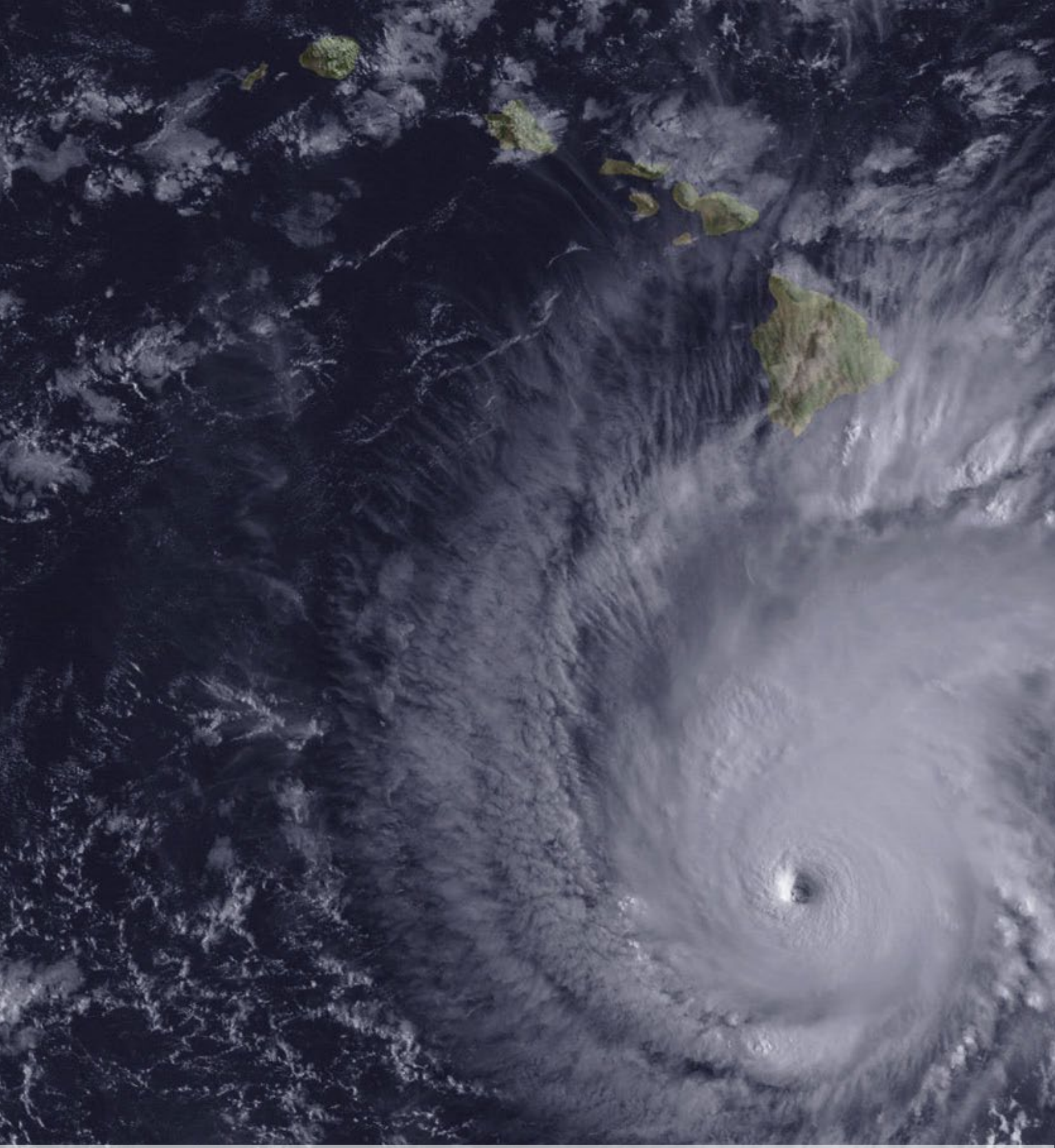

Section 4.9 Hurricane

Hurricane

Hurricane season generally runs from the beginning of June to the end of November, but storms can form before and after the season. Hurricanes and tropical storms threaten the State with excessive rain, storm surge, and strong winds. Statistics below represent the Category 4 SLOSH (Sea, Lake and Overland Surges from Hurricanes) inundation area.

CHANGES SINCE 2018

+4
Declared Disasters

+7
Hurricane Events

COUNTIES MOST VULNERABLE

Kaua'i Honolulu Maui Hawai'i

SOCIALLY VULNERABLE POPULATION

2.14%
Of Total Population

30,320
Persons

HAZARD RANKING

Low Medium High

COMMUNITY LIFELINES

217
Total

Food, Water, Shelter
Greatest

CLIMATE PROJECTIONS

Hurricanes and tropical storms are projected to grow in average size and strength due to climate change and rise in sea level

El Niño events will be more frequent, increasing tropical cyclone activity

The northeast trade winds may shift large-scale pressure and wind patterns that impact the State of Hawai'i

654
State Buildings

SQUARE MILES

33
Environmental Resources

2.5
Hawaiian Home Lands

22
Cultural Resources

78
Miles of State Road

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[1] *Section Cover Photo: Hurricane Lane. Photo courtesy of NOAA*

SECTION 4. RISK ASSESSMENT

4.9 HURRICANE

2023 SHMP Update Changes

- Hurricane and tropical storm events 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 hurricanes impact socially vulnerable populations and community lifelines.
- In Environmental Resources, reefs (both artificial and coral) were analyzed in their own category.
- Six types of cultural resources (archaeology, burial sensitivity area, historic building, historic district, historic object, and historic structure) were added to the vulnerability assessment.

4.9.1 HAZARD PROFILE

Hurricanes and tropical storms can bring excessive amounts of rain, strong and damaging winds, storm surge, high waves, erosion along shorelines, and tidal and coastal flooding. While the occurrence of such storms is low in the state, when they do occur, they can have dramatic, damaging, and potentially deadly effects. For the 2023 SHMP Update, this profile and associated vulnerability assessment will focus on hurricane-force winds and storm surge and include events identified as hurricanes and tropical storms. Other hazards associated with tropical cyclone events are generally addressed in other hazard sections. Please refer to Section 4.6 (Flood) and Section 4.16 (Windstorm) for high winds.

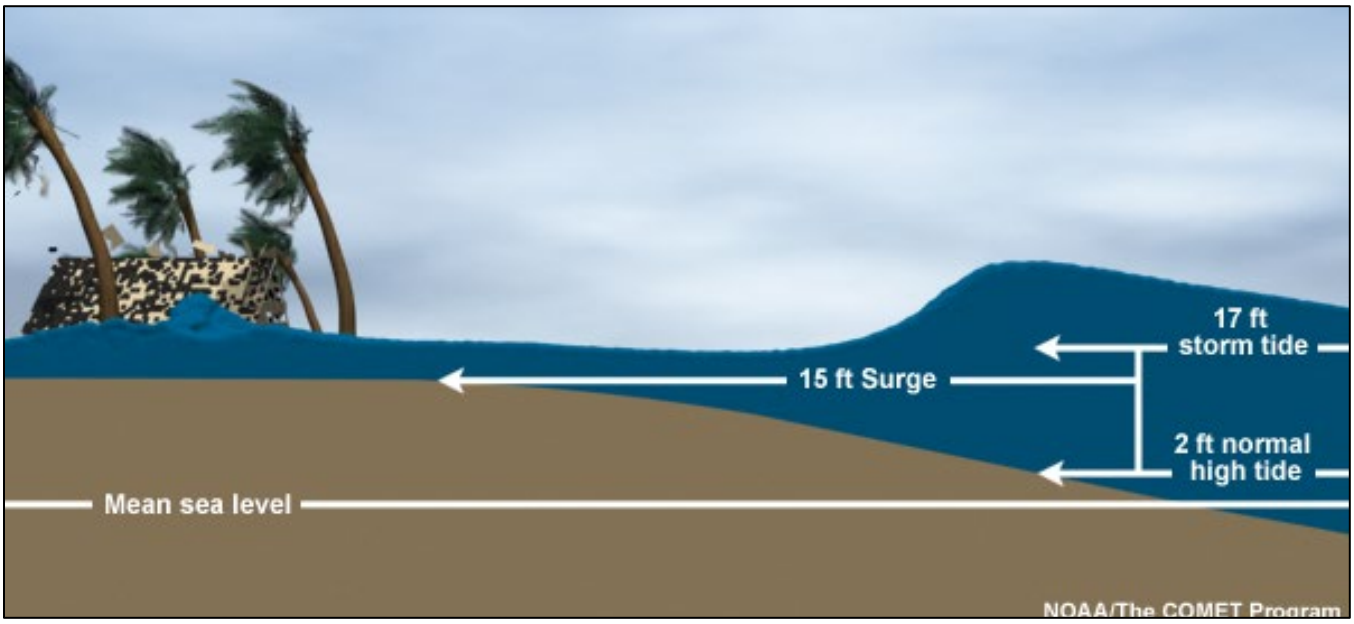
HAZARD DESCRIPTION

A tropical cyclone is a rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters and has a closed low-level circulation. Tropical depressions, tropical storms, and hurricanes are all types of tropical cyclones that are distinguished by their sustained wind speeds. These storms rotate counterclockwise in the northern hemisphere around the center and are accompanied by heavy rain and strong winds (NOAA 2022). The weather associated with tropical cyclones typically lasts between 12 and 18 hours, with a slow-moving storm lasting around 24 hours. The State of Hawai'i is located in the Central Pacific basin, where hurricane season runs from June 1 to November 30.

