Kauaʻi General Plan Update Technical Study

# Kauaʻi Climate Change and Coastal Hazards Assessment

University of Hawaiʻi Sea Grant College Program

*June 2014*

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June 2014

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# Executive Summary

According to an overwhelming body of science, the Earth is warming at significant rates resulting in a myriad of climatic changes. According to the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report:

> *Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.*[1]

These changes are already impacting Hawai‘i and the Pacific Islands through rising sea levels, increasing ocean acidity, changing rainfall patterns, decreasing base flow in streams, changing wind and wave patterns, changing extremes, and changing habitats and species distribution.[2]

The island of Kaua‘i is subject to a variety of coastal hazards, including marine inundation and terrestrial flooding, coastal erosion, hurricanes, and tsunamis. Coastal flooding, marine inundation, and coastal erosion in particular are predicted to be exacerbated by climate change related sea-level rise (SLR). Although the Kaua‘i General Plan (GP) does address coastal hazards such as coastal erosion, it does not specifically recognize climate change and SLR and its potential to exacerbate existing coastal hazards. The Kaua‘i County Planning Department requested this technical study with the update of the GP as a catalyst for beginning to address climate change and SLR.

Through the Kaua‘i Climate Change and Coastal Hazards Assessment ($KC_3HA$), we focus in on the coastal hazards present on Kaua‘i (erosion, flooding, wave inundation, and wind), and the how these hazards are affected by climate change and SLR. A large part of the assessment focuses on SLR due to potential for changing erosion, flooding, and wave inundation hazards.

The goals of $KC_3HA$ are to:

1. Improve Kaua‘i’s community resilience and preparedness to coastal hazards and changing climate through the better understanding and utilization of coastal hazard information and planning tools.
2. Compile and summarize available science-based coastal and climate hazard information to assist in informing the Kaua‘i GP update.

We used the following methodology to achieve these goals:

1. Develop an inventory and assessment of planning information and data products supporting the integration of science-based coastal hazards information in land use planning through the Kaua‘i GP update.
2. Conduct a gap analysis that reviews and analyzes existing hazards data and planning information, its implications for Kaua‘i, and identifies gaps in planning information, guidance, and policy.
3. Map SLR projections for specific geographic areas on Kaua‘i, utilizing data from the National Oceanic and Atmospheric Administration’s (NOAA) Digital Coast SLR and Coastal Flooding Impacts Viewer, to demonstrate the utility of the data for planning purposes and to identify areas in need of further study and planning.
4. Identify resources and techniques to address the identified problems and gaps.
5. Develop planning and policy recommendations for the Kaua‘i GP update.

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[1] IPCC, January 30, 2014. Climate Change 2013: The Physical Science Basis. Headline Statements from the Summary for Policy Makers. http://www.climatechange2013.org/images/uploads/WG1AR5_Headlines.pdf. Visited 3/17/14.

[2] Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.). (2012). *Climate Change and Pacific Islands: Indicators and Impacts. Report for The 2012 Pacific Islands Regional Climate Assessment*. Washington, DC: Island Press.

6. Conduct training and outreach with identified Kaua'i County (County) department representatives to get input on the concepts, products, and recommendations of the study.

The body of this report discusses the above efforts, with detailed resources provided in the Appendices. **Section I** provides detailed background and scientific information on Kaua'i's coastal hazards and the latest science on climate change and SLR. **Section II** provides an assessment of SLR consequences for various sectors on Kaua'i including critical infrastructure, economy, coastal habitats, public access, and residential communities. **Section III** details some scientific, policy, and planning resources available to address coastal hazards, including climate change related hazards. This includes discussion of the Inventory of Planning Information and Data Products contained in Appendix B, summary of the Gap Analysis for Implementation of Hazard Science into the Community,[3] and discussion of the SLR Inundation Assessment and Needs for Select Areas (Needs Assessment) contained in Appendix C. **Section IV** details recommendations for the Kaua'i GP update.

As shown in **Appendix B,** Inventory of Data and Planning Products, there are many existing hazards data sets and planning tools that can be utilized by planners for long range and current planning for coastal hazards and climate change on Kaua'i. Of particular note is the NOAA SLR and Coastal Flooding Impacts Viewer, which was developed in partnership with University of Hawai'i researchers and now available for use. The County has been provided with the SLR inundation geographic information systems (GIS) data associated with this tool for more detailed analysis. However, as discussed in Section III, there are gaps in planning information and guidance on how future accelerated SLR will affect coastal erosion rates and wave inundation. In addition, there is a gap in planning information, guidance, and policy to deal with an Aleutian Island earthquake event with tsunami impacts in Hawai'i.

**Appendix C** the SLR Inundation Assessment and Needs for Select Areas (Needs Assessment) provides an important first step for examining SLR in the General Plan. It includes a set of SLR inundation maps for select coastal areas on the island using the NOAA/UH data described above. It also includes a written assessment for each area identifying potential SLR risks and vulnerabilities, as well as future planning and research needs for the area. The maps do not include every area of the island, and are intended to be examples of what planners may create utilizing the GIS data and the tools suggested in this report. These maps may be used in the general planning process as a preliminary screening tool for SLR inundation hazards for long range planners and the community to identify areas where planning efforts should be focused. Due to gaps in planning information, the maps do not include erosion or wave inundation data from future accelerated SLR. The Needs Assessment highlights the need to conduct more detailed hazard, risk, and vulnerability assessments in the future. The data in its current form is not intended to be used for parcel-level regulatory purposes.

## Recommendations

Based on the findings of $KC_3HA$, we provide a host of policy and planning options to address climate change related coastal hazards. The detailed recommendations from this study can be found in Section IV. In summary, the recommendations fall under the following broad categories:

1. Support the development of improved climate related hazard planning information
2. Conduct detailed coastal hazard, risk, and vulnerability assessments based on best available climate change science
3. Include relevant background information and maps for climate change related coastal hazards in the General Plan

[3] Hwang, Dennis and Laura Hamilton. 2014. Gap Analysis for Implementation of Hazard Science into the Community with Test Applications for Kaua'i, Hawai'i and Majuro, Republic of the Marshall Islands. Prepared for National Sea Grant Office, NOAA Sea Grant –NOAA Regional Collaboration Team, and the University of Hawai'i Sea Grant College Program.

4. Incorporate additional General Plan overarching goals/principles pertaining to planning for climate change related coastal hazards
5. Use existing planning and regulatory programs to address climate change related coastal hazards
6. Develop new programmatic strategies to address climate change related coastal hazards

***Recommendation 1*** is for the county to acknowledge and support research efforts to fill the gaps identified in planning information and guidance for how SLR will affect coastal erosion and wave inundation. When the planning information is available, ***Recommendation 2*** suggests conducting detailed hazard, risk, and vulnerability assessments for select planning areas on Kaua‘i.

The fact that there are some gaps in planning information should not delay the County in taking certain policy and planning actions that may be done now through the GP or other efforts. Indeed, policies can articulate the supportive efforts that can be done to address gaps as well as to take proactive approaches to protect the community in the absence of complete information. This is often termed a ‘no regrets’ approach to climate change adaptation. *Recommendations 3* through *6* suggest policy and planning actions that can be taken now, regardless of the identified gaps in scientific data and planning information.

***Recommendation 3*** provides suggestions for how to include coastal hazards, climate change, and SLR in the background sections of the General Plan. ***Recommendation 4*** suggests some overarching principles that could be incorporated into the GP to guide planning for climate change and coastal hazards. These include the use of credible climate and hazard science in decision-making, avoiding or minimizing coastal hazard risk through planning and development standards, and avoiding and minimizing impacts to coastal natural resources (e.g., beaches, dunes, wetlands) when addressing risks.

***Recommendation 5*** suggests options for utilization of existing county regulatory and non-regulatory programs to address coastal hazards, such as updating the shoreline setback ordinance to account for future SLR in setback decision or participating in the Federal Emergency Management Agency (FEMA) National Flood Insurance Program’s (NFIP) Community Rating System (CRS) program.

Lastly, ***Recommendation 6*** provides some suggested new programmatic strategies to address climate change related coastal hazards, such as incentive programs for relocation of development out of hazardous areas and beach management plans.

# I. Kaua‘i’s Coastal Hazards

## Environmental Framework of the Kaua‘i Shoreline

Kaua‘i is the oldest and most eroded of the main Hawaiian Islands. Kaua‘i was formed more than 5 million years ago and consists principally of a single shield volcano with basaltic lavas known as the Waimea Canyon Volcanic Series. More than 1.5 million years after the primary shield-building volcanism ended, and a long-period of erosion, volcanism was renewed from several vents and the younger lava covered the eastern portion of the island and is known as the Koloa Volcanic Series.[4]

Mount Wai‘ale‘ale, located in the middle of the island, is one of the wettest places on Earth. As a result, stream erosion and flooding are common, carving deep valleys and canyons and transporting abundant sediment to the coast.[5] Kaua‘i has high sea cliffs where Waimea Canyon volcanic series rocks are at the shore, and low sea cliffs where the shore is Koloa volcanic series rocks. Kaua‘i has the longest stretches of beaches in the Hawaiian Islands. Shallow fringing reefs are common on the north and east coasts, and less regular reefs are present elsewhere.

The last 5 million years on Kaua‘i has been characterized by intensive weathering and erosion of its relatively unstable volcanic rocks. This process, combined with stream erosion has created lush watersheds. Large ocean waves from all directions have eroded the coasts and carried away sediment. Meanwhile, biogenic reefs comprised mainly of coralline algae and coral have grown around the island, creating the fringing reefs we see today. The calcareous skeletal material from these reefs provides the sand for all the beaches that rim nearly half of the island. Also, large sand dunes were formed where locally prevailing trade winds have transported this beach sediment. These eventually became lithified to form the limestone sequences we see on the south coast.[6]

## Coastal Hazards

The Kaua‘i coastline is susceptible to a variety of natural hazards, including coastal storms, high wave events, flooding, coastal erosion, and tsunamis. All of these hazards threaten lives, property, the natural environment, and, ultimately, economies. Increasing development in coastal areas not only places more people and property at risk to coastal hazards, but it can also degrade the natural environment and interfere with nature's ability to protect the human environment from severe hazard events. For instance, seawalls can contribute to beach erosion and inhibit the beach's ability to absorb storm energy, thus exposing buildings to the full force of wind and waves. Development can also degrade wetlands that serve as important buffers against storm surge and other types of flooding. So, while little can be done to prevent coastal hazard events, their adverse impacts can be reduced through proper planning.

**The key coastal hazard impacts to consider for Kaua‘i are: (1) coastal flooding and wave inundation, (2) erosion, (3) inland flooding, and (4) wind (Figure 1).**[7] Each of these hazard impacts are described in the following sections. These impacts may be the result of one or many hazard events or processes, including storms, high surf, sea-level rise, sediment budget deficits, etc. Mitigation programs and practices should be designed around these key impacts and not just the event that causes them.

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[4] Moberly, Ralph, 1963. *Coastal Geology of Hawai‘i*. HIG Report Number 41. 216pp.

[5] Fletcher, C.H., Grossman, E.E., Richmond, B.M., Gibbs, A.E., 2002. *Atlas of Natural Hazards in the Hawaiian Coastal Zone*. U.S. Geological Survey Geologic Investigations Series I-2761. 182pp.

[6] Blay, Chuck. Siemers, Robert. 2013. Kaua‘i’s Geologic History: A Simplified Overview. Updated and Expanded Edition. The Edge of Kaua‘i investigations.

[7] Hwang, Dennis and Laura Hamilton. January 2014. Gap Analysis for Implementation of Hazard Science into the Community with Test Applications for Kaua‘i, Hawai‘i and Majuro, Republic of the Marshall Islands.

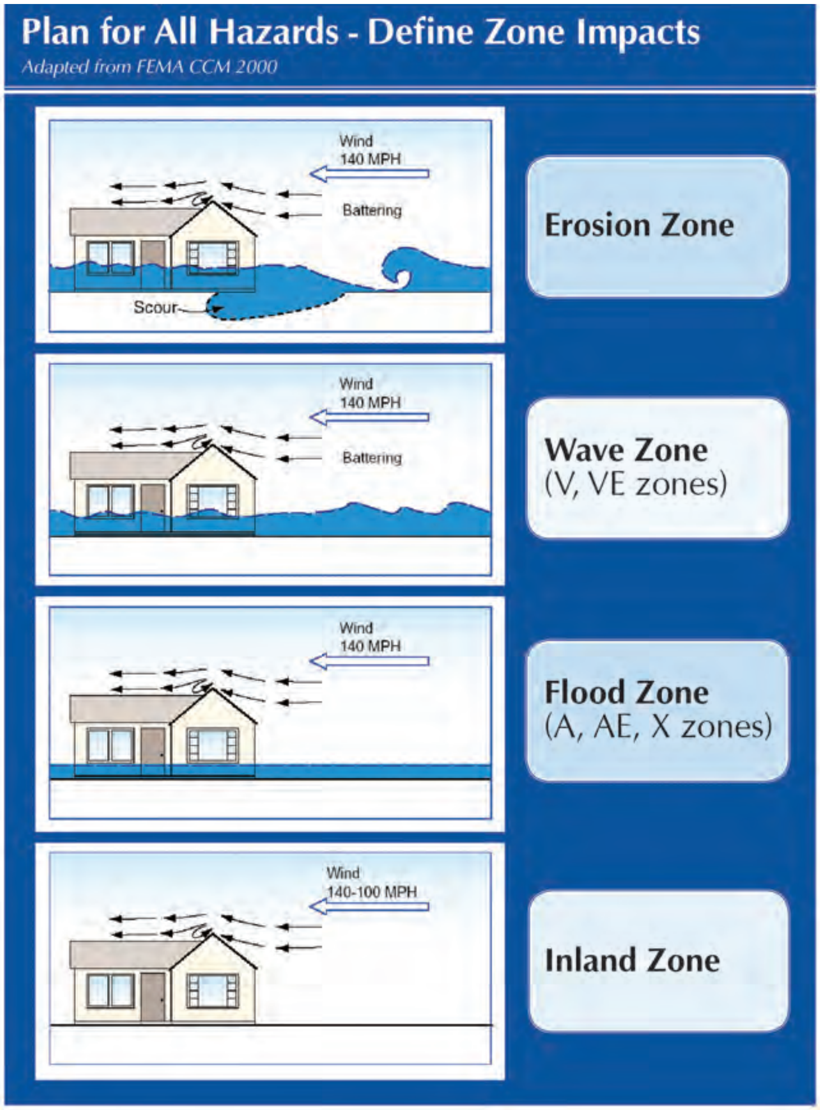

Figure 1. Plan for All Hazards – Define Zone Impacts. Hwang 2014

For example, according to the Gap Analysis for Implementation of Hazard Science into the Community,

> *…we plan mitigation not for the hurricane event, but for the associated erosion, storm surge, flooding and wind that occurs during the event. Similarly, it will aid implementation if planners concentrate not on the sea-level rise event, but the associated erosion, wave inundation and flooding impacts caused by sea-level rise. A failure to account for all three would underestimate the hazard risk from sea-level rise and leave properties, inhabitants, or the community at greater risk.*[8]

## Coastal Flooding and Wave Inundation

Coastal flooding, or coastal inundation, is the flooding of normally dry, low-lying coastal land. It can be caused by elevated sea surfaces from static sea level rise or large tidal fluctuations, seasonal high waves that push water inland, and storm surge associated with low pressure systems, tropical storms, and hurricanes that cause an abnormal rise in the water level. Also, coastal erosion can effectively bring the built environment within the reach of normal or seasonal high waves to flood property. Finally, wave runup from tsunamis can be responsible for extensive flooding of coastal properties.

In Hawai‘i, exposure of a shoreline to waves depends on shoreline orientation (swell “window”) and coastal geomorphology (e.g., headlands, reefs). The four dominant wave regimes affecting Hawai‘i are North Pacific swell, northeast trade wind swell, southern swell, and Kona storm waves (including hurricanes)

[8] Hwang et al, 2014

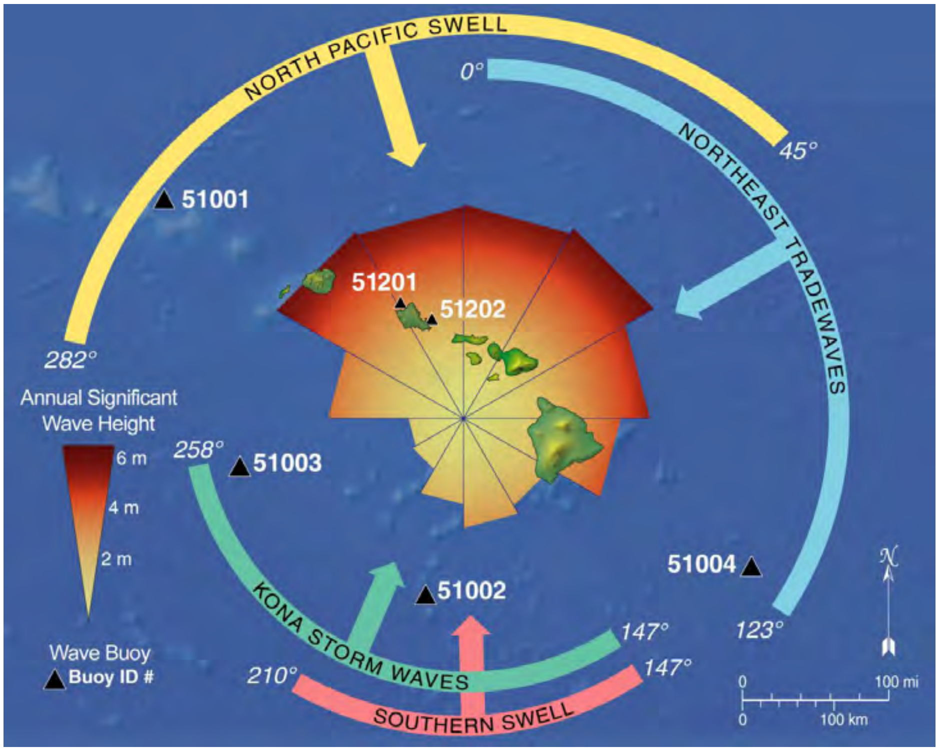


Figure 2. Wave Regimes, from Vitousek and Fletcher, 2008, Vitousek, S. and Fletcher, C.H. (2008) Maximum annually recurring wave heights in Hawai‘i. Pacific Science, vol. 62, no. 4: 541-553.

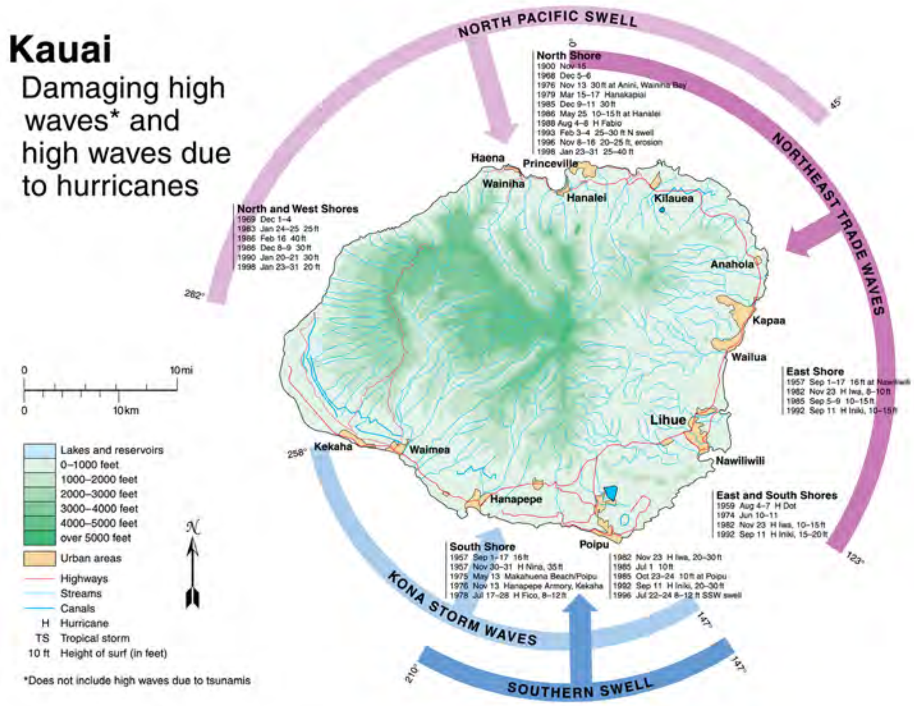


Figure 3. Kaua‘i Damaging High Waves and high waves due to hurricanes. (Atlas of Natural Hazards in the Hawaiian Coastal Zone). Fletcher, Charles H. III (et al.). Atlas of Natural Hazards in the Hawaiian Coastal Zone. Reston, VA: The Survey; Denver, CO: USGS Information Services, 2002: p.31.

(Figures 2 and 3). Breaking waves at the shoreline at any given time may be composed of swells from two or more directions, and the contributions are often seasonally varied. The most common contributions for north-facing shores are North Pacific swell (dominant in winter) and tradewind waves (common year-round but typically dominant in summer). The most common contributions for south-facing shores are Southern swell (dominant in summer) and tradewind waves.

The Atlas of Natural Hazards in the Hawaiian Coastal Zone, page 31, identifies notable high wave events, not including tsunamis, from the early 1900s through the late 1990s. These same events are also provided in a table in the County of Kaua‘i Hazard Mitigation Plan (Chapter 3, Table 3-17). The largest wave events have occurred on the north shore due to swell generated from strong storms in the North Pacific. In a 1996 event, 20-25 ft. waves were recorded causing beach erosion and overwash and even knocking a house off of its foundation.[9] The west shore waves are usually on the order of 15-20 ft., but have reached as large as 40 ft. in 1996. South swells are generally smaller in height, but can reach 8-12 ft. and have sufficient energy to cause erosion and overwash. Hurricanes with large wave heights and storm surge have historically caused extensive erosion and property damage. Waves with heights from 15-30 ft. were produced along west and south shores in association with Hurricanes Nina (1957), Iwa (1982), and Iniki (1992). Storm surge from Iniki caused severe damage to many condominiums, hotels, and homes along the Po‘ipū coast where the greatest inundation occurred.

[9] Fletcher, C.H., Grossman, E.E., Richmond, B.M., Gibbs, A.E., 2002. *Atlas of Natural Hazards in the Hawaiian Coastal Zone*. U.S. Geological Survey Geologic Investigations Series I-2761. 182pp.

A tsunami is a series of waves generated by sudden movement of the seafloor that displaces a large volume of water. Tsunamis can be generated locally or thousands of miles away in the Pacific Rim by earthquakes, volcanic eruptions, underwater landslides, or onshore slope failures. Tsunamis pose a significant coastal hazard for Hawai'i. Hawai'i has experienced a total of 95 tsunamis in 175 years (1813-1988)[10]. The recorded history of Hawaiian tsunamis shows that 26 large tsunamis have made landfall within the islands and eight have had significant damaging effects on Kaua'i. The most recent tsunamis that have caused damage in Hawai'i occurred in 1946 (Aleutian Islands), 1952 (Kamachatka), 1960 (Chile), 1964 (Alaska), 1975 (Kalapana on the Big Island), and 2011 (Japan). Between 1868 and 1946, a damaging tsunami reached Kaua'i on average once every 12 years. However, during a more active period between 1946 and 1964, five tsunamis had damaging impacts to Kaua'i at an average frequency of 3.5 years. Interestingly, in a less active period since 1964, tremendous coastal development has occurred on Kaua'i, raising the risk of damage from future tsunamis.

Tsunamis manifest themselves as either large breaking waves, often largest around headlands where they are concentrated by wave refraction, or as rapidly rising sea level like a flooding tide. The geography of the shoreline often plays an important role in the form and impact of the tsunami. Unlike storm waves, tsunami waves may be very large in embayments, actually experiencing amplification in long funnel-shaped bays. As with high wave events, fringing and barrier reefs appear to have a mitigating influence on tsunamis by dispersing the wave energy.

There are many examples of tsunami inundation on Kaua'i that demonstrate the magnitude and variability of tsunami impact on the shoreline. One example of localized variability with tsunami run-up heights occurred during the 1946 tsunami on the north shore, where a runup height of 45 ft. was recorded at Haena, while only a few miles away in Hanalei Bay, runup was 19 ft. Tsunami Evacuation Zone Maps that are based on historical tsunami runup and hypothetical models of near and far source tsunami runup are available at the County of Kaua'i Civil Defense Agency website.

Climate Change/Sea-Level Rise Impacts

Understanding how climate related changes will affect wave climatologies is an area of active research. This is particularly challenging because long historic records of wave heights are lacking and because the Pacific Region is characterized by high natural variability.[11] One example is the El Niño-Southern Oscillation (ENSO), an interannual pattern that has a large influence on year-to-year variability in rainfall, sea level, and other climate variables. Some studies incorporating models of global climate change reveal a substantial increase in tropical cyclone frequency around the Hawaiian Islands in the future.[12] In general, extreme water levels will occur when sea-level rise related to longer-term climate change combines with seasonal high tides, interannual and interdecadal sea-level variations, and surge and/or high runup associated with storms and tsunamis.

## Coastal Erosion

Since most Hawaiian beaches are losing sediment through erosion, it is important to understand a little about Hawai'i's limited sand supply and production in order to promote sustainable beach systems. Sand storage in Hawaiian beach systems occurs as either beach reservoirs or nearshore bodies of sediment. Beach reservoirs in the Hawaiian Islands are low relative to those in continental settings. More than one-third of

[10] Fletcher, C.H., Grossman, E.E., Richmond, B.M., Gibbs, A.E., 2002. *Atlas of Natural Hazards in the Hawaiian Coastal Zone*. U.S. Geological Survey Geologic Investigations Series I-2761. 182pp.

[11] Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.). 2012. *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment*. Washington, DC: Island Press.

[12] Murakami, H., Wang, B., Li, T., Kitoh, A., 2013. Projected increase in tropical cyclones near Hawai'i. Nature Climate Change 3, 749-754.

Figure 4. Kealia-Kumuukumu, aka Donkey Beach, Kaua‘i. Hwang 2005

beach sand in the Hawaiian Islands is found on the beaches of Kaua‘i (Figure 4).[13] Hawaiian sand is primarily biologic in origin and is composed of grains of calcium carbonate from fragmented marine invertebrates, algae, and corals that have been re-worked into sand grains by wave activity. There is a much smaller contribution of sand grains from eroded volcanic materials. Radiocarbon ages of carbonate sand has been used as an indicator of source, productions rate, and longevity of sand grains. Radiocarbon dates of surface beach sands on O‘ahu show ages of more than 1,500 years. The older grains indicate periods of higher sand production, relative to today, during periods of higher sea level with expanded shallow, nearshore areas in the mid- to late-Holocene Epoch (~12,000 years ago to present). While there are no dates for Kaua‘i beach sand samples, it can be generally assumed that sand reservoirs statewide are of older origin. As such, the implication of this older sand reservoir on our beaches is that existing beach sand is of limited quantity and should be carefully managed. In other words, once the sand is gone, it's gone.

Historical erosion studies using shoreline positions mapped from aerial photographs and survey charts show that beach erosion is the dominant trend of shoreline change on Kaua‘i, overall. The *National Assessment of Shoreline Change: Historical Shoreline Change in the Hawaiian Islands* reports that 71% of beaches on Kaua‘i are eroding with nearly 4 miles of beach completely lost to erosion over the past century. On average, shorelines on Kaua‘i retreated over 36 feet over the past century (-0.36 ft./yr x 100 yr). Beaches on the north and east coasts of Kaua‘i are undergoing the most erosion (76% and 78% of beaches, respectively). The majority of beaches are also eroding on the south and west coasts (63% and 64% of beaches, respectively). In addition to long-term or chronic erosion, Hawai‘i beaches are also highly prone to erosion on shorter time scales from seasonal high waves and storms. In the case of episodic or seasonal erosion, a beach tends to recover to near its pre-storm condition, unless there is an additional underlying trend of chronic sand loss from the beach system. Temporary and chronic erosion exposes homes, property, and infrastructure to increased flooding and land loss during high waves.

The observed shoreline erosion trends can generally be explained by a combination of causes, including: 1) human impacts to sand supply, 2) seasonal and storm waves and wave-driven currents that move sand, and 3) sea-level rise forcing shoreline retreat.

Human Impacts to Sand Supply

In Hawai‘i, human impacts that have notably contributed to erosion and/or beach loss include the practice of sand mining and shoreline hardening (seawalls and revetments). Sand mining from beaches has been documented in reports and aerial photographs from O‘ahu and Maui. It is highly likely that sand mining occurred on Kaua‘i beaches, though, we are not aware of documentation of particular locations or quantities. On all islands, shoreline hardening has historically been a common reaction to protect property from coastal erosion and flooding. Several studies have shown that the practice of shoreline hardening often

[13] Fletcher, C.H., Romine, B.M., Genz, A.S., Barbee, M.M., Dyer, Matthew, Anderson, T.R., Lim, S.C., Vitousek, Sean, Bochicchio, Christopher, and Richmond, B.M., 2011. *National Assessment of Shoreline Change: Historical Shoreline Change in the Hawaiian Islands.* U.S. Geological Survey Open-file Report 2011-1051, 55 p.

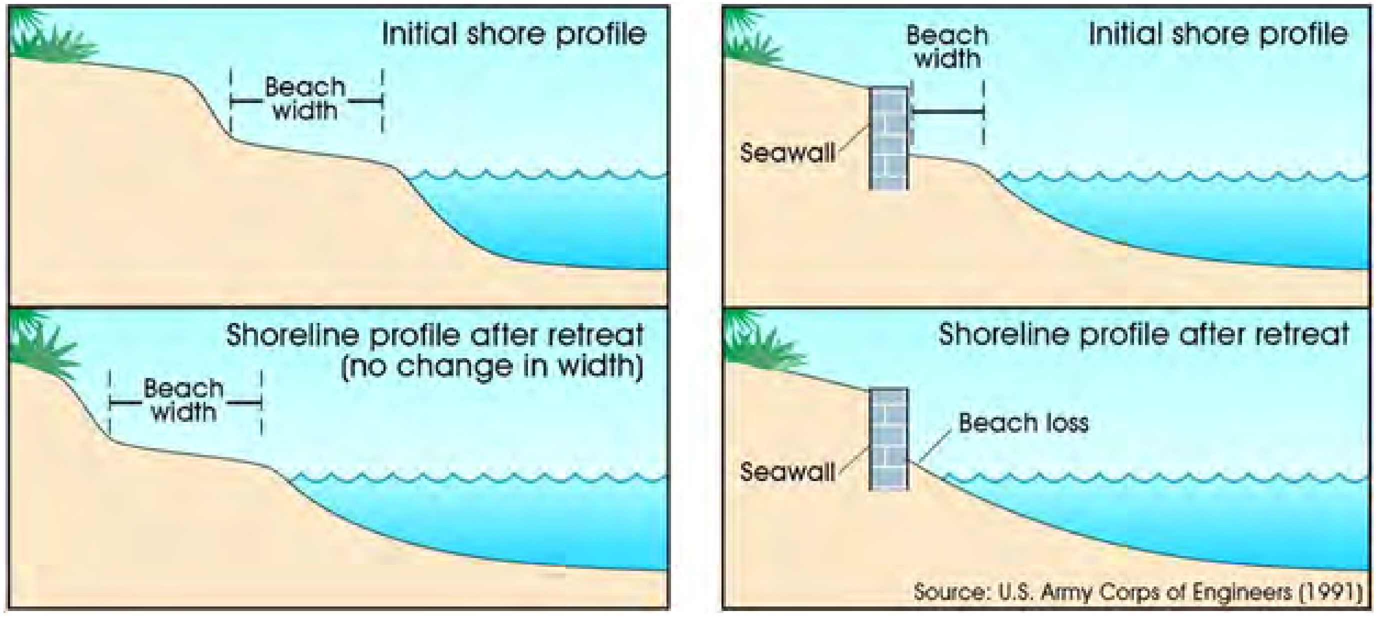


Figure 5. Shore profile, retreat, and seawalls. USACE 1991

leads to loss of public beaches and shoreline access (Figure 5).[14,15] While the practice of shoreline hardening in Hawai‘i has been discouraged in the last two decades by the State Department of Land and Natural Resources (DLNR) and county planning departments, shoreline planners are anecdotally noting increased requests for seawall repairs and new seawalls. In the face of continuing erosion, it will be important to find alternative management strategies to shoreline hardening.

Other types of hard structures that are used for erosion control include jetties, groins, and breakwaters. If not used appropriately, these types of structures can alter or disrupt sand supply and transfer a problem at one location to another. There are currently 194 shoreline protection structures covering 10% of Kaua‘i's shoreline, and extending approximately 11 miles.[16,17]

<u>Waves and Currents</u>

Hawai‘i wave exposure was described previously in the section for "Wave Inundation." Seasonal beach changes result from seasonal changes in wave direction, and are also strongly influenced by coastal geomorphology and bathymetry of nearshore reefs. In general, wave activity is associated with increased wave run-up and impacts to the beach and coastal dunes. Wave-driven currents can transport sand offshore or alongshore with the seasonally-dominant current direction. Beaches exist in a delicate balance between wave energy, sand supply, and water level, with shoreline position and beach volume constantly changing with ocean conditions. Seasonal changes are most noticeable on beaches exposed to two seasonal wave directions, such as the beaches along the Mānā Plain of west Kaua‘i where summer south swells generally drive currents and sand to the north and winter north swells drive sand to the south. Shorelines exposed to winter North Pacific swells are particularly prone to temporary erosion during large waves, which can further expose property and homes to damage and flooding.

