Section 4.2 Climate Change and Sea Level Rise

Climate Change and Sea Level Rise

The Hawaiian Islands are highly exposed to the effects of climate change and sea level rise. The State has seen a decline in total rainfall, but increases in sea level, sea surface temperature, and acidification of ocean water over the last three or more decades. The statistics below represent the Sea Level Rise Exposure Area (SLR-XA) 3.2 feet.

CHANGES SINCE 2018

+0
Declared Disasters

+0
Events

COUNTIES MOST VULNERABLE

Kaua'i Honolulu Maui Hawai'i

SOCIALLY VULNERABLE POPULATION

0.5%
Of Total Population

7,127
Persons

HAZARD RANKING

Low Medium High

COMMUNITY LIFELINES

33
Total

Food, Water, Shelter
Greatest

CLIMATE PROJECTIONS

Warmer, more acidic ocean will drive changes in circulation and biologic activity

Climate change can lead to a decrease in precipitation, streamflow, and groundwater levels and increase the number of and duration of droughts

Coastline erosion alters the habitats of endemic Hawaiian species and may displace residents and business owners

SQUARE MILES

54
State Buildings

32
Environmental Resources

1
Hawaiian Home Lands

14
Cultural Resources

39
Miles of State Road

CONTENTS

TABLES

FIGURES

[1] *Section Cover Photo: Bleached coral from increased sea temperatures. Photo courtesy of DLNR*

SECTION 4. RISK ASSESSMENT

4.2 CLIMATE CHANGE AND SEA LEVEL RISE

2023 SHMP Update Changes

- New and updated statistics and figures from federal, state, academic, and local agencies are incorporated.
- Discussion of how climate change and sea level rise impact socially vulnerable populations and community lifelines is incorporated.
- In Environmental Resources, reefs (both artificial and coral) are analyzed in their own category.
- Six types of cultural resources (archaeology, burial sensitivity area, historic building, historic district, historic object, and historic structure) are added to the vulnerability assessment.

4.2.1 HAZARD PROFILE

Climate is defined as long-term averages and variations in weather measured over a period of time. A change in the state of the climate can be identified by changes in the mean and/or variability of its properties that persist for an extended period of time, typically decades or longer. Key drivers and indicators of the changing climate include rising carbon dioxide in the atmosphere, rising air and sea temperatures, rising sea levels and upper-ocean heat content, changing ocean chemistry and increasing ocean acidity, changing rainfall patterns, decreasing base flow in streams, changing wind and wave patterns, changing extremes, and changing habitats and species distributions (Department of Land and Natural Resources 2016).

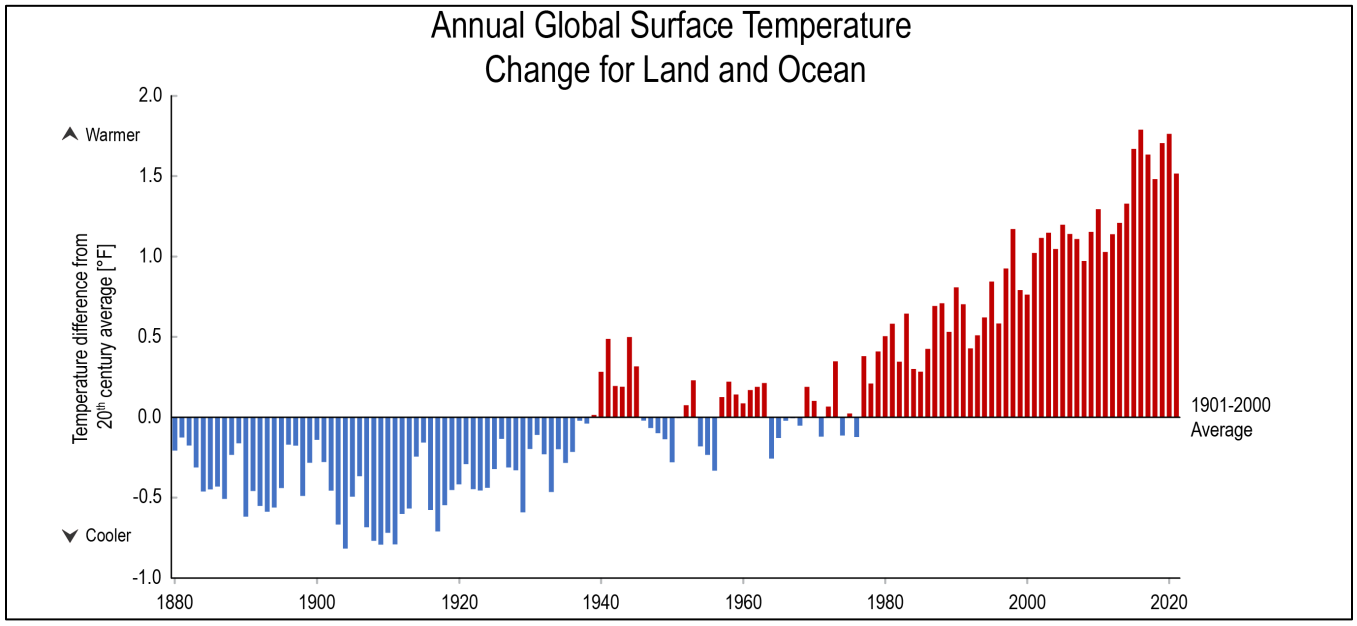
This section provides general information on the climate change hazard with an enhanced discussion on sea level rise. For an analysis of how climate change impacts natural hazards, see each natural hazard profile in this plan.

HAZARD DESCRIPTION

Climate Change

Since 1880, global average surface air temperatures have increased 1.82 degrees Fahrenheit (˚F) (NASA 2022). Figure 4.2-1 shows the number of degrees between the 1880s and the 2020s that the average global temperature for each year differs from the baseline, or average global temperature calculated during the last century (1901–2000).

Figure 4.2-1. Global Temperature Change



Source: (U.S. Global Change Research Program 2021)

The Intergovernmental Panel on Climate Change (IPCC) stated in its Sixth Assessment Report that "It is unequivocal that the increase of CO_2, methane, and nitrous oxide in the atmosphere over the industrial era is the result of human activities and that human influence is the principle driver of many changes observed across the atmosphere, ocean, cryosphere, and biosphere." It continues, "Since systematic scientific assessments began in the 1970s, the influence of human activity on the warming of the climate system has evolved from theory to established fact (IPCC 2021)." Sixteen of the last 17 years having been the warmest ever recorded.

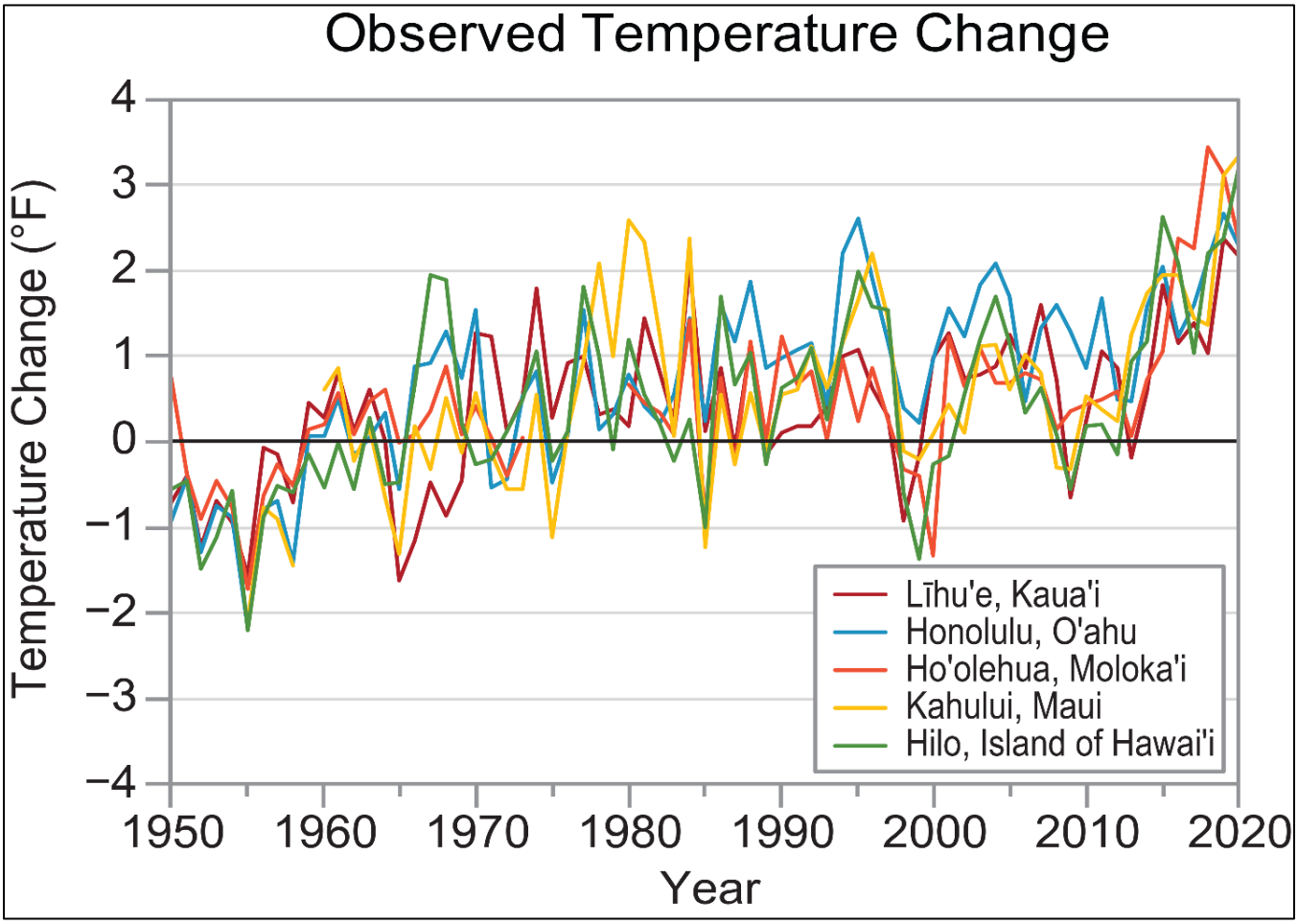
In the State of Hawai'i, climate is changing in ways that are consistent with the influence of global warming. The State of Hawai'i has experienced rising air temperatures, changing rain intensity, rainfall and stream flow changes, increased sea level and sea surface temperatures, and acidification of the ocean.

- **Surface Air Temperature**. Figure 4.2-2 shows temperature changes across Hawai'i since 1950. The lines on the graph show observed changes (compared to the 1951–1980 average; horizontal black line) in annual near-surface air temperature for five long-term reporting stations in Hawai'i from 1950 to 2020. Temperatures across the islands have risen by about 2°F since 1950, with a sharp increase in warming over the last decade (NOAA 2022). As average air temperatures rise, heat disorders among the population also increase.
- **Rain Intensity**. Historical extreme rainfall trends vary among studies conducted throughout the state. Some studies show a decrease in daily rainfall intensity while other studies indicate that consecutive wet and dry days are both increasing statewide. What was considered a rare storm event in 1960 with nearly 12 inches of daily precipitation was considered common in 2009 (City and County of Honolulu Climate Change Commission 2023). Intense rain events may lead to more flash flooding, damage to infrastructure, runoff, and sedimentation.
- **Rainfall and Stream Discharge**. The State of Hawai'i has seen an overall decline in rainfall in the last 30 years, with widely varying precipitation patterns on each island. Projections show that the State of Hawai'i will see

more drought and heavy rain events. A decline in overall precipitation totals have caused a decrease in stream base flow, which may reduce aquifer recharge and freshwater supplies. This may also negatively impact aquatic and riparian ecosystems and agriculture.

- **Sea Level**. Refer to the following subsection for information on sea level changes in the State of Hawai'i.
- **Sea Surface Temperature**. At Station ALOHA, marine researchers at the University of Hawai'i and cooperating institutions have measured an increase of sea surface temperature of 0.22°F per decade. With climate change, this rate is likely to increase, potentially exposing coral reefs and other marine ecosystems to negative impacts related to increased temperatures, including coral bleaching. Increasing air surface temperatures due to increasing sea surface temperatures may further impact the population as mentioned above.

Figure 4.2-2. Observed Hawai'i Surface Air Temperature Change



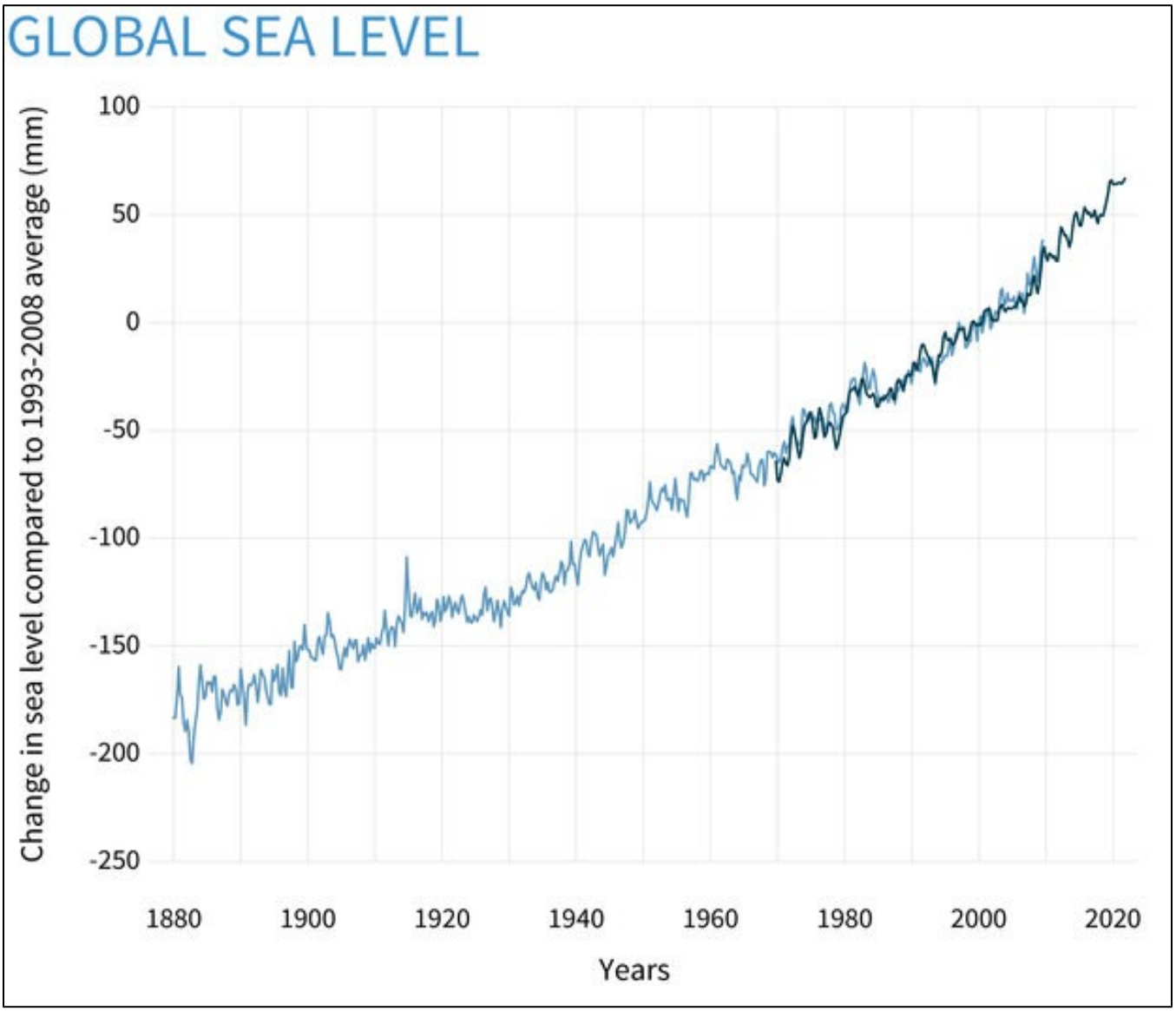
Source: (NOAA 2022)

- **Ocean Acidification**. Rising carbon dioxide in the atmosphere is taken-up (dissolved) in seawater, causing the pH of the ocean to drop or acidify with negative impacts to organisms that make calcium carbonate shells, such as calcareous plankton, corals, and mollusks. Measurements at Station ALOHA over the last 20 years have documented that the surface ocean around the State of Hawai'i has grown more acidic (University of Hawai'i at Mānoa Sea Grant College Program 2014) (Fletcher 2010).

