Hawai‘i Climate Adaptation

Pili Na Mea A Pau

Sea Level Rise Information Brief

November 2015

Office of Planning
State of Hawaii

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INTRODUCTION

In 2014, the Hawaii State legislature declared, through the passage of the Hawaiʻi Climate Adaptation Initiative Act (Act 83, Session Laws of Hawaiʻi) that climate change is the paramount challenge of this century, posing both an urgent and long-term threat to the State's economy, sustainability, security, and way of life. The purpose of the Hawaiʻi Climate Adaptation Initiative Act is to address the effects of climate change in order to protect the State's economy, health, environment, and way of life. Act 83 notes that, "Hawaiʻi is one of the few coastal states that has not adopted a statewide climate adaptation plan, yet is among the most vulnerable." Act 83 calls for the establishment of an Interagency Climate Adaptation Committee (ICAC), attached administratively to the Hawaiʻi Department of Land and Natural Resources (DLNR) and co-chaired by the Board of Land and Natural Resources (BLNR) and the director of the Hawaiʻi Office of Planning (OP). The first task of the ICAC is to develop a statewide Sea Level Rise Vulnerability Assessment and Adaptation Report (SLR Report) by December 31, 2017. This information brief is the first in a series of documents that will provide updates on climate science and adaptation. This information brief will be updated as new science and information become available.

CLIMATE CHANGE

Climate change is anticipated to have profound effects in the Hawaiian Islands. Key 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 (Figure 1) [5].

Climate change - A change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties that persist for an extended period, typically decades or longer [1].

Climate variability - The variations in the mean state and other statistics (e.g., standard deviations, the occurrence of extremes) of the climate on all spatial and temporal scales beyond that of individual weather events. Examples of climate variability include interannual El Niño and La Niña events that occur every two to seven years and influence weather patterns over vast regions of the globe [1].

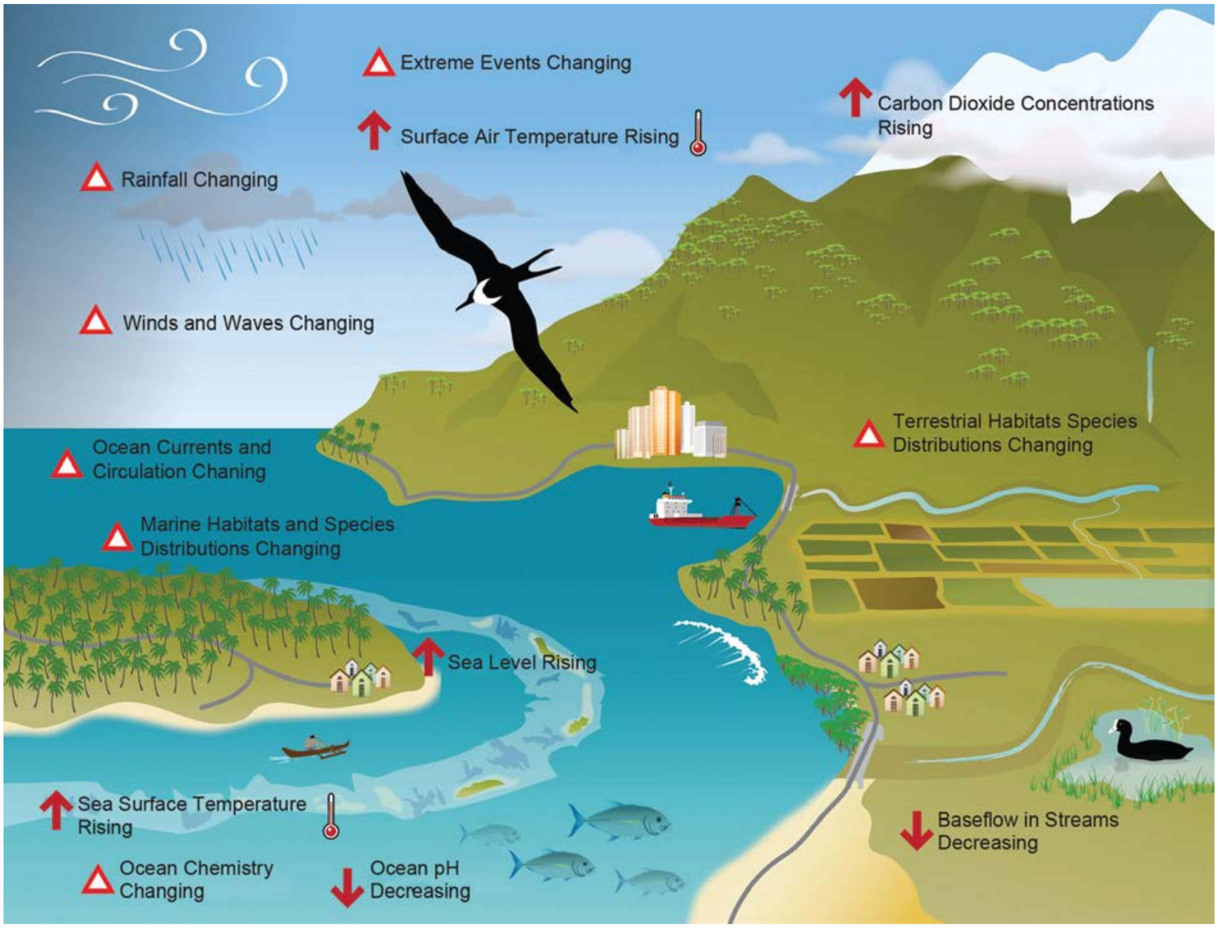

Figure 1. Indicators of climate change in the Pacific Islands region (adapted from [5])

Atmospheric concentrations of carbon dioxide and other greenhouse gases, including methane and nitrous oxide, are increasing due to human activity. Hawaii's Mauna Loa Observatory is one of the world's leading scientific stations for monitoring the atmosphere. For more than fifty years, beginning with atmospheric chemist Charles Keeling's readings of carbon dioxide levels in the atmosphere, the Mauna Loa Observatory has provided climate scientists a continuous record of the atmosphere's increasing concentration of carbon dioxide—and sparked the international debate over global warming. The Keeling Curve is a measurement of the concentration of carbon dioxide in the atmosphere made atop Hawaii's Mauna Loa since 1958 [6] and is the longest-running such measurement in the world (Figure 2 and Figure 3).

