SECTION 4. RISK ASSESSMENT

4.11 Hurricane

2018 HMP Update Changes

- The hazard profile has been significantly enhanced to include a detailed hazard description, location, extent, previous occurrences, and probability of future occurrence (including climate change). New and updated figures from federal and state agencies are incorporated.
- This hazard name has changed to Hurricane from Tropical Cyclones to correspond with the State's Threat Hazard Identification and Risk Assessment (THIRA) but will still include information regarding hurricanes and tropical storms.
- Hurricane and tropical storm events that occurred in the State of Hawai'i from January 1, 2012, through December 31, 2017, were researched for this 2018 HMP Update.
- The following have been analyzed: hurricane storm surge and high wind areas per county for exposure to geocoded state assets, critical facilities, population, general building stock, and environmental resources and cultural assets.

4.11.1 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 2018 HMP 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 4.3 (Chronic Coastal Flood) for annual high waves, coastal erosion, and tidal flooding; Section 4.7 (Event-Based Flood) for coastal flooding; and Section 4.10 (High Wind Storm) for high winds.

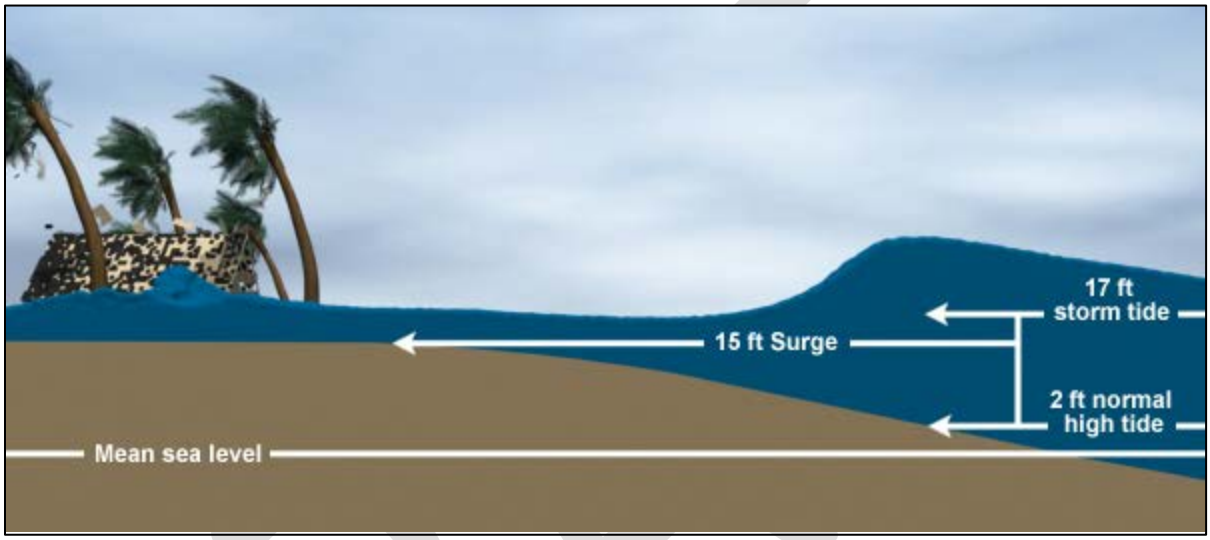
Hazard Description

A tropical cyclone is a rotating, organized system of clouds and thunderstorms that originates over tropical or sub-tropical 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 2013). 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. 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 with storm surge coincides with normal high tide (National Hurricane Center 2018) (Figure 4.11-1).

Figure 4.11-1. Storm Surge



Source: National Hurricane Center 2018

All types of tropical cyclones often 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 actually 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 2018a).

Heavy Rain

Hurricanes and other tropical cyclones often produce widespread, torrential rains in excess of six inches, which may result in deadly and destructive flooding. 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 2018b).

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 section of this profile for details regarding the Saffir-Simpson Scale (National Hurricane Center 2018b).