Sea Level Rise

Global mean sea level rise has been observed over the last century in tide station data from around the world and, more recently, in satellite-based ocean height measurements. The rate of global sea level rise has accelerated over the past century, as seen in Figure 4.2-3, and global mean sea level has risen by 8 to 9 inches since 1880. In 2017 and 2020, the Honolulu Harbor Tide gauge recorded its highest daily mean water levels over the previous 112 years. The record high sea levels included a combination of global sea level rise, peak astronomical tides, wave setup, and migration of warm waters brought by winds and currents (DLNR OCCL 2022).

Figure 4.2-3. Global Sea Level Since 1880

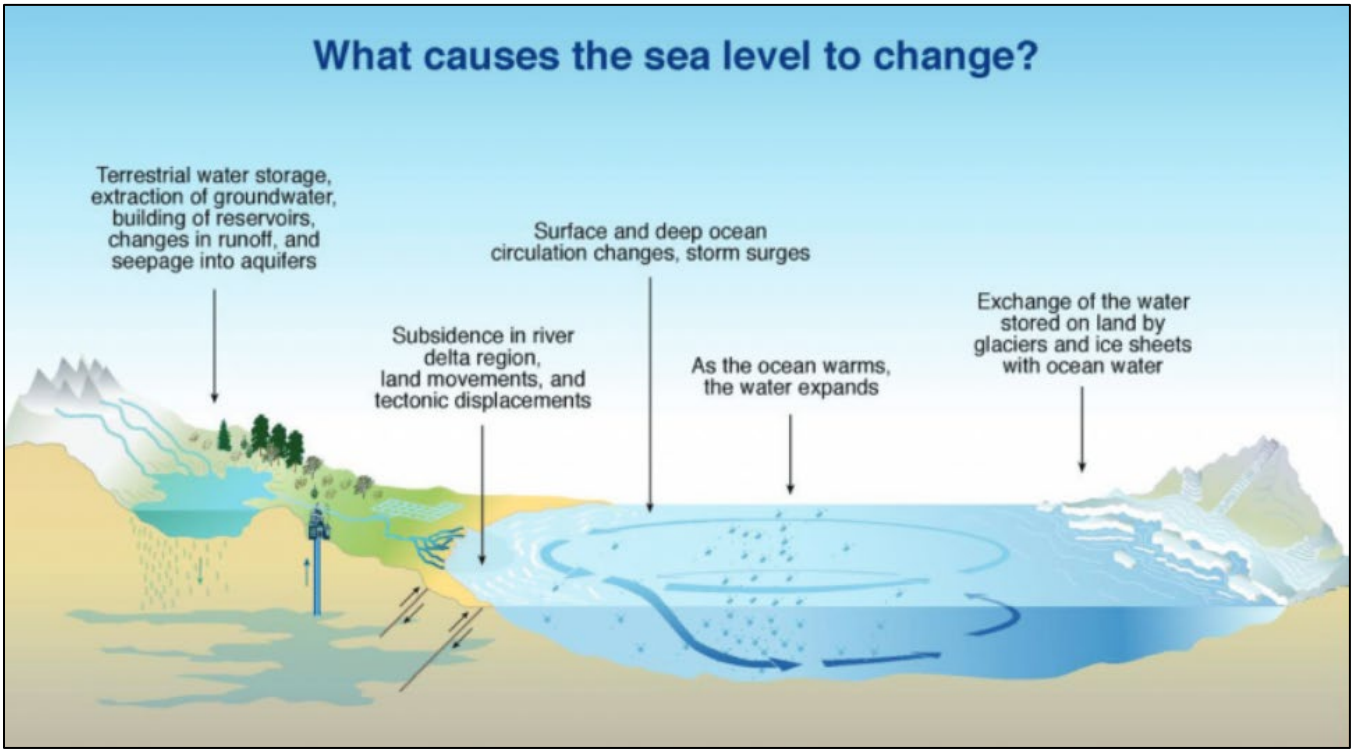


Source: *(Lindsey 2022)*

Note: *The light blue line shows seasonal (3-month) sea level estimates from Church and White (2011). The darker line is based on University of Hawai'i Fast Delivery sea level data.*

There are two types of sea level rise: global and relative (local). Global sea level rise refers to the increase currently observed in the average global sea level trend. This is primarily attributed to changes in ocean volume due to ice melt and thermal expansion. The melting of glaciers and continental ice masses can contribute significant amounts of freshwater input to the earth's oceans. In addition, observed increase in global ocean temperature causes an expansion of seawater, increasing ocean volume (NASA 2020). Refer to Figure 4.2-4 for an illustration of what causes sea level to change.

Figure 4.2-4. Causes of Sea Level Change



Source: (NASA 2020)

Relative (or local) sea level is affected by global sea level fluctuations, changes in land elevation, winds, and ocean circulation. It refers to the height of the water as measured along the coast relative to a specific point on land. Tide stations measure local sea level rise. Water measurements at the tide stations are referenced to stable vertical points on the land, and a known relationship is established. Measurements at any given tide station include both global sea level rise and vertical land motion (subsidence, glacial rebound, or large-scale tectonic motion). Since the heights of both the land and water change, the land-water interface can vary spatially and temporally and must be defined over time. Depending on the rates of vertical land motion relative to changes in sea level, observed local sea level trends may differ from the average rate of global sea level rise and vary from one location to the next. Relative, local sea level change should be considered in hazard assessment and adaptation planning, including coastal mapping, marine boundary delineation, coastal zone management, coastal engineering, sustainable habitat restoration design, and the general public enjoying their favorite beach (NOAA 2022).

Rising sea level and projections of stronger and more frequent El Niño events and tropical cyclones in waters surrounding the State of Hawai‘i all indicate a growing vulnerability to coastal flooding and erosion (Hawai‘i Climate Change Mitigation and Adaptation Commission 2017) (EPA 2016). Changing sea levels can affect human activities in coastal areas. Rising sea level inundates low-lying wetlands and dry land, erodes shorelines, contributes to coastal flooding, and increases the flow of salt water into estuaries and nearby groundwater aquifers. Coastal areas become more vulnerable to damage from storms as well (EPA 2016).

LOCATION

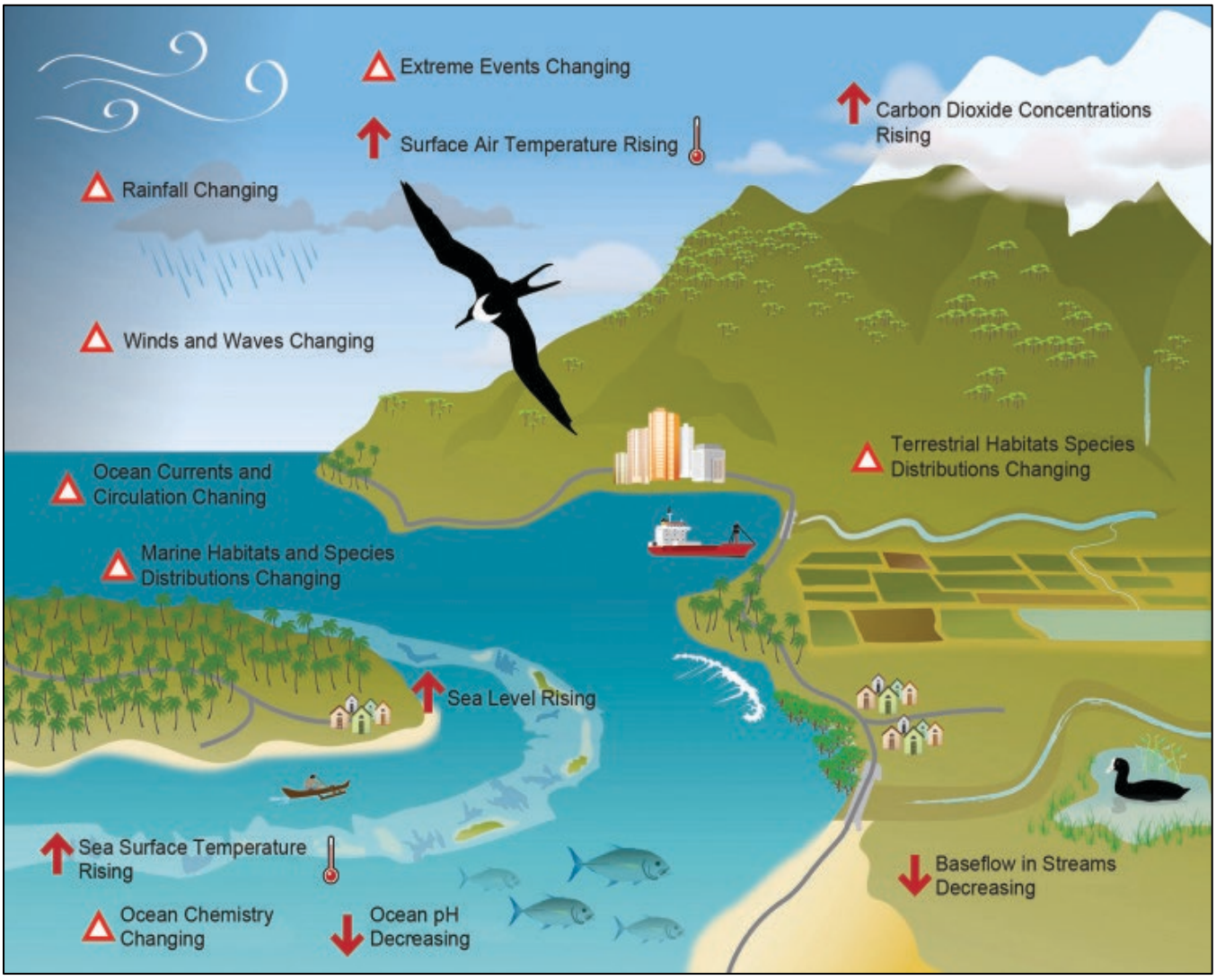
The State of Hawai‘i is experiencing climate change and sea level rise impacts in unique, region-specific ways. Climate change and sea level rise can impact marine ecosystems, coasts and the built environment, terrestrial ecosystems, freshwater resources, and human health. Some of these impacts have already been observed, while others are projected to manifest in the coming years (U.S. Global Change Research Program 2018)

Climate change will increasingly be felt from the upper reaches of each island to the sea and throughout the entire archipelago, including the main Hawaiian Islands and Northwestern Hawaiian Islands. Figure 4.2-5 shows the key indicators of climate change in the Hawaiian Islands and the relative location of these changes.

The local relative rates of sea level rise vary among the Hawaiian Islands due to varying rates of subsidence along the volcanic island chain and possibly, in part, due to oceanic variability. As seen in Figure 4.2-6, the relative rate of sea level rise on the Island of Hawai‘i is almost twice the rate on the Island of Kaua‘i. This is due to the fact that the Island of Hawai‘i is slowly subsiding as it gains mass from active volcanoes, resulting in a higher relative rate of sea level rise while the Islands of Kaua‘i and O‘ahu, which are older islands, are relatively stable (Hawai‘i Climate Change Mitigation and Adaptation Commission 2017) (NOAA 2022).