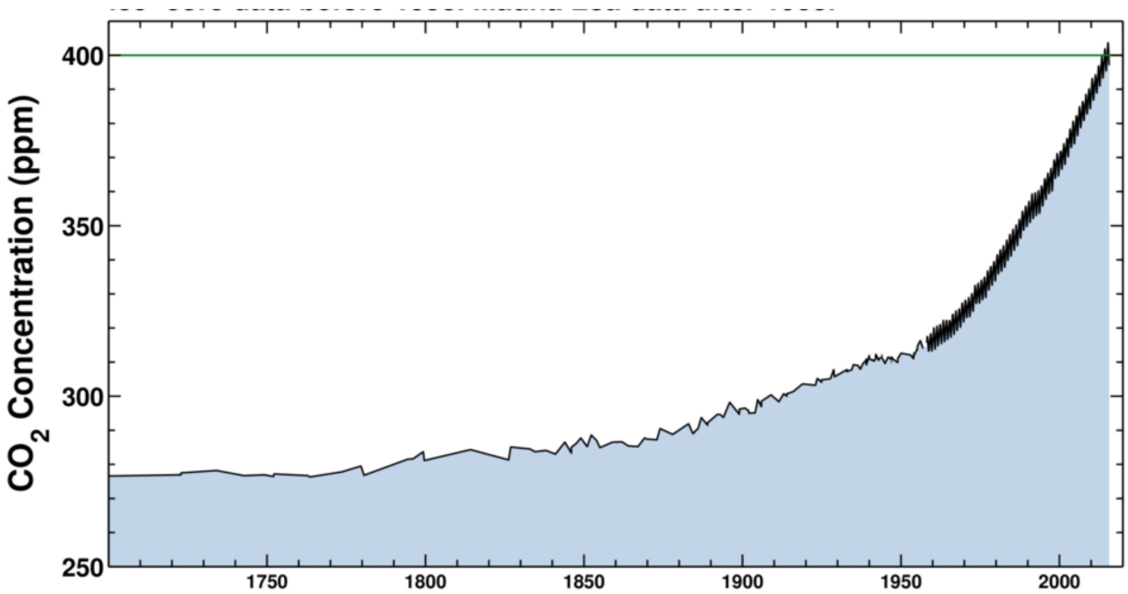

Figure 2. The concentration of carbon dioxide in the atmosphere is increasing as a result of human activities [6]. Data before 1958 is from ice cores and data after 1958 are measurements taken from the Mauna Loa Observatory. Green line marks concentration of 398.02 ppm measured on October 11, 2015.

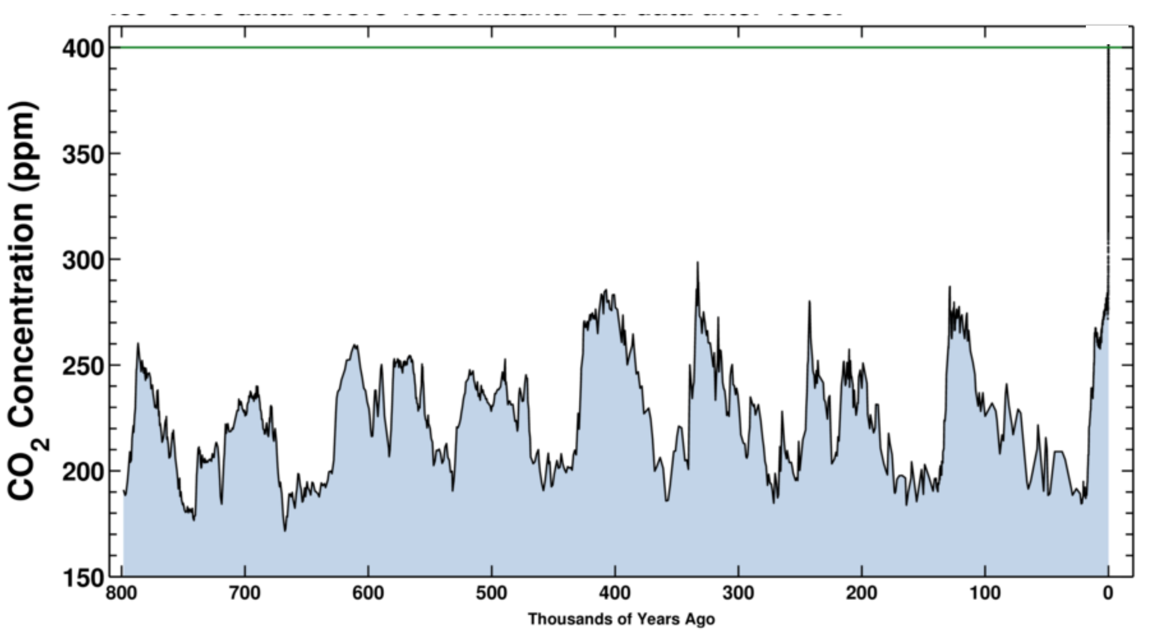

Figure 3. Current carbon dioxide concentrations in Earth's atmosphere have vastly exceeded levels measured in ice cores over the last 800,000 years [6]. Data before 1958 is from ice cores and data after 1958 are measurements taken from the Mauna Loa Observatory. Green line marks concentration of 398.02 ppm measured on October 11, 2015.

SEA LEVEL RISE

> "Given what we know now about how the ocean expands as it warms and how ice sheets and glaciers are adding water to the seas, it's pretty certain we are locked into at least 3 feet [0.9 meter] of sea level rise," said Steve Nerem of the University of Colorado, Boulder, and lead of the NASA Sea Level Change Team. "But we don't know whether it will happen in 100 years or 200 years."[2]

Climate change has the potential to profoundly impact our wellbeing and way of life. In particular, rising sea levels will increase the occurrence and severity of coastal erosion and flooding, threatening natural resources and economic sectors concentrated along low-lying shores.