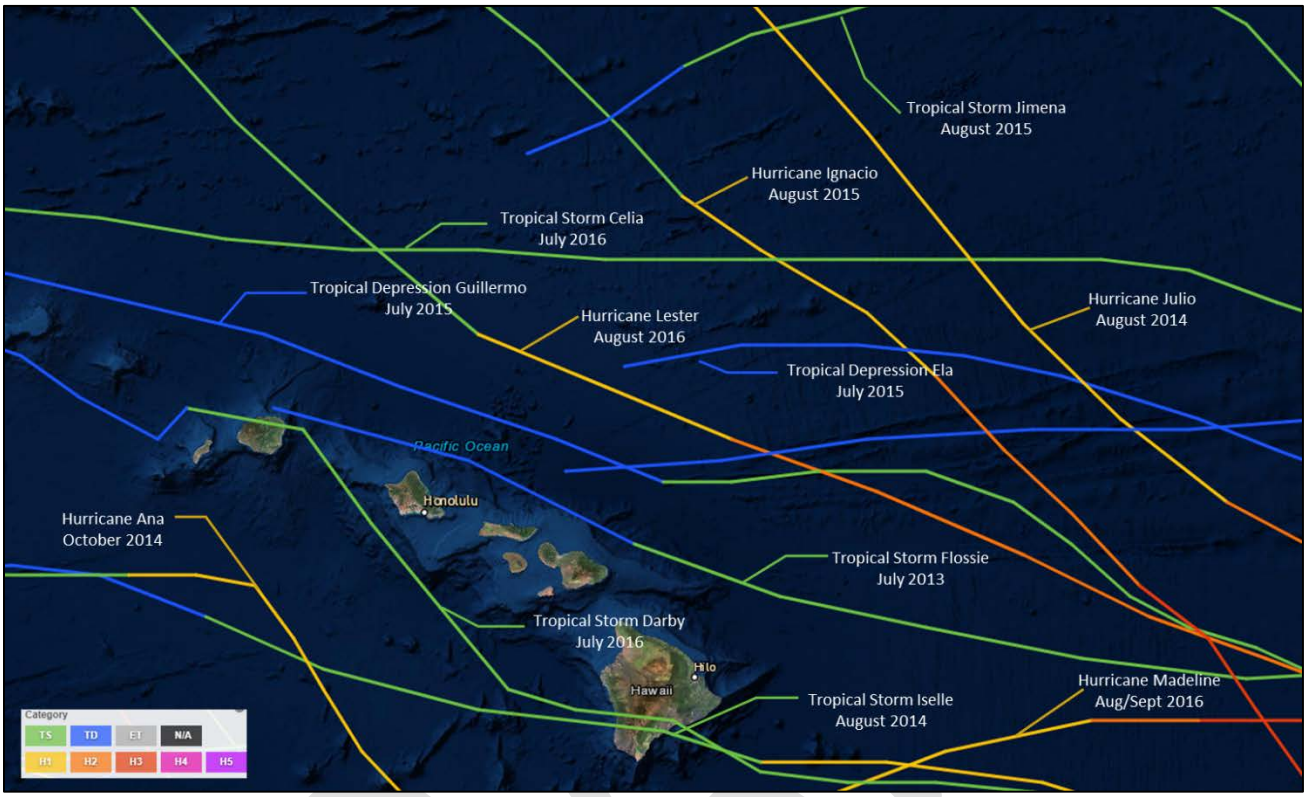
Microbursts and mini-swirls are small, localized wind bursts that can reach speeds of greater than 200 mph. During Hurricane Iniki, damage patterns and debris indicated that there were more than 26 microbursts (sudden intense downdrafts) and two mini-swirls (a violent whirlwind, not tornado) that occurred in the County of Kaua‘i (Hawai‘i State HMP 2013).

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. Every county in the state has been affected by hurricanes and each are at risk to damages from these storms (USGS 2002). 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, are also at risk to flooding because of heavy rains associated with the storms. Refer to Section 4.6 (Event Based Flooding) 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 2016 (latest date available from data source). Figure 4.11-2 displays tropical cyclone tracks for the Central Pacific, which includes the State of Hawai‘i. The figure shows tropical cyclone events that occurred between 2002 and 2016.

Figure 4.11-2. Historical Tropical Storm and Hurricane Tracks, 2002 to 2016



Source: National Hurricane Center 2018

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 4.11-1). 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 preventative measures (NOAA 2013b).

Table 4.11-1. Saffir-Simpson Hurricane Scale

Category	Wind Speed (miles per hour [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 Dot

Category	Wind Speed (miles per hour [mph])	Storm Surge (feet)	Expected Damage
			(landfall on Kaua‘i in 1959) 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 material, 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 Jeanne (2004, 120 mph landfall in southeast Florida) 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	>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 Hawai‘i. Elsewhere in the United States, Hurricane Camille (1969, 190 mph at landfall in Mississippi) and Hurricane Andrew (1992, 165 mph at landfall in Southeast Florida) are examples of Category 5 hurricanes at landfall.

Source: Central Pacific Hurricane Center 2017; University of Hawai‘i 2012
> Greater than

As stated earlier, storm surge inundation from hurricanes can be devastating to areas along the coastline. Table 4.11-2 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 has the greatest number of square miles that may be inundated by storm surge.

Table 4.11-2. Storm Surge Inundation Area by County

County	Area (in square miles)								
	Total County Area	Cat 1	Cat 1 Area as % of Total Area	Cat 2	Cat 2 as % of Total Area	Cat 3	Cat 3 as % of Total Area	Cat 4	Cat 4 as % of Total Area
County of Kaua'i	620.0	4.5	0.7%	5.8	0.9%	10.1	1.6%	12.2	2.0%
City and County of Honolulu	600.7	10.9	1.8%	22.3	3.7%	31.8	5.3%	38.2	6.4%
County of Maui	1,173.5	5.8	0.5%	7.9	0.7%	9.8	0.8%	11.4	1.0%
County of Hawai'i	4,028.4	1.9	0.0%	2.5	0.1%	3.7	0.1%	5.3	0.1%
Total	**6,422.6**	**23**	**0.4%**	**39**	**0.6%**	**55**	**0.9%**	**67**	**1.0%**

Notes: Cat 1 Category 1 Hurricane
Cat 2 Category 2 Hurricane
Cat 3 Category 3 Hurricane
Cat 4 Category 4 Hurricane
Source: NOAA National Hurricane Center 2018

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.

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).

Previous Occurrences and Losses

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 2015).