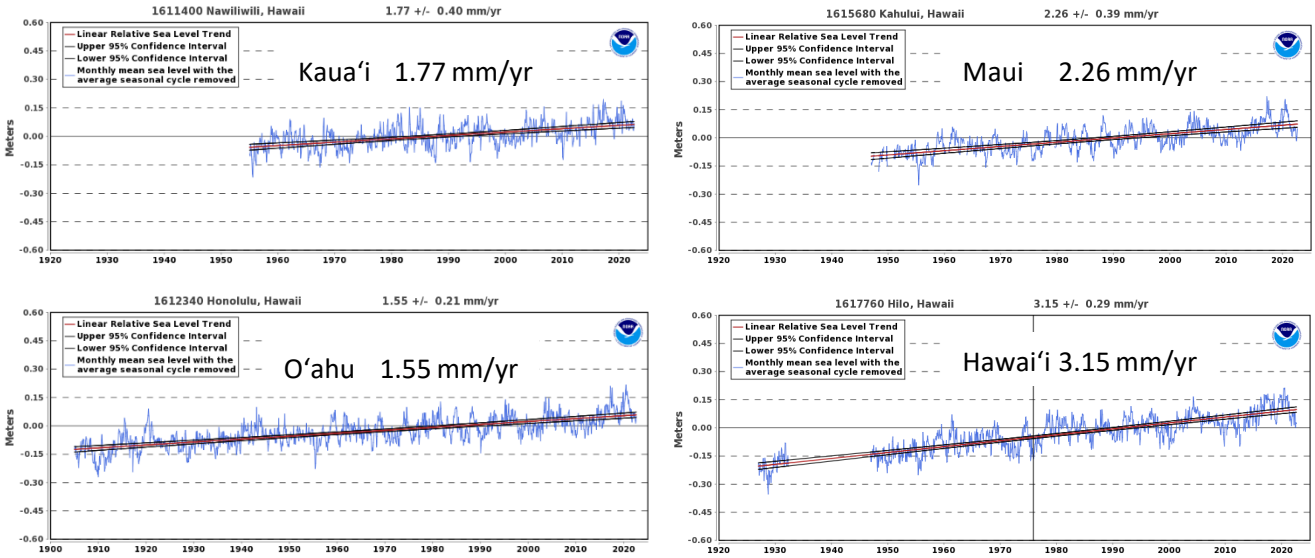
Modeling was conducted using the best available data and methods to determine the potential future exposure of the State of Hawai‘i to multiple coastal hazards as a result of sea level rise (Hawai‘i Climate Change Mitigation and Adaptation Commission 2017). In a 2022 update to an interagency report looking at the latest peer-reviewed science on sea level rise projections, findings included that a 3.2 feet of sea level rise will happen by 2100 in an “intermediate” (mid-range) scenario (Sweet, et al. 2022) for the contiguous United States. However, the “intermediate” scenario for Hawai‘i is estimated at 3.9 feet of sea level rise by 2100 (DLNR OCCL 2022). As noted in the 2017 *Hawai‘i Sea Level Rise Vulnerability and Adaptation Report* and discussed in the chronic coastal flood section of this plan (Section 4.6 Flood), current or near-term exposure to coastal hazards is assessed using the Sea Level Rise Exposure Area with 1.1 feet of sea level rise (SLR-XA-1.1). To assess mid- to late century sea level rise on chronic coastal flooding, the Sea Level Rise Exposure Area with 3.2 feet of sea level rise (SLR-XA-3.2) is used for the 2023 SHMP Update, which is the best available exposure data. These maps may be seen on the Hawai‘i Sea Level Rise Viewer located at: hawaiisealevelriseviewer.com.

Figure 4.2-5. Indicators of Climate Change in the Pacific Islands Region



Source: (V. W. Keener 2012)

Figure 4.2-6. Observed Mean Sea Level Rise Trends and Rates of Rise in the Hawaiian Islands



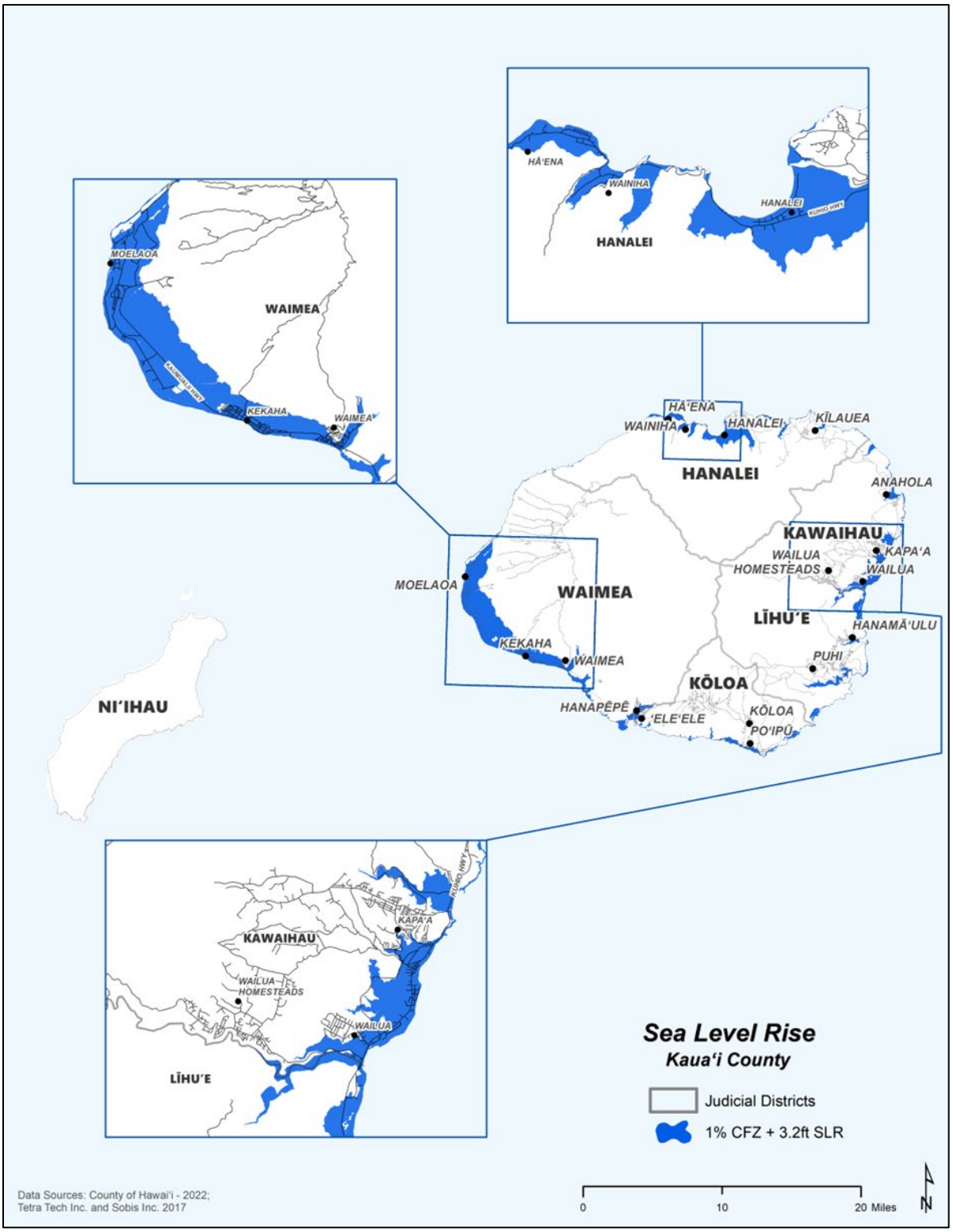
Source: (NOAA Tides & Currents 2022)

Key Terms

- **SLR-XA** – The Sea Level Rise Exposure Area represents the area exposed to chronic coastal flooding and land loss based on modeling of passive flooding, annual high wave flooding and coastal erosion (refer to Section 4.0 for further details).
- **Chronic Coastal Flood** – The SLR-XA with 1.1 feet of sea level rise (SLR-XA-1.1) approximates current or near-term exposure to chronic coastal flooding discussed in Section 4.2.
- **SLR-XA-3.2** – The SLR-XA with 3.2 feet of sea level rise was used to assess mid- to late century exposure to chronic coastal flooding.
- **Event-Based Flood** – The 1% annual chance flood as depicted on the FEMA Flood Insurance Rate Maps, also known as the Special Flood Hazard Area (inclusive of V- zones, or wave velocity zones with waves 3 feet or greater, and A-zones or flooded areas not subject to waves greater than 3 feet), was assessed in Section 4.7.
- **1%CFZ-3.2** – The 1% annual chance coastal flood zone with 3.2 feet of sea level rise was used to assess mid- to late century event-based coastal flooding.

The 1% annual chance coastal flood zone (referred to as the 1%CFZ) will expand with sea level rise meaning that more land area will be exposed to damaging wave impacts from a 100-year flood event. The 1%CFZ with 3.2 feet of sea level rise (1%CFZ-3.2) was utilized to assess mid- to late century sea level rise on coastal event-based flooding. The event-based flood hazard discussed in Section 4.6 assesses the entire Special Flood Hazard Area (V- and A-zones). Sea level rise effects on event-based flooding only includes the coastal flood zones. The 1%CFZ-3.2 areas are shown in Figure 4.2-7 through Figure 4.2-10.

Figure 4.2-7. 1% Annual Chance Coastal Flood Event with 3.2-feet of Sea Level Rise (1%CFZ-3.2) for the County of Kaua'i



Note: Ni'ihau was not modeled

Figure 4.2-8. 1% Annual Chance Coastal Flood Event with 3.2-feet of Sea Level Rise(1%CFZ-3.2) for the City and County of Honolulu

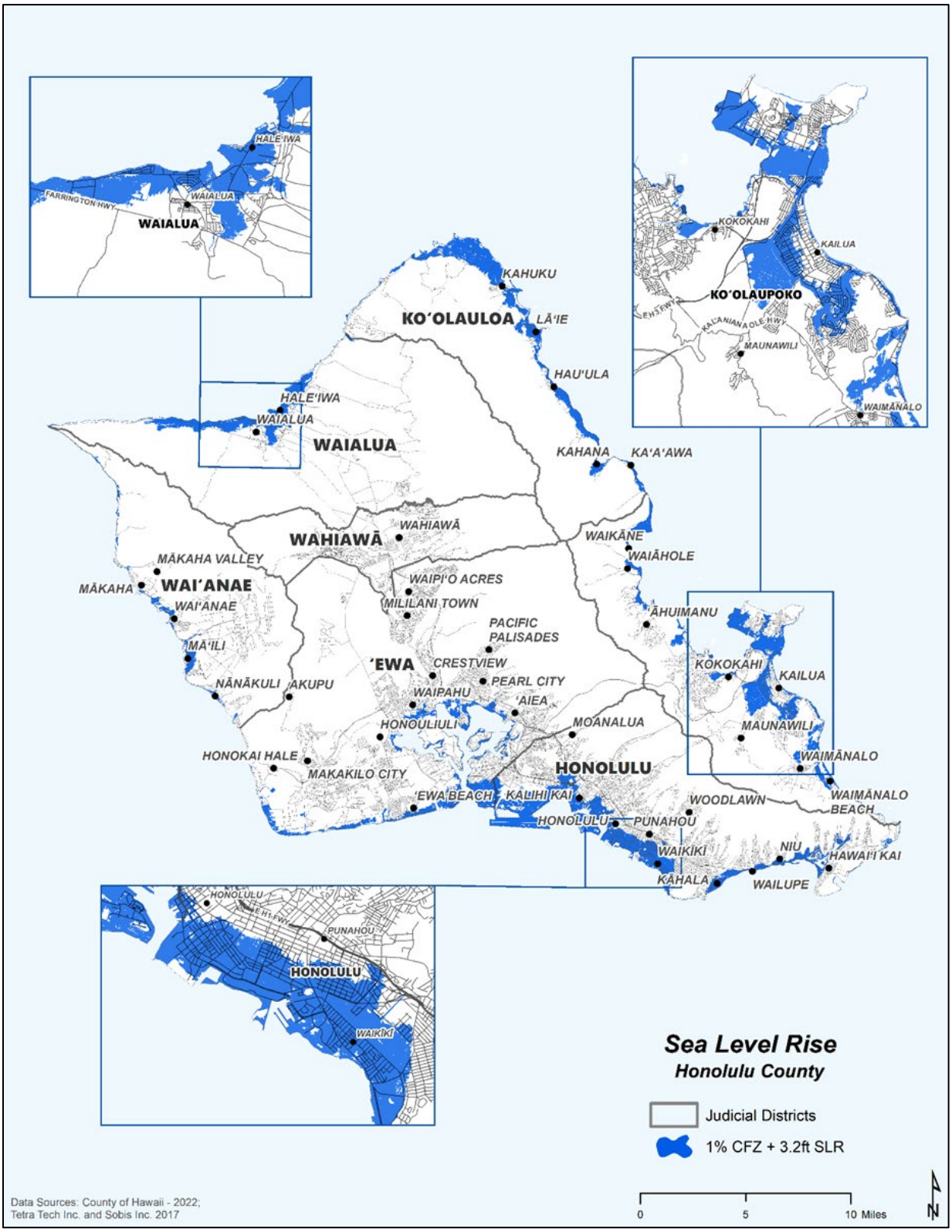
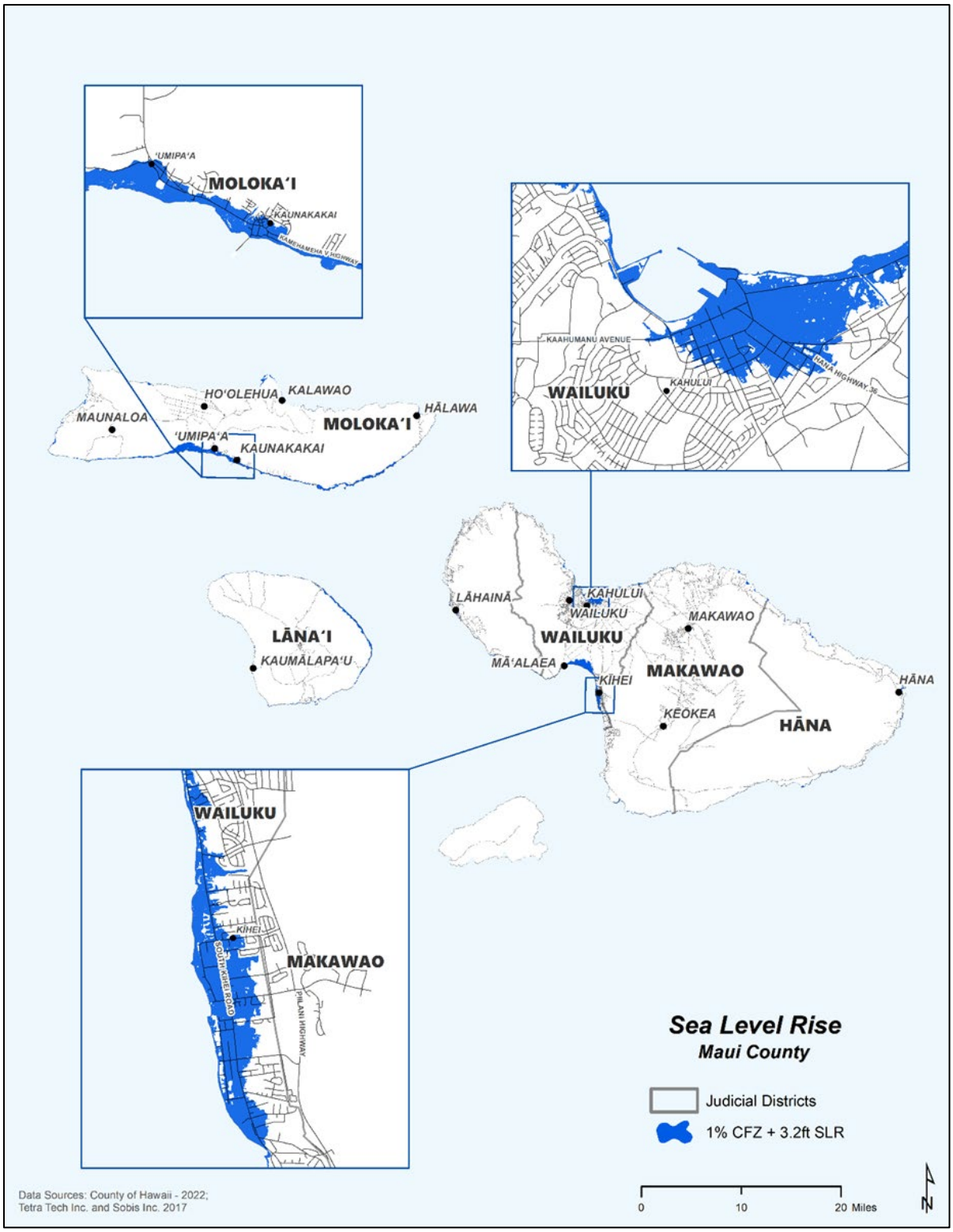


