West Kaua'i Community Vulnerability Assessment

June 2020

Department of Urban and Regional Planning

Prepared by:
University of Hawai'i Sea Grant College Program

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ACRONYMS AND ABBREVIATIONS

ADC	Agribusiness Development Corporation
BMP	Best Management Practices
CERT	Community Emergency Response Team
CO_2	Carbon Dioxide
CRS	Community Rating System
CVA	Community Vulnerability Assessment
DEM	Digital Elevation Model
DHHL	Department of Hawaiian Home Lands
DOBOR	Department of Boating and Recreation
DOW	Department of Water
ERP	Emergency Response Plan
EWS	Early warning systems
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GWI	Groundwater Infiltration
HEMA	Hawaiʻi Emergency Management Agency
HHARP	Hawaiʻi Hazards Awareness and Resilience Program
HI SLR Report	Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report
IAL	Important Agricultural Lands
IPCC	Intergovernmental Panel on Climate Change
KAA	Kekaha Agricultural Association
KEMA	Kauaʻi Emergency Management Agency
KIUC	Kauaʻi Island Utility Cooperative
LID	Low Impact Development
MOU	Memorandum of Understanding
NFIP	National Flood Insurance Program
NRCS	Natural Resources Conservation Service
OHA	Office of Hawaiian Affairs
OSDS	Onsite Disposal Systems
PDO	Pacific Decadal Oscillation
PI	Principal Investigator
PMRF	Pacific Missile Range Facility
ppm	Parts Per Million
PV	Photo Voltaic
PVC	Polyvinyl Chloride
RCP	Representative Concentration Pathways of Greenhouse Gases
SFHA	Special Flood Hazard Area
SHPD	State Historic Preservation Department
SLR	Sea Level Rise
SLR-XA	SLR exposure area
VCAPS	Vulnerability, Consequences, and Adaptation Planning Scenarios
VUE	Visual Understanding Environment

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Coastal erosion threatening Kaumualiʻi Highway in Kekaha, 2012. Source: Ruby Pap.

EXECUTIVE SUMMARY

Sea level in Kauaʻi has risen 6.6 inches in the past century and could rise up to 96 inches by the end of this century[1,2]. West Kauaʻi's coastline is vulnerable to sea level rise (SLR) and its associated coastal hazards. With miles of beaches, dunes, wetlands, and countless properties and community assets threatened by SLR, the West Kauaʻi community engaged in the critical task of assessing these threats and identifying actions that can be taken to address them.

The West Kauaʻi Community Vulnerability Assessment (CVA) is the culmination of community members, leaders, and asset managers who dedicated hundreds of hours to providing their in-depth knowledge about how natural, cultural, and community resources could be vulnerable to sea level rise. This CVA is a thorough documentation of places, resources, and structures that could be impacted by SLR, by integrating the best available climate change science with on-the ground community knowledge and expertise. Led by the University of Hawaiʻi Sea Grant College Program, the West Kauaʻi CVA began February 2018 with financial support from the National Oceanic and Atmospheric Association (NOAA) funding Grant #NA18OAR170076 and in kind support from the County of Kauaʻi Planning Department.

One of the four hour-long West Kauaʻi Community Vulnerability Assessment Workshops. Source: Ruby Pap

An important outcome of the West Kauaʻi CVA process is the critical information it provides for the update of the West Kauaʻi Community Plan, a planning tool used by the County of Kauaʻi to guide development and the protection of resources. The outcomes from the West Kauaʻi CVA are also important for the next steps of the climate change adaptation process, typically involving an adaptation plan, climate action plan, or resiliency plan. The information provided can also inform future hazard mitigation plans or be used by community organizations and public agencies during their efforts to protect coastal resources, public safety and access to resources.

This vulnerability assessment presents profiles of assets, facilities, and resources identified by the community as management concerns, and describes their vulnerability to three primary coastal hazards: (1) coastal erosion; (2) passive flooding; and (3) annual high wave flooding. These management concerns include:

- Transportation and evacuation
- Drainage
- Critical infrastructure, including levees, wastewater, water, and electricity
- Beaches and coastal properties
- Cultural resources
- Agriculture

Each management concern chapter describes key take-away issues, provides exposure data of the assets or resources, details about potential impacts, and circumstances that increase or decrease vulnerability.

Community profiles highlight vulnerable assets in Hanapēpē-ʻEleʻele, Pākalā Village, Waimea, Kekaha, and Mānā-Polihale. Community profiles summarize key issues for each town or community, the geographic location, highlight community assets that are particularly vulnerable and identify opportunities for adaptation.

Findings from this CVA are based on an inventory of exposed assets to a near-term SLR scenario (1.1 feet) and mid-to-late century scenario (3.2 feet), and in-depth knowledge gathered from community members and asset managers during workshops, interviews, and follow-up conversations. Geospatial SLR exposure data for the three coastal hazards was acquired from the 2017 Hawai'i Sea Level Rise Vulnerability and Adaptation Report (HI SLR Report) and associated online SLR viewer for the 1.1 and 3.2 foot scenarios[3]. The project team used this data to create maps of West Kaua'i exposure overlain on various community assets.

Summary of Findings

In the near-term (1.1' SLR) nearly 100 buildings in West Kaua'i are vulnerable to SLR, 40 percent of which are residential homes. By the second half of the century, with 3.2' SLR, the number of buildings projected to be exposed to SLR more than quadruples. The majority of these buildings are in the town of Kekaha. In the near-term, only two commercial buildings are projected to be exposed to SLR, in the form of passive flooding. However, by mid-to-late century, the number of commercial buildings categorized as vulnerable increases exponentially to 62. These are primarily in Waimea. This amounts to an estimated loss of $423,445,928 in building and property loss (in 2016 U.S. dollars). The following is a summary of findings from this CVA for each of the management concerns and each town. A full list of recommendations can be found in Chapter VI.

Transportation and evacuation

The West Kaua'i transportation system is vulnerable to SLR (i.e., erosion, passive flooding, wave inundation), heavy rainfall, and storm events. Due to a lack of alternative access and evacuation routes, the West Kaua'i community could become cut off and isolated. Several sections of the transportation system are particularly vulnerable and deserve specific study with regard to SLR impacts and alternative options. These are termed, 'roadway choke points' and are discussed in Chapter IV(A).The Pacific Missile Range Facility (PMRF) could become isolated from the rest of West Kaua'i due to the highway's vulnerability in Kekaha. This would have a myriad of economic and social consequences for the community. Ports, harbors, and airports are also vulnerable because they could become inaccessible if the roadway transportation system is not addressed.

There are a number of short-term actions that can be taken to address near-term, nuisance flooding on roads and highways, including developing cane haul roads as alternative access or evacuation routes, and developing maintenance and response plans for water ponding on roads. Long-term options for roadways include relocation, raising, and armoring, each with its own set of impacts and feasibility issues. Detailed feasibility studies of these options are needed.

Drainage

Drainage is insufficient for present day large rain events leading to flooding. Groundwater in the areas surrounding Kekaha is currently pumped to keep the area dry, and has been since the sugar plantation days. High groundwater conditions are expected to worsen with future SLR. The drainage system needs to be studied in detail to better understand the combined risks caused by SLR and changing rainfall patterns. Better coordination across responsible parties, improved maintenance, as well as updating and redesign of the drainage systems is needed to accommodate larger storms. Flooding from inadequate drainage can impact sewer pipes, cesspools, roads, and homes. In Kekaha, this is especially of concern where there are mostly cesspools, no central sewer system.

