Hazardous Material	Health & Medial	Safety & Security	Transportation	Total in the Hazard Area	
County of Kaua'i	0	0	0	0	0	0	0	0	0
City and County of Honolulu	1	0	2	0	0	0	0	3	0
County of Maui	0	0	0	0	0	1	0	1	0
County of Hawai'i	13	0	21	2	19	19	0	74	17
Total	**14**	**0**	**23**	**2**	**19**	**20**	**0**	**78**	**17**

Source: Pacific Disaster Center 2017; United States Geological Survey 2016; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020

Table 4.11-8. Community Lifelines and Critical Facilities Located in High Landslide Susceptibility Areas, by Category

Category	Total Number of Facilities	Total Replacement Cost Value	Number of Facilities in Hazard Area	Percent (%) of Total Facilities	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Communications	188	$776,797,683	14	7.45%	$45,723,339	5.89%
Energy	89	$3,093,949,530	0	0.00%	$0	0.00%
Food, Water, Shelter	345	$11,847,189,588	23	6.67%	$835,555,050	7.05%
Hazardous Material	12	$436,474,800	2	16.67%	$72,588,000	16.63%
Health and Medical	193	$4,606,713,364	19	9.84%	$508,897,856	11.05%
Safety and Security	486	$38,164,188,232	20	4.12%	$776,190,099	2.03%
Transportation	56	$2,039,091,600	0	0.00%	$0	0.00%
Additional Critical Facilities	106	$447,698,794	17	16.04%	$54,245,500	12.12%
Total	**1,475**	**$61,412,103,591**	**95**	**6.44%**	**$2,293,199,844**	**3.73%**

Source: Pacific Disaster Center 2017; United States Geological Survey 2016; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020

Assessment of Local Vulnerability and Potential Losses

This section provides a summary of vulnerability and potential losses to population, general building stock, environmental resources, and cultural assets by county. Similar to the analysis for state assets, a spatial exposure

analysis was conducted, and the results are summarized below. Landslide and rockfall events do not just impact assets located in the defined hazard area. Cascading impacts affect surrounding communities that rely on assets that are damaged or lost as a result of a disaster.

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

- **County of Kaua'i** – The County provided a qualitative overview of risks posed by a landslide hazard. (County of Kaua'i 2020).
- **City and County of Honolulu** – The County provided a qualitative overview of risks posed by a landslide hazard. The HMP also discusses rockfall risk, with a focus on rockfalls occurring along transportation routes (City and County of Honolulu 2020).
- **County of Maui** – The County provided a qualitative overview of risks posed by a landslide hazard, including descriptions of different categories of landslides (County of Maui 2020).
- **County of Hawai'i** – The County provided a qualitative overview of risks posed by a landslide hazard. The HMP includes a landslide susceptibility map from the Pacific Disaster Center demonstrating areas of high landslide vulnerability in the county (County of Hawai'i 2020).

Socially Vulnerable and Total Populations

According to the CDC, health threats from landslides include: 1) trauma caused by rapidly moving water and debris; 2) broken electrical, water, gas and sewage lines that can lead to injury or illness; and 3) disrupted roadways that can endanger motorists and disrupt transport and access to health care (CDC 2018). Disasters can exacerbate stressful social conditions. Populations considered most vulnerable to natural hazard events include children, the elderly (persons over the age of 65), people with access and functional needs, and individuals experiencing poverty. The high vulnerability population located in the landslide and rockfall hazard area makes up about 22.8% of the total population of the State of Hawai'i.

Flash flooding or ongoing heavy rains can be precursors to landslide and rockfall events. The concurrent hazard of flooding further disrupts access to roadways and endangers motorists. Landslide and rockfall events can hinder evacuation routes, prevent the delivery of necessary goods to vulnerability populations, and can delay emergency and medical responses to the area. Some residential areas in Hawai'i that are susceptible to landslides and rockfalls have just one means of ingress and egress, making them highly vulnerable in the event of an evacuation.