Figure 4.2-9. 1% Annual Chance Coastal Flood Event with 3.2-feet of Sea Level Rise (1%CFZ-3.2) for the County of Maui



Note: Kaho'olawe was not modeled

Figure 4.2-10. 1% Annual Chance Coastal Flood Event with 3.2-feet of Sea Level Rise (1%CFZ-3.2) for the County of Hawai'i

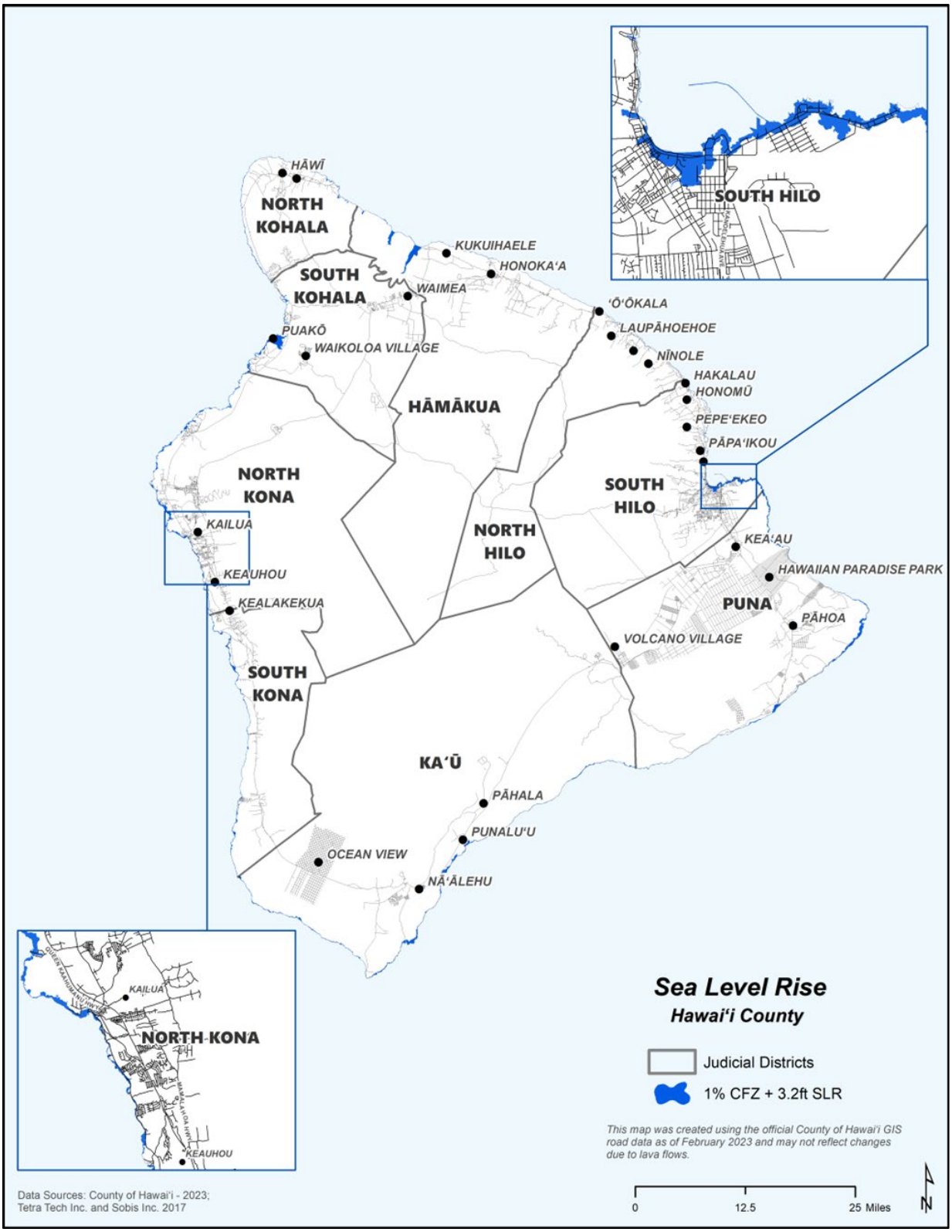


Table 4.2-1 shows the estimated square miles of potential land loss/impact due to 3.2 feet of sea level rise for each county. The state's total potential lost area due to chronic coastal flooding with sea level rise will amount to an estimated 0.5 percent of the state's total land area; however, it comprises of some of the most developed and valued land. When examining the 1% annual chance coastal flood event with 3.2 feet of sea level rise, 1.7 percent of the state's land will be impacted. The City and County of Honolulu, with its expansive coastal plains, will have the most land unusable due to sea level rise, followed by the Counties of Kaua'i and Maui.

Table 4.2-1. Sea Level Rise Hazard Areas by County

County	Area				
	Total Area (square miles)	SLR-XA-3.2 (square miles)	SLR-XA-3.2 as % of Total Area	1%CFZ-3.2 (square miles)	1%CFZ-3.2 Area as % of Total Area
County of Kaua'i	624.3	8.8	1.4%	32.8	5.3%
City and County of Honolulu	598.6	13	2.2%	41.2	6.9%
County of Maui	1,176.3	7.8	0.7%	15.7	1.3%
County of Hawai'i	4,039.6	4.3	0.1%	19.4	0.5%
Total	**6,438.8**	**33.9**	**0.5%**	**109.1**	**1.7%**

Source: Hawai'i Climate Change Mitigation and Adaptation Commission 2017; Tetra Tech Inc. and Sobis Inc. 2017, U.S. Census Bureau 2021

EXTENT

Climate Change

Increasing temperatures, and in some areas, reduced rainfall will stress native plants and animals, especially in high-elevation ecosystems with increasing exposure to invasive species, increasing the risk of extinctions and wildfire (see Section 4.15 Wildfire). Increasing temperatures will significantly impact the population due to the health risks of heat stress and heat emergencies, the increase of vector-borne diseases, and increased wildfire and wildfire smoke hazards. Marine heatwaves will become more frequent, extensive, and intense (IPCC 2019). Freshwater supplies are already constrained and will become more limited on many Hawaiian Islands (Keener, et al. 2018). In areas where precipitation does not increase, freshwater supplies will be adversely affected as the air temperature rises.

Sea Level Rise

Rising sea levels, coupled with high water levels caused by storms, will incrementally increase coastal flooding and erosion, damaging coastal ecosystems, infrastructure, and agriculture, and negatively affecting tourism (Keener, et al. 2018). As noted earlier, the latest peer-reviewed science on Hawai'i sea level rise projections and finds that 3.9 feet of sea level rise will happen by 2100 in an "intermediate" (mid-range) scenario (DLNR OCCL 2022).

Sea level is measured by two main methods: tide gauges and satellite laser altimeters. Tide gauge stations from around the world have measured the daily high and low tides for over a century. Using data from these stations, scientists can calculate a global average of change. Since the early 1990s, sea level has been measured from space using laser altimeters. This method determines the height of the sea surface by measuring the return speed and intensity of a laser pulse directed at the ocean. The higher the sea level, the faster and stronger the return signal

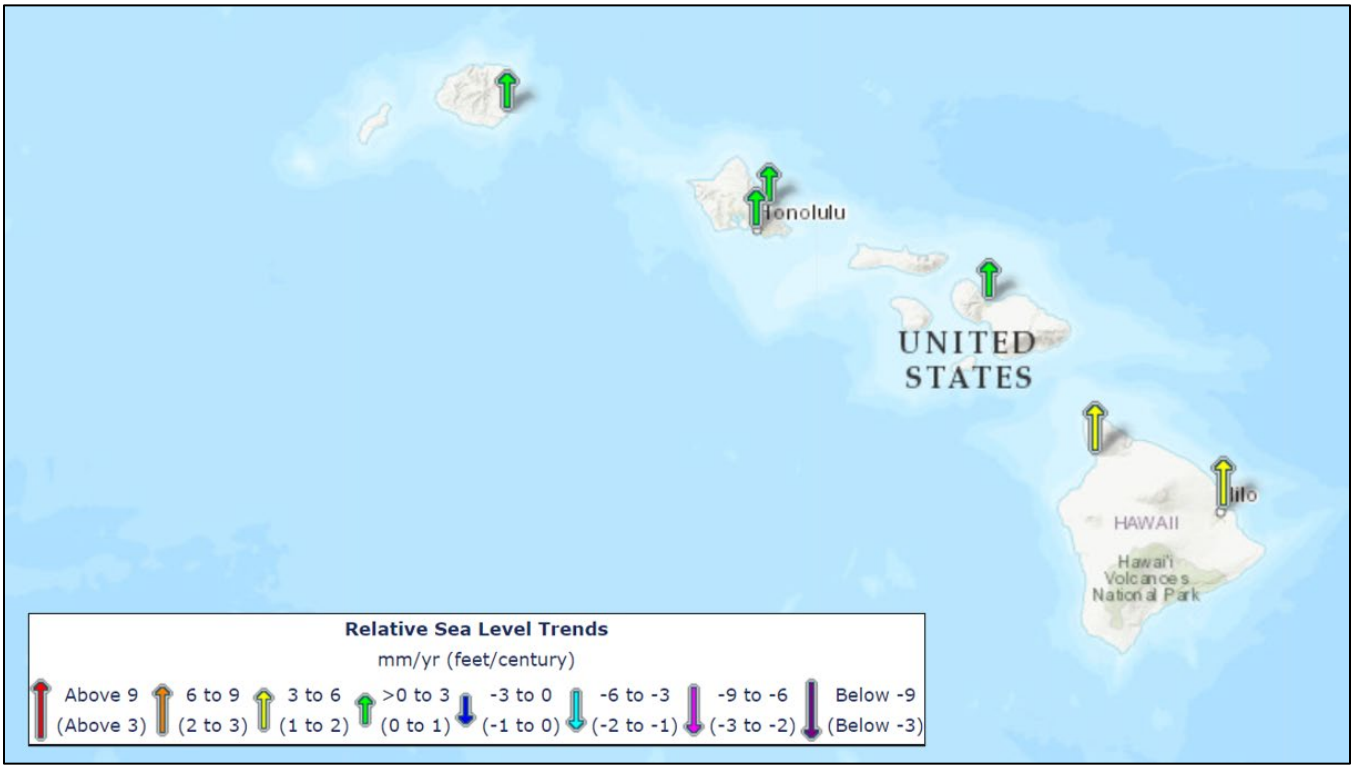
(NASA Earth Observatory 2020). Figure 4.2-11 illustrates the regional trends in sea level rise from local tide gauges for the State of Hawai'i. The arrows represent the direction and magnitude of change. Sea level trends in the State of Hawai'i are on the rise and range between 1.55 to 3.87 millimeters per year (mm/yr). Table 4.2-2 lists these changes for the State of Hawai'i by station. These rates are based on linear trends (a best-fit straight line). Global sea level rise is accelerating. Extrapolating these local linear trends decades into the future would underestimate future sea level rise based on scenarios in the *Global and Regional Sea Level Rise Scenarios for the United States* (Sweet, et al. 2022). Acceleration is expected and may already be occurring around Hawai'i but has not been measure due to shorter-term variability in the individual tide gauge records.

Table 4.2-2. Linear Mean Sea Level Trends and 95% Confidence Intervals

Station Name	First Year	Year Range	Mean Sea Level Trend (millimeter per year)	+/- 95% Confidence Interval	Equivalent To
Nāwiliwili	1955	66	1.77	0.40	0.58 feet in 100 years
Mokuolo'e	1957	64	1.69	0.52	0.55 feet in 100 years
Honolulu	1905	116	1.55	0.21	0.51 feet in 100 years
Kahului	1947	74	2.26	0.39	0.74 feet in 100 years
Kawaihae	1988	33	3.87	1.13	1.27 feet in 100 years
Hilo	1927	94	3.15	0.29	1.03 feet in 100 years

Source: (NOAA Tides & Currents 2022)

Figure 4.2-11. Sea Level Trends in the State of Hawai'i



Source: (NOAA Tides & Currents 2022)

Previous Occurrences and Losses

Disaster and Emergency Declarations

No FEMA, USDA, or State of Hawai'i disaster declarations or proclamations for climate change and sea level rise have been issued relevant to Hawai'i or any of its counties.

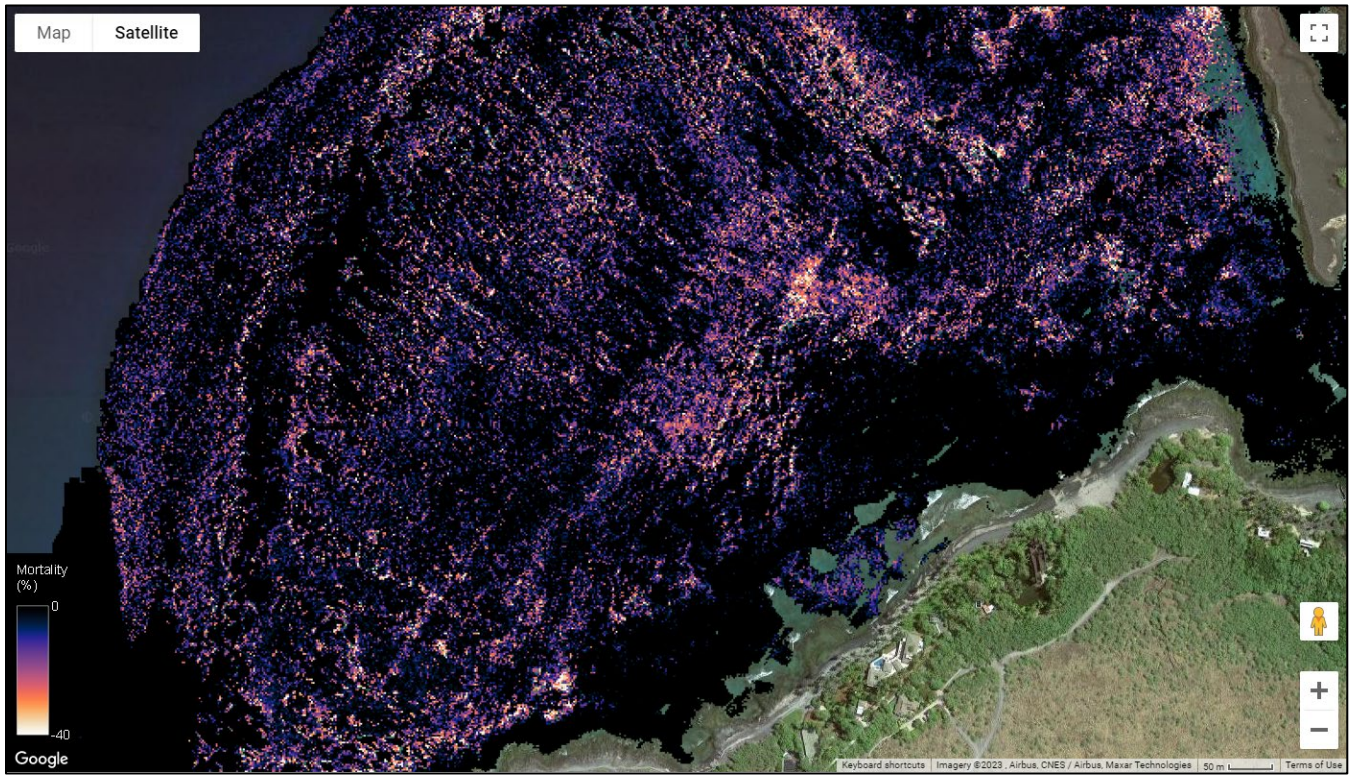
Event History

Climate Change

Climate change is a broad category that encompasses different types of events such as extreme heat, increased drought, and intense storms. Drought, Flood, Hurricane, and Windstorm event histories are discussed in their respective sections. Historical extreme heat is discussed here.