Storm Surge

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides (see Figure 4.9-1). Storm surge occurs when water is pushed toward the shoreline by the force of winds from the storm. Friction between the water and the moving air creates drag that, depending upon the distance of water (fetch) and velocity of the wind, can pile water up to depths greater than 20 feet from the shoreline inland. The rise in water level can cause extreme flooding in coastal areas, especially when storm surge coincides with normal high tide (National Hurricane Center 2022).

Figure 4.9-1. Storm Surge



Source: (National Hurricane Center 2022)

All types of tropical cyclones generate large swells, causing varying degrees of damage. This is characteristic of hurricanes that pass close but do not directly impact the State of Hawai‘i. For example, communities on the Wai‘anae Coast in the City and County of Honolulu suffered severe damage from Hurricanes Iwa and Iniki, yet neither of these storms hit the Island of O‘ahu.

According to the National Hurricane Center, there are many factors that contribute to the amount of surge a given storm produces at a given location:

- **Central Pressure:** Lower pressure of the storm will produce a higher surge; however, the central pressure of the storm is a minimal contribution compared to the other factors.
- **Storm Intensity:** Stronger winds will produce higher surge.
- **Storm Forward Speed:** On the open coast, a faster storm will produce a higher surge. However, a higher surge is produced in bays, sounds, and other enclosed bodies of water with a slower storm.
- **Angle of Approach to Coast:** The angle at which a storm approaches a coastline can affect how much surge is generated. A storm that moves onshore perpendicular to the coast is more likely to produce a higher storm surge than a storm that moves parallel to the coast or moves inland at an oblique angle.

- **Shape of the Coastline:** Storm surge will be higher when a hurricane makes landfall on a coastline that is curved inward, as opposed to a coastline that is curved outward.
- **Size:** A larger storm will produce a higher surge. The winds of a larger storm push on a larger area of the ocean. The strong winds of a larger storm tend to affect a larger area than a smaller storm.
- **Width and Slope of the Ocean Bottom:** Higher storm surge occurs with wide, gently sloping continental shelves, while lower storm surge occurs with narrow, steeply sloping shelves.
- **Local Features:** Storm surge highly depends on local features and barriers that will affect the flow of water. In the state, this includes inlets, bays, and rivers (National Hurricane Center 2022).

Heavy Rain

Hurricanes and other tropical cyclones often produce widespread, torrential rains in excess of 6 inches, which may result in deadly and destructive flooding (see Figure 4.9-2 and Figure 4.9-3). Rainfall amounts are not directly related to the strength of the storm but rather to the speed and size. Slower moving, larger storms produce more rainfall. Additionally, mountainous terrain enhances rainfall from a hurricane (National Hurricane Center 2022).

Figure 4.9-2. Flooding in Hilo from Hurricane Lane, 2018

Source: Hawai'i Emergency Management Agency

Figure 4.9-3. Road Washout in Maui from Hurricane Lane Flooding

Source: Hawai'i Emergency Management Agency

Strong Winds

The strongest winds are typically found on the right side of the center of the hurricane. Wind speeds decrease with increased distance away from the center of the storm. Atlantic and Central Pacific hurricanes are classified into five categories according to the Saffir-Simpson Hurricane Wind Scale, which estimates potential property damage according to the hurricane's sustained wind speed. Refer to the Extent subsection of this profile for details regarding the Saffir-Simpson Scale (National Hurricane Center 2022).

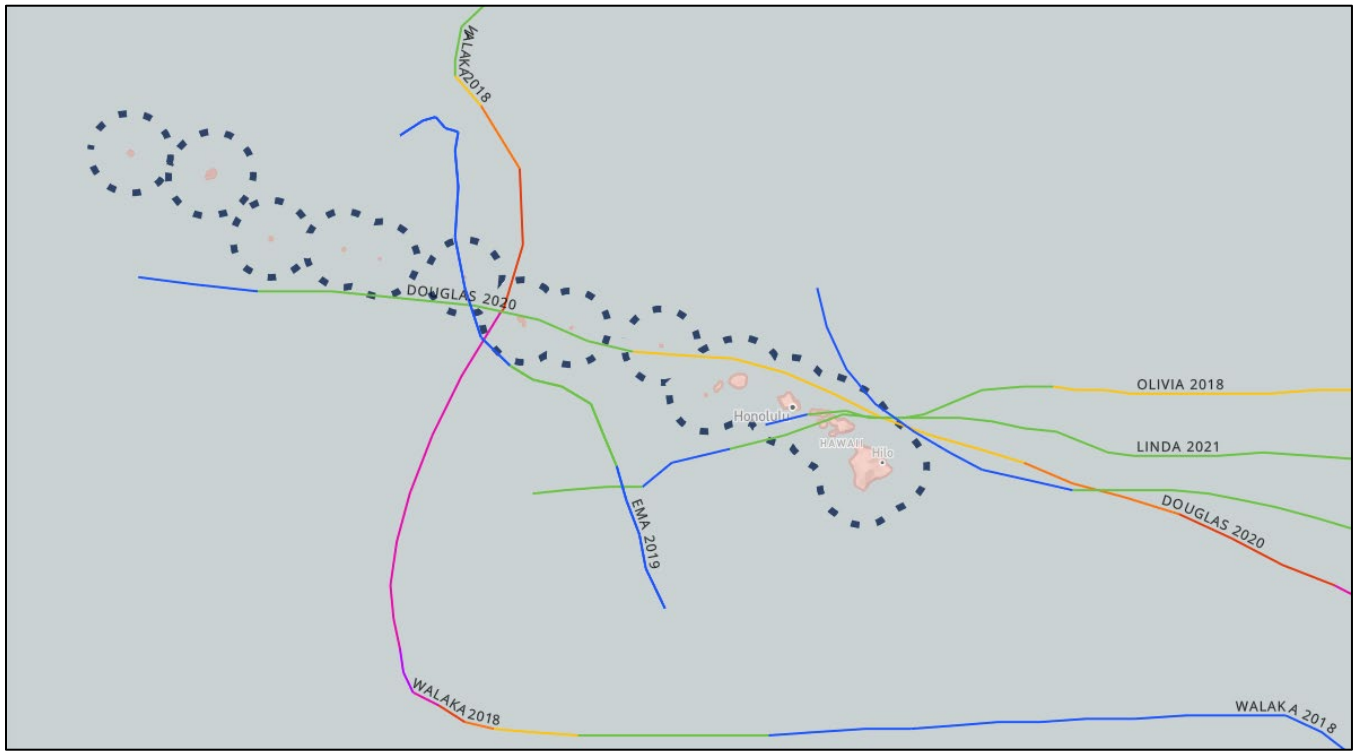
Microbursts and mini swirls are small, localized wind bursts that can reach speeds of greater than 200 mph. During Hurricane Iniki, damage patterns and debris indicated that there were more than 26 microbursts (sudden intense downdrafts) and two mini swirls (a violent whirlwind, not tornado) that occurred in the County of Kaua'i (State of Hawai'i 2018).

Location

The entire State of Hawai'i and its communities are vulnerable to the damaging impacts of hurricanes. Historically, it has been relatively rare for a hurricane to intersect the state; however, large swells and high winds from near misses are quite common. Each county in the state has been affected by hurricanes and are at risk to damages from these storms (NOAA 2022). The coastal areas of the State of Hawai'i are more susceptible to damage caused by a combination of high winds and tidal surge. Inland areas, especially those in the 1% and 0.2% annual chance flood areas depicted on the FEMA DFIRMs, are also at risk to flooding because of heavy rains associated with the storms. Refer to Section 4.6 (Flood) for details regarding inland flooding.

NOAA's Historical Hurricane Tracks tool is a public interactive mapping application that displays Atlantic Basin and East-Central Pacific Basin tropical cyclone data. This interactive tool catalogs tropical cyclones that have occurred from 1842 to 2022 (latest date available from data source). Figure 4.9-4 displays tropical cyclone tracks within 60 nautical miles of the State of Hawai'i. The figure shows tropical cyclone events that occurred between 2018 and 2022.

Figure 4.9-4. Historical Tropical Storm and Hurricane Tracks, 2018 to 2022



Source: (NOAA 2022)

EXTENT

Once a tropical cyclone has been characterized as a hurricane, its intensity is measured by the Saffir-Simpson Hurricane Scale. The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 rating based on a hurricane's sustained wind speed. This scale estimates potential property damage (refer to Table 4.9-1). Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. Category 1 and 2 storms are still dangerous and require preventive measures (State of Hawai'i 2018).