Many sources provided hurricane and tropical storm information regarding previous occurrences and losses throughout the State of Hawai‘i. The 2013 HMP discussed specific hurricane and tropical storm events that occurred in the State of Hawai‘i through 2012. For this 2018 HMP Update, hurricane and tropical storm events were summarized between January 1, 2012, and December 31, 2017. Table 4.11-3 includes details of major hurricane and tropical storm events that occurred in the state between 2012 and 2017. 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 2012, please refer to Appendix X.

Table 4.11-3. Tropical Storm and Hurricane Events in the State of Hawai‘i, 2012 to 2017

Date(s) of Event	Event Type	Counties Affected	Description
July 26 to 30, 2013	Tropical Storm Flossie	Maui and Hawai‘i	Tropical Storm Flossie affected the state, bringing high surf, thunderstorms, heavy rain, flash flooding and strong winds. Strong winds downed trees and power lines across the State, closing roads and leading to power outages. Widespread power outages were reported on the Islands of Hawai‘i, Maui and Moloka‘i. There were several injuries reported due to lightning strikes. The state EOC was activated during this event. Total cost of damages was not readily available for this event.
August 4 to 21, 2014	Tropical Storm Iselle (FEMA-DR-4194)	City and County of Honolulu, Maui, and Hawai‘i	Tropical Storm Iselle brought heavy rain, strong winds, downed trees and wires, and widespread power outages. Overflowing streams flooded roadways in throughout the State of Hawai‘i. There were over 200 reports of damage to homes and businesses and over 100 reports of infrastructure issues (downed utility poles and power lines; damaged roadways). Agriculture was heavily impacted by the storm with approximately 50% of the state’s papaya crop destroyed (an estimated $55 million loss). The storm also caused damage to other crops; including flowers, macadamia nuts, and coffee. Estimated total losses ranged from $148 million to $325 million. On September 5, 2014, Governor Neil Abercrombie requested a major disaster declaration due to Tropical Storm Iselle during the period of August 7 to 9, 2014. The Governor requested a declaration for public assistance for three counties and hazard mitigation statewide. On September 12, 2014, President Obama declared that a major disaster existed in the State of Hawai‘i. The declaration made public assistance available to state and eligible local governments and certain private non-profit organizations on a cost-sharing basis for emergency work and the repair or replacement of facilities damaged by the Tropical Storm Iselle in the City and County of Honolulu, County of Maui, and County of Hawai‘i. Total public assistance was estimated at over $8 million, with over $4.9 million obligated.
October 13 to 19, 2014	Hurricane Ana	Kaua‘i and Hawai‘i	Hurricane Ana brought heavy rain to the Counties of Kaua‘i and Hawai‘i. The system also generated isolated thunderstorms that moved westward. The swell from the hurricane produced high surf that ranged from 8 to 15 feet along the south shores of the islands. Roads were closed throughout the impacted areas due to flash flooding. The state EOC was fully activated as a result of this event. Overall, there were no reports of significant property damage or injuries associated with Hurricane Ana.
July 31 to August 5, 2015	Tropical Storm Guillermo	Kaua‘i, Maui, and Hawai‘i	A swell from Tropical Storm Guillermo produced surf of 10 to 20 feet along the east-facing shores of the Islands of Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i. The high surf forced county officials to close beaches in the Counties of Maui and Hawai‘i. The high water also brought debris onto coastal roads near inundated areas. There were no reports of significant property damage or injuries associated with Tropical Storm Guillermo. County EOCs were partially activated as a result of this event.
August 20 to 24, 2015	Hurricane Kilo	Honolulu, Maui, and Hawai‘i	On August 20, 2015, from west to east, Hurricane Kilo was located 1,200 miles west-southwest of the City and County of Honolulu. It passed over the southern end of the state, bringing heavy rain, thunderstorms, and flash flooding to the area. Many roads were closed throughout the impacted counties due to flash flooding. Several schools were closed for several days due to flooded roadways and power outages. On O‘ahu (City and County of Honolulu), sewers overflowed

Date(s) of Event	Event Type	Counties Affected	Description
			and water was coming through manholes. Thousands of gallons of water escaped from the sewer system. All county EOCs were monitoring the situation. There were direct impacts to Johnston Island and portions of the Northwestern Hawaiian Islands.
August 26 to September 4, 2015	Hurricane Ignacio	Kaua‘i, City and County of Honolulu, Maui, and Hawai‘i	On August 30, 2015, from west to east, Hurricane Ignacio was located 515 miles east-southeast of Hilo (County of Hawai‘i). A swell from the storm generated surf of 10 to 20 feet along the east-facing shores, and 6 to 8 feet along the south-facing shores of all the islands except Lāna‘i. The unusually high surf on eastern shorelines led to the occasional deposited sand and other debris on roadways along the coastlines. There were no reports of serious property damage; however, there was one injury reported on O‘ahu (City and County of Honolulu). All EOCs were monitoring the event. There were direct impacts to Johnston Island and portions of the Northwestern Hawaiian Islands.
September 2 to 9, 2015	Hurricane Jimena	Kaua‘i, City and County of Honolulu, Maui, and Hawai‘i	On August 30, 2015, from west to east, Hurricane Jimena was located 1,815 miles east-southeast of Hilo. Remnants of Hurricane Jimena moved north of the State. It brought heavy rain and flooding over parts of the State. Roads were closed due to flooding of local streams and creeks. All EOCs were monitoring this event. There were direct impacts to Johnston Island and portions of the Northwestern Hawaiian Islands.
September 22, 2015	Tropical Storm Niala	Kaua‘i, City and County of Honolulu, Maui, and Hawai‘i	All state and county EOCs were monitoring the event.
October 2 to 5, 2015	Tropical Storm Oho	Kaua‘i, City and County of Honolulu, Maui, and Hawai‘i	All state and county EOCs were monitoring the event.
October 20 to 23, 2015	Hurricane Olaf	Kaua‘i, City and County of Honolulu, Maui, and Hawai‘i	A swell from Hurricane Olaf produced surf of 10 to 20 feet along the east-facing shores of the Island of Hawai‘i, 8 to 12 feet along the east-facing shores of the Island of Maui, and 6 to 9 feet along the south-facing shores of all the major islands of the State of Hawai‘i. Several roadways were inundated by several inches of water. There were no significant injuries or property damage reported. All EOCs were monitoring the event.

