SECTION 4. RISK ASSESSMENT

4.12 Landslide and Rockfall

2018 HMP UPDATE CHANGES

- The hazard profile has been significantly enhanced to include a detailed hazard description, location, extent, previous occurrences, and probability of future occurrence (including climate change).
- Landslide events, including rockfalls and mudslides, that occurred in the State of Hawai'i from January 1, 2012, through December 31, 2017, were researched for the 2018 HMP Update. Due to the severity of recent events, the April 2018 event is also discussed; however, details regarding monetized impacts are not available at the time of this plan update.
- Landslide susceptibility maps for each county have been added and used to assess exposure in the vulnerability assessment.

4.12.1 Hazard Profile

HAZARD DESCRIPTION

Landslide is the broad term that involves 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 types of movements are: flows, topples, slumps, slides, creeps and falls (USGS 2004). Figure 4.12-1 illustrates the movement mechanisms in graphical form. For the purposes of the 2018 HMP Update, this section focuses on landslides (inclusive of all types of soil movement and debris flow) and rockfalls.

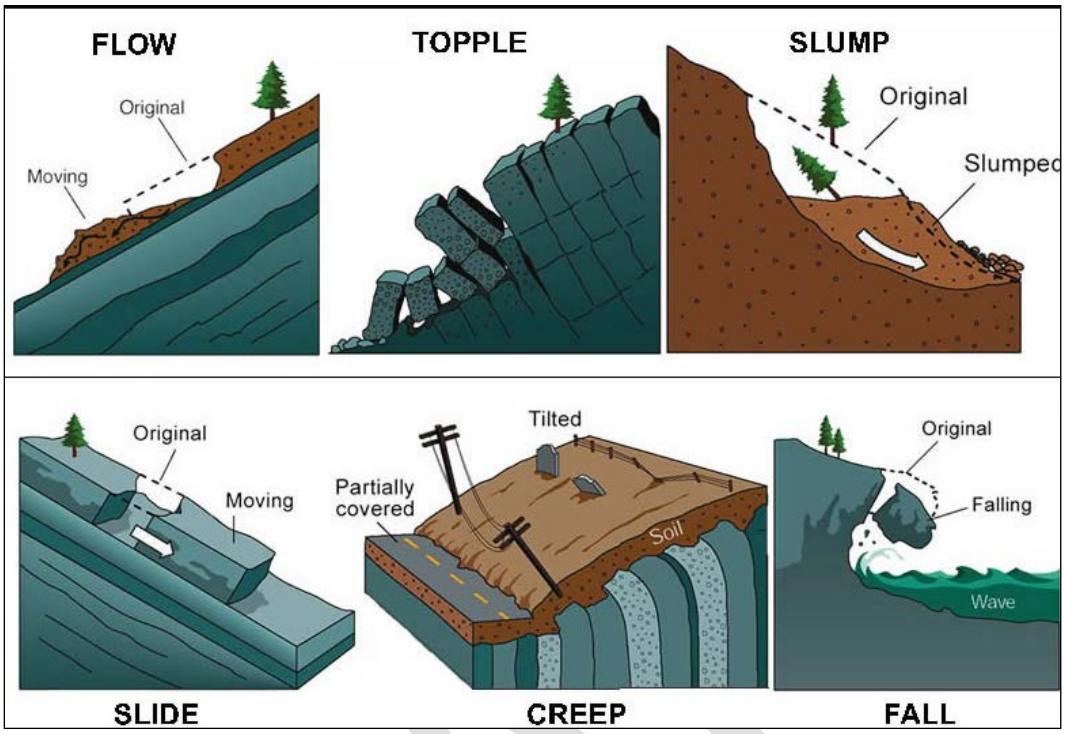
Summary of Key Terms

Landslide – *The movement of a mass of rock and/or soil down a slope.*

Debris Flow (Mudslide) – *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.*

Rockfall – *The falling of newly detached mass of rock from a cliff or down a very steep slope.*

Figure 4.12-1. Types of Landslides



Source: State of Hawai'i HMP 2013

While there are many factors that cause landslides and rockfalls, the following cause the most damage and are prevalent in the State of Hawai'i include: water, seismic activity, volcanic activity and human activity.

- **Water** – Slope saturation by water in the form of 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 cause of landslides and rockfalls. Landslides and flooding are closely related because both are related to precipitation, runoff and the saturation of ground from water. They often occur simultaneously in the same area (USGS 2004).
- **Seismic Activity** – Earthquakes occurring in landslide-prone areas greatly increases 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 2004).
- **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 weakened by the rise and eruption of molten rock. Magma releases volcanic gases that partially dissolve in groundwater, resulting in a hot acidic hydrothermal system that weakens rock by altering minerals to clay. Furthermore, the mass of thousands of layers of lava and loose fragmented rock debris can lead to fault zones that move frequently (USGS 2004).
- **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 a mass movement of material, where there is a distinct zone of weakness that separates the slide material from the more stable underlying material (USGS 2004). Several features on land may be noticeable prior to a landslide. These features include:

- Springs, seeps, or saturated ground appears in areas usually not wet
- New cracks or unusual bulges in the ground, street pavements, or sidewalks
- Soil moves away from foundations
- Ancillary structures (e.g. decks) tilt or move relative to the house
- Concrete floors or foundations tilt or crack
- Water lines and other underground utilities break
- Telephone poles, trees, retaining walls, or fences tilt
- Roadbeds sink, or drop down (State of Hawai'i HMP 2013)

Debris flows, sometimes referred to as mudslides, mudflows, lahars, or debris avalanches, are common types of fast-moving landslides and occur in a wide variety of environments. Flows are characterized by shear strains distributed throughout the mass of material. Flows are distinguished from slides by high water content and the distribution of velocities resembles that of viscous fluids. These flows are a form of rapid mass movement in which loose soils, rocks, and organized matter, combined with air and water, form slurry that flow down-slope. These flows generally occur during periods of intense rainfall (State of Hawai'i HMP 2013).

Rockfall

Rockfall may be initiated through a combination of weathering, fracture and the presence of a steep slope. Physical weathering is the breaking up of rock by physical disintegration. Examples physical weathering are stream erosion, wave erosion or the fragmentation of rock faces caused by the enlargement of fractures. Physical and chemical weathering between rock formation boundaries may be aided by withdrawal of support underlying lava flows. Larger lava tubes may collapse, rendering the surrounding rock unstable and prone to more physical weathering. Wave action occurring during higher sea levels over geologic time may rapidly increase the rate of physical weathering and undermining by removal of loose rock or clinker zones and enlargement of lava tubes and pre-existing fractures. Because of withdrawal of underlying support, stresses on vertical joints and fractures may increase over time, enlarging the fracture/joint spaces, and concurrently increasing the surface area available for chemical weathering (State of Hawai'i HMP 2013).

