16. LANDSLIDE

16.1 HAZARD PROFILE

16.1.1 HAZARD DESCRIPTION

Overview

For the 2025 LHMP update, the landslide hazard of concern includes landslides (inclusive of all types of soil/rock movement and debris flow) as well as rockfalls. A landslide is a mass movement of rock, debris, or earth down a slope, where a distinct zone of weakness separates the moving material from the more stable underlying material. Rockfalls typically result from a combination of rock fracture, erosion, chemical weathering, and the presence of a steep slope.

The primary cause of landslides is gravity acting on an over-steepened slope. This happens when gravity forces land downward, often due to precipitation, runoff, or ground saturation; however, several other factors can contribute to landslide events (USGS n.d.):

- Erosion by rivers or ocean waves, which can lead to over-steepened slopes
- Saturation of rocks and soil resulting from heavy rainfall, weakening the slope's structural integrity
- Earthquake-induced stresses that can trigger slope failure

Areas generally prone to landslide hazards include previous landslide areas, bases of steep slopes, bases of minor drainage hollows, and developed hillsides. Landslide materials may be composed of natural rock, soil, artificial fill, or a combination of these materials. These events can transpire quickly with little to no warning. Depending on the location of landslides, they can pose significant risks to health, safety, transportation, as well as other services.

Landslide Types and Causes

Landslides may be triggered by both natural and human-caused changes in the environment. Many factors cause landslides and rockfalls, but the following are particularly prevalent on Oʻahu:

- **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).

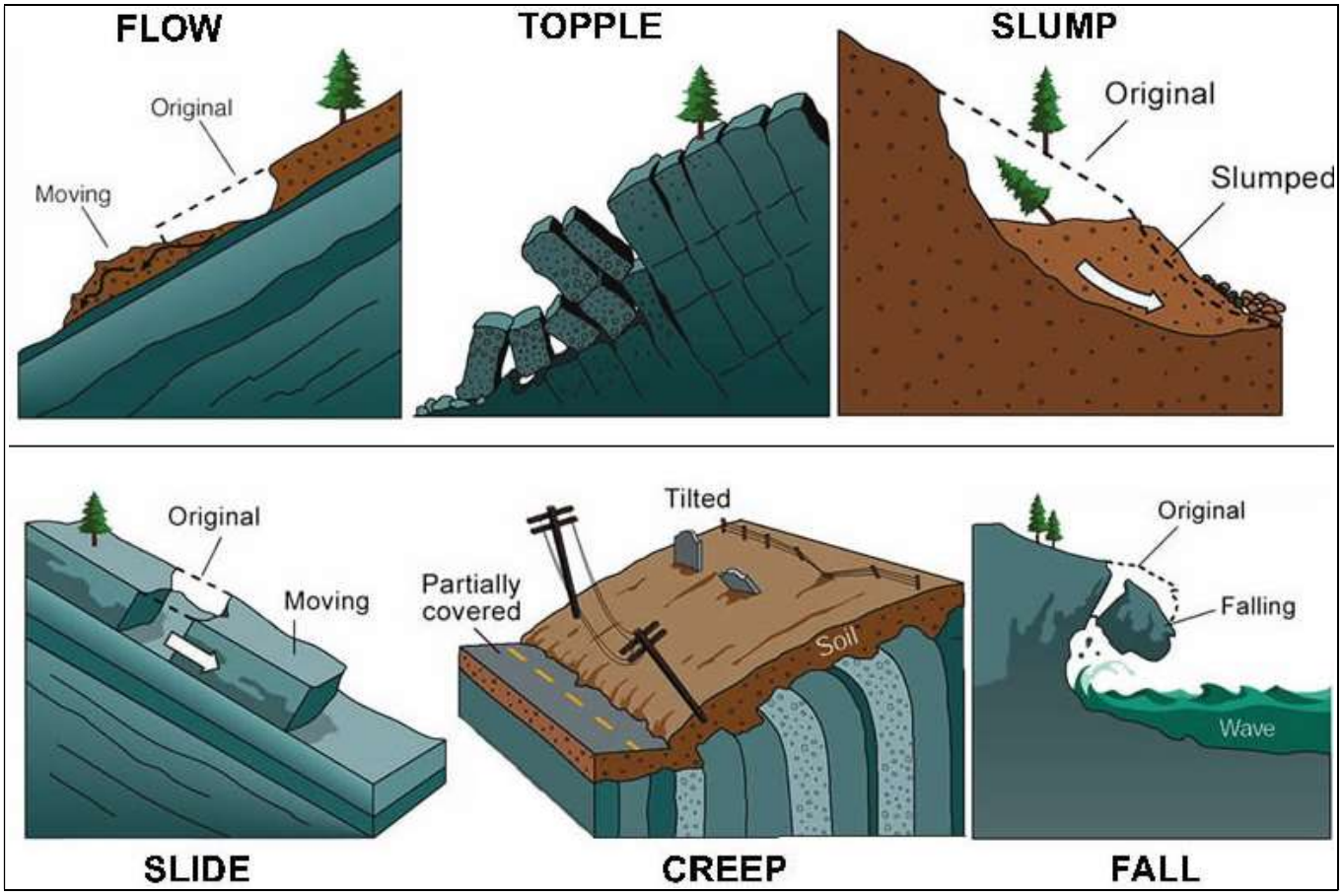
- **Seismic Activity**—Earthquakes in landslide-prone areas greatly increase the likelihood that landslides will occur, either due to ground shaking alone or shaking-caused dilation of soil materials. Rockfalls can also occur as a result of earthquakes because the shaking loosens rocks (USGS 2016).
- **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.

