6. CLIMATE CHANGE AND SEA LEVEL RISE

This section provides a description of the climate change and sea level rise hazard, including causes, hazard or incident characteristics, and potential impacts. For an analysis of how climate change exacerbates natural hazards, see each natural hazard profile in this plan.

6.1 HAZARD PROFILE

6.1.1 HAZARD DESCRIPTION

Overview

Climate change refers to changes in average weather conditions that persist over multiple decades or longer. Climate change encompasses both increases and decreases in temperature, as well as shifts in precipitation, changes in frequency and location of severe weather events, and changes to other features of the climate system (NOAA n.d.). 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 (DLNR 2016).

Global sea level rise refers to the overall average increase in sea level across the entire planet, primarily due to factors like the warming of ocean water and melting ice sheets. Local sea level rise means that the level of the ocean is rising relative to the land next to it.

Climate Change and Sea Level Rise Causes

While long-term shifts in earth's temperatures and weather patterns can occur natural causes, such as changes in the sun's activity or volcanic eruptions, the main driver of climate change since the 1800s has been human activities, primarily resulting from the burning of fossil fuels like coal, oil and gas. Burning fossil fuels for activities generates greenhouse gas emissions that trap the sun's heat and raising temperatures. The main greenhouse gases that are causing climate change include carbon dioxide and methane. Agriculture, oil and gas operations are major sources of methane emissions. Clearing land and cutting down forests can also release carbon dioxide. Energy, industry, transport, buildings, agriculture and land use are among the main sectors causing greenhouse gases.

Sea level rise is primarily driven by climate change. As a result of increasing concentrations of greenhouse gases in the atmosphere, the earth's oceans are warming and sea levels are rising as a result. As water warms, it expands. Melting ice sheets and glaciers also contribute to seal-level rise.

Hazard Characteristics and Potential Impacts

This section provides an overview of hazard characteristics and potential impacts. The impacts of climate change and sea level rise described below are anticipated to increase the impacts of other hazards such as extreme heat events, wildfires, and coastal flooding.

CLIMATE CHANGE

As noted above, climate change is characterized by long-term shifts in global temperatures and other atmospheric conditions, including changes in precipitation patterns, extreme weather events, and rising sea levels. The City's Climate Change Commission published a brief noting the following climate change trends (HCCC 2018).

Temperature Increase

The earth's average surface temperature is rising, with global temperature increasing approximately 1.8 °F from the late 19th Century. Statewide, average air temperature has risen by 0.76 °F over the past 100 years, and 2015 and 2016 were the warmest years on record.

Extreme heat events are projected to cover double the amount of global land by 2020 and quadruple by 2040, regardless of future emissions trends (HCCC 2023). O'ahu and other Pacific islands are exposed to extreme heat events, and the impacts are growing. Extreme heat is a weather condition that is hotter than typical for a specific place and timeframe according to the EPA. Forests are natural water and climate regulators and serve as homes to endemic species that exist nowhere else on the planet, so climate impacts on forests will impact populations of native species. Extreme heat may increase vector-borne diseases, water-borne diseases such as cholera, fish poisoning, heat-related illnesses, mental health problems, respiratory diseases and other non-communicable diseases.

Ocean and Soil Warning

In addition to warmer air, ocean and soil temperatures rise due to climate change. Globally averaged sea surface temperature (SST) increased by 1.8 °F over the past 100 years. Half of this rise has occurred since the 1990s. North Central Pacific averaged SST trends follow the globally averaged trend. Over the last 5 years almost the entire tropical Pacific, in particular areas along the equator, have seen temperatures warmer than the 30-year average.

Because global temperatures are strongly influenced by ocean temperatures, warmer oceans will contribute to climate change heat impacts. Warming oceans also provide fuel to hurricanes and other severe weather and lead increases in storm frequency and intensity.

Wind Patterns

Climate change is projected to alter global wind patterns, with some regions experiencing increased wind speeds while others may see a decrease. In Hawai'i, climate change is impacting wind patterns, leading to a decrease in the frequency of northeast trade winds and an increase in the frequency of east trade winds. This shift, coupled with a strengthening of northeast trade winds over the islands, has been observed over the past few decades. Average daily wind speeds are slowly declining in Honolulu and Hilo, while remaining steady across western and south Pacific sites.

Changing wind patterns may increase vulnerability to increased heat caused by climate change, affect air quality and alter rainfall patterns

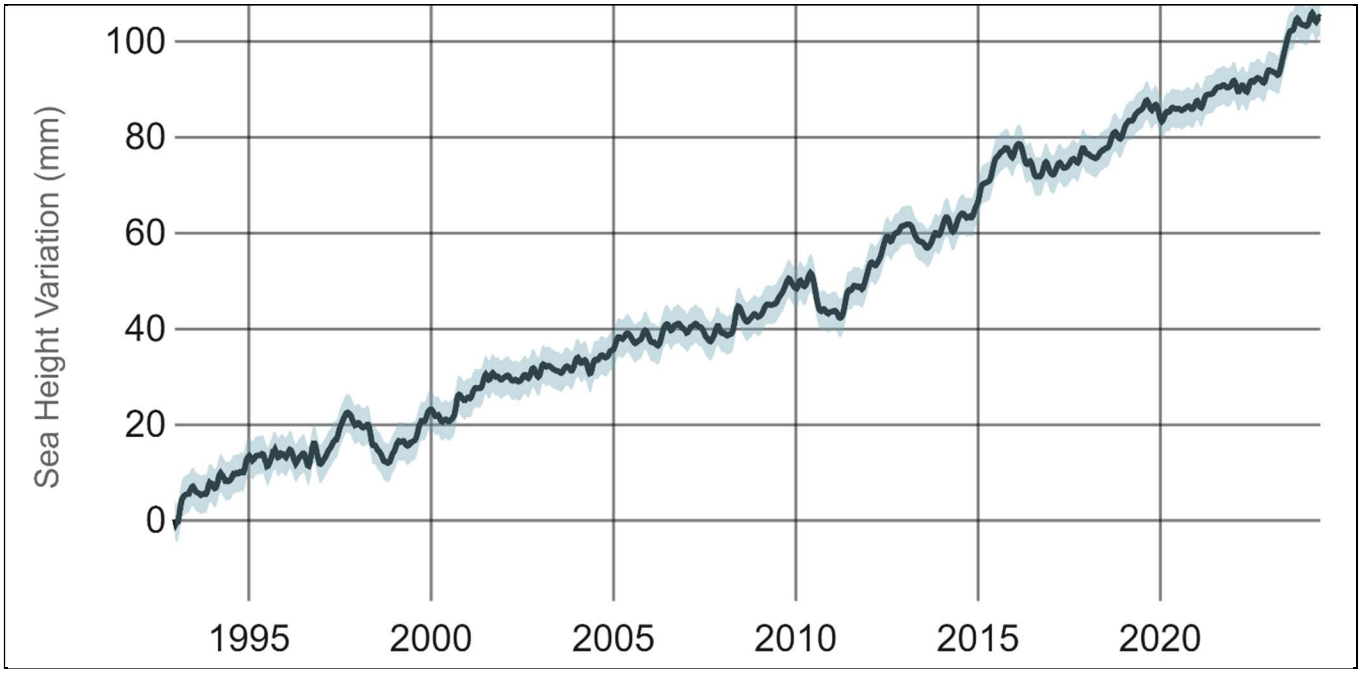
Changes in Precipitation

Climate change is expected to alter rainfall patterns in Hawaii, with increased drought and more frequent heavy rain events. Hawai'i has seen an overall decline in rainfall over the past 30 years. Drier conditions are expected to increase the frequency of drought and increase the potential for wildland fire activity.

SEA LEVEL RISE

According to NOAA, global sea level has been rising over the past century and the rate has increased in recent decades. Global sea levels have, on average, risen more than 4 inches since 1992 (NASA n.d.), as seen in Figure 6-1, and continue to rise at a rate of about one-eighth of an inch per year (NOAA 2024).

Figure 6-1. Satellite Measurement of Sea Height, 1993 to 2024



Source: (NASA 2024)

Per a NOAA 2022 report, sea level rise along the Hawaiian island is expected to rise 6 to 8 inches over the next three decades (W. B. Sweet 2022). Rising ocean and air temperatures are also melting ice sheets and glaciers, which adds freshwater to the ocean and further raises sea levels.

Sea level rise leads to the displacement of beaches, flooding, and erosion. Inundation and flooding exacerbated by sea level rise can lead 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 previously caused the closure of the beaches around the State of Hawai'i annually.