LOCATION

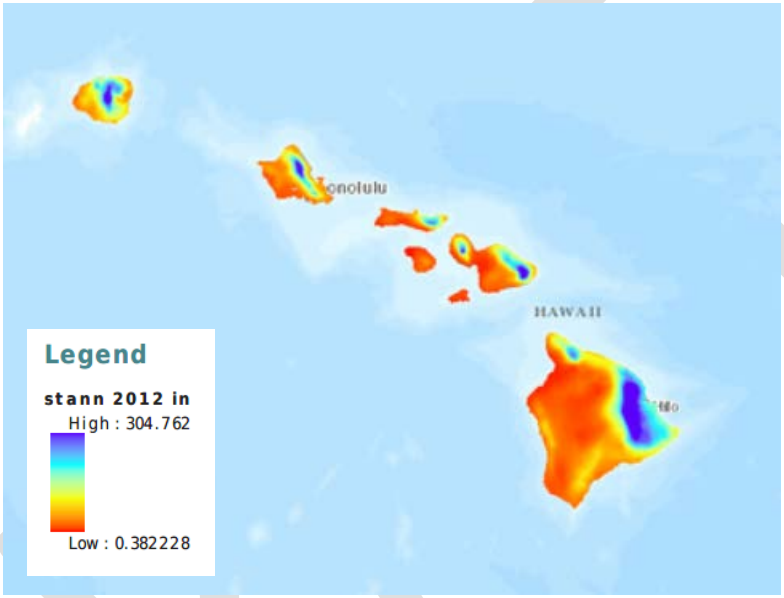
The State of Hawai'i has several characteristics that make it susceptible to landslides and rockfalls: steep hillsides, heavy rainfall, and residential development and other types of construction in upland areas. Areas that may be considered prone to landslides and rockfalls may include the following:

- 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 (State of Hawai'i HMP 2013)

Heavy or prolonged rainfall is the main source of landslide and rockfall initiation in the state (State of Hawai'i HMP 2013). These events generally occur during or immediately after severe rainfall of more than 3 inches in a peak 6-hour period. Figure 4.12-2 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.

Figure 4.12-2. Average Annual Rainfall in the State of Hawai'i, 1920 to 2012



Source: Frazier et al 2015

Wildfire locations and/or vegetation that has been destroyed on slopes are particularly vulnerable to landslides during and after heavy rain events (CDC 2018). Refer to Section 4.14 (Wildfire) for further discussion on high risk wildfire areas in the state.

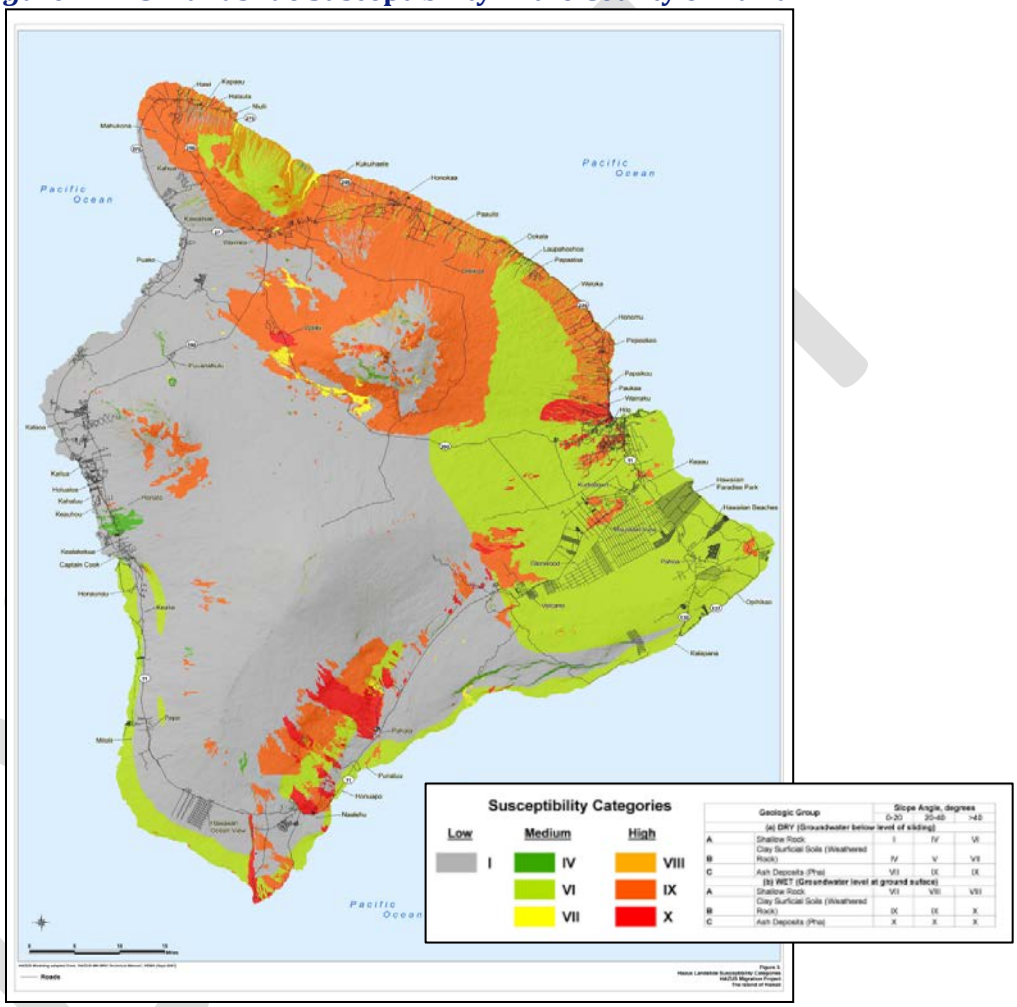
Areas with higher risk to landslide were determined for the County of Hawai'i by spatially categorizing slope, soil type and moisture content. The following summarizes the criteria used to characterize landslide susceptibility in the county; refer to Figure 4.12-3 which illustrates the aggregate of these results depicted as high, moderate and low landslide susceptibility areas in the County of Hawai'i.

- **Slope**
  - Low Susceptibility – Slope less than 20 degrees
  - Moderate Susceptibility – Slope of 20 to 40 degrees
  - High Susceptibility – Slope greater than 40 degrees
- **Geology**
  - Low Susceptibility - Shallow rock, fresh volcanics
  - Moderate Susceptibility – Clay surficial soils, weathered rock

- High Susceptibility – Weak soft soils, ash deposits, mapped historic slide talus

- **Soil Moisture** - Soil moisture assignments are derived from NOAA rainfall mapping of the island since regional groundwater and soil moisture data is unavailable island wide. Areas receiving greater than 2000 mm (78.7 inches) annual precipitation are considered wet soil, corresponding largely to the windward side of the island. In addition, coastal areas below elevations of 200 feet are considered wet due to potential groundwater seepage gradients from higher elevations, except in the arid Kona coast areas.

Figure 4.12-3. **Landslide Susceptibility in the County of Hawai'i**



Source: State of Hawai'i HMP 2013

The County of Hawaii's landslide susceptibility data was provided by the PDC to spatially assess risk for the 2018 HMP Update risk assessment. This data has not been generated for the County of Kaua'i, City and County of Honolulu and County of Maui. To determine the areas at greatest risk to landslide for these three counties, slope was calculated using a USGS 10-meter DEM. Areas of slope were assigned low, moderate and high landslide susceptibility categories to align with the slope categories for the County of Hawai'i. This data is considered suitable for planning purposes only.