Additionally, the location and geological characteristics of Oʻahu contribute to the island's vulnerability to landslides and rockfalls. Volcanic rocks in Hawaiʻi tend to fracture naturally as they form. Over time, various processes can promote the development and expansion of these fractures, including increased water pressure within fractures, the wedging effect of plant roots, and rock flexure. Erosion mechanisms—such as rainfall runoff, stream activity, and wave action—can undermine slopes. Historical sea level fluctuations during geological periods have also resulted in wave erosion beneath loose or weak rock formations. Chemical weathering further weakens rock layers, increasing their susceptibility to failure. These processes often occur simultaneously; for instance, removal of support through erosion or the collapse of lava tubes can alter internal stress conditions within a slope, leading to fracture opening and growth, while also increasing the surface area exposed to chemical weathering.

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-16-1 illustrates the movement mechanisms in graphical form. Landslide types are as follows (USGS 2023):

- **Flow**—A flow, commonly referred to as debris flows, mudslides, mudflows, or lahars, are common types of fast-moving landslides in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope. Debris flows generally occur during periods of intense rainfall.
- **Topple**—Toppling failures happen when a part of a cliff tilts forward and falls over. This usually occurs around a point near the bottom of the cliff as gravity and pushes from nearby sections or as fluids in cracks cause it to lean and then topple.
- **Slump**—A slump is when a large amount of soil and rocks move down a slope all together, often sliding along a curved surface. When the land breaks and slides away, it creates a steep edge called a scarp. Sometimes, the landslide happens in steps, creating a series of these steep edges, which can happen as smaller cracks and movements happen within the moving material.
- **Slide**—A slide is when a large chunk or a few connected pieces of surface material move downslope together as a single, fairly solid unit.
- **Creep**—A creep is a slow, steady, downward movement of slope-forming soil or rock. Movement happens when forces are strong enough to cause lasting changes in the material, but not so strong that it breaks or causes a failure. There are generally three types of creep. Creep is indicated by curved tree trunks, bent fences, or retaining walls, titled poles or fences, and small soil ripples or ridges.
- **Fall**—Rockfalls are abrupt movements of masses of geologic materials, such as rocks and boulders, which become detached from steep slopes or cliffs. Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling.

Figure-16-1 Types of Landslides



Source: (Tara 2017)

Potential Impacts

Landslides and rockfalls can have considerable impacts on people, property, infrastructure, and the environment. Key potential impacts include (USGS n.d.):

- **Property Damage**—Landslides and rockfalls may damage or destroy residential and commercial properties.
- **Infrastructure Disruption**—Obstruction or damage to transportation routes, such as roadways being blocked or utilities being damaged.
- **Environmental Impact**—Landslides can modify landforms, disrupt ecosystems, and contribute to soil erosion.
- **Economic Consequences**—The damages incurred from landslides can lead to substantial financial costs related to repairs and decreased productivity.
- **Human Safety**—Rapid landslides pose immediate threats to safety, while slower-moving events can cause prolonged structural issues and long-term hazards.