The population in the hazard area (65,049) and percentage of population exposed (4.58%) does not include the number of tourists and visitors in the state or the impacted population located outside of high landslide susceptibility areas. Historic landslide and rockfall events in the state have caused road closures and bridge failures, which isolated residents and prevented access to evacuation routes and medical services. Therefore, the analysis conducted and figures reported may be underestimating landslide exposure and vulnerability.

Overall, the County of Hawai'i has the highest population exposed as a percentage, both for population in the hazard area (25.95%) and high vulnerability population in the hazard area (5.98%). Table 4.11-9 summarizes the 2020 U.S. Census population residing in high landslide susceptibility areas by county.

Table 4.11-9. 2020 U.S. Census Population Located in High Landslide Susceptibility Areas by County

County	Population				
	Total Population	Population in Hazard Area	Population Exposed as Percent (%) of Total Population	Socially Vulnerable Population in the Hazard Area	Socially Vulnerable Population Exposed as Percent (%) of Total Population
County of Kaua'i	71,949	1,029	1.43%	469	0.65%
City and County of Honolulu	979,682	10,376	1.06%	2132	0.22%
County of Maui	167,093	1,388	0.83%	191	0.11%
County of Hawai'i	201,350	52,256	25.95%	12,031	5.98%
Total	**1,420,074**	**65,049**	**4.58%**	**14,823**	**1.04%**

Source: Pacific Disaster Center 2017; United States Geological Survey 2016; U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018

General Building Stock

To further assess what is at risk, each county's general building stock exposure was examined. The general building stock located in high landslide susceptibility areas is considered exposed and potentially vulnerable. Damages to buildings can displace people from their homes, threaten life safety, and impact a community's economy and tax base. Table 4.11-10 indicates that the County of Hawai'i has the greatest replacement cost value ($14,831,484,138) for general building stock located in high landslide susceptibility areas.

Table 4.11-10. General Building Stock Located in High Landslide Susceptibility Areas

County	Total Replacement Cost Value	Replacement Cost Value in Hazard Area	Percent of Total in Hazard Area
County of Kaua'i	$24,246,497,228	$3,809,018	0.02%
City and County of Honolulu	$239,152,051,766	$61,415,806	0.03%
County of Maui	$50,796,693,140	$12,861,364	0.03%
County of Hawai'i	$58,395,349,136	$14,831,484,138	25.40%
Total	**$372,590,591,270**	**$14,909,570,325**	**4.00%**

Source: Pacific Disaster Center 2017; United States Geological Survey 2016; NIYAM IT 2022; United States Army Corps of Engineers 2022

The Honolulu district in the City and County of Honolulu has a high concentration of inventoried rock hillslopes. This reflects the high density of development in areas of high topographic relief that require significant earthwork and grading. More than 1,779 landslides and debris flows have been recognized in aerial photographs of the Honolulu District taken during a period of approximately 50 years from 1940 to 1989 (USGS 1993). Most of the debris flows caused relatively little direct property damage because they occurred in undeveloped or relatively inaccessible upland areas. However, some of the areas affected by past debris flows have since been developed, and if development continues in these upland areas, the impacts from debris flows in future storms could become even more frequent and costly (State of Hawai'i 2018).

The geography in the County of Kaua'i includes the two mountains, Kawaikini Peak and Mount Wai'al'ale, that are among the rainiest places on Earth. The county receives an estimated 460 inches of rain annually. Steep slopes and climatic conditions make the county highly vulnerable to flooding and landslides as well as mudslides and rockslides (County of Kaua'i 2020). In April 2018, flash flooding and mudslides that resulted from heavy rainfall

caused major damage to roads, including Kūhiō Highway, and bridges across the mountainous island. Many communities became isolated, and homes damaged or destroyed.

Mudslides can cause damage either directly by impacting man-made structures or indirectly by plugging drainage systems so that flood waters are diverted out of their channels. Debris flows also can sever or cover roads, block access to (or egress from) neighborhoods, and thus interfere with emergency operations and evacuations (State of Hawai'i 2018).