As stated earlier, storm surge inundation from hurricanes can be devastating to areas along the coastline. Table 4.9-2 summarizes the area of coastline that may be potentially inundated by storm surge from hurricane Categories 1 through 4. The City and County of Honolulu have the greatest number of square miles that may be inundated by storm surge.

Table 4.9-1. Saffir-Simpson Hurricane Scale

Category	Wind Speed (mph)	Storm Surge (feet)	Expected Damage
1	74 to 95	4 to 5	Damaging winds are expected. Some damage to buildings could occur, primarily to unanchored structures (such as school portables). Some damage is likely to poorly constructed signs. Loose outdoor items will become projectiles, causing additional damage. Persons struck by windborne debris risk injury and possible death. Numerous large branches of healthy trees will snap. Some trees will be uprooted, especially where the ground is saturated. Many areas will experience power outages with some downed power poles. Hurricane Iwa (passing just northwest of Kaua'i in 1982) and Hurricane Norman (2018, passing just northeast of the Hawaiian Islands) are examples of Category 1 hurricanes that directly impacted the State of Hawai'i.
2	96 to 110	6 to 8	Very strong winds will produce widespread damage. Some roofing, door, and window damage of buildings will occur. Considerable damage to unanchored structures and poorly constructed signs is likely. A number of glass windows in high-rise buildings will be dislodged and become airborne. Loose outdoor items will become projectiles, causing additional damage. Persons struck by windborne debris risk injury and possible death. Numerous large branches will break. Many trees will be uprooted or snapped. Extensive damage to power lines and poles will likely result in widespread power outages that could last a few to several days. There is no record of a Category 2 hurricane directly impacting Hawai'i. Elsewhere in the United States, Hurricane Erin (1995, 100 mph at landfall in northwest Florida) and Hurricane Isabel (2003, 105 mph at landfall in North Carolina) are examples of Category 2 hurricanes at landfall.
3 (major)	111 to 129	9 to 12	Dangerous winds will cause extensive damage. Some structural damage to houses and buildings will occur with a minor amount of wall failures. Unanchored structures and poorly constructed signs are destroyed. Many windows in high-rise buildings will be dislodged and become airborne. Persons struck by windborne debris risk injury and possible death. Many trees will be snapped or uprooted and block numerous roads. Near total power loss is expected with outages that could last from several days to weeks. There is no record of a Category 3 hurricane directly impacting Hawai'i. Elsewhere in the United States, Hurricane Rita (2005, 115 mph landfall in east Texas/Louisiana) and Hurricane Darby (2016, Category 3 storm that weakened to a tropical depression shortly after making landfall in Hawai'i) are examples of Category 3 hurricanes at landfall.
4 (major)	130 to 156	13 to 18	Extremely dangerous winds causing devastating damage are expected. Some wall failures with some complete roof structure failures on houses will occur. All signs are blown down. Complete destruction of unanchored structures. Extensive damage to doors and windows is likely. Numerous windows in high-rise buildings will be dislodged and become airborne. Windborne debris will cause extensive damage, and persons struck by the wind-blown debris will be injured or killed. Most trees will be snapped or uprooted. Fallen trees could cut off residential areas for days to weeks. Electricity will be unavailable for weeks after the hurricane passes. Hurricane Iniki, which made landfall on Kaua'i in 1992, is an example of a Category 4 hurricane at landfall in Hawai'i.
5 (major)	157 or more	greater than 18	Catastrophic damage is expected. Complete roof failure on many residences and industrial buildings will occur. Some complete building failures with small buildings blown over or away are likely. All signs blown down. Complete destruction of unanchored structures. Severe and extensive window and door damage will occur. Nearly all windows in high-rise buildings will be dislodged and become airborne. Severe injury or death is likely for persons struck by wind-blown debris. Nearly all trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. There is no record of a Category 5 hurricane directly impacting the State of Hawai'i. Elsewhere in the United States, Hurricane Andrew (1992, 165 mph at landfall in Southeast Florida) and Hurricane Michael (2018, 160 mph landfall in northwest Florida) are examples of Category 5 hurricanes at landfall.

Source: (National Hurricane Center 2022)

Table 4.9-2. Storm Surge Inundation Area by County

County	Area (in square miles)								
	Total County Area	Category 1 Hurricane	Cat 1 as % of Total Area	Category 2 Hurricane	Cat 2 as % of Total Area	Category 3 Hurricane	Cat 3 as % of Total Area	Category 4 Hurricane	Cat 4 as % of Total Area
County of Kaua'i	624.2914	4.5	0.72%	5.8	0.93%	10.1	1.62%	12.2	1.95%
City and County of Honolulu	598.5707	10.9	1.82%	22.3	3.73%	31.8	5.31%	38.2	6.38%
County of Maui	1,176.28	5.8	0.49%	7.9	0.67%	9.8	0.83%	11.4	0.97%
County of Hawai'i	4,039.64	1.9	0.05%	2.5	0.06%	3.7	0.09%	5.3	0.13%
Total	**6,438.78**	**23.1**	**0.36%**	**38.5**	**0.60%**	**55.4**	**0.86%**	**67.1**	**1.04%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration

Warning Time

Tropical cyclones are a unique weather phenomenon because they can be closely monitored and tracked. As a result, accurate warnings up to days in advance of the event are possible with the track modeling offering possible storm movement up to a week prior. Track forecasts have improved partly due to an increase in the number of satellites outfitted with more sophisticated weather-monitoring devices. Additionally, supercomputing has increased, and computer models used for forecasting keep improving. Intensity forecasts, by contrast, show little improvement over the last 20 years (Freedman 2011). Lack of improvement in intensity forecasts presents a problem for the State of Hawai'i because most hurricane-related damages come from destructive winds.

The Central Pacific Hurricane Center issues tropical cyclone advisory packages whenever a tropical cyclone is active in the Central North Pacific Basin. If a tropical cyclone is active in the Eastern North Pacific, the National Hurricane Center issues the package. The following provides definitions, as defined by the Central Pacific Hurricane Center, for the tropical cyclone advisory packages.

- **Tropical Cyclone Public Advisory.** The Tropical Cyclone Public Advisory gives the cyclone position in terms of latitude and longitude coordinates and distance from a selected land point or island, as well as the current motion. The advisory includes the maximum sustained winds in miles per hour and the estimated or measured minimum central pressure in millibars and inches. The advisory may also include information on potential storm tides, rainfall, or tornadoes associated with the cyclone as well as any pertinent weather observations.
- **Public advisories are issued for all Central Pacific tropical cyclones.** Public advisories are normally issued every six hours. They may be issued every two or three hours when coastal watches or warnings are in effect. Special public advisories may be issued at any time due to significant changes in warnings or in the cyclone.
- **Tropical Cyclone Forecast/Advisory.** The Tropical Cyclone Forecast/Advisory contains a list of all current watches and warnings on a tropical or subtropical cyclone as well as the current latitude and longitude coordinates, intensity, and system motion. The advisory contains forecasts of the cyclone positions, intensities, and wind fields for 12, 24, 36, 48, and 72 hours from the current synoptic time. The advisory may also include information on any pertinent storm tides associated with the cyclone. All wind speeds in

the forecast advisory are given in knots (nautical miles per hour). They are issued on all Central Pacific tropical cyclones. Special Forecast/Advisories may be issued at any time due to significant changes in warnings or in the cyclone.

- **Tropical Cyclone Discussion.** The Tropical Cyclone Discussion explains the reasoning for the analysis and forecast of a tropical or subtropical cyclone. It includes a table of the forecast track and intensity. They are issued on all Central Pacific tropical cyclones every six hours. Special Forecast/Advisories may be issued at any time due to significant changes in warnings or in the cyclone.
- **Tropical Cyclone Surface Wind Speed Probabilities.** The Tropical Cyclone Surface Wind Speed Probabilities text product provides probabilities, in percent, of sustained wind speeds equal to or exceeding 34-, 50-, and 64-knot wind speed thresholds. These wind speed probabilities are based on the track, intensity, and wind structure forecasts and uncertainties from the Central Pacific Hurricane Center. These wind speed probabilities are computed for coastal and inland cities as well as offshore locations (e.g., buoys) (National Hurricane Center 2022).

Previous Occurrences and Losses

Disaster and Emergency Declarations

Many sources provided information regarding previous occurrences and losses associated with hurricane-related events throughout the State of Hawai'i. The 2018 SHMP discussed specific hurricane-related events that occurred in the state through 2017. For the 2023 SHMP Update, previous events for all hazards assessed were summarized between January 1, 2018, and December 31, 2022. Hurricane events that have affected the state and were declared a FEMA disaster between 2018 and 2022 are identified in Table 4.9-3. For details regarding all declared disasters, refer to Section 4.1 (Overview). Refer to Appendix D (Map Atlas) which illustrates the number of tropical cyclone and hurricane FEMA-declared disasters by county.