<u>Climate Change/Sea-Level Rise Impacts</u>

Sea level has been rising globally and around the Hawaiian Islands over the last century or longer. Sea level

[14] Romine, B.M. and Fletcher, C.H. 2012, Armoring on Eroding Coasts Leads to Beach Narrowing and Loss on O‘ahu, Hawai‘i, in Pitfalls of Shoreline Stabilization: Selected Case Studes, J.A.G. Cooper, G. Andrew and O.H. Pilkey (eds.), Coastal Research Library 3, DOI 10.1007/978-94-007-4123-2_10, Springer Science and Business Media, Dordrecht, Netherlands.
[15] Fletcher, C.H., Mullane*, R.A., and Richmond, B.M. (1997) Beach loss along armored shorelines on O‘ahu, Hawaiian islands. Journal of Coastal Research, v. 13, p. 209-215.
[16] Bezore, Rhiannon. 2013. Kaua‘i Shoreline Structure Geographic Information Systems (GIS) Inventory. Prepared by the University of Hawai‘i Sea Grant College Program for the County of Kaua‘i Planning Department.
[17] This statistic includes the following shoreline structures: seawalls, retaining walls, sandbags, riprap revetments, bridges, jetties, piers, breakwaters, docks, drain outlets, lookouts, boat launch ramps, historic structures (e.g., docks/piers from sugar and pineapple industry), fences, and groins.

has risen about 6 inches around Kaua‘i over the past century.[18] Rates of sea-level rise (SLR), globally and locally around Hawai‘i, are expected to accelerate over this century.[19, 20, 21] SLR leads to shoreline retreat through two processes: 1) by simply moving the water line up the coastal slope and 2) by increasing erosional effects of waves on the upper beach, dune, or cliff. A beach will "find" a new equilibrium in response to increased sea level and wave effect. A recent study finds that historically low rates of SLR in Hawai‘i are an important factor in the overall trend of erosion on Hawai‘i beaches. Expected future increases in sea level will result in increases to historical erosion rates and will add pressure to already eroding beaches and beaches that were previously stable.[22] A more detailed description of sea level trends is discussed in this report in the section "Climate Change and Sea Level Trends."

## Inland (Stream) Flooding

Stream flooding on Kaua‘i is characterized by numerous flash floods as well as prolonged flooding associated with slowly passing rainstorms that saturate the soils. There is a long history of development in and near active stream valleys on Kaua‘i, originally for the agricultural benefit of naturally irrigating taro and other wetland crops. However, with the increase in development of homes, resorts, and public infrastructure along low-lying stream lands during the past several decades, flooding is not considered as beneficial today as it once was. As a result, many flood prone regions are now being artificially channelized to the detriment of wetland and floodplain ecosystems.

There are many instances on Kaua‘i of intense flooding associated with runoff, mudslides, bank failures, dam breaches, and erosion that have caused deaths and millions of dollars in property damages. The challenge to mitigating the hazard due to stream flooding is in large part one of obtaining adequate warning in the case of flash floods and in improved planning of developments in areas of known flood history. The County of Kaua‘i Hazard Mitigation Plan provides a table (Chapter 3, Table 3-3) of stream flooding events from the late 1800s through 2009.

Climate Change/Sea-Level rise Impacts

In the future, the IPCC reports that climate changes in the Equatorial (Tropical) Pacific are expected to cause an increase in precipitation.[23] However, Hawai‘i falls at the northern edge of the tropic zone and may not experience the described trends. Historically, annual rainfall has decreased in Hawai‘i and this is reflected in decreased groundwater discharge to streams.[24] Also, all four major Hawaiian Islands have experienced more severe droughts since the 1950s. However, rainfall patterns in Hawai‘i vary dramatically both temporally and spatially based on trade winds, topography, mid-latitude weather systems, storms and cyclones, the El Niño Southern Oscillation (ENSO) phases, and more.[25,26] This natural variability along with future climate changes presents a challenge to predict future rainfall and runoff patterns. Some coarse global models indicate that the southerly main Hawaiian islands (Hawai‘i and Maui) may become wetter towards the end of the 21st century, while those in the north (Kaua‘i and O‘ahu) become slightly drier,

[18] National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS), Silver Spring, MD. http://tidesandcurrents.noaa.gov/sltrends/index.shtml. Last Accessed April 2014.

[19] IPCC, 2013. IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker,T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.climate2013.org/spm Last Accessed November 14, 2013

[20] U.S. National Academy of Sciences, 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future.*

[21] Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

[22] Romine, Bradley M., Fletcher, Charles H., Barbee, Matthew M., Anderson, Tiffany R., Frazer, L. Neil. 2013. Are Beach Erosion Rates and Sea-Level Rise Related in Hawai‘i? In: Global and Planetary Change 108 (2013) 149-157

[23] IPCC, 2013. IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker,T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.climate2013.org/spm Last Accessed November 14, 2013

[24] Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.), 2012. *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment*. Washington, DC: Island Press.

[25] Schroeder, T.A. 1993. Climate controls. In Sanderson, M. (eds.) *Prevailing trade winds*. Honolulu: University of Hawai‘i Press. P 12-36.

[26] Eversole, D. and Andrews, A., in press. Climate Change Impacts in Hawai‘i: A summary of climate change and its impacts to Hawai‘i ecosystems and communities. 44pp.

though again this is still uncertain.[27] Projections also suggest that more frequent extreme rain events could lead to impacts from inland flooding including landslides and slope failure, coastal erosion, and runoff.

### Wind

Strong winds throughout the Hawaiian Islands are associated with strong trade wind events, Kona storms, and tropical storms and hurricanes. Kaua'i in particular has a history of wind events associated hurricanes that have been exceptionally damaging, including Hurricanes Dot in August 1959, Iwa in November 1982, and Iniki in 1992[28]. Hurricane Dot packed sustained winds of 75 mph with gusts of 165 mph as it passed directly over Kaua'i. While the storm-generated surf was not particularly damaging, winds and flooding led to $5.5-6 million in agricultural losses and hundreds of houses and trees were damaged. Hurricanes Iwa and Iniki both produced high waves ranging 20-30 ft. in addition to winds over 125 mph. Interestingly, there has been dense redevelopment in the same areas that were impacted by those events, raising the risk of damage from future storms. The County of Kaua'i Hazard Mitigation Plan provides a table (Chapter 3, Table 3-2) of hurricane and strong wind events from the early 1900s through 2009.

Climate Change Impacts

Some studies incorporating models of global climate change reveal a substantial increase in tropical cyclone frequency around the Hawaiian Islands in the future.[29] These results highlight possible future increases in storm-related economic and ecosystem damages.

## Climate Change and Sea Level Trends

The Intergovernmental Panel on Climate Change is a scientific body that provides periodic peer-reviewed assessments of all available climate science to inform international decision making on climate issues. The international panel - made up of scientists, government representatives and experts in the climate field - uses a peer review process to assess the latest scientific, technical, and socioeconomic findings, providing an objective source of information about climate trends and projections. In 2013, the panel issued its fifth report on the physical science of global climate change. In its report, the IPCC concludes that warming of Earth's climate system is unequivocal[30] and that most of the temperature increases since the mid-20th century is "extremely likely"[31] caused by increased concentrations of greenhouse gases from human activities. This warming is observed in land and sea temperature increases, changes in global water cycle, reductions in snow and ice, sea-level rise, and changes in climate extremes. Observed climate change trends highlighted by the IPCC report, and relevant to Hawai'i, include:

- The last three decades were the warmest since 1850, and the last 30 years were likely the warmest 30 years in the last 1400 years.
- Atmospheric concentrations of $CO_2$ (carbon dioxide), $CH_4$ (methane), and $N_2O$ (nitrogen dioxide) are higher than they've been in 800,000 years. $CO_2$ concentrations are 40% higher than pre-industrial times.
- Pre-industrialization levels of atmospheric $CO_2$ fluctuated between 180 to 280 parts per million (ppm) by volume.
- In the modern industrial age $CO_2$ levels have surpassed that range, peaking near 400 ppm in 2013.
- Arctic sea ice, ice sheets, glaciers, and snow cover have shrunk over the last two decades, with most melting rates increasing in the last ten years (Figure 6).

[27] Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.), 2012. *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment*. Washington, DC: Island Press.
[28] Fletcher, C.H., Grossman, E.E., Richmond, B.M., Gibbs, A.E., 2002. *Atlas of Natural Hazards in the Hawaiian Coastal Zone*. U.S. Geological Survey Geologic Investigations Series I-2761. 182pp.
[29] Murakami, H., Wang, B., Li, T., Kitoh, A., 2013. Projected increase in tropical cyclones near Hawai'i. Nature Climate Change 3, 749-754.
[30] IPCC, 2013. IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.climate2013.org/spm Last Accessed November 14, 2013
[31] Extremely likely is defined as 95–100% probability by the IPCC, 2013 Summary for Policy Makers.

- Oceans have absorbed 30% of the additional $CO_2$ we have added to the atmosphere, contributing to a 26% change in the acidity of the ocean.

In terms of sea levels, the observed increases in global land and ocean temperatures are contributing to rising seas from thermal expansion (warmer water expands to take up more volume) and melting glacier ice (contributing more water to the global ocean). The IPCC report concludes that thermal expansion accounts for 30-55% of 21st century global mean sea-level rise, and glaciers account for 15-35% of sea-level rise. The instrumental record of modern global sea level change shows onset of rising sea levels during the 19th century. During the 20th century, global average sea level rose at a rate of about 1.7 mm/yr (about 7 in/century). Since 1993, satellite observation data has shown sea level to be rising at a rate of about 3 mm/yr[32] (about 12 in/century).

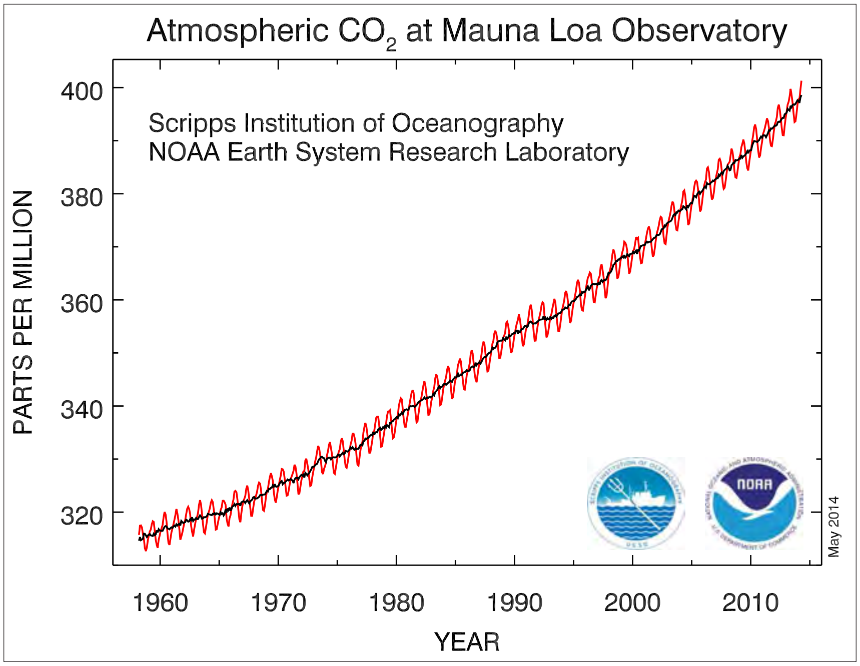


Figure 6. Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawai'i, 1958-2013 (http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo)

## Sea-Level Rise Variability

It is important to understand that sea levels do not rise uniformly around the world because of climatic and oceanographic factors (winds and currents) with annual and decadal variations. For example, the highest rises in sea level since 1993 have occurred in the Western Pacific[33] in part because strong trade winds have acted to 'pile' warm water up in the Western Pacific (Figure 7). Accelerated sea-level rise has not yet been detected in the Hawai'i tide gauge records.[34,35]

Locally, in the Hawaiian Islands, rates of relative sea-level rise will also vary among the islands with distance from Hawai'i Island because of differences in lithospheric flexure (island subsidence) from the weight of actively growing volcanoes. Direct measurements of sea-level rise over the past century from NOAA tide gages show that Hawai'i Island's rate of sea-level rise is 3.27 ± 0.35 mm/yr[36] (about 13 inches/century). The next closest island, Maui Island, has a rate of sea-level rise at 2.32 ± 0.53 mm/yr (about 9 in/century). Sea-level rise is roughly 65% slower around Kaua'i and O'ahu, at 1.53 ± 0.59 mm/yr and 1.50 ± 0.25 m/yr (about 6 inches/century), respectively.[37]

## Sea-Level Rise Projections

Global sea-level rise is projected to accelerate during the 21st century. The IPCC report concludes that it is very likely that sea level will rise in more than about 95% of the ocean area. About 70% of the coastlines worldwide are projected to experience sea level change within 20% of the global mean sea level change.

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[32] IPCC, 2013. IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker,T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.climate2013.org/spm Last Accessed November 14, 2013

[33] Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.), 2012. *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment*. Washington, DC: Island Press.

[34] Church, J.A. and White, N.J., 2006. A 20th century acceleration in global sea-level rise. Geophysical Research Letters, 33(L01602).

[35] Merrifield, M.A.; Merrifield, S.T., and Mitchum, G.T., 2009. An anomalous recent acceleration of global sea-level rise. Journal of Climate, 22(21), 5772–5781.

[36] NOAA (National Oceanic and Atmospheric Administration), 2012. Center for Operational Oceanographic Products and Services. http://tidesandcurrents.noaa.gov/index.shtml.

[37] Moore, J.G., 1987. Subsidence of the Hawaiian Ridge. In: Decker, R.W.; Wright, T.L., and Stauffer, P.H. (eds.). *Volcanism in Hawai'i*. Reston, Virginia: U.S. Geological Survey Professional Paper 1350, pp. 85–100.

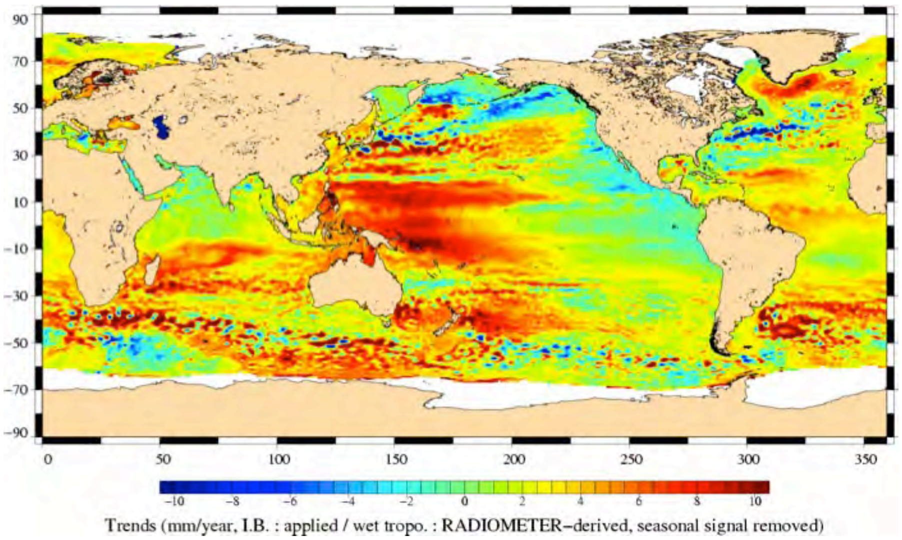


Figure 7. Global sea-level trends for 1993-2010. Map of sea level change 1993-2010 (mm/yr) as measured by satellite altimetry. (CREDIT: CLS/Cnes/Legos: http://www.aviso.oceanobs.com/en/news/ocean-indicators/mean-sea-level/)

There are a range of sea-level rise projections to accompany climate projections from greenhouse gas emission scenarios and model outputs. The IPCC report concludes that sea-level rise will likely be in the range of 10-36 inches (0.26-0.98 meters) by the year 2100. These ranges are derived from climate projections in combination with process-based models and literature assessment of glacier and ice sheet contributions.

These projections are consistent with projections published in 2012 by the National Academy of Sciences National Research Council (NRC) for the West Coast of the United States, of 3-9 inches by 2030, 7-18 inches by 2050, and 19-55 inches by 2100.[38]

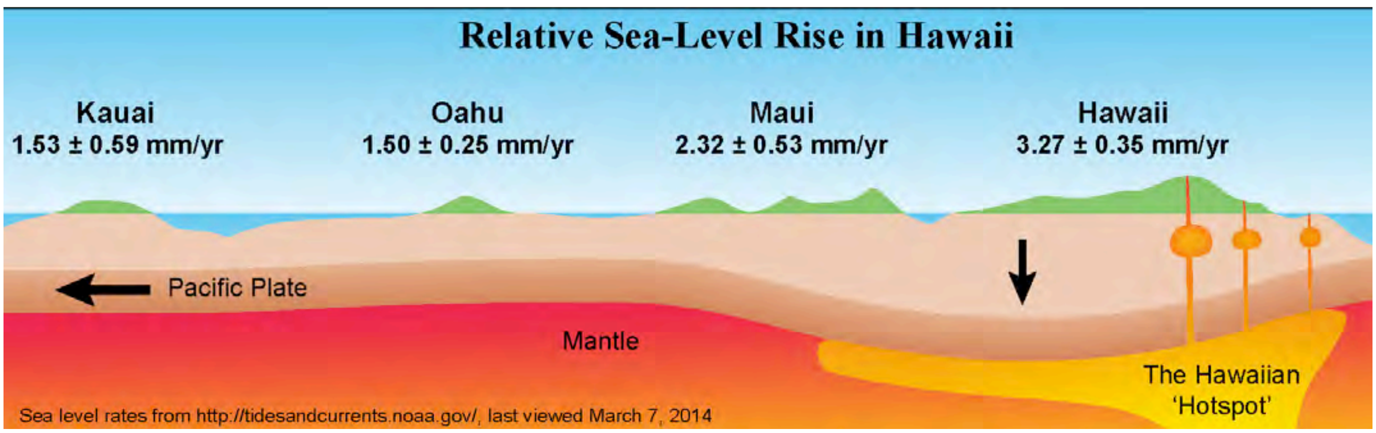


Figure 8. Relative sea-level rise in Hawai'i. University of Hawai'i Coastal Geology Group, adapted from Moore, J.G., 1987, Subsidence of the Hawaiian Ridge, in Decker, R.W., Wright, T.L., and Stauffer, P.H., eds., Volcanism in Hawai'i: U.S. Geological Survey Professional Paper 1350, p. 85–100.

NOAA also presents estimates of global sea level rise by 2100, ranging from 8 inches (0.2 meters) to 79.2 inches (6.6 feet or 2 meters) (Figures 9 and 10).[39] NOAA's high end scenario of 6.6 feet is based on projections that use a calculation of the maximum possible glacier and ice sheet loss by the end of the century. At this stage, the greatest uncertainty surrounding projections of future global SLR is the rate and magnitude of ice sheet loss, primarily from Greenland and West Antarctica.

Given the range of uncertainty, NOAA recommends a scenario-based planning approach, whereby planning decisions consider multiple future scenarios and response options, where the highest scenario should be considered in situations where there is little tolerance for risk (e.g., new infrastructure with a long anticipated life cycle such as a power plant) and the lowest scenario should be considered when there is a great tolerance for risk.

Based on the best available science, as described above, a range of sea-level rise of 1 foot by 2050 and

[38] National Academy of Sciences, 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future.*
[39] Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

| Scenario | SLR by 2100 (m)* | SLR by 2100 (ft)* |
|---|---|---|
| Highest | 2.0 | 6.6 |
| Intermediate-High | 1.2 | 3.9 |
| Intermediate-Low | 0.5 | 1.6 |
| Lowest | 0.2 | 0.7 |

* Using mean sea level in 1992 as a starting point.

Figure 9. Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. 2012. Global Sea Level Rise Scenarios for the US National Climate Assessment. NOAA Tech Memo OAR CPO-1. 37 pp.

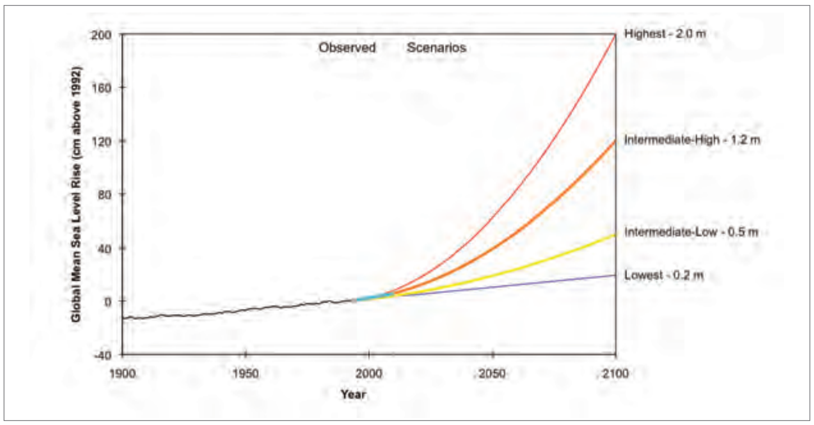


***Figure 10.*** Global mean sea level rise scenarios. Present Mean Sea Level (MSL) for the US coasts is determined from the National Tidal Datum Epoch (NTDE) provided by NOAA. The NTDE is calculated using tide gauge observations from 1983 – 2001. Therefore, we use 1992, the mid-point of the NTDE, as a starting point for the projected curves. The Intermediate High Scenario is an average of the high end of ranges of global mean SLR reported by several studies using semi-empirical approaches. The Intermediate Low Scenario is the global mean SLR projection from the IPCC AR4 at 95% confidence interval.

Figure 10. Global meal sea-level rise scenarios.

3 feet by 2100 is a reasonable, and possibly even conservative, planning target for Kauaʻi and other Hawaiian Islands. This is consistent with recommendations from the University of Hawaiʻi Sea Grant College Program Center for Island Climate Adaptation and Policy (ICAP) report titled Sea-Level Rise and Coastal Land Use in Hawaiʻi: A Policy Tool Kit for State and Local Governments[40] and the State of Hawaiʻi Ocean Resources Management Plan.[41]

In order to provide locally relevant planning information, the U.S. Army Corps of Engineers (USACE) has developed a Sea Level Change Calculator that incorporates land movement detected at tide gages with sea-level rise projections from the National Research Council (NRC), previously referenced above. Applying this calculator to NOAA's tide gage in Nāwiliwili Harbor on Kauaʻi provides estimates of sea-level rise at user selected time intervals to 2100 and beyond (Figure 11). The "low" column represents the historic rate of sea level change at the tide gage with no future acceleration. The "intermediate" column represents the NRC global projection of 0.5 m (1.6 ft) in addition to local land movement detected at the tide gage. The "high" column represents the NRC global projection of 1.5 m (5 ft) with local land movement detected at the tide gage.

## Sea-Level Rise Maps

To visualize future inundation from sea-level rise, the NOAA Digital Coast Sea-level rise and Coastal Impacts Flooding Viewer provides a "bathtub model" of sea-level rise inundation for all coastal states, including Hawaiʻi.[42] The Viewer allows users to visualize potential impacts from sea-level rise via an interactive map and a slide bar to select inundation scenarios from 0 to 6 feet of sea-level rise. Additionally, this data was to develop a set of maps, featured in Appendix C of this report, showing the inundation scenarios for 1 foot, 3 feet, and 6 feet of sea-level rise for selected areas of the Kauaʻi coast. Some notable limitations of these maps are that increases in water levels from waves (wave runup) is not evaluated and they do not predict the potential for coastal erosion.

[40] Douglas Codiga and Kylie Wager. *Sea-Level Rise and Coastal Land Use in Hawaiʻi: A Policy Tool Kit for State and Local Governments*. 2011. Center for Island Climate Adaptation and Policy. Honolulu, HI. *Available at* http://icap.seagrant.soest.hawaii.edu/icap-publications.

[41] Hawaiʻi Coastal Zone Management Program. 2013. Hawaiʻi Ocean Resources Management Plan. http://files.hawaii.gov/dbedt/op/czm/ormp/ormp_update_reports/final_ormp_2013.pdf

[42] National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, Charleston, SC. http://csc.noaa.gov/digitalcoast/tools/slrviewer (last visited Feb, 2014)

**USACE Curves computed using criteria in USACE EC 1165-2-212**

| Gauge HI, Nawiliwili: 52 yrs All values are in feet | | | |
|---|---|---|---|
| Year | USACE Low | USACE Int | USACE High |
| 2010 | 0.09 | 0.12 | 0.21 |
| 2020 | 0.14 | 0.21 | 0.43 |
| 2030 | 0.19 | 0.32 | 0.72 |
| 2040 | 0.24 | 0.44 | 1.09 |
| 2050 | 0.29 | 0.58 | 1.53 |
| 2060 | 0.33 | 0.75 | 2.05 |
| 2070 | 0.38 | 0.92 | 2.64 |
| 2080 | 0.43 | 1.12 | 3.30 |
| 2090 | 0.48 | 1.34 | 4.04 |
| 2100 | 0.53 | 1.57 | 4.86 |

Figure 11. Projected SLR scenarios at the Nawiliwili tide gage, using the U.S. Army Corps of Engineers' Sea Level Change Calculator (http://www.corpsclimate.us/ccaceslcurves.cfm).

## Sea-Level Rise Impacts

Future accelerated sea-level rise is expected to alter the frequency and severity of wave inundation, erosion, and flooding events. While it is unclear exactly what scale and timeframe the Hawaiian Islands will experience accelerated sea-level rise, there are already very clear analogs for the type of impact that can be expected. On Hawai‘i Island, entire lots and portions of the coastal road in the Kapoho region are completely submerged during the highest tides due to localized land subsidence causing increased relative sea-level rise. The condition can be more extreme when wind and/or waves are also factors.

With respect to beach erosion the overall, island-wide erosion trend on Kaua‘i and throughout Hawai‘i, is due in-part to historical trends of sea-level rise around Hawai‘i.[43] Coastal erosion rates on Kaua‘i and other Hawaiian Islands is expected to increase with future accelerated sea-level rise. The existing Kaua‘i Shoreline Erosion Maps[44] provide erosion rates based on the positions of historical shorelines over the past century, and reflect rising sea levels that have been measured at the Nāwiliwili Harbor[45] tide gauge, but they do not account for the projected accelerations to sea-level rise in coming decades. On Maui, the erosion experienced in Kā‘anapali in the summer of 2003 provides an example of the potential impacts of SLR to erosion patterns. That summer, short-term increases in sea level were measured from a mesoscale eddy (large rotating water masses) passing through the islands. These eddies produced water levels that were consistently 0.5 foot higher than the predicted tide level. The elevated water levels coupled with a moderate south swell resulted in increased wave angle of approach impacting the upper beach, which eroded tens of thousands of cubic yards of beach sand from the affected area. The beach disappeared entirely at some locations exposing beachfront resort facilities to flooding and damage. Temporary emergency protection measures (sand bags and other temporary measures) were implemented at great cost to the resort owners and the beach recovered over a period of strong north swell that returned the beach sand back to the depleted areas as water level and wave conditions subsided. However, the implication is that a small increase in water level, only 0.5 foot in this case, can lead to dramatic beach erosion coastal inundation.

[43] Romine, B.M., Fletcher, C.H., Barbee, M.M., Anderson*, T.R., and Frazer, L.N., 2013. Are beach erosion rates and sea-level rise related in Hawai‘i?. Global and Planetary Change, 108: 149-157

[44] University of Hawai‘i Coastal Geology Group. 2009. Kaua‘i Shoreline Study Erosion Maps. Prepared for the County of Kaua‘i, State of Hawai‘i. http://www.soest.hawaii.edu/coasts/kauaicounty/KCounty.html

[45] NOAA (National Oceanic and Atmospheric Administration), 2012. Center for Operational Oceanographic Products and Services. http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=1611400

# II. Climate Change and Coastal Hazard Consequences

| | Low Adaptive Capacity | Medium Adaptive Capacity | High Adaptive Capacity |
|---|---|---|---|
| High Impact | HIGH CONSEQUENCES | HIGH CONSEQUENCES | MEDIUM CONSEQUENCES |
| Medium Impact | HIGH CONSEQUENCES | MEDIUM CONSEQUENCES | LOW CONSEQUENCES |
| Low Impact | MEDIUM CONSEQUENCES | LOW CONSEQUENCES | LOW CONSEQUENCES |

Figure 12. Conceptual framework of the relationship between impact and adaptive capacity, and the ultimate consequences of decisions. California Ocean Protection Council, 2010, *State of California Interim Sea Level Rise Guidance Document*, Appendix B, Figure 1.

What will the consequences of climate change, coastal hazards, and SLR in particular be for Kaua‘i? As described in Section I, SLR is expected to have a multiplier impact on erosion and wave inundation with a conversion of infrequent flood zones to ones more permanently flooded. Coastal communities are already highly prone to these hazards, threatening roads, homes, and other infrastructure. Kaua‘i County has made strides in addressing these hazards through programs such as its floodplain and shoreline setback ordinances, Special Management Area (SMA) permit program, and the Kaua‘i Multi-Hazard Mitigation Plan. With accelerated SLR comes exacerbated impacts in all of these hazard categories, and the consequences will be seen across many sectors, regions, and ecosystems.

## Coastal Communities

Being an island in the middle of the Pacific, Kaua‘i’s residents and visitors and the communities in which they reside are already vulnerable to the coastal hazards described above. Of Kaua‘i’s 67,226 residents, approximately 20% live close to the shoreline,[46] which poses particular challenges for hazard planning and adapting to SLR. Some larger communities that are particularly vulnerable include Waimea-Kekaha, Po‘ipū, Kapa‘a, Hanalei and Hā‘ena. As shown in the U.S. Geological Survey (USGS) and UH shoreline change studies Kaua‘i’s beaches are already eroding under modern environmental conditions. Adding in high wave events, hurricanes, tsunamis, extreme tidal events, the effects of which are compounded by SLR, will cause increased coastal erosion, coastal bluff/cliff failure, and inundation of low-lying areas.[47] This will increase the likelihood of property damage, and community exposure to hazards. Existing flood control systems will be challenged (e.g., Waimea-Kekaha), further exposing these communities. Shoreline properties will be threatened with land loss and increased wave inundation as beaches erode and shoreline retreat and faced with expensive choices to relocate or protect in place with hard structures (e.g., seawalls and revetments). Kaua‘i will be faced with challenging choices between protecting important coastal resources (e.g., beaches and associated ecosystems) and private property.

## Critical Infrastructure

Critical infrastructure vulnerable to climate change and SLR impacts in Hawai‘i include roads, ports and harbors, water supply, and wastewater systems.[48] In many cases these impacts will stress an already ailing infrastructure. For example, 47% of Hawai‘i’s bridges are structurally deficient or functionally obsolete. Needed repairs to drinking water infrastructure are already estimated to cost $146 million over the next 20

[46] Email communications with Marie Williams, Long Range Planner, Kaua‘i County Planning Department
[47] UHSG 2014
[48] Eversole, D. and Andrews, A., in press. Climate Change Impacts in Hawai‘i: A summary of climate change and its impacts to Hawai‘i ecosystems and communities. 44pp.


Figure 13. Kaumualiʻi Highway in Kekaha, during emergency placement of sandbags, before construction of drilled pier wall, July 2012. R. Pap


Figure 14. Kaumualiʻi Highway in Kekaha, during construction of drilled pier wall, October 2012. R. Pap

years, and this does not count the added costs from climate change. Wastewater infrastructure repair costs are estimated at $1.74 billion.[49]

On Kauaʻi, low-lying roads, wastewater systems, energy facilities, stormwater infrastructure, docking facilities in harbors, breakwaters will be at risk of impaired function due to increased erosion, flooding, and wave inundation. As examples, Kaumualiʻi Highway in Kekaha is already vulnerable to erosion, and has been protected by a rip rap revetment since Hurricane Iwa in 1982. More recently the Hawaiʻi Department of Transportation took additional action to protect the road by installing a 300-foot drilled pier retaining wall at the west end of the revetment just south of MacArthur Park (Figures 14 and 15). Many of Kauaʻi's roads and highways are similarly positioned next to the shoreline and will be increasingly vulnerable to erosion and wave inundation.

Wastewater systems, stormwater infrastructure, water supply and energy facilities are also sited in low lying areas in close proximity to the coast, and each facility should be analyzed carefully for vulnerability. Flooding will not only damage equipment, but block discharge from coastal outfall structures and force facilities to release untreated wastewater. Kauaʻi already experiences these types of overflows during flashflood events, and with SLR this will only increase. One example of an area particularly vulnerable is in Waimea-Kekaha, on Kauaʻi's west side. This area is already at sea level and is drained by an extensive series of ditches and outfalls.