Sources: NOAA-NCEI 2018; FEMA 2018; State of Hawai‘i 2018; NOAA 2015
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, Table 4.10-3 may not include all events that have occurred in the state and the accuracy of monetary figures discussed is based only on the available information identified during research for this 2018 HMP Update.
DR Major Disaster Declaration (FEMA)
EOC Emergency Operations Center
FEMA Federal Emergency Management Agency
NCEI National Centers for Environmental Information
NOAA National Oceanic and Atmospheric Administration

FEMA Disaster Declarations

Between 1954 and 2017, FEMA included the State of Hawai'i in three hurricane-related disasters (DR) or emergencies (EM). Generally, these disasters cover a wide region of the State; therefore, they may have impacted many counties. However, not all counties were included in the disaster declarations as determined by FEMA (FEMA 2018).

Tropical cyclone events that have affected the state and were declared a FEMA disaster, between 2012 and 2017, are identified in Table 4.11-4. For details regarding all declared disasters, refer to Section 4.1 (Risk Assessment Overview). Refer to Appendix X (Map Atlas) that illustrates the number of tropical cyclone FEMA-declared disasters by county since 1954.

Table 4.11-4. Tropical Cyclone-Related Federal Declarations (2012 to 2017)

Year	Event Type	Date Declared	Federal	Counties Affected
2014	Tropical Storm Iselle	September 12, 2014	DR-4194	Hawai'i and Maui

Source: FEMA 2018

Probability of Future Hazard Events

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 HMP 2013). Since 1950, eight tropical cyclones have passed within 65 nautical miles of the State of Hawai'i. All islands have been in the direct path of a tropical cyclone at least once (NOAA 2018).

In evaluating the potential for hazard events of a given magnitude, a mean return period (MRP) is often used. A MRP is the average period of time, in years, between occurrences of a particular hazard event, equal to the inverse of the annual frequency of exceedance. The MRP provides an estimate of the magnitude of an event that may occur within any given year based on past recorded events (Dinicola 2009). Utilizing the FEMA Hazus wind model, the peak gust wind speeds for a statewide 100-year 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). It is important to note that every hurricane will be unique and wind speeds will vary based on the storm track and present conditions.

For the 2018 HMP 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 2013 State HMP, FEMA, NOAA-NCEI, and the National Hurricane Center were used to identify the number of hurricane events that occurred between 1871 and 2017. Using these resources ensures the most accurate probability estimates possible. Based on historic statistics, the State of Hawai'i has a 25.2% chance of a hurricane, of any magnitude (tropical storm, tropical depression, and category 1 through 4 hurricanes), occurring in any given year. Based on historical record, the State of Hawai'i has experienced four 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 16 years (a 3.1% chance of receiving a FEMA declaration in any given year).

Impacts of Climate Change on Future Probability

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 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 (Hawai'i Climate Change Mitigation and Adaptation Commission 2017; 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).

4.11.2 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. 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.

Hurricane
Hazard Area Definition

Wind – *To assess the state's vulnerability to the hurricane wind hazard, a statewide Category 4 hurricane scenario was run in Hazus to estimate potential losses.*