- Federal disaster (DR) or emergency (EM) declarations, 1955 – 2022: 7 events, classified as hurricane or typhoon
- USDA agricultural disaster declarations, 2012 – 2022: none
- Hawai'i state emergency proclamations, 2018 – 2022: 3 hurricane events

Table 4.9-3. Hurricane-Related Federal Declarations (2018 to 2022)

Event Type	Date Declared	Federal Declaration	Counties Affected
Hurricane Lane	August 22, 2018	EM-3399-HI	Hawai'i, Honolulu, Kaua'i, Maui
Tropical Storm Olivia	September 12, 2018	EM-3404-HI	Hawai'i, Honolulu, Kaua'i, Maui
Hurricane Lane	September 27, 2018	DR-4395-HI	Hawai'i, Kaua'i, Maui
Hurricane Douglas	July 25, 2020	EM-3529-HI	Hawai'i, Honolulu, Kaua'i, Maui

Source: FEMA 2022

Event History

While hurricanes are relatively rare in the State of Hawai'i, records have shown that the storms can bring very heavy rainfall and strong, damaging winds that lead to storm surge and extremely high waves. The first officially recognized hurricane in the State of Hawai'i was Hurricane Hiki in August 1950. Since 1950, five tropical cyclones have caused serious damage in the state. Hurricane Nina (1957) produced record winds in the City and County of Honolulu. Hurricane Dot (1959) caused damage to the County of Kaua'i. Hurricane Estelle (1986) produced very high surf on the Islands of Hawai'i (County of Hawai'i) and Maui (County of Maui), and floods on the Island of O'ahu (City and County of Honolulu). The County of Kaua'i also received the brunt of Hurricane Iwa, which struck on November 23, 1982, and produced an estimated $234 million in damage (Storm Evolution and Energetics Research 2018). Hurricane Iniki was a Category 4 hurricane that hit the County of Kaua'i in September 1992, causing almost $2 billion in damages. In 2015, an El Niño year, the Central Pacific saw 15 named storms (eight hurricanes and five major hurricanes), making 2015 the most active season since 1970 (NOAA 2016).

Many sources provided hurricane and tropical storm information regarding previous occurrences and losses throughout the State of Hawai'i. The 2018 SHMP discussed specific hurricane and tropical storm events that occurred in the State of Hawai'i through 2017. For this 2023 SHMP Update, hurricane and tropical storm events were summarized between January 1, 2018 and December 31, 2022. Table 4.9-4 includes details of major hurricane and tropical storm events that occurred in the state between 2018 and 2022. Major events include those that resulted in losses or fatalities, as reported by NOAA National Centers for Environmental Information (NCEI), events that resulted in the activation of the state and/or County Emergency Operations Center (EOC), and/or events that led to a FEMA disaster declaration. For events prior to 2018, please refer to Appendix E (Hazard Profile Supplement).

Table 4.9-4. Tropical Storm and Hurricane Events in the State of Hawai'i, 2018 to 2022

Date(s) of Event	Event Type	Counties Affected	Description
August 22, 2018 – August 26, 2018	Hurricane Lane	Hawai'i, Honolulu, Kaua'i, Maui	With Hurricane Lane just west of the Big Island of Hawai'i, and south of Maui County and O'ahu, torrential rain fell over parts of the state, especially the Big Island. Flash flooding was the most serious weather problem, with parts of the Big Island seeing total rainfall of 40 to 50 inches. Strong winds also downed trees and power lines, leading to power outages on most isles. Parts of the Big Island got more than 4 feet of rain, triggering widespread flooding and washing out roads. At least 39 people were rescued from flood waters. The torrential rains overwhelmed three sewage pump stations, sending more than 9 million gallons of untreated sewage into Hilo Bay. On Maui, three wind-whipped wildfires quickly spread, forcing more than 300 people to evacuate and destroying more than 20 homes. More than 16 inches of rain fell on the island, which made three homes inaccessible after storm water and debris washed out a road. 45 utility poles and to be replaced due to the hurricane. Areas previously affected on Kaua'i by April's historic floods were flooded again. One individual died from drowning.
September 01, 2018 – September 14, 2018	Hurricane Olivia	Hawai'i, Honolulu, Kaua'i, Maui	Hurricane Olivia was the first tropical cyclone to make landfall on Maui and Lanai in recorded history. Olivia originated from a broad area of low pressure that formed several hundred miles southwest of Mexico on August 30.

Date(s) of Event	Event Type	Counties Affected	Description
			Olivia weakened into a tropical storm on September 11, before making brief landfalls in northwest Maui and Lāna‘i on the next day. Olivia was downgraded to a tropical depression on September 13. Maui reported over 8 inches of rain and many flooded areas. Several homes had to be evacuated along the Honoapiilani Highway. Several trees were knocked down on both Maui and Honolulu. Wind gusts up to 55 miles per hour were reported in Lāna‘i, while Honolulu saw wind gusts of 40 miles per hour.
July 30, 2019 – August 04, 2019	Hurricane Erick	Hawai‘i, Kaua‘i, Maui	Hurricane Erick was the first tropical cyclone of the season in the Central Pacific, moving into the basin from the east on July 30. Erick rapidly intensified to a major Category 4 hurricane later that day, then steadily weakened as it passed far south of the main Hawaiian Islands. Erick did not make a direct impact on the Hawaiian Islands; however, the then tropical storm did cause swells and high surf along the eastern and southern shores on the islands of Hawai‘i and Maui. Erick also contributed heavy rains on Hawai‘i and Kaua‘i Counties.
July 28, 2019 – August 07, 2019	Tropical Storm Flossie	Hawai‘i, Maui	Tropical Storm Flossie entered the basin on August 3 and approached Hawai’i from the east, eventually dissipating before reaching the islands. Flossie did not make a direct impact on the Hawaiian Islands; however, the tropical storm did cause swells and high surf along the eastern and southern shores on the islands of Hawai’i and Maui.
October 11, 2019 – October 16, 2019	Tropical Storm Ema	Papahānaumokuākea Marine National Monument	Tropical Storm Ema, the second cyclone to be named from the Central Pacific list of names, developed southwest of the main Hawaiian Islands on October 12. Ema dissipated over the southern portion of the Papahānaumokuākea Marine National Monument shortly before crossing between French Frigate Shoals and Maro Reef.
July 20, 2020 – July 30, 2020	Hurricane Douglas	Hawai‘i, Honolulu, Kaua‘i, Maui	Hurricane Douglas was a strong tropical cyclone that became the closest passing Pacific hurricane to the island of O‘ahu on record, surpassing the previous record held by Hurricane Dot in 1959. The eighth tropical cyclone, fourth named storm, first hurricane, and first major hurricane of the ongoing 2020 Pacific hurricane season, Douglas originated from a tropical wave, which entered the basin in mid-July. The southern eyewall of Douglas tracked just north of Maui, O‘ahu, and Kaua‘i, sparing those islands from seeing the worst of the hurricane's strong winds and heavy rainfall. Heavy rain and strong winds were apparent on Maui and Moloka‘i, but no major damage came to any of the Hawaiian Islands. Some trees fell across highways and Kamehameha Highway in O‘ahu was closed because of debris on the road. Most areas of Hawai‘i County, Maui County, and Kaua‘i County picked up 1 to 3 inches of rain from Douglas. Isolated wind gusts above 55 mph were clocked in a few areas, but, for the most part, gusts remained from 30 to 50 mph.
August 09, 2021 – August 24, 2021	Hurricane Linda	Hawai‘i, Honolulu, Kaua‘i, Maui	Hurricane Linda rapidly developed into a Category 4 hurricane off the southern coast of Mexico. As the storm approached the State of Hawai’i, it was a tropical storm, dropping to a tropical depression just a few days prior to making landfall. The post-tropical storm brought heavy rains and 20–30 mile per hour winds to the state.

Sources: NOAA 2023; NOAA 2022; Hawai’I News Now 2018; The Weather Channel 2018; Hawai’I News Now 2019; CDC 2021; NWS 2019
Note:
Hurricane documentation for the State of Hawai‘i is extensive, and not all sources have been identified or researched. Additionally, loss and impact information for many events could vary depending on the source. Therefore, the table may not include all events that have occurred in the state.

PROBABILITY OF FUTURE HAZARD EVENTS

Overall Probability

A myth in the State of Hawai'i is that the islands that constitute the County of Maui (the Islands of Moloka'i, Lāna'i, Kaho'olawe, and Maui) and the City and County of Honolulu (the Island of O'ahu) are less vulnerable to a direct hit by a hurricane than the Counties of Kaua'i and Hawai'i. This myth has developed because, until 1950, tropical storms hitting the Hawaiian Islands were not classified as hurricanes. It was not until the advent of weather satellites that the nature of storms in this part of the world was understood to be hurricanes (State of Hawai'i 2018). Since 1950, 30 tropical cyclones have passed within 200 nautical miles of the State of Hawai'i. All islands have been in the direct path of a tropical cyclone at least once (NOAA 2022).