The mean sea level trend at the Honolulu tide station is 0.055 inches per year with a 95 percent confidence interval of about 0.01 inches per year based on monthly mean sea level data, 1905 to 2015. This is equivalent to a change of 0.46 feet over the past century.

6.1.2 LOCATION

Climate Change

The entire island of O'ahu is vulnerable to climate change, and climate change is expected to exacerbate other hazard impacts, such as flooding, hurricanes, and tsunamis. The island has already seen impacts from climate change, including rising sea levels, and the effects will continue to be seen over time. The state and O'ahu have experienced rising temperatures and sea levels and less frequent yet heavy rain events (Hawaii 2018). Changes in temperature and precipitation are expected to influence weather patterns on the island.

TEMPERATURE

Currently, the average surface air temperature in downtown Honolulu is 72 °F in February, the coolest month, and 78°F in August, the warmest month; temperatures rarely exceed 90 °F except in dry, leeward (western) areas, and nighttime temperatures rarely fall below 50 °F at low elevations (PacIOOS n.d.). However, average air temperature has already risen by about 2.6 °F in Honolulu since 1950 with a sharp increase in warming over the last decade (HCCC 2023). Model projections for the late 21st century for Hawai'i indicate that surface air temperature over land will increase 1.8 °F to 7.2 °F, dependent on the emission scenario, with the greatest warming at the highest elevations and on leeward sides of the major islands (HCCC 2023). The increase in temperatures will be amplified in low-lying urban areas with a diminished tree canopy, especially in Downtown Honolulu. Hawai'i has lost 1.5 million acres of native forests statewide, due to agricultural practices and invasive species (USGCRP 2023).

Along with rising air temperature, globally averaged sea surface temperature increased by 1.8 °F over the past 100 years, and the North Central Pacific follows the globally averaged trend (HCCC 2023). Over the last five years, the majority of the tropical Pacific has seen temperatures warmer than the 30-year average.

PRECIPITATION

Hawai'i has seen an overall decline in rainfall over the past 30 years, with varying precipitation patterns on each island. The period since 2008 has been particularly dry across the state (HCCC 2023). Rainfall declined in both the wet and dry seasons on all the major islands; on Oʻahu, the largest declines have occurred in the northern Koʻolau Mountains (HCCC 2023). Additionally, heavy rainfall events and droughts have become more common, which increases erosion, flooding, and water shortages (HCCC 2023).

The models that project changes in total rainfall for Hawaiʻi are not consistent across recent studies; with some studies showing a decrease in daily rainfall intensity while other studies indicate that consecutive wet and dry days are both increasing statewide. Although projections of future rainfall are uncertain, streams and rivers on the Hawaiian Islands have experienced a reduction in flow over the last century, resulting in less fresh water available for people, ecosystems, and agriculture (EPA 2016). With climate change, it is also increasingly likely O'ahu will experience more extreme variability with increased frequency of drought and heaving flooding rain events.

WIND

Tradewinds serve as a natural air conditioner for Oʻahu, delivering steady breezes from the northeast that help cool the islands by enhancing evaporation and dispersing heat and humidity. These winds also play a key role in maintaining air quality and supporting rainfall patterns. However, a 2012 study by the University of Hawaiʻi found that the number of trade wind days has significantly decreased over the past decades—from 291 days per year in the 1970s to only 210 in the 2000s. More recent data, such as the 2022 Hawaiʻi State Climate Summary, indicate continuing changes in atmospheric patterns, including increases in trade wind inversion frequency, which may further reduce the cooling benefits of the trade winds (Stevens, et al. 2022). These trends suggest that climate change could lead to even fewer trade wind days in the future, increasing the risk of heat stress, air pollution, and drought.

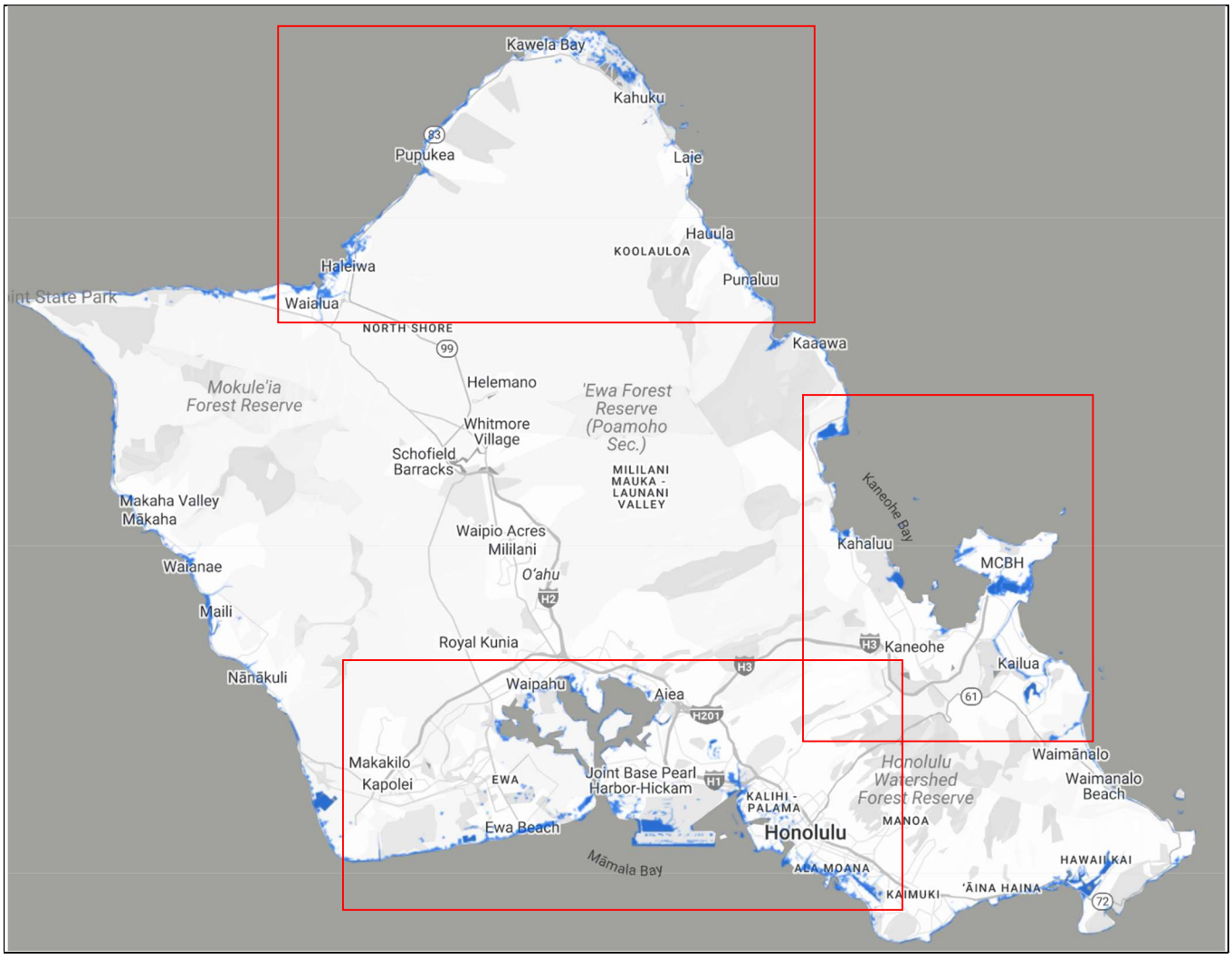
Sea Level Rise

Sea level rise (SLR) will impact the coastal areas of Oʻahu and is expected to exacerbate flooding.

In 2017 and 2020, the Honolulu Harbor Tide gauge recorded its highest daily mean water levels observed over its 112-year history. These record high water levels were produced by a combination of phenomena that included long-term global sea level rise, peak annual astronomical tides ("king tides"), wave setup, and migration of warm buoyant waters brought in by regional winds and currents (Hawaii State Climate Commission 2022).