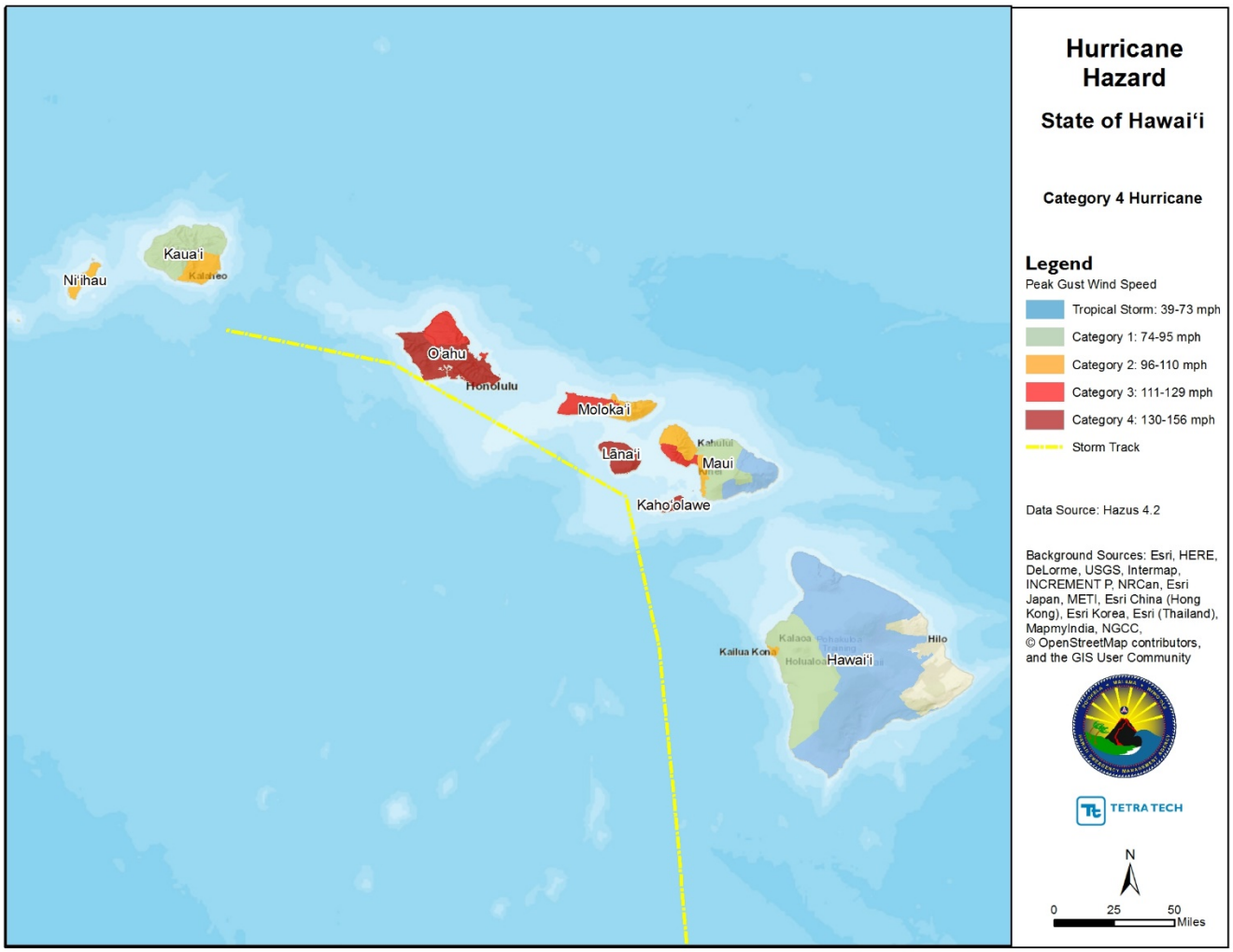
Storm Surge – *To assess the state's vulnerability to storm surge, the Category 4 SLOSH data was used to estimate exposure. The hazard area is called the Category 4 SLOSH Inundation Area.*

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

For the 2018 HMP Update, the following two analyses were conducted to assess hurricane vulnerability:

1. For the wind component of the hurricane hazard, a statewide Category 4 hurricane scenario 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. Figure 4.11-3 below displays the storm track and wind speeds associated with the evaluated scenario. These 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 X.

Figure 4.11-3. Category 4 Hurricane Statewide Scenario



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.

Assessment of State Vulnerability and Potential Losses

This section discusses statewide vulnerability of exposed state assets (state buildings and state roads) and critical facilities to the 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 (10.7%) 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 $2.672 billion). The majority of these buildings are occupied by the Department of Education buildings. Table 4.11-5 summarizes the state buildings located in the Category 4 SLOSH inundation area by county; Table 4.11-6 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 2018 HMP Update.

Table 4.11-5. State Buildings Located in the Category 4 SLOSH Inundation Area by County

County	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings in Hazard Area	Percent (%) of Total State Buildings	Total Value of State Buildings in Hazard Area	Percent (%) of Total Value
County of Kaua'i	531	$957,679,537	82	15.4%	$150,412,802	15.7%
City and County of Honolulu	3,472	$16,750,785,426	503	14.5%	$2,672,078,167	15.9%
County of Maui	831	$2,862,316,819	51	6.1%	$159,482,279	5.6%
County of Hawai'i	1,261	$4,209,774,236	18	1.4%	$76,190,807	1.8%
Total	**6,095**	**$24,780,556,017**	**654**	**10.7%**	**$3,058,164,055**	**12.3%**

Source: Hawai'i State Risk Management Office 2017; NOAA National Hurricane Center 2018
Notes: Total Value = Replacement cost value of the structure and contents
SLOSH Sea, Lake and Overland Surges from Hurricanes

Table 4.11-6. 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	$946,504,656	11	16.7%	$162,035,162	17.1%
Dept of Agriculture	70	$133,065,375	0	0.0%	$0	0.0%
Dept of Attorney General	15	$95,151,863	13	86.7%	$24,444,262	25.7%
Dept of Budget & Finance	16	$26,624,294	4	25.0%	$27,501,719	103.3%
Dept of Business, Economic Development and Tourism	25	$612,574,032	3	12.0%	$20,071,906	3.3%
Dept of Commerce & Consumer Affairs	2	$35,611,360	6	300.0%	$529,204,718	1486.1%
Dept of Defense	69	$246,099,477	9	13.0%	$26,767,373	10.9%