Wastewater
Flooding from SLR and heavy rainfall can impact both sewer pipes and cesspools. In both the near-term and mid-to-late century SLR projections, wastewater treatment plants appear to be safe from the impacts of SLR. However, two pump stations in Waimea could be impacted by high wave inundation with 3.2 feet of SLR. Higher rates of erosion and groundwater inundation could compromise on-site sewage disposal systems (OSDS), many of which are cesspools. By the latter half of the century, SLR will most likely impact over 100 existing OSDS. Groundwater is also expected to rise with sea level with consequences for wastewater infrastructure, although a more detailed study is needed to better estimate areas at risk.

Conversion of cesspools is paramount, particularly those at risk of flooding in areas with a high water table and/or are located directly on the coast. A feasibility analysis is needed to assess the best alternative which could be either septic systems, other onsite disposal systems, or extending municipal sewer to homes. In 2018, Hawaiʻi Act 132 was adopted, which requires conversion of all cesspools by 2050. In the long-term, possible public actions include upgrading sewage pipes and fittings to reduce cracks, and raising manholes, which would require raising the streets.

Levees
The river levees provide critical flood protection services to the towns of Waimea and Hanapēpē. The current height of levees is most likely inadequate to protect both towns from future SLR, heavy rainfall, and a combination of both. Sediment build-up in the Hanapēpē and Waimea rivers, as well as a sandbar at Waimea's river mouth, further reduce the capacity of the levees to protect from flooding. Flap and sluice gates on the Waimea levee that help drain the town need to be addressed as they can leak and cause flooding in the town. With SLR and a permanent higher river, their placement could prevent drainage into the river.

Short and long-term adaptation actions that were discussed included the need to increase dredging of both of the rivers, and repair the flap and sluice gates on the Waimea levee. There is a need for additional study of both levees to understand their capacity for flood protection under a one percent chance annual storm with 3.2 feet of SLR. In addition, the County should consider participating in FEMA's Community Rating System to incentivize flood mitigation measures on both private and public lands, and to reduce flood insurance rates for the community.

Electricity
Power lines, substations, and underground electricity assets will likely be more vulnerable to inundation by mid-century with 3.2 feet of SLR. Many of these facilities are already vulnerable to a major storm event. Relocation of energy and electricity related assets may be necessary in the long-term, but will depend upon the relocation of highways, communities, and other critical infrastructure. Since Hurricane Iniki, significant efforts to increase the resilience of the electricity infrastructure have been implemented, including hardening and "micro-gridding" the infrastructure. For example, the development of the AES PMRF and West Kauai Energy Projects will increase the ability of the west side to quickly recover in the event of an island-wide or major event. The Kauaʻi Island Utility Cooperative

(KIUC) is working on and should continue to work on distributed energy generation. However, they should also conduct a detailed vulnerability assessment of planned future projects to SLR.

Water

No deep wells appear to be at risk from SLR, however, other water supply assets such as water meters, valves, and pipes are vulnerable in the near term and potentially many more by mid-century. The risk of future droughts may also put strain on the future supply of potable water. Increasing water conservation strategies will be key to protecting West Kaua'i sources of water. There is a need to incorporate SLR into prioritization of pipe upgrades and replacements. A coordinated approach/assessment is needed when considering relocation between water infrastructure, electricity, and roads.

Beaches & Coastal Properties

Many of West Kaua'i's beaches are currently threatened by erosion. SLR will likely result in increased erosion and flooding of beaches, and shoreline properties and infrastructure are vulnerable to erosion and beach loss. As erosion increases, the pressure for seawall development increases. Seawall construction can protect structures for some time, but they also cause erosion on neighboring properties resulting in overall beach loss. As properties are lost or unbuildable due to erosion, the housing shortage is exacerbated and the community loses a source of income due to reduced property taxes and reduced property values.

Beaches are very important to West Kaua'i's way of life, for instance, beach loss has consequences to cultural resources and practices, wildlife habitat, public access to the beach, recreation, reduced property values, economic loss, social impacts, and the eventual need for shoreline dwellers to move. A number of actions were discussed to address these outcomes, including dune restoration; elevation of threatened structures; relocation of threatened structures; protection of threatened structures; and land acquisition (i.e. buyouts).

Agriculture

By the latter half of the century, over 2000 acres of state zoned agricultural lands will be potentially exposed to SLR. Approximately 14.5 acres of these exposed lands are identified as Important Agricultural Lands (IAL) and are of the highest quality. The main types of agriculture that may be threatened include aquaculture, diversified crops, taro, and land used for agriculture research and development. More research is needed on salt-tolerant plants and alternative types of agricultural methods (e.g., aquaponics and greenhouses) that could be viable for West Kaua'i. Workshop participants suggested that the Dutch polder system should be studied as a potential adaptation strategy for agriculture in flooded environments.

Many small truck farmers are vulnerable to extreme storm events in the river valleys. These farms are so small that many of their locations are unknown, which can make post-disaster recovery efforts difficult. Public and private actions identified include developing post-disaster readiness and planning for small taro farmers (look to ongoing North Shore recovery); collaborating with OHA, DHHL and other sectors to develop a response for small farmers; and mapping small farms. Increasing temperatures and drought are also expected to impact agriculture negatively. Several public and private actions were suggested, including planting drought resistant crops and shade crops, adding water storage, increasing efficient irrigation systems for farms, and identifying additional sources of water supply.

Cultural resources

Due to West Kauaʻi's exposure to SLR, and the inherent sensitivity of cultural resources, a number of resources are vulnerable. These include historically registered buildings/sites, cultural features such as burials and traditional cultivation areas such as loʻi kalo and loʻi paʻakai. Iwi kūpuna, which are Hawaiian burials typically in sand dunes, are highly sensitive to beach erosion and high wave runup. It is paramount that property owners work with family members on adaptation actions through existing processes, such as the State Historic Preservation Department (SHPD) consultation process.

The loʻi paʻakai of ʻUkula at Hanapēpē (Hanapēpē Salt Pond) is very vulnerable to SLR both in the near and long-term due to wave runup, passive flooding, and erosion of the beach and dune system, as well as a rising groundwater table. All result in flooding of the salt pans, which can destroy a salt crop. If the pond is not able to drain quickly enough, an entire salt making season can be cut short. Protecting this unique practice of salt making is very important to the community. Actions identified by workshop participants include hydrological studies in close collaboration with Hui Hāna Paʻakai, instituting drainage measures to divert water away from the pond during salt making, keeping vehicles off the beach, and beach berm restoration.

Traditional cultivation of kalo is vulnerable in the river valleys to riverine floods and in the lowlands to increased saltwater intrusion. Loss of this practice equates to the loss of a key component of the West Kauaʻi cultural landscape. Potential adaptation actions discussed by participants include planting a diversity of salt tolerant crops, and regulating development in former (historical) loʻi areas to allow for expansion or relocation of farming outside of vulnerable areas.

TOWN SPECIFIC RECOMMENDATIONS

Waimea

For Waimea, the project team recommends limiting new development and/or density increases in the downtown area makai (toward the sea) of Kaumualiʻi Highway. The team suggests reserving areas mauka (toward the mountain) of the highway and on the west side of the town for additional development or as receiving areas for future retreat. It is also important that flood accommodation measures for existing development, including elevation of buildings, low impact development (LID) design standards such as bioswales and permeable surfaces, and adding 'freeboard' standards to the floodplain ordinance be implemented. The County joining the FEMA flood program's Community Rating System (CRS), which incentivizes increased flood mitigation practices could result in reductions in flood insurance premiums. We suggest that armoring for erosion control be avoided as much as possible to help preserve beaches. More details on these recommendations can be found in *Chapter VI: Recommendations*.