The observed rate of global sea level rise (SLR) has been accelerating: 0.6 mm/year (1900 – 1930), 1.2 mm/year (1930 – 1992), 3.2 mm/year (1993 – 2005) and 4.4 mm/year (2010 – 2015) (Figure 4). The worst case scenario or "business as usual" projection of SLR reported by the Intergovernmental Panel on Climate Change (IPCC) 2013 ranges from 1.6 feet (0.5 m) to 3.3 feet (0.98 m) by 2010 (Figure 4) [7]. Recent evidence suggests that ice sheets and glaciers are melting at rates greater than predicted, making this scenario the more likely scenario [2].

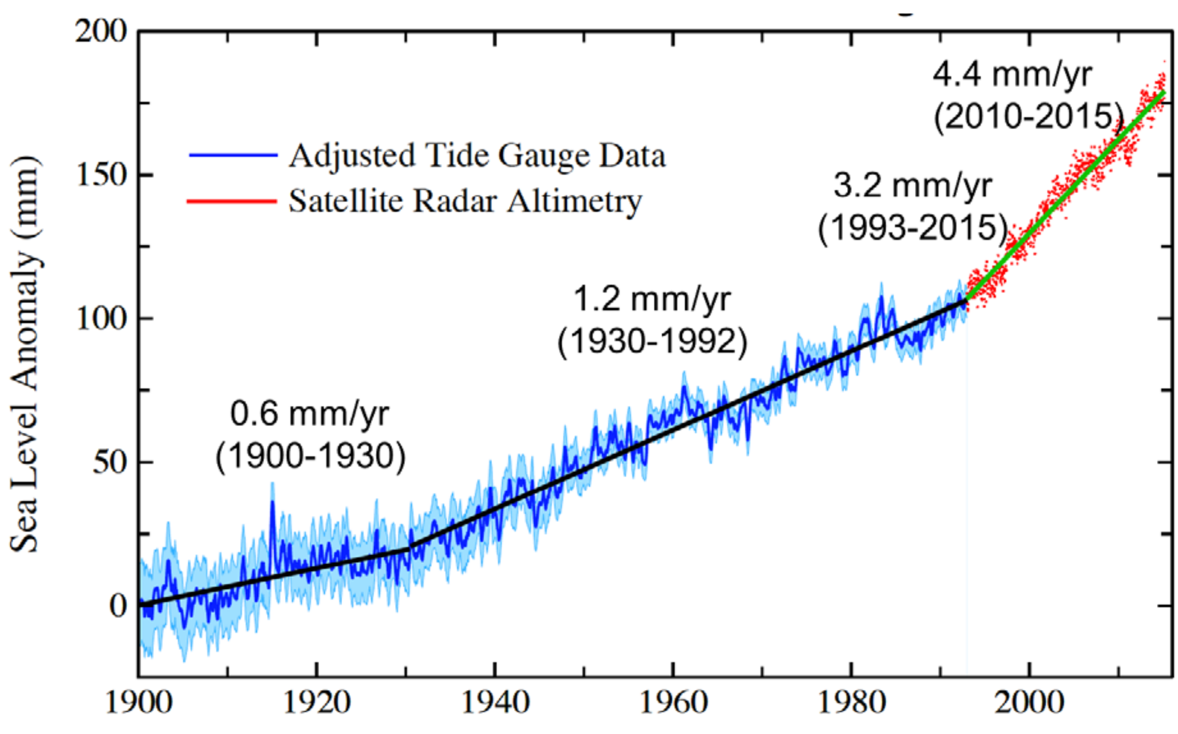

Figure 4. The observed rate of global mean sea level rise is accelerating [8-12]

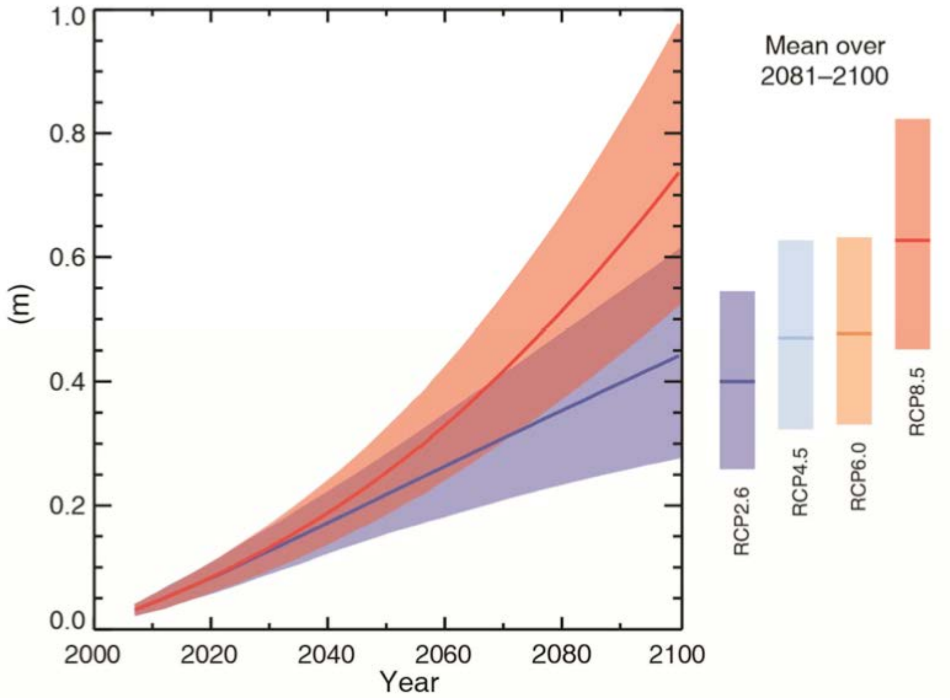

Figure 5. Projected rate of global mean sea level rise under different greenhouse gas emissions scenarios [7]. The projected rate of global sea level rise, based on the IPCC RCP 8.5 scenario, ranges from 1.6 feet (0.5 m) to 3.2 feet (0.98 m) by 2100 [4]. Recent evidence suggests that this high end scenario is the likely scenario because ice sheets and glaciers are melting at rates greater than accounted for in the IPCC report [2]

Sea level has risen around Hawaiʻi approximately 0.06 inches per year (1.5 mm per year or 6 inches over the next 100 years. Local relative sea level around Hawaiʻi (Figure 6) is not only dependent on the global average trend but also local oceanographic patterns, meteorology, geomorphology and tectonics related to the Hawaiian hotspot.