Land Use Districts

Table 4.11-11 shows the number of square miles of high landslide susceptibility areas in each state land use district statewide; refer to Appendix F for results for each county. Approximately 4.5% of the Urban District lands statewide are located in high landslide susceptibility areas. Urban development on steep slopes or unstable soils could result in adverse visual impacts and exacerbate hazardous conditions. Most of the vacant lands in the state urban district with steep slopes or unstable soils are located in valley and hillside neighborhoods. Where hillside locations have stable soils, the primary impact is aesthetic, since structures built along the slopes tend to be visually prominent and can interrupt the silhouette of the natural ridgeline when viewed from below. Building on the lower slopes of valley walls can also have a visual impact. Where these valley locations have deposits of unstable soils, slow-moving landslides can cause property damage; situations like this in Mānoa and Moanalua have prompted claims against the City and County of Honolulu (State of Hawai'i 2018).

Table 4.11-11. State Land Use Districts Located in High Landslide Susceptibility Areas

Land Use District	Total (square miles)	Square Miles in High Landslide Susceptibility Areas	Percent (%) of Total Area
Agricultural	2,973.6	645.5	21.71%
Conservation	3,202.9	512.8	16.01%
Rural	16.3	0.2	1.22%
Urban	319.1	14.4	4.51%
Total	**6,511.95**	**1,172.90**	**18.01%**

Source: Pacific Disaster Center 2017; United States Geological Survey 2016; State Land Use Commission, Hawai'i Statewide GIS Program 2021; Honolulu County GIS 2022

Environmental Resources

The state's abundant natural resources are one of the many elements that attract visitors to the islands, and as discussed, tourism is a major contributor to the local and state economy. Unfortunately, natural hazard events, including landslide and rockfall events, can harm the environment. Landslides can lead to flooding by blocking stream channels or culverts, allowing water to back up and overflow. Landslide events can also lead to overtopping of reservoirs and/or reduced capacity of reservoirs to store water (USGS 2004).

Monetizing impacts to environmental resources as a result of hazard events is a challenge. To understand which environmental resources are exposed to landslide hazards, a spatial analysis was conducted using the available critical habitats (or habitats that are known to be essential for an endangered or threatened species), wetlands, and parks and reserves spatial layers. These results are summarized in Table 4.11-12. As noted, large areas of critical habitats, parks, and reserves are vulnerable to landslide events.

Table 4.11-12. Environmental Resources Located in the High Landslide Susceptibility Area

Environmental Resource	Total Square Miles of Resource (square miles)	Resource Area in the Hazard Area (square miles)	Percent (%) of the Total Asset Area
Critical Habitat [a]	951	216	22.7%
Wetlands	3,637	14	0.4%
Parks and Reserves	2,778	413	14.9%
Reefs [b]	55	0	0.0%
Total [c]	**7,420**	**642**	**8.7%**

Source: U.S. Fish and Wildlife Service, Pacific Islands Office, 2022a, U.S. Fish and Wildlife Service 2021e; 2017b, Hawai'i State Department of Land and Natural Resources, Division of Forestry and Wildlife 2022, NOAA raster nautical charts 2020b, State of Hawai'i Department of Land and Natural Resources, Division of State Parks 2021; Pacific Disaster Center 2017; United States Geological Survey 2016

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.

Cultural Assets

Loss of native species and ecosystems, and harm to them, will adversely impact the Hawaiian cultural traditions and practices, which are closely tied to the natural environment. To understand what portion of the Hawaiian Home Lands are exposed to the high landslide susceptibility area, an exposure analysis was conducted. Nearly 60% of the Hawaiian Home Lands in the County of Hawai'i are located in landslide hazard areas (Table 4.11-13).

Table 4.11-13. Hawaiian Home Lands Located in High Landslide Susceptibility Areas by County

County	Hawaiian Home Lands Area (in square miles)		
	Total Area	Hawaiian Home Lands Located in the Hazard Area	Percent (%) of Total Area
County of Kaua'i	32.09	1.34	4.19%
City and County of Honolulu	10.61	1.46	13.72%
County of Maui	102.59	2.16	2.10%
County of Hawai'i	191.46	114.47	59.79%
Total	**336.75**	**119.43**	**35.46%**

Source: Pacific Disaster Center 2017; United States Geological Survey 2016; Hawai'i State Department of Hawaiian Homelands 2021

Table 4.11-14 discusses the cultural resources in high landslide risk hazard areas. The cultural resource type with the largest total area and largest area in the hazard area is the Historic District; however, the district with the largest percentage of area in the high wildfire risk hazard area is the Archaeology.