The Wailuku-Kahului Wastewater Reclamation Facility on Maui provides a harbinger of the future for public infrastructure sited in low-lying coastal areas, and highlights the need to begin advance planning to adapt to sea-level rise and its associated impacts. The County has plans to increase the length and height of a boulder revetment to protect the plant from erosion and tsunami inundation. The height of the revetment is to be elevated an additional 2 feet to account for increasing water levels with SLR. While most agreed that the facility should be relocated to avoid potential impacts to or failure of the facility and damage of coastal resources, the estimated expense and logistical challenges associated with this option resulted in a decision to protect the facility in place.[50]

Water supply faces threats both from rising groundwater and saltwater intrusion in wells, as well as decline in quality and quantity due to drought and downward trends in groundwater base flows. The water table rises as sea level rises, and it will eventually break the land surface creating and expanding wetlands, changing drainage

[49] Center for Integrative Environmental Research (CIER). 2007. The U.S. Economic Impacts of Climate Change and the Cost of Inaction. College Park, MD.
[50] Owens, Tara Miller. 2013. Personal communication

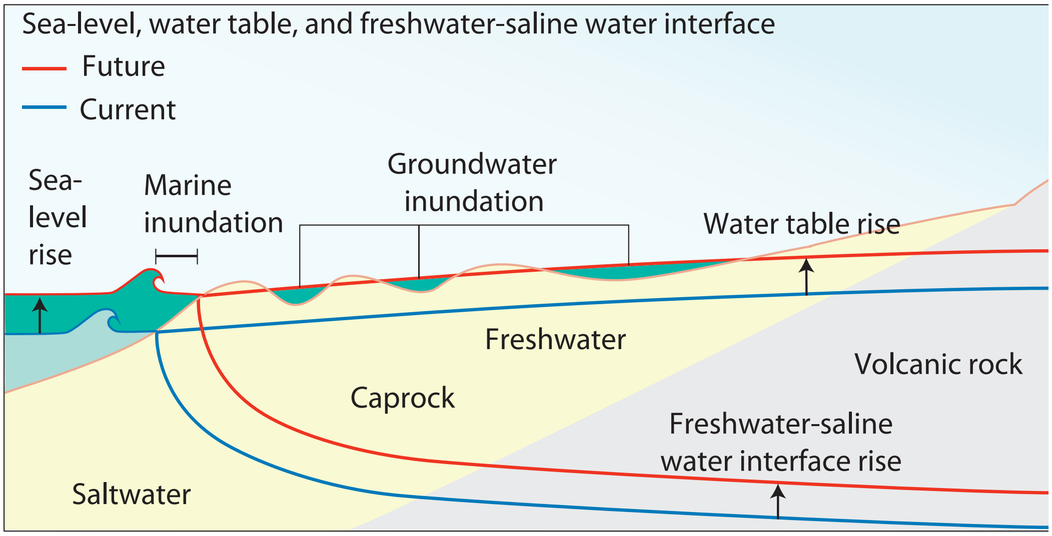


Figure 15. Conceptual diagram of a freshwater lens, and marine and groundwater inundation under SLR in the Southern O'ahu Aquifer. Rotzoll and Fletcher, 2012

Figure 16. Hanalei Bridge. M Gonser

patterns, saturating the soil, and causing increased flooding. This could cause problems with water supply infrastructure, including aquifer salinization and flooding of facilities. These will be costly to mitigate on an ongoing basis. A study conducted in Honolulu took measurements of coastal groundwater elevation and tidal influence and assessed the vulnerability of the water table to groundwater inundation from SLR. Researchers found that 0.6m of potential SLR would cause substantial flooding, and 1 meter of SLR would cause groundwater to flood at twice the amount of marine inundation (Figure 15).[51]

Higher water levels could increase difficulty for cargo handling facilities at harbors like Nawiliwili, and increased water heights could also reduce bridge clearance, bringing to mind low-lying historical bridges on the North Shore (Figure 15). According to the Pacific Islands Regional Climate Assessment (PIRCA):

> "As storm intensity and frequency are predicted to change in some Pacific Island sub-regions and storm paths may shift, reliance of the majority of the Pacific Islands on imported oil for primary energy production renders them highly vulnerable to climate-related disruption of delivery and subsequent energy production. Because the Pacific Islands are almost entirely dependent on imported food, fuel, and material, the vulnerability of ports and airports to extreme events, especially typhoons, is of high concern."[52]

## Economy

Various sectors of Kaua'i's economy could be affected by accelerated sea-level rise. Kaua'i's economy is less diversified than O'ahu, and tourism is the main sector.[53] Kaua'i is known for having the best and the most extensive beaches in Hawai'i - a major attraction for visitors. Beach erosion will increase as sea levels rise. Beach nourishment can be used to restore beaches and reduce property loss from erosion, but the high cost of these projects generally limits them to beaches of high economic importance.

[51] Rotzoll, Kolja and Charles H. Fletcher. November 11, 2012. Assessment of Groundwater Inundation as a Consequence of SLR. Nature Climate Change Letters. http://www.nature.com/doifinder/10.1038/nclimate1725

[52] Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.), 2012. *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment*. Washington, DC: Island Press, page 56

[53] County of Kaua'i Multi-Hazard Mitigation Plan, 2010 Update

A recent economic impact analysis of Waikīkī Beach on O‘ahu suggested that if the beach eroded away, there would be approximately $661.2 million in lost annual hotel revenues, and $2 billion overall in lost visitor expenditures, and a loss of approximately 6,352 hotel jobs.[54] There has not been a specific study on the economic impacts to the tourism industry as a result of climate change and SLR-related impacts, such as beach erosion and coastal flooding. However, given the tourism revenues and the concentration of tourists near beaches, one can infer that the consequences will be significant. According to the Hawai‘i Tourism Authority’s 2012 Annual Visitor Research Report, Kaua‘i had 1,211,482 visitors, with $1.3 billion in expenditures.[55] Other states have addressed concerns of climate-related impacts on tourism and found the potential for major economic impacts. In Florida, the cost of ‘inaction’ on climate change to the tourism industry is estimated at $40 billion by 2050 and $167 billion by 2100 (not including costs incurred from hurricanes).[56]

Another economic sector of importance to the community is agriculture (Figures 17 and 18). SLR could lead to an increase of flooding and inundation of low lying agricultural land, salt water intrusion into agricultural water supplies, and a decrease in the amount of freshwater available.[57] Saltwater intrusion could affect lowland agriculture, such as taro lo‘i and rice.[58] In addition to the coastal hazards, in Hawai‘i and the Pacific Islands, agriculture will be affected by drought, possible increases in storm intensity, and changes in rainfall patterns. The increase in storms could lead to damaged infrastructure.[59]

Figure 17. Ha‘ena agricultural areas. M. Gonser

Figure 18. Hanalei agricultural areas. M. Gonser

## Public Access/Recreation

SLR and its associated impacts of erosion and inundation could permanently inundate or erode low-lying public access and recreation areas, including trails, parks, and beaches. If not permanently inundated, these

[54] Eversole, D. and Andrews, A., Climate Change Impacts in Hawai‘i: A summary of climate change and its impacts to Hawai‘i ecosystems and communities.

[55] Hawai‘i Tourism Authority (HTA). 2012 Annual Visitor Research Report. http://www.hawaiitourismauthority.org/default/assets/File/reports/visitor-statistics/2012%20ANNUAL%20REPORT%20(FINAL2)(1).pdf

[56] Stanton and Ackerman 2007. Florida and Climate Change: The Costs of Inaction. Tufts University Global Development and Environment Institute and Stockholm Environment Institute - US Center.

[57] California Coastal Commission (CCC). 2013. Draft SLR Policy Guidance Document. Public Review Draft Comment Period: October 14, 2013 - January 15, 2014

[58] UH Coastal Geology Group. 2013. Sea Level Rise http://www.soest.hawaii.edu/coasts/sealevel/

[59] Keener, V. W., Marra, J. J., Finucane, M. L., Spooner, D., & Smith, M. H. (Eds.), 2012. *Climate Change and Pacific Islands: Indicators and Impacts. Report for the 2012 Pacific Islands Regional Climate Assessment*. Washington, DC: Island Press.


Figure 19. Poʻipū Beach parking lot regularly floods after heavy rains. The situation in this low-lying area may be a harbinger for future SLR inundation at this popular recreation area. R. Pap

areas could suffer from increased episodic flooding and beach erosion (Figure 19). In areas where beaches cannot migrate inland due to development or hard structures, or in areas already suffering from a deficit in sand, beaches will become narrower and eventually disappear. Also, changing water levels and altering sediment transport patterns could lead to changes in surfing conditions and affect the safety of harbors.[60]

## Cultural Resources

Native Hawaiian coastal burials, artifacts, and structures may be particularly vulnerable to inundation and erosion associated with SLR. According to the 2012 Pacific Islands Regional Climate Assessment:

> "Threats to traditional lifestyles of indigenous communities in the region (including destruction of coastal artifacts and structures, reduced availability of traditional food sources and subsistence fisheries, and the loss of the land base that supports Pacific Island cultures) will make it increasingly difficult for Pacific Island cultures to sustain their connection with a defined place and their unique set of customs, beliefs, and languages."[61]

Researchers at the University of Hawaiʻi Coastal Geology Group conducted a vulnerability assessment of Hawaiʻi's cultural assets attributable to erosion at Kawela Bay on Oʻahu. Cultural features identified included iwi kupuna (burials), artifacts, and Punaulua (a freshwater spring). All of these cultural features except for the Punaulua were found to be vulnerable to erosion at historical rates.[62] These rates will only increase with accelerated SLR, putting these resources at increased risk.

In addition, post-contact historic structures along the coast, for example historic shipping/transportation systems associated with the sugar and pineapple plantation era could become destabilized.

## Natural Habitats

### Coral Reefs and Nearshore Habitats

Nearshore reefs and coastal ecosystems in Hawaiʻi are already under great pressure from overfishing, land-based runoff, and other human impacts. Increasing temperatures, ocean acidification, and runoff with changing precipitation patterns will further destabilize nearshore ecosystems. SLR and related impacts such as increasing storm surge heights threaten to alter the physical setting and impacts for nearshore environments. Fish species that depend on shallow water or inter-tidal and sub-tidal plant communities will be at risk of habitat loss. Changing water depths could affect species types and quantities. While reefs can grow vertically to adapt to rising sea levels, around 10-20 mm per year, this may not be enough to adapt to higher SLR rates, particularly when other impacts such as degraded water quality are considered.[63]

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[60] California Coastal Commission (CCC). 2013. Draft SLR Policy Guidance Document. Public Review Draft Comment Period: October 14, 2013 - January 15, 2014

[61] Keener et al. 2012. P. vi

[62] Haunani H. Kane, Charles H. Fletcher, Bradley M. Romine, Tiffany R. Anderson, Neil L. Frazer, and Matthew M. Barbee. 2012. Vulnerability Assessment of Hawaiʻi's Cultural Assets Attributable to Erosion Using Shoreline Trend Analysis Techniques. Journal of Coastal Research

[63] Eversole et al. 2013; citing Grigg 1989.

Figure 20. Mahaulepu Beach, Kaua'i. Hwang 2005

Figure 21.Wailua River mouth from Opaeka'a Falls. M. Gonser

## Coastal Habitats

SLR will affect rocky intertidal areas, beaches, dunes, wetlands, estuaries, lagoons and tidal marshes, tidal flats, and tidally influenced streams and rivers. Inundation and erosion from SLR will reduce habitats and/or convert habitats from one type to another, including sandy beaches and rocky intertidal areas.[64] As sea levels rise, beaches backed by a sediment-rich backshore will migrate landward, but may be drowned or eroded away if coastal development prevents that migration. Coastal sediment transport and storage may be affected by SLR, resulting in erosion of beaches, dunes, bluffs, estuarine shorelines, and tidal wetlands. While new wetlands may be created due to the rise in the groundwater table (if adequate land area is available), saltwater intrusion due to SLR could occur in existing aquatic ecosystems, including wetlands, streams, and estuarine systems, changing their character and vastly affecting the species that depend on them.[65] The loss of wetlands could mean a loss in natural storm buffers for future hazards.[66] Documented wetland accretion and inland migration as well as shoreline erosion is already occurring on many of Hawai'i's coastlines. On Kaua'i, approximately 70% of beaches are experiencing erosional trends. These existing erosional trends, which are due in part to historical SLR, will only accelerate with projected SLR.[67]

## Water Quality

Future inundation of coastal lands with SLR and changing precipitation and runoff patterns could further degrade coastal water quality, in addition to the existing threats to water quality from nonpoint source pollution, such as sediment, nutrients, pathogens, oil, toxins, and trash runoff (Figure 21).[68] Increased turbidity from resuspension of sediments due to changing wave energy and erosion patterns with SLR is expected to contribute to increased degradation of fringing coral reefs in Hawai'i.[69] Increased coastal inundation could bring toxic soils from agricultural or industrial practices into the marine environment. Flooded wastewater systems, including treatment plants, cesspools, and septic tanks, could bring untreated sewage into waterways. In addition, saltwater intrusion into valuable water supplies affects household and agricultural water quality and supply. The loss of wetlands is a loss in filtering capacity, leading to additional degradation of coastal waters.[70] Degraded water quality affects marine habitat, biological productivity, recreation and human health. Inundation has already lead to contamination of surface water and groundwater on some low-lying Pacific islands and contaminants in stormwater runoff already cause the closure of Hawai'i's beaches annually. Inundation and flooding in the future will lead to continued contamination of surface waters, causing infection from exposure through recreation or occupation (e.g., taro farming).[71]

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[64] California Coastal Commission. 2013. Draft SLR Policy Guidance
[65] UH Coastal Geology Group. 2013. SLR Hawai'i. Accessed at http://www.soest.Hawaii.edu/coasts/sealevel/
[66] Eversole et. al. 2013
[67] UH Coastal Geology Group. 2013.
[68] Eversole et. al 2013
[69] Ogston, A.S., and Field, M.E., 2010, Predictions of turbidity due to enhanced sediment resuspension resulting from sea-level rise on a fringing coral reef; evidence from Molokai, Hawai'i: Journal of Coastal Research, v. 26, i. 6, p. 1027-1037, doi:10.2112/JCOASTRES-D-09-00064.1.
[70] California Coastal Commission. 2013
[71] Eversole et al. 2013; citing Keener et al. 2012, Nancy Lewis, Katz et al 2011

# III. Resources to Address Climate Change and Coastal Hazards

While greenhouse gas (GHG) emissions **mitigation** is an important global element to combating climate change and its associated coastal hazard impacts, **adaptation** is critical for Kaua‘i’s community resilience. The impacts from climate change have been observed in Hawai‘i, and detailed scientific studies are being conducted to enhance prediction of future conditions.[72] The following sections summarize the County’s mitigation efforts, but the primary focus is on adaptation to coastal hazards related to climate change.

## Climate Change Mitigation

Although outside the primary focus of this work, this section, contributed by Ben Sullivan, Energy Coordinator for the County of Kaua‘i Office of Economic Development, provides a brief discussion on the issue of mitigation of carbon emissions for the Island of Kaua‘i.

According to the state’s *Hawai‘i Greenhouse Gas Inventory: 1990 and 2007,* [73] Kaua‘i contributed 1.2 million metric tons $C0_2$ equivalent in 2007, primarily from the combustion of fossil fuels. This compares to the almost 50 gigatons $C0_2$ equivalent emissions globally for the same year. It is sometimes put forward that the island’s contribution to global emissions is so miniscule that it is summarily dismissed when viewing the challenge of emissions reductions globally. This sentiment is certainly understandable from a purely quantitative level. However, it may be helpful to view Kaua‘i as a microcosm of the larger state, national, and global emissions reductions challenges. From the latest IPCC report:

> *Effective mitigation will not be achieved if individual agents advance their own interests independently.*[74]

Policy makers at all levels of government have identified the urgent need to reduce our dependence on fuels for numerous reasons, including GHG emissions reductions. Kaua‘i depends on fossil fuel in three primary areas – the electricity grid, ground transportation, and air transportation, with each sector in a different state of progress. The local electric cooperative, Kaua‘i Island Utility Cooperative (KIUC), is integrating renewable energy onto the grid. Their strategic goal is to replace 50% of their electricity generation with renewable sources by 2023 in order to reduce their emissions to 1990 levels by the same year.[75] With an expected 40% renewable energy level by next year, they are well on their way to achieving it. The progress made to date is notable for the utility industry in the U.S.

Similar transformation can be seen in the ground transportation sector, if not as far along. Kaua‘i County is implementing plans for transportation mode shifting that will stem the increase in emissions from ground transportation.[76] Combined with alternative fuels and efficiency gains, such work puts net reductions in emissions from the ground transportation sector within reach within the next decade. There is clearly a need for greater and more measured progress in order to align with global emissions reduction targets. However, the attainability of a *net decrease* in emissions in this area was not something policy makers even *perceived* as attainable until only a few years ago.

Finally, the air transportation sector remains a very difficult challenge for the island of Kaua‘i. The local economy is dependent primarily on the tourism, which is in turn wholly dependent on air transportation. Very few solutions to this challenge have surfaced to date.

[72] Fletcher, C. 2010. Hawai‘i’s Changing Climate - Briefing Sheet. University of Hawai‘i Sea Grant College Program: Honolulu, HI.
[73] *Hawaii Greenhouse Gas Inventory:1990 and 2007* for DBEDT by ICF International, December 31, 2008
[74] *Summary for Policy Makers, IPCC WGIII AR5, page 4*
[75] *Kaua‘i Island Utility Cooperative 2008 Strategic* Plan - http://website.kiuc.coop/content/strategic-plan
[76] *Kaua‘i Multi-Modal Land Transportation Plan*, Charlier & Associates, 2010

For all three of these sectors, there are innumerable technological solutions available or under development to create cleaner fuels, smarter electric grids, more efficient planes, etc. However, in order to achieve the necessary emissions reductions, these solutions will need to be coupled with institutional policy changes that enable and target implementation of these technologies.

## Adaptation and Resiliency

> *Coastal community resilience refers to the ability of linked social, ecological, and economic systems within the coastal zone to adapt to and recover from disturbances such as hurricanes, tsunamis, floods, SLR, Great Lake level fluctuation, and harmful algal blooms. A resilient coastal community can absorb shocks while maintaining function. When change does occur, resilience promotes renewal and reorganization.*[77]
>
> *Adaptation - adjustment in natural or human systems to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities; a process whereby individuals and communities respond to actual or expected climatic stimuli and their effects.*[78]
>
> *Adaptation presents formidable challenges to governance, science and ultimately to the sustainability of society and the environment on which it depends.*[79]
>
> *Adaptation is made up of actions throughout society, by individuals, groups, and governments.*[80]

From natural hazards, to those enhanced by changes in the global climate due to global warming, we are becoming more aware of threats to our health, safety, livelihoods, and survival. The Kaua'i County Civil Defense Agency explicitly states as its mission, "To protect the lives and property of all the people living in Kaua'i County during emergencies or disaster events."[81] Recognizing that this emphasizes a particular moment of time, what can be done to ensure that actions taken outside of those events do not further complicate an agency, such as Civil Defense, from upholding its mission? As a health and safety issue, it is important for the County of Kaua'i to include proactive considerations for the projected impacts of climate change, including SLR and its associated hazards.

With the adoption of a revised shoreline setback ordinance in 2008 (Ordinance 863), incorporating erosion-rate based construction setbacks, the County of Kaua'i has already taken certain steps to protect life and property from shoreline hazards and preserve beach ecosystems and public shoreline access. The setback is determined based on the annual average shoreline erosion rate, multiplied by a planning period of 70-100 years, plus 40 feet (Figure 22).

Climate change adaptation comprises purposeful actions to reduce the sensitivity of a system to climate change (e.g., increased reservoir capacity), alter the exposure of a system to climate change (e.g., hazards preparedness), and increase the resilience of a system to cope with changes (i.e., increase access to resources during non-stress periods and enable recovery during events).[82] Adaptation is grounded in certain

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[77] Coastal States Organization. 2008. Coastal Community Resilience: An Evaluation of Resilience as a Potential Performance Measure of the Coastal Zone Management Act. Final Report of the CSO Coastal Resilience Steering Committee.
[78] Intergovernmental Panel on Climate Change (IPCC). 2001. McCarthy, J., Canziani, O., Leary, N, Dokken, D., and White, K. (editors), Climate Change 2001: Impacts, Adaptation, and
Vulnerability, Contribution of Working Group II to the Third Assessment Report of the
Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and
New York.
[79] Adger, W.N., Arnell, N.W., and Tompkins E.L. 2005a. Editorial: Adapting to climate change: perspectives across scales, *Global Environmental Change*, 15: 75-76.
[80] Adger, W.N., Arnell, N.W., and Tompkins, E.L. 2005b. Successful adaptation to climate change across scales, Global Environmental Change, 15: 77-86.
[81] http://www.Kauai.gov/Government/Departments/CivilDefenseAgency/tabid/90/Default.aspx
[82] Adger, W.N., Arnell, N.W., and Tompkins, E.L. 2005b. Successful adaptation to climate change across scales, Global Environmental Change, 15: 77-86.

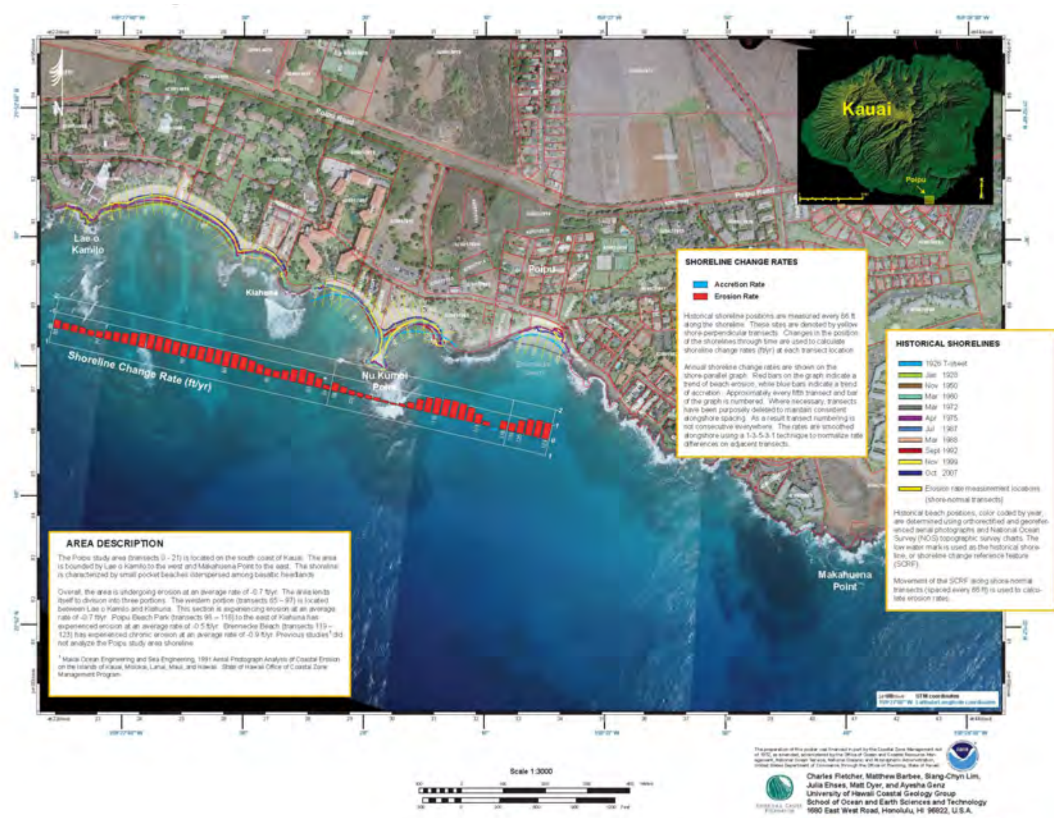


Figure 22. Example of an erosion map from Poʻipū, which is used to determine a property's shoreline setback.

strategies, which are followed by identified practices to meet contextual needs. In their survey of local climate change and related coastal hazard management best practices from over 30 municipalities on the east coast of the continental U.S. (*Cost-Efficient Climate Change Adaptation in the North Atlantic*), Schechtman and Brady (2013) identified five adaptation strategies and six adaptation practices (Table 1).[83]

Schechtman and Brady (2013) go on further to ask does the *action explicitly incorporate climate change: yes-no?* A "yes" means the action mentions, is based on, or responds to climate change or SLR specifically; a "no" means the action has an impact on climate resilience, but does not specifically respond to or incorporate climate change, such as flood protection and land preservation. The researchers also assessed the enforceability of the municipal actions, i.e., the ability to have an impact. Actions fell into three categories: "recommendation" - the outcome of the action is a set of recommendations that do not have the force of law; "incentive" or "permissive" - the action influences subsequent action by providing some type of special benefit or the action removes a barrier to other actions that were not previously permissible; and, "mandatory" - requires the action by force of law.

Applying their classification system, this report would qualify as a "procedural study" that provides "recommendations," which span the spectrum of adaptation strategies (as seen in later sections). Depending on the actions taken during the GP update, the language and actions adopted therein may be considered explicit climate change adaptation measures.

Lastly, the Third Assessment Report of the IPCC distinguishes three types of adaptation:

1. <u>Anticipatory Adaptation</u> - takes place before the impacts of climate change are felt
2. <u>Autonomous Adaptation</u> - does not constitute a conscious response to climatic stimuli, but is triggered by ecological changes and by market changes in human systems (aka <u>spontaneous adaptation</u>) - *likely to be very costly and disruptive*

[83] Schechtman, J. and Brady, M. 2013. Cost-Efficient Climate Change Adaptation in the North Atlantic, National Oceanic and Atmospheric Administration, Sea Grant and North Atlantic Regional Team: Washington, D.C.

3. Planned Adaptation - the result of deliberate policy decisions, 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 - *preferred type of adaptation*.

This report and the ultimate GP update are planned adaptations.

Table 1. Adaptation Strategies and Practices, adapted from Schectman and Brady, 2013

| *Adaptation Strategies* | *Adaptation Practices* |
|---|---|
| **Accommodation** - adaptations that strengthen the resilience of existing or new structures, but do not attempt to prevent flooding or the advance of the sea | **Plans** - process-driven documents that serves as guidance for future decision-making (e.g., comprehensive plans and hazard mitigation plans) |
| **Protection** - actions taken to protect land from inundation by rising seas and storm surge; protect land from exacerbating coastal hazards such as flooding | **Studies/Pilot Projects** - stand-alone documents that issue recommendations and are sometimes woven into a climate change plan |
| **Retreat/Restoration** - the intentional relocation, over time, of structures and infrastructures to areas identified as outside of a hazard zone; allowing for existing coastal ecosystems to shift landward; measure taken to restore natural ecosystems | **Education/Outreach** - projects to help build knowledge among residents and government<br><br>**Capital Investments** - financing the construction or maintenance of a green or gray infrastructure project |
| **Prevention** - anticipatory actions taken to protect or preserve land in its natural state that prevents exacerbation of exposure to coastal hazards; anticipatory rather than reactionary | **Policies** - executive orders or administrative rules and/or procedures<br><br>**Laws and Administrative Actions** - ordinances, bylaws, etc., that create mandatory expectations of compliance; and activities and actions taken by a government that involve process |
| **Procedural** - projects that aim to generate climate information, disseminate such information, or incorporate such information into other plans or policies (e.g., studies, mapping exercises, administrative or educational programs, or those projects that incorporate climate change considerations into other administrative processes) | |

## Science and Data Tools

The following sections outline scientific data and planning tools available to planners and the wider community in planning for climate change and coastal hazards.

### Inventory of Planning Information and Data Products

Appendix B: Inventory of Planning Information and Data Products provides a list and description of available data products and decision support tools for planning for coastal hazards on Kaua‘i, including those related to climate change and SLR. The data inventory is intended to support the integration of science-based coastal hazards information in land use planning through the GP update. This report highlights applicable and current hazards data sources for coastal land use planning. This report may also provide complimentary and updated information to existing documents, such as the Kaua‘i Multi-Hazard Mitigation Plan (see Part 3), though the $KC_3HA$ is not directly related to that report.

The data inventory features ten land use planning support tools and data products, which may be utilized to varying degrees by Kaua'i County in planning for coastal hazards, including those related to climate change and SLR. These include:

1. NOAA Kaua'i Online Hazard Assessment (KOHA): Flood Hazard Assessment Tool
2. USGS Atlas of Natural Hazards in the Hawaiian Coastal Zone
3. County of Kaua'i Multi-Hazard Mitigation Plan
4. Kaua'i Shoreline Erosion Maps (University of Hawai'i)
5. Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs)
6. Tsunami Evacuation Zones (Kaua'i Civil Defense)
7. NOAA SLR and Coastal Flooding Impacts Viewer
8. NOAA Critical Facilities Flood Exposure Tool
9. Variations in Community Exposure and Sensitivity to Tsunami Hazards in the State of Hawai'i (USGS)
10. U.S. Army Corps of Engineers Sea Level Change Calculator

The description of each data product includes access information, description of the product and intended use, how the data product was created, utility in climate change and SLR planning, and limitations of the data set. A discussion is provided under each data product on which of the four hazards the data set provides information and guidance on: coastal erosion, wave inundation, flooding, or wind.

### Gap Analysis

A forthcoming report, *Gap Analysis for Implementation of Hazard Science into the Community With Test Application for Kaua'i, Hawai'i and Majuro, Republic of the Marshall Islands* by Dennis Hwang conducts a gap analysis for Kaua'i:

> *A Gap Analysis is, in general, a formal study that identifies gaps in processes or performance so that deficiencies can be identified and the weaknesses filled… The purpose of this report is to develop a Gap Analysis Methodology ("GAM") that will assist in efficient implementation of hazard science into the community so that hazard risks are reduced. This can potentially lead to the more efficient utilization of research, planning, implementation, administration and regulatory resources while at the same time increasing Community Resilience.*[84]

The key hazard processes to consider in coastal areas are: erosion, wave inundation, flooding, and wind. These processes can be generated by a variety of events. For example, Hurricane Iniki, a hazard event, caused high winds, storm surge (wave inundation), flooding, and erosion (i.e., hazard processes). Climate change can contribute and accelerate all of these processes.

Additionally, Hwang 2014 identifies seven key elements that form building blocks to the implementation of hazard mitigation measures (i.e., adaptation): knowledge, planning information, guidance, policy, industry standards, existing authority, and new regulation. An important note is that action often doesn't always require new rules, laws, or regulations, but may be carried out through existing authority or agency procedures.

Hwang's gap analysis identifies the following gaps in implementing hazard mitigation, and these could begin to be resolved through GP policy:

1. Planning information, guidance, and policy to deal with an Aleutian Island earthquake event with tsunami impacts in Hawai'i. Hawai'i State Civil Defense is working with the University of

[84] Hwang et al. 2014.

Hawaiʻi to confirm the risk and develop maps, which, when finished, will fill the gap in planning information.

2. Erosion affected by accelerated SLR: there is a lack of planning information on how SLR will affect erosion rates, resulting in a gap in existing shoreline setback regulation, which relies on historical erosion rates.
3. Planning information and guidance for wave inundation affected by future SLR and erosion: The FIRMs do not factor in future erosion or SLR, and therefore underestimate the inundation risk.
4. Guidance and policy regarding flooding affected by future and accelerated SLR: The Flood Insurance Rate Maps (FIRMs) do not account for SLR inundation. There is now SLR mapping available from the National Oceanic and Atmospheric Administration (NOAA) Digital Coast project providing some key planning information, however guidance is needed on how to use the information. This $KC_3HA$ report, in part, will help provide that guidance to the County.

**$KC_3HA$ Recommendation #1:** Support the Generation of Hazard Planning Information, Guidance, and Policy and when planning information is available, conduct a detailed hazard, risk, and vulnerability assessment See Section IV, page 40 for details.

### SLR Inundation Assessment and Needs for Select Areas

Appendix C presents a SLR needs assessment for select areas on Kauaʻi. A series of 1:10,000 scaled maps are presented depicting SLR and coastal flooding impacts for select areas around Kauaʻi. The maps and needs assessment are intended to provide guidance to planners on the use and interpretation of the NOAA SLR and Coastal Impacts Viewer (http://csc.noaa.gov/digitalcoast/tools/slrviewer, referred to herein as the NOAA SLR Viewer) and data layers using examples from select coastal areas around Kauaʻi. This is not intended to be a comprehensive assessment of SLR-related flooding hazards for all coastal areas of Kauaʻi. The maps are produced using flooding hazard GIS layers from the NOAA SLR Viewer.

The maps show flooding scenarios for 1 foot, 3 feet, and 6 feet of SLR. The 1 foot and 3 feet scenarios were selected as roughly consistent with the National Research Council[85] mid-range projection of about 1 foot by 2050 and about 3 feet by 2100. The 6 foot scenario is shown as a high end scenario. Though the confidence of 6 feet of SLR by 2100 is relatively low, it is within the upper range of predicted scenarios in recent publications (e.g., NOAA 2012). The 6 foot SLR scenario also demonstrates the potential impact of a lesser SLR scenario (e.g., 3 feet) combined with additional flooding from an event such as a hurricane (storm surge) or tsunami, which are probabilistically much more likely.

The maps depict the extent of a static increase in sea level that are hydraulically connected to the ocean without the effects of ocean waves or tides. The SLR model does not account for natural processes such as coastal erosion, shoreline migration, groundwater table emergence, wave inundation, and marsh migration that will be exacerbated by future SLR. As such these maps are limited in that they may not reflect the full impact of future water level conditions compounded by waves, erosion, and groundwater. For more information, please see "Limitations" under the NOAA SLR and Coastal Impacts Viewer in the Inventory of Planning Information and Data Products (Appendix B).

The overall findings of the needs assessment are outlined below:

- First, it is important to note that NOAA SLR Viewer and these maps show the results of a numerical model of a static (level) increase in sea-level. In reality, the effects of this increase in average sea level height will be event-based or episodic, with impacts punctuated and compounded by events such as seasonal high waves, and storms and rainfall, which are not accounted for in the maps.

[85] NRC 2012

- The NOAA SLR Viewer data generally shows limited flooding/inundation hazards in shorefront areas. This is an important gap to note in this data set, as described above. Some numerical models and observations of shoreline response to SLR indicate that 1 foot of SLR can lead to as much as 100 feet of shoreline recession, which will threaten coastal properties with increased flooding and land loss.[86, 87, 88] This is not depicted in the NOAA SLR Viewer layers and following maps.
- The 1 foot SLR scenario, a plausible planning scenario for the year 2050 based on the National Research Council (NRC) (2012) mid-range projection, shows potential for widespread flooding, particularly in the featured (sample) areas in this assessment of Hanalei, Anahola, Kapaʻa-Wailua, and Hanapēpē.
- The 3 foot SLR scenario, which is a reasonable planning scenario for 2100 based on the NRC (2012) mid-range projection, shows potential for widespread flooding on a regular basis for many coastal properties, particularly in areas already within the FEMA 100-year flood zones.
- The 6 foot SLR scenario, which is shown as a high-end scenario from recent studies (e.g., NOAA 2012), indicates a potential for permanent flooding and geomorphic change (e.g., wetland creation) in low-lying coastal areas.
- The results indicate flooding in many areas that may not have a direct hydraulic connection to the sea. This type of flooding can result from elevation of the underlying water table and/or impaired drainage with rising water level. The severity of this type of flooding may be underestimated in these maps in areas where the water table is above high tide elevation.