In Hawaiian, *papiha,* means "the ocean is full" and overflowing.

Hawaiʻi-specific projections are in line with global projections of SLR with a mean height of 3 feet by 2100 [13] (Table 1). The consequences of SLR for Hawaiʻi are severe compared to many other coastal states, as the majority of our population, public infrastructure, and economic sectors exist on low-lying coastal plains which are highly susceptible to coastal hazards. Hawaiʻi and other Pacific islands are expected to experience significantly greater than average SLR [13]. In addition, chronic erosion in Hawaiʻi causes beach loss, damages homes and infrastructure, and endangers critical habitat. These problems will likely worsen with increased SLR.

Table 1. Projected Heights of Sea Level Rise for Honolulu *[13]*

YEAR	RANGE (FEET)	MEAN (FEET)
2030	0.3 to 0.7	0.5
2050	0.6 to 1.4	1.0
2100	1.6 to 4.6	3.0

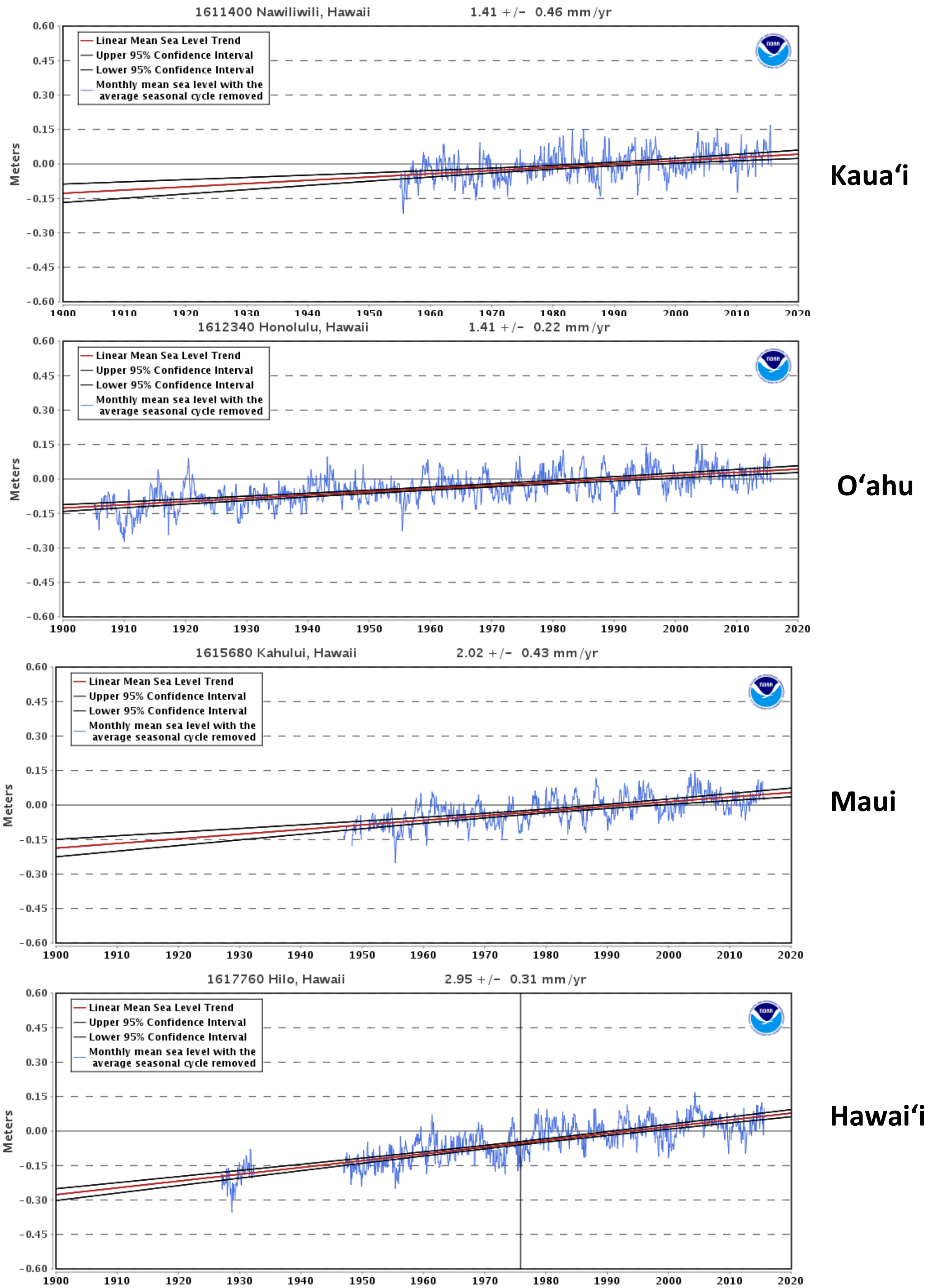

Figure 6. Observed mean-sea-level trends in the Hawaiian Islands [14]

Key Social, Economic, and Environmental Impacts

SLR will have a wide range of impacts on Hawaiʻi and throughout the Pacific Islands [15]. Low-lying islands and islets are especially vulnerable. Key impacts of SLR in our coastal zone include [16]:

- Damage to residential and commercial buildings and critical infrastructure from extreme sea level events (extreme tides, storm surges, etc.)
- Disruption to basic services and businesses from flooding, inundation, and erosion
- Land loss due to flooding, inundation, and erosion
- Saltwater intrusion into surface waters and groundwater impeding drainage and water quality
- Loss and change of wetlands and beaches that support threatened and endangered wildlife such as sea turtles and monk seals

Coastal flooding, inundation, and erosion exacerbated by SLR threaten residential and commercial structures and property, critical infrastructure, groundwater reservoirs, harbor operations, wastewater systems, sandy beaches, coral reef ecosystems, and other social, economic, and environmental concerns.