Waimea Town exposed to a 3.2' SLR scenario. An aerial photograph of Waimea exposed to a 3.2 ft. SLR-XA layer (in navy-blue). The white lines depict State and County roads. Source: Hawai'i Office of Planning GIS Portal, Google Maps

Kekaha

Prior to implementing significant density increases in Kekaha, we suggest that the County and other stakeholders partner with scientists to conduct a focused hydrological assessment of the West Kaua'i drainage system and a groundwater study with SLR. If new development or additional density is planned prior to the above, the safest place appears to be those areas that are highest in elevation (e.g., the west side of town). Like Waimea, flood accommodation measures for existing development or redevelopment is recommended.

Kekaha Town exposed to a 3.2' SLR scenario. An aerial photograph of the town of Kekaha exposed to a 3.2 ft. SLR-XA layer (in navy-blue). The white lines depict State and County roads. Source: Hawai'i Office of Planning GIS Portal, Google Maps

Hanapēpē – ʻEleʻele

In Hanapēpē – ʻEleʻele, consider placing new development or density increases in high elevation neighborhoods in ʻEleʻele, Hanapēpē Heights, and Port Allen. If revitalization and redevelopment of Hanapēpē town or low–lying areas makai of the highway is desired, implement flood accommodation measures. For all the towns, individual homeowners and renters living in the 1.1 SLR-XA or within the river floodplain should consider purchasing flood insurance even outside of regulated FEMA flood zones. A 3D groundwater inundation study with various scenarios of SLR is also recommended for all of the towns.

Hanapēpē-ʻEleʻele Exposed to 3.2' of SLR scenario. An aerial photo of Hanapēpē/ʻEleʻele/Port Allen exposed to a 3.2 ft. SLR-XA layer (in navy-blue). The white lines depict State and County roads. Source: Hawaiʻi Office of Planning GIS Portal

Need for Additional Studies

In order to make meaningful strides towards adapting West Kauaʻi to climate change impacts, additional study will most likely be needed, much of which includes what is termed 'feasibility' studies that vet suggested adaptation actions. Chapter VI provides a full list of recommendations. The project team identified studies that are most pressing. These include:

- Drainage:
    - Partner with scientists to conduct a focused hydrological assessment of West Kauaʻi drainage system, including pumps, ditches, canals, pipes and outfalls to handle various projections of SLR in the short-term and long-term.
    - Partner with scientists to conduct groundwater studies and mapping for various SLR scenarios in low-lying areas of Kekaha, Waimea, and Hanapēpē.
- Roads:
    - Evaluate the costs, benefits, and feasibility of relocating the highway.
    - Evaluate the costs, benefits and feasibility of armoring or continuing to armor and maintain the roads in place, taking into account SLR projections.

In this evaluation consider the long-term impacts to the beach and coastal processes.

- Wastewater:
    - o Conduct a focused study of all impacts to the municipal wastewater system and use the results of the assessment to schedule future adaptation actions to line pipes, relocate pipes, raise manholes, etc.
    - o Conduct a feasibility study of wastewater treatment alternatives in Kekaha that would consider replacing cesspools by: (a) extending municipal wastewater system to the town of Kekaha; or (b) replacing with alternative onsite disposal systems that are resilient to SLR and compatible with the environment and community priorities.

Organization of Report
The remainder of this report elaborates on these vulnerability findings and provides recommendations for moving forward. *Chapter I, Introduction*, provides a thorough description of the study and an overview of climate change trends and projections. *Chapter II* is the methodology section and details all three phases of the project. *Chapter III* presents an inventory of exposed assets to SLR in West Kauaʻi in tabular form. Seven community workshops were organized around the management concerns described above. *Chapter IV* provides a brief description of each management concern through an individual community lens, broken up by each West Kauaʻi town. *Chapter V* provides a detailed description and analysis of each management concern based on the results of the community workshops. Lastly, *Chapter VI* provides recommendations for adaptation and next steps that can be taken to help ensure West Kauaʻi's resiliency into the future.

Waimea River Valley Buddhist temple grounds flooded after Kona rainstorm 3/19/20. Source: Ruby Pap

Community members telling researchers about flooding issues at Salt Pond. Source: Ruby Pap

I. INTRODUCTION

A. Project Purpose

Like many low-lying coastal regions of the world, West Kauaʻi is vulnerable to the impacts of present and future coastal hazards associated with climate change. While the State of Hawaiʻi has generated important exposure data and mapping for different sea level rise (SLR) scenarios, and a statewide economic vulnerability assessment[4], coastal communities have valuable local knowledge about hazards that greatly informs their vulnerability and capacity to adapt.

The purpose of the West Kauaʻi Community Vulnerability Assessment (CVA) is to integrate what the community knows about areas that are vulnerable to coastal hazards with the best available climate change science. Community members are intimately familiar with areas that are vulnerable to natural hazards in places where they live, work, and play. They may know when certain areas flood or may have observed changes over time at their favorite beaches. Climate change exacerbates current day hazards, and the CVA is an opportunity to think about solutions and prepare for the future.

This report is the culmination of community residents, members, asset managers and resource managers dedicating hundreds of hours and providing their in-depth knowledge during workshops, interviews and follow-up conversations. The overall objective was to document places, resources, and structures that could be impacted by SLR, and to generate a better understanding of how they are uniquely vulnerable.

A secondary objective was to identify public and private actions that could address the vulnerabilities discussed throughout the course of this assessment. This CVA is crucial for the subsequent steps that follow, such as an adaptation plan, a climate action plan, or a resiliency plan. This CVA also provides key elements for future community planning such as the West Kauaʻi Community Plan and future hazard mitigation plans.

B. Regional and Local Setting

West Kauaʻi can be characterized not just by its unparalleled beauty and natural resources, but also as a community that is deeply rooted in Native Hawaiian tradition, as well as its more recent sugar plantation history. This has produced historic plantation towns, and a richly diverse and proud population. The plantation economy played an important part in creating and shaping the towns, infrastructure, and the development patterns seen today. The geographic scope of this project is the West Kauaʻi planning district, as defined by the Kauaʻi County General Plan and the West Kauaʻi Community Plan. The West Kauaʻi planning district is between Nuʻalolo to the west and Lokoawa Bay to the east, and includes the towns of Kekaha, Waimea and Hanapēpē-ʻEleʻele, as well as the smaller communities of Kapalawai, Kekupua, Pākalā Village, Kaawanui Village, Kaumakani, and McBryde Plantation Camp. (Figure 1).