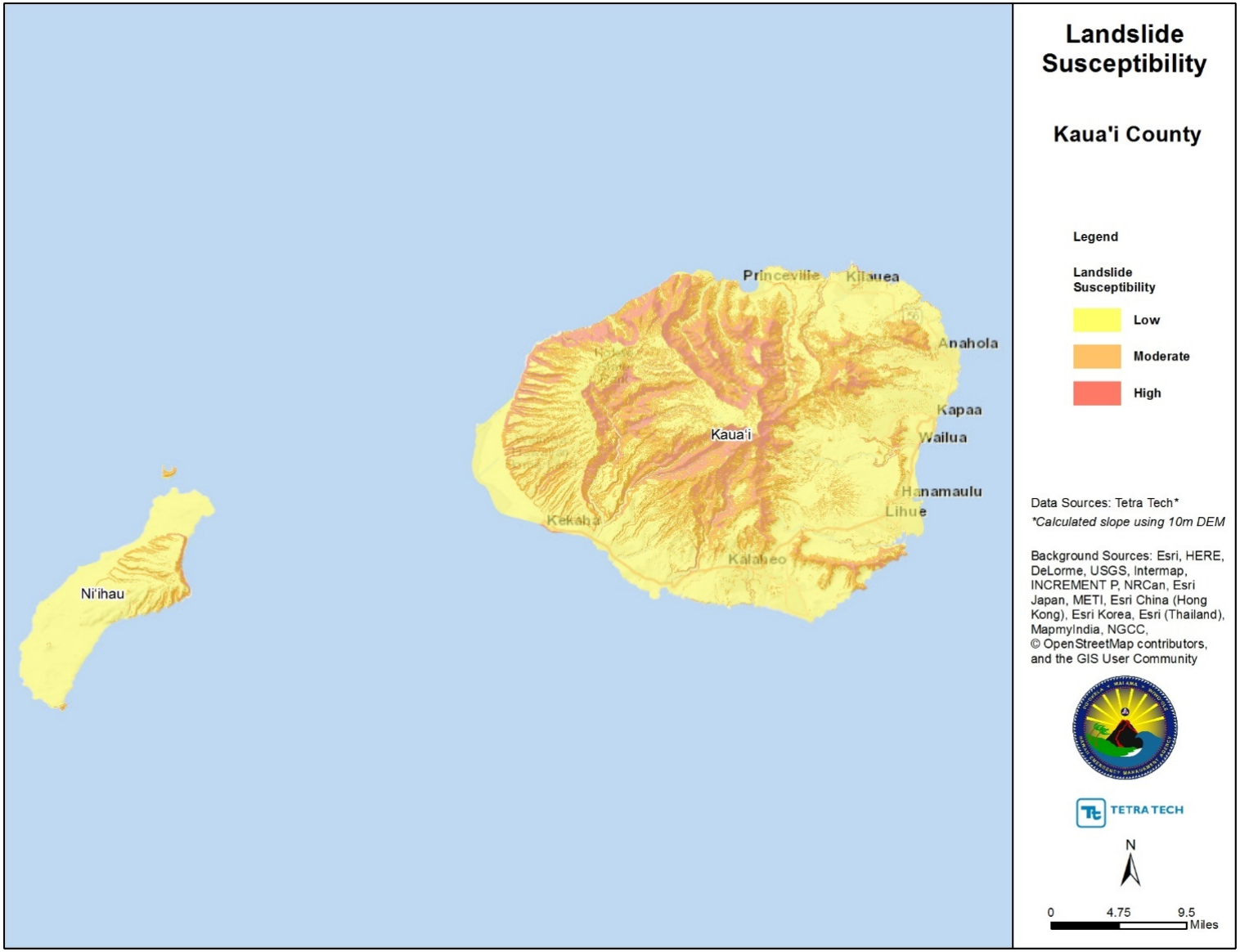
Table 4.12-1 shows the high landslide susceptibility area in square miles and the percent of the total area in each county based on the methodologies described above for each county. The County of Hawai'i has the largest percent (23.5%) of high landslide susceptibility areas. Landslide susceptibility areas that were used for the vulnerability assessment presented later in this section are shown in Figure 4.12-4 through Figure 4.12-7.

Table 4.12-1. High Landslide Susceptibility Area by County

County	Total Area	High Landslide Susceptibility Area	High Susceptibility as Percent (%) of Total Area
County of Kaua'i	620.0	69.0	11.1%
City and County of Honolulu	600.7	54.9	9.1%
County of Maui	1,173.5	82.5	7.0%
County of Hawai'i	4,028.4	944.9	23.5%
Total	**6,422.6**	**1,151**	**17.9%**

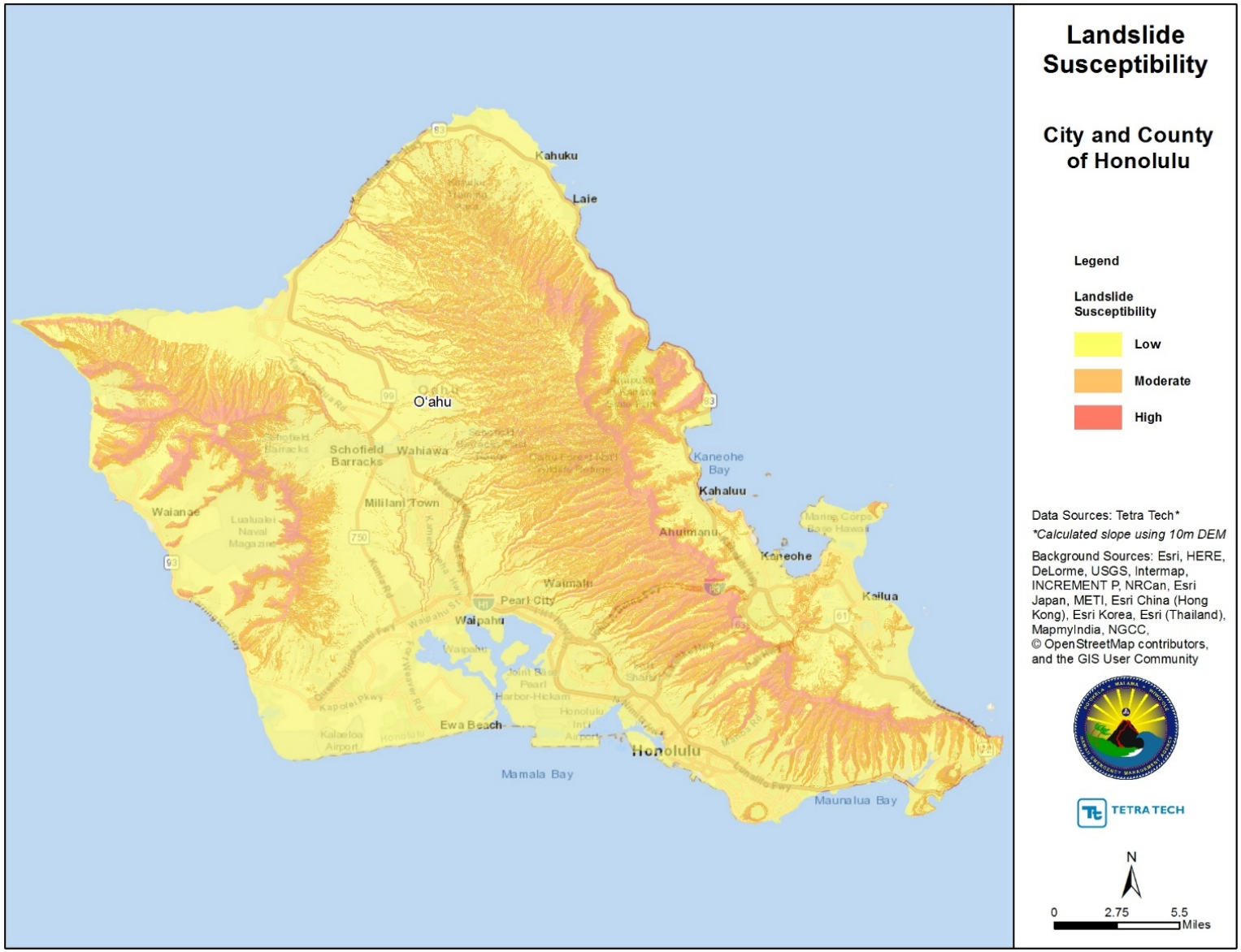
Source: PDC 2017; USGS 2016; State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