In addition to the direct effects, landslides and rockfalls can lead to secondary impacts, such as isolation of residents and businesses due to road blockages and disruption of transportation for commercial, public, and private purposes. These events can also cause damage to vegetation and utility poles on slopes, resulting in power and utility outages. Landslides have the potential to compromise the stability of building foundations, leading to financial losses for property owners. They may also impact water bodies by damaging rivers or streams, thereby affecting water quality, fisheries, and spawning habitats. Additionally, landslides into floodplains can obstruct water flow and increase the risk of flooding.

16.1.2 LOCATION

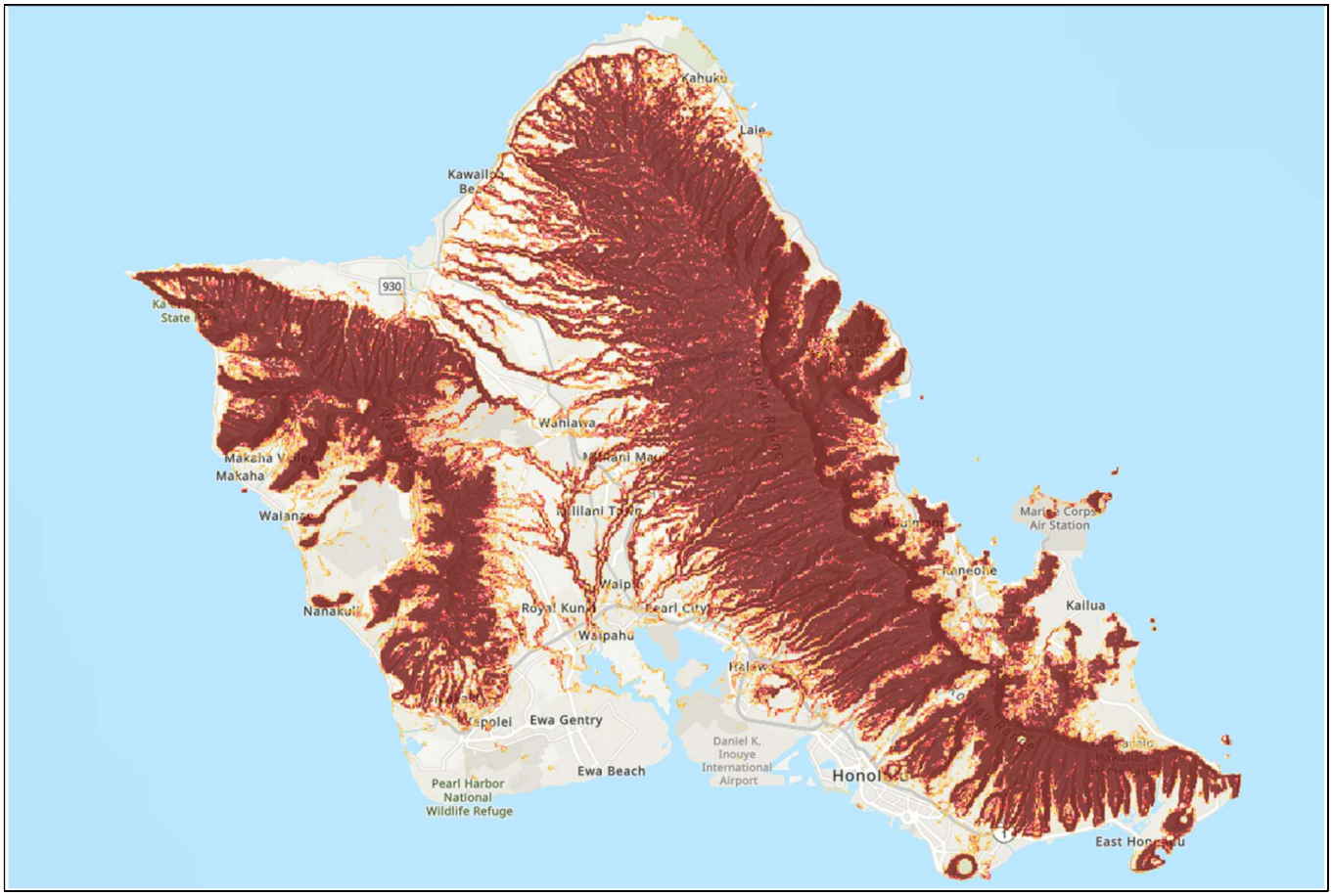
The City is highly susceptible to landslides due to its unique combination of steep hillsides, heavy rainfall, warm climate, lush vegetation, and extensive residential development in upland areas. Key areas prone to landslides include steep slopes; existing old landslides; and slopes with fractures materials, deep soils, or thin soils over bedrock (USGS n.d.).