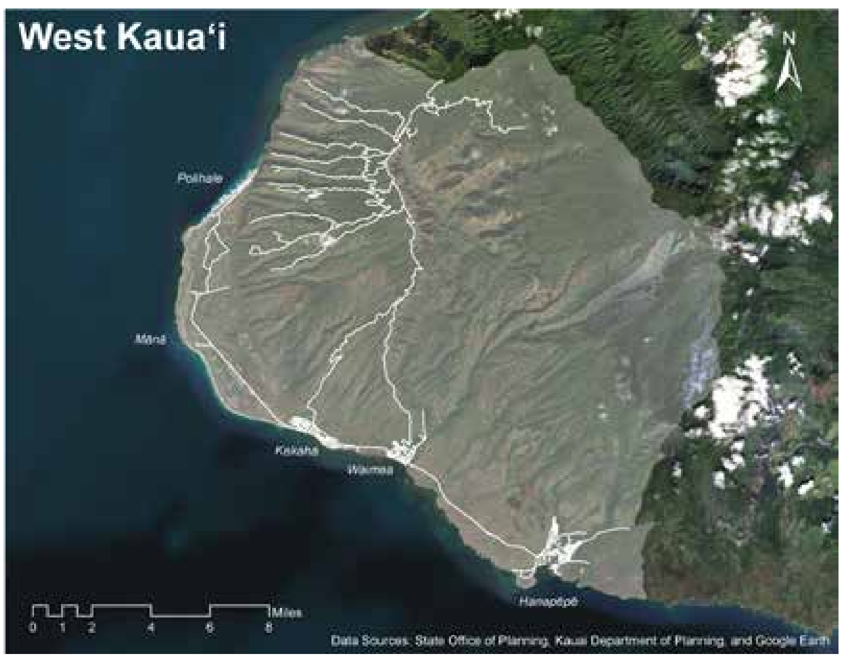


FIGURE 1. WEST KAUAʻI PLANNING DISTRICT. The project area between Nuʻalolo to the west and Lokoawa Bay to the east.

West Kauaʻi has a strong sense of community pride and knowledge of the area. As a result, there are local community groups dedicated to community safety and resiliency (e.g., E Ola Mau, Kekaha Emergency Response Team, and Hanapēpē ʻEleʻele Community Association). These groups understand SLR is an important issue, but may not have identified it in their day to day activities. "Community knows about climate change, but doesn't know about rising tides"[5]. Also, while the understanding of the impacts may be there, the community wants more information on what to do about it. The CVA aimed to help bridge that gap by holding a series of workshops with community members, asset managers, and scientists to learn from the data and each other, identify vulnerabilities and discuss potential adaptation actions.

C. The Threat: Near-Term and Long-Term Climate Change

There are myriad impacts associated with climate change in Hawai'i and West Kaua'i including, SLR, changes in precipitation patterns, extreme heat, drought, and extreme storms, among others[6]. The focus of this CVA is chronic SLR due to its serious consequences to present and future land use decisions, existing infrastructure, and cultural and environmental resources. We also now have a robust dataset and mapping products from the State of Hawai'i that provide SLR exposure mapping on all the islands[7,8]. We acknowledge that impacts from SLR induced flooding can be exacerbated by large storm events such as torrential rainfall events and hurricanes. However, due to the limitations in projected rainfall data and lack of refined storm surge models, the extent of 'event based' flooding combined with SLR is less certain. This section documents the best available science we have with regard to chronic SLR in West Kaua'i. Despite the limited downscaled rainfall and hurricane projections for West Kaua'i, it remained a large focus of the vulnerability conversations in the community workshops. Therefore, we discuss some references in the sections that follow.

1. Observations

Global Warming

Rapid buildup of greenhouse gases in the earth's atmosphere due to human activity is a major contributor to global warming and climate disruption. Carbon dioxide (CO_2) concentration, whose effect on the global climate system can last for centuries, is approximately 40 percent above pre-industrial levels, and is the highest humanity has ever seen. CO_2 levels reached a record peak in May 2019 of 414.7 parts per million (ppm), the highest seasonal peak recorded in 61 years of observations at NOAA's Mauna Loa observatory[9]. According to NASA, global atmospheric temperature is increasing and has been accelerating since 1980. Sea surface temperatures are also increasing and are expected to rise[10].

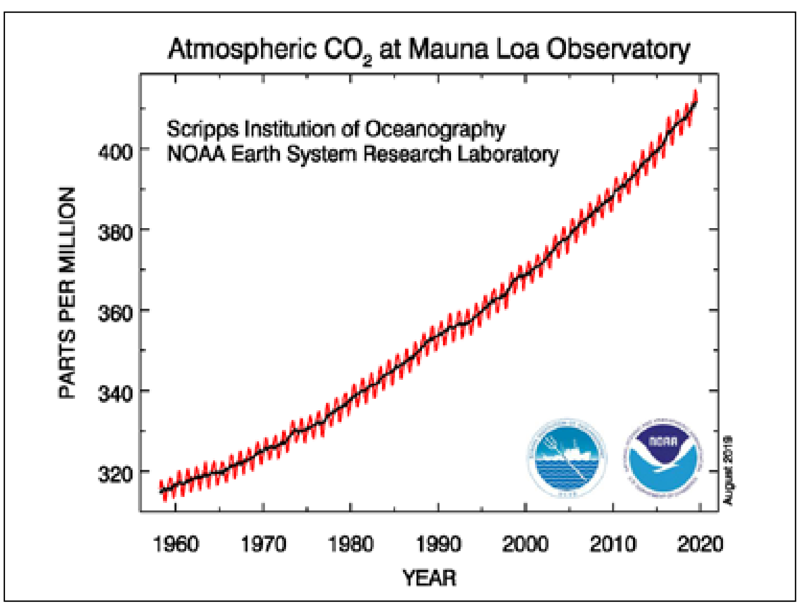


FIGURE 2. ATMOSPHERIC CO2 AT MAUNA LOA OBSERVATORY. Monthly mean carbon dioxide measured at Mauna Loa Observatory, Hawai'i. The carbon dioxide data (red curve) is the longest record of direct measurements of CO_2 in the atmosphere.[11]

Annual average temperatures over the past century have shown a warming trend in Hawai'i. This is based on a network of weather stations throughout the islands. As this trend continues and cloud cover decreases in some areas, evaporation will likely increase causing higher water demand and reduced supply. Sea surface temperatures and ocean pH are beyond levels seen since records have been taken, with serious implications for ocean ecosystems such as coral reefs. Oxygen levels in the ocean are also declining, negatively impacting fish populations and other marine life[12].

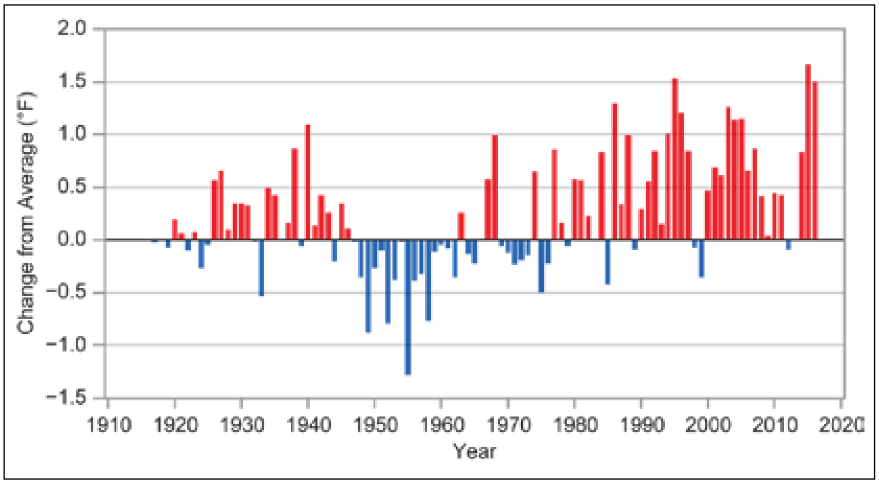


FIGURE 3. HAWAI'I'S ANNUAL AVERAGE TEMPERATURE. Hawai'i's annual average temperature changes as compared to the average during 1944-1980. The red bars show the years where average temperatures were above average. The blue bars show below average temperatures[13].