Figure 4.12-4. Landslide Susceptibility in the County of Kaua'i



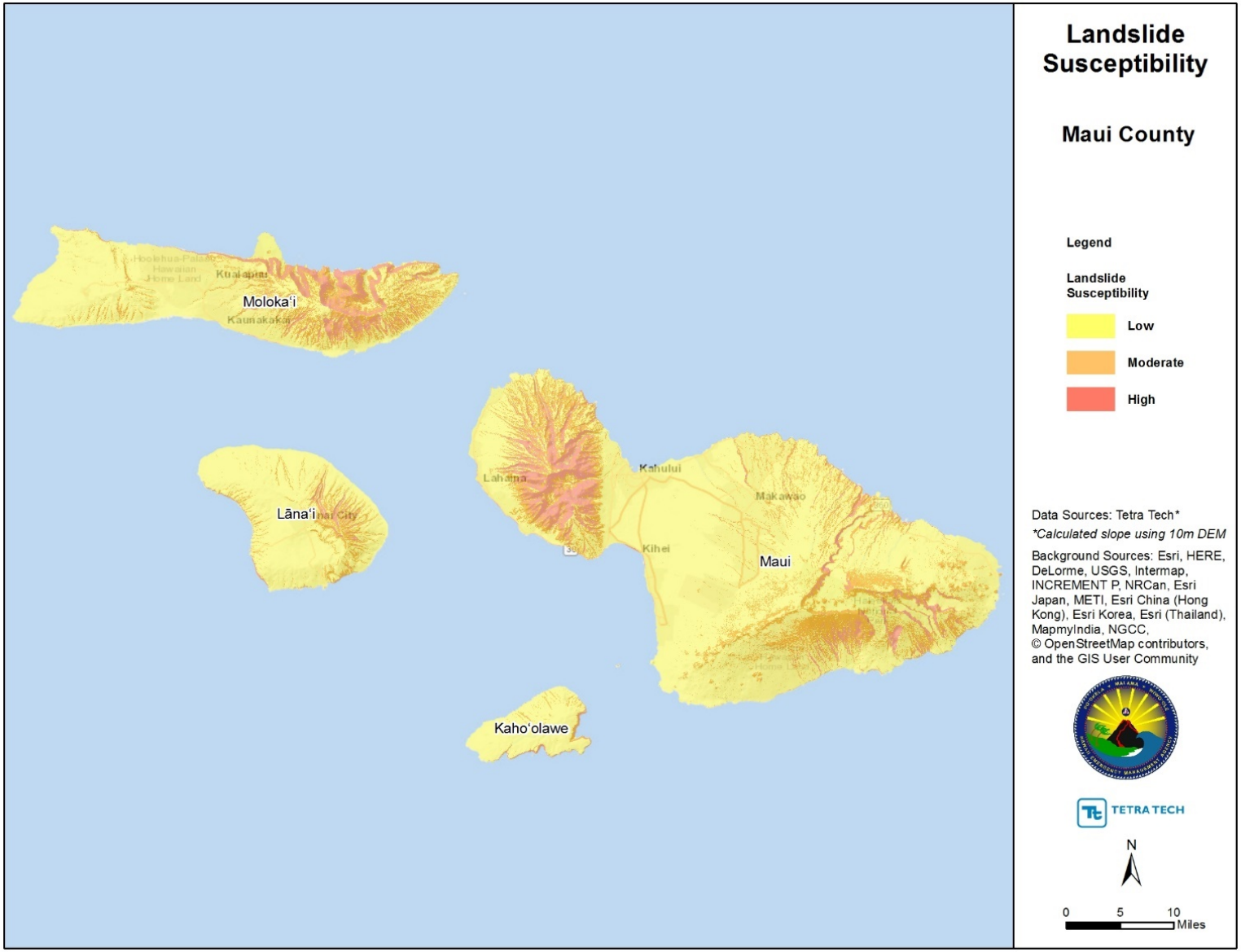
Source: PDC 2017; USGS 2016; State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

Figure 4.12-5. Landslide Hazard Areas in the City and County of Honolulu



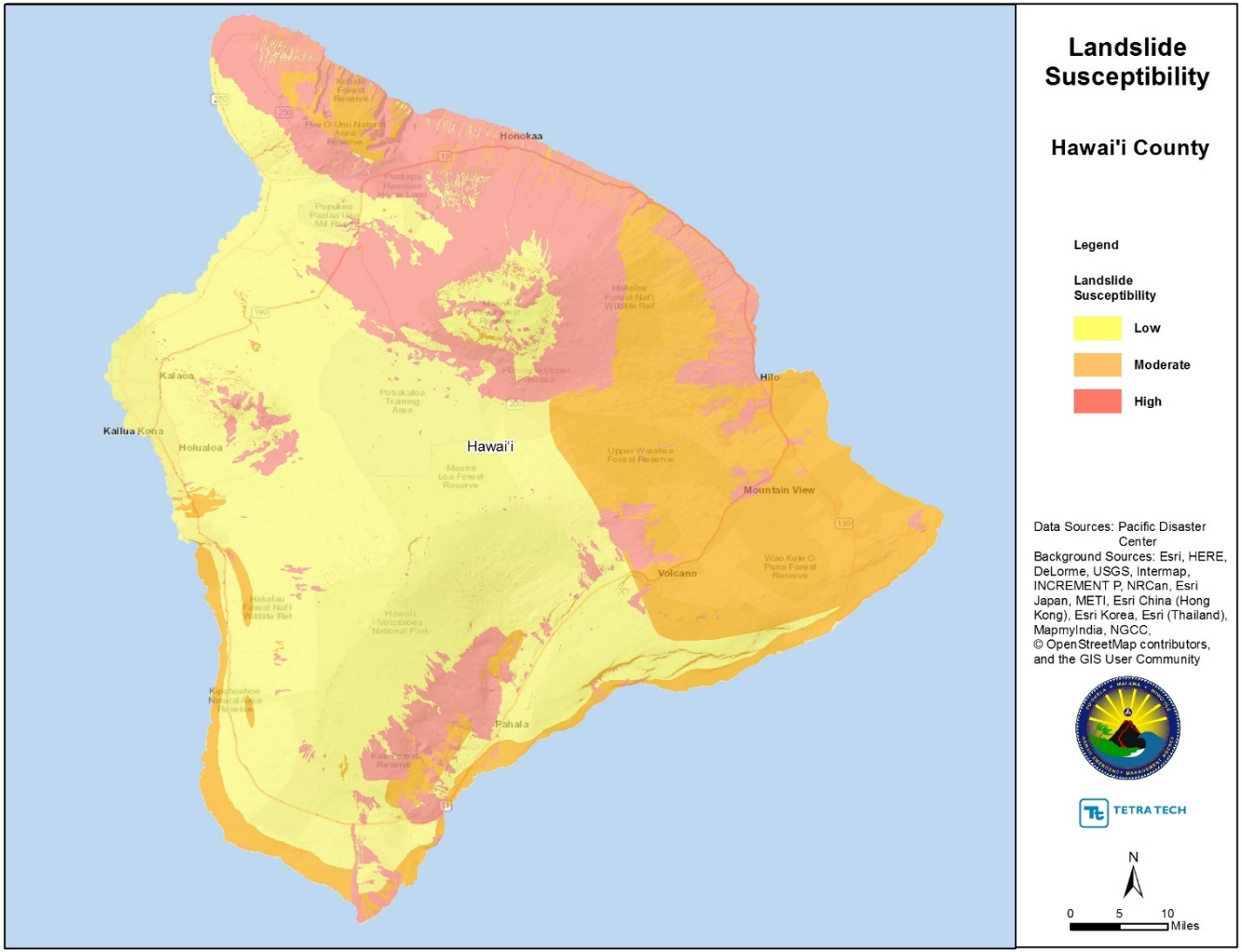
Source: PDC 2017; USGS 2016; State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