The needs assessment also identified the following research and planning needs:

- Historical shoreline studies by the U.S. Geological Survey and University of Hawaiʻi indicate that 71% of beaches are eroding on Kauaʻi.[89] This percentage is sure to increase with increasing SLR. The NOAA SLR Viewer does not account for coastal processes such as shoreline erosion and wave-induced inundation. Detailed modeling at the parcel-level scale is needed to predict future shoreline locations and identify erosion hazard areas with increasing SLR to facilitate vulnerability assessments and adaptation measures.
- The purpose of the NOAA SLR Viewer is to provide a preliminary look at SLR and coastal flooding impacts. It is intended to be used as a screening tool to inform management decisions and long-range planning. The data depicted in the Viewer and following maps should be used as a screening tool to gauge the need for more detailed community-scale hazard, risk, and vulnerability assessments and long-range adaptation planning. The elements of such a hazard assessment are described below.
- In many locations, the SLR flooding areas are similar in extent to the FEMA FIRM flood zones. This indicates that these flood zones will flood more frequently and with increased severity - over a larger area and higher base flood elevation. The County could consider adopting requirements for flood hazard mitigation/adaptation that account for SLR hazards and are above and beyond the FIRM flood zones and base flood elevations (BFEs). There are many examples of counties around the nation requiring higher building elevations above the FIRM minimums, sometimes referred to as "freeboard."
- Special provisions for coastal land use and development are needed to protect public safety and limit economic risk from increased flooding and coastal land loss (erosion) with SLR. Where possible, county and state agencies should use existing rules and policy to promote adaptation for climate change and SLR. Important policies for SLR and climate adaptation include shoreline building

[86] Bruun, P., 1954. Coastal Erosion and Development of Beach Profiles. Vicksburg, Mississippi: U.S. Army Corps of Engineers, Waterways Experimental Station, Technical Memorandum No. 44.
[87] Zhang, K., Douglas, B.C., Leatherman, S.P., 2004. Global warming and coastal erosion. Climatic Change 64, 41–58.
[88] Romine, B.M., Fletcher, C.H., Barbee, M.M., Anderson, T.R., and Frazer, L.N., 2013. Are beach erosion rates and SLR related in Hawaiʻi? Global and Planetary Change, 108: 149-157
[89] Fletcher et al 2012

setbacks, flood zone building regulations, limitations on property subdivision, and prohibition of coastal armoring (seawalls) in select areas to conserve beach ecosystems.

- Impacts from climate change and SLR will not happen at a steady pace along Kaua'i's coast. Rather, these changes will be compounded by events such as high waves, storms, and tsunamis with increasing frequency and severity with climate change and SLR. Post-disaster plans are needed to chart a course for suitable re-development of coastal areas after a large event. Properly designed post-disaster plans will ensure that communities and infrastructure are rebuilt with increased capacity to withstand future events. Alternatives to coastal hardening, such as landward relocation, should be considered in post-disaster plans to move buildings and infrastructure out of chronic flooding and erosion areas. This option is discussed further below.

## Policy and Planning Tools

The process and steps for adapting to hazards and SLR are similar to the standard methodical steps of a long-range planning process. Several reports have recently been produced and released from both the California Coastal Commission (CCC) and other California researchers, providing guidance for municipalities and counties along California's coast to address SLR and its associated impacts (i.e., erosion, wave inundation, flooding) in local coastal programs. While the report was targeted toward SLR, the same principles can be applied to any hazard planning effort:

1. Determine range of scenarios, forecasts, and projections relevant to the planning area, i.e., planning horizons of concern and use of best available science
2. Identify potential impacts in the planning area. This involves **conducting a Hazard Assessment** that identifies the type, magnitude, and frequency of the hazard or hazards.
3. Conduct a **Risk and Vulnerability Assessment that** assesses the risk to coastal resources and development in the planning area and assesses vulnerability to the risk, including whether current and planned land uses are feasible given those impacts, and if those land uses should be revised in response.
4. Identify adaptation measures and policy options to minimize risks
5. Develop, update, and adopt plans and procedures
6. Monitor and revise as needed, i.e., identify key resources to monitor and periodically update plans and procedures.[90]

### Hazard, Risk, and Vulnerability Assessment

**$KC_3HA$ Recommendation #1b:** Conduct Hazard Risk and Vulnerability Assessments (Figure 23). See Section IV, page 40 for the detailed language of this recommendation.

In the face of uncertainty, data gaps, and/or indecision, "adaptation through vulnerability reduction" is recommended.[91] This is premised, however, on conducting hazard, risk, and vulnerability assessments. The Kaua'i County Comprehensive Zoning Ordinance defines "hazard assessment" as: "assessment for erosion, wave, flood, and inland zones following Section 4.3 of the *Hawai'i Coastal Mitigation Guidebook* (Hwang, 2005)." From the guidebook:

- <u>Hazard Assessment</u> - determines the threat of various hazards to a coastal area, tailored to provide information before development proceeds so that unnecessary risk can be avoided by proper siting and design

[90] California Coastal Commission. 2013.
[91] Brooks, N., Adger. W.N., and Kelly, P.M. 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation, *Global Environmental Change*, 15:151-63.


Figure 23. Hazard, Risk, and Vulnerability Diagram. Buttress Risk Management Services.

- Risk and Vulnerability Study - determines the existing structures in a hazard area, the threat of natural hazards to those structures and the measures that can be taken to reduce risk to life and property ranging from structure design changes to evacuation measures.

**Risk:** The possibility of interaction of physically defined hazards with the exposed systems; the likelihood of an event and its consequences; probability consequence, a function of hazard and vulnerability[92],[93] a combination of the magnitude of the potential consequence(s) of climate change impact(s) and the probability or likelihood that the consequences will occur (Figure 24).[94]

**Risk Assessment:** Process of identifying, evaluating, selecting, and implementing actions to reduce risk to human health and to ecosystems[95]

**Vulnerability Assessment:** exposure, sensitivity, and ability to cope
-a practice that identifies who and what is exposed and sensitive to a hazard or change in climate and how able a given system is to cope with extremes and change.[96]
-risk-based evaluation of the likely sensitivity and response capacity of natural and human systems to the effects of expected phenomena.[97]

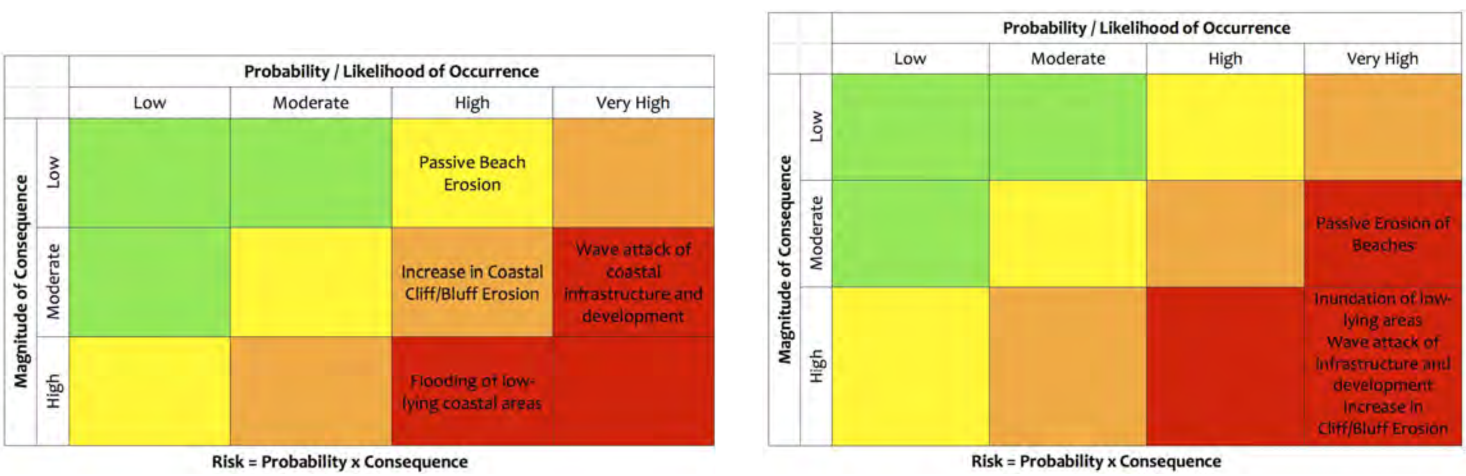


Figure 24. Example risk analyses for the short to intermediate term (2010-2050, left) and the intermediate to long-term (2050-2100, right where Risk = Probability x Consequence. Russell and Griggs, 2012

[92] California Coastal Commission. 2013
[93] Dessai, S., Lu, X., and Risbey, J. 2005. On the role of climate scenarios for adaptation planning, Global Environmental Change, 15: 87-97.
[94] Russell, N. and Griggs, G. 2012. Adapting to SLR: A Guide for California's Coastal Communities
[95] Dessai et al. 2005.
[96] California Coastal Commission. 2013
[97] Russell and Griggs. 2012

In essence, the objectives of conducting a Hazard, Risk, and Vulnerability Assessment are to determine existing development that is and/or will be in harm's way, and to determine strategies for adaptation. These planning processes can lead to directed policy decisions to protect the health and safety of individuals, property, infrastructure, and coastal resources through the various adaptation strategies. For example, The County of Kaua'i Multi-Hazard Mitigation Plan includes risk and vulnerability assessments for flood, tsunami, and wind.[98] Risk and vulnerabilities are generally based on present and past conditions and do not account for changing (increasing) hazard baselines with changing climate and SLR. For other examples of SLR and climate change vulnerability assessments, see the Cities of Santa Barbara[99] and Santa Cruz.[100] These examples provide varying degrees of hazard assessment, and may lack 'perfect' planning information on SLR. However, they do provide good case studies on other jurisdictions as well as nice descriptions of the risk assessment process.

> In determining adaptation strategies for coastal hazards, it is helpful to think about three broad categories of action: accommodation, protection, and retreat.
>
> "***Accommodation***. Adjustment of an existing system to changing natural conditions (e.g., strengthening flood-proofing regulations or expanding hazard zones). ***Protection***. Hardening of a system in its existing location to withstand impacts from changing conditions (e.g., shoreline hardening such as seawalls and revetments). ***Retreat***. Relocating existing structures to avoid impacts."[101]

### Use of Existing Regulatory and Planning Framework

The fact that there are some gaps in knowledge and planning information does not mean that certain policy and planning actions cannot be taken now. Indeed, policy and planning can help to support efforts to address gaps as well as to take proactive approaches to protect the community in the absence of complete information. This 'no regrets' approach will go a long way to ensuring a healthy community and environment that is resilient to coastal hazards.

Addressing coastal hazards associated with climate change does not require the adoption of brand new programs, ordinances, or statutes. Kaua'i County already has a broad regulatory framework that covers the four major hazard categories: (1) erosion; (2) wave inundation; (3) flooding; and (4) wind. The degree to which those hazards are addressed or factored in new scientific information such as SLR should be analyzed when assessing whether amendments or updates are necessary to program components. The following sections describe the general framework and suggest key areas to be utilized in climate change coastal hazard adaptation (Figure 25).

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98 http://edev3.socialsciences.Hawaii.edu/temp/hazards/Kauaiplan.html
99 http://www.energy.ca.gov/2012publications/CEC-500-2012-039/CEC-500-2012-039.pdf
100 http://www.cityofsantacruz.com/Modules/ShowDocument.aspx?documentid=21198
101 Codiga, D. and Wager, K. 2011. Sea-Level Rise and Coastal Land Use in Hawai'i: A Policy Tool Kit for State and Local Governments, Center for Island Climate Adaptation and Policy. Honolulu, HI. Available at http://icap.seagrant.soest.hawaii.edu/icap-publications.

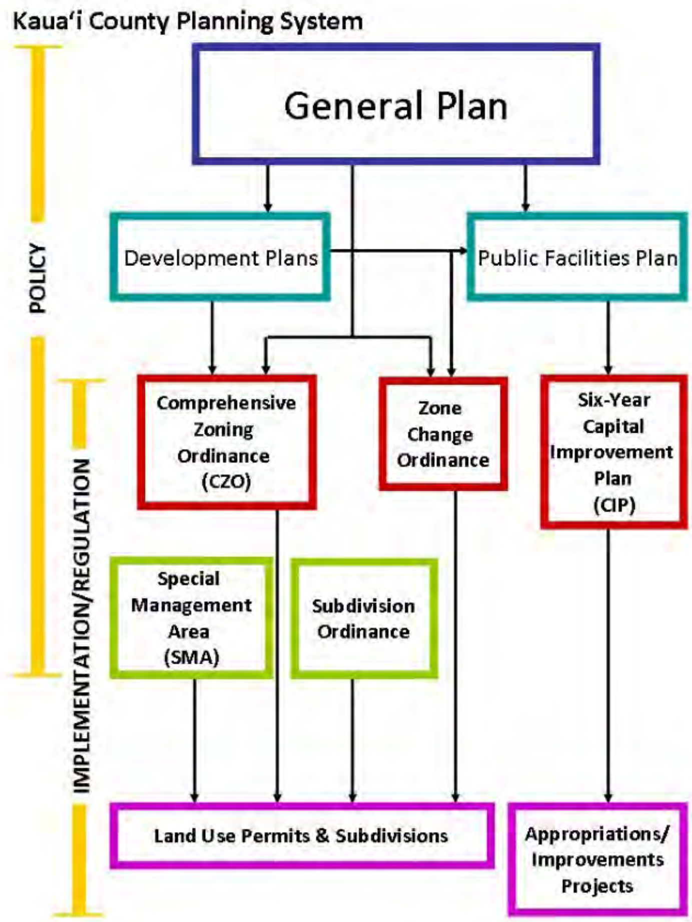



Figure 25. County of Kaua'i Planning System. County of Kaua'i Planning Department.

**General Plan**

The GP serves as a guide for Council action concerning land use and development regulations, urban renewal programs and expenditures for capital improvements. The GP provides the policy setting and legal basis guide for subsequent community development plans and public facilities plans. From there, the comprehensive zoning ordinance, zoning maps, and capital improvement plans (CIP) implement in details these plans. The policies in the GP set the stage by mapping the direction for future development, describing the kind of future development desired, and setting priorities for public improvements.

Incorporating climate change and coastal hazards information and policy into the GP and subsequent community plans is essential to plan for a future Kaua'i that is resilient to hazards. In addition, the community development plans that extend the GP vision to specific community areas are an opportune venue in which to conduct hazard, risk, and vulnerability assessments, as described above.[102] The current GP 2020 is not organized according to topics such as 'hazards' or 'land use,' but instead is arranged according to themes which came out of the community visioning process. Coastal hazards and coastal development issues are discussed in Chapter 1 'Vision for Kaua'i,' Chapter 3 'Caring for Land, Water, and Culture,' Chapter 5 'Preserving Kaua'i's Rural Character,' Chapter 6 'Enhancing Towns and Communities and Providing for Growth,' and Chapter 7 'Building Public Facilities and Services.'

Erosion, flooding, tsunami, and hurricanes are discussed in the GP 2020, and there are policies to acquire shoreline lands and accessways. Special mention is given to the use of the 'open' zoning district and the state's 'conservation district' as buffers from coastal development to preserve coastal resources. Also, discussed at length are the 'constraints districts' in the comprehensive zoning ordinance and the need to update these districts to eliminate regulations that are no longer relevant, improve effectiveness of relevant regulations, simplify zoning administration, and align with GP policy.

Climate change and SLR is not discussed in the current GP. Since climate change and SLR exacerbate all the hazards already recognized, serious consideration should be given to updating the GP and the Community Development Plans to incorporate these topics. In this way, the constraints posed by climate change and coastal hazards will be a major driver for land use decisions, and major steps will be taken towards coastal community resilience.

In 2012, Hawai'i State Governor Neil Abercrombie signed into law Act 286, which amended the Hawai'i State Planning Act (HSPA, Hawai'i Revised Statutes (HRS) §226-109) to include ten climate change

[102] However, hazard, risk, and vulnerability assessments may be conducted separately from these plans

adaptation priority guidelines (CCA Priority Guidelines; Appendix A). The stated purpose of the CCA Priority Guidelines is to:

> "…encourage collaboration and cooperation among county, state, and federal agencies, policy makers, businesses, and other community partners to plan for the impacts of climate change and avoid, minimize, or mitigate loss of life, land, and property of future generations."

The guidelines are intended to prepare the state for climate change impacts to agriculture, conservation lands, coastal and nearshore marine areas, natural and cultural resources, education, energy, higher education, health, historic preservation, water resources, the built environment, and the economy, as both near-term implementation options and a strategy for the State over the long-term.[103] Additionally, under the HSPA, priority guidelines "shall take precedence when addressing areas of statewide concerns" – these include "State and County decision-making and allocation of resources, state functional plans, county general plans and development plans, state programs, fund appropriation, [as well as] capital improvement project appropriations, state budgetary review and state land use decision making."[104]

Figure 26. Stages of Development Versus Impact on Property, Landowner, Community and Agencies. Hwang 2014

It is prudent of the county to incorporate climate change adaptation and hazard mitigation considerations in the GP update, because with each progressive stage of the development process the government's ability to mitigate associated damage diminishes significantly (Figure 26).

Furthermore, within the state planning system, county general plans hold an important position for coordination and conformance of higher state level planning as well as implementation tools through zoning ordinances and functional plans.[105] That is, state land use districts, and any subsequent reclassifications, must be in conformance with existing general plans; and, community plans, zoning ordinances, subdivision ordinances and administrative actions by county agencies must be in conformance with the County GP.[106]

There are a few approaches for including climate change and hazards considerations in the GP each of which have pros and cons. The approach the County chooses may be dependent on a number of factors,

[103] Wager, K. 2012. Center for Island Climate Adaptation and Policy, Climate Change Law and Policy in Hawai‘i, Briefing Sheet. University of Hawai‘i Sea Grant College Program.
[104] Coastal Resilience Networks (CRest) Team. In print. Opportunities and Guidance for the Development and Implementation of the Hawai‘i State Planning Act Climate Change Adaptation Priority Guidelines, NOAA Coastal Resilience Networks (CRest) Project, University of Hawai‘i William S. Richardson School of Law, Loli Aniau Maka‘ala Aniau (LAMA), State of Hawai‘i Office of Planning.
[105] Hawai‘i Revised Statute §226-52(a)(4).
[106] Hwang 2005

such as the availability of resources (i.e., staff time and expertise, data and information, funding, etc.), as well as the explicit intent for including climate change and coastal hazards considerations in the GP and the County's desire to address the tough questions their impacts pose. Citing the California Sustainability Alliance, Helber, Hastert, & Fee, Planners[107] note three approaches local governments in California are using to incorporate principles into their General Plans (Table 2):[108]

Table 2. Approaches for incorporating new material into a General Plan.

| Approach | Pro | Con |
|---|---|---|
| 1. ***Include a separate chapter*** that establishes guiding principles to define the community's vision, and identifies policies and implementation actions | Simplest and easiest approach to satisfy the objective of incorporation into the General Plan; leaves the existing document intact while providing guidance | Lacks the detail of clarifying which measures overlap multiple subject areas |
| 2. Identify policies and implementation actions ***as part of other subject area*** | Weaves topic into the subject areas/chapters of the General Plan | Buries the topic within the substance of the General Plan and minimizes its significance; does not provide a framework to correlate overlapping measures |
| 3. ***Integrate throughout the General Plan using a combined approach***, with a discussion grouped into a separate chapter that outlines the community's priorities, and identification of policies and implementation actions as part of other subject areas | Most detailed and thorough approach for internal consistency (i.e., ensuring no policy conflicts between subject areas) | Most resource intensive approach |

**$KC_3HA$ Recommendations #3:** Include climate change and coastal hazards background information in the General Plan.

**KC3HA Recommendation #4:** Incorporate into the General Plan overarching goals pertaining to planning for climate change and coastal hazards. See Section IV, pages 41-42 for details.

**Kaua'i Capital Improvement Program (CIP)**

The County plans capital improvements on a six-year cycle pursuant to Sections 14.05 and 19.09 of the Kaua'i County Charter. Capital improvements occur in the areas of 'buildings and facilities,' 'multi-modal capacity,' 'parks and recreation,' 'roads and roadways,' 'solid waste,' and 'wastewater.' An important purpose of the CIP is to ensure that County expenditures are guided by the General Plan, and it therefore plays an important role in the implementation of the vision, goals, and policies of the General Plan.[109]

The CIP is an important vehicle for furthering climate change and coastal hazard adaptation and community residence, and one that is anticipated in the Hawai'i State Planning Act Priority Guidelines. When developing and approving the next CIP, the County should consider adopting a policy to analyze multiple scenarios of SLR and associated flooding, wave inundation, and erosion impacts to the proposed project and its location. This will not only save the County costs associated with hazard mitigation, it will help ensure the health and safety of the community and the longevity of facilities.

[107] Helber, Hastert, & Fee, Planners. 2011. *O'ahu GP Update: Sustainability Trend Report*. Accessed July 18, 2013. http://dev.honoluludpp.org/Portals/0/pdfs/planning/generalplan/GPUpdate/TrendReports/Sustainability.pdf

[108] Largely due to State statutory requirements under the California Environmental Quality Act to address climate change impacts and greenhouse gas emissions reductions.

[109] County of Kaua'i Six – Year Capital Improvements Program (CIP) FY 2014/2015 – 2019/2020 Final Report. Prepared by the Kaua'i County Planning Department and the Kaua'i County CIP Manager

**Comprehensive Zoning Ordinance**

The Comprehensive Zoning Ordinance (CZO) (Chapter 8 of the County Code) implements the intent and purpose of the GP and community development plans by regulating the use, location, and size of land, buildings and structures. Among other purposes, the CZO promotes the health, safety and welfare of Kauaʻi's residents and to assure that any growth is consistent with the unique landscape and environmental character of the island. Coastal hazards are addressed to different extents in Article 9, the Open (O) District, Article 12 Constraint Districts (Drainage, Shore, Slope, Soils and Tsunami Districts), and Article 7 Shoreline Setback and Coastal Protection.

Zoning and Overlay Zones

Using existing authority, a zoning regime could feature overlay zones in areas identified as currently and predicted to be impacted by SLR and its effects on erosion, inundation, and flooding. This technique could be utilized after completion of hazard, risk, and vulnerability assessments, described above. These zones "could regulate armoring, density, retrofitting, relocation, and preservation" to implement a suite of adaptation goals. Other zones could address wind impacts. Various overlay zones could be adopted based on the adaptation strategies of accommodation, protection, and retreat with elements and policies to meet those respective strategies.[110]

**KC$_3$HA Recommendation #5:** Use existing County regulatory and non-regulatory programs to address climate change related coastal hazards (See Section IV):

- Capital Improvement Program
- Shoreline Setback Article of CZO
- Special Management Area (SMA)/Zoning Permits
- Subdivision Ordinance
- Floodplain Management Program
- Public Access, Open Space, and Natural Resources Preservation Fund

The Shoreline Setback and Coastal Protection Ordinance

The Shoreline Setback and Coastal Protection Article of the CZO utilizes scientific shoreline setback calculations based on documented erosion rates island wide. Climate change and SLR are not specifically addressed in the CZO. As described in Hwang 2014, significant gaps planning information include how to factor in SLR in erosion rate calculations for shoreline setback decisions. As discussed in Section I, predictions of future erosion are complicated by uncertainty associated with future water levels, waves, storms, geology, sediment supply, etc. As a result, there is no standardized method for predicting future shoreline erosion. Dr. Chip Fletcher and colleagues at the University of Hawaiʻi are working on a project to model the effects of SLR on the beaches of Kauaʻi using a standard geometric model of beach profile response that is improved with assimilation of historical shoreline change data. Funding is needed to move this research project forward into actionable science. While research results are forthcoming, proactive techniques for incorporating SLR into erosion predictions include (Figure 27):

a. For coastlines with a sea-level ranking risk of 4 or 3 in the Atlas of Natural Hazards in the Hawaiʻi Coastal Zone, increase the erosion rate by a default value of 10% (multiplied by a factor of 1.1).[111]
b. Have a qualified professional consultant calculate the expected increase in the rate of erosion at the specific site using the Bruun Rule,[112] a geometric model, or other generally accepted methodologies utilized in the coastal engineering industry.
c. Add a defined additional safety buffer (e.g., 20 feet) to the shoreline setback to account for SLR and other uncertainties until such time that addition SLR planning information and guidance is generated.

[110] Codiga and Wager, 2011

[111] See the following for guidance: Hwang, Dennis J. Hawaiʻi Coastal Hazard Mitigation Guidebook. January 2005.

[112] Komar, P.D., McDougal, W.G., Marra, J.J. and Ruggiero, P. 1999. The Rational Analysis of Setback Distances: Applications to the Oregon Coast, Shore and Beach Vol. 67, No. 1, p. 41-49

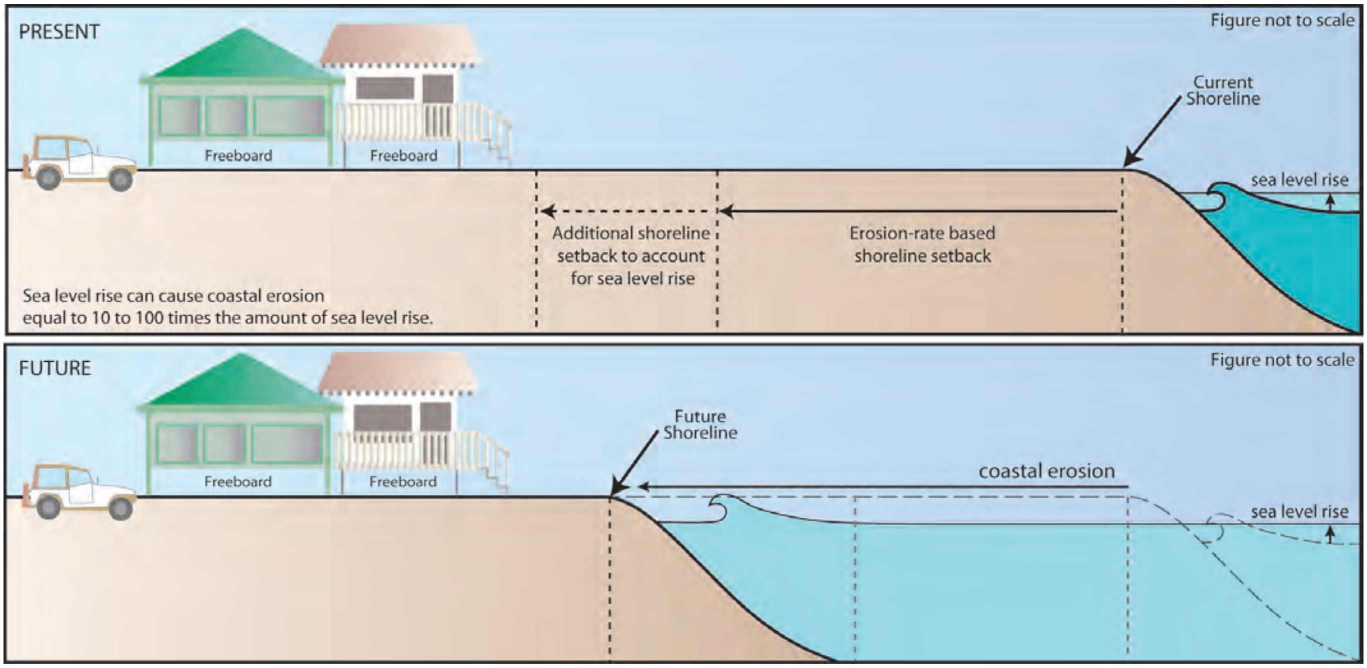



Figure 27.Conceptual illustration of an erosion-based shoreline setback with an additional setback for future accelerated sea-level rise. This figure also shows elevated homes, illustrating an additional vertical setback, or 'freeboard,' via the flood program.

**Subdivision Ordinance**

Kaua'i's subdivision ordinance is contained in Chapter 9 of the County Code, and regulates all subdivisions made of land on Kaua'i. The ordinance contains environmental standards, land alteration standards, and preliminary and final subdivision map requirements that contain provisions for erosion, flood, drainage, and tsunamis. Subdivisions must be consistent with the constraint district requirements of the CZO. In addition, the shoreline setback ordinance (Article 7 of Chapter 8 of the Code) applies to subdivisions, although specific setback requirements have not been written into the subdivision ordinance itself.

Like the GP and CZO, climate change and SLR is not specifically addressed in the subdivision rules. A similar approach to that described above for the shoreline setback ordinance could be utilized to address this in the subdivision rules. Other options include prohibiting subdivision in known hazard areas.

**Special Management Area (SMA) Rules and Regulations**

Pursuant to Hawai'i Revised Statutes (HRS) Chapter 205A, Kaua'i County's Special Management Area (SMA) rules have the stated purpose to preserve, protect, and where possible, to restore natural resources of the coastal zone. As such, the rules set special controls on development along the shoreline. While the SMA rules do not reference climate change or SLR specifically, the development review guidelines require reasonable terms and conditions that construction minimizes danger from floods, wind damage, storm surge, landslides, erosion, siltation, or failure in the event of an earthquake. Development may not be approved unless it will not have any substantial adverse environmental effect (individually or cumulatively), unless such concerns are outweighed by public health, safety, welfare, or other compelling public interest.

Rules in the SMA could require applicants to analyze coastal hazard impacts and include mitigation in permit applications.[113] Development conditions could be imposed upon permits that minimize the impacts of exacerbated flooding, storm surge, and erosion due to SLR. Also, the SMA permit program could strengthen rebuilding restrictions for nonconforming structures such that these structures are relocated a safe distance from the shoreline in hazardous areas.

[113] These same requirements could be used for zoning permits in areas where the SMA permits are not required, for example for the 1st residence on a lot.


Figure 28. Floodwaters overtop the Hanalei River bank and flood Kūhio Highway in Hanalei, September 20, 2013. Mark Marshall, Emergency Management Officer, Kaua'i Civil Defense Agency

**Floodplain Management Ordinance**

The County Flood Program is administered by the County Public Works Department Engineering Division. Ordinance 831, 'Floodplain Management Ordinance,' was enacted in accordance with the National Flood Insurance Program pursuant to the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973. County participation in this program enables property owners to obtain flood insurance and to assure future federal financial assistance.

The Floodplain Management Ordinance (Ordinance 831) regulates development and impacts from floods from heavy rains, high wave action, and tsunamis. The ordinance requires facilities in flood areas to be protected to minimize flood damage, control activities that may increase flood hazards (grading, filling, and dredging), control alteration of natural floodplains, and regulate the construction of flood barriers that would unnaturally divert floodwaters into other areas (Figure 28).

The flood maps currently do not account for increased flooding from climate change and inundation from SLR. This is a major gap in the flood program nationally however there are ways that this can be addressed. For example, SLR inundation maps have been produced for Kaua'i, and will continually be refined and updated. The County floodplain manager could utilize this mapping and other best available science in addition to the FIRMs in reviewing projects for potential future flood hazards. The Ordinance currently states that the County Engineer may designate additional areas for regulation under the ordinance. Another option could be to overlay these maps onto the existing flood maps in making its decisions under the flood program, or add additional freeboard (elevation) requirements in the floodplain management ordinance for areas subject to SLR inundation. In addition, County participation in the National Flood Insurance Program's (NFIP) Community Rating System (CRS) could further equip the County for adaptation to SLR and secure discounted flood insurance rates for its citizens. Actions like those described above could boost the County's rating.

Joining the NFIP CRS is a good incentive approach that will help the County to fill all of the gaps. The CRS is a voluntary program where homeowners in a *county that adopts floodplain management regulations that exceed the NFIP minimums* qualify for discounts on flood insurance premiums. This is a tool that uses the strategies of accommodation and retreat. As a result of their 8 classification[114] residents of both Maui and Hawai'i Counties receive 10% discounts on insurance premiums for structures located in a Special Flood Hazard Area (SFHA)[115] and 5% discounts on insurance premiums for structures located outside of a SFHA.

[114] The CRS ranks classifications from 1-10, with 10 receiving the lowest discount on NFIP insurance premiums and 1 receiving the greatest discount (up to a 45% discount on policies located within a Special Flood Hazard Area).

[115] From FEMA: Special Flood Hazard Areas (SFHA) are those areas covered by the floodwaters of the base flood on NFIP maps, where the NFIP floodplain management regulations must be enforced, and the area where the mandatory purchase of flood insurance applies.

Under the CRS, flood insurance premium rates are discounted to reflect "the reduced flood risk resulting from the community actions meeting the three goals of the CRS:

1. Reduce flood damage to insurable property;
2. Strengthen and support the insurance aspects of the NFIP; and
3. Encourage a comprehensive approach to floodplain management."[116]

Under the system, the County could receive credit for having a shoreline setback that is a greater distance for SLR and having additional freeboard above base flood elevation for wave inundation.[117]

Furthermore, local communities can attain credit points through 18 creditable activities, which determine their classification within the CRS (1-10), and their ultimate insurance premium reduction.

**The creditable activities of the CRS are organized under four categories:**

1. **Public Information**
    a. Elevation Certificates
    b. Map Information Services
    c. Outreach Projects
    d. Hazard Disclosure
    e. Flood Protection Information
    f. Flood Protection Assistance
2. **Mapping and Regulations**
    a. Additional Flood Data
    b. Open Space Preservation
    c. Higher Regulatory Standards
    d. Flood Data Maintenance
    e. Stormwater Management
3. **Flood Damage Reduction**
    a. Floodplain Management Planning
    b. Acquisition and Relocation
    c. Flood Protection
    d. Drainage System Maintenance
4. **Flood Preparedness**
    a. Flood Warning Program
    b. Levee Safety
    c. Dam Safety

The Federal Emergency Management Agency (FEMA) provides guidance on how to apply and attain credits through the CRS (including "extra credit"). It should be noted that FEMA requires a CRS coordinator, appointed by the Mayor, to handle the application and serve as the liaison between the community and FEMA. Ultimately, participation in the CRS makes use of an existing incentive-based program that helps communities and their floodplain management programs adapt to changing conditions, while making use of the best available science.