Sea Level Rise (SLR)

Global sea level is rising at increasing rates due to global warming, ocean thermal expansion and the melting of land-based glaciers and ice sheets. Evidence for this is shown in tide station data from around the world and satellite-based ocean height measurements (satellite altimetry). Global mean sea level has increased by 8-9 inches since 1880, with a third of that rise occurring since 1993[14,15,16,17].

Long-term records from Hawai'i tide stations show SLR with local relative rates varying due to varying rates of subsidence along the volcanic chain[25]. The historic rate of SLR on Kaua'i

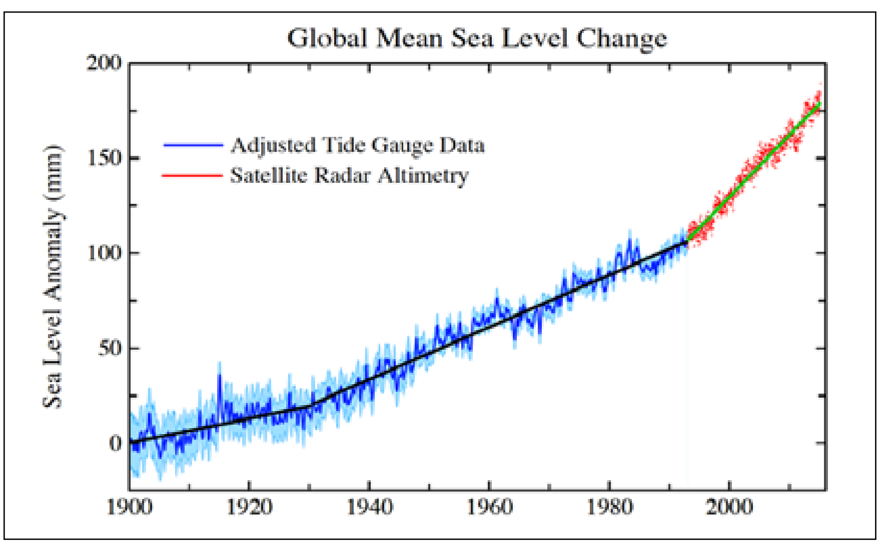


FIGURE 4. GLOBAL MEAN SEA LEVEL CHANGE. The increase in global mean sea level over the last century[18,19,20,21,22,23,24].

according to the tide gauge at Nāwiliwili Harbor is 1.67 mm/year based on monthly mean sea level data from 1955 to 2018 which is equivalent to a change of 0.55 feet in 100 years[26]. SLR exacerbates temporary high sea level events caused by natural climate and oceanic variability in the Pacific related to mesoscale eddies, El Niño events, the Pacific Decadal Oscillation (PDO), and wind stress. This natural variability is visible in the blue monthly sea level lines shown in Figure 5 and can result in fluctuations of 6 inches or more from the long-term average[27,28]. In other words, while the overall trend on Kaua'i has been 1.67 mm, at times sea levels have risen higher.

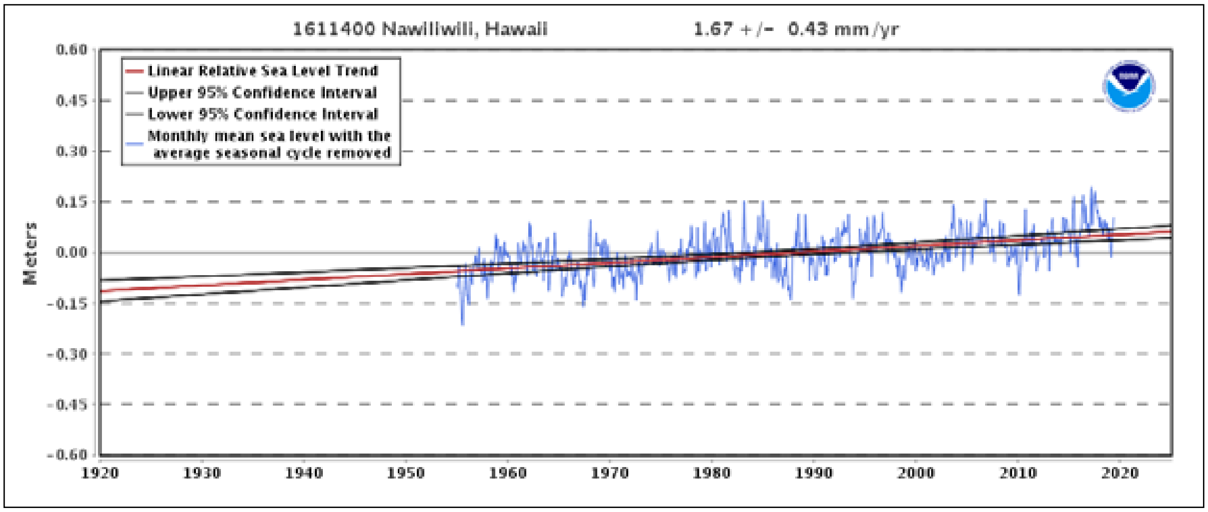


FIGURE 5. KAUA'I RELATIVE SEA LEVEL TREND. The relative sea level trend for the Nāwiliwili tide gauge on Kaua'i[29].

Sea Level Rise Impacts

SLR manifests itself on land through various chronic impacts, including passive flooding, coastal erosion, and annual high wave runup. As SLR accelerates, these chronic impacts will be exacerbated (see the following future projections).

Passive flooding at Nawiliwili Harbor during the King Tides. Source: Carl Berg

Beach erosion West of Kikiaola Harbor. Source: Ruby Pap

Wave runup in Kekaha (Waimea Beach) Source: Ruby Pap

Hurricanes

Kaua'i has a history of large storm events such as hurricanes, tsunamis, and Kona storms. Among those that have been exceptionally damaging include Hurricanes Dot in August 1959, Iwa in November 1982, and Iniki in 1992. Hurricane Dot packed sustained winds of 75 mph and gusts of 165 mph which. Combined with the flooding, caused approximately 6 million dollars in damage. Iniki and Iwa both produced high waves ranging 20-30 feet in addition to winds over 125 mph. Although Hurricane Iwa passed to the northwest of Kaua'i, the high surf it produced combined with a 5 to 6 foot storm surge, flooded 600 feet inland in areas between Kekaha and Po'ipū and caused $312 million in damage. Ironically, there has been dense redevelopment in the same areas that were impacted by the events, raising the risk of damage from future storms. On September 11, 1992, Hurricane Iniki, the strongest and most destructive hurricane to hit the Hawaiian Islands, made landfall just west of Port Allen. Iniki's winds were sustained at 130 mph and gusts topped 160 mph. The wind and waves destroyed 1,421 houses and caused minor to heavy damage to approximately 13,000[30,31].

Destruction of the Kekaha Sugar Company Facility after Hurricane Iniki. Source: The National Archive

Rainfall Flooding

A decrease in the prevailing northwesterly trade winds, which drive orographic precipitation on windward coasts, has been recorded in Hawai'i over the last 40 years. Hawai'i has seen an overall decline in rainfall since 2012[32]. There has also been a decline in stream base flow over the last 100 years[33,34,35]. However, there are many instances on Kaua'i of intense flooding associated with stream runoff, mudslides, bank failures, dam breaches, and erosion that have caused deaths and millions of dollars in property damage[36]. The 2015 County of Kaua'i Multi-Hazard Mitigation and Resilience Plan contains a table of stream flooding on

Kaua'i since 1963 with approximately 16 inland floods occurring in West Kaua'i[37]. Since then, Kaua'i experienced record-breaking rainfall in April 2018 causing major flooding damage on the North Shore. According to the 2018 4th National Climate Assessment, while overall rainfall has decreased in Hawai'i, it has also become more extreme. Both extreme rainfall events and droughts have become more common[38].