Figure 4.12-6. Landslide Hazard Areas in the County of Maui



Source: PDC 2017; USGS 2016; State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

Figure 4.12-7. Landslide Hazard Areas in the County of Hawai'i



Source: PDC 2017; USGS 2016; State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

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 norther side of the county. Landslides also occur frequently near road cuts. Significant historical landslides have occurred along the highway 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) near Anahola and Lumahai, and portions of Kuamoo Road (State Highway 580) near Kapa'a (State of Hawai'i HMP 2013).
- **City and County of Honolulu** – Several key components of debris flows exist in the county: steep hillsides, heavy rainfall, and residential development in upland areas. Significant events that have occurred 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 and 10 were identified as the top high scoring rockfall hazard sites in the City and County. This included: Pali Highway, Kalaniana'ole Highway, Kamehameha Highway, and Farrington Highway (State of Hawai'i HMP 2013).
- **County of Maui** – There is a high risk of landslides in the County of Maui caused by the volcanic activity in the County of Hawai'i (Maui County HMP 2015). Landslides, debris flows and rockfalls occur along coastal highways in the county, where the road is up against mountain slopes (State of Hawai'i HMP 2013).
- **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. Also, the three major gulches of Maulua, Laupāhoehoe and Ka'awali'i are areas prone to rockfalls (State of Hawai'i HMP 2013).

EXTENT

Landslides and rockfalls are natural events that can vary widely, 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 impacts incurred as a result of the event.

The consistency of debris flow ranges from watery mud to thick, rocky mud that can carry large items such as boulders, trees and cars. Debris can also include larger rocks and even boulders causing extensive damage. Debris flows from many different sources can combine in channels where their destructive power may be greatly increased. They continue flowing down hills and through channels, growing in volume with the addition of water, sand, mud, boulders, trees and other materials in the pathway. When the flows reach flatter ground, the debris spreads over a broad area, sometimes 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 the outlets of valleys and slopes excavated for buildings and roads (State of Hawai'i HMP 2013).

Warning Time

Mass movements can occur suddenly or slowly. The velocity of movement may range from a slow creep of inches per year to many feet per second, depending on slope angle, material and water content. Some methods used to monitor mass movements can provide an idea of the type of movement and the amount of time prior to failure (Nelson 2015).

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 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 as the landslide nears
- Unusual sounds, such as trees cracking or boulders knocking together (USGS 2018).

According to USGS, the interactions and real-time monitoring of rainfall, soil water content and soil water pressure with the aid of numerical modeling, may be used to assist with the development of real-time debris-flow warning systems in the future. The following summarizes recent findings that 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 affects 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 from FEMA, USGS, and DLNR provided information regarding previous occurrences and losses associated with landslide and rockfall events throughout the State of Hawai'i. The 2013 HMP discussed specific landslide and rockfall events that occurred in the State of Hawai'i through 2012 (see Appendix X for events prior to 2012). For the 2018 HMP Update, pervious events for all hazards assessed were summarized between January 1, 2012, and December 31, 2017. However, due to the heavy rains, flooding, and mud/rockslides that caused damages and losses to areas in the City and County of Honolulu and the County of Kaua'i during the time of the 2018 HMP Update, the April 2018 event was included. Table 4.12-2 lists major landslide and rockfall events that occurred in the state between 2012 and 2017, with the addition of the April 2018 event.

Table 4.12-2. Landslide Events in the State of Hawai'i, 2012 to 2018

Date(s) of Event	Event Type and Federal Disaster Declaration (if applicable)	Counties Affected	Description
March 3 to 11, 2012	Severe Storms, Flooding, and Landslides (FEMA-DR-4062)	Kaua'i, Honolulu, and Maui	On March 3 and 4, an upper trough in the vicinity of the Hawaiian Islands brought heavy rain, landslides, and flash flooding to the County of Kaua'i and the City and County of Honolulu. Numerous roads and bridges were closed throughout the impacted counties due to flooding. The City and County of Honolulu EOC was activated. This event resulted in a FEMA declaration for the counties of Kaua'i and Maui. A total of $3.6 million in public assistance was approved for the impacted counties.
April 4, 2012	Rockfall	O'ahu	Boulders fell from loose soil and damaged homes and roadways along Kula Kōlea Place in Kāhili Valley. Three homes were damaged, two severely. There were no injuries, but nine homes were evacuated. Several other boulders on the hillside needed to be stabilized or removed to prevent further damage, at a cost of $150,000.
May 26, 2016	Flash Flood, Landslide	Honolulu	Rocks fell on a portion of the Pali Highway. The Honolulu Emergency Operations Center was activated.
September 11 to 14, 2016	Severe Storms, Flooding, Landslides, and Mudslides (FEMA-DR-4282)	Maui and Hawai'i	As a weak tropical disturbance with abundant low-level moisture moved through the Hawaiian Islands, an upper low moved in from the northwest. This combination generated heavy showers and thunderstorms, which then resulted in landslides, mudslides, and flash flooding over the County of Maui. In the County of Hawai'i, flash flooding was reported closing roadways in the Mountain View area of the county. Other parts of the State received heavy rainfall as well. Overall damages were estimated at $15 million and created approximately 9,000 truckloads of debris. On September 27, 2016, Governor Ige requested a major disaster declaration due to this event. On October 6, 2016, President Obama declared that a major disaster existed in the State of Hawai'i. The County of Maui was included in the declaration. Public assistance for the event reached over $7.4 million.
April 2018	Heavy Rains, Flooding, and Mud & Rock Slides (FEMA-DR-4365)	Honolulu and Kaua'i	Heavy rains and flooding caused damages and losses to areas in Honolulu and Kaua'i. According to the NWS, 27.52 inches of rain fell in two days in the Town of Hanalei. In Kaua'i County, heavy rain caused extensive damage to the slopes adjacent to Kuhio Highway and impacted the communities of Wainiha and Haena. Multiple landslides led to the closure of the road. Numerous road closures reported in the impacted areas. Many homes were damaged or destroyed. American Red Cross conducted damage assessments and distributed clean up kits to residents in Aina Haina, Niu Valley, Kuliouou, Waimanalo, and Kailua. In Kaua'i County, the American Red Cross opened five shelters. Ten residents from Wainiha were airlifted to be taken to a shelter. Between April 13th and 19th, the Red Cross provided shelter to 110 individuals on Kaua'i.

Date(s) of Event	Event Type and Federal Disaster Declaration (if applicable)	Counties Affected	Description
			Governor Ige declared the District of Hanalei in Kaua'i County a disaster area. This declaration provided relief for damage caused by the event. Details regarding monetized impacts are not available at the time of this plan update

Sources: FEMA 2012; Hawai'i DLNR 2012; McAvoy 2012; Star Advertiser Staff 2012;Tsai 2012; FEMA 2016; Kakesako 2016; KHON2 Web Staff 2016; Office of Governor Ige 2016
Notes: DLNR Department of Land and Natural Resources
FEMA Federal Emergency Management Agency

FEMA Disaster Declarations

Between 1954 and 2018, FEMA included the State of Hawai'i in seven landslide/mudslide-related disasters (DR) or emergencies (EM) classified as one or a combination of landslide or mudslide. Generally, these disasters cover a wide region of the state; therefore, they may have impacted several counties. However, not all counties were included in the disaster declarations as determined by FEMA (FEMA 2018). Table 4.12-3 lists the FEMA declared landslide/mudslide disaster events between 2012 and 2018.