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 Education	4,090	$9,604,111,443	403	9.9%	$818,917,910	8.5%
Dept of Hawaiian Home Lands	12	$100,471,477	1	8.3%	$4,748,597	4.7%
Dept of Health	44	$387,068,440	3	6.8%	$7,922,830	2.0%
Dept of Human Resources Development	1	$5,523,320	0	0.0%	$0	0.0%
Dept of Human Services	130	$420,004,555	29	22.3%	$154,851,502	36.9%
Dept of Labor and Industrial Relations	22	$79,322,626	4	18.2%	$52,739,884	66.5%
Dept of Land and Natural Resources	90	$98,666,185	26	28.9%	$12,052,509	12.2%
Dept of Public Safety	154	$427,884,909	15	9.7%	$32,889,853	7.7%
Dept of Taxation	1	$6,864,408	1	100.0%	$6,864,408	100.0%
Dept of Transportation	68	$2,912,510,888	40	58.8%	$384,036,949	13.2%
Hawai'i State Ethics Commission	1	$891,212	0	0.0%	$0	0.0%
Hawai'i Health Systems Corporation	106	$1,223,962,810	1	0.9%	$829,553	0.1%
Hawai'i Housing Finance & Development Corporation	86	$333,526,064	5	5.8%	$118,247,972	35.5%
Hawai'i Public Housing Authority	273	$933,255,767	37	13.6%	$82,190,258	8.8%
Hawai'i State Legislature	2	$43,024,855	0	0.0%	$0	0.0%
Hawai'i State Public Library System	53	$525,584,082	11	20.8%	$32,473,857	6.2%
Judiciary	41	$511,093,204	7	17.1%	$73,951,176	14.5%
Legislative Reference Bureau	1	$2,686,408	0	0.0%	$0	0.0%
Office of Hawaiian Affairs	11	$53,991,251	6	54.5%	$42,915,963	79.5%
Office of the Auditor	2	$1,789,788	0	0.0%	$0	0.0%
Office of the Governor	1	$2,686,408	0	0.0%	$0	0.0%
Office of the Lieutenant Governor	2	$3,977,640	0	0.0%	$0	0.0%
Office of the Ombudsman	1	$1,620,944	0	0.0%	$0	0.0%
Research Corporation of the University of Hawai'i	3	$3,713,497	0	0.0%	$0	0.0%
University of Hawai'i	637	$5,000,692,783	19	3.0%	$442,505,696	8.8%
Total	**6,095**	**$24,780,556,017**	**654**	**10.7%**	**$3,058,164,055**	**12.3%**

Source: Hawai'i State Risk Management Office 2017; NOAA National Hurricane Center 2018
Notes Dept Department
NOAA National Oceanic and Atmospheric Administration
SLOSH Sea, Lake and Overland Surges from Hurricanes

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 4.11-7 summarizes the length of state road in the Category 1 through 4 hurricane storm surge inundation areas by county. A complete list of state roads located in Category 1 through 4 hurricane storm surge inundation areas is included in Appendix X.

Table 4.11-7. State Roads Exposed to SLOSH Inundation Areas by County

County	Total Length (Sq. Miles)	Cat 1		Cat 2		Cat 3		Cat 4	
		Length	Percent (%) of Total	Length	Percent (%) of Total	Length	Percent (%) of Total	Length	Percent (%) of Total
County of Kaua'i	104.0	2.6	2.5%	4.2	4.1%	8.9	8.6%	12.5	12.0%
City and County of Honolulu	375.3	14.7	3.9%	26.5	7.1%	34.2	9.1%	43.3	11.5%
County of Maui	238.6	7.3	3.0%	11.7	4.9%	16.9	7.1%	19.9	8.3%
County of Hawai'i	378.7	0.1	0.0%	0.1	0.0%	0.4	0.1%	1.8	0.5%
Total	**1,096.5**	**24.6**	**2.2%**	**42.4**	**3.9%**	**60.4**	**5.5%**	**77.4**	**7.1%**

Source: Hawai'i Department of Transportation State Routes GIS layer 2017; NOAA National Hurricane Center 2018

Notes: *% Percent*
Cat 1 Category 1 Hurricane *Cat 2 Category 2 Hurricane*
Cat 3 Category 3 Hurricane *Cat 4 Category 4 Hurricane*
GIS Geographic Information System *NOAA National Oceanic and Atmospheric Administration*
Sq. Miles = Square Miles *SLOSH Sea, Lake and Overland Surges from Hurricanes*

Critical Facility

A hurricane event could result in significant impacts to 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 Oahu 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 (HI-EMA 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 4.11-8 and Table 4.11-9 summarize the critical facilities located in the Category 4 SLOSH inundation area. The City and County of Honolulu has the largest number of critical facilities (134) located within the Category 4 SLOSH inundation area. Of the core critical facility types, the water, waste, and wastewater systems category has the greatest number of facilities exposed. Additional Category 1 through 3 hurricane storm surge analyses on critical facilities are included in Appendix X. Economic loss resulting from impacts to critical facilities was not monetized as part of the 2018 HMP Update.