The Yamase Building under water during a 1940 flood in Waimea, prior to construction of the Waimea River Levee. Source: Larry Sakoda

2. Sea Level Rise (SLR) Projections

The SLR projections used in this CVA are a 1.1' near term projection and a 3.2' mid-to-late century projection. This is consistent with the recommendations of the HI SLR Report [39] and the Kaua'i County General Plan[40].

According to the 2018 4th U.S. National Climate Assessment, relative to the year 2000, global average sea level is very likely to rise 0.3 to 0.6 feet by 2030, 0.5 to 1.2 feet by 2050, and 1-4 feet by 2100[41]. These estimates don't take into account the full range of what is physically plausible by the end of the century, albeit less certain. Recent studies indicate that High and Extreme scenarios of 6-8 feet of global mean sea level rise are physically plausible by the end of the century if high-end scenarios of greenhouse gas emissions and polar ice cap melt are realized. Hawai'i and other areas in the tropical oceans are expected to exceed global mean sea level rise projections due to mass and gravitational changes with the melting of the Greenland and Antarctic ice sheets[42,43]. As such, we present a range of projections released by NOAA in 2017, documented in Figure 6, showing different scenarios ranging from low to extreme[44]. The higher end scenarios are considered less likely and are the focus of intense study. The low-end scenarios are also less likely as they include little or no acceleration of rates in the coming decades.

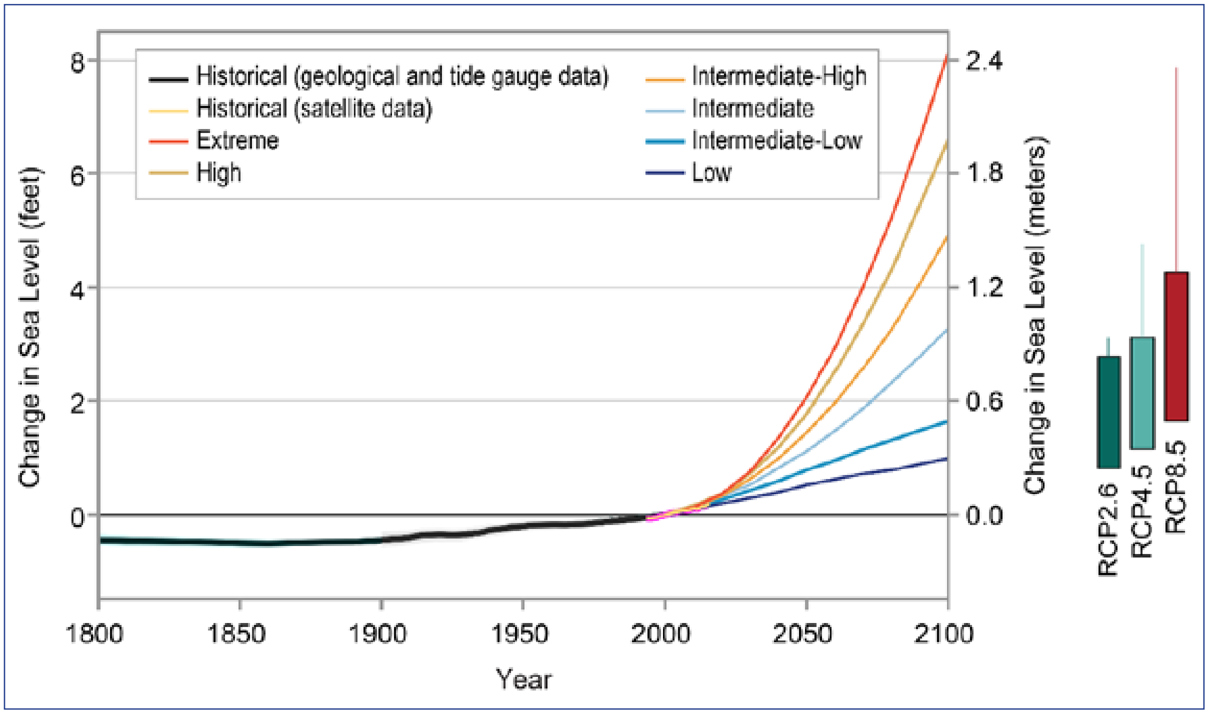
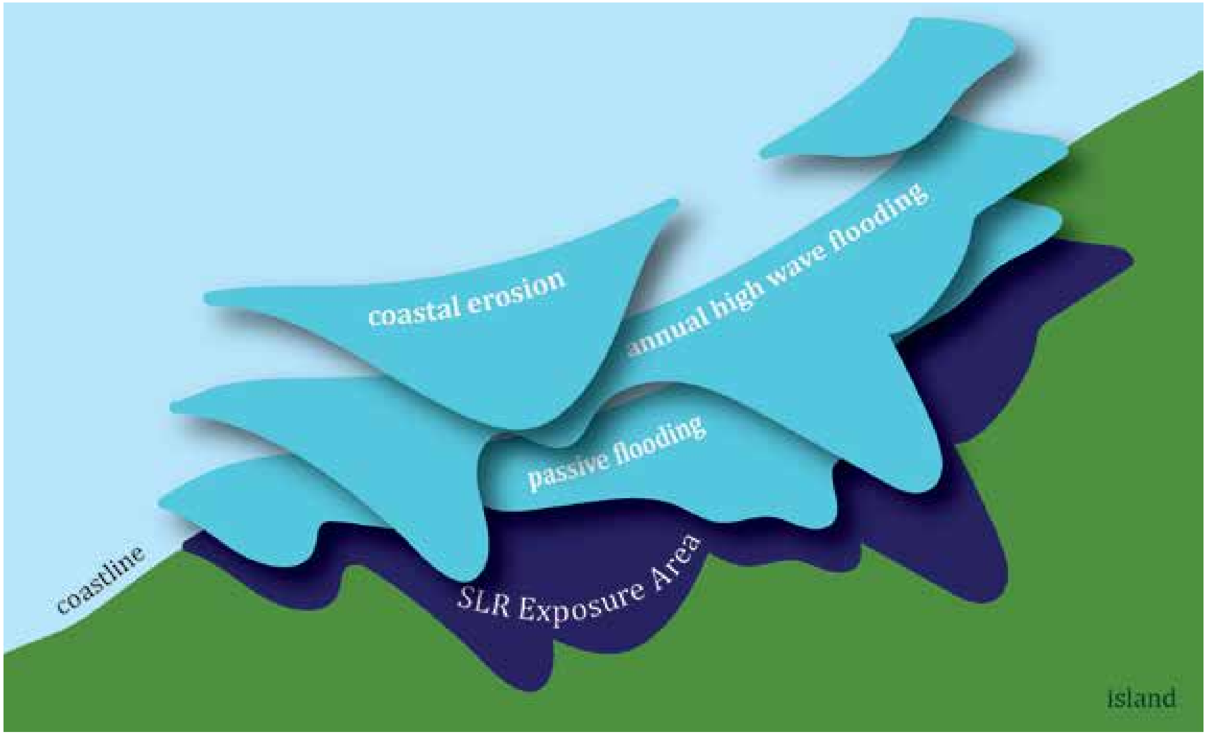


FIGURE 6. HISTORICAL AND PROJECTED SEA LEVEL. Different projections for SLR, which are dependent on future scenarios of human-caused emissions of greenhouse gases as well as the response of the climate system. The colored lines show latest 2017 information on the different SLR scenarios relative to the year 2000 developed by the U.S. Federal Interagency SLR Taskforce. The boxes on the right show how they compare to the 'very likely' SLR ranges by 2100 for different RCP scenarios (representative concentration pathways of greenhouse gases) from the 4th Assessment Report of the Intergovernmental Governmental Panel on Climate Change (IPCC) from 2013. The lines above these boxes show possible increases from the Antarctic from the latest research on ice melt[45].