Table 4.12-3. Landslide and Mudslide-Related Federal Declarations, 2012 to May 2018

Year	Event Type	Date Declared	Federal	Counties Affected
2012	Severe Storms, Flooding, and Landslides	April 18, 2012	DR-4062	Kaua'i, Maui
2016	Severe Storms, Flooding, Landslides, and Mudslides	October 6, 2016	DR-4282	Maui
2018	Severe Storms, Flooding, Landslides and Mudslides	May 8, 2018	DR-4364	Honolulu and Kaua'i

Probability of Future Hazard Events

As discussed in detail earlier, landslides and rockfalls are commonly related to precipitation (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 hazards. Refer to Section 4.5 (Earthquakes), Section 4.10 (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, increasing 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 will 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 of these factors may increase the probability for landslide occurrences.

4.12.2 Vulnerability Assessment

A statewide assessment was conducted based on landslide susceptibility data from two sources. For County the Hawai'i, landslide susceptibility data was provided by the PDC. The data is based on slope, geology and soil moisture as described earlier in this section. For the Counties of Kaua'i, Maui and the City and County of Honolulu, landslide susceptibility data was not available; therefore, slope was calculated using a USGS 10-meter DEM (USGS 2016). Areas of slope were assigned landslide susceptibility categories as follows to align with the slope categories used by the County of Hawai'i:

Landslide Hazard Area Definition

To assess vulnerability to the landslide hazard, the high landslide susceptibility areas were used.

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

A qualitative discussion regarding rockfall impacts is also included below.

Assessment of State Vulnerability and Potential Losses

This section discusses statewide vulnerability of exposed state assets (state buildings and state roads) and critical facilities to the high landslide susceptibility area. Exposure results to the moderate landslide susceptibility area are presented in Appendix X.

State Assets

There are 357 state buildings located in the high landslide susceptibility area statewide. The greatest number of state buildings exposed are located in the County of Hawai'i (353 buildings with a replacement cost value of $1.775 billion); most of these buildings are occupied by the Department of Education and Hawai'i Health Systems Corporation. The remaining four buildings are located in the City and County of Honolulu. Table 4.12-4 summarizes the state buildings by county and Table 4.12-5. summaries the state buildings by agency located in the high landslide susceptibility area.

Table 4.12-4. State Buildings Located in the High Landslide Susceptibility Area 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	$1,775,623,914
Total	**357**	**$1,787,185,024**

Source: Hawai'i State Risk Management Office 2017; PDC 2017; USGS 2016; State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

Notes: GIS Geographic Information System
PDC Pacific Disaster Center
USGS U.S. Geological Survey

Table 4.12-5. State Buildings Located in the High Landslide Susceptibility Area 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	$946,504,656	14	21.2%	$9,484,078	1.0%
Dept of Agriculture	70	$133,065,375	12	17.1%	$10,357,255	7.8%

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 Attorney General	15	$95,151,863	0	0.0%	$0	0.0%
Dept of Budget & Finance	16	$26,624,294	1	6.3%	$408,119	1.5%
Dept of Business, Economic Development and Tourism	25	$612,574,032	0	0.0%	$0	0.0%
Dept of Commerce & Consumer Affairs	2	$35,611,360	0	0.0%	$0	0.0%
Dept of Defense	69	$246,099,477	4	5.8%	$12,857,832	5.2%
Dept of Education	4,090	$9,604,111,443	258	6.3%	$1,471,586,403	15.3%
Dept of Hawaiian Home Lands	12	$100,471,477	2	16.7%	$2,270,065	2.3%
Dept of Health	44	$387,068,440	2	4.5%	$1,220,303	0.3%
Dept of Human Resources Development	1	$5,523,320	0	0.0%	$0	0.0%
Dept of Human Services	130	$420,004,555	5	3.8%	$7,627,218	1.8%
Dept of Labor and Industrial Relations	22	$79,322,626	2	9.1%	$4,792,826	6.0%
Dept of Land and Natural Resources	90	$98,666,185	0	0.0%	$0	0.0%
Dept of Public Safety	154	$427,884,909	14	9.1%	$32,535,086	7.6%
Dept of Taxation	1	$6,864,408	0	0.0%	$0	0.0%
Dept of Transportation	68	$2,912,510,888	2	2.9%	$1,363,600	0.0%
Hawai'i State Ethics Commission	1	$891,212	0	0.0%	$0	0.0%
Hawai'i Health Systems Corporation	106	$1,223,962,810	21	19.8%	$171,136,243	14.0%
Hawai'i Housing Finance & Development Corporation	86	$333,526,064	0	0.0%	$0	0.0%
Hawai'i Public Housing Authority	273	$933,255,767	3	1.1%	$8,864,400	0.9%
Hawai'i State Legislature	2	$43,024,855	0	0.0%	$0	0.0%

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
Hawai'i State Public Library System	53	$525,584,082	4	7.5%	$15,073,630	2.9%
Judiciary	41	$511,093,204	5	12.2%	$6,638,449	1.3%
Legislative Reference Bureau	1	$2,686,408	0	0.0%	$0	0.0%
Office of Hawaiian Affairs	11	$53,991,251	0	0.0%	$0	0.0%
Office of the Auditor	2	$1,789,788	0	0.0%	$0	0.0%
Office of the Governor	1	$2,686,408	0	0.0%	$0	0.0%
Office of the Lieutenant Governor	2	$3,977,640	0	0.0%	$0	0.0%
Office of the Ombudsman	1	$1,620,944	0	0.0%	$0	0.0%
Research Corporation of the University of Hawai'i	3	$3,713,497	0	0.0%	$0	0.0%
University of Hawai'i	637	$5,000,692,783	8	1.3%	$30,969,518	0.6%
Total	**6,095**	**$24,780,556,017**	**357**	**5.9%**	**$1,787,185,024**	**7.2%**

Source: Hawai'i State Risk Management Office 2017; PDC 2017; USGS 2016; State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

Notes: Dept Department
GIS Geographic Information System
PDC Pacific Disaster Center
USGS U.S. Geological Survey

The State has jurisdiction over many roads and highways in all four counties; many of which are adjacent to rock slopes that are subject to rockfall and landslide events. A Rockfall Hazard Rating System (Publication No. FWHA SA-93-057, November 1993) is a tool that allows transportation agencies to evaluate and rate the risk of rockfall sites and may be used to prioritize construction funds. There are preliminary and detailed rating methodologies. The preliminary rockfall rating is a subjective rating that groups the hazard conditions into three classes (A, B and C) based on historic rockfall activity and the probability the rock falling will reach roadway pavement (U.S. DOT 1993). The detailed rating is based on the 12 categories below.

- 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)
- Difference in erosion rates
- Volume of 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 to develop a systematic rockfall hazard management system for the State of Hawai'i utilizing rockfall hazard rating methodology. Overall, 66 highways sites were identified as being at high risk to rockfall (State of Hawai'i HMP 2013).