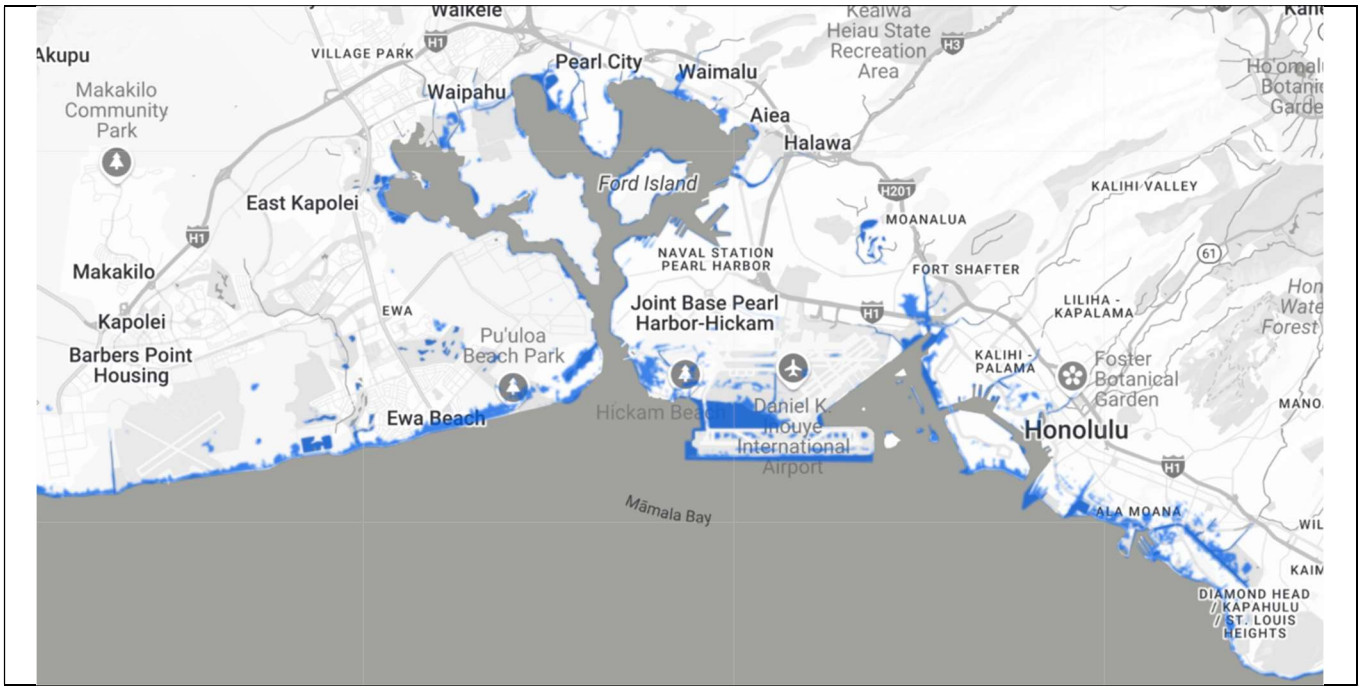
The Pacific Islands Ocean Observing System (PacIOOS) Sea Level Rise Viewer provides exposure mapping using the projection of 3.2 feet of global mean sea level rise by the year 2100. Figure 6-2 displays Oʻahu's map with 3.2 feet of sea level rise, which will impact coastal homes, infrastructure, cultural resources, and ecosystems. Specific areas of the island that are most impacted by SLR are shown on Figure 6-3 through Figure 6-5.

Figure 6-2. O'ahu 3.2 Foot Sea Level Rise Exposure Area



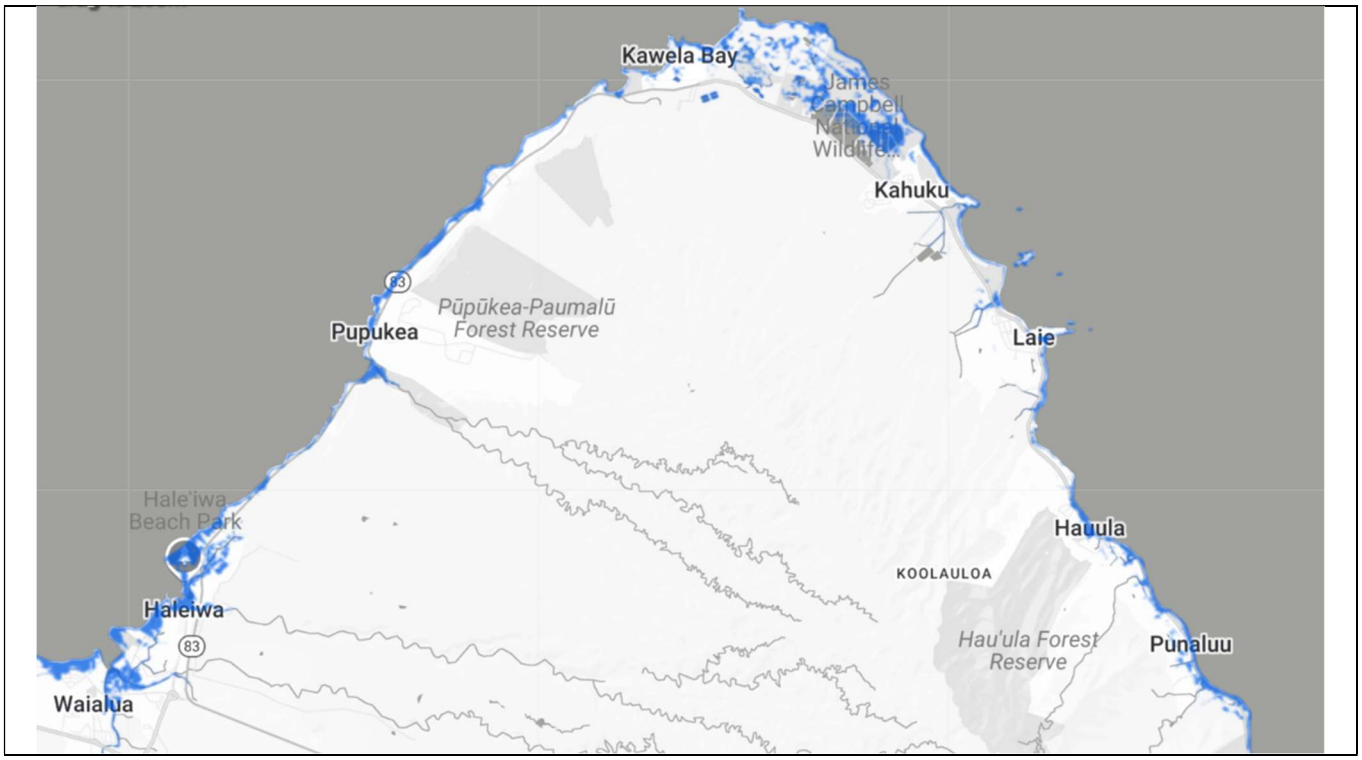
Source: (PacIOOS 2024)

Figure 6-3. ‘Ewa and Primary Urban Center 3.2 Foot Sea Level Rise Exposure Area



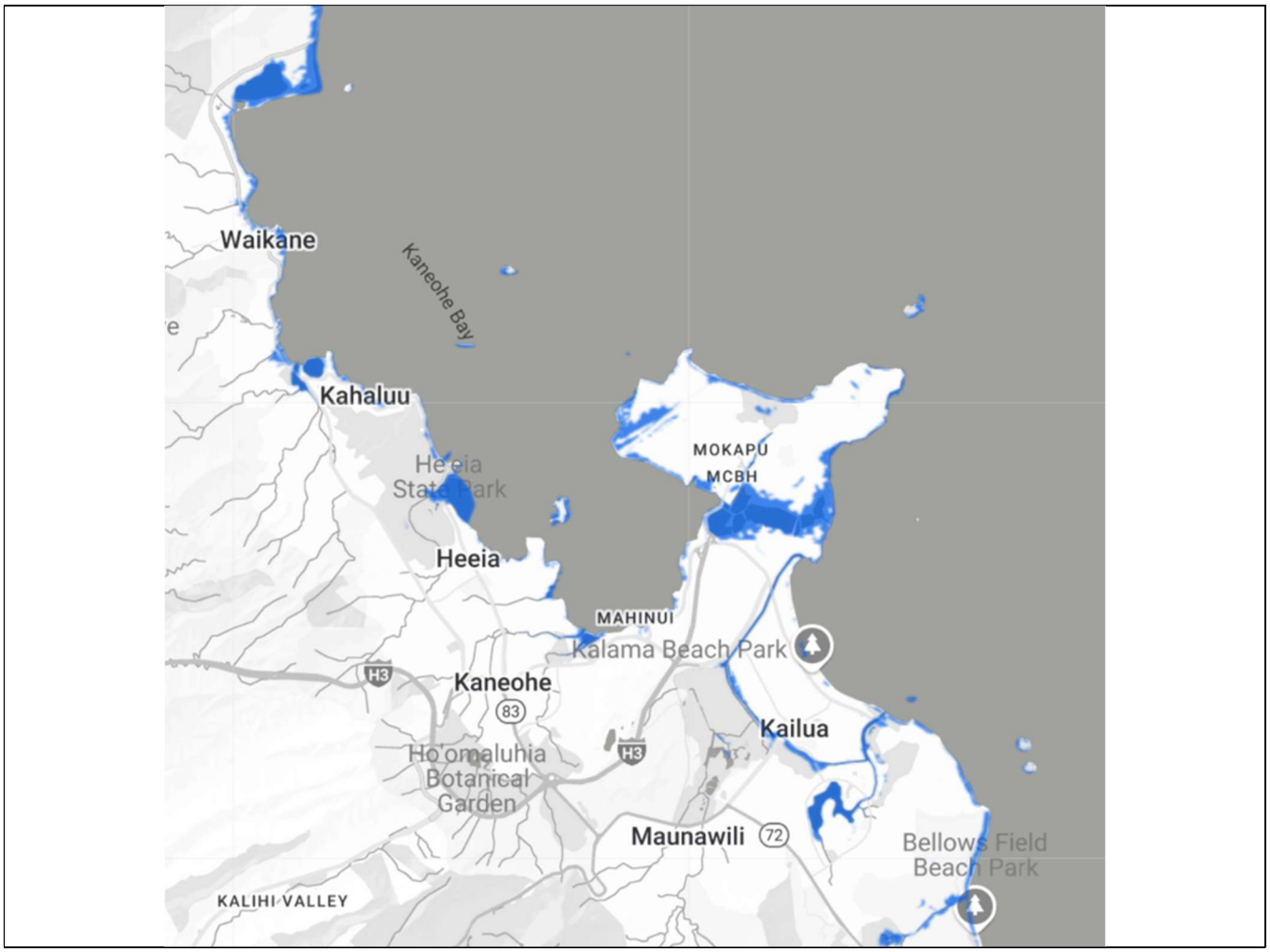
Source: (PacIOOS 2024)