<u>SLR planning target</u>

The 3.2 feet planning target in the Kaua'i General Plan and used in this vulnerability assessment, falls within the 'intermediate' scenario above and is 'very likely' according to numerous studies documented in the NCA as well as the Intergovernmental Panel on Climate Change (IPCC). In terms of timing of SLR, 3.2' by 2100 is likely, but occurring earlier in mid-century is possible. Therefore it is characterized as a mid-to-late century projection. The 1.1 feet of SLR is considered a near term projection.

SLR will manifest itself on land through various chronic impacts, including increased passive flooding, coastal erosion, and annual high wave runup. The University of Hawai'i Coastal Geology group modeled each of these hazards under different SLR projections. The SLR exposure area (SLR-XA) is simply the furthest landward extent of these three hazards. This is the data that was used in the 2017 Hawai'i SLR Vulnerability and Adaptation Report, and was used for this CVA (See *Chapter II, Methodology*).



SLR-XA is the combined exposure of the following three coastal hazards: coastal erosion, annual high wave flooding, and passive flooding[46].

Groundwater flooding is another impact of SLR. There are no groundwater studies with SLR for West Kaua'i, however it is understood that the passive flooding model provides a first cut estimation of groundwater induced inundation, but is likely an underestimation[47].

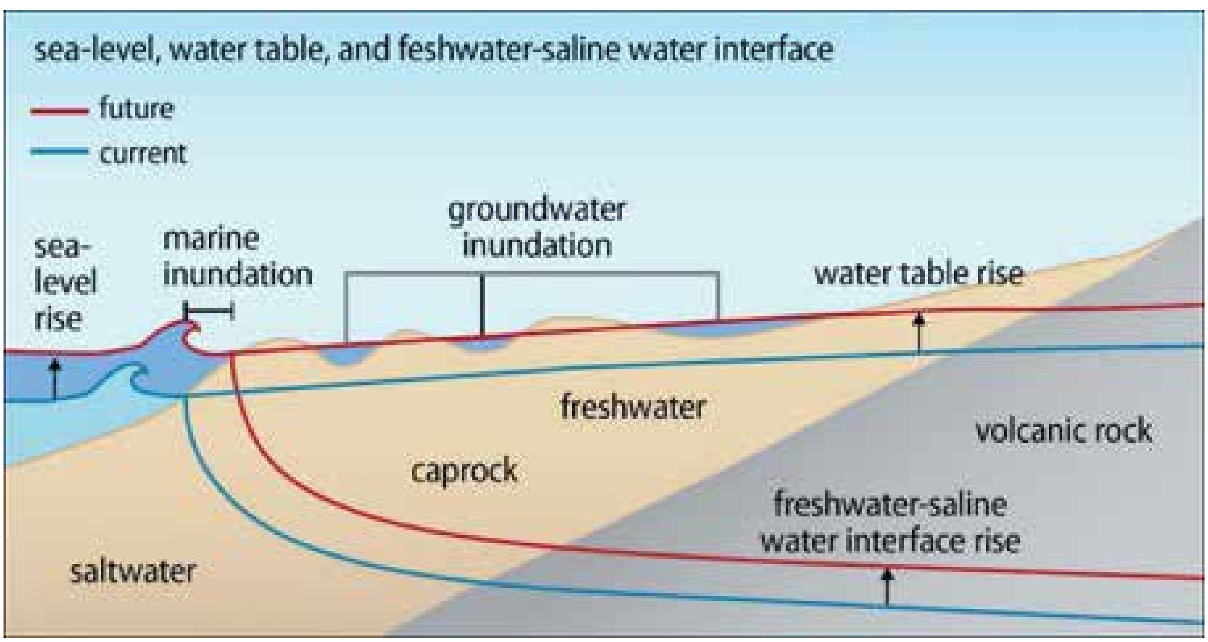


FIGURE 7. PASSIVE MARINE AND GROUNDWATER FLOODING. Schematic diagram of passive marine and groundwater flooding from current sea level (blue) to future sea level (red).[48]

High Tide Flooding

In 2018, NOAA released national projections for minor high tide flooding based on future SLR[49]. This 'nuisance' or 'minor high tide flooding' is something we will likely see sooner than the more 'permanent' SLR scenarios discussed above. This data is based on analysis of many years' worth of historical tide gauge data across the States and Hawai'i. Based on Kaua'i's Nāwiliwili tide gauge, predictions are given as to when minor high tide flooding will occur on Kaua'i (Table 1). Under the intermediate greenhouse gas scenario, by 2039 high tide flooding will occur 6 times per year, 12 times per year by 2042 and 24 times per year by 2045. Under the high scenario, we could see minor high tide flooding upwards of 6 times per year by 2026[50]. However, these estimates may be conservative for Hawai'i because the study's baseline for nuisance flooding in Hawai'i may be too low. "Minor" high tide flooding is already being seen in many areas of the state (especially Honolulu) several times per year[51].

Table 1. Minor High Tide Flooding

When will minor high tide flooding occur in Kauai?			
Scenario	6 x per year	12 x per year	24 x per year
Intermediate Scenario	2039	2042	2045-2046
Intermediate High Scenario	2030-2031	2033	2035-2036
High Scenario	2026-2027	2028-2029	2031
Extreme Scenario	2024	2026	2028-2029

Adapted from Sweet et al 2018, shows when and how often minor high tide flooding is projected to occur on Kaua'i as a result of different scenarios of SLR[52].

Rainfall Projections

Unlike the U.S. continent, Hawai'i has a limited amount of downscaled precipitation models to predict future changes in precipitation. The information and studies that we do have shown that end-of-century rainfall projections under a higher emissions scenario (RCP8.5 – business as usual) range from small increases to increases of to up to 30 percent in wet areas, and from small decreases to decreases of up to 60 percent in dry areas[53].

D. Summary of County of Kaua'i General Plan Policy

The West Kaua'i Community Vulnerability Assessment is an outgrowth of the 2018 Kaua'i County General Plan policies and actions. Policy #14, "Prepare for Climate Change," states that the island must prepare for the impacts to the island's economy, food systems, and infrastructure and to plan for at least 3 feet of SLR. Actions 3.2B1 and B4 are to conduct detailed hazard, risk, and vulnerability assessments in low lying communities, and to use the results to inform adaptation strategies to be incorporated into Community Plans or other planning processes.