Coastal Flooding and Inundation

Coastal inundation and flooding are terms often used interchangeably. For the purpose of long-range planning for SLR, we will distinguish between these terms [17]. Coastal flooding is the condition where dry areas become wet temporarily—either periodically or episodically (Figure 7). The term coastal inundation is the process of a dry area being permanently drowned or submerged. Overtime, dry areas that are repeatedly flooded may be considered inundated as the land cannot be used.

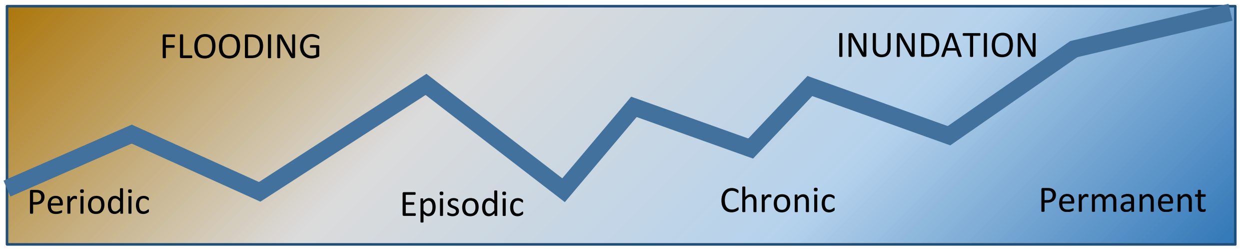

Figure 7. Coastal flooding is the condition where dry areas become temporarily wet. Coastal inundation is the process of a dry area being permanently drowned or submerged.

The key factors contributing to coastal flooding and inundation in Hawaiʻi are SLR, extreme tides, waves, storm surge, groundwater inundation, and heavy rainfall (Figure 8). As sea level rises, the frequency and severity of coastal flooding from extreme tides, high waves and storms (as well as infrequent tsunamis) will increase negative impacts to low-lying environments, ecosystems, and developed areas including coastal roads and communities. Sea level rise will raise the groundwater table leading to increased flooding, poor drainage, and storm damage on low-lying areas behind the shoreline [18]. At some point in the future, areas experiencing frequent coastal flooding will become permanently drowned or submerged creating new intertidal areas and wetlands.

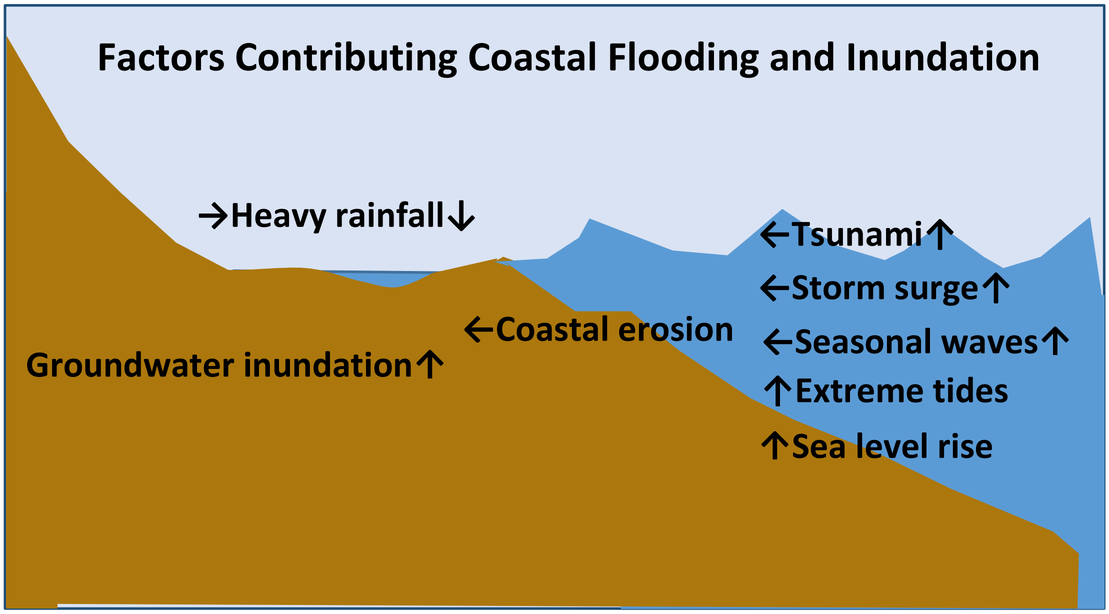

Figure 8. A combination of factors contributes to coastal flooding and inundation. Together these factors can cause shoreline erosion and permanent loss of coastal lands.

Hawai'i is exposed to large waves near-round and tsunamis due to our location in the Central Pacific. Unusually large wave events when combined with high tides cause damaging overwash and inundation on exposed low-lying coasts. Waves from four dominant sources impact Hawaii's coasts: North Pacific swell in winter months, South Pacific swell in summer months, easterly tradewind waves year round, and southerly "Kona" storm waves (including hurricanes) [19] (Figure 9). Tropical storms and hurricanes bring strong winds, high waves and heavy rains. Winds and storm surge raise water levels and drive large waves on shore, while heavy rains cause flooding from the landward side. Storm surge is an elevated water level resulting from low atmospheric pressure and strong winds within a storm. A substantial increase in the likelihood of tropical cyclone frequency has been predicted in the Hawaiian Islands [20, 21].

Currently, the Federal Emergency Management Agency (FEMA) defines the coastal Special Flood Hazard Area (SFHA) on Flood Insurance Rate Maps (FIRM) as two primary zones: Zone VE and Zone AE (Figure 10). Zone VE, also known as the Coastal High Hazard Area, has a 1% or greater chance of experiencing an annual flooding event and an additional hazard associated with storm waves three feet in height or greater. The coastal Zone AE has a wave component of less than 3 feet in height. Base Flood Elevations (BFEs) will vary in each zone. Changes in flood zones and BFEs can have a significant impact on building requirements and flood insurance costs.