**Kaua'i Public Access, Open Space, and Natural Resources Preservation Fund (Open Space Fund)**
County Ordinance No. 812 (03) required the establishment of an open space preservation fund to be used to acquire lands or property entitlements, or fund projects relating to outdoor recreation and education; public access to beaches, mountains, public lands, and open space; preserve culturally and historically important

[116] National Flood Insurance Program Community Rating System. Accessed on December 2, 2013; last updated November 21, 2013. http://www.fema.gov/national-flood-insurance-program-community-rating-system
[117] Hwang et al 2014

areas; protect habitats and ecosystems and watershed lands; preserve forests, beaches, coastal areas, and agricultural lands; and conservation of land to reduce erosion, floods, landslides, and runoff.

Land acquisition is an important tool for climate change and coastal hazard adaptation (Figure 29). Financing the acquisition of vulnerable shoreline lands can protect natural resource areas for public use, including areas that could serve as refugia for species impacted by SLR, or areas that could be appropriate sites for coastal habitat creation or restoration. Given the Open Space Fund's broad mandate to conserve land to reduce erosion and flooding, the County could consider using and augmenting this program to address specific areas identified to be vulnerable. In addition, the fund could be used to purchase conservation easements or support a transfer and purchase of development rights program (see 'Relocation Incentives: Transfer of Development Rights').

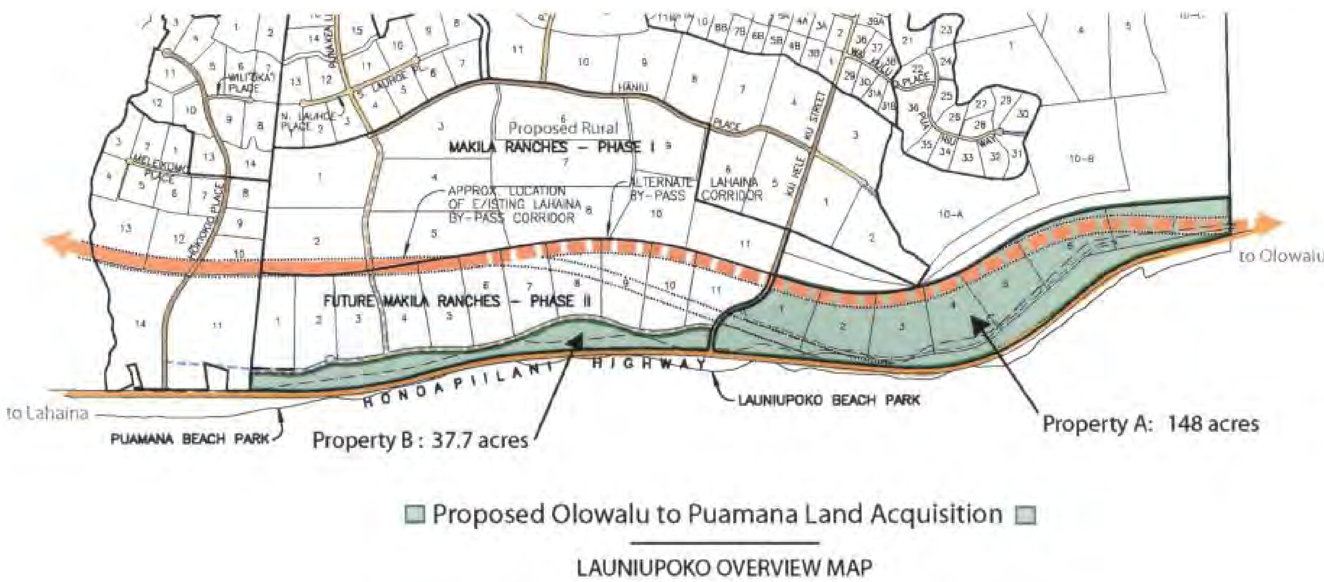



Figure 29. Recent land acquisition by the County of Maui at Launiupoko, Maui, to preserve open space. Maui County Council

Different from direct acquisition, conservation easements are legal agreements between landowners, land trusts (e.g., Hawai'i Island Land Trust [HILT]) or government agencies that restrict development or uses of the land. In Hawai'i, conservation easements can be created by deed restrictions, covenants, or conditions. By keeping the land undeveloped, like direct acquisition, conservation easements can serve an important purpose for coastal hazard/SLR adaptation. It is helpful conduct public education programs so that landowners understand the tax breaks and other benefits of conservation easements.[118]

## Development of New Programs

### Post-Disaster Reconstruction Guidelines

Taking a proactive approach to coastal storm mitigation, developing Post-Disaster Reconstruction Guidelines will help to conserve coastal resources and streamline repair and reconstruction needs. After a damaging coastal storm, reconstruction guidelines and protocols must be implemented within a very short time frame to meet community needs for expedited reconstruction and protection of the coastal environment. Establishing guidelines in advance can engage a variety of stakeholders in the planning

[118] Codiga and Wager 2011

process to develop guidelines and protocols that currently do not exist. The resulting protocols will enhance coastal planning and policy, emergency/disaster management, and community hazard resilience. Maui County is currently developing a pilot project to identify and implement post-disaster reconstruction guidelines with support from the NOAA Coastal Storms Program and UH Sea Grant.

> **“Economists are in broad agreement that the most cost-effective way to avoid future losses is for government to pay for elevating some properties and to buy out others. For every $1 spent this way, the U.S. Treasury would save $3.65 in costs, studies have shown.”**
> **- David Shipley**[119]

**Relocation Incentives: Transfer of Development Rights**

Transfer of Development Rights (TDR) programs involve the selling or dedicating some or all of the rights to develop property or properties (“sending districts”) to other areas/lands (“receiving districts”). The intent of TDR is to direct development toward more desirable areas in order to preserve and conserve other lands and resources a community desires not to be developed. Explained another way, TDR is a policy option and planning tool to limit development in environmentally sensitive and existing and projected hazard prone areas, to the end result of protecting life and property from harm. Another similar land use tool is Purchase of Development Rights (PDR). PDR “allows non-profit land trusts or local government agencies to buy development rights from willing sellers.”[120]

Under Hawai‘i Revised Statutes §46-161, counties have the authority to utilize TDR to, “(1) Protect the natural, scenic, recreational, and agricultural qualities of open lands; (2) Enhance sites and areas of special character or special historical, cultural, aesthetic, or economic interest or value; and (3) Enable and encourage flexibility of design and careful management of land in recognition of land as a basic and valuable natural resource.”[121]

Implementation of a TDR program would require the following steps:

- Designate Sending Districts
- Designate Receiving Districts
- Calibrate Credit Values
- Develop Pool of Development Rights
- Establish a Procedure for Transferring Rights

The City and County of Honolulu currently allows TDR in order to protect historic properties and Maui County is investigating TDR and PDR programs “to fulfill the GP 2030 objectives of developing a directed growth strategy.”[122]

**Beach Management Plans**

Beach management planning is a cross-jurisdictional approach to managing and preserving beach and dune resources in Hawai‘i. Beaches and dunes provide important hazard buffers that protect the land and the communities behind them. They are also significant to Native Hawaiian people, provide important habitat for wildlife, provide public access and recreational opportunities, and are a significant driver in Hawai‘i’s tourism economy. A coordinated approach to their management and protection can go a long way to ensure their survival in the face of shoreline development pressure, rising sea levels, and accelerated erosion rates.

[119] Bloomberg Opinion. Congress Should Stop Shoring Up Beach Homes
Feb 4, 2014 10:08 AM GMT-1000
http://www.bloomberg.com/news/2014-02-04/congress-should-stop-shoring-up-beach-homes.html

[120] Codiga and Wager 2011

[121] HRS §46-163

[122] Chris Hart & Partners, Inc. 2007. *GP 2030 Maui Island Plan: Directed Growth Strategy - Transfer and Purchase of Development Rights Program Implementation Study*, Accessed November 26, 2013. http://www.co.maui.hi.us/documents/17/69/71/332/Preliminary%20Draft%20TDR%20PDR%20Report.pdf

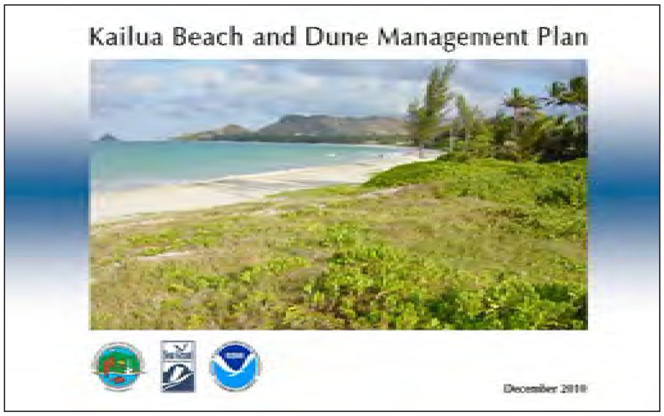



Figure 30. An example of a UH Sea Grant-completed beach management plan for Kailua, O‘ahu.

All three of these things cause the proliferation of shoreline armoring to protect development from erosion, which contributes to further beach narrowing and eventual loss.

Because shoreline conditions are variable and unique beach to beach, and the regulatory regime is complex and multi-jurisdictional, and has had limited success in preventing damage to these environments, beach management plans provide an opportunity to tailor management and planning to specific, unique beach areas. For these reasons and more, the State Department of Land and Natural Resources, in conjunction with the University of Hawai‘i Sea Grant College Program, is interested in developing beach management plans for selected shoreline environments throughout the state (Figure 30).

Kaua‘i has incredible beaches, many of which would be great candidates for a beach management plan. For, The County in partnership with the tourist industry has already partnered on a Poipu Beach Restoration Study, which could provide a foundation for a future plan. DLNR Office of Coastal Lands has already expressed interest in partnering in such an effort.

### Suggested Guidance Documents to Use in Designing Development Projects

The following section provides some suggested guidance documents to use in reviewing or designing current development projects. These documents can be used by developers or planners alike, in the interest in proactively designing and reviewing projects to safeguard for the future.

<u>Hawai‘i Coastal Hazard Mitigation Guidebook</u>

The Hawai‘i Coastal Hazard Mitigation Guidebook (2005) provides guidance in the planning and siting of coastal projects to reduce risk from natural hazards at every stage in the development process: (1) State district classification; (2) county general and community planning, (3) county zoning, (4) subdivision of land, (5) infrastructure improvements, (6) lot purchase, and (7) construction permits.

The guidebook provides techniques for doing hazard assessments for erosion, flooding, wave inundation, and wind. Techniques for factoring future accelerated SLR into shoreline setbacks are also provided. In addition, there are appendices that provide information about regulatory takings and lists of coastal engineering consultants.[123]

<u>California Coastal Commission (CCC) recommended steps for addressing SLR</u>

The California Coastal Commission (CCC) released a draft guidance document on addressing SLR in site design in October 2013. A similar approach could be used and adapted for Hawai‘i, with some adjustments for local conditions. The steps for addressing SLR can be universally applied and added to coastal hazard assessment for new development in Hawai‘i, making them useful for property owners, developers, and planners. This assessment will help ensure that development risk is minimized, and impacts to coastal resources are avoided in light of current and future conditions. The steps are as follows:

1. Establish the projected SLR range for the proposed project.
2. Determine how impacts from SLR may constrain the project site.
3. Determine how the project may impact coastal resources, considering influence of future SLR upon the landscape.

[123] Hwang, Dennis J. 2005. Hawai‘i Coastal Hazard Mitigation Guidebook. Prepared for the Hawai‘i Office of Conservation and Coastal Lands, the Coastal Zone Management Program, the University of Hawai‘i Sea Grant College Program, and the NOAA Pacific Services Center.

4. Identify project design alternatives to both avoid impacts to coastal resources and minimize risks to the project.
5. Finalize project design.

Establishing the appropriate SLR range for a project involves seeking out the best available science, since the data and information is continually evolving. One can also use a 'scenario based approach,' taking the high end and low end of the range, and plan out different scenarios for your site, so in the end the decision is influenced by the best and worst case scenarios. This task also involves adjusting the rate for local conditions.

<u>Army Corps of Engineers SLR Calculator</u>

In order to provide locally relevant planning information, the U.S. Army Corps of Engineers (USACE) has developed a Sea Level Change Calculator (see Figure 11, page 12) that incorporates land movement detected at tide gages with SLR projections from the National Research Council (NRC) using a "Low, Medium and High" approach similar to the National Oceanic and Atmospheric Administration's (NOAA) SLR curves introduced in Section I.

# IV. Recommendations

Section I and II described the key hazard categories (erosion, wave inundation, flooding, and wind) and the impacts and consequences of climate change, SLR in particular, will have on Kaua'i. Section III identified the gaps in planning information and guidance to adequately address those hazards, protect health and safety of Hawai'i's communities, and protect coastal resources. Hence, our first recommendation to the County is to prioritize and support efforts to fill those gaps. Filling those gaps will provide a solid foundation for future actions to adapt to climate change related coastal hazards.

## 1. Support the Generation of Hazard Planning Information, Guidance, and Policy

a. Acknowledge, support, and take part in university, government, and private efforts to:
   i. Develop planning information (e.g., maps), guidance, and policy to address an Aleutian Island earthquake event and tsunami impacts;
   ii. Develop planning information (e.g., maps) and guidance to address how accelerated SLR will effect erosion rates;
   iii. Develop planning information (e.g., maps) and guidance to address how accelerated SLR and associated erosion will effect wave inundation;
   iv. Develop guidance and policy for how to address the flooding associated with future accelerated SLR.

b. When Planning Information is available, a detailed Hazard, Risk, and Vulnerability Assessment is recommended as an adaptation planning step, building on the work that was conducted for the Kaua'i Multi-Hazard Mitigation Plan (2010 Update[124]), for planning areas in coastal areas. This could include areas designated in the GP and Community Development Plans. Such assessment(s) should:
   i. Include a hazard assessment that identifies the extent, magnitude, and frequency of the hazard. Hazards to consider include: erosion (and accelerated erosion due to SLR as the models become available), wave inundation, flooding (including SLR inundation and groundwater penetration), tsunami inundation and wind;
   ii. Include a risk and vulnerability assessment that identifies priority community assets' exposure to the hazard, sensitivity to exposure, and ability to cope/adaptive capacity. Such assets should include at a minimum: critical infrastructure, transportation systems, utilities, existing population centers, water supplies and future growth areas. Other community assets to consider include important agricultural lands, sensitive ecosystems, public access/ recreation areas, and cultural resources. This assessment could also identify potential pollutant sources at risk of inundation due to SLR, including waste disposal sites, ocean outfalls and wastewater treatment facilities, as well as aquifers and wells at risk of saltwater intrusion;
   iii. Identify priority planning areas where resources and planning efforts need to be focused and identify how and where to use adaptation strategies such as accommodation, retreat, and protection;
   iv. Encourage strategic retreat and relocation to safer areas based on the results of the assessments above;
   v. Identify lands/areas that may serve as buffer from coastal hazards; "growth boundaries" may be used to restrict development from hazard-prone areas;

[124] *County of Kaua'i Multi-Hazard Mitigation Plan, 2010 Update*. http://edev3.socialsciences.Hawaii.edu/temp/hazards/Kauaiplan.html

## 2. Take Action Now to Ensure Community Resiliency to Coastal Hazards

The fact that there are some gaps in knowledge and planning information does not mean that certain policy and planning actions cannot be taken now. Indeed, policy and planning can help to support efforts to address gaps as well as to take proactive approaches to protect the community in the absence of complete information. These approaches are described in the science and planning tools Section III of this report. This 'no regrets' approach will go a long way to ensuring a healthy community and environment that is resilient to coastal hazards. In this regard, recommendations three through six suggest policy and planning actions that can be taken now, concurrent with filling the gaps described in Recommendation #1.

## 3. Include Relevant Background Information and Maps for Climate Change Related Coastal Hazards in the General Plan

a. Consider including in the GP a thorough description of coastal hazards on Kauaʻi, including erosion, wave inundation, flooding, and wind, and include background and description of climate change and SLR impacts. In particular, the GP background sections could:

   i. Describe existing best-available science, the recommended planning benchmarks for Kauaʻi (at least 1 foot of SLR by 2050 and 3 feet by 2100), and discuss the potential for adjustments in the rate based on best available science;
   ii. Describe the long-term effects that rising sea levels will have on Kauaʻi's physical development and the need to safeguard existing developed areas and ensure adequate protection for future developments;
   iii. Acknowledge that climate change is an important public health and safety factor that needs to be considered when developing policies for the location and pattern of future development in accordance with Hawaiʻi State Planning Act Priority Guidelines;
   iv. Identify and include on County GP land-use maps natural hazard areas or include separate hazard overlay zones for planning purposes;
   v. Identify and map environmental systems that protect development from natural hazards (e.g., beaches, dunes, floodplains, wetlands, etc.);
   vi. Refer to the Hawaiʻi State Planning Act Priority Guidelines (HRS 226, Part III particularly Sections 108 and 109, "Sustainability" and "Climate Change Adaptation," respectively) (Appendix A).

## 4. Incorporate Additional GP Overarching Goals/Principles Pertaining to Planning for Climate Change Related Coastal Hazards

a. The GP should consider adopting overarching goals pertaining to planning for climate change related coastal hazards. Suggested goals include:
   i. Use Credible Climate and Hazard Science to Inform and Guide Decisions
      1. Use the best available science to determine a range of locally relevant (context-specific) SLR projections for all stages of planning, project design, and permitting reviews.
      2. Recognize scientific uncertainty by using scenario planning and adaptive management techniques.
   ii. Minimize Coastal Hazard Risks through Planning and Development Standards
      1. Ensure the safety of individuals, families, and communities
      2. Discourage development or redevelopment within hazardous areas, while preserving adequate space for expected future growth in areas located outside these areas.
      3. If unavoidable, minimize hazard risks to new development in hazardous areas over the life of authorized structures.
      4. Ensure property owners assume the risks associated with new development in hazardous areas.

5. Limit development near vulnerable water supplies: Limit new development in areas dependent on water supplies susceptible to saltwater intrusion.
6. Manage water supply issues resulting from saltwater intrusion, such as limits on groundwater withdrawal or diversification of water supplies.

iii. Avoid or minimize coastal resource impacts when addressing risks to new or existing development

1. Maximize protection of coastal natural resources and ecosystems.
2. Protect public beach, dune, wetland, river, stream and recreational resources in all coastal planning and regulatory decisions.
3. Avoid the perpetuation of shoreline armoring.
4. Require mitigation of unavoidable coastal resource impacts related to permitting and shoreline management decisions.

## 5. Use Existing Programs to Address Climate Change Related Coastal Hazards

As identified in Section III, the County of Kaua'i has an existing regulatory, planning, and management framework that provides a good basis for future adaptive capacity to climate change related hazards. The following options would help to retrofit these existing programs to account for these hazards.

a. Floodplain Management Program:
   i. Participate in the FEMA National Flood Insurance Program's (NFIP) Community Rating System (CRS) program;
   ii. Develop building standards (such as additional freeboard and construction standards) in the existing 100-year floodplain that are more protective than the federal minimum standards;
   iii. Work with FEMA to update FIRMs that incorporate best-available information on climate change and SLR, eventually including a 100-year storm event under future SLR scenarios;
   iv. Develop an overlay zone adjacent to existing special flood hazard areas by overlaying SLR inundation maps and/or future coastal erosion maps with federal FIRMs.

b. Shoreline Setback Article of CZO: Update the shoreline setback and coastal protection article to allow for adjustments in the setback calculations based upon best-available SLR data. Options include: [125]
   i. For coastlines with a sea-level ranking risk of 4 or 3 in the Atlas of Natural Hazards in the Hawai'i Coastal Zone, increase the erosion rate by a default value of 10% (multiplied by a factor of 1.1); or
   ii. A qualified professional consultant calculates the expected increase in the rate of erosion at the specific site using the Bruun Rule,[126] a geometric model, or other generally accepted methodologies utilized in the coastal engineering industry; or
   iii. Add a defined additional safety buffer to the shoreline setback to account for SLR and other uncertainties until such time that addition SLR planning information and guidance is generated.

c. Special Management Area (SMA) and Zoning Permit Programs:
   i. Require applicants to analyze coastal hazard impacts and include mitigation in permit applications. Impose development conditions upon permits that minimize the impacts of exacerbated flooding, storm surge, and erosion due to SLR;
   ii. Strengthen rebuilding restrictions for nonconforming structures such that these structures are relocated a safe distance from the shoreline in hazardous areas.

d. Environmental review:
   i. When considering project alternatives, evaluate relocation, accommodation-elevation, and "soft" hazard mitigation;

[125] See the following for guidance: Hwang, Dennis J. Hawai'i Coastal Hazard Mitigation Guidebook. January 2005.
[126] Komar et al 1999

ii. When considering environmental mitigation, incorporate climate resilience measures.

e. Subdivision Ordinance:
   i. Utilize available data to protect public health and safety by restricting residential subdivisions in areas prone to current and future coastal hazards, including SLR;
   ii. Outside of these natural hazards areas, provide for conservation subdivisions or cluster subdivisions in order to conserve environmental resources.
f. Building Code:
   i. Provide provisions in the building code to strengthen or elevate construction to withstand hazard forces in hazardous areas;
g. Public Access, Open Space, and Natural Resources Preservation Fund:
   i. Finance the acquisition of additional shoreline lands and protect natural resource areas for public use, including areas that could serve as refugia for species impacted by SLR, or areas that could be appropriate sites for coastal habitat creation or restoration;
   ii. Promote the use of conservation easements, and transfer and purchase of development rights programs.
h. Capital Improvement Program (CIP):
   i. In accordance with Hawaiʻi State Planning Act Priority Guidelines, consider multiple scenarios of SLR and associated flooding, wave inundation, and erosion impacts when developing and approving CIPs.

## 6. Develop New Programmatic Strategies to Address Climate Change Related Coastal Hazards

Consider the following actions to develop the County's adaptive capacity to climate change and coastal hazards:

a. Develop an incentive program, such as a tax incentive program or a transfer of developments rights program to relocate potential or existing development out of hazardous or sensitive areas. Consider creating a relocation fund through increased development fees, in lieu fees, or other funding mechanisms.[127]
b. Work with the state to develop a comprehensive beach management strategy to address loss of beach areas, including loss of lateral access, or changes in beach manag ement due to SLR. Establish a program to minimize loss of beach area through, as may be appropriate, a beach nourishment program, restoring sand and sediment supply to littoral cell, removal or adjustments to shoreline protection structures, or other actions.
c. Develop local financing plan for beach and dune maintenance activities.

[127] For detailed information, see Douglas Codiga and Kylie Wager. SLR and Coastal Land Use in Hawaiʻi: A Policy Tool Kit for State and Local Governments. 2011. Center for Island Climate Adaptation and Policy. Honolulu, HI. Available at http://icap.seagrant.soest.hawaii.edu/icap-publications

# APPENDIX A

Photo: Dolan Eversole

# Appendix A: Hawai‘i State Planning Act

**Hawai‘i State Planning Act:**
**Sustainability and Climate Change Adaptation Priority Guidelines**
**Hawai‘i Revised Statutes Chapter 226**

**Part III. Priority Guidelines**
**§226-101 Purpose.** The purpose of this part is to establish overall priority guidelines to address areas of statewide concern. [L 1978, c 100, pt of §2; am L 1984, c 236, §14]

**§226-102 Overall direction.** The State shall strive to improve the quality of life for Hawai‘i's present and future population through the pursuit of desirable courses of action in seven major areas of statewide concern which merit priority attention: economic development, population growth and land resource management, affordable housing, crime and criminal justice, quality education, principles of sustainability, and climate change adaptation. [L 1978, c 100, pt of §2; am L 1986, c 276, §29; am L 2011, c 181, §4; am L 2012, c 286, §3]

**§226-108 Sustainability.** Priority guidelines and principles to promote sustainability shall include:
(1) Encouraging balanced economic, social, community, and environmental priorities;
(2) Encouraging planning that respects and promotes living within the natural resources and limits of the State;
(3) Promoting a diversified and dynamic economy;
(4) Encouraging respect for the host culture;
(5) Promoting decisions based on meeting the needs of the present without compromising the needs of future generations;
(6) Considering the principles of the ahupuaa system; and
(7) Emphasizing that everyone, including individuals, families, communities, businesses, and government, has the responsibility for achieving a sustainable Hawai‘i. [L 2011, c 181, §2]

**§226-109 Climate change adaptation priority guidelines**. Priority guidelines to prepare the State to address the impacts of climate change, including impacts to the areas of agriculture; conservation lands; coastal and nearshore marine areas; natural and cultural resources; education; energy; higher education; health; historic preservation; water resources; the built environment, such as housing, recreation, transportation; and the economy shall:
(1) Ensure that Hawai‘i's people are educated, informed, and aware of the impacts climate change may have on their communities;
(2) Encourage community stewardship groups and local stakeholders to participate in planning and implementation of climate change policies;
(3) Invest in continued monitoring and research of Hawai‘i's climate and the impacts of climate change on the State;
(4) Consider native Hawaiian traditional knowledge and practices in planning for the impacts of climate change;
(5) Encourage the preservation and restoration of natural landscape features, such as coral reefs, beaches and dunes, forests, streams, floodplains, and wetlands, that have the inherent capacity to avoid, minimize, or mitigate the impacts of climate change;
(6) Explore adaptation strategies that moderate harm or exploit beneficial opportunities in response to actual or expected climate change impacts to the natural and built environments;

(7) Promote sector resilience in areas such as water, roads, airports, and public health, by encouraging the identification of climate change threats, assessment of potential consequences, and evaluation of adaptation options;
(8) Foster cross-jurisdictional collaboration between county, state, and federal agencies and partnerships between government and private entities and other non-governmental entities, including nonprofit entities;
(9) Use management and implementation approaches that encourage the continual collection, evaluation, and integration of new information and strategies into new and existing practices, policies, and plans; and
(10) Encourage planning and management of the natural and built environments that effectively integrate climate change policy. [L 2012, c 286, §2]

# Appendix B

Photo: Dolan Eversole

# INVENTORY OF PLANNING INFORMATION AND DATA PRODUCTS

## Introduction and Overview

The Kaua‘i Coastal Climate Change Hazards Assessment ($KC_3HA$): Inventory of Planning Information and Data Products is intended to serve as an informational supplement, providing a list and description of available data products for planning for coastal hazards on Kaua‘i, including those related to climate change and sea-level rise. The data inventory is intended to support the integration of science-based coastal hazards information in land use planning through the Kaua‘i General Plan update. The data inventory is not intended to be a comprehensive list of all scientific and planning reports related to coastal hazards and climate change for Kaua‘i. This report highlights the most applicable and current hazards data sources for coastal land use planning. This report may also provide complimentary and updated information to existing documents, such as the Kaua‘i Multi-Hazard Mitigation Plan (see Part 3), though the $KC_3HA$ is not directly related to that report.

The data inventory features ten planning tools and data products, which may be utilized to varying degrees by Kaua‘i County in planning for coastal hazards, including those related to climate change and sea-level rise. The description of each data product includes access information, description of the product and intended use, how the data product was created, utility in climate change and sea-level rise planning, and limitations of the data set. A discussion is provided under each data product on which of the four hazards the data set provides information and guidance on: erosion, wave inundation, flooding, or wind; following the framework in the Gap Analysis and the Hawai‘i Coastal Hazard Mitigation Guidebook (Figures B.1 and B.2). Users should reference the individual data products for more detailed information and consider applicability to Kaua‘i County rules and policies.

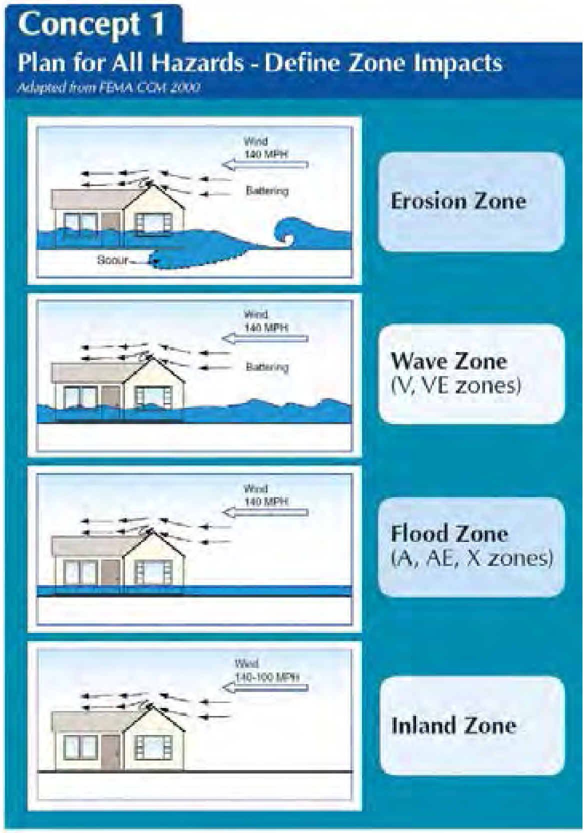



**Figure B.1**. Each data product in this inventory covers one or more of the four Coastal Hazard Zone Impacts: Erosion, Wave Inundation, Flooding and Wind (Hwang, 2014).

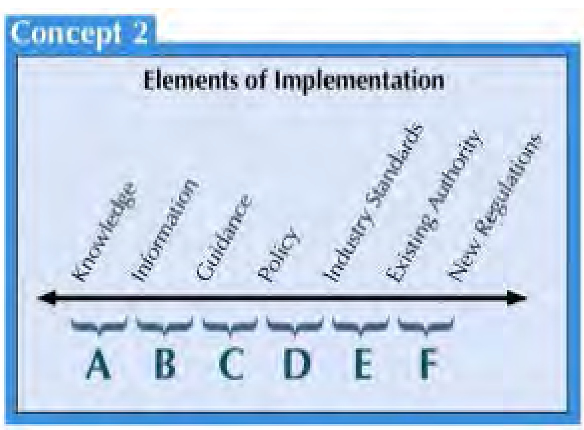



**Figure B.2.** A description is provided for each data product on where related research and planning efforts lie along the Elements of Implementation continuum (Hwang, 2014).

**Table of Contents**

## 1. Kaua'i Online Hazard Assessment (KOHA): Flood Hazard Assessment Tool

### Citation and URL

http://csc.noaa.gov/koha/

### Description and Intended Use

The Kaua'i Online Hazard Assessment (KOHA) Tool is an internet based map application allowing County staff to "rapidly and accurately identify FEMA designated flood zones for any parcel or proposed building site with the county." "KOHA will also determine if a parcel or proposed building site intersects the Special Management Area (SMA) [and Conservation District] and Tsunami Evacuation Zone." Users may search hazard information for an area using the map tools, or by entering a parcel number or address. KOHA develops reports containing specific risk information and maps for the selected parcel(s). The KOHA Tool provides information on wave inundation and flooding hazard zones as identified on the FEMA Flood Insurance Rate Maps.

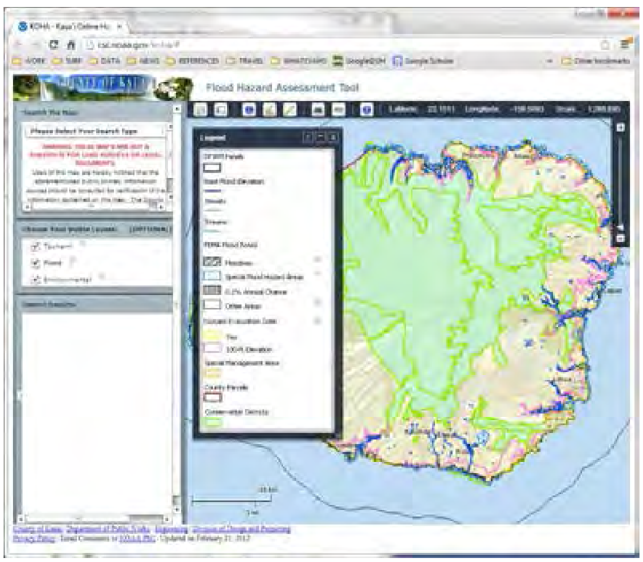



**Figure B.3.** County of Kaua'i Flood Hazard Assessment Tool. Users may select up to three visible map layers: Tsunami, Flood, and Environmental.

### How it was Created

The KOHA tool was developed in partnership between the County of Kaua'i and the NOAA Coastal Services Center. The maps display FEMA Flooding, hazard information, available from other sources, in a single map interface.

### Use in Climate and Sea-Level Rise Planning

See the following sections on FEMA Flood Insurance Rate Maps (FIRMs) and Tsunami Evacuation Zones for more information on the utility of these map products in climate and sea-level rise planning. While information is available on sea-level rise flood zones (e.g., NOAA Sea Level Rise Maps), the flood zones have not been updated to include flooding from sea-level rise. However, with the Biggert-Waters Flood Insurance Reform Act of 2012, FEMA is required to develop recommendations on how to ensure FIRMs incorporate the best available climate science and use the best available methodology to estimate the impact of sea-level rise and future development of flood risk.

### Limitations

See the following sections on FEMA Flood Insurance Rate Maps (FIRMs) and Tsunami Evacuation Zones for more information on the limitations of these map products in climate and sea-level rise planning.