In evaluating the potential for hazard events of a given magnitude, a return period is often used. This should be regarded as the inverse of the annual frequency of occurrence and not as a recurrence interval. For example, a return period of 1 in 250 years does not correspond to an event that will occur exactly every 250 years but to an event that has a 0.4% chance of occurring in any given year (World Meteorological Organization 2015). Utilizing the FEMA Hazus wind model, the peak gust wind speeds for a statewide 100-year mean return period (MRP) event ranges from 88 to 151 mph (Category 1 to 4 wind speeds); and the peak gust wind speeds for a statewide 500-year MRP event ranges from 105 to 173 mph (Category 2 to 5 wind speeds). Every hurricane will be unique and wind speeds will vary based on the storm track and present conditions.

Hurricane Hazard Scenarios

- **Wind** – To assess the state's vulnerability to the hurricane wind hazard, a statewide 500-year Mean Return Period (MRP) hurricane scenario was run in FEMA's Hazus wind model to estimate potential losses.
- **Storm Surge** – To assess the state's vulnerability to storm surge, the Category 4 SLOSH data was used to estimate exposure. The hazard area is called the Category 4 SLOSH Inundation Area.

The two datasets referenced above are not directly connected and should be used to evaluate vulnerability separately.

For the 2023 SHMP Update, the most up-to-date information was collected to calculate the probability of future occurrence of hurricane events, of all magnitudes, in the State of Hawai'i. Information from the 2018 SHMP, FEMA, NOAA-NCEI, and the National Hurricane Center were used to identify the number of hurricane events that occurred between 1950 and 2022 (NOAA 2022). Using these resources ensures the most accurate probability estimates possible. Based on historical statistics, the State of Hawai'i has a 68.5% chance of a hurricane of any magnitude (tropical storm, tropical depression, and Category 1 through 4 hurricanes) occurring within 60 nautical miles in any given year. Based on the historical record, the State of Hawai'i has experienced six FEMA declarations associated with hurricanes since 1954. Using these historic statistics, the state may expect to experience a hurricane event that leads to a FEMA declaration once every 11 years.

Climate Change Impacts

Hurricanes and tropical storms are projected to grow in average size and strength due to climate change and rise in sea level. Waves generated by these systems are anticipated to cause statewide coastal erosion and flooding, which will be worsened by sea level rise. More frequent El Niño events are also projected, increasing tropical cyclone activity and corresponding waves, flooding, and erosion for the state (Cai, et al. 2014). In addition, changes detected in the prevailing wind over the Hawaiian Islands, the northeast trade wind, may shift large-scale pressure and wind patterns that impact the State of Hawai'i (Garza, et al. 2012). The shift in trade winds may shift the track of future storm events such as tropical cyclones. For details regarding climate change as a distinct hazard and its unique impacts to the State of Hawai'i, refer to Section 4.2 (Climate Change and Sea Level Rise).

4.9.2 VULNERABILITY ASSESSMENT

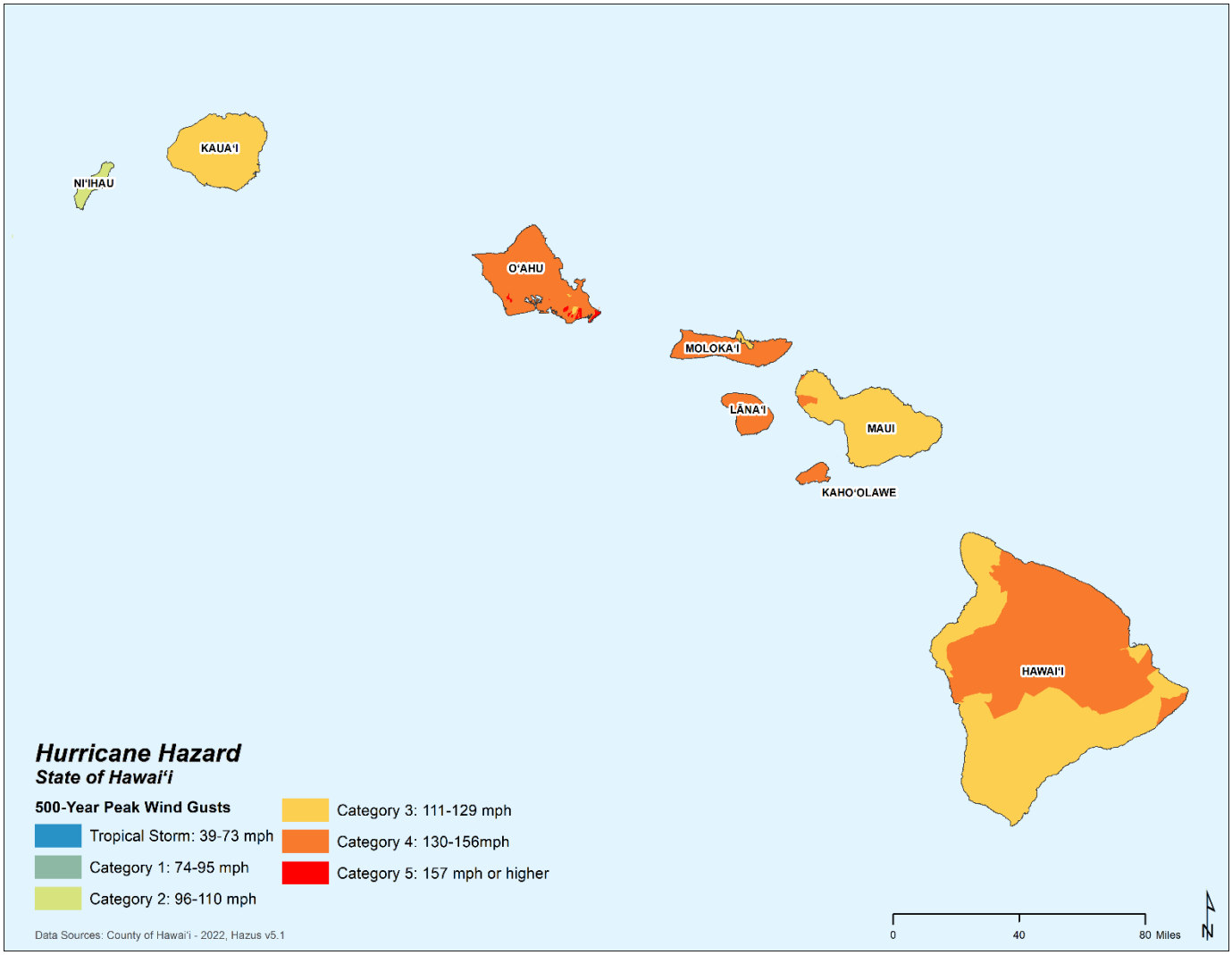
According to the *2015 Hawai'i Catastrophic Hurricane Plan/FEMA Region IX Hawai'i Catastrophic Annex*, a hurricane of any size and duration may pose a threat to the infrastructure, environment, and economy and impact the daily lives of residents (FEMA 2015). This is because of the state's geographic location and isolation, which requires high dependence on maritime cargo to maintain and sustain its economic vitality. In addition, the state is densely populated along its coastal shores. Thus, the state's population, property and economy are highly vulnerable to storm surge and high winds, which are the main threats of a hurricane. For the 2023 SHMP Update, two analyses were conducted to assess hurricane vulnerability:

1. For the wind component of the hurricane hazard, a statewide 500-year Mean Return Period (MRP) hurricane scenario (see Figure 4.9-5) was run in FEMA's Hazus wind model to estimate potential losses. This scenario was created for the *2015 Hawai'i Catastrophic Hurricane Plan/FEMA Region IX Hawai'i Catastrophic Annex*, with a specific storm track and wind speeds. Results are reported below. Four Category 4 county-specific hurricane scenarios were also run in Hazus, and general building stock losses and sheltering estimates are included in Appendix F (State Profile and Risk Assessment Supplement). Appendix D (Map Atlas) displays maps of the storm track and wind speeds associated with the four county-specific hurricane scenarios.

2. The NOAA National Hurricane Center provided the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model data for the State of Hawai'i. The storm surge inundation areas were created by multiple analysis runs for hurricanes approaching the State of Hawai'i from different directions and retaining the highest inundation value at a given location (the maximum of maximums) for each hurricane Category 1 through 4. The SLOSH data is a non-regulatory product, meaning it is not used to determine flood insurance rates. The data promotes storm surge risk awareness. This data was overlaid with the state assets to determine exposure to storm surge.

The two datasets referenced above are not directly connected. The wind data was used to determine general building stock losses, displaced households and shelter needs in the state resulting from a Category 4 hurricane. The storm surge data was used to determine exposure of state assets, critical facilities, population, general building stock, and environmental resources and culture assets to the hazard.