Table 4.11-14. Cultural Resources Located in the High Landslide Susceptibility Areas

Cultural Resource Site Type	Area (in square miles)		
	Total Square Miles of Asset	Total Square Miles in the Hazard Area	Percent (%) of Total Asset Area
Archaeology	90.892401	12.976967	14.28%
Burial Sensitivity Area	2.074551	0.019907	0.96%
Historic Building	2.680785	0.278606	10.39%

Cultural Resource Site Type	Area (in square miles)		
	Total Square Miles of Asset	Total Square Miles in the Hazard Area	Percent (%) of Total Asset Area
Historic District	849.360596	75.417033	8.88%
Historic Object	9.6143	0.045768	0.48%
Historic Structure	20.739072	0.403678	1.95%
Total	**975.361705**	**89.141959**	**9.14%**

Source: Department of Land and Natural Resources, Hawai'i State Historic Preservation Division 2022; Pacific Disaster Center 2017; United States Geological Survey 2016

Future Changes that May Impact State Vulnerability

Understanding future changes that may 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 considered the following factors in examining potential conditions that may affect hazard vulnerability:

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

High landslide susceptibility areas were overlain on areas that may experience significant changes in development or redevelopment in future years (see

Table 4.11-15 below and Section 3 [State Profile] for more information on projected development areas). The results of this exercise indicate that more than a third (36.69%) of the Enterprise Zones in the County of Hawai'i are located in high landslide susceptibility areas. Generally, county-level regulations for land use and development require special assessment and consideration of proposed development on steep slopes.

Table 4.11-15. HCDA Community Development Districts, Maui Development Projects, and Enterprise Zones located in High Landslide Susceptibility Areas by County

County	Area (in square miles)								
	Hawai'i Community Development Authority District (Total Area)	Total Area Exposed to Hazard	Hazard Area as % of Total Area	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 Kaua'i	0	0	0	0	0	0	251.0	4.6	1.83%
City and County of Honolulu	7.4	<0.1	<0.1%	0	0	0	297.3	22.8	7.67%
County of Maui	0	0	0	27.6	0.07	0.25%	1,059.8	73.4	6.93%
County of Hawai'i	0	0	0	0	0	0	1,274.9	467.7	36.69%
Total	**7.4**	**<0.1**	**<0.1%**	**27.6**	**0.07**	**0.25%**	**2,883.00**	**568.5**	**19.72%**

Source: Maui County Planning Department 2016; Hawai'i Community Development Authority 2021; Community Economic Development Program, Department of Business, Economic Development & Tourism, County Planning Departments 2021; Pacific Disaster Center 2017; United States Geological Survey 2016

Soil conditions and other geotechnical and engineering factors are supposed to be considered. Development in these areas may not be outright prohibited but are likely subject to close examination on a case-by-case basis. While these regulations may prevent development on steep slopes that would be impacted by landslides or contribute to their occurrence, new development in landslide runout areas (that is, areas at the foot of the slide where materials involved in a slide come to rest) or in areas downslope from rockfall areas are not likely to be similarly regulated and may be exposed to risk from landslide and rockfalls.

In addition, incremental build-out of hillsides and lower valley slopes can affect drainage systems, both natural and urbanized. Increased lot coverage by larger buildings and more extensive paving has increased the volume and rate of stormwater discharge. This problem is exacerbated in the interior reaches of the valleys and hillsides, where rainfall is higher. Over the long term, the cumulative impact of greater lot coverage threatens to promote the erosion of natural stream banks downstream. Mitigation efforts to curb this process could require expensive, aesthetically problematic, and ecologically undesirable structural hardening of drainage channels. Without successful mitigation efforts, the capacity of drainage systems could be exceeded, resulting in flooding. To prevent inappropriate development, hillside lands should be placed in preservation or low-density residential zoning districts. Such lands should also be subject to stricter development standards, such as maximum lot coverage and structural stability, than those that apply to level land (State of Hawai'i 2018).