## 2. Atlas of Natural Hazards in the Hawaiian Coastal Zone

### Citation and URL

Fletcher, C.H., Grossman, E.E., Richmond, B.M., Gibbs, A.E. (2002) Atlas of natural hazards in the Hawaiian coastal zone. U.S. Geological Survey, Denver, CO, Geologic Investigations Series I-2761, 182p. http://geopubs.wr.usgs.gov/i-map/i2761/

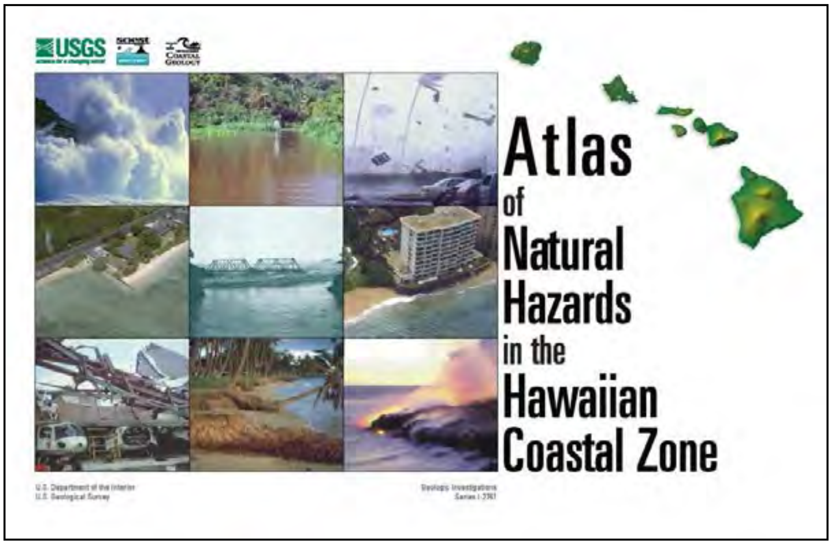



**Figure B.4.** Cover, Atlas of Natural Hazards in the Hawaiian Coastal Zone.

### Description and Intended Use

The Atlas of Natural Hazards in the Hawaiian Coastal Zone was produced by researchers at the U.S. Geological Survey and University of Hawai‘i Geology and Geophysics Department to communicate to citizens and regulatory authorities the history and relative intensity of coastal hazards in Hawai‘i (Fletcher, *et al*. 2002). The atlas was intended to aid in wise use and management of coastal resources by providing a reference atlas of coastal hazards in Hawai‘i. According to the authors, "The information contained in this document, [the authors] hope, will improve the ability of Hawaiian citizens and visitors to safely enjoy the coast and provide a strong data set for planners and managers to guide the future of coastal resources."

The atlas contains a set of technical hazard maps (Example shown in Figure 2) of the entire shoreline of the islands of Kaua‘i, Oahu, Moloka‘i, Lāna‘i, Maui, and Hawai‘i at a scale of 1:50,000 (1 inch on the map equals approximately 0.8 miles). The maps display a relative intensity ranking (on a ranked scale of 1 to 4, where 4 is most intense) of each of seven hazards following a set of specific definitions. Each map also depicts coastal geology classifications using an alphabetical code. As a cursory investigation into coastal flooding and sea-level rise hazards, the slope of the coastal zone was measured from sea level to an elevation of approximately 200 feet, or the first major change in slope. The Atlas contains information on all four key Hazard Zone Impacts: erosion, waves, flooding, and winds (storms).

The maps depict seven individual relative intensity rankings along the coast, including:

- Tsunami: Based on history of tsunami flooding and coastal slope. (See: Tsunami Evacuation Zones for more detail on Tsunami hazards).
- Stream Flooding: Based on history of coastal stream flooding and coastal slope (See: FEMA Flood Maps for more detail on flooding hazards).
- High Waves: Based on typical patterns of seasonal waves (See: FEMA Flood Maps for more information on wave inundation flooding hazards).
- Storms: Based on historical records of historical overwash (coastal inundation) and high winds during storms (See: FEMA Flood Maps for more detail on wave inundation flooding hazard zones).
- Erosion: Based on trends of long-term beach erosion or accretion (Note: updated shoreline trend data is available in the Kaua‘i Shoreline Erosion Maps).
- Sea Level: Based on measurements of coastal slope (See: NOAA Sea Level Rise and Coastal Flooding Impacts Viewer for updated modeling on sea-level rise hazards).
- Volcanic/Seismic: Base on history of damage from volcanic and seismic events.

The individual intensity rankings are combined to arrive at an Overall Hazard Assessment (OHA) for the coast, which is also depicted along the coast. “Dynamic” hazards from volcanism and seismicity, coastal stream flooding, seasonal high waves, marine overwash and high winds, and tsunami inundation are given a higher weight (greater emphasis) in calculating the OHA. Longer-term hazards from coastal erosion and sea-level rise are assigned a lower weight in the OHA.

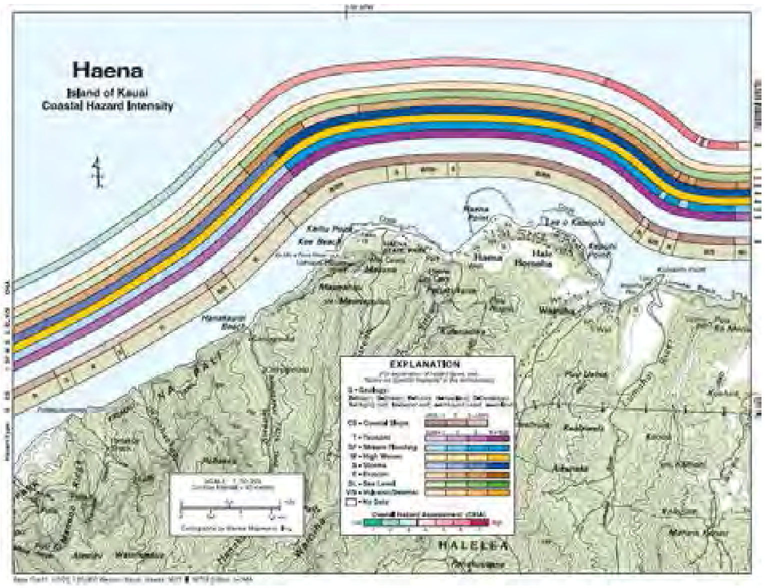



**Figure B.5.** Example Coastal Hazard Intensity map from Fletcher et al., 2002 for the Hāʻena region of Kauaʻi. Alongshore bars indicate the relative intensity of each hazard including tsunami, stream flooding, high waves, storms, beach erosion, sea level rise, seismicity and volcanism, and overall hazard assessment. Also shown in the bars nearest the coast is coastal geology type and coastal slope.

**How it was Created**

The hazard rankings in the Atlas are largely based on results from previous investigations by scientific and engineering researchers and county, state, and federal offices and agencies. The Atlas "assimilates prior efforts in documenting Hawaiian coastal hazards and combines existing knowledge into a single comprehensive coastal hazard data set. This is by no means the final word on coastal hazards in Hawaiʻi" (Fletcher, *et al*. 2002).

The Atlas contains two types of maps:

1. Small scale maps showing a general history of hazards on each island and summarizing coastal hazards in a readily understandable format for general use.
2. Large-scale series of technical maps (1:50,000) depicting coastal sections approximately 5 to 7 miles in length with color bands along the coast ranking the relative intensity of each hazard at the adjacent shoreline.

**Use in Climate and Sea-Level Rise Planning**

As the authors of the Atlas state, it was developed to "provide a strong data set for planners and managers to guide the future of coastal resources." The Atlas is probably best used for initial, rudimentary coastal hazard assessment (*e.g*., Overall Hazard Assessment, OHA) for a region prior to consulting more detailed data sets, reports, and guidance on particular hazards. The

Atlas was an important source of information for the 2010 Kauaʻi Hazard Mitigation Plan. Much of the information in the maps has been succeeded by more recent and higher resolution data. As examples, updated stream and coastal flooding hazards are available in the FEMA FIRMs and coastal erosion trends have been calculated for all Kauaʻi beaches in the Kauaʻi Shoreline Erosion Maps. The tables and large-scale technical maps provide a valuable and comprehensive summary of historical hazard events including floods, hurricanes, and tsunami.

**Limitations**

The Atlas was published in 2002 and much of the information has been superseded by more current or more detailed data sets. Because the Coastal Hazard Intensity Ratings in the maps are based largely on historical records, the hazard ratings may not capture the risk of events outside the observed magnitude range. Additionally, they may not account for potential increases in event frequency (return period), intensity, and duration of many of the hazards likely with climate change and sea-level rise. The maps were produced at a scale of 1:50,000 using USGS topographic maps as the base layer. Therefore, the maps are useful for hazard assessment only at the community-level scale, not at the scale of individual parcels, and do not depict important geographic data for planning purposes such as property boundaries and critical infrastructure. In addition, the maps do not depict a spatial extent or coverage for hazard areas. For example, the maps do not depict the inland extent of inundation for high waves and sea level. Individual hazard ratings should not be used in place of more recent and detailed reports, such as Tsunami inundation maps from Pacific Disaster Center, FEMA FIRMs for stream flooding, Shoreline Erosion Maps from the U.H. Coastal Geology Group, and NOAA Coastal Storms Program Sea-Level Rise Maps (in production).

3. **County of Kaua‘i Multi-Hazard Mitigation Plan**

**Citations and URL**

University of Hawai‘i Social Science Research Institute, Climate Hazards and Environment Program (2009) *County of Kaua‘i Multi-hazard Mitigation Plan, Update 2009*. For the Kaua‘i County Civil Defense Agency.
http://edev3.socialsciences.Hawai‘i.edu/temp/hazards/Kaua‘iplan.html

**Description and Intended Use**

The Kaua‘i Multi-Hazard Mitigation Plan (KMMP) is a document defining the County’s long-term strategy for reducing the risk of natural hazards. “The purpose of a hazard mitigation plan is to protect lives and property from loss and destruction during a natural hazard (KMMP).” The development of local hazard mitigation plans is required to qualify for FEMA mitigation and disaster recovery funding. The goal is to build disaster resilient communities in the County of Kaua‘i. The KMMP addresses a range of natural hazards including winds, floods, drought, wildfires, climate variability and change, coastal erosion, earthquakes, tsunamis, landslides, volcanoes, dam failures, hazardous materials, and homeland security, and health related hazards (all four key coastal Hazard Impact Zones, and more). The plan utilizes the best available data for inclusion in identification and mitigation of these hazards. In addition to addressing natural hazards, the plan identifies key County assets and provides risk and vulnerability assessments and mitigation strategies by hazard type.

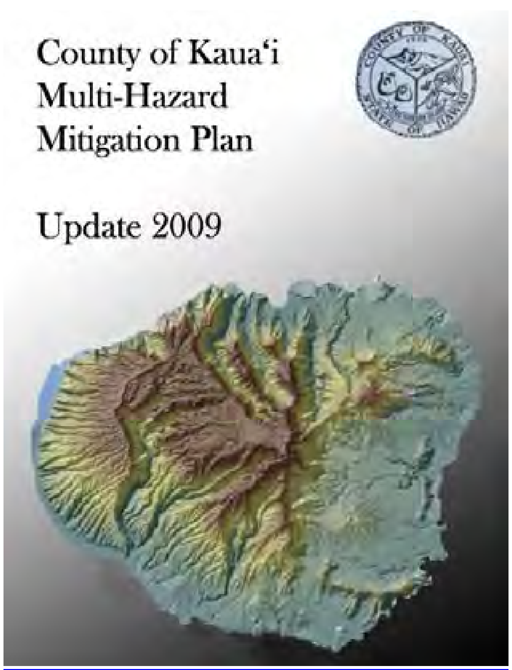



**Figure B.6.** Cover, Kaua‘i Multi-Hazard Mitigation Plan.

### How it was Created:

The County of Kauaʻi used the best available data to identify hazards, including maps from the USGS Atlas of Natural Hazards in the Hawaiian Coastal Zone, the Kauaʻi Shoreline Erosion Maps, Drought Vulnerability Maps, Maps of State Regulated Dams, and the Kauaʻi County Tsunami and Flood Inundation Maps. This hazard information was combined with data on critical County assets, such as emergency services, infrastructure, and built environment to arrive at a risk and vulnerability assessment by hazard type, including maps. From the risk and vulnerability assessments, mitigation practices, policies, and strategies are developed.

### Use in Climate and Sea-Level Rise Planning

The KMMP incorporates many of the coastal hazard information products described in this inventory, including print-outs of maps in the report appendices. Risk and vulnerabilities are generally based on present and past conditions and do not account for changing (increasing) hazard baselines with changing climate and sea-level rise. Several maps included in the plan identify critical facilities located in coastal hazard flood zones. Chapter 3, Hazard Identification, specifically addresses Climate Variability and Change, including sea-level rise. Mitigation recommendations are not provided, directly, for increasing coastal hazards with sea-level rise.

### Limitations

The KMMP is not intended to be utilized specifically in review of individual land uses but provides a more general emergency management focus.

## 4. Kauaʻi Shoreline Erosion Maps

### Citations and URLs

Fletcher, C.H., Barbee, M., Lim, S.C., Dyer, M., Senter, C., Genz, A., 2011. *Kauaʻi Shoreline Study Erosion Maps*. University of Hawaiʻi Coastal Geology Group for the County of Kauaʻi, under contract #7249 and State of Hawaiʻi Department of Land and Natural Resources under contract #C25514.

Related technical reports and GIS data:

Fletcher, C.H., Romine, B.M., Genz, A.S., Barbee, M.M., Dyer, M., Anderson, T.R., Lim, S.C., Vitousek, S., Bochicchio, C., and Richmond, B.M., 2012, *National assessment of shoreline change: Historical shoreline change in the Hawaiian Islands*. U.S. Geological Survey Open-File Report 2011–1051, 55 p. http://pubs.usgs.gov/of/2011/1051/

Romine, B.M., Fletcher, C.H., Genz, A.S., Barbee, M.M., Dyer, Matthew, Anderson, T.R., Lim, S.C., Vitousek, Sean, Bochicchio, Christopher, and Richmond, B.M., 2012, *National Assessment of Shoreline Change: A GIS compilation of vector shorelines and associated shoreline change data for the sandy shorelines of Kauai, Oahu, and Maui, Hawaii*. U.S. Geological Survey Open-File Report 2011-1009.

### Description and Intended Use

The Hawaiʻi Shoreline Study Erosion Maps were developed by the University of Hawaiʻi Coastal Geology Group in partnership with the Counties of Kauaʻi, Oahu, and Maui, and other State and Federal partners to provide historical shoreline change data to assist in coastal hazard assessment, coastal zone management, and coastal land use planning. The Kauaʻi Shoreline Study Erosion Maps includes 40 individual maps of the Kauaʻi coast at 1:3,000 scale allowing for interpretation of shoreline trends at individual properties. The maps depict historical shoreline change rates over the past century shown in plots along the shore and historical shoreline positions, overlaid on a recent aerial photograph. The erosion maps depict the annual rate of shoreline change every 20 meters (66 feet) along all Kauaʻi beaches, with the exception of the Nā Pali Coast. This information has application in local coastal management issues such as hazard assessments, understanding local processes and projection of future shoreline positions for land use and siting concerns. The maps and erosion rates are used by the Kauaʻi County Planning Department as a basis for shoreline setback requirements pursuant to Article 27 of the Comprehensive Zoning Ordinance. In a general sense, the maps identify coastal erosion hazard "hotspots" and provide an overview of coastal processes and historical shoreline trends for each map area. The Erosion Maps provide the most current information for long-term land-use planning in the Erosion Hazard Zone (Figure 1), though improved information (research) is needed to assess changes in erosion hazards with projected acceleration in SLR rates. In addition, more research and monitoring of short-term, seasonal erosion patterns is needed.

### How it Was Created

Historical shoreline positions were mapped from aerial photographs and survey charts going back to the early 1900s. The historical shorelines were digitized using specialized photogrammetric and Geographic Information System (GIS) software. A low water mark ("beach toe") position was used as the proxy for measuring shoreline changes. Annual rates of change in feet per year were calculated at regularly-spaced transects (measurement locations, every 20 m or 66 ft) along the shore. The historical shoreline positions, transect (measurement) locations, alongshore plots of annual shoreline change rates, and TMK boundaries are displayed in maps over a recent aerial photograph (Figure 3).

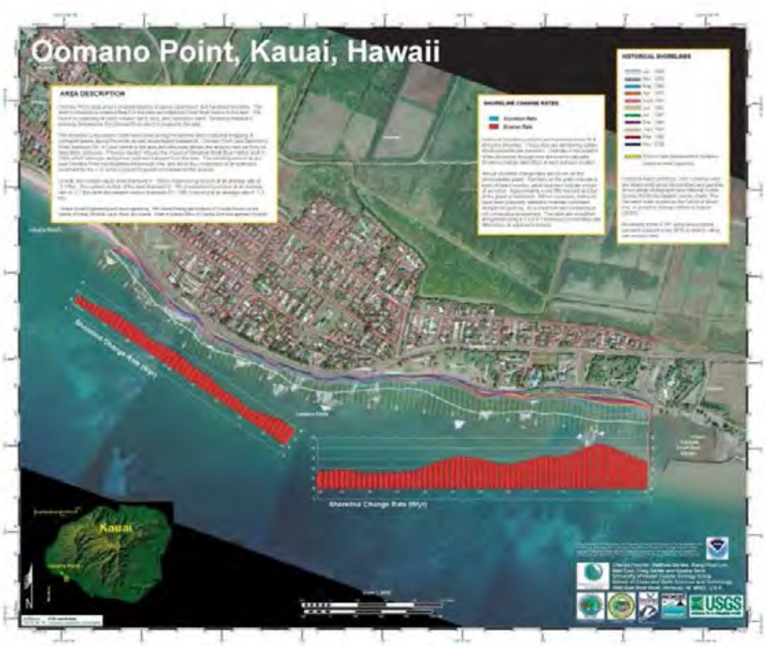



**Figure B.7.** Example of a Shoreline Erosion Map for ʻŌʻōmanō Point, west Kauaʻi. Colored lines along the shore are historical shoreline positions going back to the 1920s. Annual erosion rates (feet per year) are displayed in red in the alongshore plots.

### Use in Climate and Sea-Level Rise Planning

The erosion maps depict past changes in shoreline position. They are useful in identifying existing erosion hazard areas. Sea level has been rising around Hawaiʻi, including Kauaʻi, over the last century. Therefore, sea-level rise is likely a component in the observed historical shoreline changes. Erosion hotspots identified in the maps are likely to be the areas most affected by increasing beach erosion with sea-level rise, assuming that future shoreline trends have a relationship with the historical trends. In planning for sea-level rise, the erosion maps may provide a cursory indication of the areas facing the greatest threat of increasing beach erosion. This is important information, because the NOAA sea-level rise inundation maps (see

#7) do not account for increasing coastal erosion with sea-level rise. The maps provide key information on erosion hazards. Guidance and policy for planning for erosion hazards with the maps are provided through existing erosion rate-based setback policy. Though, the existing setback policy does not account for increasing SLR. New information (research) is required to provide better understanding and prediction of shoreline change with increasing SLR.

**Limitations**

For sea-level rise planning purposes, the most important limitation of the historical erosion maps is that they do not account for increasing erosion expected with accelerating sea-level rise. Research studies of shoreline change related to sea-level rise suggest typical horizontal shoreline retreat of one to two orders of magnitude (10 to 100 times) the rate of vertical sea-level rise. Using this rough estimate, a 1 foot rise in sea level could result in 10 to 100 feet of horizontal shoreline change. On a shorter term basis, hazards from seasonal and/or episodic beach erosion (where the beach fully or partially recovers) may not be accounted for in the long-term analysis. For some highly dynamic beaches, such as along the north shore, seasonal erosion and wave inundation may pose a greater hazard than long-term trends. The data sets available for historical shoreline studies are typically sparse (limited shorelines) and noisy (high positional uncertainties). Therefore, uncertainty values with erosion rates can be high, in some cases greater than the rates - an inconclusive erosion or accretion trend, statistically speaking. However, even where uncertainties are high, the maps depict the most likely long-term trend, which is valuable information for planning purposes Erosion rates are only available for sandy beach shorelines and do not include the Nā Pali Coast beaches.

## 5. Federal Emergency Management Agency FEMA Flood Insurance Rate Maps (FIRMs)

### Citations and URLs

FEMA Map Service Center: https://msc.fema.gov

FEMA Mapping Information Platform: https://hazards.fema.gov/wps/portal/mapviewer

Hawaiʻi National Flood Insurance Program (NFIP) Flood Hazard Assessment Tool (FHAT): http://gis.Hawaiʻinfip.org/FHAT/

Kauaʻi Flood Insurance Study (last revision 2010), County of Kauaʻi and the Federal Emergency Management Agency

### Description and Intended Use

According to the FEMA Map Service Center, the FIRMS are intended to be the "Primary regulatory tool for state and local governments to mitigate the effects of flooding in mapped communities." The maps are intended to be used in land-use planning and building design including elevation-based building codes. The FIRMS establish risk that is used for flood insurance rates for private policy holders.

The National Flood Insurance Program (NFIP) is a Federal program, which was established to allow property owners in participating communities to purchase insurance protections against losses from flooding. Participation in the NFIP is based on an agreement between local communities and the Federal Government that states if a community will adopt and enforce a floodplain management ordinance to reduce future flood risks to new construction and substantial improvements in Special Flood Hazard Areas, the Federal Government will make flood insurance available within the community at a low cost.

The maps identify Special Flood Hazard Areas (SFHAs), which fall within the 100-year flood boundary. A property within an SFHA has a 1% or greater probability of flooding in any given year. This one-percent annual chance flood is also known as the "base flood" or "100-year flood." The elevation that flood waters are expected to rise to in the 100-year flood is known as the Base Flood Elevation (BFE).


**Figure B.8**. Sample Digital Flood Insurance Rate Map (FIRM) for the Anahola Bay area of Kaua'i.

### How it was Created

The FEMA FIRMs are developed from historical flood events and hydrologic modeling of 100 year inundation events. Statistical analysis of stream gauge data provides peak discharges and frequencies for flooding sources (e.g., streams). Flood surface elevations are estimated on topographic maps through hydraulic analyses using the statistical peak discharges. Inundation limits for the 1% chance annual tsunami and wave inundation (V, VE Zone) is also calculated from historical accounts and numerical modeling. Delineations of flood hazard areas and elevations may be revised based on historical flooding events. FIRMs are referenced to a Local Tidal Datum providing a common reference to compare flood, ground, and structure elevations. The FIRMs provide information on the Wave and Flood Impact Zones following the Hazard Zone Impacts in Figure 1.

### Use in Climate and Sea-Level Rise Planning

The FIRMs may provide a cursory assessment of areas at risk from increased inundation and flooding hazards with increasing sea-level rise. FIRMs identify areas historically prone to land-based and wave inundation flooding. These areas may represent the minimal area at risk for flooding with increased sea-level rise. The FIRM boundaries are available in a variety of formats, including GIS layers, allowing the SFHAs to be overlaid on other see-level rise and flooding data for comparison. The FIRMs provide information on flood hazard zones, which is supported by Industry Standards (e.g., BFEs). However, inclusion of SLR flood hazard zones is needed to allow for improved planning and industry standards.

### Limitations

FIRMs do not account for increases in Base Flood Elevations (BFEs) with sea-level rise, future erosion, or changes in rainfall patterns with changing climate (e.g., possible increases in flash flooding). Additionally, the hydraulic analysis assumes a "bare earth" model for inundation, so actual inundation may vary considerably based on natural and man-made features. Updates to FIRMS sometimes take years and may not reflect changes to flood risk due to changes in land use or new information available.

## 6. Tsunami Evacuation Zones

### Citations and URLs

Pacific Disaster Center: http://www.pdc.org/iweb/tsunami_zones.jsp

NOAA Coastal Services Center: http://tsunami.csc.noaa.gov/map.html

Kaua'i Online Hazard Assessment (KOHA) tool: http://csc.noaa.gov/koha


**Figure B.9.** Tsunami Evacuation Zones at Hanelei, Kaua'i from the NOAA Coastal Services Center website.

### Description and Intended Use

The Tsunami Evacuation Zone Maps are intended for evacuation purposes in the event of a tsunami warning. The tsunami evacuation maps are not intended for hazard analysis. The FEMA Flood Insurance Rate Maps (FIRMs) provide risk information for coastal flooding hazards, including tsunamis. Though the tsunami maps are not intended for hazard analysis, they provide important information on the key Hazard Zones for Waves and Flood (Figure 1).

### How it Was Created

Tsunami evacuation zone maps were produced by the Joint Institute for Marine and Atmospheric Research (JIMAR) at the University of Hawai'i in cooperation with the State of Hawai'i Civil Defense System. Base tsunami inundation maps were produced by the University of Hawai'i under contract by Hawai'i State Civil Defense using state of the art computer models of five historical and five hypothetical tsunami events. The inundation maps are based on the most landward inundation extent of the ten scenarios. Evacuation maps were developed by Kaua'i County Civil Defense by interpreting the UH tsunami inundation maps for evacuation and emergency management purposes.

### Use in Climate and Sea-Level Rise Planning

The Tsunami Evacuation Maps have little applicability to sea-level rise planning in the current form.  Tsunamis are unpredictable, episodic events.  However, increased base water level due to rising mean sea level may increase flood heights for future tsunami, though tidal height (± 1m) at the time of tsunami arrival will be as or more important than mean water level.  New information is needed on how the tsunami zones may change with increasing SLR.

### Limitations

The tsunami evacuation maps do not consider the effects of increasing sea level rise.  They are intended for evacuation hazard purposes, only, and are not intended for coastal flooding risk assessment.  However, the maps may be useful as part of a multi-hazard assessment (*e.g.*, the Kaua‘i Online Hazard Assessment).

## 7. NOAA Sea Level Rise and Coastal Flooding Impacts Viewer

### Citations and URLs

Available at the NOAA Coastal Services Center, Digital Coast, Sea Level Rise and Coastal Flooding Impacts Viewer: http://www.csc.noaa.gov/digitalcoast/tools/slrviewer

Related data products will also likely be available from the University of Hawai‘i Coastal Geology Group at http://www.soest.Hawai‘i.edu/coasts/sealevel/, and Pacific Islands Ocean Observing System (PacIOOS) http://oos.soest.Hawai‘i.edu/pacioos/.

GIS layers for the Kaua‘i NOAA Viewer flooding areas are presently available at the following links (last viewed December, 2013):
http://csc.noaa.gov/htdata/Inundation/SLR/SLRdata/Pacific/HI_Kauai_slr_data_dist.zip
http://csc.noaa.gov/htdata/Inundation/SLR/ConfData/Distribution/Pacific/HI_Kauai_conf_data.zip
http://csc.noaa.gov/htdata/Inundation/SLR/SLRdata/Pacific/HI_Kauai_dems.zip

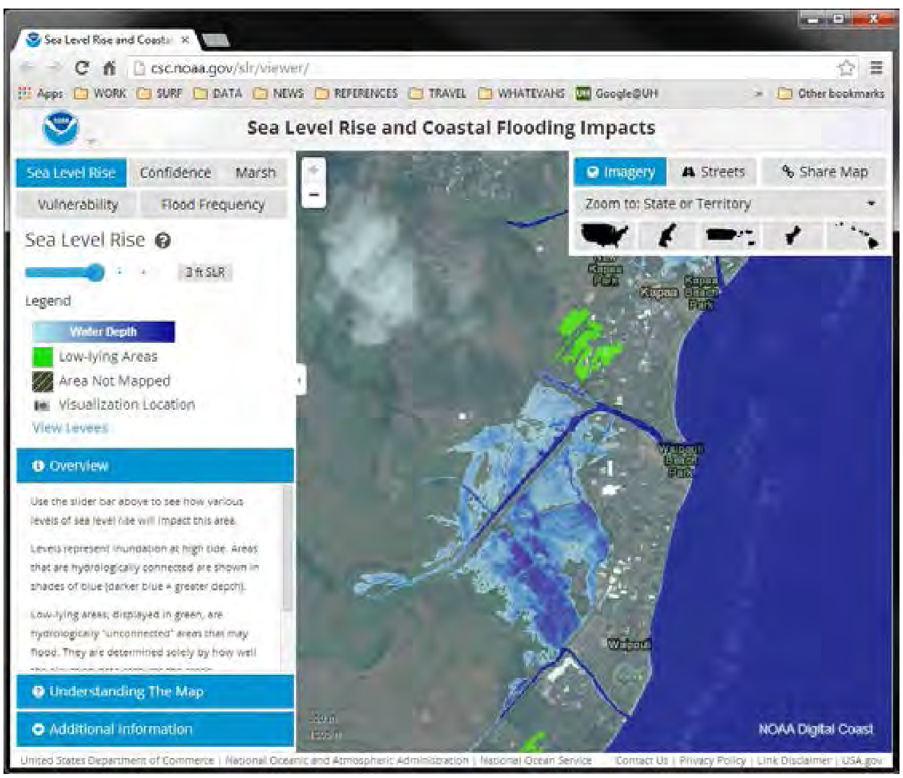



**Figure B.10**. Sample Sea-Level Rise Map from the NOAA Sea Level Rise and Coastal Flooding Impacts Viewer for Kapa‘a.

### Description and Intended Use

The Hawai‘i Sea-Level Rise Maps are available through the NOAA Coastal Services Center Sea Level Rise and Coastal Impacts Viewer, an online interactive mapping and visualization tool intended to “provide coastal managers with a preliminary look at sea-level rise and coastal flooding impacts.” The maps depict inundation levels above Mean Higher High Water (MHHW) on 1-foot increments from 0 to 6 feet. A slider bar on the web-based graphical display is used to show how various levels of sea level rise will impact coastal communities. The online mapping tool allows the use to display five data layers:

1. Sea-level rise, from 1 to 6 feet, showing areas impacted.
2. Mapping confidence, differentiating between areas of high confidence of inundation and areas of uncertainty.
3. Marsh impacts and migration, indicating potential changes to wetland areas.
4. Vulnerability rating (high, medium, low) developed by overlaying social and economic map layers on the sea-level rise inundation areas.
5. Flood frequency plots describing changes in frequency and duration of flood events with sea-level rise.

### How it Was Created

Sea-level rise scenarios (0-6 feet, 0-1.8 meters) are based on a range of estimates for the year 2100 from peer-reviewed scientific literature. The project utilizes the best publicly-available elevation data; typically, Digital Elevation Models (DEMs) developed from airborne Coastal LiDAR data. Using geographic software, inundation areas are mapped by identifying topographic areas lying below sea level at each 1-foot increment of sea-level rise above MHHW. This type of study is often referred to as a “bathtub” flooding model, where a static sea level is raised in increments on a digital topographic model. The study also evaluates hydrologic connectivity between inundation areas and the sea. Inundation areas with high (80%) confidence are differentiated from areas of lower confidence.

### Use in Climate and Sea-Level Rise Planning

The NOAA Sea Level Rise and Coastal Flooding Impacts Viewer allows coastal communities and planners to “visualize potential impacts from sea level rise [as a] powerful teaching and planning tool.” The online viewer displays areas vulnerable to potential future flooding from sea level rise, provides simulations of sea level rise at local landmarks, communicates the spatial uncertainty of mapped sea levels, models potential marsh migration due to sea level rise, overlays social and economic data onto potential sea level rise, and examines how tidal flooding will become more frequent with sea level rise (http://www.csc.noaa.gov/digitalcoast/tools/slrviewer). The NOAA Sea Level Maps provide vital new information towards improved long-range SLR planning.

### Limitations

While the NOAA Sea Level Rise maps provide the best available information on coastal flooding hazards with sea-level rise, the maps have several limitations. For beach-front properties, this type of "bathtub" model does not account for or depict increased beach erosion (shoreline recession) that is expected with sea level rise. Research studies of shoreline change related to sea-level rise suggest typical horizontal shoreline retreat of one to two orders of magnitude (10 to 100 times) the rate of vertical sea-level rise. As a result the maps may under-represent the "true" hazard for many coastal properties. The maps depict only an incremental increase above high tide level. They do not account for additional inundation from high-wave setup, storm surge, extreme high tides, etc.

## 8. NOAA Critical Facilities Flood Exposure Tool

### Citations and URLs

Available through the NOAA Coastal Services Center, Critical Facilities Exposure Tool website: http://www.csc.noaa.gov/criticalfacilities/

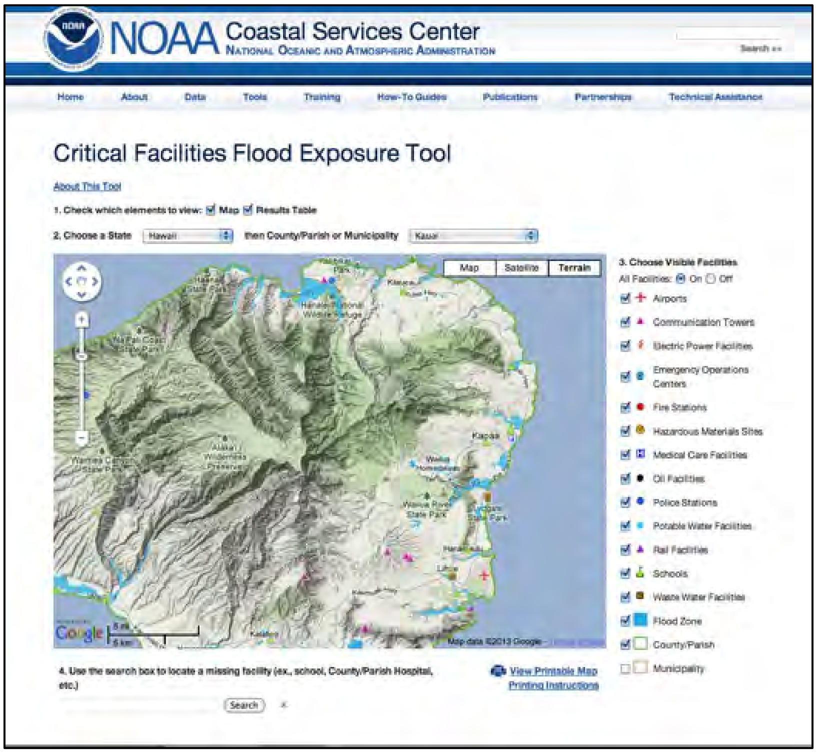



**Figure B.11**. NOAA web-based Critical Facilities Exposure Tool map viewer.

### Description and Intended Use

The NOAA Critical Facilities Flood Exposure Tool is a web-based map viewer identifying critical facilities located in FEMA flood zones. From the *NOAA Critical Facilities Exposure Tool* website: “The intent of this tool is to provide an initial assessment of a community's critical facilities and road miles within the FEMA 1% annual chance flood zone. This tool was initially created to assist the Mississippi/Alabama Sea Grant in conducting their "Coastal Resiliency Index: A Community Self-Assessment" workshops and has been expanded based on available flood data.” Map layers available for display in addition to FEMA flood zones include airports, communications and power facilities, emergency operations centers, fire and police stations, hazardous materials sites, medical care facilities, oil facilities, potable water facilities, schools, and waste water facilities. The tool provides information on Hazard Zone Impacts within the Wave and Flood Zones following four key Hazard Zones in Figure 1.