Figure 6-4. North Shore and Koʻolau Loa 3.2 Foot Sea Level Rise Exposure Area



Source: (PacIOOS 2024)

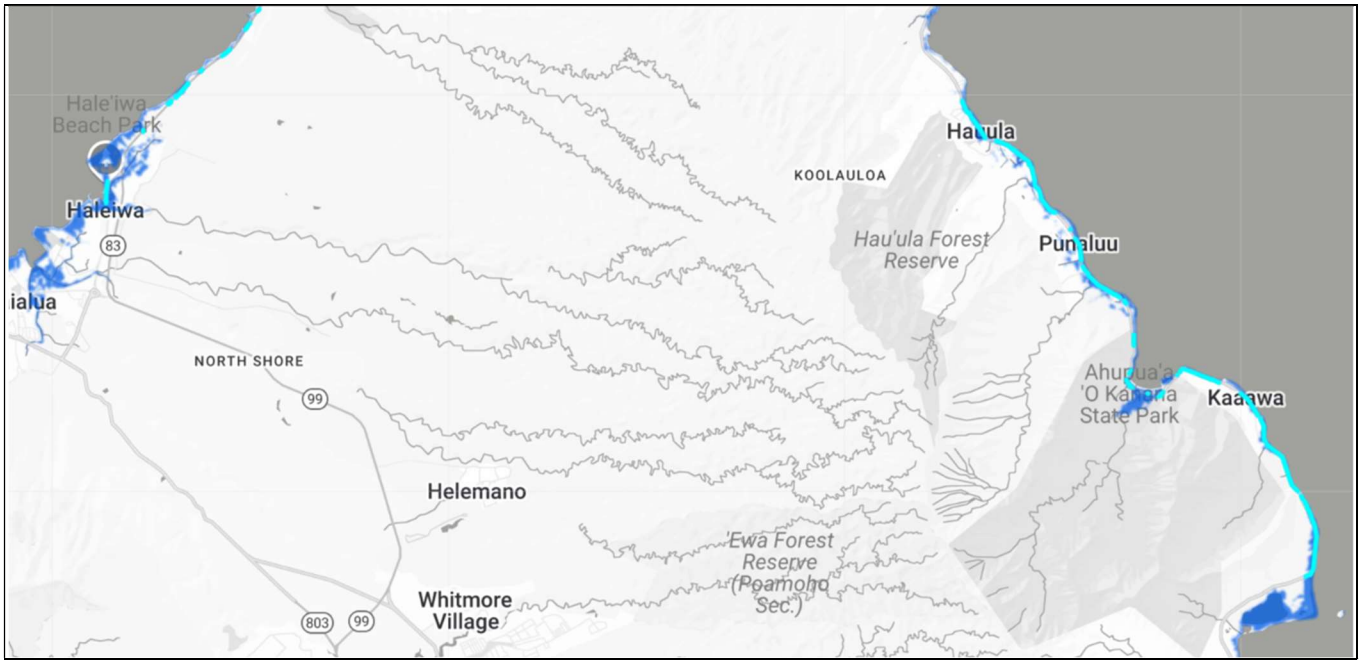
Figure 6-5. Koʻolau Poko 3.2 Foot Sea Level Rise Exposure Area



Source: (PacIOOS 2024)

The 2021 Hawaii Department of Transportation Climate Adaptation Action Plan estimated that 131 miles of state roads are exposed to sea level rise, annual high wave flooding, coastal erosion, or storm surge. On Oʻahu, sections along the Kamehameha Highway, a vital two-lane highway along the entire windward side of the island, have been affected by coastal erosion along Oʻahu's Windward coast. This highway experienced service disruptions at multiple locations due to erosion, most notably Kaʻaʻawa to the southeast of Hauʻula and the Laniākea area farther northwest on the North Shore. In 2015, the governor signed an Emergency Proclamation authorizing emergency repairs of the roadway at Kaʻaʻawa. More recently, HDOT earmarked a project to move the highway farther from the shoreline at Laniākea, and this stretch of highway has been identified as a top-20 priority site (HDOT 2021). Figure 6-6 displays the PacIOOS Sea Level Rise Viewer with highlighted areas in light blue displaying the 3.2 feet SLR scenario where Kamehameha Highway is impacted. Other coastal highways on the island are exposed to sea level rise and coastal erosion, with other areas of concern in Waiʻanae and Waikīkī.

Figure 6-6. Kamehameha Highway 3.2 Foot Sea Level Rise Exposure Area



Source: (PacIOOS 2024)

The island of Oʻahu is already losing homes to sea level rise. An aggressive episode of coastal erosion in early 2022 critically undermined one single family home, leading to its collapse and deposition of dangerous debris along Pūpūkea Beach Park. The collapse followed four years of a progressively worsening combination of chronic and seasonal erosion between Rocky Point and Sunset Beach Park in Paumalu (Hawaii State Climate Commission 2022). In September 2024, a second home on the north shore partially collapsed onto the beach following years of legal actions between the DLNR and the homeowner.

6.1.3 EXTENT

Hazard extent refers to the potential severity or magnitude of hazard events in a given area. This section describes measurements used to indicate the extent of this hazard.

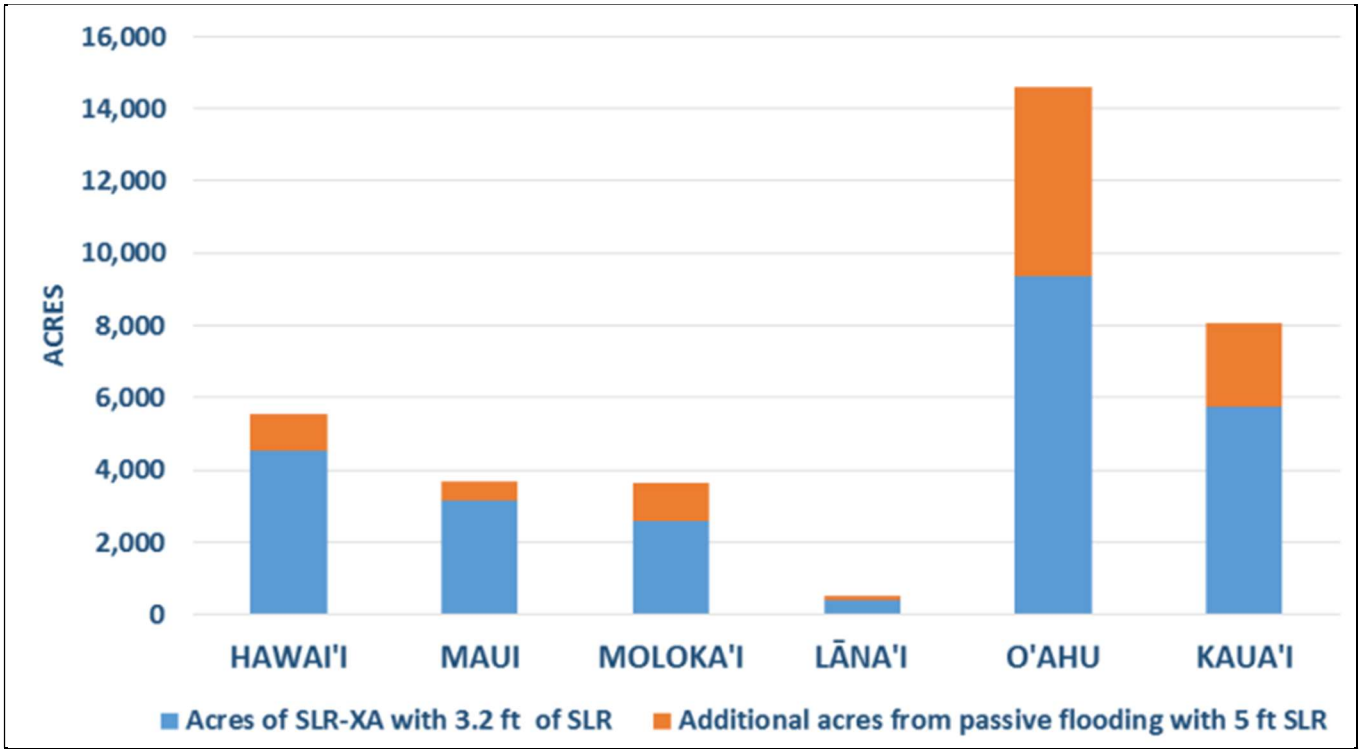
While many sea level rise studies provide estimates through the year 2100, it is important to note that climate and sea level will continue to change after that date. The latest peer-reviewed science on Hawai'i sea level rise projections finds that 3.9 feet of sea level rise will happen by 2100 in an "intermediate" (mid-range) emissions scenario and could be up to 5.8 feet under a high emissions scenario (Hawaii State Climate Commission 2022). While many sea level rise studies provide estimates through 2100, it is important to note that climate and sea level will continue to change after that date.