SEA LEVEL RISE IS NOT CURRENTLY INCLUDED IN THE COASTAL FIRM ZONES.

DLNR's Flood Hazard Assessment Tool can be used to determine what flood hazard zone your property is in http://gis.hawaiinfip.org/fhat/. In the future, vulnerability to sea level rise will need to be incorporated in coastal hazard zones.

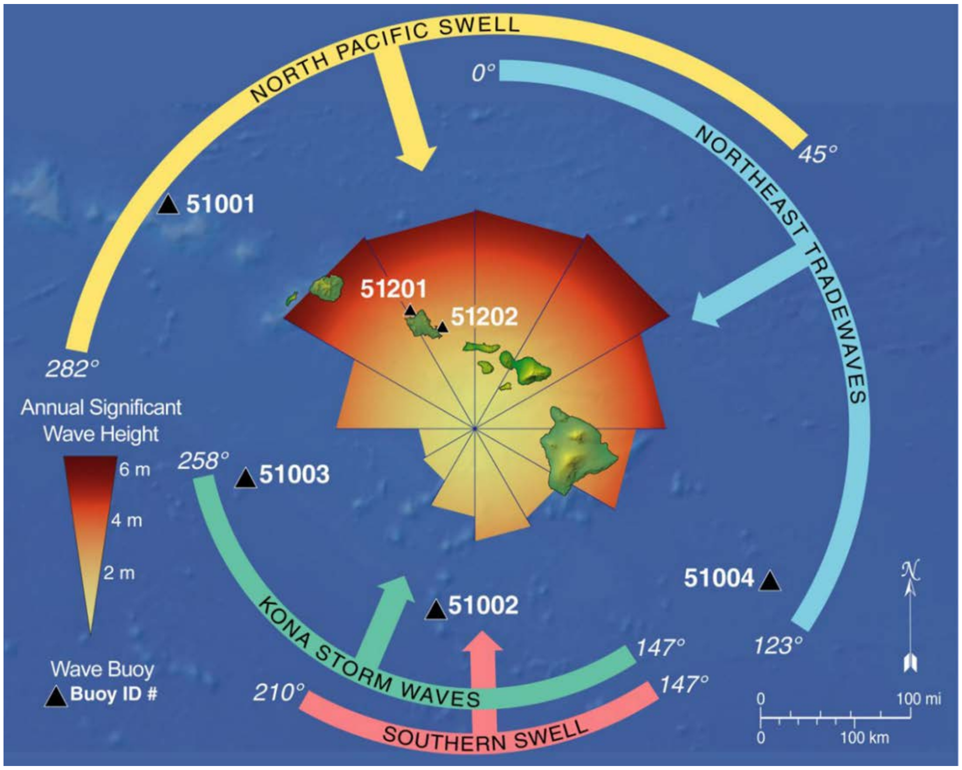

Figure 9. Dominant swell regimes and wave-monitoring buoy locations in Hawai‘i [19]

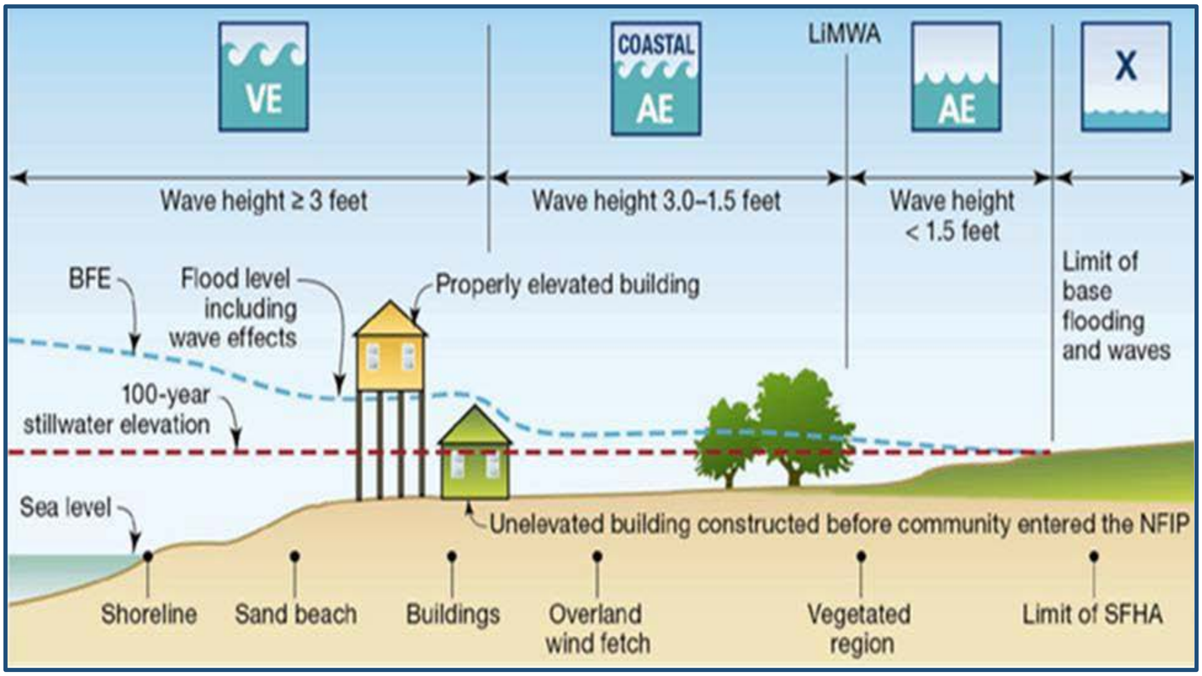

Figure 10. Coastal hazards incorporated into coastal Special Flood Hazard Zones on FEMA’s Flood Insurance Rate Maps

Coastal Erosion

Coastal erosion will exacerbate flooding and inundation resulting in the permanent loss of beaches and dry land which will then become submerged at increasing rates due to SLR. In their natural state, beaches, dunes and other coastal environments, such as reefs and wetlands, can provide effective protection from impacts of high waves and storms. Shoreline recession and beach loss due to coastal erosion is already a serious problem along Hawaii's shoreline, threatening shorefront development and infrastructure. Coastal erosion is the wearing away of beach and dune sediments and land by wave action and currents. Statewide, 70% of our beaches are undergoing chronic erosion, meaning the shoreline is retreating over years to decades [11]. On Maui, the erosion problem is particularly severe with 85% of beaches undergoing chronic erosion. Beaches are highly variable environments. The shape of a beach and location of the shoreline at any given moment results from a delicate balance between water level, wave energy and sand supply. In addition to chronic erosion, Hawaiʻi's beaches are prone to short-term erosion (hours to months) due to seasonal changes in wave direction, intermittent high wave events, and periodic or episodic high water levels.