The State of Hawai'i Department of Transportation mitigates landslides near roadways by erecting a metal mesh covering around the edge of the cliff. The purpose of these meshes is to prevent rocks and other debris from sliding out onto the highway. Since the identification of the City and County of Honolulu high-risk sites along highways and roads, many have been mitigated to date including along the Diamond Head State Monument trail, completed in December 2017.

Due to the County of Kauai's mountainous terrain, there are few roads that connect the island; many are under the jurisdiction of the State of Hawai'i Department of Transportation (e.g., Kuhio Highway and Kaumualii Highway). The roads are connected by bridges and only a few areas for roadway bypass or alternate routes (Kaua'i County HMP 2015). For this reason, any impacts to main roadways in the county as a result of natural hazard events can have devastating impacts to residents and visitors. Roadway closures due to a landslide or rockfall, as demonstrated by the April 2018 event, can isolate communities; prevent residents from commuting to work; and cut-off access to emergency response services.

The County of Maui has a recurrent history of landslides, debris flows and rockfalls. Most of these types of events have occurred along coastal highways were the road is right up against mountain slopes (State of Hawaii HMP 2013). The Kiholo Bay and Mahukona Earthquakes of October 15, 2006 resulted in several landslides and rockfalls at various locations on the Island of Maui including Piilani Highway (State Highway 30). Similar to other islands, road closures due to a landslide can isolate communities. In some cases, it can take years to fully repair the roadway and reopen for use (County of Maui HMP 2015).

Due to the lack of redundancy in the road network on the County of Hawai'i, which has the greatest state road exposure to the landslide hazard, the closure of roads will significantly hamper emergency response and potentially isolate communities. Table 4.12-6 shows the length of State roads in high landslide susceptibility areas by county. The County of Hawai'i has the greatest number of miles (146.9 miles) exposed. A complete list of State roads located in the hazard area is included in Appendix X.

Table 4.12-6. State Roads Located in the High Landslide Susceptibility Area by County

County	Length (in miles)		
	Total Length	High Hazard Area Length	Hazard Length as % of Total Length
County of Kaua'i	104.0	0.2	0.2%

County	Length (in miles)		
	Total Length	High Hazard Area Length	Hazard Length as % of Total Length
City and County of Honolulu	375.3	1.7	0.5%
County of Maui	238.6	1.5	0.6%
County of Hawai'i	378.7	146.9	38.8%
Total	**1,096.5**	**150.4**	**13.7%**

Source: State of Hawai'i SDOT State Routes GIS layer 2017; PDC 2017; USGS 2016; State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal

Notes: GIS Geographic Information System
PDC Pacific Disaster Center
SDOT State Department of Transportation

CRITICAL FACILITIES

There are 95 critical facilities located in the high landslide susceptibility area (see Table 4.12-7). All of these facilities are located in the County of Hawai'i; the majority of which are categorized as Mass Care Support Services. Table 4.12-8 summaries the number and percentage of exposed critical facilities by core category.

Table 4.12-7. Critical Facilities by Core Category Located in the High Landslide Susceptibility Area by County

County	Core Category of Critical Facilities										Total in the Hazard Area
	Commercial Facilities	Communications	Emergency Services	Energy	Food and Agriculture	Government	Healthcare and Public Health	Mass Care Support Services	Transportation Services	Water, Waste, and Wastewater Systems	
County of Kaua'i	0	0	0	0	0	0	0	0	0	0	0
City and County of Honolulu	0	0	0	0	0	0	0	0	0	0	0
County of Maui	0	0	0	0	0	0	0	0	0	0	0
County of Hawai'i	4	10	6	0	7	3	19	28	0	18	95
Total	4	10	6	0	7	3	19	28	0	18	95

Source: Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2

Table 4.12-8. Critical Facilities Located in the High Landslide Susceptibility Area by Core Category

Core Category	Total Number of Critical Facilities	Total Replacement Cost Value	Number of Critical Facilities in Hazard Area	Percent (%) of Total Facilities	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Commercial Facilities	60	$206,894,206	4	6.7%	$9,804,970	4.7%
Communications	130	$523,848,060	10	7.7%	$29,447,180	5.6%
Emergency Services	149	$1,017,628,710	6	4.0%	$42,437,650	4.2%
Energy	90	$2,591,975,628	0	0.0%	$0	0.0%
Food & Agriculture	39	$829,869,410	7	17.9%	$212,329,590	25.6%

Core Category	Total Number of Critical Facilities	Total Replacement Cost Value	Number of Critical Facilities in Hazard Area	Percent (%) of Total Facilities	Replacement Cost Value in the Hazard Area	Percent (%) of Total Value
Government Facilities	100	$399,781,575	3	3.0%	$11,617,980	2.9%
Healthcare & Public Health	193	$3,399,521,375	19	9.8%	$274,585,310	8.1%
Mass Care Support Services	353	$11,497,547,155	28	7.9%	$270,766,960	2.4%
Transportation Services	56	$1,739,256,960	0	0.0%	$0	0.0%
Water, Waste, & Wastewater Systems	305	$9,481,445,760	18	5.9%	$558,846,720	5.9%
Total	1,475	$31,687,768,838	95	6.4%	$1,409,836,360	4.4%

Source: Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2

Assessment of Local Vulnerability and Potential Losses

This section provides a summary of vulnerability and potential losses to population, general building stock, and 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. It is important to note that landslide and rockfall events do not just impact assets located in the defined hazard area. There are cascading impacts to surrounding communities that rely on the assets that are damaged/lost as a result of a disaster.

Population

According to the CDC, health threats from landslides include: 1) trauma caused by the 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). To understand the population located in the high landslide susceptibility area, a spatial analysis was conducted using the 2010 U.S. Census data; refer to Table 4.12-9.

The County of Hawai'i has the greatest number of people (53,349) located in the hazard area. It is important to note that this analysis does not include the number of tourists and visitors in the State or the impacted population located outside of the high landslide susceptibility area. Historic landslide and rockfall events in the state have caused road closures and bridge failures, isolating residents and preventing access to evacuation routes and medical services. Therefore, this estimate may be underestimating exposure and vulnerability.

Disasters can exacerbate and stress social conditions. Populations considered most vulnerable to natural hazard events include children, the elderly (persons over the age of 65), population with access and functional needs and individuals living below the U.S. Census poverty threshold. The County of Hawai'i has the largest population over 65, with 4.9% exposed and 8.5% of the low-income population exposed to the high landslide hazard. Section 3.0 (State Profile) summarizes the state's demographics by county further.

Table 4.12-9. 2010 U.S. Census Population Located in the High Landslide Susceptibility Area by County

County	Population						
	Total Population	Population in Hazard Area	Population Exposed as Percent (%) of Total Population	Population Over 65 in Hazard Area	Population Over 65 Exposed as Percent (%) of Total Population	Income <$30K/yr in Hazard Area	Income <$30K/yr Exposed as Percent (%) of Total
County of Kaua'i	67,091	0	0.0%	0	0.0%	0	0.0%
City and County of Honolulu	953,207	890	0.1%	117	0.0%	186	0.0%
County of Maui	154,924	0	0.0%	0	0.0%	0	0.0%
County of Hawai'i	185,079	53,349	28.8%	9,071	4.9%	15,702	8.5%
Total	1,360,301	**54,239**	**4.0%**	**9,188**	**0.7%**	**15,888**	**1.2%**

Source: U.S. Census 2010; PDC 2017; USGS 2016

Notes: PDC Pacific Disaster Center
USGS U.S. Geological Survey
The poverty threshold for the State is $24,000/year (Federal Register 2017). Utilizing the demographic layer in Hazus, the total households with an income of $30,000 or less was calculated. Per the U.S. Census Bureau QuickFacts, the average number of persons per household (2012-2016) is 3.03 for the State of Hawai'i. To convert households to residents, three people per household was used.