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 (HCCMAC 2017) (EPA 2016). Figure 6-7 illustrates acreage in the Hawaiian Islands at risk of chronic flooding with 3.2 and 5 feet of sea level rise; O'ahu contains the most acres at risk for both scenarios.

El Niño

El Niño is a climate phenomenon characterized by the periodic warming of the central and eastern tropical Pacific Ocean. Global temperatures, already rising due to climate change, increase during El Nino events because they are significantly influenced by ocean temperatures. El Niño is associated with some of the hottest years on record due to the significant amount of heat transferred from Pacific waters to the atmosphere.

Figure 6-7. Potential Additional Acres of Chronic Flooding with Sea Level Rise



Source: (HCCMAC 2017)

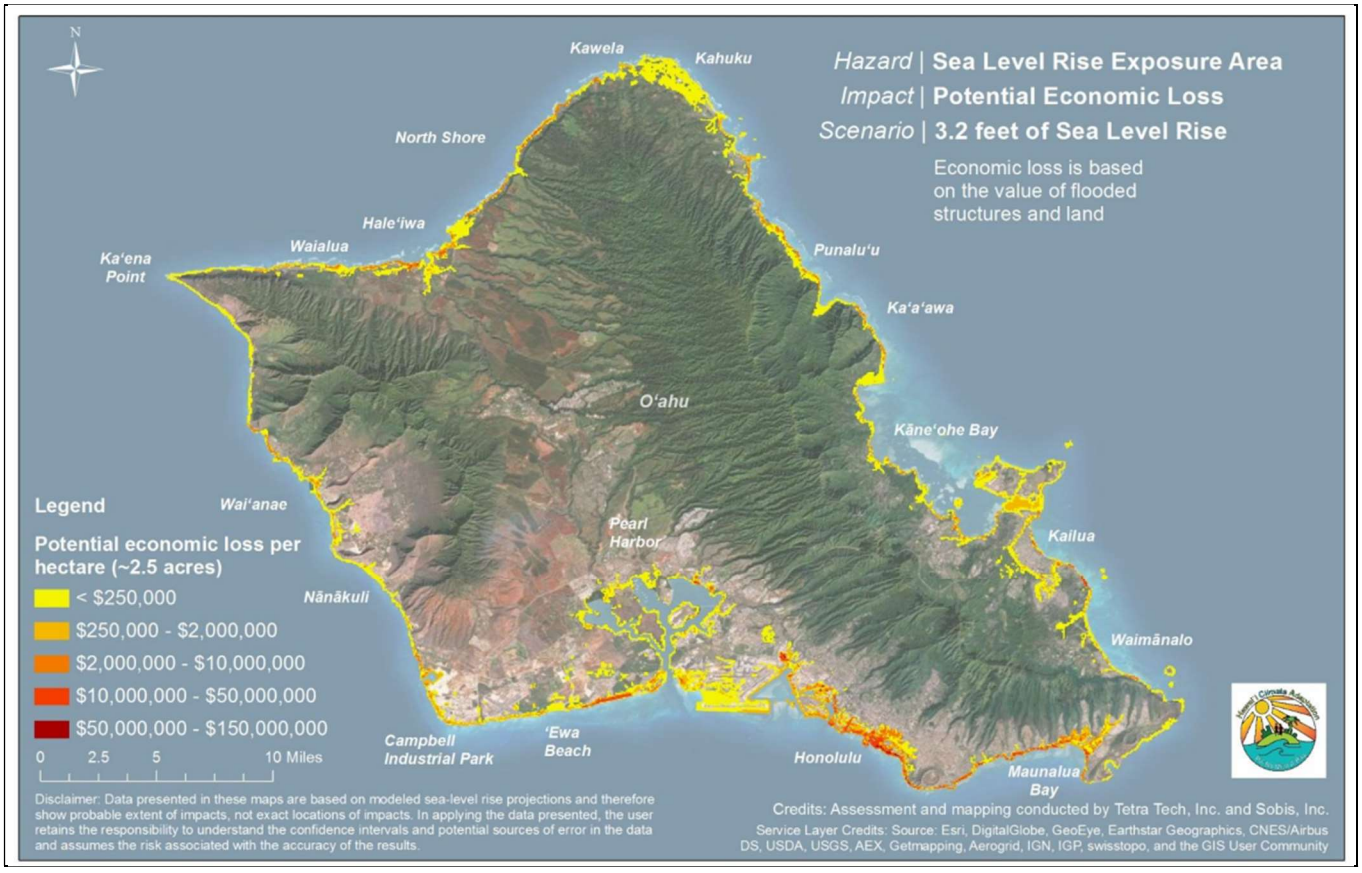
The 2017 Hawai'i Sea Level Rise Vulnerability and Adaptation Report estimated that even 1.1 feet of sea level rise will result in the loss of hundreds of structures and billions in structure and land loss; 3.2 feet of sea level rise will result in thousands of lost structures and more than $12 billion in structure and land loss. Table 6-1 illustrates the potential impacts of 1.1 and 3.2 feet of sea level rise on O'ahu's people, structure, and roads. Figure 6-8 shows potential economic losses across the island for 3.2 feet of sea level rise. The costs associated with potential impacts on critical infrastructure was not calculated in the Hawai'i Sea Level Rise Vulnerability and Adaptation report. Such losses, associated with flooded roads, water/wastewater facilities, and other critical infrastructure, would add significant increases in losses.

Table 6-1. Potential O'ahu Impacts of Sea Level Rise

	Damage to Structures and Land	Number of Structures Flooded	Residents Displaced	Length of Major Road Flooded
1.1-Foot Sea Level Rise	$4.1 billion	650	2,000	5.5 miles
3.2-Foot Sea Level Rise	$12.9 billion	3,800	13,300	17.7 miles

Source: (HCCMAC 2017)

Figure 6-8. Potential O'ahu Economic Loss per Sea Level Rise Exposure



Source: (HCCMAC 2017)

6.1.4 PREVIOUS OCCURRENCES

Climate change and sea level rise are contributors to other hazards identified in this plan, not separate events. There are no standalone disaster events, federal declarations or state or local emergency proclamations to be listed here. Refer to other plan sections for ways in which climate change may contribute to the frequency, severity or magnitude of those hazards and recent impacts.