Significant landslide events have notably impacted the eastern part of the City, especially in the Kuliʻouʻou and Hahaʻione valleys. Additionally, 66 highway sites, including Pali Highway, Kalanianaʻole Highway, Kamehameha Highway, and Farrington Highway, have been identified as high-risk areas for rockfalls (HI EMA 2023).

Heavy or prolonged rainfall, particularly during severe storms, is the most common trigger for these events, often occurring when rainfall exceeds 3 inches within a 6-hour period (USGS n.d.). Sites of wildfire and sites where vegetation has been destroyed on slopes are particularly vulnerable to landslides during and after heavy rain events (CDC 2024). Refer to Chapter 19 for further discussion on high-risk wildfire areas in the City.

Figure 16-2 depicts the susceptibility to landslides across the City.

Figure 16-2 USGS Landslide Susceptibility for the City



Source: (USGS n.d.)

16.1.3 EXTENT

Hazard extent refers to the potential severity or magnitude of hazard events in a given area. This section describes measurements used to indicate the extent of this hazard and the systems in place for monitoring severity and providing warnings as necessary.

Landslides and rockfalls can range in scale from small debris falling onto a roadway to extensive landslides or mudflows affecting multiple acres. Landslides can be measured using the size/volume of the material that was moved during the events. This is also affected by the velocity, or the rate at which materials move, which can range from inches per year to tens of miles per hour (mph) (USGS n.d.). Historic events have highlighted the ongoing impact of landslides on residential areas and infrastructure, resulting in significant service disruptions and affecting the daily lives of community members.

- On May 9, 1999, a landslide at Sacred Falls State Park killed seven hikers and injured 50 others. One of the injured later died, prompting then-Governor Ben Cayetano to close the park due to ongoing

landslide hazards. In 2006, heavy rains caused flooding and mudslides, including debris flows onto Highway 61 and flooding at Kahala Mall, which closed for up nine months.

- A landslide in 2016 in Nu'uanu Valley caused considerable property damage and led to legal proceedings. This landslide developed over a three-year period, starting in 2013, involving a gradual slope failure. Community members observed land movement, property damage, and a hill collapse in the area, resulting in cliffs approximately 15 feet in height. (Hawaiian News Now 2016)
- In April 2018, record rainfall caused debris to clog drainage systems, exacerbating flooding on O'ahu's eastern side.
- A rockfall event in 2000 in Waimea Bay closed Highway 83 for over two weeks
- A 2002 rockslide at Makapu'u Point affected Highway 72 for several months.

These events highlight the ongoing risk of landslides in O'ahu, particularly in areas with steep slopes and heavy rainfall. In addition, the Primary Urban Core regional planning areas has a high concentration of inventoried rock hillslopes. This reflects the high density of development in areas of high topographic relief that requires significant earthwork and grading. More than 1,779 landslides and debris flows have been recognized in aerial photographs of the Honolulu District taken 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 impact from debris flows in future storms could become even more frequent and costly (HI EMA 2023).