In 2019, an intense marine heatwave impacted areas from Alaska to Caliornia and Hawai'i. Across the State of Hawai'i, 273 daily high air temperature records were tied or broken (Harlow 2020). The increased ocean tempertures caused coral bleaching and loss. Figure 4.2-12 shows the percentage of coral mortality in the Kiholo Bay area of Hawai'i Island from the 2019 marine heatwave.

Figure 4.2-12. Coral Loss From the 2019 Marine Heatwave



Source: (Hawai'i Coral 2023)

Sea Level Rise

Sea level has been rising in the State of Hawai‘i for the past century or more (refer to Table 4.2-2, Figure 4.2-6, and Figure 4.2-11). Rates of rise vary among the islands due to differing rates of subsidence based on distance from the actively-growing Island of Hawai‘i. Other observations related to climate change and sea level rise in the State of Hawai‘i include 70 percent of the beaches in the State of Hawai‘i are undergoing chronic erosion (landward retreat), and over 13 miles of beach have been completely lost to erosion over the past century fronting seawalls and other shoreline structures. This dominant trend of beach erosion appears to be driven in part by local sea level rise (Anderson, et al. 2018, Romine, et al. 2013). Additional factors in addition to sea level rise contribute to coastal erosion and may be discussed in more detail pending further studies and development of erosion data. Shoreline retreat, wetland migration, and cliff collapse due to erosion are occurring on many of the coastlines in the State of Hawai‘i. Groundwater tables in the state’s low-lying coastal plains will rise with sea level rise and increasingly contribute to chronic coastal flooding and flooding (i.e., reduced drainage) with heavy rainfall events (Habel, et al. 2017). In addition, rising sea level will reduce the effectiveness and cause flooding through the state’s coastal storm water drainage infrastructure.

Probability of Future Hazard Events

Overall Probability

The State of Hawai‘i is currently experiencing the impacts of climate change. Surface temperatures are rising, rainfall and stream flow have decreased, rain intensity is increasing, sea level and sea surface temperatures have increased, and the ocean is acidifying. It is anticipated that these trends will continue or accelerate, causing further increases in temperature, extreme variation in precipitation (resulting in droughts or flooding), potential changes in storm systems (possibly more frequent or increased magnitude), and continued rise in sea levels, impacting the state’s water resources and forests, coastal communities, and marine ecology (Fletcher 2010).

As global temperatures continue to increase, sea level will rise at increasing rates. The rate of future carbon dioxide emissions and future climate change determines how much the sea level will rise. The speed at which it rises depends mostly on the rate of glacier and ice sheet melting (Lindsey 2022, Sweet, et al. 2022). Sea level is projected to rise 3.2 feet the latter half of the century and impacts are assessed further in the Vulnerability Assessment below (Hawai‘i Climate Change Mitigation and Adaptation Commission 2017). In summary, consequences of sea level rise for the State of Hawai‘i are severe compared to many other coastal states, as the majority of the population, public infrastructure, and economic sectors exist on low-lying coastal plains which are highly susceptible to coastal hazards (Courtney, et al. 2020)

Research using numerical climate models point to increasing frequency and severity of extreme El Niño and La Niña events (Cai, et al. 2014). The impacts of El Niño may exacerbate the consequences of sea level rise. El Niño events in the tropical Pacific Ocean can cause sea levels to rise 6 to 12 inches above mean conditions in some areas are typically characterized by higher waves in winter (Hawai‘i Climate Change Mitigation and Adaptation Commission 2017). Tropical cyclone activity is also increased around Hawai‘i in El Niño years (NOAA n.d.).

Climate Change Impacts

Extreme heat events are expected to increase statewide. The increase in temperatures will be amplified in low-lying urban areas with a diminished tree canopy. This may include the built-up areas of the City and County of Honolulu, Kahului in Maui County, Līhu'e in Kaua'i County, and Kona and Hilo in Hawai'i County. Average temperatures are increasing by 0.3°F every decade, at four times the rate of 50 years ago.

Hawai'i has lost 1.5 million acres of native forests statewide. Forests are natural water and climate regulators. Climate change and forest contribute to a drier and hotter environment throughout the state. Wildfires amplified by climate change are anticipated to degrade air quality and increase landslides. Increases in sea surface temperatures will cause increasingly irregular patterns of drought, heavy rainstorms, and instense hurricanes. Warmer ocean water will continue to degrade and destroy coral reefs which will leave coastal areas unprotected from coastal flooding hazards (State of Hawai'i Climate Change Portal 2023).

Sea level rise is driven by climate change. As the planet warms, land ice melts and flows into the ocean. The volume of the ocean is expanding as the water temperature increases (Lindsey 2022, Sweet, et al. 2022). The "intermediate" scenario for Hawai'i is estimated at 3.9 feet of sea level rise by 2100. Models indicate that Hawai'i will experience sea level rise that is 16 to 20 percent higher than the global average (DLNR OCCL 2022).

4.2.2 VULNERABILITY ASSESSMENT

A statewide sea level rise exposure analysis was conducted for two flood scenarios, chronic coastal flooding (SLR-XA-3.2) and event-based coastal flooding with 3.2 feet of sea level rise (1%CFZ-3.2). The SLR-XA-3.2 data was generated for the Hawai'i Climate Mitigation and Adaptation Commission. Overall, vulnerability to SLR-XA-3.2 is the potential permanent loss of land and buildings and displacement of population located in the SLR-XA-3.2 hazard area due to chronic flooding. Land that is flooded in the 1%CFZ-3.2 is not considered "lost" because it is assumed the flooding is temporary and the floodwaters would recede. However, buildings and natural resources on that land may be damaged or destroyed as a result of the event. Therefore, vulnerability to the 1%CFZ-3.2 is the potential damage to assets as a result of the event-based coastal flooding exacerbated by sea level rise.

Sea Level Rise Hazard Area Definitions

SLR-XA-3.2 – To assess chronic coastal flood with mid- to late century sea level rise, the Sea Level Rise Exposure Area with 3.2 feet of sea level rise was used. The hazard area is called SLR-XA-3.2.

1%CFZ-3.2 – To assess the 1% annual chance coastal flood in mid- to late century, the 1% annual chance coastal flood with 3.2 feet of sea level rise was used. The hazard area is called 1%CFZ-3.2.

ASSESSMENT OF STATE VULNERABILITY AND POTENTIAL LOSSES

This section discusses statewide vulnerability of exposed state assets (state buildings and roads), community lifelines, and critical facilities to climate change and sea level rise hazards.

State Assets

Across the state, there are 54 state buildings that may be compromised or lost due to sea level rise (SLR-XA-3.2). Almost all of these buildings are located in the City and County of Honolulu (51 of the 55 buildings with a replacement cost value of nearly $57 million). Only replacement cost value was available for state buildings and reported as the total economic loss. However, a more accurate reflection of loss to the SLR-XA-3.2 hazard would be the combined value of the land and structure.

Table 4.2-3 summarizes the state buildings located in the SLR-XA-3.2 by county. The Department of Education has the greatest number of buildings (37) in the SLR-XA-3.2 hazard area as seen in Table 4.2-4. The loss of these structures may result in the interruption and/or relocation of state services if they remain in their present locations.

Table 4.2-3. Estimated State Building Loss from Sea Level Rise (SLR-XA-3.2) by County

County	Total Number of State Buildings	Total Value	Number of State Buildings in SLR-XA-3.2	Percent (%) of Total Buildings	Total Value of State Buildings in SLR-XA-3.2	Percent (%) of Total Value
County of Kaua'i	531	$990,850,824	1	0.2%	$248,896	0.03%
City and County of Honolulu	3,472	$17,393,945,915	51	1.5%	$56,886,036	0.3%
County of Maui	831	$3,097,491,689	2	0.2%	$370,372	0.01%
County of Hawai'i	1,261	$4,638,567,141	0	0.0%	$0	0.0%
Total	**6,095**	**$26,120,855,568**	**54**	**0.90%**	**$57,505,304**	**0.2%**

Source: State of Hawai'i Risk Management Office 2017; Hawai'i Climate Change Mitigation and Adaptation Commission 2017

Table 4.2-4. Estimated State Building Loss from Sea Level Rise (SLR-XA-3.2) by Agency

Agency	Total Number of State Buildings	Total Value	Number of State Buildings in SLR-XA-3.2	Percent (%) of Total Buildings	Total Value in SLR-XA-3.2	Percent (%) of Total Value
Dept. of Accounting & General Services	66	$953,963,738	0	0.0%	$0	0.0%
Dept. of Agriculture	70	$147,607,399	1	1.4%	$2,350,211	1.6%
Dept. of Attorney General	15	$108,425,480	0	0.0%	$0	0.0%
Dept. of Budget & Finance	16	$28,968,679	0	0.0%	$0	0.0%
Dept. of Business, Economic Development and Tourism	25	$645,480,379	1	4.0%	$2,300,000	0.4%
Dept. of Commerce & Consumer Affairs	2	$40,197,360	0	0.0%	$0	0.0%
Dept. of Defense	69	$267,352,836	0	0.0%	$0	0.0%
Dept. of Education	4,090	$10,598,205,739	37	0.9%	$16,732,208	0.2%
Dept. of Hawaiian Home Lands	12	$110,427,352	1	8.3%	$5,489,080	5.0%
Dept. of Health	44	$387,068,440	0	0.0%	$0	0.0%
Dept. of Human Resources Development	1	$5,973,872	0	0.0%	$0	0.0%
Dept. of Human Services	130	$480,212,294	2	1.5%	$3,234,562	0.7%
Dept. of Labor and Industrial Relations	22	$90,076,209	0	0.0%	$0	0.0%

Agency	Total Number of State Buildings	Total Value	Number of State Buildings in SLR-XA-3.2	Percent (%) of Total Buildings	Total Value in SLR-XA-3.2	Percent (%) of Total Value
Dept. of Land and Natural Resources	90	$101,441,821	8	8.9%	$1,232,468	1.2%
Dept. of Public Safety	154	$440,774,415	0	0.0%	$0	0.0%
Dept. of Taxation	1	$7,174,162	0	0.0%	$0	0.0%
Dept. of Transportation	68	$2,935,208,214	1	1.5%	$3,754,468	0.1%
Hawai'i State Ethics Commission	1	$984,533	0	0.0%	$0	0.0%
Hawai'i Health Systems Corporation	106	$1,230,852,871	0	0.0%	$0	0.0%
Hawai'i Housing Finance & Development Corporation	86	$360,851,671	0	0.0%	$0	0.0%
Hawai'i Public Housing Authority	273	$982,981,701	1	0.4%	$5,340,000	0.54%
Hawai'i State Legislature	2	$48,555,381	0	0.0%	$0	0.0%
Hawai'i State Public Library System	53	$525,584,082	0	0.0%	$0	0.0%
Judiciary	41	$534,877,354	0	0.0%	$0	0.0%
Legislative Reference Bureau	1	$2,996,162	0	0.0%	$0	0.0%
Office of Hawaiian Affairs	11	$54,125,645	1	9.1%	$248,896	0.5%
Office of the Auditor	2	$1,921,180	0	0.0%	$0	0.0%
Office of the Governor	1	$2,996,162	0	0.0%	$0	0.0%
Office of the Lieutenant Governor	2	$4,588,849	0	0.0%	$0	0.0%
Office of the Ombudsman	1	$1,818,060	0	0.0%	$0	0.0%
Research Corporation of the University of Hawai'i	3	$4,189,026	0	0.0%	$0	0.0%
University of Hawai'i	637	$5,014,974,503	1	0.2%	$16,823,413	0.3%
Total	**6,095**	**$26,120,855,568**	**54**	**0.9%**	**$57,505,304**	**0.2%**

Source: State of Hawai'i Risk Management Office 2017; Hawai'i Climate Change Mitigation and Adaptation Commission 2017

Event-based coastal flooding from waves generated by infrequent but severe storms and other coastal hazards could occur at any time but will be exacerbated by sea level rise. There are 638 state buildings located in the 1%CFZ-3.2 area, of which the majority are in the City and County of Honolulu (458 buildings with a replacement cost value of $1.994 billion). Table 4.2-5 summarizes the state buildings located in the 1%CFZ-3.2 area by county. The Department of Education occupies the greatest number of buildings (392) that may be impacted as seen in Table 4.2-6.