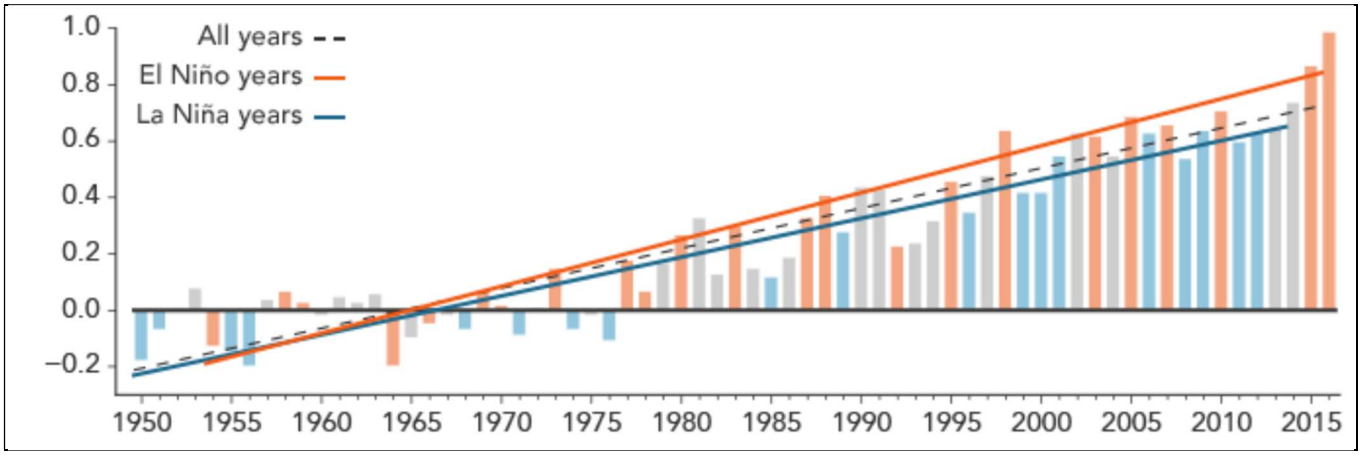
El Niño/La Niña

El Niño events are not directly caused by climate change, but El Nino events can produce conditions that exacerbate climate change impacts already being experienced. El Niño events occur approximately every two to seven years, alternating irregularly with La Niña, which represents a cooling pattern in the eastern Pacific. These events generally peak between November and January, although the buildup can be detected months in advance, and their effects can take time to manifest globally.

During an El Niño event, Pacific Ocean surface waters experience a marked increase in temperature, which is closely linked to atmospheric conditions and wind patterns over the ocean. Easterly trade winds, which typically flow from the Americas toward Asia, may weaken or even shift to westerly winds, allowing substantial volumes of warm water to move from the western Pacific toward the Americas. This shift also diminishes the upwelling of cooler, nutrient-rich waters, disrupting ocean currents along the equator and the west coast of South and Central America.

Conditions that create more risk of severe weather and other hazard impacts, which climate change helps create, can be further amplified during El Nino events. Historically significant El Niño events, notably those in 1972-73, 1982-83, 1997-98, and 2015-16, have been linked to extreme weather conditions such as severe floods, droughts, forest fires, and coral bleaching over the past fifty years (NASA 2017). Figure 6-9 illustrates the impact of El Niño and La Niña years on average temperatures.

Figure 6-9. Annual Temperature Anomaly vs 1951-1980 Average (Celsius)



Source: (NASA 2017)

6.1.5 PROBABILITY OF FUTURE OCCURRENCES

Oʻahu is currently experiencing the impacts of climate change and sea level rise. The probability that impacts will continue is 100%. 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. 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).

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 at least 3.2 feet the latter half of the century (HCCMAC 2017) and the impacts are assessed further in the vulnerability assessment below.

6.2 VULNERABILITY AND IMPACT ASSESSMENT

To understand risk, a community must evaluate what assets are exposed and vulnerable in the identified hazard area. The following text evaluates and estimates the potential impact of the climate change and sea level rise hazard on the county.

6.2.1 LIFE, HEALTH, AND SAFETY

Changing sea levels and compounding climate change impacts can affect human activities in coastal areas. Extreme weather events can have lasting effects on health that extend beyond the immediate aftermath of a disaster. These impacts include heightened risks of food- and waterborne diseases, direct exposure to contamination, increased heat stress, reduced access to medical treatment and emergency services, loss of power necessary for medical equipment and facilities, and disruptions to transportation networks, all of which can lead to increased morbidity and mortality. Any healthcare facilities that are situated along coastlines are particularly vulnerable to tropical cyclones and flooding and may have limited capacity and resources for relocation (USGCRP 2023).

Sea level rise poses a significant risk to facilities that discharge wastewater or hazardous materials into nearshore waters and coastal habitats. On-site sewage disposal systems, such as septic tanks and cesspools, as well as hazardous materials storage and disposal sites may be susceptible to flooding, potentially leading to the release of wastewater or contaminants into publicly trafficked areas and coastal waters. There are approximately 1,330 on-site sewage disposal systems located within 3.2 feet of projected sea level rise across the island (HCCMAC 2017). A recent study conducted in Honolulu highlighted the risk of direct and widespread seepage of untreated sewage into low-lying public areas and coastal waters due to the inundation of these systems attributed to rising groundwater levels (Habel et al. 2017), Habel et al., 2020, McKenzie et al., 2021). The study further revealed that 86% of the on-site sewage disposal systems within the coastal flood zone were not in compliance with established construction standards.

Overall Population

The entire population of the City and County of Honolulu is vulnerable to climate change and sea level rise impacts due to the city's exposure, isolation, small size, and concentration of infrastructure and economy along

the coasts. The 2022 PacIOOS data estimated that more than 15,000 residents could be displaced with 3.2 feet of sea level rise (PacIOOS 2024). This displacement is due to economic impacts on major employers and from the loss of land associated with their homes. Table 6-2 displays the analysis conducted for this LHMP, which includes the latest estimates and data. The analysis shows that the estimate of displaced persons rose to more than 15,000 with 3.2 feet of sea level rise. While the ʻEwa area could see the highest number of displaced people, it will only comprise 3% of the area's population. In contrast, the North Shore could see 15% of its population displaced.

Table 6-2. Population Displacement from 3.2-Foot Sea Level Rise Scenario

Regional Planning Area	Total Population (2022 ACS)	Population in the Sea Level Rise (SLR-XA-3.2 ft) Hazard Area	
		Number of Persons	% of Regional Planning Area Total
Central Oʻahu	175,966	23	<0.1%
East Honolulu	49,947	1,070	2.1%
ʻEwa	128,498	3,910	3.0%
Koʻolau Loa	14,512	1,868	12.9%
Koʻolau Poko	120,704	1,002	0.8%
North Shore	18,176	2,729	15.0%
Primary Urban Center	451,030	2,701	0.6%
Waiʻanae	51,266	1,707	3.3%
City and County of Honolulu (Total)	**1,010,100**	**15,010**	**1.5%**

Source: U.S. Census Bureau ACS 2022; SOEST, UH Coastal Geology Group, PacIOOS, Tetra Tech 2022

Socially Vulnerable Population

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 (EPA 2021). The high cost of land and housing makes relocating a challenge and presents a challenge for buyouts of impacted housing.

Table 3-7 displays socially vulnerable populations living in the City, including older adults over the age of 65, children under the age of 5, individuals who do not speak English, individuals living with a disability, and individuals living below the poverty line. Table 6-3 describes the number of socially vulnerable people living within the sea level rise hazard area. The North Shore stands out as the area with the highest percentage of at-risk populations.

Table 6-3. Socially Vulnerable Populations Located in Sea Level Rise Hazard Area

Regional Planning Area	Estimated Number of Vulnerable Persons Located in the Sea Level Rise (SLR-XA-3.2 ft) Hazard Area									
	Persons Over 65	% of Total	Persons Under 5	% of Total	Non-English Speaking Persons	% of Total	Persons with a Disability	% of Total	Persons in Poverty	% of Total
Central O'ahu	3	<0.1%	1	<0.1%	0	0.0%	2	<0.1%	1	<0.1%
East Honolulu	294	2.1%	46	2.1%	33	2.1%	103	2.1%	44	2.1%
'Ewa	444	3.0%	297	3.0%	81	3.0%	390	3.0%	275	3.0%
Ko'olau Loa	201	12.8%	125	12.8%	31	12.7%	164	12.8%	160	12.8%
Ko'olau Poko	196	0.8%	62	0.8%	11	0.8%	100	0.8%	56	0.8%
North Shore	519	15.0%	208	15.0%	65	14.9%	329	15.0%	277	15.0%
Primary Urban Center	563	0.6%	135	0.6%	290	0.6%	311	0.6%	259	0.6%
Wai'anae	221	3.3%	147	3.3%	28	3.3%	230	3.3%	311	3.3%
City and County of Honolulu (Total)	**2,441**	**1.3%**	**1,021**	**1.7%**	**539**	**0.9%**	**1,629**	**1.5%**	**1,383**	**1.6%**

Source: U.S. Census Bureau ACS 2022; SOEST, UH Coastal Geology Group, PacIOOS, Tetra Tech 2022

While the entire population faces risk, recovery from such events is particularly challenging for vulnerable populations. (USGCRP 2018). Vulnerable populations are often more physically vulnerable to hazard impacts and may be disproportionately impacted as the frequency of these hazards increases. For example, the population over age 65 may have more difficulty evacuating during severe flooding or wildland fire events fueled by changing climate conditions. (EPA 2021). With increased temperatures, vulnerable populations could face increased vulnerability to extreme heat and its associated illnesses, such as heatstroke and cardiovascular and kidney disease. In addition to these physical vulnerabilities, vulnerable populations often face a more challenging and prolonged recovery processes following such events due to financial challenges or a lack of services or supports to adequately address unique needs.