Table 4.11-8. Critical Facilities Located in the Category 4 SLOSH Inundation Areas by County

County	Core Category of Critical Facilities										Total Number of Facilities in the Hazard Area
	Commercial Facilities	Communications	Emergency Services	Energy	Food and Agriculture	Government Facilities	Healthcare and Public Health	Mass Care Support Services	Transportation Services	Water, Waste, and Wastewater Systems	
County of Kaua'i	0	1	4	2	2	2	0	4	2	8	25
City and County of Honolulu	10	17	8	23	1	9	6	13	2	45	134
County of Maui	0	3	4	0	0	5	5	4	7	10	38
County of Hawai'i	0	0	0	1	4	1	0	2	5	7	20
Total	**10**	**21**	**16**	**26**	**7**	**17**	**11**	**23**	**16**	**70**	**217**

Source: Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; NOAA National Hurricane Center 2018
Notes: NOAA National Oceanic and Atmospheric Administration
SLOSH Sea, Lake and Overland Surges from Hurricanes

Table 4.11-9. Critical Facilities Located in the Category 4 SLOSH Inundation Areas by Core Category

Core Category	Total Number of Critical Facilities	Total Replacement Cost Value	Number of Critical Facilities in Hazard Area	Percent (%) of Total Facilities	Value in the Hazard Area	Percent (%) of Total Value
Commercial Facilities	60	$206,894,206	10	16.7%	$25,019,578	12.1%
Communications	130	$523,848,060	21	16.2%	$55,921,705	10.7%
Emergency Services	149	$1,017,628,710	16	10.7%	$91,293,940	9.0%
Energy	90	$2,591,975,628	26	28.9%	$733,367,393	28.3%
Food & Agriculture	39	$829,869,410	7	17.9%	$82,119,490	9.9%
Government Facilities	100	$399,781,575	17	17.0%	$66,636,460	16.7%
Healthcare & Public Health	193	$3,399,521,375	11	5.7%	$116,740,353	3.4%
Mass Care Support Services	353	$11,497,547,155	23	6.5%	$573,263,005	5.0%

Core Category	Total Number of Critical Facilities	Total Replacement Cost Value	Number of Critical Facilities in Hazard Area	Percent (%) of Total Facilities	Value in the Hazard Area	Percent (%) of Total Value
Transportation Services	56	$1,739,256,960	16	28.6%	$496,930,560	28.6%
Water, Waste, & Wastewater Systems	305	$9,481,445,760	70	23.0%	$2,185,480,320	23.1%
Total	**1,475**	**$31,687,768,838**	**217**	**14.7%**	**$4,426,772,803**	**14.0%**

Source: Makani Pahili 2017 Emergency Power Prioritization Workshop Series final report; Hazus v4.2; NOAA National Hurricane Center 2018

Notes: Hazus Hazards-U.S.
NOAA National Oceanic and Atmospheric Administration
SLOSH Sea, Lake and Overland Surges from Hurricanes

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.

Population

As noted, 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 4.11-10 below.

Table 4.11-10. Estimated Population Impacted by a Category 4 Hurricane

County	Total Population	SLOSH Category 4		Hazus Wind (Category 4)	
		Population Located in the Storm Surge Area	Percent (%) of Total Population	Displaced Households from Wind	Short-Term Sheltering Needs
County of Kaua'i	67,091	5,974	8.9%	560	126
City and County of Honolulu	953,207	144,981	15.2%	111,830	24,234
County of Maui	154,924	3,808	2.5%	2,179	484
County of Hawai'i	185,079	663	0.4%	211	45
Total	**1,360,301**	**155,426**	**11.4%**	**114,780**	**24,889**

Source: U.S. Census 2010; 2015 Hawai'i Catastrophic Hurricane Plan/FEMA Region IX Hawai'i Catastrophic Annex; NOAA National Hurricane Center 2018

Notes: FEMA Federal Emergency Management Agency

Hazus *Hazards-U.S.*
NOAA *National Oceanic and Atmospheric Administration*
SLOSH *Sea, Lake and Overland Surges from Hurricanes*
It is recognized that combining the population from these separate analyses may overestimate the vulnerable population.

As a result of the statewide Category 4 Hazards-U.S. (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. It is important to note that these sheltering estimates are based on Census population. This analysis does not include the tourist and visitor population 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. The elderly are considered most vulnerable because they require extra time or outside assistance during evacuations and are more likely to seek or need medical attention that may not be available during a storm event.

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 (Event-Based 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 4.11-11 summarizes the square miles and percent of total area in each State Land Use District statewide exposed to the Category 4 hurricane storm surge inundation area; refer to Appendix X for results by County. Overall the City and County of Honolulu has the greatest area of land, with a majority in the Urban District, located in the Category 4 SLOSH inundation area (6.5% of the total land in the County). It is notable that 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 Event-Based Flood for more information). The land use with the greatest exposure to Category SLOSH in the Counties of Kaua'i and Maui is agricultural land. 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 4.11-11. 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	2,942.8	18.1	0.6%
Conservation	3,156.3	11.7	0.4%
Rural	16.1	1.3	8.0%
Urban	319.7	37.5	11.7%
Total	**6,434.9**	**68.6**	**1.1%**

Source: State of Hawai‘i GIS layers, State of Hawai‘i GIS Program Geospatial Data Portal; NOAA National Hurricane Center 2018
Notes: Total area calculated from the State of Hawai‘i State Land Use District GIS layer
Hazard area clipped to coastline downloaded from State of Hawai‘i GIS Program Geospatial Data Portal
Total area may differ slightly between this and other calculations due to slight differences in the shoreline geography.
GIS Geographic Information System
NOAA National Oceanic and Atmospheric Administration

General Building Stock

All structures in the Stare 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 4.11-12 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 (21.8%) of building exposure to Category 4 hurricane storm inundation, followed by the County of Kaua‘i (12.7% of the county total building stock replacement cost value). The Hazus wind analysis estimates greater than $43 billion in potential building loss in the City and County of Honolulu (26.3% of their total building inventory) as a result of the Category 4 hurricane scenario evaluated. All counties are estimated to experience millions in building damages.