Figure 4.9-5. 500-year Mean Return Period Hurricane Statewide Scenario



Assessment of State Vulnerability and Potential Losses

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

State Assets

All state buildings are exposed to the wind and rain associated with a hurricane event. The spatial analysis utilizing the SLOSH data determined there are 654 state buildings (10.73%) located in the Category 4 SLOSH inundation area, of which the greatest number are located in the City and County of Honolulu (503 buildings with a replacement cost value of $2.807 billion). The majority of these buildings are occupied by the Department of Education. Table 4.9-5 summarizes the state buildings located in the Category 4 SLOSH inundation area by county; Table 4.9-6 summarizes by agency. Estimated potential losses to state buildings as a result of the storm surge Category 4 hurricane were not calculated as part of the 2023 SHMP Update.

Table 4.9-5. State Buildings Located in the Category 4 SLOSH Inundation Area by County

County	Total Number of State Buildings	Total Replacement Cost Value (structure and contents)	Number of State Buildings in Hazard Area	Percent (%) of Total State Buildings	Total Value of State Buildings in Hazard Area (structure and contents)	Percent (%) of Total Value
County of Kaua'i	531	$990,850,824	82	15.44%	$165,931,851	16.75%
City and County of Honolulu	3,472	$17,393,945,915	503	14.49%	$2,807,560,873	16.14%
County of Maui	831	$3,097,491,689	51	6.14%	$179,762,806	5.80%
County of Hawai'i	1,261	$4,638,567,141	18	1.43%	$87,811,399	1.89%
Total	**6,095**	**$26,120,855,568**	**654**	**10.73%**	**$3,241,066,929**	**12.41%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; State of Hawai'i Risk Management Office 2017

Table 4.9-6. State Buildings Located in the Category 4 SLOSH Inundation Area by Agency

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent (%) of Total State Buildings	Value in the Hazard Area	Percent (%) of Total Value
Dept of Accounting & General Services	66	$953,963,738	11	16.67%	$162,105,561	16.99%
Dept of Agriculture	70	$147,607,399	13	18.57%	$25,977,208	17.60%
Dept of Attorney General	15	$108,425,480	4	26.67%	$31,246,321	28.82%
Dept of Budget & Finance	16	$28,968,679	3	18.75%	$21,515,418	74.27%
Dept of Business, Economic Development and Tourism	25	$645,480,379	6	24.00%	$560,518,082	86.84%
Dept of Commerce & Consumer Affairs	2	$40,197,360	0	0.00%	$0	0.00%
Dept of Defense	69	$267,352,836	9	13.04%	$29,801,107	11.15%
Dept of Education	4,090	$10,598,205,739	403	9.85%	$902,271,366	8.51%
Dept of Hawaiian Home Lands	12	$110,427,352	1	8.33%	$5,489,080	4.97%
Dept of Health	44	$387,068,440	3	6.82%	$7,922,830	2.05%
Dept of Human Resources Development	1	$5,973,872	0	0.00%	$0	0.00%
Dept of Human Services	130	$480,212,294	29	22.31%	$178,734,660	37.22%
Dept of Labor and Industrial Relations	22	$90,076,209	4	18.18%	$59,693,544	66.27%
Dept of Land and Natural Resources	90	$101,441,821	26	28.89%	$13,075,258	12.89%
Dept of Public Safety	154	$440,774,415	15	9.74%	$36,397,935	8.26%
Dept of Taxation	1	$7,174,162	1	100.00%	$7,174,162	100.00%
Dept of Transportation	68	$2,935,208,214	40	58.82%	$397,604,634	13.55%
Hawai'i State Ethics Commission	1	$984,533	0	0.00%	$0	0.00%
Hawai'i Health Systems Corporation	106	$1,230,852,871	1	0.94%	$936,734	0.08%
Hawai'i Housing Finance & Development Corporation	86	$360,851,671	5	5.81%	$118,247,972	32.77%
Hawai'i Public Housing Authority	273	$982,981,701	37	13.55%	$85,423,311	8.69%
Hawai'i State Legislature	2	$48,555,381	0	0.00%	$0	0.00%
Hawai'i State Public Library System	53	$525,584,082	11	20.75%	$32,473,857	6.18%

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent (%) of Total State Buildings	Value in the Hazard Area	Percent (%) of Total Value
Judiciary	41	$534,877,354	7	17.07%	$75,272,153	14.07%
Legislative Reference Bureau	1	$2,996,162	0	0.00%	$0	0.00%
Office of Hawaiian Affairs	11	$54,125,645	6	54.55%	$43,013,415	79.47%
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	19	2.98%	$446,172,321	8.90%
Total	**6,095**	**$26,120,855,568**	**654**	**10.73%**	**$3,241,066,929**	**12.41%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; State of Hawai'i Risk Management Office 2017

Roads and bridges are also considered critical infrastructure, particularly those providing ingress and egress for evacuees and those allowing emergency vehicles access to those in need. Throughout the state, roads may become flooded as a result of storm surge inundation. The roads may be undermined or fully submerged under water for a period, thus degrading the integrity of the road and isolating population and communities. Sometimes the damage is apparent—a road that washes away, a sinkhole that appears, a bridge that crumbles—but often the damage is less obvious on the surface. Table 4.9-7 summarizes the length of state road in the Category 1 through 4 hurricane storm surge inundation areas by county. While the County of Hawai'i has the most total length in square miles at 379.2, it is the City and County of Honolulu that has the most length exposed to SLOSH inundation areas for each category hurricane. A complete list of state roads located in Category 1 through 4 hurricane storm surge inundation areas is included in Appendix F (State Profile and Risk Assessment Supplement).

Table 4.9-7. State Roads Exposed to SLOSH Inundation Areas by County

County	Total Length (Sq. Miles)	Category 1 Hurricane		Category 2 Hurricane		Category 3 Hurricane		Category 4 Hurricane	
		Length	Percent (%) of Total	Length	Percent (%) of Total	Length	Percent (%) of Total	Length	Percent (%) of Total
County of Kaua'i	103.7	2.5	2.41%	4.2	4.05%	9	8.68%	12.4	11.96%
City and County of Honolulu	374.9	14.6	3.89%	26.7	7.12%	34.3	9.15%	43.4	11.58%
County of Maui	245.9	7.4	3.01%	11.9	4.94%	17.2	6.99%	20.2	8.21%
County of Hawai'i	379.2	0.1	0.03%	0.1	0.03%	0.4	0.11%	1.7	0.45%
Total	**1,103.70**	**24.6**	**2.23%**	**42.9**	**3.89%**	**60.9**	**5.52%**	**77.7**	**7.04%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; State of Hawai'i Department of Transportation 2022

Community Lifelines and Critical Facilities

A hurricane could have significant impacts on community lifelines and critical facilities including airports, harbors, transportation and utility infrastructure and other public services. The interruption of these critical services and operations utility will impact resident and visitor travel, and all forms of economic activity. According to the O'ahu Metropolitan Planning Organization *Transportation Asset Climate Change Risk Assessment* report, in terms of vessels, there is sufficient warning time associated with a hurricane to direct out to sea until the storm passes. Of greater concern is the effect of storm surge on the piers and storage areas, as well as containers that could fall into Honolulu Harbor, blocking ships from accessing the piers themselves. The largest disruption would be to the supply chain (i.e., food, goods materials and fuel) with cascading impacts statewide (SSFM International 2011).

The Port of Honolulu is the single major supply port for the state. All petrol products arrive by sea. In addition, millions of tons of food and supplies enter the port each year. The ports and electrical systems are interdependent and a disaster event such a hurricane that may close or damage port assets will result in impacts cascading throughout the state (State of Hawai'i 2018).

The Honolulu International Airport is the largest airport in the state and accommodates approximately 60% of the state's air passengers. The airport is approximately 13 feet above sea level. In the event of a severe hurricane event, it is estimated the airport would experience one-to-two-week downtime from commercial flights and one to three days of downtime for emergency response. Due to the City and County of Honolulu's population, tourism, and employment base, damage to the airport could have long-term, devastating social and economic consequences to the island and the entire state (SSFM International 2011).

Table 4.9-8 and Table 4.9-9 summarize the community lifelines and critical facilities in the Category 4 SLOSH inundation area. The City and County of Honolulu has the largest number of community lifelines (129) located within the Category 4 SLOSH inundation area. The food, water, shelter, safety and security, and communications categories have the greatest number of facilities exposed. Additional Category 1 through 3 hurricane storm surge analyses on critical facilities are included in Appendix F. Economic loss resulting from impacts to critical facilities was not monetized as part of the 2023 SHMP Update.