Table 4.2-5. State Buildings Located in the 1%CFZ-3.2 by County

County	Total Number of State Buildings	Total Replacement Cost Value (RCV)	Number of State Buildings Exposed	Percent (%) of Total Buildings	Total RCV Exposed	Percent (%) of Total RCV
County of Kaua'i	531	$990,850,824	112	21%	$205,951,080	21%
City and County of Honolulu	3,472	$17,393,945,915	458	13%	$1,994,518,893	11%
County of Maui	831	$3,097,491,689	50	6%	$176,627,159	6%
County of Hawai'i	1,261	$4,638,567,141	18	1%	$38,714,514	1%
Total	**6,095**	**$26,120,855,568**	**638**	**10%**	**$2,415,811,646**	**9%**

Source: State of Hawai'i Risk Management Office 2017; Tetra Tech Inc. and Sobis Inc. 2017

Table 4.2-6. State Buildings Located in the 1%CFZ-3.2 by Agency

Agency	Total Number of State Buildings	Total Replacement Cost Value	Number of State Buildings Exposed	Percent (%) of Total Buildings	Total RCV Exposed	Percent (%) of Total Value
Dept. of Accounting & General Services	66	$953,963,738	10	15.15%	$167,495,223	17.56%
Dept. of Agriculture	70	$147,607,399	13	18.57%	$26,049,092	17.65%
Dept. of Attorney General	15	$108,425,480	4	26.67%	$31,157,323	28.74%
Dept. of Budget & Finance	16	$28,968,679	4	25.00%	$21,653,840	74.75%
Dept. of Business, Economic Development and Tourism	25	$645,480,379	4	16.00%	$15,921,383	2.47%
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	392	9.58%	$891,873,401	8.42%
Dept. of Hawaiian Home Lands	12	$110,427,352	1	8.33%	$5,489,080	4.97%
Dept. of Health	44	$387,068,440	6	13.64%	$10,848,499	2.80%
Dept. of Human Resources Development	1	$5,973,872	0	0.00%	$0	0.00%
Dept. of Human Services	130	$480,212,294	30	23.08%	$179,075,774	37.29%
Dept. of Labor and Industrial Relations	22	$90,076,209	6	27.27%	$62,294,284	69.16%
Dept. of Land and Natural Resources	90	$101,441,821	32	35.56%	$16,570,694	16.34%
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	39	57.35%	$248,429,656	8.46%
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	34	12.45%	$38,602,393	3.93%
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%	$25,026,076	4.76%
Judiciary	41	$534,877,354	5	12.20%	$74,290,061	13.89%
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**	**647**	**10.62%**	**$2,496,520,425**	**9.56%**

Source: State of Hawai'i Risk Management Office 2017; Tetra Tech Inc. and Sobis Inc. 2017

Approximately 38.8 miles of state roads could be chronically flooded with 3.2 feet of sea level rise; with the majority of these roads located in the City and County of Honolulu (19.4 miles). The flooding may cause these roads to be impassible, which would jeopardize critical access to many communities and eventually lead to permanent road closures.

Statewide, there are more than 100 miles of state roads exposed to event-based coastal flooding in the 1%CFZ-3.2 hazard area. Many state roads serve as evacuation routes to higher ground. Not only will these roads be closed during coastal flood events and potentially isolate communities, the flood waters may accelerate the degradation of these roads leading to increased repair and replacement costs. The City and County of Honolulu has the greatest number of state (State Profile and Risk Assessment Supplement) road miles (50.9 miles) exposed to the 1%CFZ-3.2, followed by the Counties of Kaua'i and Maui, respectively. More than 25% of the County of Kauai's state roads are located in the 1%CFZ-3.2 hazard area. Table 4.2-7 shows the length of state roads exposed to sea level rise by county. A complete list of state roads exposed is included in Appendix F (State Profile and Risk Assessment Supplement).

Table 4.2-7. State Roads Located in the Sea Level Rise Hazard Areas by County

County	Total Length (miles)	Miles of State Road in the SLR-XA-3.2	Percent (%) of Total Length	Miles of State Road in the 1%CFZ-3.2	Percent (%) of Total Length
County of Kaua'i	103.7	7.4	7.1%	26.9	25.9%
City and County of Honolulu	374.9	19.4	5.2%	50.9	13.6%
County of Maui	245.9	11.8	4.8%	20.3	8.3%
County of Hawai'i	379.2	0.2	0.05%	2.8	0.7%
Total	**1,103.7**	**38.8**	**3.5%**	**100.9**	**9.1%**

Source: State of Hawai'i Department of Transportation 2022; Hawai'i Climate Change Mitigation and Adaptation Commission 2017; Tetra Tech Inc. and Sobis Inc. 2017

Community Lifelines and Critical Facilities

Sea level rise may result in the permanent loss of community lifelines, including roads, airports, harbors, utility infrastructure, water/wastewater facilities and conveyance systems, and other public service facilities with cascading impacts statewide. There are 33 community lifelines located in the SLR-XA-3.2 hazard area (see Table 4.2-8). The County of Maui has the greatest number of community lifelines (14) exposed with the majority of the facilities being food, water, and shelter. Table 4.2-9 summarizes the number and percentage of exposed community lifelines. Food, water, and shelter have more than 4% of their facilities located in the SLR-XA-3.2 hazard area statewide. It is recognized that the replacement cost value listed in Table 4.2-9 does not depict an accurate loss estimate; however, this was the best available data for the 2023 SHMP Update. A more accurate reflection of loss to the SLR-XA-3.2 would be the combined value of the land and structure using tax-assessed data. In addition to land and structural loss, the loss of service by that community lifeline would further increase the total loss as a result of sea level rise.

Table 4.2-8. Community Lifelines and Critical Facilities Located in the SLR-XA-3.2, by County

County	Community Lifeline Categories								Additional Critical Facilities
	Communications	Energy	Food, Water, Shelter	Hazardous Material	Health & Medial	Safety & Security	Transportation	Total in the SLR-XA-3.2	
County of Kaua'i	0	0	2	0	0	4	0	6	0
City and County of Honolulu	1	1	6	0	2	3	0	13	
County of Maui	1	1	7	0	0	3	2	14	
County of Hawai'i	0	0	0	0	0	0	0	0	
Total	**2**	**2**	**15**	**0**	**2**	**10**	**2**	**33**	**0**

Source: Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020; Hawai'i Climate Change Mitigation and Adaptation Commission 2017

Table 4.2-9. Community Lifelines Located in the SLR-XA-3.2, by Category

Category	Total Number of Facilities	Total Value	Number of Facilities in SLR-XA-3.2	Percent (%) of Total Facilities	Value in the SLR-XA-3.2	Percent (%) of Total Value
Communications	188	$776,797,683	2	1.1%	$12,149,409	1.6%
Energy	89	$3,093,949,530	2	2.3%	$74,710,900	2.4%
Food, Water, Shelter	345	$11,847,189,588	15	4.4%	$546,303,600	4.6%
Hazardous Material	12	$436,474,800	0	0.0%	$0	0.0%
Health and Medical	193	$4,606,713,364	2	1.0%	$11,018,840	0.2%
Safety and Security	486	$38,164,188,232	10	2.1%	$4,218,454,122	11.1%
Transportation	56	$2,039,091,600	2	3.6%	$72,588,000	3.6%
Total	**1,369**	**$60,964,404,797**	**33**	**14.3%**	**$4,935,224,870**	**8.1%**

Source: Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020; Hawai'i Climate Change Mitigation and Adaptation Commission 2017

summarizes the total number of community lifelines and additional critical facilities located in the 1%CFZ-3.2 area by county. The City and County of Honolulu has the greatest number of critical facilities (119) within the hazard area with the majority of the facilities being food, water, and shelter.

Table 4.2-11 summarizes the number and percentage of exposed community lifelines and additional critical facilities. The transportation lifeline has 28.6% of its facilities within the hazard area.

Table 4.2-10. Community Lifelines and Critical Facilities Located in the 1%CFZ-3.2, by County

County	Community Lifelines								Additional Critical Facilities
	Communications	Energy	Food, Water, Shelter	Hazardous Materials	Health and Medical	Safety and Security	Transportation	Total in the 1%CFZ-3.2	
County of Kaua'i	2	3	13	0	1	11	2	32	4
City and County of Honolulu	26	19	40	0	5	24	1	115	4
County of Maui	3	0	19	0	4	9	8	43	0
County of Hawai'i	2	2	17	1	0	1	5	28	2
Total	**33**	**24**	**89**	**1**	**10**	**45**	**16**	**218**	**10**

Source: Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020; Tetra Tech Inc. and Sobis Inc. 2017

Table 4.2-11. Community Lifelines and Critical Facilities Located in the 1%CFZ-3.2, by Category

Category	Total Number of Facilities	Total Replacement Cost Value	Number of Facilities in 1%CFZ-3.2	Percent of Total Facilities	Value in the 1%CFZ-3.2	Percent of Total Value
Communications	188	$776,797,683	33	17.6%	$100,222,641	12.9%
Energy	89	$3,093,949,530	24	27.0%	$823,383,230	26.6%
Food, Water, Shelter	345	$11,847,189,588	89	25.8%	$3,004,912,440	25.4%
Hazardous Material	12	$436,474,800	1	8.3%	$36,294,000	8.3%
Health and Medical	193	$4,606,713,364	10	5.2%	$112,519,594	2.4%
Safety and Security	486	$38,164,188,232	45	9.3%	$3,690,769,905	9.7%
Transportation	56	$2,039,091,600	16	28.6%	$581,650,800	28.5%
Additional Critical Facilities	106	$447,698,794	10	9.4%	$38,486,080	8.6%
Total	**1,369**	**$60,964,404,797**	**218**	**15.9%**	**$8,349,752,609**	**13.7%**

Source: Hawai'i Emergency Management Agency 2017; Federal Emergency Management Agency Lifeline Data 2020; Tetra Tech Inc. and Sobis Inc. 2017

Community lifelines located on the coast are exposed to the sea level rise hazard. The primary transportation arteries for the entry of people and goods to the state are the Daniel K. Inouye International Airport and Honolulu Harbor. The International Airport serves more than 21 million passengers and receives more than 382,000 tons of cargo annually (Daniel K. Inouye International Airport 2022). More than 10 million tons of commodities and more than 275,000 cruise ship passenger sailing pass through Honolulu Harbor each year (Department of Business, Economic Development & Tourism 2021).

In addition, each island has critical points of entry for people and goods which are considered vulnerable to sea level rise if located along the coast. Interruption of interisland and transoceanic shipping and travel would impact residents, visitors and all forms of economic activity (Hawai'i Climate Change Mitigation and Adaptation Commission 2017).

Assessment of Local Vulnerability and Potential Losses

This section provides a summary of vulnerability and potential losses to socially vulnerable and total populations, general building stock, environmental resources, and cultural assets. Similar to the analysis for state assets, a spatial exposure analysis was conducted. As noted above, vulnerability to SLR-3.2 is the potential permanent loss of assets and displacement of population located in the SLR-XA-3.2 hazard area. Vulnerability to the 1%CFZ-3.2 is the potential damage to assets as a result of event-based coastal flooding exacerbated by sea level rise.

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 of Kaua'i HMP provides an overview of how climate change will impact other hazards outlined in the County Risk Assessment, as well as an overview of sea level rise impacts to the county. To determine risk presented by sea level rise, Kaua'i County utilized data from the Hawai'i Interagency Climate Adaptation Committee's Sea Level Rise Vulnerability and Adaptation Report to determine a Chronic Sea Level Rise Exposure Area (the area predicted to be inundated under ongoing normal conditions in the future) and Event-Based Sea Level Rise Inundation Area (the area that would be inundated under a 3.2-foot chronic sea-level-rise scenario if a 1 percent annual chance coastal flood event occurs). These analyses found that 17,221 Kaua'i residents and 8,448 buildings would be exposed in the Event-Based sea level rise area and 2,960 residents and 1,255 building would be exposed in the Chronic Exposure area. The County identified 229 critical facilities that would be impacted by both Chronic and Event-Based sea level rise. (County of Kaua'i 2020).
- **City and County of Honolulu** – The City and County of Honolulu included climate change as a standalone risk in the HMP. The City and County included an explanation of how El Niño/La Niña would impact climate change within the region; anticipated future impacts from climate change; historical and projected sea level rise impacts; projected changes to tropical cyclone impacts; costs associated with sea level rise; and mitigation strategies to decrease climate risk to critical assets. The City and County explored two 500-year flood analyses for the end of century: one study with 2 feet of sea level rise and one study with no sea level rise. These analyses found that 2 feet of sea level rise exposed an additional 1,750 properties to a 500-year flood event by end-of-century, with a total of $1.228 billion assets exposed (City and County of Honolulu 2020).
- **County of Maui** – The County of Maui did not include climate change as a stand-alone hazard; however, climate change impacts are discussed throughout the plan
- **County of Hawai'i** – The County of Hawai'i HMP characterized both current and projected risks to the County due to climate change, as well as providing an overview of how climate change will impact the other hazards outlined in the County Risk Assessment. Projected changes include mean sea level rise of 1 to 3 feet by 2100; the potential submersion of low-lying coastal areas such as Hilo; a rise in sea surface temperatures by 2.3 ºF to 4.9 ºF by 2100; and an increasingly wet climate through 2100. To determine risk presented by sea level rise, Hawai'i County utilized data from the Hawai'i Interagency Climate Adaptation Committee's Sea Level Rise Vulnerability and Adaptation Report to determine a Chronic Sea Level Rise Exposure Area (the area predicted

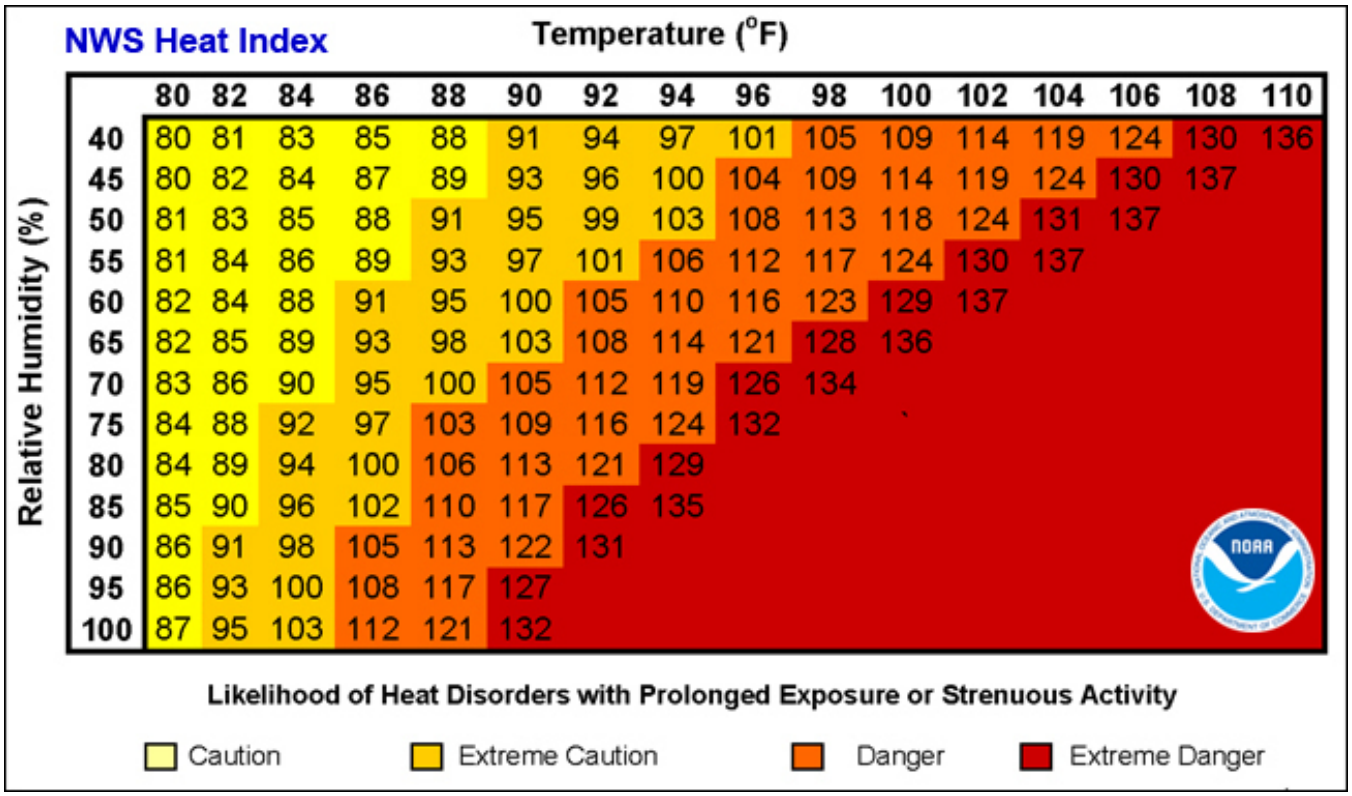
to be inundated under ongoing normal conditions in the future) and Event-Based Sea Level Rise Inundation Area (the area that would be inundated under a 3.2-foot chronic sea-level-rise scenario if a 1 percent annual chance coastal flood event occurs). The County identified 80 critical facilities that would be impacted by both Chronic and Event-Based sea level rise (County of Hawai'i 2020).