### How it Was Created

The online mapping viewer includes Flood Zones based on FEMA 1% annual flood zones, Critical Facilities from 2000-2001 FEMA HAZUS-MH data, and Roads based on 2005 ESRI/TeleAtlas streets data.

### Use in Climate and Sea-Level Rise Planning

The NOAA Critical Facilities Flood Exposure Tool identifies critical facilities located in FEMA flood zones. These maps may be useful for inclusion in sea-level rise adaptation plans and general hazard assessments. The maps provide information on flood hazard zones, which is applied through Industry Standards. New information is needed to update the flood hazard zones for SLR, which may then be applied through existing, updated Industry Standards.

### Limitations

The FEMA Flood zones do not include projected changes in flood area or elevations due to climate changes or sea-level rise. Disclaimers from the NOAA Critical Facilities Flood Exposure Tool website: "In some cases a community's list of critical facilities may not be exhaustive or locations may be incorrect. The data used are from FEMA's HAZUS-MH database and may be out-of-date, in the wrong location, or not correctly attributed. It is recommended that local, up-to-date data be used for official planning activities. This tool and its associated data is meant to be an initial assessment and is not intended to be used for or in place of local planning data."

9. **Variations in Community Exposure and Sensitivity to Tsunami Hazards in the State of Hawai‘i**

### Citations and URLs

Wood, N., Church, A., Frazier, T., and B. Yarnal, 2007, Variations in community exposure and sensitivity to tsunami hazards in the State of Hawai‘i: U.S. Geological Survey Scientific Investigation Report 2007-5208, 38 p. http://pubs.usgs.gov/sir/2007/5208/

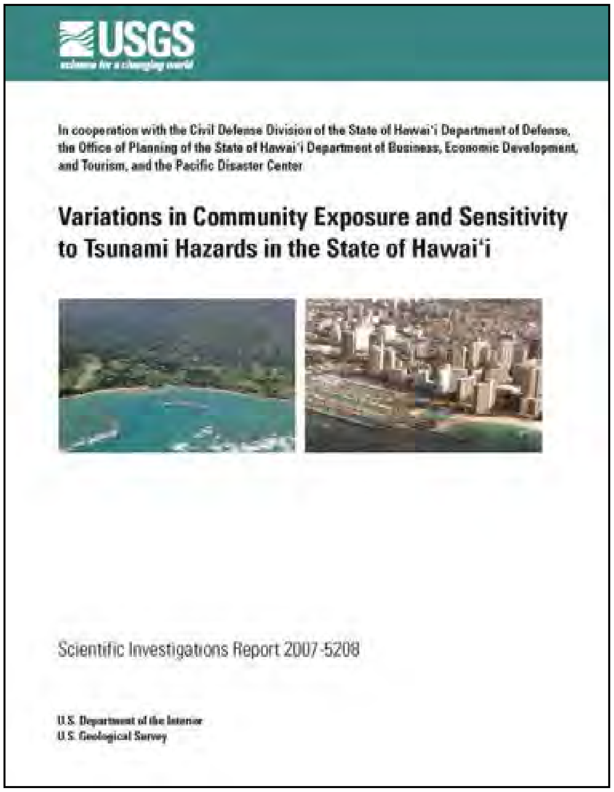



**Figure B.12**. Cover page, USGS report on Variations in Community Exposure and Sensitivity to Tsunami Hazards in the State of Hawai‘i

### Description and Intended Use

Variations in Community Exposure and Sensitivity to Tsunami Hazards in the State of Hawai‘i is a Scientific Investigations Report by the U.S. Geological Survey Prepared in cooperation with the Civil Defense Division of the State of Hawai‘i Department of Defense, the Office of Planning of the State of Hawai‘i Department of Business, Economic Development, and Tourism, and the Pacific Disaster Center. From the report, “The purpose of this report is to describe tsunami-prone landscapes on the Hawaiian coast and to document geographic variations in community vulnerability to tsunamis. Data presented in this report include descriptions of land cover, human population, economic assets, and critical facilities relative to tsunami-evacuation zones. This report provides an initial estimate of community exposure and sensitivity to tsunamis in Hawai‘i and results of this community-level analysis are intended to serve as a foundation for additional risk-related studies and outreach efforts.”

The report also includes a *Supporting Database* containing community-specific data on exposure and sensitivity to tsunami hazards, available at http://pubs.usgs.gov/sir/2007/5208/ and described in Appendix B of the report. The database is presented as an Excel workbook with worksheets displaying tsunami exposure and sensitivity arranged by Tsunami Evacuation Map #, Census-Designated Places (*i.e.*, community), and State Business Types. The report and database provide added information on community vulnerability in the Wave and Flood Zones, following Figure 1, four Hazard Zone Impacts.

**How it Was Created**

From the report, “A community-level vulnerability assessment using geographic-information-system tools was conducted to describe tsunami-prone landscapes on the Hawaiian coast and to document variations in land cover, demographics, economic assets, and critical facilities among 65 communities.”

**Use in Climate and Sea-Level Rise Planning**

As with the Tsunami Evacuation Maps the report and database have little applicability to sea-level rise planning in the current form. Tsunamis are unpredictable, episodic events. However, increased base water level due to rising mean sea level may increase flood heights for future tsunamis, though tidal height (± 1m) at the time of tsunami arrival will be as or more important than mean water level. The tsunami maps and database provide important information on tsunami vulnerabilities. New information is need on if/how these zones may change significantly with increasing SLR.

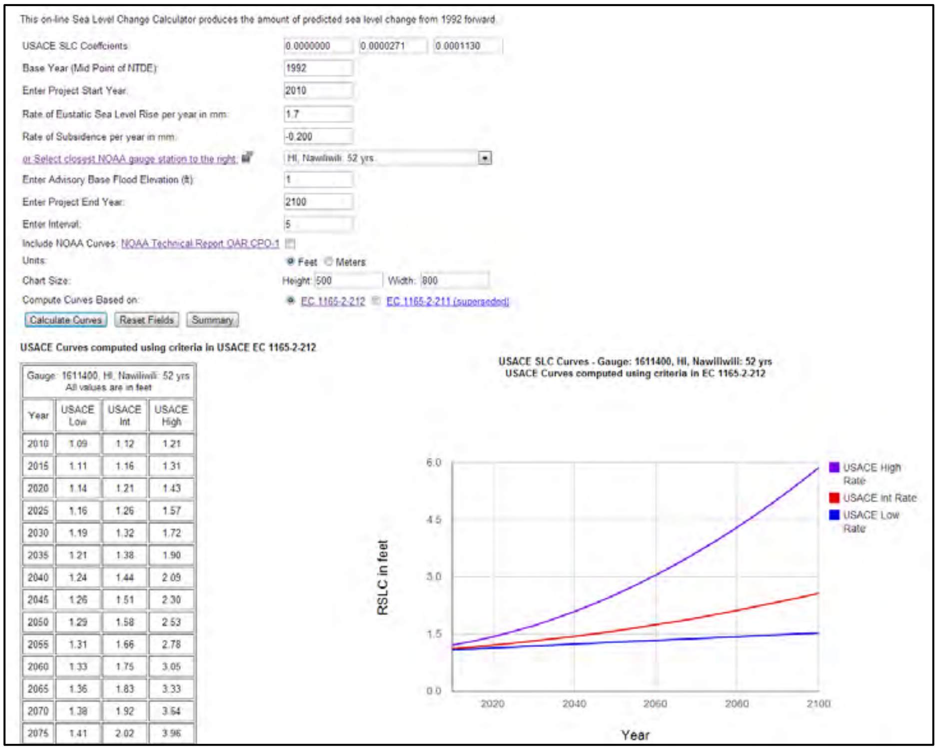
**Limitations**

Similar to the tsunami evacuation maps, the report and database do not consider the effects of increasing sea level rise. They are intended for community-level vulnerability assessment to tsunami. However, the maps in the report and database tables may be useful as part of a multi-hazard assessment.

## 10. U.S. Army Corps of Engineers Sea Level Change Calculator

### URL

U.S. Army Corps of Engineers Climate Change Adaptation, Comprehensive Evaluation of Projects with Respect to Sea-Level Change website:
http://www.corpsclimate.us/ccaceslcurves.cfm



This on-line Sea Level Change Calculator produces the amount of predicted sea level change from 1992 forward.

USACE SLC Coefficients: 0.0000000 0.0000271 0.0001130
Base Year (Mid Point of NTDE): 1992
Enter Project Start Year: 2010
Rate of Eustatic Sea Level Rise per year in mm: 1.7
Rate of Subsidence per year in mm: -0.200
or Select closest NOAA gauge station to the right: HI, Nawiliwili: 52 yrs
Enter Advisory Base Flood Elevation (ft): 1
Enter Project End Year: 2100
Enter Interval: 5
Include NOAA Curves: NOAA Technical Report OAR CPO-1
Units: Feet Meters
Chart Size: Height: 500 Width: 800
Compute Curves Based on: EC 1165-2-212 EC 1165-2-211 (superseded)
Calculate Curves Reset Fields Summary

USACE Curves computed using criteria in USACE EC 1165-2-212

Gauge: 1611400, HI, Nawiliwili: 52 yrs
All values are in feet

| Year | USACE Low | USACE Int | USACE High |
|---|---|---|---|
| 2010 | 1.09 | 1.12 | 1.21 |
| 2015 | 1.11 | 1.16 | 1.31 |
| 2020 | 1.14 | 1.21 | 1.43 |
| 2025 | 1.16 | 1.26 | 1.57 |
| 2030 | 1.19 | 1.32 | 1.72 |
| 2035 | 1.21 | 1.38 | 1.90 |
| 2040 | 1.24 | 1.44 | 2.09 |
| 2045 | 1.26 | 1.51 | 2.30 |
| 2050 | 1.29 | 1.58 | 2.53 |
| 2055 | 1.31 | 1.66 | 2.78 |
| 2060 | 1.33 | 1.75 | 3.05 |
| 2065 | 1.36 | 1.83 | 3.33 |
| 2070 | 1.38 | 1.92 | 3.64 |
| 2075 | 1.41 | 2.02 | 3.96 |



**Figure B.13**. Screen capture of a sea level change calculation example for Nāwiliwili out to 2100 using the U.S. Army Corps of Engineers (Army Corps) Sea Level Change Calculator. The calculator provides a table and curves of sea level predictions for low, intermediate, and high scenarios.

### Description and Intended Use

The U.S. Army Corps of Engineers (Army Corps) Sea Level Change Calculator ("the Calculator") was developed to allow evaluation of Army Corps construction projects with respect to projected sea level change. Calculator inputs include Project Start Year (e.g., construction), Base Flood Elevation (BFE), and Project End Year (e.g., lifetime of structure). The Calculator also accounts for localized subsidence by selecting the nearest NOAA tide gauge station form a dropdown list. The Calculator produces sea level predictions at Low, Intermediate, and High scenarios. The three scenarios result in global eustatic SLR (global average, disregarding local rates of subsidence) by the year 2100 of 0.5, 1.0, and 1.5 meters. The predictions are presented in a table (at an adjustable interval in years) and a plot showing predicted sea level height curves for the three scenarios over time.

### How it Was Created

The Calculator was developed with assistance from coastal scientists at NOAA and the U.S. Geological Survey to infuse federal guidance on sea level change into Army Corps engineering projects. The "Low" scenario is based on the historical rate of sea-level rise at the selected NOAA gauge station. The "Intermediate" scenario is computed from a modified National Research Council (NRC) Curve (Curve I) with local rate of vertical land motion considered. The "High" scenario is computed from a modified NRC Curve II considering land motion.

### Use in Climate and Sea-Level Rise Planning

The Calculator was developed specifically for use in evaluation of Army Corps projects with respect to sea level changes. To our knowledge the Calculator has not been used for evaluation of projects outside of the Army Corps. However, the Calculator is presented here as an example of an excellent way of looking at scenario-based SLR hazards (e.g., Low, Med., High) based on the projected life of a project. The Calculator is particularly useful in predicting localized SLR flooding hazards, in that it allows the user to input a FEMA or other BFE on top of the predicted sea level at a given year. A similar tool could be developed for Kaua‘i County based on the County's preferred/adopted SLR planning scenarios (SLR curves).

### Limitations

The Calculator is intended for Army Corps projects only. While it may be useful for estimating SLR hazards for County projects, the County would probably need to adopt specific SLR planning scenarios (e.g., SLR curves) and new policy before this or a similar tool could be used in evaluation of development plans (e.g., calculation of BFE).

# Appendix C

Photo: Dolan Eversole

## SEA-LEVEL RISE INUNDATION ASSESSMENTS AND NEEDS FOR SELECT COASTAL AREAS

## INTRODUCTION

Here we present a series of maps depicting sea-level rise (SLR) and coastal flooding impacts for select areas around Kauaʻi. The following maps are intended to provide guidance on the use and interpretation of the NOAA Sea Level Rise and Coastal Impacts Viewer (http://csc.noaa.gov/digitalcoast/tools/slrviewer, referred to herein as the NOAA SLR Viewer) and data layers using examples from select coastal areas around Kauaʻi. This is not intended to be a comprehensive assessment of SLR-related flooding hazards for all coastal areas of Kauaʻi. The maps are produced using flooding hazard GIS layers from the NOAA SLR Viewer.

The areas depicted in the maps were selected based on the following criteria: 1) to provide a geographically-diverse selection of areas around the island, 2) to highlight areas of concentrated population and/or economic vulnerability (e.g., buildings, infrastructure), 3) to provide examples of use and limitations of the NOAA SLR Viewer and dataset, and 4) to feature some areas that stand-out as having particularly high exposure to SLR related hazards.

Please see the Data Inventory (Appendix B) for a detailed description of the methods used by NOAA to develop the flooding hazard areas in the NOAA SLR Viewer. The 11"x17" maps presented here are shown at 1:10,000 scale to be consistent with the zoom limitation in the NOAA SLR Viewer. The maps show flooding scenarios for 1 foot, 3 feet, and 6 feet of SLR. The 1 foot and 3 feet scenarios were selected as roughly consistent with the National Research Council (NRC, 2012) mid-range projection of about 1 foot by 2050 and about 3 feet by 2100. The 6 foot scenario is shown as a high end scenario. Though the likelihood of 6 feet of SLR by 2100 is relatively low, it is within the upper range of predicted scenarios in recent publications (*e.g.*, NOAA 2012). The 6 foot SLR scenario also demonstrates the potential impact of a lesser SLR scenario (e.g., 3 feet) combined with additional flooding from an event such as a hurricane (storm surge) or tsunami.

Blue areas in the maps represent areas that are most likely (have high statistical confidence) of being flooded at the given sea-level rise scenario during the highest tides. In other words, there is high likelihood that these areas will be below sea level based on the accuracy of the topographic analysis and mapping methods by the NOAA and University of Hawaiʻi researchers. Yellow areas are susceptible to flooding at the given SLR scenario but have lower confidence/likelihood. Areas with no shading have high confidence of not being flooded at the given SLR scenario. Further description of methods and accuracy of the data is available in the Data Inventory, the enclosed map sidebars, and in the NOAA SLR Viewer.

The maps depict the effect of a static (flat water) increase in sea level. The model does not consider natural processes such as coastal erosion or marsh migration that will be intensified by future sea-level rise.  See Limitations under the NOAA Sea Level Rise and Coastal Impacts Viewer in the Inventory of Planning Information and Data Products (Appendix B).

The NOAA SLR Viewer provides the following disclaimer, which also applies to these maps, developed from the NOAA data: The data and maps in this tool illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excludes wind driven tides). The data, maps, and information provided should be used only as a screening-level tool for management decisions. As with all remotely sensed data, all features should be verified with a site visit. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. This tool should be used strictly as a planning reference tool and not for navigation, permitting, or other legal purposes.

## OVERALL FINDINGS: HAZARDS AND NEEDS ASSESSMENT

Following is a summary of the results of the SLR-Related Hazards Assessments and Needs for Select Coastal Areas, which are common to some or all of the example map areas:

### SLR-Related Hazards

- First, it is important to note that NOAA SLR Viewer and these maps show the results of a numerical model of a static increase in sea-level.  In reality, the effects of this increase in average sea level height will be event-based or episodic, with impacts punctuated and compounded by events such as seasonal high waves, and storms and rainfall, which are not accounted for in the maps.
- The NOAA SLR Viewer data generally shows limited flooding/inundation hazards in shorefront areas.  This is an important gap in this data set.  Numerical models and observations of shoreline response to SLR indicate that 1 foot of SLR can lead to as much as 100 feet of shoreline recession, which will threaten coastal properties with increased flooding and land loss and is not depicted in the NOAA SLR Viewer layers and following maps.
- The 1 foot SLR scenario, which is a reasonable planning scenario for 2050 based on the NRC (2012) mid-range projection, shows potential for widespread flooding, particularly in the featured (sample) areas in this assessment of Hanalei, Anahola, Kapaʻa-Wailua, and Hanapēpē.
- The 3 foot SLR scenario, which is a reasonable planning scenario for 2100 based on the NRC (2012) mid-range projection, shows potential for catastrophic flooding on a regular basis for many coastal properties, particularly in areas already within the FEMA 100-year flood zones.

- The 6 foot SLR scenario, which is shown as a high-end scenario from recent studies (*e.g.*, NOAA 2012), indicates a potential for permanent flooding and geomorphic change (*e.g.*, wetland creation) in low-lying coastal areas.
- The results indicate flooding in many areas that may not have a direct hydraulic connection to the sea. This type of flooding can result from elevation of the underlying water table and/or impaired drainage with rising water level. The severity of this type of flooding may be underestimated in these maps in areas where the water table is above high tide elevation.

**Needs**

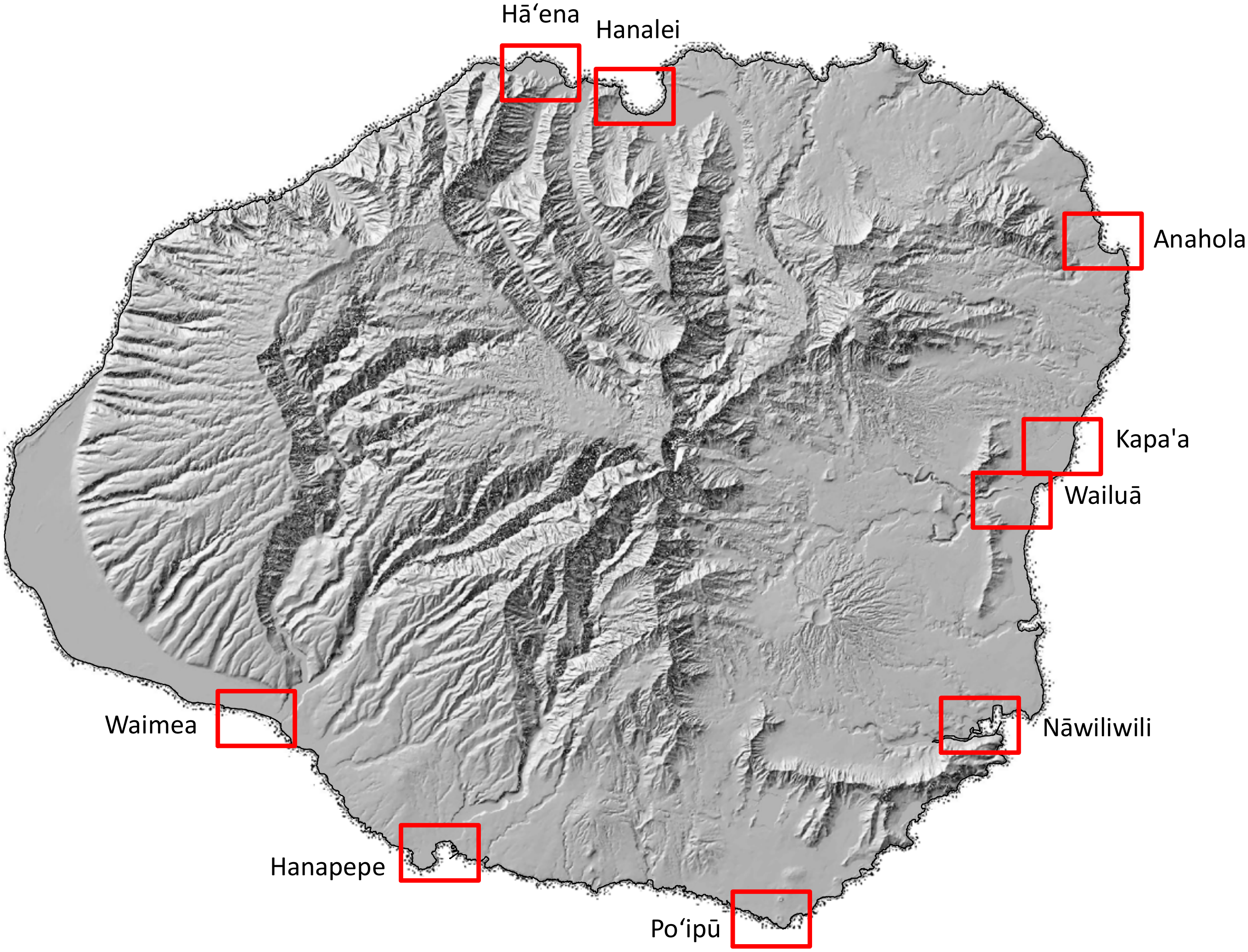
- The purpose of the NOAA SLR Viewer is to provide a preliminary look at SLR and coastal flooding impacts. It is intended to be used as a screening tool to inform management decisions and long-range planning. The data depicted in the Viewer and following maps should be used as a screening tool to inform development of more detailed community-scale vulnerability assessments and long-range adaptation planning.
- Historical shoreline studies by the U.S. Geological Survey and University of Hawaiʻi (Fletcher et al., 2012) indicate that 71% of beaches are eroding on Kauaʻi. This percentage is sure to increase with increasing SLR. The NOAA SLR Viewer does not account for coastal processes such as shoreline erosion and wave-induced inundation. Detailed modeling at the parcel-level scale is needed to predict future shoreline locations and identify erosion hazard areas with increasing SLR to facilitate vulnerability assessments and adaptation measures.
- In many locations, the SLR flooding areas are similar in extent to the FEMA FIRM flood zones. This indicates that these flood zones will flood more frequently and with increased severity - over a larger area and higher base flood elevation. The County may adopt requirements for flood hazard mitigation/adaptation that account for SLR hazards and are above and beyond the FIRM flood zones and BFEs.
- The NOAA SLR Viewer provides a first-order assessment of hazards for many critical facilities and infrastructure including roadways and port facilities. Detailed vulnerability analysis and adaptation plans are needed for critical facilities and infrastructure around the island.
- Restrictions on coastal land use and development are needed to protect public safety and limit economic risk from increased flooding and coastal land loss (erosion) with SLR. Where possible, County and State agencies should use existing rules and policy to promote adaptation for climate change and SLR. Important policies for SLR and climate adaptation include shoreline building setbacks, flood zone building regulations, limitations on property subdivision, and prohibition of coastal armoring (seawalls) in select areas to conserve beach ecosystems.
- Impacts from climate change and SLR will not happen at a steady pace along our coasts. Rather, these changes will be compounded by events such as high waves, storms, and

tsunamis with increasing frequency and severity with climate change and SLR. Post-disaster plans are needed to chart a course for suitable re-development of coastal areas after a large event. Properly designed post-disaster plans will ensure that communities and infrastructure are rebuilt with increased capacity to withstand future events. Alternatives to coastal hardening, such as landward relocation, should be considered in post-disaster plans to move buildings and infrastructure out of chronic flooding and erosion areas.

KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

*Potential Sea Level Rise Scenarios*

**Map Index - Island of Kauaʻi**



## HĀ‘ENA

The community of Hā‘ena is featured as an example area for SLR hazard and needs assessment because of relatively dense north shore coastal community development and exposure to other coastal hazards, including flooding from high waves and tsunami. The area includes Hā‘ena Beach Park and Tunnels Beach, one of the north shore's most popular ocean recreation sites.

SLR-Related Hazards

- The NOAA SLR Viewer layers indicate little or no flooding of backshore areas at +1 and +3 feet, except at Wainiha where there is high potential for flooding of areas near the stream mouth.
- Some areas of flooding begin to appear (mostly low confidence, yellow) in Hā‘ena, landward of Kūhiō Highway in the +3 foot scenario.
- The +6 foot scenario indicates substantial areas of flooding at Hā‘ena, particularly landward of Kūhiō Highway.
- The +6 foot scenario also indicates flooding of much of the lower valley at Wainiha and the potential for dramatic morphological change around the stream mouth.

Needs

- Given the high degree of exposure to coastal hazards at Hā‘ena - Wainiha, a community-scale risk and vulnerability assessment is advised.
- Develop an adaptation plan for areas with high SLR-related hazards, including coastal areas facing increased erosion and wave inundation.
- All SLR scenarios in the NOAA data show little or no inundation of beach front parcels. Historical shoreline studies indicate a long-term trend of beach erosion (recession) throughout Hā‘ena - Wainiha. Erosion is sure to increase with increasing SLR. Modeling and mapping of increased erosion and wave inundation hazards is needed at the parcel level to fill this obvious gap in the NOAA SLR data.
- Nearly all of the parcels at Hā‘ena – Wainiha are within the Flood Insurance Rate Map (FIRM) Zone VE (additional hazards due to wave action) with Base Flood Elevations (BFE) of 20 feet or more. How will these flood hazard areas and BFEs change with SLR? The County may adopt requirements for flood hazard mitigation/adaptation that account for SLR hazards and are above and beyond the FIRM flood zones and BFEs.
- A special assessment of the vulnerability of Kūhiō Highway, including bridges, considering climate and sea level change is needed, as this road provides the only access into and out of the area.
- Prohibition of coastal property subdivision to limit exposure to coastal hazards and prohibition of shoreline armoring to conserve beach ecosystems should be considered.


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *1 Foot Potential Sea Level Rise Scenario*

**Hāʻena, Kauaʻi**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
The data presented in this map illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excluding wind driven tides). The data should be used only as a screening-level tool for management decisions. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. The data should be used strictly as a planning reference and not for navigation, permitting, or other legal purposes.

Data Source:
National Oceanic and Atmospheric Administration (NOAA),
Ocean Services, Coastal Services Center (November 2013)
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*March 2014*


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *3 Foot Potential Sea Level Rise Scenario*

**Hāʻena, Kauaʻi**

## MAP CONTENTS

**Water Depth**

- Deeper
- Shallower
- Low Lying Areas
- TMK Boundaries
- Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
The data presented in this map illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excluding wind driven tides). The data should be used only as a screening-level tool for management decisions. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. The data should be used strictly as a planning reference and not for navigation, permitting, or other legal purposes.

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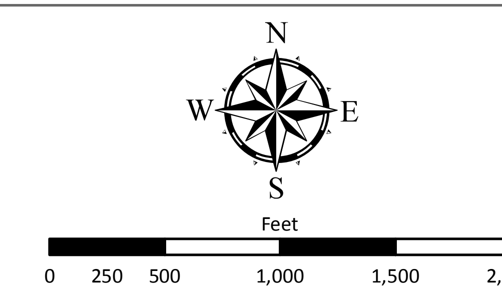


March 2014


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *6 Foot Potential Sea Level Rise Scenario*

**Hāʻena, Kauaʻi**

### MAP CONTENTS

**Water Depth**

- Deeper
- Shallower

Low Lying Areas

TMK Boundaries

Roads

### MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
The data presented in this map illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excluding wind driven tides). The data should be used only as a screening-level tool for management decisions. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. The data should be used strictly as a planning reference and not for navigation, permitting, or other legal purposes.

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## HANALEI

The community of Hanelei is one of the larger population centers on the north shore and also serves as a hub for tourism activities in the area. The community is highly susceptible to coastal hazards, particularly flooding and damage from high waves, tsunami, and land-based flooding.

SLR-related Hazards

- With just 1 foot of SLR there is potential for greatly increased frequency and severity of flooding around Hanalei and Waiʻoli Streams.
- The 3 and 6-foot SLR scenarios indicate large areas of flooding (blue areas) around Hanalei and Waiʻoli Streams, as well as around the west end of the bay around Waipā Stream, threatening a number of residential properties.
- The 3 and 6-foot scenarios indicate dramatic changes, particularly in the low-lying areas around Hanalei Stream Mouth with an apparently high likelihood of creation of new wetlands and permanently submerged areas and changes to the morphology of the stream mouth including Hanalei Black Pot Beach Park.
- This analysis also highlights the vulnerability of Kūhiō Highway to flooding, particularly between the Hanalei Bridge and Hanalei town center.

Needs

- Given the high degree of exposure to flooding hazards at Hanalei, a community-scale risk and vulnerability assessment considering climate change and SLR is advised.
- Develop an adaptation plan for areas with high SLR-related hazards, including coastal areas facing increased erosion and wave inundation.
- University of Hawaiʻi erosion studies indicate long-term accretion (seaward shoreline movement) along much of Hanalei Beach. Modeling and mapping of shoreline change, accounting for increased SLR is needed to determine if and when this overall trend of shoreline accretion-stability will change to erosion.
- The entire Hanalei community is within the 100-year FEMA FIRM flood plain. Most beach front parcels are within the VE zone with increased hazards from wave flooding and BFEs greater than 10 feet. The County may adopt requirements for flood hazard mitigation/adaptation that account for SLR hazards and are above and beyond the FIRM flood zones and BFEs.
- A special assessment of the vulnerability of Kūhiō Highway is needed as this road provides the only access between Hanalei and the rest of the north shore.
- Prohibition of coastal property subdivision to limit exposure to coastal hazards and prohibition of shoreline armoring to conserve beach ecosystems should be considered.


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *1 Foot Potential Sea Level Rise Scenario*

**Hanalei, Kaua'i**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *3 Foot Potential Sea Level Rise Scenario*

### Hanalei, Kaua'i

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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The data presented in this map illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excluding wind driven tides). The data should be used only as a screening-level tool for management decisions. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. The data should be used strictly as a planning reference and not for navigation, permitting, or other legal purposes.

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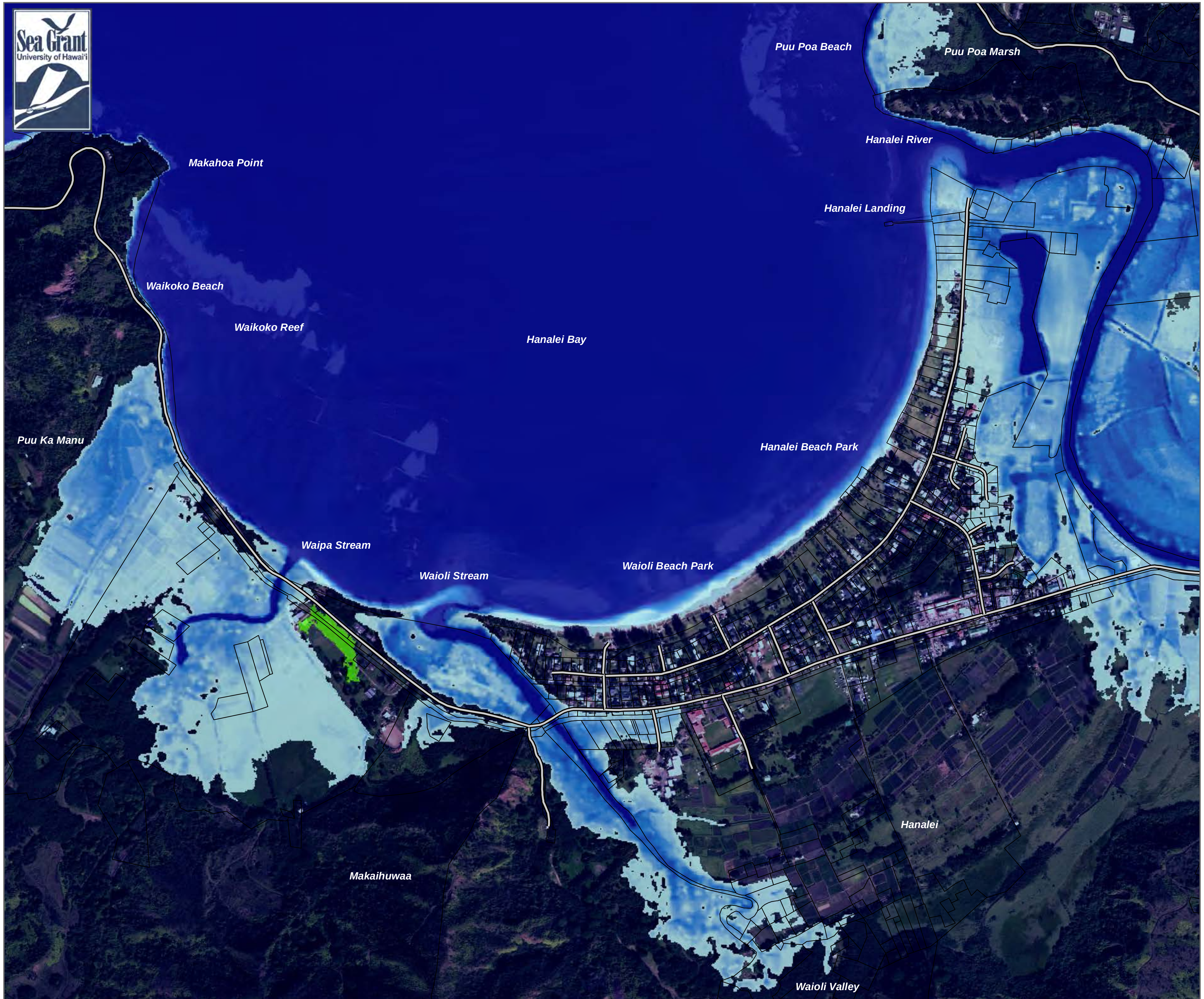


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *6 Foot Potential Sea Level Rise Scenario*

**Hanalei, Kaua'i**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
The data presented in this map illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excluding wind driven tides). The data should be used only as a screening-level tool for management decisions. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. The data should be used strictly as a planning reference and not for navigation, permitting, or other legal purposes.