General Building Stock

To further assess what is at risk, each county's general building stock's exposure was examined. The general building stock located in the high landslide susceptibility area 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 4.12-10 indicates that the County of Hawai'i has the greatest building replacement cost value located in the high landslide susceptibility area.

Table 4.12-10. General Building Stock Located in the High Landslide Susceptibility Area

County	Total Replacement Cost Value	Replacement Cost Value in Hazard Area	Percent (%) of Total in Hazard Area
County of Kaua'i	$13,287,882,000	$0	0.0%
City and County of Honolulu	$164,787,212,000	$125,389,000	0.1%
County of Maui	$31,320,693,000	$784,000	0.0%
County of Hawai'i	$33,326,392,000	$9,863,569,000	29.6%
Total	$242,722,179,000	9,989,742,000	4.1%

Source: Hazus v4.2, PDC 2017; USGS 2016, State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal 2017

Notes: GIS Geographic Information System
PDC Pacific Disaster Center
USGS U.S. Geological Survey

The Honolulu district in the City and County of Honolulu has the highest concentration of inventoried rock hillslopes. This is due to the high density of development in areas of high topographic relief, which require significant earthwork and grading. More than 1,779 landslides and resulting debris flows have been recognized in aerial photographs of the Honolulu District taken during a period of approximately 50 years (USGS Open-File

Report 93-514). Most of these 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 HMP 2013).

The geography in the County of Kaua'i which includes the two mountains, Kawaikini Peak and Mount Wai'al'ale, make this one of the rainiest places on earth. The County averages 460 inches of rain annually. Although the exposure analysis does not indicate buildings in the County of Kaua'i are located in the hazard area, the steep slopes and climatic conditions make the county highly vulnerable to flooding and landslide risk generally resulting in mudslides and rockslides (County of Kaua'i 2015). In April 2018, flash flooding and mudslides that resulted from over 27.5 inches of rain caused major damage to roads, including Kuhio Highway, and bridges across the mountainous island. Many communities became isolated and homes damaged or destroyed.

Mudslides can cause damage either directly, by colliding with man-made structures, or indirectly, by plugging drainage systems so that flood waters are diverted out of the channels. Debris flows also can sever or cover roads, blocking access to (or egress from) neighborhoods, and thus interfere with emergency operations and evacuations (State of Hawai'i HMP 2013).

Land Use Districts

Table 4.12-11 shows the square miles of high landslide susceptibility areas in each State Land Use District statewide; refer to Appendix X 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 or hazardous conditions. Most of the vacant lands in the State Urban District with these characteristics are located in valley and hillside neighborhoods. Where hillside locations have stable soil material, 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, prompting claims against the City and County of Honolulu - as has happened in Mānoa and Moanalua (State of Hawai'i 2013 HMP). The County of Hawai'i has more than 14 square miles of Urban District land in high landslide susceptibility areas, accounting for more than 15% of the total Urban District land in the county.

Table 4.12-11. 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	2,942.8	643.0	21.9%
Conservation	3,156.3	498.5	15.8%
Rural	16.1	0.2	1.2%
Urban	319.7	14.3	4.5%
Total	**6,434.9**	**1,156.1**	**18.0%**

Source: PDC 2017; USGS 2016; State Land Use Commission, 2016
Notes: Total area was calculated from the State of Hawai'i State Land Use District GIS layer
Hazard area clipped to coastline were downloaded from State of Hawai'i GIS Program Geospatial Data Portal
Total area may differ slightly between this and other calculations due to slight differences in the shoreline geography.
GIS Geographic Information System

Environmental Resources

Natural hazard events, including landslide and rockfall events, can harm the environment. 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 contribute to the local and state economy.

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).

It is challenging to monetize impacts to environmental resources as a result of hazard events. To understand what environmental resources are exposed to the landslide hazard, an exposure analysis was conducted using the critical habitat, wetlands and parks and reserves spatial layers. Results are summarized in Table 4.12-12. As noted, large areas of critical habitats, parks and reserves are vulnerable to a landslide event.

Table 4.12-12. 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]	915.2	207.1	22.6%
Wetlands	260	7.3	2.8%
Parks and Reserves	2,607.70	387.6	14.9%
Total[b]	**3,837.60**	**602.0**	**15.7%**

Source: State of Hawai'i GIS layers, State of Hawai'i Hawai'i GIS Program Geospatial Data Portal; PDC 2017; USGS 2016

Notes: GIS Geographic Information System
PDC Pacific Disaster Center
USGS U.S. Geological Survey

Cultural Assets

Loss of and harm to native species and ecosystems 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 the landslide hazard area; followed by 13% of the total land area in the City and County of Honolulu (Table 4.12-13).

Table 4.12-13. Hawaiian Home Lands Located in the High Landslide Susceptibility Area by County

County	Hawaiian Home Lands Area (in square miles)		
	Total Area	Hawaiian Home Lands Located in the Hazard Area	Hazard Area as Percent (%) of Total Area
County of Kaua'i	32.0	1.3	4.2%
City and County of Honolulu	10.9	1.4	13.3%
County of Maui	92.6	1.4	1.5%
County of Hawai'i	190.3	114.0	59.9%
Total	325.8	118	36.3%

Source: State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal 2017; PDC 2017; USGS 2016

Notes: *GIS* *Geographic Information System*
PDC *Pacific Disaster Center*
USGS *U.S. Geological Survey*

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 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.

The high landslide susceptibility area was overlain on areas that may experience significant changes in development or redevelopment in future years (see Table 4.12-14 below and Section 3 [State Profile] for more information on projected development areas). The results of this assessment indicate that more than a third (36.7%) of the Enterprise Areas in the County of Hawai'i are located in high landslide susceptibility areas. Generally, county-level land use and development regulations require special assessment and consideration of proposed development on steep slopes, such as soil evaluation or geotechnical and engineering evaluations. 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 down slope from rockfall areas are not likely to be similarly regulated and may be exposed to risk from the landslide and rockfall hazard.

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 erode natural stream banks downstream - requiring expensive, aesthetically and ecologically undesirable structural hardening of the drainage channel - or even to exceed the capacity of the drainage system, resulting in flood conditions. 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 (Hawai'i State HMP 2013).

Table 4.12-14. HCDA Community Development Districts, Maui Development Projects, and Enterprise Zones located in the High Landslide Susceptibility Area 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	-	-	-	-	-	-	1,286.6	471.9	1.8%
City and County of Honolulu	7.4	0.0	0.0%	-	-	-	288.3	19.4	6.7%
County of Maui	-	-	-	27.6	0.1	0.2%	252.3	4.6	6.2%
County of Hawai'i	-	-	-	-	-	-	1,016.7	63.3	36.7%
Total	**7.4**	**0.0**	**0.0%**	**27.6**	**0.1**	**0.2%**	**2,843.9**	**559.3**	**19.7%**

Source: PDC 2017; USGS 2016

Notes: Total area calculated from: (1) HCDA Community Development District GIS layer from Hawai'i Community Development Authority (2) Maui Development Projects GIS layer from Maui County Planning Department (3) Enterprise Zones from Community Economic Development Program, DBEDTS

Hazard area clipped to coastline downloaded from State of Hawai'i GIS Program Geospatial Data Portal

HCDA Hawai'i Community Development Authority