6.2.2 ECONOMY AND GENERAL BUILDING STOCK

To further assess sea level rise risk, Oʻahu's general building stock exposure was examined. Table 6-4 illustrates the total building stock within the planning areas and the replacement cost of those buildings.

Table 6-4. Oʻahu Building Stock and Replacement Cost

Regional Planning Area	Regional Planning Area Total Buildings	
	Count	Replacement Cost Value
Central Oʻahu	32,090	$31,358,898,963
East Honolulu	14,670	$12,765,314,977
ʻEwa	23,477	$23,523,097,571
Koʻolau Loa	3,131	$3,703,783,129
Koʻolau Poko	28,843	$24,614,804,769
North Shore	4,723	$3,819,600,126
Primary Urban Center	71,191	$137,698,243,063
Waiʻanae	10,213	$7,730,241,840
City and County of Honolulu (Total)	**188,338**	**$245,213,984,438**

Source: U.S. Army Corps of Engineers, National Structure Inventory 2022; SOEST, UH Coastal Geology Group, PacIOOS, Tetra Tech 2022; RSMeans 2024

Table 6-5 summarizes buildings that may be permanently lost due to 3.2 feet of projected sea level rise. These vulnerable structures include residential commercial, industrial, and government, religion, agricultural and education structures. Again, the North Shore is at risk of losing the highest percentage of its buildings; however, the replacement cost of buildings lost in the Primary Urban Center represent almost ten times the cost of at-risk North Shore buildings.

Table 6-5. O'ahu Building Stock in Sea Level Rise Hazard Area

Regional Planning Area	Buildings in the Sea Level Rise (SLR-XA-3.2 ft) Hazard Area			
	Number of Buildings		Replacement Cost Value	
	Count	% of Regional Planning Area Total	Value	% of Regional Planning Area Total
Central O'ahu	7	<0.1%	$6,132,897	<0.1%
East Honolulu	326	2.2%	$407,873,372	3.2%
'Ewa	699	3.0%	$370,895,994	1.6%
Ko'olau Loa	385	12.3%	$232,022,778	6.3%
Ko'olau Poko	237	0.8%	$191,880,958	0.8%
North Shore	695	14.7%	$489,623,041	12.8%
Primary Urban Center	800	1.1%	$4,057,198,843	2.9%
Wai'anae	393	3.8%	$657,366,064	8.5%
City and County of Honolulu (Total)	**3,542**	**1.9%**	**$6,412,993,948**	**2.6%**

Source: U.S. Army Corps of Engineers, National Structure Inventory 2022; SOEST, UH Coastal Geology Group, PacIOOS, Tetra Tech 2022; RSMeans 2024

Table 6-6 represents the class of buildings located within the sea level rise hazard area by residential, commercial, industrial, and government, religion, agricultural, and education. Almost three thousand residential buildings are located in the hazard area.

Table 6-6. Building by Class in Sea Level Rise Hazard Area

Regional Planning Area	Buildings in the Sea Level Rise (SLR-XA-3.2 ft) Hazard Area by General Occupancy Class			
	Residential	Commercial	Industrial	Other[a]
Central O'ahu	4	2	1	0
East Honolulu	299	17	5	5
'Ewa	676	14	5	4
Ko'olau Loa	366	13	4	2
Ko'olau Poko	223	10	2	2
North Shore	646	36	11	2
Primary Urban Center	354	343	75	28
Wai'anae	324	58	7	4
City and County of Honolulu (Total)	**2,892**	**493**	**110**	**47**

Source: U.S. Army Corps of Engineers, National Structure Inventory 2022; SOEST, UH Coastal Geology Group, PacIOOS, Tetra Tech 2022

a. Other = Government, Religion, Agricultural, and Education

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 the island through loss of commerce, loss of access to emergency services, and increased traffic on other roads and highways.

6.2.3 COMMUNITY LIFELINES AND OTHER CRITICAL FACILITIES

To further assess sea level rise risk, Oʻahu's community lifeline facility exposure was examined. Table 6-7 illustrates the 189 community lifeline facilities within the planning area that are exposed to sea level rise. Structure types include wastewater pump stations, harbors, schools, hotels, long-term care facilities, gas stations and bridges.

Additional critical infrastructure at risk from sea level rise include the Daniel K. Inouye International Airport and Honolulu Harbor. Honolulu International Airport, the busiest airport in the state, serves more than 19 million passengers a year and receives more than 228,000 tons of cargo. More than 14.6 million tons of commodities pass through Honolulu Harbor annually and more than 400,000 cruise ship passengers sailed into or out of the harbor in 2015 (HCCMAC 2017). Interruption of interisland and transoceanic shipping and travel would impact residents, visitors, and all forms of economic activity.

Table 6-7. Community Lifelines in Sea Level Rise Hazard Area

Regional Planning Area	Number of Facilities in the Sea Level Rise (SLR-XA-3.2) Hazard Area, by Lifeline Category									Total Facilities in Hazard Area	
	Communications	Energy	Food, Hydration, Shelter	Hazardous Materials	Health & Medical	Safety & Security	Transportation	Water Systems	Other Critical Facilities	Count	% of Regional Planning Area Total
Central O‘ahu	0	0	0	0	0	0	5	1	0	6	2.1%
East Honolulu	0	0	2	0	1	1	15	1	0	20	20.4%
‘Ewa	0	0	0	2	2	0	2	0	0	6	2.4%
Ko‘olau Loa	0	0	2	1	0	1	17	0	0	21	21.6%
Ko‘olau Poko	0	0	3	0	0	0	12	0	0	15	4.9%
North Shore	0	0	10	0	0	0	13	0	0	23	26.4%
Primary Urban Center	0	1	20	2	1	1	45	3	0	73	6.3%
Wai‘anae	0	2	3	1	0	1	18	0	0	25	19.7%
City and County of Honolulu (Total)	**0**	**3**	**40**	**6**	**4**	**4**	**127**	**5**	**0**	**189**	**7.8%**

Source: City and County of Honolulu 2023, 2024; State of Hawaii 2017, 2021, 2022, 2023, 2024; US Energy Atlas 2024; SOEST, UH Coastal Geology Group, PacIOOS, Tetra Tech 2022

6.2.4 NATURAL, HISTORIC, AND CULTURAL RESOURCES

Natural Resources

O‘ahu’s natural resources and 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 human-caused influences, such as change in land use, pollution, fragmentation of natural systems, and overexploitation of resources.

The physical, chemical, and biological characteristics of the ocean are shifting due to climate change. The ocean is getting warmer and more acidic, which has the potential to drive changes in circulation and biologic activity. In addition, changing precipitation patterns over the Hawaiian Islands influence the stormwater runoff that enters coastal waters. These changing conditions will have a number of impacts, some of which are already being observed.