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## ANAHOLA

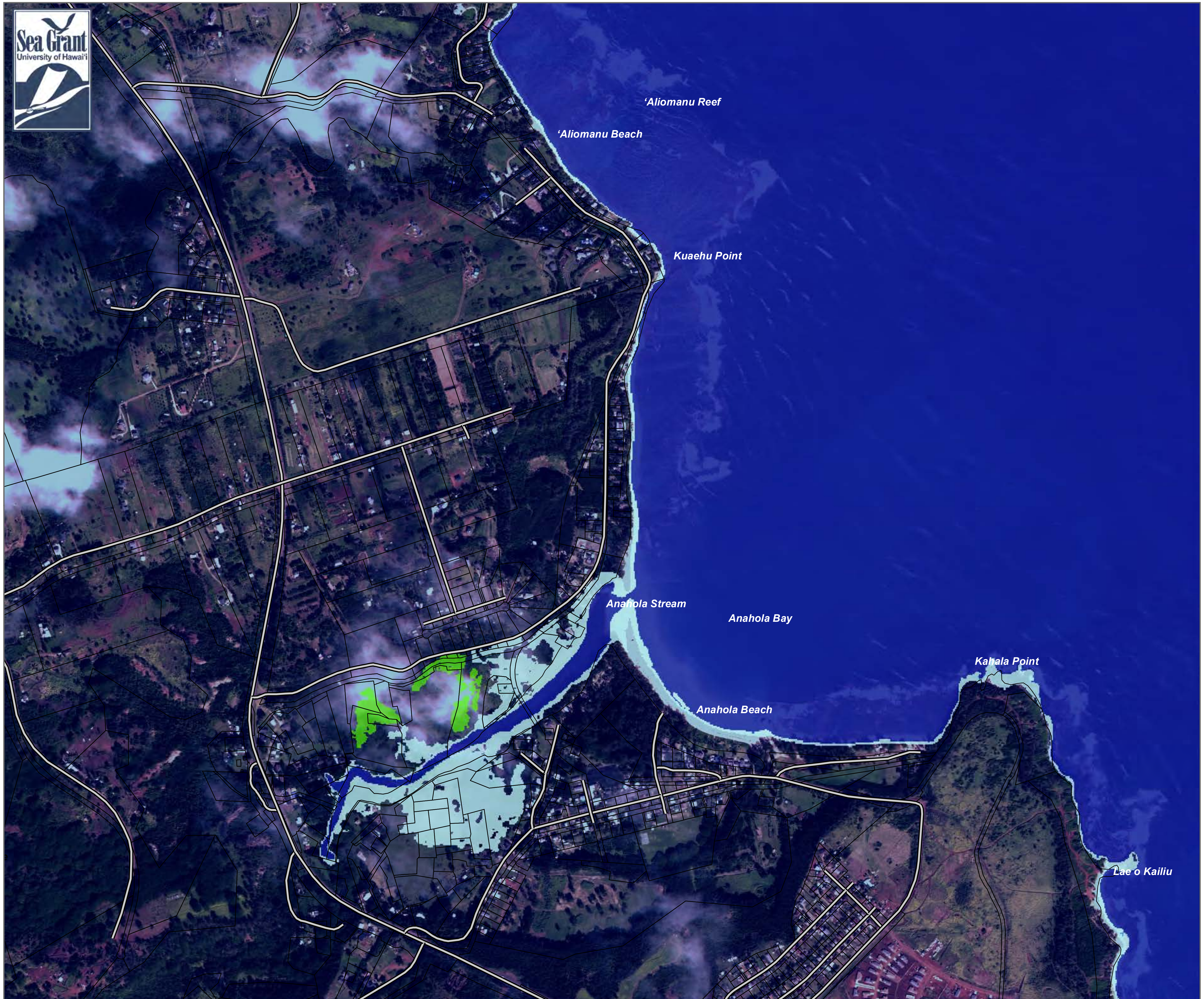
Anahola is presented as the largest of several communities along the northeast coast occupying low-lying coastal areas adjacent to stream mouths that are exposed to coastal hazards. Other examples not shown here but visible in the NOAA SLR Viewer include Kalihiwai and Moloaʻa.

SLR-Related Hazards

- The 1-foot SLR flood hazard zones are largely aligned with the FEMA FIRM Floodway and 100-year flood zones around Anahola Stream.
- The 3-foot SLR hazard zone indicates high confidence of inundation of areas around Anahola Stream and potential (low confidence, yellow) of other backshore areas.
- The 6-foot SLR scenario indicates high confidence of flooding throughout the valley.

Needs

- Given the high degree of exposure to flooding hazards at Anahola, Moloaʻa, and Kalihiwai, community-scale risk and vulnerability assessments considering climate change and SLR are advised.
- Develop an adaptation plan for areas with high SLR-related hazards, including coastal areas facing increased erosion and wave inundation.
- The NOAA SLR Viewer layers indicate little change at the shoreline at Anahola. Improved modelling and mapping is needed to show how these areas will be affected by increased erosion and wave overtopping with increasing SLR.
- While the 1 and 3 foot SLR flooding areas appear to be approximately aligned with the FEMA Flood Ways and 100-Year Flood Areas. This indicates that the Floodways and 100-year flood areas will be expanding as the frequency and severity of flooding events increases with SLR and needs to be updated in the FIRMs. The County may adopt requirements for flood hazard mitigation/adaptation that account for SLR hazards and are above and beyond the FIRM flood zones and BFEs.
- ʻAliomanu Road at the north end of the bay has recently been threatened by coastal erosion. A vulnerability assessment considering SLR is needed for the road adjacent to the stream and shoreline.




# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *1 Foot Potential Sea Level Rise Scenario*

**Anahola, Kaua'i**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:

The data presented in this map illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excluding wind driven tides). The data should be used only as a screening-level tool for management decisions. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. The data should be used strictly as a planning reference and not for navigation, permitting, or other legal purposes.

Data Source:

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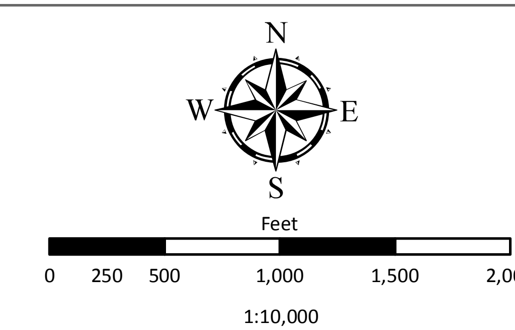


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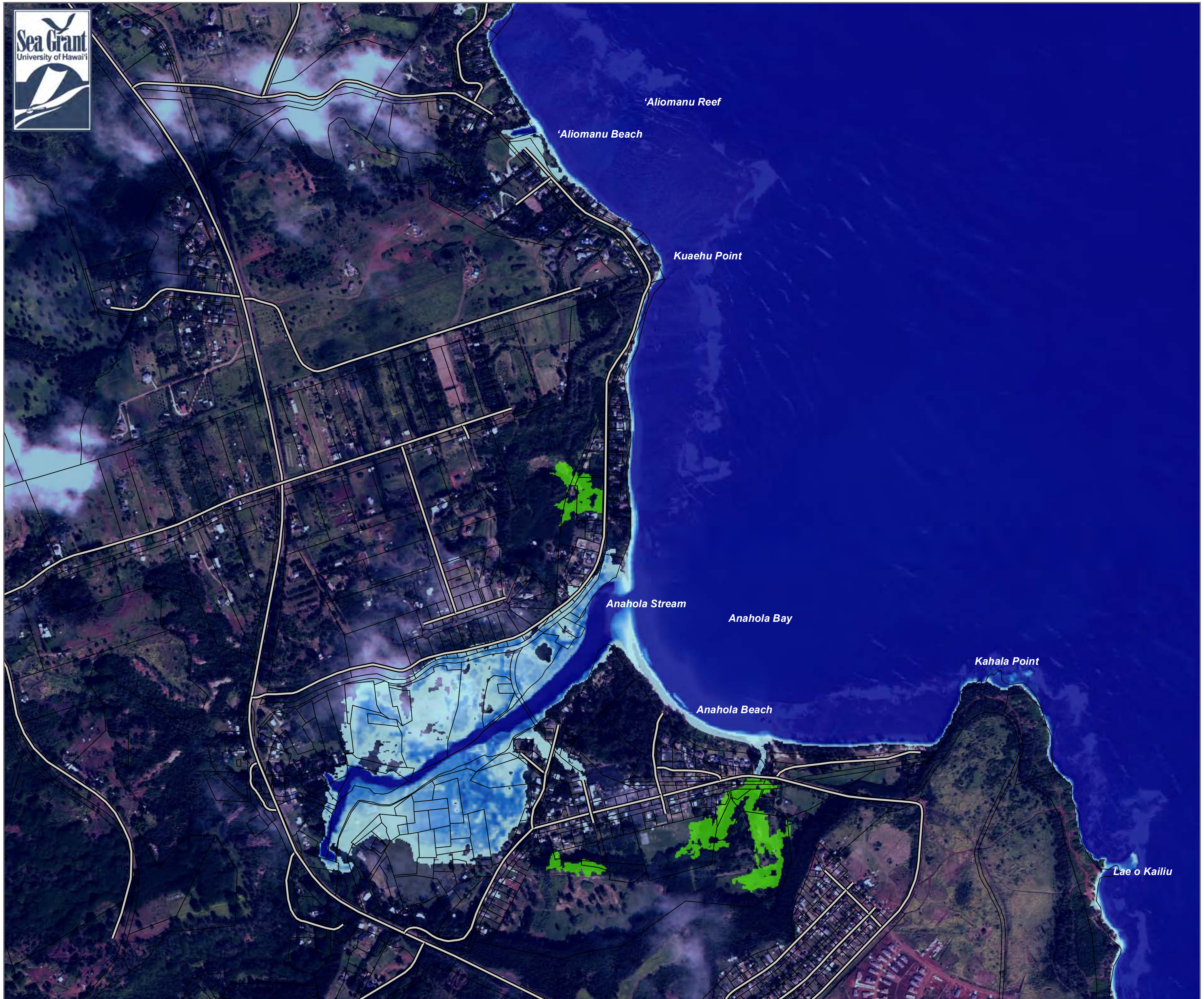


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *3 Foot Potential Sea Level Rise Scenario*

**Anahola, Kaua'i**

## MAP CONTENTS

**Water Depth**

- Deeper
- Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
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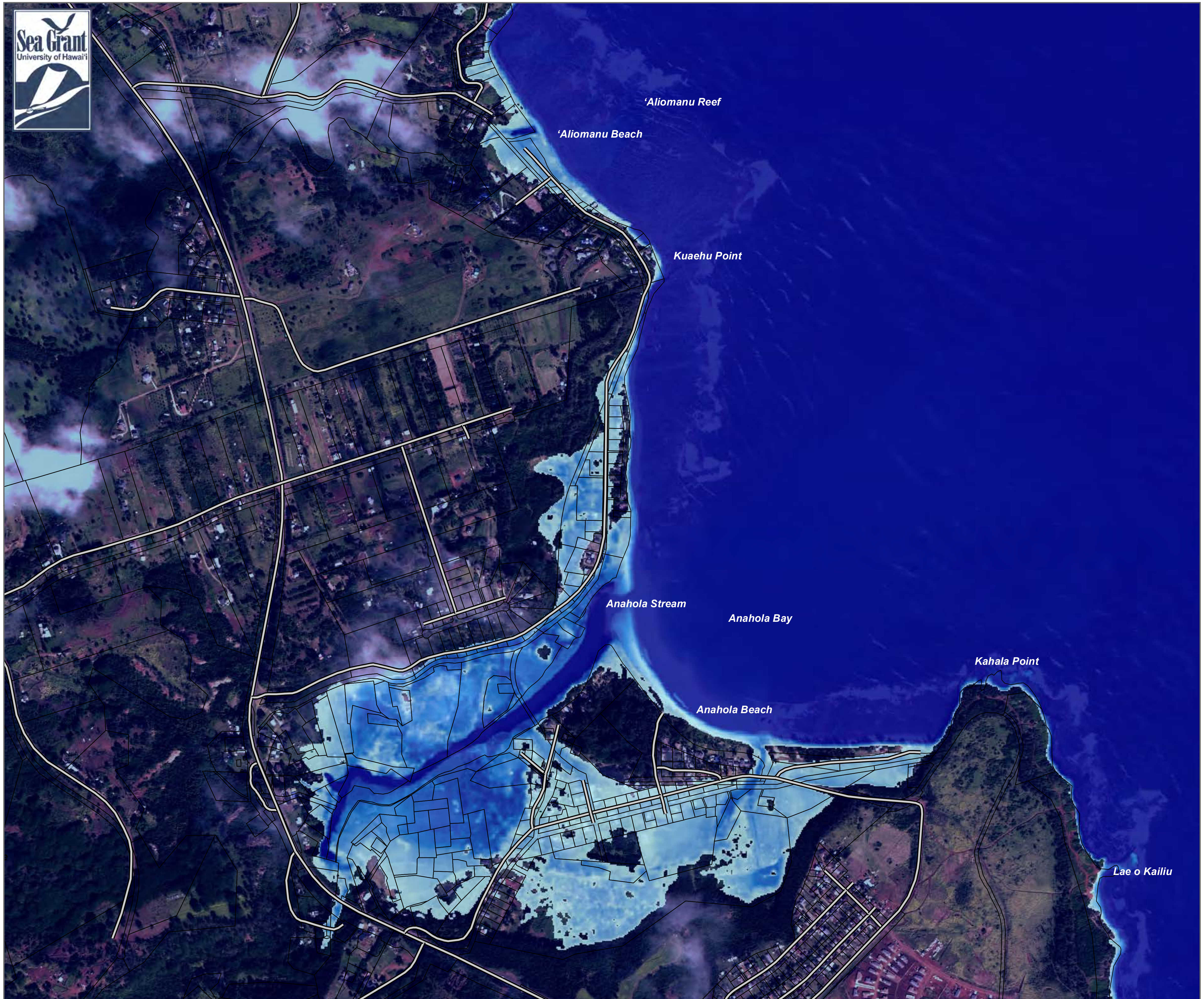


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *6 Foot Potential Sea Level Rise Scenario*

**Anahola, Kaua'i**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
The data presented in this map illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excluding wind driven tides). The data should be used only as a screening-level tool for management decisions. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. The data should be used strictly as a planning reference and not for navigation, permitting, or other legal purposes.

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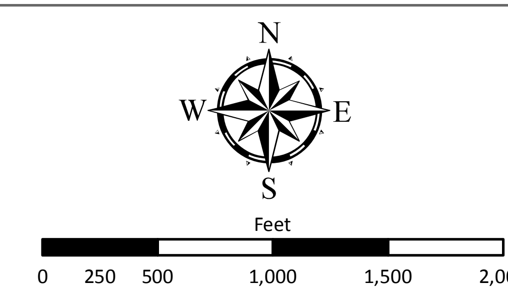


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**KAPAʻA – WAILUA**

SLR hazard maps are shown for the Kapaʻa-Wailua area due to the importance of this area as a residential and economic sector and to show SLR-related impacts for a windward coastal area.

SLR-Related Hazards

- The 1-foot SLR scenario shows potential for flooding, largely confined to presently undeveloped / agricultural areas on the landward side of Kapaʻa town and in low lying areas near the Wailua River mouth.
- The 3-foot SLR scenario shows large areas of flooding mostly landward of Kapaʻa residential areas and around Moikeha and Waiākea Canals and Waialua River. The landward flooding will apparently occur as a result of a rising water table and may create in permanently submerged wetland areas.
- The 6-foot SLR scenario depicts flooding entering more of the shopping and residential areas of Kapaʻa and Wailua, with major inundation around the Wailua River mouth.

Needs

- A community-scale risk and vulnerability assessment for coastal hazards with climate change and SLR with particular focus on vulnerability of essential services and facilities in this population and economic center is recommended.
- Develop an adaptation plan for areas with high SLR-related hazards, including coastal areas facing increased erosion and wave inundation.
- The NOAA SLR flooding hazard layers show little flooding or coastal change along the shoreline - flooding is largely isolated to areas landward of town and around canals and the river. Historical shoreline change studies indicate a long-term trend of shoreline erosion for most of this area, which is sure to increase with increasing SLR. Detailed modeling and mapping of shoreline change and wave inundation hazards is needed to determine the severity hazards to coastal properties, which is not shown in the NOAA data.
- The County may adopt requirements for flood hazard mitigation/adaptation that account for SLR hazards and are above and beyond the FIRM flood zones and BFEs. Limit development in flood-prone areas and prohibit subdivision of ocean-front parcels under existing rules, if possible.
- Consider a regional coastal and beach management plan including regional sand management and beach conservation and restoration as alternatives to increased coastal armoring in residential areas.
- Identify critical facilities and infrastructure that may need protection through a vulnerability assessment.


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *1 Foot Potential Sea Level Rise Scenario*

**Kapaʻa, Kauaʻi**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *3 Foot Potential Sea Level Rise Scenario*

**Kapaʻa, Kauaʻi**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
The data presented in this map illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excluding wind driven tides). The data should be used only as a screening-level tool for management decisions. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. The data should be used strictly as a planning reference and not for navigation, permitting, or other legal purposes.

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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *6 Foot Potential Sea Level Rise Scenario*

**Kapaʻa, Kauaʻi**

### MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

### MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *1 Foot Potential Sea Level Rise Scenario*

**Wailuā, Kaua'i**

### MAP CONTENTS

**Water Depth**

- Deeper
- Shallower
- Low Lying Areas
- TMK Boundaries
- Roads

### MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *3 Foot Potential Sea Level Rise Scenario*

**Wailuā, Kaua'i**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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*March 2014*


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *6 Foot Potential Sea Level Rise Scenario*

**Wailuā, Kaua'i**

## MAP CONTENTS

**Water Depth**

- Deeper
- Shallower
- Low Lying Areas
- TMK Boundaries
- Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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## NĀWILIWILI

Nāwiliwili is shown as an example for SLR hazard assessment using the NOAA SLR Viewer data due to its importance as an industrial and port area. Nāwiliwili provides an example of an area with key infrastructure that may require protection to maintain essential services (*e.g.*, shipping).

SLR-Related Hazards

- The 1-foot SLR scenario indicates potential flooding (yellow, low confidence) around Nāwiliwili Stream (Kalapaki Beach), Nāwiliwili Small Boat Harbor, and the banks for Hule‘ia Stream.
- The 3 and 6 foot SLR scenario indicate increasing severity of flooding around Nāwiliwili Stream (Kalapaki Beach) and residential areas at the back of the harbor, and inundation of harbor facilities.

Needs

- Develop a risk and vulnerability assessment for port facilities and resort area at Kalapaki with consideration of climate change and SLR impacts.
- Develop an adaptation plan for improved protection of critical port facilities based on a vulnerability assessment.
- FEMA FIRMs indicate most of the shoreline around Kalapaki and Nāwiliwili is outside the 100-year floodplain (X Zone). The County may adopt requirements for flood hazard mitigation/adaptation that account for SLR hazards and are above and beyond the FIRM flood zones and BFEs.


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *1 Foot Potential Sea Level Rise Scenario*

**Nāwiliwili, Kauaʻi**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
The data presented in this map illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction. Water levels are shown as they would appear during the highest high tides (excluding wind driven tides). The data should be used only as a screening-level tool for management decisions. The data and maps in this tool are provided "as is," without warranty to their performance, merchantable state, or fitness for any particular purpose. The entire risk associated with the results and performance of these data is assumed by the user. The data should be used strictly as a planning reference and not for navigation, permitting, or other legal purposes.

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March 2014


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *3 Foot Potential Sea Level Rise Scenario*

**Nāwiliwili, Kaua'i**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

Disclaimer:
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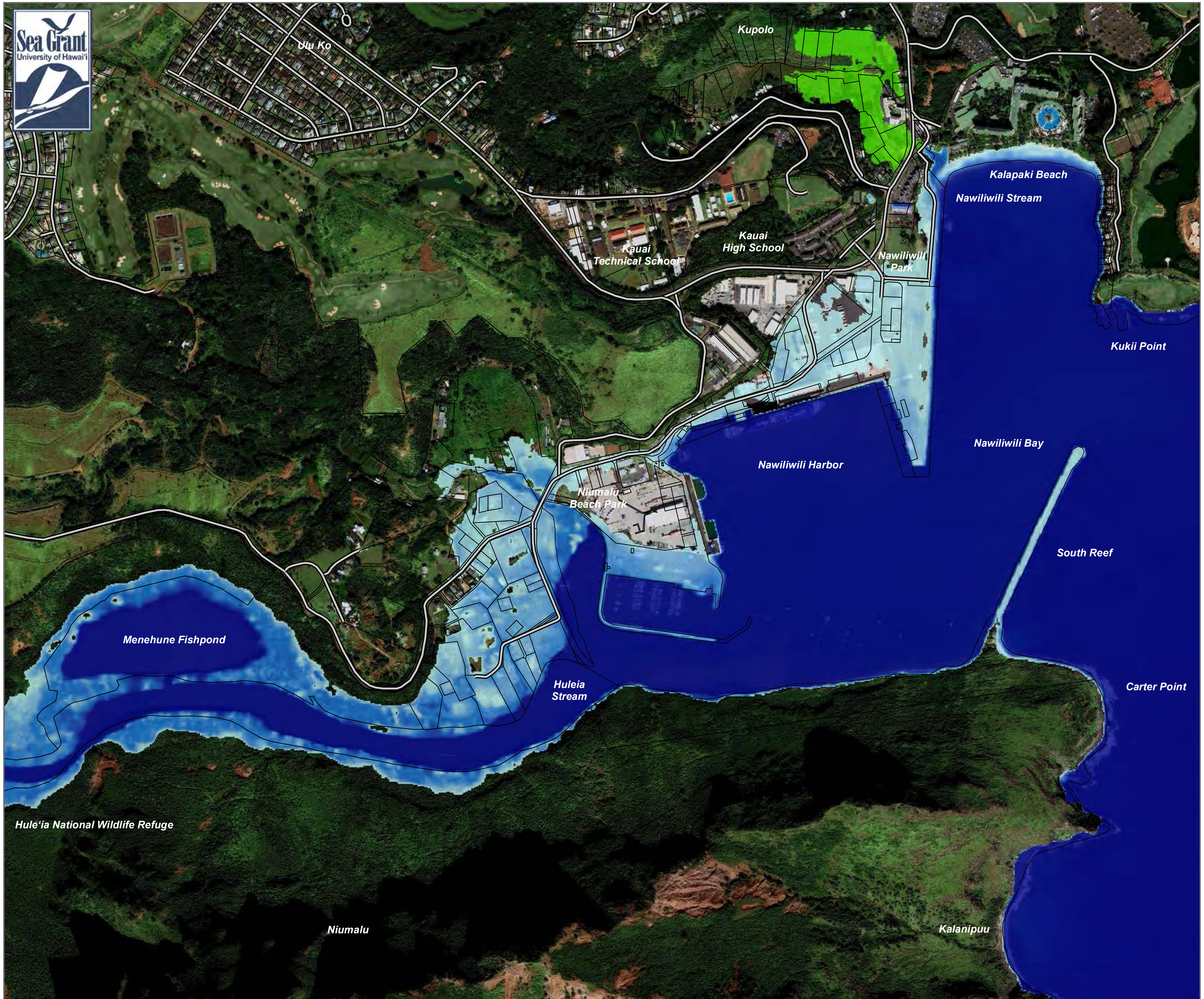


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *6 Foot Potential Sea Level Rise Scenario*

### Nāwiliwili, Kaua'i

## MAP CONTENTS

**Water Depth**

- Deeper
- Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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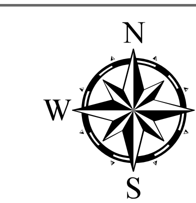


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**PO‘IPŪ**

The area around Po‘ipū Beach is shown as an example of SLR hazards for a south shore community and critical visitor-based economy. Po‘ipū provides one example where the NOAA SLR Viewer may greatly underestimate SLR-related hazards because the model does not account for increased coastal erosion and wave-induced flooding with increasing SLR.

SLR-Related Hazards

- The 1-foot SLR scenario shows limited potential for flooding in a few backshore areas (yellow, low confidence) at Po‘ipū.
- Flooding in the 3 and 6 foot scenarios is limited to isolated areas in the backshore.

Needs

- Develop a community-scale risk and vulnerability assessment for coastal hazards with climate change and SLR with particular focus on vulnerability of beach resources and resort facilities.
- Develop an adaptation plan for areas with high SLR-related hazards, including coastal areas facing increased erosion and wave inundation.
- The NOAA SLR flooding hazard layers show little flooding or coastal change at the shoreline. Historical shoreline change studies indicate a long-term trend of shoreline erosion for most of this area, which is sure to increase with increasing SLR. Detailed modeling and mapping of shoreline change and wave inundation hazards is needed to determine the severity hazards to coastal properties and beach resources, which is not shown in the NOAA data.
- Develop a regional coastal and beach management plan (County, DLNR, UH Sea Grant) to conserve the beach resources critical to the local visitor industry and community, promoting alternatives to increased coastal armoring such as beach restoration.


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *1 Foot Potential Sea Level Rise Scenario*

**Po'ipū, Kaua'i**

## MAP CONTENTS

**Water Depth**

- Deeper
- Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *3 Foot Potential Sea Level Rise Scenario*

**Po'ipū, Kaua'i**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *6 Foot Potential Sea Level Rise Scenario*

**Po'ipū, Kaua'i**

### MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

### MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

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## HANAPĒPĒ

The Hanapēpē area is shown as an example for analysis of SLR-related hazards for a south shore community including critical port facilities.

SLR-Related Hazards

- The 3 foot SLR scenario indicates potential for widespread flooding along the east bank of the Hanapēpē River and Salt Pond Beach Park.
- The 6 foot SLR scenario indicates widespread inundation along both sides of the River and Salt Pond Beach Park.

Needs

- Conduct a risk and vulnerability assessment with particular focus on the Hanapēpē River mouth and Port Allen facilities.
- The NOAA SLR data shows limited flooding hazard to the Port Allen Harbor and industrial facilities. Improved modeling is needed to understand changing wave inundation and flooding hazards with increasing SLR along this engineered, rocky coast.
- Develop climate change and SLR adaptation plans for Hanapēpē community (e.g., protection, levees?) and Port Allen (e.g., improved coastal protection, relocation of critical facilities and hazardous materials)

The County may adopt requirements for flood hazard mitigation/adaptation that account for SLR hazards and are above and beyond the FIRM flood zones and BFEs.


# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *1 Foot Potential Sea Level Rise Scenario*

**Hanapepe, Kaua'i**

## MAP CONTENTS

**Water Depth**

- Deeper
- Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *3 Foot Potential Sea Level Rise Scenario*

**Hanapepe, Kaua'i**

### MAP CONTENTS

**Water Depth**

- Deeper
- Shallower

Low Lying Areas

TMK Boundaries

Roads

### MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *6 Foot Potential Sea Level Rise Scenario*

### Hanapepe, Kaua'i

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

Sea level around the Island of Kauai is currently rising at an average rate of 1.53mm/yr and is projected to continue to rise at an accelerated rate both globally and locally. The purpose of this data is to provide a preliminary look at sea level rise and coastal flooding impacts. It is intended to be used as a screening level tool to inform management decisions and long-range planning. The data depicted in this map can assist local planning authorities in better understanding the potential impacts of rising sea levels and developing appropriate adaptation strategies. The data does not consider future changes in coastal geomorphology and natural processes such as erosion, subsidence, or future construction. The data does not accurately depict vulnerability to future coastal hazards such as hurricanes and tsunamis. The data does not specify timing of inundation depths and is not appropriate for conducting detailed spatial analysis.

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## WAIMEA – KEKAHA

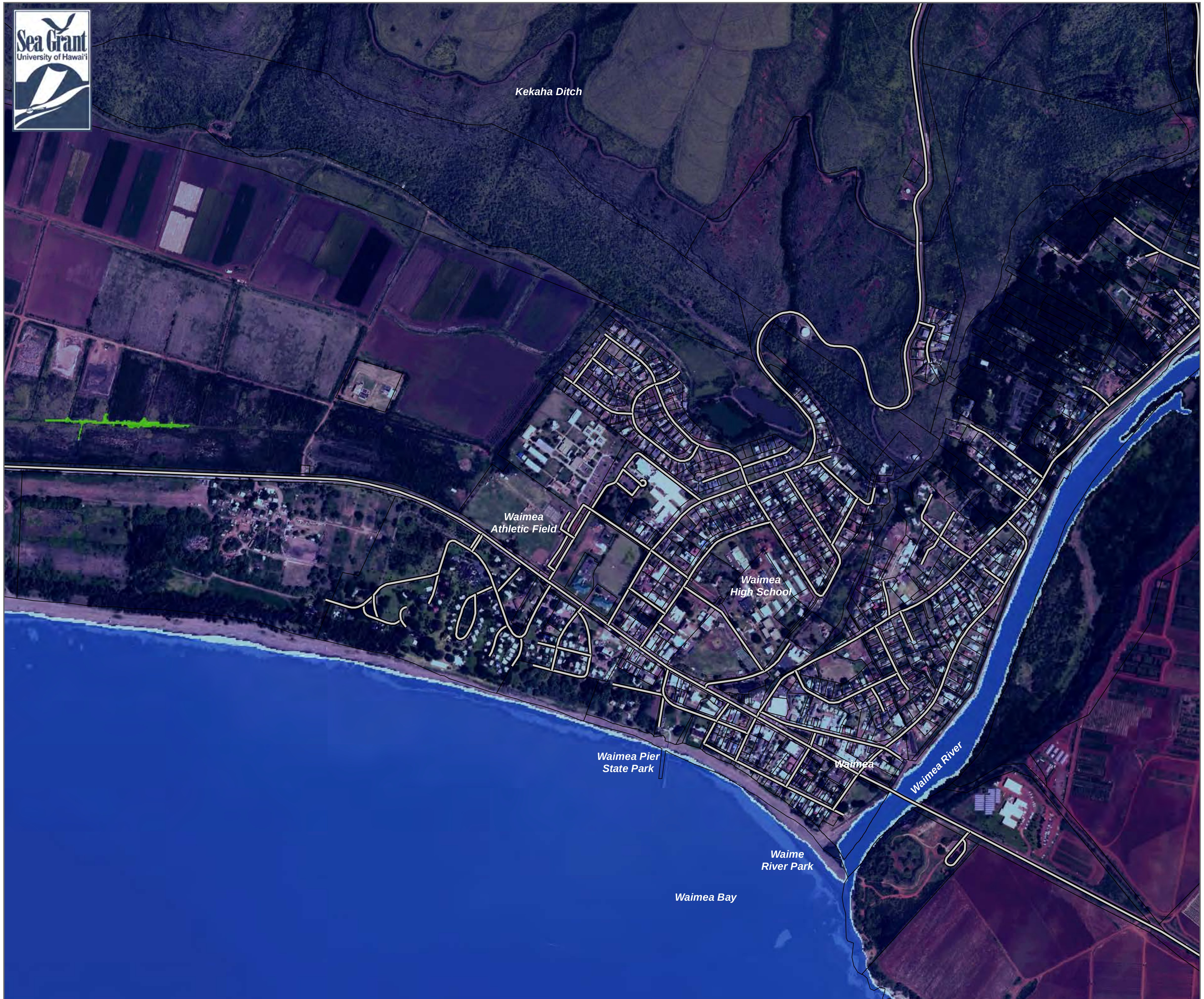
The Waimea – Kekaha area is shown as an example of the vulnerability of areas on the low-lying Mānā coastal plain to flooding hazards, which will increase with increasing SLR. SLR-induced flooding threatens both residential and agricultural areas in the region.

SLR-Related Hazards

- Agricultural areas landward of Kaumuali'i Highway are at risk of flooding (yellow, low confidence) with only 1 foot of SLR, which will probably be manifested as reduced drainage capacity in this already flood-prone area (within the FIRM 100-year flood plain). A rising water table with increasing SLR could threaten these low-lying agricultural areas with contamination from intruding salt water.
- The 3-foot SLR scenario results increasing flood hazard for residential properties on the west bank of the Waimea River (yellow, low confidence) and increased flooding hazard to agricultural lands landward of Kaumuali'i Highway (blue, high confidence), perhaps resulting in creation of new wetland areas.
- The high-end 6-foot SLR scenario results in flooding across most of the lower areas of Waimea adjacent to the river mouth and widespread inundation across agricultural lands landward of Kaumuali'i Highway. The 6-foot scenario also begins to show flooding along shorefront areas (yellow, low confidence) from the increase in static water level – not including the influence of waves.

Needs

- Conduct a risk and vulnerability assessment with particular focus on low-lying areas adjacent to the Waimea River, low-lying agricultural lands, beach-front properties, and Kīkīaola Small Boat Harbor.
- Develop climate change and SLR adaptation plans with particular focus on the areas mentioned above.
- The County may adopt requirements for flood hazard mitigation/adaptation that account for SLR hazards and are above and beyond the FIRM flood zones and BFEs. Limit or prohibit re-zoning of flood-prone agricultural lands.
- Develop a sediment management plan (regular sand bypassing) at Kīkīaola Small Boat Harbor, which is acting to trap sand against the east breakwall and exposing properties to the west to increased erosion and wave inundation.




# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *1 Foot Potential Sea Level Rise Scenario*

**Waimea, Kauaʻi**

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

***3 Foot Potential Sea Level Rise Scenario***

**Waimea, Kaua'i**

## MAP CONTENTS

**Water Depth**

- Deeper
- Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

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# KAUA'I CLIMATE CHANGE AND COASTAL HAZARDS ASSESSMENT

## *6 Foot Potential Sea Level Rise Scenario*

Waimea, Kauaʻi

## MAP CONTENTS

**Water Depth**

Deeper

Shallower

Low Lying Areas

TMK Boundaries

Roads

## MAP DESCRIPTION

Blue areas denote the potential for inundation due to future sea level rise. Levels represent inundation at high tide. Areas that are hydrologically connected are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data captures the area's hydraulics. A more detailed analysis of these areas is required to determine the susceptibility to flooding.

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