Table 4.9-8. Community Lifelines and Critical Facilities Located in the Category 4 SLOSH Inundation 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	1	2	10	0	0	8	2	23	2
City and County of Honolulu	27	22	45	1	6	26	2	129	5
County of Maui	3	0	12	0	5	10	7	37	1
County of Hawai'i	0	1	10	1	0	1	5	18	2
Total	**31**	**25**	**77**	**2**	**11**	**45**	**16**	**207**	**10**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020

Table 4.9-9. Community Lifelines and Critical Facilities Located in the Category 4 SLOSH Inundation Areas, by Category

Category	Total Number of Facilities	Total Replacement Cost Value	Number of Facilities in Hazard Area	Percent of Total Facilities	Value in the Hazard Area	Percent (%) of Total Value
Communications	188	$776,797,683	31	16.49%	$94,805,112	12.20%
Energy	89	$3,093,949,530	25	28.09%	$865,785,050	27.98%
Food, Water, Shelter	345	$11,847,189,588	77	22.32%	$2,604,539,490	21.98%
Hazardous Material	12	$436,474,800	2	16.67%	$73,534,800	16.85%
Health and Medical	193	$4,606,713,364	11	5.70%	$118,029,014	2.56%
Safety and Security	486	$38,164,188,232	45	9.26%	$3,159,828,837	8.28%
Transportation	56	$2,039,091,600	16	28.57%	$582,597,600	28.57%
Additional Critical Facilities	106	$447,698,794	10	9.43%	$39,426,004	8.81%
Total	**1,475**	**$61,412,103,591**	**217**	**14.71%**	**$7,538,545,906**	**12.28%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020

Assessment of Local Vulnerability and Potential Losses

For this vulnerability assessment, it is assumed that the entire State of Hawaii's resident and visitor population and property is exposed to the hurricane hazard, though the impact of a hurricane/tropical cyclone on life, health, and safety is dependent upon several factors, including the severity of the event and whether or not adequate warning time was provided.

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 HMP combines tropical cyclones and high winds into one hazard. The County of Kaua'i included a qualitative assessment of risks presented by tropical cyclones, including storm surge, wind damage, and rainfall/flooding. Tropical cyclone storm surge impacts were assessed using storm surge inundation mapping for a Category 4 hurricane, as determined using the NOAA National Hurricane Center's SLOSH (Sea, Lake and Overland Surges from Hurricanes) methodology. The County performed a Level 2 Hazus analysis for a Category 4 hurricane and found that over 14,100 households would be displaced, and total losses would amount to more than $9.1 billion (County of Kaua'i 2020).
- **City and County of Honolulu** – The City and County of Honolulu included a qualitative assessment of risks presented by tropical cyclones, including storm surge and wind damage. The HMP discusses the vulnerability of different housing types to wind damage. A Hazus-MH study found that Average Annualized Loss is $140 million. (City and County of Honolulu 2020).
- **County of Maui** – The Maui County HMP combines hurricanes, tropical storms, and Kona storms into one hazard. The County of Maui included a qualitative assessment of risks presented by hurricanes, including storm surge, wind damage, and rainfall/flooding. 34 critical facilities were found to be in the storm surge area in Maui County. Additionally, the HMP lists residents who are most vulnerable to flood risk, including single parent and dependent households, residents living below the poverty line, residents without adequate communication infrastructure and/or limited English proficiency, residents living in properties built prior to the 1950s, and residents with limited mobility (County of Maui 2020).

- **County of Hawai'i** – The County of Hawai'i included a qualitative assessment of risks presented by tropical cyclones, including three major categories of threat: storm surge, wind damage, and rainfall/flooding. The HMP used Hazus to model wind and storm surge for a Category 4 storm. Population impacts were found to be county-wide for wind damage; 1,081 residents would be impacted by storm surge. 523 critical facilities would be impacted by a Category 4 storm, with over $11.2 billion in property damages. Socially vulnerable populations, such as the economically disadvantaged and elderly, were found to be at particular risk (County of Hawai'i 2020).

Socially Vulnerable and Total Population

The entire population in the state is vulnerable to the hurricane hazard. Downed trees, damaged buildings, and debris carried by high winds can lead to injury or loss of life. Storm surge inundation is a significant threat to the population along the coast. To estimate the population that may be impacted by a Category 4 hurricane event, the FEMA Hazus wind model was used to estimate displacement and sheltering needs, and the SLOSH Category 4 spatial layer was used to estimate the population along the coast located in the inundation area. It is recognized that combining the population from these separate analyses may overestimate the vulnerable population. Refer to Table 4.9-10.

Table 4.9-10. Estimated Population Impacted by a Category 4 Hurricane

County	Total Population	SLOSH Category 4			
		Total Population Located in the Storm Surge Area	Population Exposed as Percent (%) of Total Population	Socially Vulnerable Population Located in Hazard Area	Socially Vulnerable Population Exposed as Percent (%) of Total Population
County of Kaua'i	71,949	2,462	3.42%	189	0.26%
City and County of Honolulu	979,682	135,313	13.81%	29,010	2.96%
County of Maui	167,093	3,755	2.25%	812	0.49%
County of Hawai'i	201,350	1,092	0.54%	309	0.15%
Total	**1,420,074**	**142,622**	**10.04%**	**30,320**	**2.14%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018

As a result of the statewide Category 4 Hazus wind analysis, the City and County of Honolulu has the greatest number of estimated displaced households and the greatest number of short-term sheltering needs. These sheltering estimates are based on Census population. This analysis does not include the tourist, visitor, and homeless populations in the state and therefore sheltering needs may be higher.

Socially vulnerable populations are most susceptible based on many factors, including their physical and financial ability to react or respond during a hazard and the location and construction quality of their housing. Economically disadvantaged populations are likely to evaluate their risk and make decisions based on the major economic impact to their family and may not have funds to evacuate. Vulnerable populations are the elderly, low income or linguistically isolated populations, people with life threatening illnesses, and residents living in areas that are isolated from major roads. Power outages can be life-threatening to those dependent on electricity for life support and are a significant concern. These populations face isolation and exposure during hurricanes and could suffer more secondary effects of the hazard.

Floods resulting from a hurricane and its aftermath present numerous threats to public health and safety, including unsafe food, contaminated drinking and washing water and poor sanitation, mosquitoes and animals, mold and mildew, carbon monoxide poisoning, and mental stress and fatigue. Refer to Section 4.6 (Flood) for further details on these impacts. Current loss estimation models such as Hazus are not equipped to measure public health impacts. The best preparation for these effects includes awareness that they can occur, education of the public on prevention, and planning to deal with them during responses to hurricane events.

Land Use Districts

Table 4.9-11 summarizes the area and percent of total area in each state land use district statewide exposed to the Category 4 hurricane storm surge inundation area; Appendix F shows results by county. More than 11% of the Urban District land in the state is exposed to storm surge impacts from a Category 4 hurricane, especially when considering that only 2.5% of the Urban District land area statewide is located in coastal high hazard areas with mandatory construction standards that account for wave action (see Section 4.6 Flood for more information). Only a very small amount of Conservation District lands are exposed statewide. Conservation District Lands contain valuable environmental resources. Additional discussion of exposure and vulnerability of these resource areas can be found in the Environmental Resources section below.

Table 4.9-11. State Land Use Districts Located in Category 4 SLOSH Inundation Area

Land Use District	Total (square miles)	Square Miles in Category 4 SLOSH Area	% of Total Area
Agricultural	2,973.6	17.9	0.60%
Conservation	3,202.9	11.7	0.37%
Rural	16.3	1.3	7.96%
Urban	319.1	37.0	11.59%
Total	**6,511.95**	**67.9**	**1.04%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; State Land Use Commission, Hawai'i Statewide GIS Program 2021; Honolulu County GIS 2022

General Building Stock

All structures in the state are exposed to the hurricane hazard. Hurricane-force winds (74 mph or higher) can destroy buildings and mobile homes. Street signs, roofing material, siding and small items left outside become flying objects during a storm and not only cause property damage but may injure residents. Exposure is particularly severe along the coastline and in areas prone to riverine flooding due to the heavy rains that accompany these storm events and/or high wind gusts. Damages to buildings can displace people from their homes, threaten life safety and impact a community's economy and tax base.

Once all counties adopt the Hawai'i State Building Code, it requires new structures to be built to withstand a Category 3 hurricane wind speed. The Category 4 hurricane storm surge inundation areas may extend beyond the boundaries of regulatory flood zones discussed in Section 4.6, meaning that currently enforced standards offer some level of protection but are likely not sufficient to prevent damage from a Category 4 hurricane in many areas. Information regarding the year built and current building conditions was not factored into this analysis.

Table 4.9-12 summarizes the number of buildings located in the Category 4 storm surge inundation area based on the spatial analysis and the estimated potential losses to structures from Category 4 winds generated by Hazus. Overall, the City and County of Honolulu has the highest percent (21.52%) of building exposure to Category 4 hurricane storm inundation, followed by the County of Kaua'i (11.07% of the county total building stock replacement cost value). The Hazus wind analysis estimates greater than $51 billion in potential building loss in the City and County of Honolulu as a result of the Category 4 hurricane scenario evaluated. All counties are estimated to experience millions in building damages.