Warning Time

The following are generally accepted warning signs for landslide activity (USGS n.d.):

- Springs, seeps, or saturated ground in areas that have not typically been wet before
- New cracks or unusual bulges in the ground, street pavement, or sidewalk
- Soil moving away from foundations
- Ancillary structures, such as decks and patios, titling and moving relative to the main house
- Broken water lines and other underground utilities
- Leaning telephone poles, trees, retaining walls, or fences
- Offset fence lines
- Sunken or down dropped roadbeds
- Rapid increase in stream water levels, possibly accompanied by increased turbidity
- Sudden increase in stream water levels while rain is still failing or just recently ended
- 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

Landslides exhibit a wide range of speeds—from a slow creep of inches per year to many feet per second, depending on slope angle, materials, and water content. Rockfalls are often sudden events that are difficult to

predict, providing very limited or no warning time. Earthquake-induced landslides may be almost instantaneous. As a result of the range of speeds, the amount of warning time ranges widely. 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.

16.1.4 PREVIOUS OCCURRENCES

This section provides an overview of hazard occurrences since the publication of the previous LHMP, covering the period between January 2020 and February 2025. It identifies events that resulted in federal disaster declarations and/or state or local emergency proclamations. For events prior to 2020, refer to the 2020 LHMP.

Recent Events

Table 16-1 shows recent events identified in the NCEI database or identified by stakeholders and news articles.

Table 16-1 Landslide Events in the City and County of Honolulu (2020 to 2024)

Event Date	Disaster Declaration/ Proclamation			Description
	Federal	State	Mayoral	
December 6-7, 2021	DR-4639	-	-	A wall and roadway failed due to a landslide in the vicinity of 4120 Round Top Drive caused by sustained showers and thunderstorms. Landslides also blocked portions of Kamehameha Hwy near Kaaawa and Farrington Hwy near Makua Valley.
December 20, 2023	N/A	-	-	Periods of heavy rainfall led to flooding over portions of the islands. Heavy rainfall over the Koolau Mountain Range led to a landslide on the Pali Highway. Honolulu Police Department reported the closure of the town-bound lanes of the Pali Highway due to a landslide.
May 13, 2023	N/A	-	-	Thunderstorms and heavy rain causing flooding and flash flooding. A landslide caused the right land of the Pali Highway to close. Additionally, the town-bound portion of Kalanianaole Highway was closed near Kapaa Quarry Road due to a landslide.
May 16 to 18, 2024	-	-	-	A kona low storm pulled deep tropical moisture over the state from the south for several days which led to periods of heavy rainfall and flash flooding. Impacts included flooded roads and landslides.
June 25, 2024	N/A	-	-	The segment of 3800 to 3900 Tantalus Drive was temporarily closed. During this period, the City and the landowner collaborated to remove debris, prune and remove hazardous trees, and install water-filled barriers and sand-filled barrels to ensure safety. The road was safely reopened on September 10, 2024.

Source: (NOAA NCEI 2024) (FEMA 2024)

Federal Disaster Declarations

Under the Stafford Act, the President of the United States may issue an Emergency Declaration (EM) or Major Disaster Declaration (DR) and activate certain federal assistance programs based on factors related to the magnitude of the hazard threat or impacts. No Stafford Act declarations for this hazard type that included the City occurred during this period. Table 16-1 indicates the one recent event that received a federal emergency (EM) or disaster (DR) declaration.

State and Local Emergency Proclamations

State law authorizes the Governor to issue emergency proclamations if an emergency or disaster has occurred, or there is imminent danger or threat of an emergency or disaster in any portion of the state. County Mayors have the authority to issue local emergency proclamations when such conditions exist within any part of their respective jurisdictions. No state or local emergency proclamations related to this hazard were issued for the City during this period.

16.1.5 PROBABILITY OF FUTURE OCCURRENCES

Information on previous landslide and rockfall occurrences in the City was used to calculate the probability of future occurrence of such events, as summarized in Table 16-2. Landslides and rockfalls are frequently associated with factors such as precipitation (including tropical cyclone events and heavy rainfall on saturated ground), earthquakes, and human activities. Consequently, the occurrence rates of landslides and rockfalls are often correlated with the frequency of these contributing events.