Socially Vulnerable and Total Populations

Climate Change

As the climate changes in the State of Hawai'i, residents will face increasing natural hazard threats. With increased temperatures, vulnerable populations could face increased exposure to extreme heat and its associated illnesses such as heatstroke and cardiovascular and kidney disease (Figure 4.2-13). The State of Hawai'i may also see an increase in levels of vector-borne diseases, water-borne diseases such as cholera, fish poisoning, heat-related illnesses, mental health problems, respiratory diseases and other non-communicable diseases, and injury and death from tropical storms and cyclones. Inundation and flooding has led to contamination of surface water and groundwater. Polluted runoff associated with excessive stormwater can contain sewage from overflowing manholes or chemicals from commercial and industrial facilities and has already caused the closure of the beaches around the State of Hawai'i annually (University of Hawai'i at Mānoa Sea Grant College Program 2014).

Figure 4.2-13. National Weather Service Heat Index Chart



Source: (National Weather Service n.d.)

Additionally, climate change can threaten food and water security, infrastructure, and public health and safety, all of which is expected to increase human migration from low- to high-elevation islands and continental sites.

This will make it increasingly difficult for residents to sustain the unique customs, beliefs, and languages of the state. Climate change impacts such as reduced streamflow, saltwater intrusion, and long periods of drought threaten the cultivation of taro and other traditional crops. Low-income families that practice subsistence farming would be especially vulnerable to food insecurity. The entire population of Hawai'i is vulnerable to climate change impacts due to the state's exposure, isolation, small size, and concentration of infrastructure and economy along the coasts. Hazard events amplified by climate change are expected to become more frequent so recovery from these events will be increasingly difficult for vulnerable populations (U.S. Global Change Research Program 2018).

Sea Level Rise

People living and working in the SLR-XA-3.2 hazard area may be displaced as homes and businesses become flooded and permanently lost. The loss of structures in this area may result in nearly 20,000 displaced residents, both homeowners and renters, in need of new homes statewide (Table 4.2-12). The greatest number of people that may be displaced by mid- to late century are located in the City and County of Honolulu (13,300 people). The people displaced would include a range of incomes and living situations.

Table 4.2-12. Estimated Population Displaced by Sea Level Rise (SLR-XA-3.2), by County

County	Total Population	Displaced Population	Percent of Total Population	Total Population in SLR-XA-3.2	Population Exposed as Percent of Total	Socially Vulnerable Population in SLR-XA-3.2	Socially Vulnerable Population Exposed as Percent of Total
County of Kaua'i	71,949	0	0.00%	1007	1.4%	12	0.2%
City and County of Honolulu	979,682	13,300	1.4%	26681	2.7%	6469	0.7%
County of Maui	167,093	2,160	1.3%	2930	1.8%	484	0.3%
County of Hawai'i	201,350	1,000	0.5%	308	0.2%	48	0.02%
Total	**1,420,074**	**19,830**	**1.4%**	**30927**	**2.2%**	**7,127**	**0.5%**

Source: U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018; Hawai'i Climate Mitigation and Adaptation Commission 2017

The cost of interventions to protect properties from coastal flooding and erosion risk may financially stress lower- or middle-income residents. Relocating may be difficult because of the expenses and the availability of accessible housing or the time needed to make housing accessible (U.S. Environmental Protection Agency 2021).

The population over the age of 65 is more vulnerable and, physically, may have more difficulty evacuating during severe coastal flooding events. They may require extra time or outside assistance during evacuations and are more likely to seek or need medical attention, which may not be available due to isolation during a flood event (U.S. Environmental Protection Agency 2021).

Over 138,000 total residents and nearly 24,000 high vulnerability residents are vulnerable to temporary flooding from the 1%CFZ-3.2 if a severe coastal flood event impacts the entire state (Table 4.2-13). This represents the added risk of event-based coastal flooding from severe waves resulting from hurricanes and tropical cyclones that poses a potential for loss of human life and property and for severe and long-term economic disruption.

Table 4.2-13. 2020 U.S. Census Population Located in the 1%CFZ-3.2, by County

County	Population				
	Total Population	Population in 1%CFZ-3.2	Population Exposed as Percent (%) of Total	Socially Vulnerable Population Located in 1%CFZ-3.2	Socially Vulnerable Population Exposed as Percent (%) of Total
County of Kaua'i	71,949	4813.9	6.7%	559	0.8%
City and County of Honolulu	979,682	125,472	12.8%	21,533	2.2%
County of Maui	167,093	5,538	3.3%	1,038	0.6%
County of Hawai'i	201,350	2,624	1.3%	701	0.3%
Total	**1,420,074.00**	**138,448.20**	**9.7%**	**23,830**	**1.7%**

Source: U.S. Census Bureau 2020; Centers for Disease Control and Prevention 2018; Tetra Tech Inc. and Sobis Inc. 2017

Land Use Districts

Table 4.2-14 shows the number of square miles and percent of total acres in each state land use district statewide; refer to Appendix F for results by county. Statewide, Nearly 35 square miles of land are exposed to 3.2 feet of sea level rise. Conservation District lands, which contain valuable environmental resources, have the most area exposure, statewide; however, the exposure accounts for less than 1% of the total Conservation District land in the state. Additional discussion of exposure and vulnerability of environmental resource areas can be found in the Environmental Resources section below.

Table 4.2-14. State Land Use Districts within the Sea Level Rise Hazard Areas

Land Use District	Total (square miles)	Square miles in SLR-XA-3.2	Percent (%) of Total Area	Square miles in 1%CFZ-3.2	Percent (%) of Total Area
Agricultural	2,973.6	9.0	0.3%	35.8	1.0%
Conservation	3,202.9	13.7	0.4%	30.1	0.9%
Rural	16.3	0.6	3.7%	2.2	13.5%
Urban	319.1	11.7	3.7%	41.5	13.0%
Total	**6,511.95**	**34.9**	**0.5%**	**109.6**	**1.7%**

Source: State Land Use Commission, Hawaii Statewide GIS Program 2021; Honolulu County GIS 2022; Hawai'i Climate Mitigation and Adaptation Commission 2017; Tetra Tech Inc. and Sobis Inc. 2017

Urban District lands have the second highest area exposed, accounting for 3.7% of total Urban District land in the state. This is significant as development in these areas would need to be adapted in place to chronic flood conditions or moved elsewhere, which may result in encroachment or conversion of agricultural or Conservation District lands.

The 1%CFZ will expand with sea level rise meaning that more land area will be exposed to damaging wave impacts from a 1% Annual Chance Flood event. This is of particular concern for Urban Districts, which have the greatest share of developed land. With 3.2 feet of sea level rise, 13% of the state's Urban Districts are projected to be exposed to wave heights of more than 3 feet from a 1% Annual Chance Storm. This does not include exposure to wave heights of between 1.5 feet and 3 feet, which can also include significant structural damage.

General Building Stock

To further assess what is at risk, each county's general building stock's exposure was examined. Table 4.2-15 summarizes buildings that may be permanently lost due to 3.2 feet of projected sea level rise. These vulnerable structures include residential structures, hotels, and businesses. Due to the high concentration of development along the coast, the City and County of Honolulu has the greatest potential economic loss of the counties.

Table 4.2-15. Estimated Potential Structure and Property Value (Structure and Land) Loss from Sea Level Rise (SLR-XA-3.2)

County	Number of Structures	Estimated Structure and Land Value Loss
County of Kaua'i	940	$2,600,000,000
City and County of Honolulu	3,800	$12,900,000,000
County of Maui	1,553	$3,490,000,000
County of Hawai'i	130	$430,000,000
Total	**6,423**	**$19,420,000,000**

Source: Hawai'i Climate Mitigation and Adaptation Commission 2017

To more fully understand the potential economic loss to 3.2 feet of sea level rise, both the value of the land and structure must be considered. According to the 2017 *Hawai'i Sea Level Rise Vulnerability and Adaptation Report*, the value of projected flooded structures, combined with the land value projected to be flooded, amounts to over $19 billion across the state. The economic loss due to chronic flooding of roads, utilities, and other public infrastructure was not analyzed but will likely amount to a far greater loss. Utilities, such as water, wastewater, and electrical systems, often run parallel underneath roadways, making lost road mileage a good indication of extent of lost utilities. This chronically flooded infrastructure would have significant impacts on local communities as well as reverberating effects around each island through loss of commerce, loss of access to emergency services, and increased traffic on other roads and highways. Repair and relocation of vulnerable roadways are already costly efforts for the state and counties, which will only worsen as the sea level rises. Harbors and airports, often located in low-lying coastal areas in the state, face chronic flooding. For this reason, the economic loss due to flooded critical infrastructure is expected to be an order of magnitude greater than the potential economic loss from land and structures. Refer to the 2017 *Hawai'i Sea Level Rise Vulnerability and Adaptation Report* for more detailed discussion on vulnerable areas by island.

Damages to buildings as a result of a 1% annual chance coastal flood event may also displace people from their homes, threaten life safety, and impact a community's economy and tax base. Table 4.2-16 lists the estimated cost to repair or replace flooded structures and their contents in the 1%CFZ-3.2. Statewide, this would be more than $125 billion, of which 94% would occur in the City and County of Honolulu. This figure does not include the cost of damage to roads or utilities, which would be considerable. Areas with the highest potential economic loss resulting from a flood event are low-lying urban areas.

Table 4.2-16. Estimated General Building Stock Loss (Structure and Contents) to the 1%CFZ-3.2

County	Number of Structures Impacted	Potential Damages
County of Kaua'i	5,360	$5,700,000,000
City and County of Honolulu	17,700	$120,000,000,000
County of Maui	2,830	$7,880,000
County of Hawai'i	470	$110,000,000
Total	**26,360**	**$125,817,880,000**

Source: Tetra Tech Inc. and Sobis Inc. 2017

Environmental Resources

The observed and projected influences of climate change on global and local ecosystems are diverse and often detrimental. Some of the changes likely to impact the state's ecosystems include accelerated sea level rise, ocean and atmospheric warming, increased flooding, ocean acidification, changing distributions of terrestrial and marine biota, and changing intensity and frequency of storms, among others (U.S. Global Change Research Program 2018).

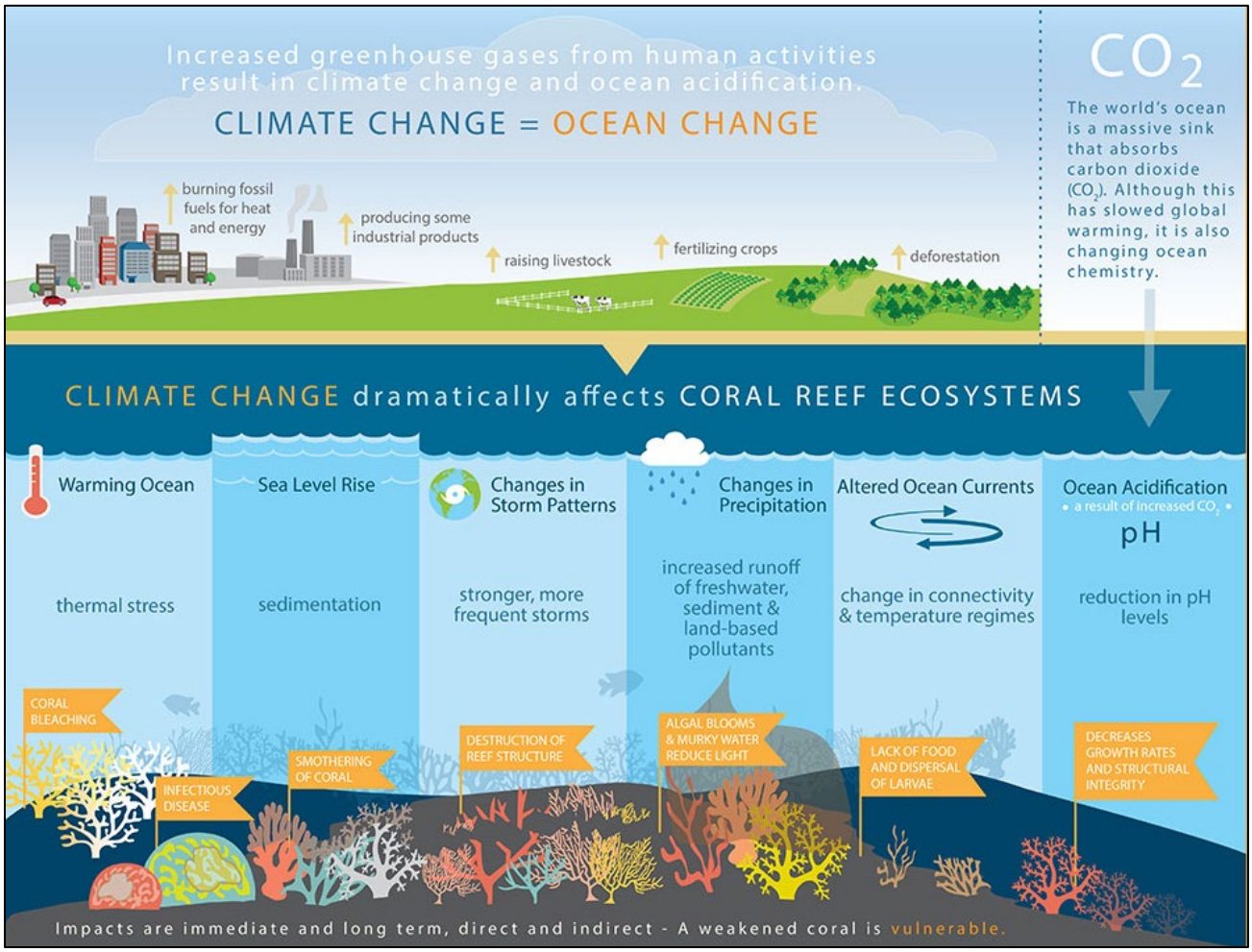
Climate Change

Hawaiian ecosystems will be challenged by increasing frequency and severity of climate-related disturbances (for example, storms, flooding, drought, wildfire, invasive species, and ocean acidification) and continued pressure from anthropogenic influences, such as change in land use, pollution, fragmentation of natural systems, and overexploitation of resources. Evidence of many of these climate-related impacts has already been observed in the State of Hawai'i (University of Hawai'i at Mānoa Sea Grant College Program 2014). The following provides details on how the ecosystems in the State of Hawai'i may be impacted by climate change.