Table 4.9-12. General Building Stock Exposure to SLOSH Category 4

County	Total RCV	SLOSH Category 4	
		RCV in Cat 4 SLOSH area	Percent (%) of Total RCV
County of Kaua'i	$24,246,497,228	$2,685,058,109	11.07%
City and County of Honolulu	$239,152,051,766	$51,463,869,170	21.52%
County of Maui	$50,796,693,140	$3,597,621,126	7.08%
County of Hawai'i	$58,395,349,136	$1,113,740,437	1.91%
Total	**$372,590,591,270**	**$58,860,288,842**	**15.80%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; NIYAM IT 2022; United States Army Corps of Engineers 2022

Environmental Resources

The state has numerous environmental resources along the shore, including beaches, wetlands, critical habitats (habitats that are essential for an endangered or threatened species) and parks and reserves. Further, natural features such as coral reefs, wetlands, beaches, and dunes provide protection from storms and rising sea levels (Virginia Institute of Marine Science n.d.). Impacts to these assets will not only damage the natural environment but also have cascading impacts on the economy. Refer to the *Hawai'i Sea Level Rise Vulnerability and Adaptation Report*, which further outlines impacts of flooding, storm surge, and sea level rise on the natural environment, including coral reefs and endangered and threatened species such as the Hawaiian monk seal and Hawaiian green turtle. Table 4.9-13 summarizes the environmental assets located in the Category 4 hurricane storm surge area.

Table 4.9-13. Environmental Assets Located in the Category 4 SLOSH Storm Surge Inundation Area

Environmental Asset	Statewide		
	Total Square Miles of Asset	Square Miles in Hazard Area	% of Total Asset Area
Critical Habitat [a]	951	1	0.1%
Wetlands	3,637	22	0.6%
Parks and Reserves	2,778	9	0.3%
Reefs [b]	55	1	2.4%
Total [c]	**7,420**	**33**	**3.4%**

Source: U.S. Fish and Wildlife Service, Pacific Islands Office, 2022, U.S. Fish and Wildlife Service 2021; 2017; Hawai'i State Department of Land and Natural Resources, Division of Forestry and Wildlife 2022; NOAA raster nautical charts 2020; State of Hawai'i Department of Land and Natural Resources, Division of State Parks 2021; Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration

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.*

Due to its geographic location and isolation, the state faces unique challenges in addressing disaster debris. With limited landfill capacity, advanced planning for large amounts of debris generated by a hurricane, which will include both tree debris and construction debris, is critical.

Cultural Assets

Cultural and historical resources are located near the shore and vulnerable to storm surge inundation. Beaches may erode, impacting fishing and cultural practices. Portions of the Hawaiian Home Lands may become flooded due to storm surge inundation. Table 4.9-14 summarizes the area of Hawaiian Home Lands located in the SLOSH Category 1 through 4 hurricane storm surge inundation areas. While the County of Hawai'i has the largest total area of Hawaiian Home Lands, the County of Maui has the largest area of Hawaiian Home Lands in each of the hurricane storm surge inundation categories. Table 4.9-15 summarizes the cultural resources located in the SLOSH Category 1 through 4 storm surge inundation areas. The cultural resource type with the largest total area and largest area in each of the storm surge inundation areas in the Historic District.

Table 4.9-14. Hawaiian Home Lands Located in the SLOSH Category 1 through 4 Hurricane Storm Surge Inundation Areas

County	Area (in square miles)								
	Total Area	Cat 1 Hazard Area	Hazard Area as % of Total Area	Cat 2 Hazard Area	Hazard Area as % of Total Area	Cat 3 Hazard Area	Hazard Area as % of Total Area	Cat 4 Hazard Area	Hazard Area as % of Total Area
County of Kaua'i	32.1	0.2	0.5%	0.2	0.7%	0.4	1.2%	0.4	1.3%
City and County of Honolulu	10.6	0.05	0.4%	0.1	0.6%	0.1	1.2%	0.2	1.5%
County of Maui	102.6	1.4	1.4%	1.6	1.6%	1.7	1.7%	1.8	1.7%
County of Hawai'i	191.5	0.05	<0.1%	0.1	0.0%	0.1	0.1%	0.2	0.1%
Total	**336.7**	**1.7**	**0.5%**	**2.0**	**0.6%**	**2.3**	**0.7%**	**2.5**	**0.7%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; Hawai'i State Department of Hawaiian Homelands 2021

Table 4.9-15. Cultural Resources Located in the SLOSH Category 1 through 4 Storm Surge Inundation Areas

Cultural Resource Site Type	Area in square miles								
	Total Area	Cat 1 Hazard Area	Hazard Area as % of Total Area	Cat 2 Hazard Area	Hazard Area as % of Total Area	Cat 3 Hazard Area	Hazard Area as % of Total Area	Cat 4 Hazard Area	Hazard Area as % of Total Area
Archaeology	90.9	2.7	3.0%	4.5	5.0%	6.6	7.2%	7.4	8.2%
Burial Sensitivity Area	2.1	0.1	3.2%	0.1	4.4%	0.1	5.7%	0.1	6.9%
Historic Building	2.7	0.1	4.4%	0.2	6.8%	0.2	9.3%	0.3	12.8%
Historic District	849.4	5.8	0.7%	8.2	1.0%	10.8	1.3%	13.6	1.6%

Cultural Resource Site Type	Area in square miles								
	Total Area	Cat 1 Hazard Area	Hazard Area as % of Total Area	Cat 2 Hazard Area	Hazard Area as % of Total Area	Cat 3 Hazard Area	Hazard Area as % of Total Area	Cat 4 Hazard Area	Hazard Area as % of Total Area
Historic Object	9.6	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Historic Structure	20.7	0.0	0.2%	0.1	0.4%	0.2	0.9%	0.3	1.4%
Total	**975.4**	**8.7**	**0.9%**	**13.1**	**1.3%**	**17.9**	**1.8%**	**21.8**	**2.2%**

Source: Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration; Department of Land and Natural Resources, Hawai'i State Historic Preservation Division 2022

Future Changes that May Impact State Vulnerability

Understanding factors of change 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 conditions identified as relevant and appropriate, including the impacts of climate change.

Potential or Projected Development

Category 4 storm surge inundation areas were overlain on areas that may experience significant changes in development or redevelopment in future years [see Table 4.9-16; refer to Section 3 for more information on projected development areas; see Appendix F (State Profile and Risk Assessment Supplement) for Category 1 through 3]. The results of this analysis indicate that significant amounts of the Hawai'i Community Development Authority (HCDA) Community Development District areas are exposed to storm surge from a Category 4 hurricane event. In addition, development in coastal areas of the Enterprise Zones throughout the state would be impacted. The Category 4 hurricane storm surge inundation areas may extend beyond the boundaries of regulatory flood zones discussed in Section 4.6 (Flood), meaning that currently enforced standards offer some level of protection, but are likely not sufficient to prevent damage from a Category 4 hurricane in many areas. This is especially important for areas that experience 1.5 feet or greater wave heights due to their damaging effects on structures.

Table 4.9-16. HCDA Community Development Districts, Maui Development Projects, and Enterprise Zones Located in Category 4 SLOSH Hurricane Areas

County	Area (in square miles)								
	HCDA Community Development Districts (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	10.3	4.10%
City and County of Honolulu	7.4	1.4	18.92%	0	0	0	297.3	16.3	5.48%
County of Maui	0	0	0	27.6	0.1	0.18%	1,059.80	11.6	1.09%
County of Hawai'i	0	0	0	0	0	0	1,274.90	3.5	0.27%
Total	**7.4**	**1.4**	**18.92%**	**27.6**	**0.1**	**0.18%**	**2,883.00**	**41.7**	**1.45%**

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; Federal Emergency Management Agency; National Weather Service; National Oceanic and Atmospheric Administration

In addition to storm surge, any new development will be subject to impacts from winds associated with a hurricane event. Building codes for new construction in the state require greater protection from high wind events than those codes that were previously enforced in the state.

Projected Changes in Population

As the population in the state ages, additional resources may be needed to support evacuation efforts in advance of a hurricane and to support emergency power for medically necessary equipment during and after an event.

Other Factors of Change

As sea levels rise, storm surge will reach further inland putting more people and property at risk. The storm surge modeling used for this assessment did not include projected sea level rise; however, increased exposure to storm surge and coastal flooding as a result of sea level rise is discussed in Section 4.2 (Climate Change and Sea Level Rise).

Hurricane Hazard Mitigation Success Story

Credit: HI-EMA

Federal funds through two different disaster declarations allowed the Honolulu Fire Department to install hurricane-resistant doors on the Waikīkī Fire Station 7. Existing aluminum doors were replaced with anodized aluminum doors, which provide higher protection from hazards, especially high winds and projectiles during severe weather conditions which will allow the fire department to provide uninterrupted essential services.

The Waikīkī Fire Station 7 is the primary response station for the Waikīkī area. The station covers nearly 29 street miles containing high-, mid-, and low-rise hotels, residential condominiums and several schools. The station serves an approximate population of 32,000, including some of the most vulnerable members of the community (HI-EMA 2021).