Table 16-2. Probability of Future Landslide Events in the City

Hazard Type	Number of Occurrences, 1996 to 2024	% Chance of Occurring in a Given Year
Landslides, Mudslides	63	100%

Source: (NOAA NCEI 2024)

Note: Due to limitations in data, not all landslide events occurring between 1954 and 1996 are accounted for in the tally of occurrences. As a result, the number of hazard occurrences is calculated using the number of occurrences between 1996 and 2024. 100% probability indicates that it is statistically likely for an event to occur every year. It does not indicate that the occurrence of an event is a certainty in any given year.

The probability of occurrence, or likelihood of the event, is one parameter used for hazard rankings. Based on historical records and input from the HMWG, the probability of occurrence for landslides in the City is considered “occasional.”

16.2 VULNERABILITY AND IMPACT ASSESSMENT

To understand risk, a community must evaluate what assets are exposed and vulnerable in the identified hazard area. The following text qualitatively evaluates the potential impact of the drought hazard on life, health, and safety; the general building stock; the economy; critical facilities; and the environment.

16.2.1 LIFE, HEALTH, AND SAFETY

Overall Population

Generally, a landslide event is an isolated incident and impacts the populations within the immediate area. Specifically, the population located downslope of high landslide incidence hazard areas are particularly vulnerable. In addition to causing damage to residential buildings and displacing residents, landslide events can block off or damage major roadways and inhibit travel for emergency responders or populations trying to evacuate the area. According to the 2023 State HMP, the City has a population total of 10,376 located in the high landslide susceptibility area (HI EMA 2023).

Socially Vulnerable Population

Research has also shown that some groups may be disproportionately impacted by hazards even though they have the same hazard exposure as the overall population. For example, individuals over the age of 65 and people below the poverty level are most vulnerable to geological hazards because of the potential limited access to mobilization or medical resources if a landslide or subsidence event occurs. Populations with access and functional needs, as well as elderly populations and the very young, may be unable to evacuate quickly enough to avoid the impacts of a landslide. Other vulnerable groups may include those experiencing homelessness or residents and visitors whose primary language is not English. Individuals below the poverty level do not have the same financial resources to recover from lost property or injuries caused by the hazard. According to the 2023 State HMP, the City has 2,132 persons who fall into one or more categories of social vulnerability located in the high landslide susceptibility areas (HI EMA 2023).

16.2.2 ECONOMY AND GENERAL BUILDING STOCK

Landslide events can impose direct and indirect impacts on society. Direct costs include the actual damage sustained by buildings, property, and infrastructure. (USGS 2022). Indirect costs, such as clean-up costs, business interruption, loss of tax revenues, reduced property values, and loss of productivity may also occur, but are difficult to measure. Table 16-3 shows the general building stock for the City located in the high landslide susceptibility area (HI EMA 2023).

Table 16-3. General Building Stock Located in High Landslide Susceptibility Areas

Total Replacement Cost Value	Replacement Cost Value in Landslide Hazard Area	% of Total in Hazard Area
$239,152,051,766	$61,415,806	0.03%

Source: (HI EMA 2023)

Note: 2023 State HMP used sources: Pacific Disaster Center 2017, USGS 2016, NIYAM IT 2022, USACE 2022

16.2.3 COMMUNITY LIFELINES AND OTHER CRITICAL FACILITIES

Landslides can disrupt essential City services affecting the operation of community lifelines and critical facilities. The transportation lifeline has the greatest vulnerability to the landslide hazard. Landslides can block egress and ingress on roads and bridges, causing isolation for neighborhoods, traffic problems, and delays for public and private transportation. Mass movements can knock out bridge abutments or significantly weaken the soil supporting them, making them hazardous for use. Table 16-4 shows the length of state roads located in the City within the high landslides susceptibility areas.

Table 16-4. State Roads Located in High Landslide Susceptibility Areas by County

Total Road Length	Road Length in Landslide Hazard Area	% of Total Length
374.9	1.8	0.48%

Source: (HI EMA 2023)

Note: Length is measured by miles; State plan sourced: Pacific Disaster Center 2017, USGS 2016, State of Hawaii Risk Management Office 2017

Power lines are generally elevated above steep slopes; but the towers supporting them can be subject to landslides. A landslide could trigger failure of the soil underneath a tower, causing it to collapse and ripping down the lines. Power and communication failures due to landslides can create problems for vulnerable populations and businesses. For example, for individuals that rely on medical equipment, a prolonged power outage can present serious health risks or complications. Similarly, water systems can become dammed or contaminated by landslide materials.