Table 4.11-12. General Building Stock Exposure to Hurricane

County	Total RCV	SLOSH Category 4		Hazus Wind (Category 4)	
		RCV in Cat 4 SLOSH area	Percent (%) of Total RCV	Estimated Loss of RCV	Percent (%) of Total RCV
County of Kaua‘i	$13,287,882,000	$1,685,509,000	12.7%	$517,583,242	3.9%
City and County of Honolulu	$164,787,212,000	$35,544,372,000	21.6%	$43,368,365,552	26.3%
County of Maui	$31,320,693,000	$1,737,860,000	5.5%	$1,422,607,990	4.5%
County of Hawai‘i	$33,326,392,000	$428,845,000	1.3%	$292,099,951	0.9%
Total	**$242,722,179,000**	**39,396,586,000**	**16.2%**	**$45,600,656,734**	**18.8%**

Source: 2015 Hawai‘i Catastrophic Hurricane Plan/FEMA Region IX Hawai‘i Catastrophic Annex, NOAA National Hurricane Center 2018; Hazus v.4.2
Notes: Cat Category
FEMA Federal Emergency Management Agency
Hazus Hazards-U.S.
NOAA National Oceanic and Atmospheric Administration
RCV Replacement cost value
SLOSH Sea, Lake and Overland Surges from Hurricanes
The results from the SLOSH and wind analyses cannot be combined to estimate total vulnerability; the SLOSH is an exposure with the total value summed for all buildings; whereas the Hazus wind analysis is an estimate of only structural building damage.

Environmental Resources

The State has numerous environmental resources located along the shore including beaches, wetlands, critical habitats (or habitats that are known to be 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 (Carey 2014). 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 4.11-13 summarizes the environmental assets located in the Category 4 hurricane storm surge area.

Table 4.11-13. 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]	915.2	1.0	0.1%
Wetlands	260.0	16.8	6.4%
Parks and Reserves	2,607.7	10.3	0.4%
Total	**3,782.9**	**28.1**	**<1%**

Source: State of Hawai'i GIS Program Geospatial Data Portal; NOAA National Hurricane Center 2018
Notes: a. Critical area mileage includes the combined area of coverage of individual critical habitat areas
GIS Geographic Information System
NOAA National Oceanic and Atmospheric Administration

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 4.11-14 summarizes the area of Hawaiian Home Lands located in the SLOSH Category 1 through 4 hurricane storm surge inundation areas.

Table 4.11-14. Hawaiian Home Lands Located in the SLOSH Category 1 through 4 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	32.0	0.1	0.5%	0.2	0.6%	0.3	1.1%	0.4	1.2%
City and County of Honolulu	10.9	0.0	0.3%	0.0	0.4%	0.1	1.0%	0.1	1.3%
County of Maui	92.6	1.4	1.5%	1.6	1.7%	1.7	1.8%	1.7	1.8%
County of Hawai'i	190.3	0.1	0.0%	0.1	0.0%	0.1	0.1%	0.2	0.1%

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
Total	**325.8**	**1.6**	**0.5%**	**1.9**	**0.6%**	**2.2**	**0.7%**	**2.4**	**0.7%**

Source: State of Hawai'i GIS layer Trust Land, State of Hawai'i GIS Program Geospatial Data Portal; NOAA National Hurricane Center 2018

Notes:
- *% Percent*
- *Cat 1 Category 1 Hurricane*
- *Cat 2 Category 2 Hurricane*
- *Cat 3 Category 3 Hurricane*
- *Cat 4 Category 4 Hurricane*
- *GIS Geographic Information System*
- *NOAA National Oceanic and Atmospheric Administration*
- *SLOSH Sea, Lake and Overland Surges from Hurricanes*

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 identified conditions 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 4.11-15 below; refer to Section 3 for more information on projected development areas; see Appendix X for Category 1 through 3). The results of this analysis indicate that significant amounts of the 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. It is important to note that 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. This is especially important for areas that experience 1.5 feet or greater wave heights due to their damaging effects on structures.

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 requires 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).

Table 4.11-15. 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	-	-	-	-	-	-	252.3	10.4	4.1%
City and County of Honolulu	7.4	1.4	19.5%	-	-	-	288.3	21.4	7.4%
County of Maui	-	-	-	27.6	0.1	0.2%	1,016.7	11.6	1.1%
County of Hawai‘i	-	-	-	-	-	-	1,286.6	3.6	0.3%
Total	**7.4**	**1.4**	**19.5%**	**27.6**	**0.1**	**0.2%**	**2,843.9**	**47.1**	**1.7%**

Notes: Total area calculated from: (1) HCDA Community Development District GIS layer from Hawai‘i Community Development Authority (2) Maui Development Projects GIS layer from Maui County Planning Department (3) Enterprise Zones from Community Economic Development Program, DBEDT
Hazard area clipped to coastline downloaded from State of Hawai‘i GIS Program Geospatial Data Portal
% Percent
SLOSH Sea, Lake and Overland Surges from Hurricanes