Much of the developed low-lying coastal plains on Kauaʻi, Oʻahu, and Maui are underlain by beach and dune sand deposits. A "healthy" beach can be sustained along a retreating coast, if the shoreline is allowed to erode into dunes and older beach deposits, releasing sand to nourish the beach. Chronic and short-term beach erosion becomes a problem when it threatens upland development. Unfortunately, we are left with a legacy of dense development fronting eroding shorelines. In many locations, the historical response to beach erosion has been to install seawalls and other coastal protection structures, which has worsened problems of beach erosion and beach loss.

Sea level has been rising around Hawaii over the past century. There is evidence that sea level rise is already contributing to the overall trend of beach erosion in Hawaiʻi [22]. The extent and rates of coastal erosion are sure to increase over the coming decades with predicted increases in sea level rise rates. A recent study by University of Hawaii researchers found that approximately 92 and 96 percent of Hawaiʻi shorelines studied are projected to retreat by 2050 and 2100, respectively [23]. Due to increasing sea level rise, the average shoreline recession by 2050 is nearly twice the distance predicted by historical extrapolation alone, and by 2100 it is nearly 2.5 times the historical extrapolation. The DLNR is using these forecasts of future erosion hazard exposure to assess vulnerabilities to coastal communities, natural resources, and economic sectors.

The cumulative effects of SLR on coastal erosion, waves and storms surge are contributing to coastal flooding and will ultimately permanently inundate many coastal areas around the State. Vulnerability and risk assessment provide important information needed to design appropriate strategies and use the right tools to adapt to climate change.

CLIMATE CHANGE MITIGATION AND ADAPTATION

The impacts of climate change – such as coastal flooding and erosion and impacts to terrestrial and marine ecosystems – will affect the built and natural environment, livelihoods, and food security [24]. Understanding the extent of these changes and their impacts and identifying early adaptation actions is essential to protecting communities and natural resources.

Climate Change Mitigation - An intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks [1].
Note: The term mitigation is also used in the context of hazard mitigation which is more closely aligned with climate adaptation.

Mitigating the effects of climate change will require immediate and unprecedented levels of intergovernmental cooperation amongst world governments to reduce greenhouse gas emissions. The State of Hawaii has a bold energy agenda – to achieve 100 percent clean energy by the year 2045. The Hawaii State Energy Office is leading the charge and has embarked on a strategic plan to position Hawaii as a proving ground for clean energy technologies and accelerate our transformation to a clean energy economy. Along with reducing our islands' dependency on fossil fuels and increasing efficiency measures, the clean energy plan is also contributing to the State's economic growth. In the meantime, it is imperative that we take immediate and unprecedented steps to prepare for climate change, given that changes are already being observed and significant impacts are expected, even under the most optimistic mitigation scenarios.

Vulnerability - Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity [1].

Despite global efforts to reduce greenhouse gas emissions, climate change impacts will require adaptation to new conditions. Adaptation will require decision making, best practices and policy development based on an understanding of current and future vulnerabilities to adverse effects of climate change.

Adaptation - Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation [1].

- Anticipatory adaptation – Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
- Autonomous adaptation – Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.
- Planned adaptation – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

ADAPTATION STRATEGIES AND TOOLS

Decision makers will need to develop adaptation strategies based on area, type of property, and other factors. Key adaptation strategies are protection, accommodation, planned retreat, and preservation [4] (Figure 11). Decision makers may choose protection as a strategy, armoring critical infrastructure as a response to SLR despite detrimental environmental impacts. In rural areas where development is sparse, a strategy of planned retreat may be feasible relocating structures upland. These adaptation strategies are not mutually exclusive and could be applied together or differently depending on localized vulnerability and the physical, environmental and socioeconomic setting. A variety of tools are needed to adapt to SLR [3] (Table 2). The effectiveness of each tool must be carefully evaluated comparing advantages and disadvantages in achieving the overall adaptation strategy. Throughout the State, communities, organizations, and agencies are examining the risks posed by climate change and identifying and implementing actions to address these risks. These stories are in the process of being documented to share across the State.