- **Open Ocean**—The physical, chemical, and biological characteristics of the ocean are shifting around the State of Hawai'i under the influence of climate change. The ocean is getting warmer and more acidic, which has the potential to drive changes in circulation and biologic activity. This could disrupt the timing of feeding and spawning of marine species and reduce primary productivity and fish catches around the Hawaiian Islands. Acidification of the oceans threatens calcifying plankton, corals, and other species. Ocean warming could also lead to a more favorable environment for pathogens and invasive species, threatening native and endemic species of the State of Hawai'I (Gove, et al. 2022).
- **Coral Reefs and Nearshore Habitats**—Coral reefs and other nearshore habitats face degradation from climate change and local anthropogenic influences (Figure 4.2-14), including sedimentation, direct physical impacts, overfishing, nutrient loading from runoff, trash and microplastics, and erosion. Warmer oceans are leading to increased coral bleaching and disease outbreaks in coral reefs (U.S. Environmental Protection Agency 2022). Research has shown that under a worst-case scenario half of the coral reef ecosystems worldwide will permanently face unsuitable conditions by 2025. These conditions will likely lead to corals dying off, and other marine life will struggle to survive due to disruptions in the food chain (University of Hawai'i News 2022). Hawaiian reefs experienced statewide bleaching events in 2014, 2015, and 2019 (National Oceanic and Atmospheric Administration 2022). Ocean acidification can cause a variety of responses in marine organisms, including inhibited development of calcium carbonate shells or skeletons in corals, shellfish, and plankton and

impaired physiological functions of some reef fish. Changing precipitation patterns over the Hawaiian Islands influence the stormwater runoff that enters coastal waters. Ocean acidification will reduce coral growth and health. Warming and acidification, combined with existing stresses, will strongly affect coral reef fish communities (University of Hawai'i at Mānoa Sea Grant College Program 2014).

Figure 4.2-14. Climate Change Threats to Coral Reefs



Source: (National Oceanic and Atmospheric Administration 2021)

- **Coasts and the Built Environment**—The coastline of the State of Hawai'i is composed of a diverse mixture of environments, including sandy carbonate beaches, dunes, steep bluffs, lava and limestone benches, marshes, and fishponds, many of which are eroding due to natural and anthropogenic causes (University of Hawai'i at Mānoa Sea Grant College Program 2014).
- **Terrestrial Ecosystems**—A changing climate can alter the habitats and conditions of endemic Hawaiian species, such as the Hawaiian honeycreeper and the Haleakalā silversword (Figure 4.2-15). Warmer temperatures could lead to a shift in the habitat ranges of native plants like the Haleakalā silversword, which is only found at high elevations on Mount Haleakalā and has experienced a decline in population over the last 20 years that is connected to temperature increase. Endemic bird species, such as the Hawaiian honeycreeper,

could decline in population due to the warming of high-elevation forests where risk of avian disease transmission was previously low. Ranges for pests, diseases, and invasive species may expand as a result of warming temperatures. The higher elevations in the State of Hawai'i are bearing the brunt of impacts and lower elevations are seeing new habitats emerge that previously did not exist in the archipelago (University of Hawai'i at Mānoa Sea Grant College Program 2014).

- **Freshwater Resources**—Climate change can lead to a decrease in annual precipitation, streamflow, and groundwater levels and increase the number of and duration of droughts. All of these factors can impact the water table of the State of Hawai'i. Groundwater provides a majority of drinking water in the State of Hawai'i and reduced total rainfall would reduce the amount of water recharging the aquifers and the amount of water available. If drought events continue to increase, dry areas could see more fire and problems with stressed water supplies (University of Hawai'i at Mānoa Sea Grant College Program 2014).

Figure 4.2-15. Hawaiian Honeycreeper ('I'iwi) and Haleakalā Silversword

Sources: (American Bird Conservancy n.d.) (Pennisi 2019)

Sea Level Rise

The loss of natural and cultural resources statewide resulting from sea level rise is difficult to quantify in dollar amounts; however, their loss would deeply impact the state. Sea level rise would take its toll on the state's world-famous beaches, including such iconic stretches of beaches such as Oahu's North Shore "Seven Mile Miracle," the beaches of Kauai's North Shore, and West Maui beaches (Hawai'i Climate Change Mitigation and Adaptation Commission 2017).

Over the past century, 70 percent of the beaches in the State of Hawai'i are undergoing chronic erosion (landward retreat) and over 13 miles of beach have been completely lost to erosion over the past century fronting seawalls and other shoreline structures. This trend of beach erosion appears to be driven in part by local sea level rise (Anderson, et al. 2018). Shoreline retreat, wetland migration and cliff collapse due to erosion are occurring now on many of the State of Hawaii's coastlines. Coastal erosion rates range from 0.5 to 1 foot per year. Nearly one-quarter of the Hawaiian Island's beaches have been significantly degraded over the past 50 years (Surfrider Foundation 2021).

Sea level rise and coastal inundation will affect coral reefs and nearshore habitats of the State of Hawai'i and may result in a shift or loss of ecosystems. Beach and wetland systems may not be able to adapt to rising sea levels and

could be lost if not allowed to migrate landward. The loss of wetlands could reduce the coast's ability to buffer impacts from storms and flooding (University of Hawai'i at Mānoa Sea Grant College Program 2014).

Additionally, sea level rise has the potential to impact facilities that could release wastewater or hazardous materials and waste to nearshore waters and coastal habitats. Septic tanks, cesspools, and other on-site sewage disposal systems (OSDS) as well as other hazard materials/waste storage and disposal sites are located along the coast. The OSDS exposed to chronic flooding in the SLR-XA with 3.2 feet of sea level rise area would not only result in failure of systems to operate properly but would also degrade nearshore water quality. In the County of Hawai'i, OSDS are located along many urban and rural shoreline areas. Releases from these OSDS may change disease risk for coral reefs and negatively impacting nearby coral resources, such as those off the coast of Puakō (Hawai'i Climate Change Mitigation and Adaptation Commission 2017).

Environmental resources, including critical habitat (or habitats that are known to be essential for an endangered or threatened species), wetlands, parks and reserves, and reefs located in the assessed hazard areas are summarized in Table 4.2-17. Wetlands and coral reefs provide protection from rising sea levels and damaging wave action (Owen 2021).

Table 4.2-17. Environmental Resources Located in the Sea Level Rise Hazard Areas

Environmental Asset	Total Square Miles of Asset	SLR-XA-3.2 Area	Percent (%) of Total Asset Area	1%CFZ-3.2 Area	Percent (%) of Total Asset Area
Critical Habitat [a]	951	2	0.18%	2	0.25%
Wetlands	3,637	22	0.61%	1,075	30%
Parks and Reserves	2,778	7	0.26%	21	1%
Reefs [b]	55	1	2.01%	49	90%
Total [c]	**7,420**	**32**	**0.43%**	**1,148**	**15.47%**

Source: Hawai'i Climate Mitigation and Adaptation Commission 2017; (U.S. Fish and Wildlife Service 2022); (U.S. Fish and Wildlife Service 2022); (Office of Planning and Sustainable Development 2022); (Department of Lands and Natural Resources 2022); Tetra Tech Inc. and Sobis Inc. 2017

Notes:

a. Critical habitat area mileage includes the combined area of coverage of individual critical habitat areas.

b. Results only show reefs within the range of the hazard area extent as delineated by the source data.

c. Total square miles may be over-reported as some environmental asset areas may overlap.

Cultural Assets

Many Native Hawaiian cultural resources would be impacted by sea level rise as well due to the number of cultural sites located within the SLR-XA-3.2. Cultural practices, including fishing, gathering, and other cultural practices that require shoreline access would be impacted (Hawai'i Climate Change Mitigation and Adaptation Commission 2017). Iwi kūpuna (ancestral remains) were often buried in dunes and beaches, now threatened by erosion and sea level rise. Table 4.2-18 summarizes the Hawaiian Home Lands by county and Table 4.2-19 summarizes cultural resources by square miles statewide that are vulnerable to sea level rise and exacerbated impacts from coastal event-based flood events due to sea level rise.

Table 4.2-18. Hawaiian Home Lands Vulnerable to Sea Level Rise

County	Area (in square miles)				
	Total Square Miles	SLR-XA-3.2 Hazard Area	Hazard Area as Percent (%) of Total Area	1%CFZ-3.2 Hazard Area	Hazard Area as Percent (%) of Total Area
County of Kaua'i	32.1	0.2	0.5%	0.7	2.2%
City and County of Honolulu	10.6	0.1	0.8%	0.3	2.4%
County of Maui	102.6	0.8	0.8%	1.9	1.9%
County of Hawai'i	191.5	0.1	0.1%	1.1	0.6%
Total	**336.8**	**1.2**	**0.4%**	**4.0**	**1.2%**

Source: Hawaii State Department of Hawaiian Homelands 2021; Hawai'i Climate Mitigation and Adaptation Commission 2017; Tetra Tech Inc. and Sobis Inc. 2017

Table 4.2-19. Cultural Resources Vulnerable to Sea Level Rise, Statewide

Cultural Resource Site Type	Area (in square miles)				
	Total Square Miles	SLR-XA-3.2 Hazard Area	Hazard Area as Percent (%) of Total Area	1%CFZ-3.2 Hazard Area	Hazard Area as Percent (%) of Total Area
Archaeology	90.9	3.7	4.1%	12.3	13.6%
Burial Sensitivity Area	2.1	0.4	20.6%	0.8	36.8%
Historic Building	2.7	0.1	4.2%	0.4	16.0%
Historic District	849.4	9.7	1.1%	141.1	16.6%
Historic Object	9.6	0.0	0.0%	0.0	0.0%
Historic Structure	20.7	0.2	0.9%	0.8	3.6%
Total	**975.4**	**14.1**	**1.5%**	**155.4**	**15.9%**

Source: Department of Land and Natural Resources, Hawai'i State Historic Preservation Division 2022; Hawai'i Climate Mitigation and Adaptation Commission 2017; Tetra Tech Inc. and Sobis Inc. 2017

Future Changes That May Impact State Vulnerability

Understanding future changes that impact vulnerability in the state can assist in planning for future development and ensuring that appropriate mitigation, planning, and preparedness measures are in place. The State of Hawai'i 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

Climate Change

Climate change is a factor of change that is already influencing vulnerability to many of the other hazards of concern. Impacts of climate change on both the probability of future events and their resulting impacts are discussed in the hazard profile and vulnerability assessment sections of each hazard of concern in the 2023 SHMP Update. The extent to which climate change will be a factor of change in vulnerability for the state is only beginning to be understood through efforts like the *Hawai'i Sea Level Rise Vulnerability and Adaptation Report*. Two major factors will influence climate change impacts including whether or not global, human-caused greenhouse gas

emissions will be reduced enough to avoid catastrophic impacts to the climate system and the extent to which feedback loops that are already occurring and little understood will exacerbate conditions.

Sea Level Rise

Sea level rise areas were overlaid on areas that may experience significant changes in development or redevelopment in future years (see Table 4.2-20; refer to Section 3 for more information on projected development areas). The results of this assessment indicate that only small portions of these areas are likely to be lost to chronic flooding from 3.2 feet of sea level rise; however, substantial portions of these areas are located in areas that will be exposed to wave action during a 1% Annual Chance Flood event with 3.2 feet of sea level rise. In the City and County of Honolulu, 18.6% of the Hawai'i Community Development Authority (HCDA) District Area and 6.5% of the Enterprise Zones would be exposed to these damaging waves. In the County of Kaua'i, 9.9% of the Enterprise Zone's total area is exposed. As development is considered in these areas, care should be taken to avoid further developing land that will be lost to sea level rise, to integrate appropriate flood mitigation into development in areas that are within the 1% annual chance flood event with 3.2 feet of sea level rise, and to allow enough room for the migration of coastal resources inland as the shoreline moves landward.

Table 4.2-20. HCDA Community Development Districts, Enterprise Zones, and Maui Development Projects Within Sea Level Rise Hazard 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
SLR-XA-3.2 Hazard Area									
County of Kaua'i	-	-	-	-	-	-	251.0	6.4	2.5%
City and County of Honolulu	7.4	0.4	5.0%	-	-	-	297.3	5.5	2.1%
County of Maui	-	-	-	27.6	0.1	0.2%	1059.8	8.2	0.8%
County of Hawai'i	-	-	-	-	-	-	1274.9	3.3	0.3%
							2883.0	**23.3**	
1%CFZ-3.2 Hazard Area									
County of Kaua'i	-	-	-	-	-	-	251.0	25.0	9.9%
City and County of Honolulu	7.4	1.4	18.6%	-	-	-	297.3	19.4	6.5%
County of Maui	-	-	-	27.6	0.1	0.3%	1059.8	15.6	1.5%
County of Hawai'i	-	-	-	-	-	-	1274.9	13.5	1.1%
Total	**7.4**	**1.4**	**18.6%**	**27.6**	**0.1**	**0.3%**	**2883.0**	**73.5**	**2.6%**

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; Hawai'i Climate Change Mitigation and Adaptation Commission 2017; Tetra Tech Inc. and Sobis Inc. 2017; U.S. Census Bureau 2021