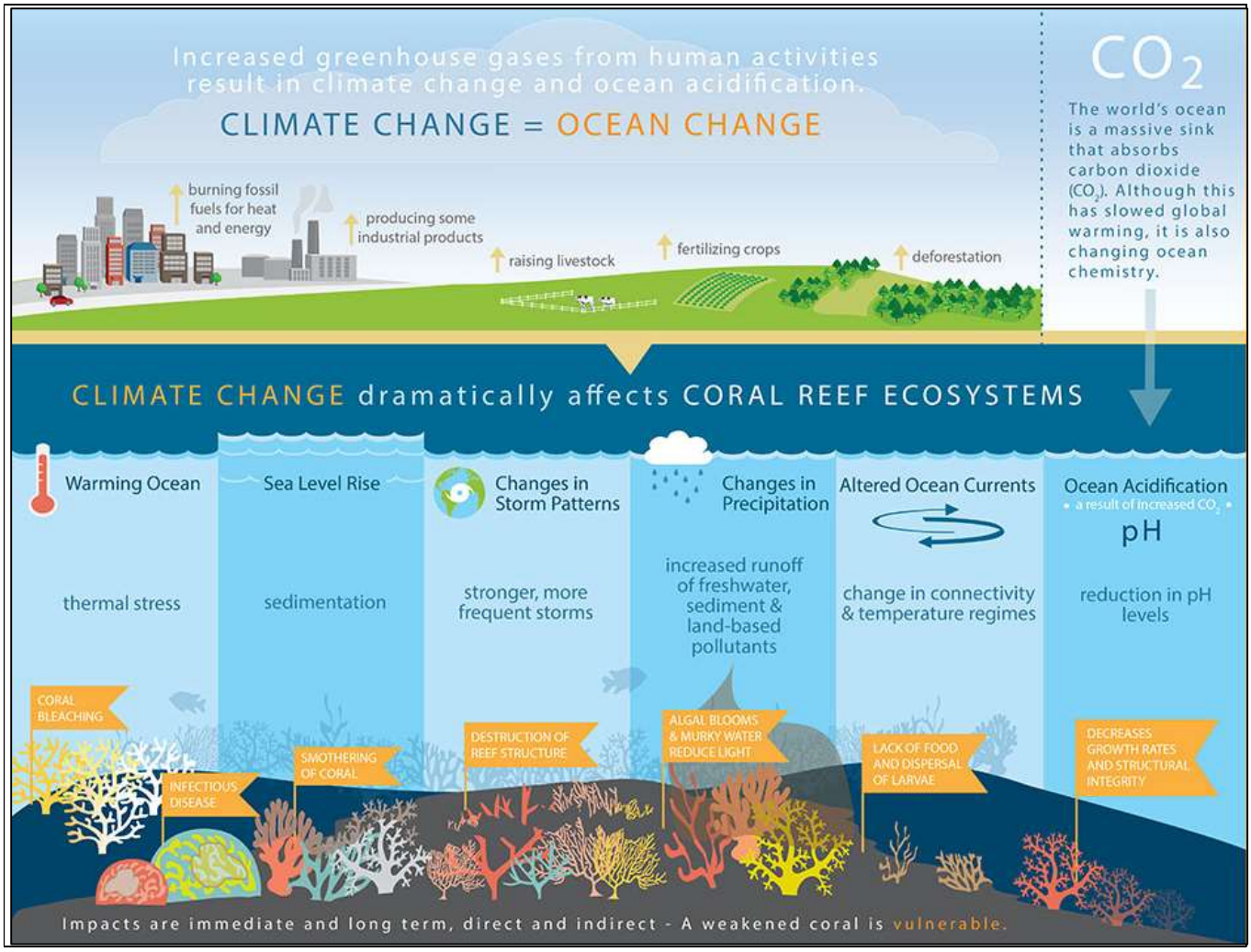
- The feeding and spawning of marine species could be disrupted and reduce primary productivity and fish catches in the open ocean.
- Ocean warming could lead to a more favorable environment for pathogens and invasive species, threatening native and endemic species on O‘ahu (Gove, et al. 2022).
- Coral reefs and other nearshore habitats face degradation from climate change and local anthropogenic influences, including sedimentation, direct physical impacts, overfishing, nutrient loading from runoff, trash and microplastics, and erosion. Warming and acidification, combined with existing stresses, will strongly affect coral reef fish communities (UH Sea Grant 2014). Warmer oceans are leading to increased coral bleaching and disease outbreaks in coral reefs (EPA 2022). Research has shown that under a worst-case scenario half of the coral reef ecosystems worldwide will permanently face unsuitable conditions over the next decade. These conditions may lead to corals dying off, and other marine life may struggle to survive due to disruptions in the food chain (UH 2022). Hawaiian reefs experienced statewide bleaching events in 2014, 2015, and 2019 (NOAA 2022).

Figure 6-10 describes anticipated effects of climate change on marine resources and the threats caused by those effects.

In addition to marine ecosystems, a changing climate can alter the habitats and conditions of land-dwelling endemic Hawaiian species. Rising temperatures, changing rainfall patterns, and increased fire risk from climate change will stress already fragile ecosystems and native species.

Climate change can also impact the island’s freshwater resources through a decrease in annual precipitation, streamflow, and groundwater levels and increase the number and duration of droughts. Groundwater provides a majority of drinking water on O‘ahu and reduced total rainfall would reduce the amount of water recharging the aquifers and the amount of water available (BWS 2024). Drought frequencies have increased in both wet and dry seasons, with the worst drought on record occurring in O’ahu during 1998-2002 (HCCC 2023).

Figure 6-10. Climate Change Threats to Coral Reefs



Source: (NOAA 2021)

Along with drought concerns, wildfire on the island is a growing problem due to drying, invasive grasses, human-caused ignitions, and increased risk due to drought and climate change. 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.

Sea level rise will also impact the island's tourism economy as sandy beaches and shoreline access are impacted. Oʻahu's beaches are estimated to provide recreational services valued at roughly $700 million per year, of which $32 million comes from Hanauma Bay (HCCMAC 2017). Waikīkī Beach is estimated to be worth over $2 billion in annual visitor expenditures (HCCMAC 2017).

Historic and Cultural Resources

Many Native Hawaiian cultural resources would be flooded by sea level rise. There are many cultural assets located on O'ahu. The State Historic Preservation Division maintains an inventory of historic and cultural resources including significant buildings, historic sites, and culturally significant areas, such as burial sites and fishponds. Other notable cultural resources include the lo'i kalo (taro fields) and the loko i'a (fishponds). Cultural practices, including fishing, gathering, and other cultural practices that require shoreline access, would be impacted. Iwi kūpuna (ancestral remains) were often buried in dunes and beaches and are now threatened by erosion and sea level rise (HI-EMA 2023).

An analysis was conducted to understand the impact of sea level rise on cultural and historic sites on Oʻahu. Table 6-8 displays the number of sites on the National and State Register of Historic Places that would be damaged by 3.2 feet of sea level rise. While these are historic and cultural sites that would be impacted by SLR, many cultural resources that require shoreline access would be impacted.

Table 6-8. Cultural Resources Vulnerable to Sea Level Rise, Statewide

	Number of Historic Sites in the Sea Level Rise (SLR-XA-3.2) Hazard Area	
Regional Planning Area	**Count**	**% of Regional Planning Area Total**
Central Oʻahu	1	11.1%
East Honolulu	3	37.5%
ʻEwa	0	0.0%
Koʻolau Loa	1	50.0%
Koʻolau Poko	5	18.5%
North Shore	4	50.0%
Primary Urban Center	13	2.9%
Waiʻanae	0	0.0%
City and County of Honolulu (Total)	**27**	**5.3%**

Source: City and County of Honolulu 2024; SOEST, UH Coastal Geology Group, PacIOOS, Tetra Tech 2022

6.2.5 FUTURE CHANGES THAT MAY AFFECT RISK

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

Potential or Planned Development

The Revised Ordinances of Honolulu (ROH) is the set of local laws passed by the City Council regulating activity within the City and County of Honolulu. The ROH Shoreline Setback was amended in 2023 to list reduced coastal hazards and increased community resilience as the primary concerns of city policymakers. In addition, the amendment increased the shoreline setback from 40 feet to 60 feet, plus 70 times the annual erosion rates up to a maximum setback of 130 feet in certain areas beginning July 1, 2024, and established a 3-foot minimum above base flood elevation requirement for new structures within a special flood hazard area (City and County of Honolulu 2023). Table 6-9 displays potential or planned development located in the sea level rise hazard area. Forty-six new developments were approved from 2020-2024 that are at risk from 3.2 feet of sea level rise.

Table 6-9. New Development in Sea Level Rise Hazard Area, 2020 to 2024

	New Development in the Sea Level Rise (SLR-XA-3.2) Hazard Area	
Regional Planning Area	**Count**	**% of Regional Planning Area Total**
Central O‘ahu	0	0.0%
East Honolulu	5	4.2%
‘Ewa	9	0.9%
Ko‘olau Loa	8	12.5%
Ko‘olau Poko	7	2.5%
North Shore	8	13.6%
Primary Urban Center	6	0.8%
Wai‘anae	3	2.6%
City and County of Honolulu (Total)	**46**	**1.8%**

Source: City and County of Honolulu 2024; SOEST, UH Coastal Geology Group, PacIOOS, Tetra Tech 2022

Projected Changes in Population

O‘ahu’s population is expected to rise by around 50,000 people by the year 2050. Population increases are unlikely to have an impact on the incidence of climate change and sea level rise; however, populations living and working near the coast can expect to see coastal structures, roads, and ecosystems change due to flooding caused by sea level rise. Table 6-10 outlines O‘ahu’s population projections through 2050.

Table 6-10. City Population Projections

Year	2020	2030	2040	2050
Population	1,012,305	1,033,600	1,054,670	1,060,110

Source: (DBEDT 2023)