Table 16-5 highlights the community lifelines and critical facilities within the City that are situated in areas highly susceptible to landslides.

Table 16-5. Community Lifelines and Critical Facilities in the High Landslide Susceptibility Area

Communications	1
Energy	0
Food, Water, Shelter	2
Hazardous Material	0
Health and Medical	0
Safety and Security	0
Transportation	0
Other Critical Facilities	0
Total in Hazard Area	**3**

Source: (HI EMA 2023)

Note: State plan sourced: Pacific Disaster Center 2017, USGS 2016, Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020

16.2.4 NATURAL, HISTORIC, AND CULTURAL RESOURCES

Natural Resources

Landslides and rockfalls can cause environmental damage. Landslides may result in flooding by obstructing stream channels or culverts, which can lead to water back-up and overflow. Additionally, soil and sediment runoff can accumulate downslope, potentially obstructing waterways and impacting water quality in streams and other water bodies. Mudflows eroding into downstream waterways can threaten the health of freshwater species (USGS 2020).

Historic and Cultural Resources

The impacts of landslides on historic and cultural resources within the City are most significant in areas near hillsides characterized by unstable soil and erosion. Many historic structures were not constructed to modern building standards and are therefore more vulnerable to damage. The loss of native species and ecosystems, as well as harm to them, can adversely affect Hawaiian cultural traditions and practices, which are deeply connected to the natural environment.

16.2.5 FUTURE CHANGES THAT MAY AFFECT RISK

Understanding future changes that affect vulnerability can assist in planning for future development and ensure establishment of appropriate mitigation, planning, and preparedness measures. The following sections examine potential conditions that may affect hazard vulnerability.

Potential or Planned Development

Within the 2023 State HMP, high landslide susceptibility areas were overlain on areas that may experience significant changes in development or redevelopment in future years. As shown in Table 16-6, the results for the City indicate that more than 297 (7.67 percent) of the Enterprise Zones (areas designated as offering economic incentives to businesses to stimulate economic activity) in the City are located in high landslide susceptibility areas. Generally, city-level regulations for land use and development require special assessment and consideration of proposed development on steep slopes.

Table 16-6. HCDA Districts and Enterprise Zones Located in High Landslide Susceptibility Areas

	Total Area	Located in Landslide Hazard Area	
		Exposed Area (acres)	Exposed Aea as % of Total Area
Hawaii Community Development Authority District	7.4	<0.1	<0.1%
Enterprise Zones	297.3	22.8	7.67%

Source: (HI EMA 2023)

Note: Sources used by 2023 State HMP: 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

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 landslides and rockfalls.

Over the long term, the cumulative impact of greater lot coverage resulting from development 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 (HI EMA 2023).

Projected Changes in Population

The population of the City is projected to increase from 1,016,508 in 2020 to 1,060,110 in 2050, which could increase the risk of infrastructure failure (DBEDT 2024). As the population grows, increased urbanization leads to more land being developed for housing, infrastructure, and services, often altering natural landscapes and destabilizing slopes, which heightens the risk of landslides. Additionally, higher population density puts pressure

on land resources, resulting in the use of marginal lands that are more susceptible to landslides, such as steeper slopes or areas with weaker soil stability.

Climate Change

Increased storm activity on O‘ahu may elevate the likelihood of landslides and rockfalls. Heavy rainfall from severe storms can saturate soil, increasing its weight and decreasing stability, thereby raising the risk of landslides. Additionally, stormwater flow and wave action can erode slopes and cliffs, compromising their structural integrity and making them more susceptible to collapse. This erosion, coupled with the added weight of saturated soil, creates conditions conducive to landslides and rockfalls. Furthermore, high-energy stormwater can dislodge rocks and debris, contributing to rockfall incidents. As climate change results in more frequent and intense storms, these hazards are anticipated to become more prevalent and impactful in the City.

Additionally, rising temperatures may lead to longer and more frequent drought periods, which can increase the risk of wildfires. Wildfires often result in significant vegetation loss, removing stabilizing plant cover from steep slopes and increasing the potential for landslides.