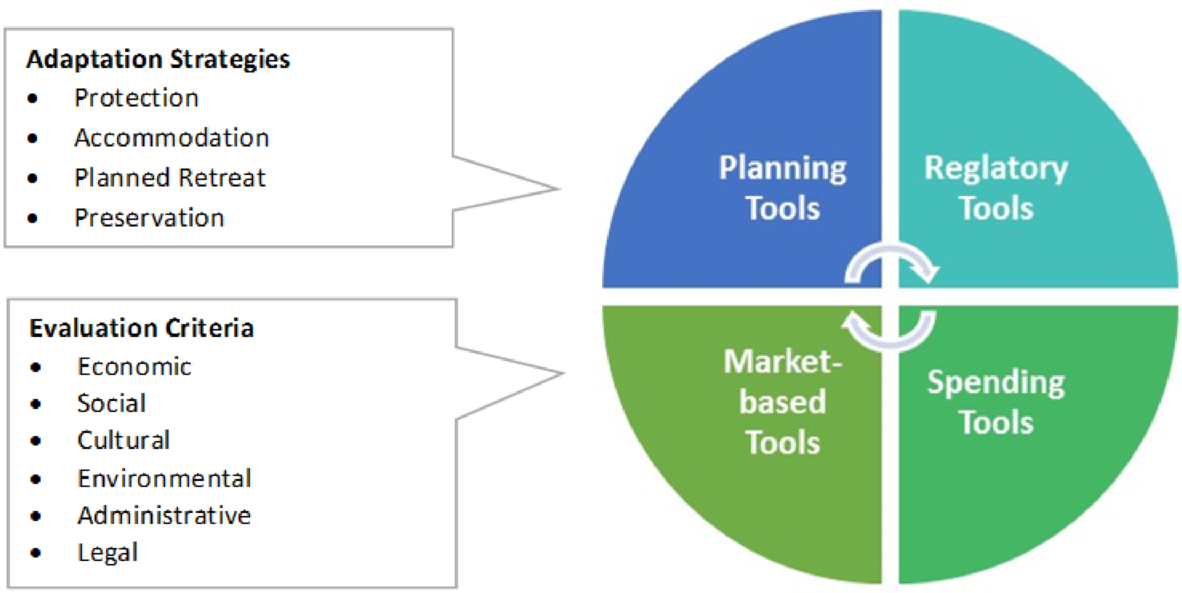

Figure 11. Adaptation tools and decision-making considerations [4]

Types of Adaptation Strategies [3, 4]

- **Protection strategy** prioritizes protecting people, property, and infrastructure from SLR impacts
- **Accommodation strategy** allows continued development of new structures but manages risks by conditioning development to require that structures be built or retrofit to be more resilient to SLR impacts and by limiting shoreline armoring.
- **Planned retreat strategy** limits armoring, discourages development and redevelopment in threatened areas, and plans for the eventual relocation of structures inland, as properties become threatened by SLR.
- **Preservation strategy** preserves and enhances lands for natural resource and habitat values; for lands at risk from SLR, the preservation strategy could limit development of land surrounding wetlands and beaches to allow for their inland migration as the seas rise.

Table 2. Examples of tools used to adapt to sea level rise [3]

Planning Tools	Regulatory Tools	Spending Tools	Market-Based tools
• Hawaiʻi Coastal Zone Management Act • General Plans • Hazard Mitigation Plans	• Shoreline Construction Setbacks • Floodplain Regulations • Hard Armoring • Rebuilding Restrictions • Subdivision Approvals • Environmental Review • Natural Resource Protection/Restoration	• Capital Improvement Programs • Land Acquisitions • Conservation Easements • Rolling Conservation Easements	• Mandatory Real Estate Disclosures • Tax Incentives • Transfer of Development Rights Programs

CLIMATE ADAPTATION IN HAWAIʻI

In 2014, the Hawaiʻi State legislature declared, through the passage of the Hawaiʻi Climate Adaptation Initiative Act (Act 83, Session Laws of Hawaiʻi) that climate change is the paramount challenge of this century, posing both an urgent and long-term threat to the State's economy, sustainability, security, and way of life. The purpose of the Hawaiʻi Climate Adaptation Initiative Act is to address the effects of climate change in order to protect the State's economy, health, environment, and way of life. Act 83 notes that, "Hawaiʻi is one of the few coastal states that has not adopted a statewide climate adaptation plan, yet is among the most vulnerable." Act 83 calls for the establishment of an Interagency Climate Adaptation Committee (ICAC), attached administratively to the Hawaiʻi Department of Land and Natural Resources (DLNR) and co-chaired by the Board of Land and Natural Resources (BLNR) Chairperson and the Director of the Hawaiʻi Office of Planning (OP). The first task of the ICAC is to develop a statewide Sea Level Rise Vulnerability and Adaptation Report (SLR Report) by December 31, 2017.

THE INTERAGENCY CLIMATE ADAPTATION COMMITTEE

The overarching goal of the ICAC is to plan for and address the effects of climate change in order to protect the State's economy, health, environment, and way of life. Over the next three years (2015 – 2017), the ICAC has been directed to focus on climate impacts related to sea level rise. To achieve this goal, the ICAC will: (1) develop, update, and use knowledge of climate risk to recommend improvements to policies, programs, projects, and business practices that reduce risk, and (2) work effectively together, sharing information and data and developing innovative sector-specific and cross-cutting recommendations to adapt to a changing climate.

The first phase of work of the ICAC is to develop the SLR Report by December 2017. The DLNR Office of Conservation and Coastal Lands (OCCL) will lead the development of the SLR Report in coordination with the ICAC. The SLR Report will serve as a framework for the State and ICAC to address other climate-related threats and climate change adaptation priorities, ultimately leading to a Climate Adaptation Plan for the State of Hawaiʻi, which will be prepared by the OP.

The SLR Report will expand upon ongoing collaborations with the University of Hawaiʻi School of Ocean and Earth Science and Technology (UH SOEST), the University of Hawaiʻi Sea Grant College Program (UH Sea Grant), the Pacific Islands Ocean Observing System (PACIOOS), and the Pacific Islands Climate Change Cooperative (PICCC). Data and mapping products will provide a basis for further analysis of vulnerabilities, socioeconomic ramifications, and recommendations for planning, management and adaptation to reduce vulnerability and increase resilience to SLR hazards. DLNR has contracted Tetra Tech, Inc. to conduct the vulnerability assessment and socioeconomic impact (VA/SEI) analysis and assist the ICAC in preparing the SLR Report. Major milestones of this sea level rise phase are shown in Figure 12.

Interagency Climate Adaptation Committee Members

- Chairperson of the Board of Land and Natural Resources (co-chair)
- Director of the Office of Planning (co-chair)
- Chairs of the standing committees of the legislature with related subject matter jurisdiction
- Director of Business, Economic Development, and Tourism
- Chairperson of the Hawaiʻi Tourism Authority Board of Directors
- Chairperson of the Board of Agriculture
- Chief Executive Officer of the Office of Hawaiian Affairs
- Chairperson of the Hawaiian Homes Commission
- Director of Transportation
- Director of Health
- Adjutant General

2015

Define SLR scenarios and VA/SEI analysis methodology

Increase public awareness of Act 83, latest climate science, and risks from SLR

2016

Initiate VA/SEI analysis

Identify public issues and concerns

Identify sector-specific and cross-cutting recommendations to adapt to SLR

2017

Finalize VA/SEI analysis

Complete SLR Report

Figure 12. Major milestones of the sea level rise phase of ICAC work

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