The West Kauaʻi Community Plan is a separate process that began in 2018 by the County of Kauaʻi that covers myriad land use and community issues in addition to natural hazards. The purpose of the Community Plan is to implement the County of Kauaʻi General Plan's policies at the regional level and provide recommendations for future land use, transportation, facilities, and infrastructure. The CVA was a parallel process led by Hawaiʻi Sea Grant (with County participation) focusing on natural hazards and climate change. The project was designed to generate recommendations that could be incorporated into the West Kauaʻi Community Plan. The Vulnerability Assessment can also stand alone and be used to inform other conversations at the local or state level and be used as support for local community initiatives or grant applications.

West Kauaʻi Community Plan open house at Hanapēpē Library, 3/18/18. Source: Ruby Pap

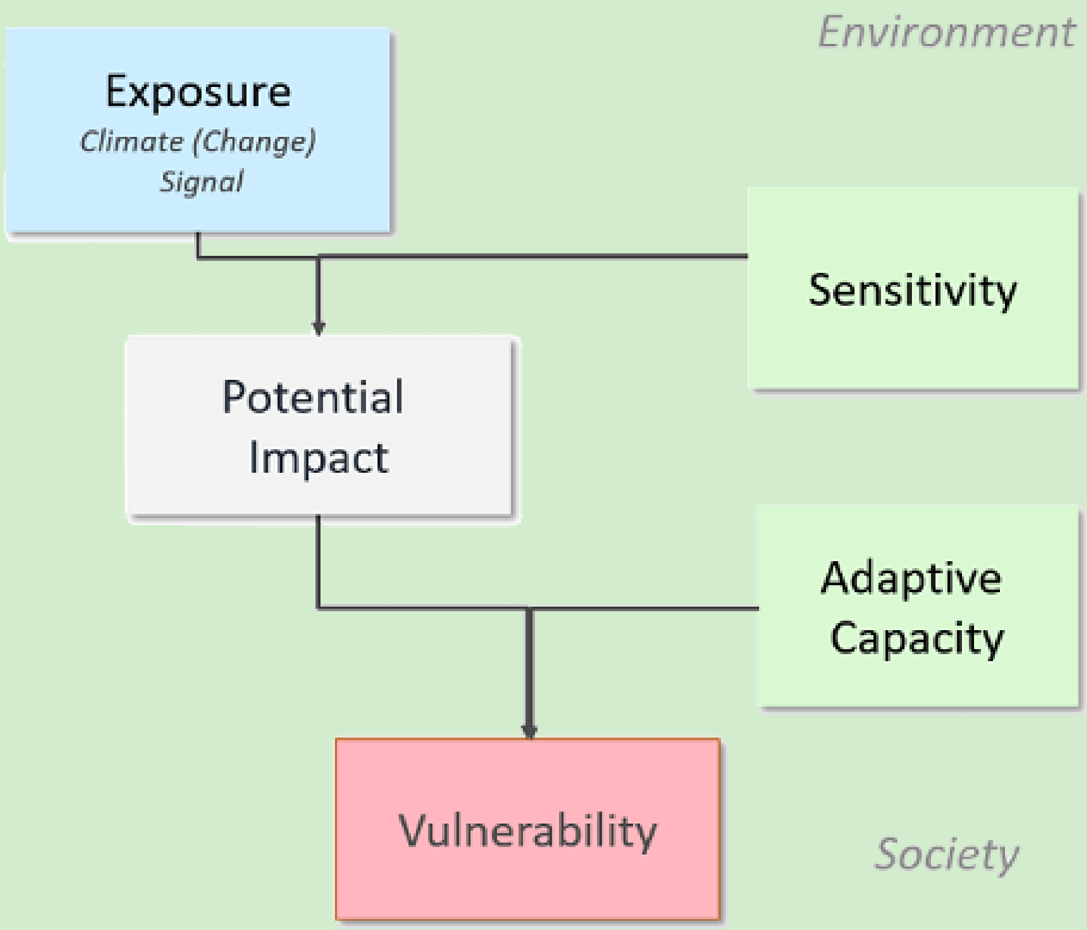


FIGURE 8. COMPONENTS OF VULNERABILITY. The relationship among the three key elements of vulnerability: exposure, sensitivity, and adaptive capacity[60].

II. METHODOLOGY

A. Definition of Vulnerability

The project team adopted the definition of vulnerability from the fourth assessment of the Intergovernmental Panel on Climate Change (IPCC) Report[54]. According to the IPCC, *Vulnerability* is defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes"[55]. *Vulnerability* is expressed as a function of the character, extent, and rate of climate change to which a system is exposed, its sensitivity, and its adaptive capacity[56]. *Exposure* is "the nature and degree to which a system is exposed to significant climatic variations"[57]. *Sensitivity* is "the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change"[58]. *Adaptive capacity* is the "ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences"[59].

Based on this definition of vulnerability, the physical and social dimensions of climate change vulnerability require a detailed assessment of an area's exposure, sensitivity and adaptive capacity reflected in the unique qualities of a place. The HI SLR Report exposure data generated by the University of Hawai'i's Coastal Geology Group was used to assess West Kaua'i's exposure to SLR[61]. Additional background research, community interviews (Phase 1) and the Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) decision modeling tool (Phase II) was utilized to assess sensitivity and adaptive capacity[62].

B. Exposure Data

Geospatial SLR exposure data for three coastal hazards was acquired from the HI SLR Report and associated online SLR Viewer for the 1.1 and 3.2 foot scenarios[63]: (1) coastal erosion; (2) passive flooding; and (3) annual high wave flooding. The project team used this data to create maps of West Kaua'i exposure overlain on various community assets.

Future exposure to coastal erosion was modeled using a combination of historical shoreline change data with a model of beach profile response to SLR[64]. Passive flooding, also known as hydrostatic flooding, was modeled using a modified "bathtub" approach that accounts for both regional tidal variability and hydrological connectivity[65]. Areas that are hydrologically connected to the ocean, as well as low-lying lands that are not hydrologically connected to the ocean, are susceptible to passive flooding. Low-lying areas can be indirectly flooded by SLR with a rising water table.

The third hazard layer, annual high wave flooding, depicts wave over wash during the largest wave events of the year. The annual high wave computer model was simulated from offshore wave buoy data[66]. For detailed methodology on how these models were created, see Hawai'i SLR Viewer (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

The SLR exposure area (SLR-XA) is the combination of these three chronic flooding hazard footprints (Figure 9). The SLR-XA data layer, which was produced by Tetra-Tech, Inc. defines the most landward projected extent of any of the three coastal hazard footprints to estimate overall exposure. This actually may be an underestimation because it does not account for compounding effects of the three hazards such as how wave runup impacts will worsen as the shoreline erodes. It is also important to note that the SLR-XA maps represent exposure on the present environment; therefore, it does not factor in the impact of land use changes, such as hardening the shoreline, or the impacts from less frequent high wave events, storm surge, or tsunami.

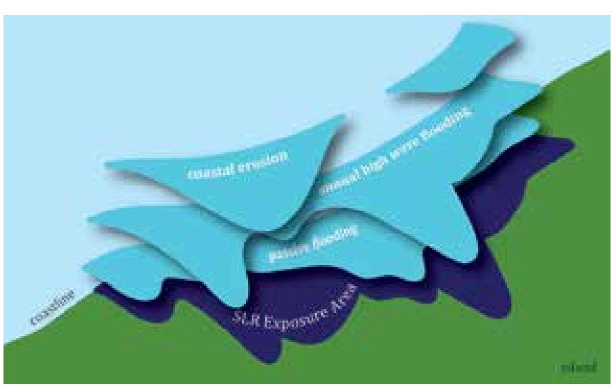


FIGURE 9. SLR EXPOSURE AREA (SLR-XA) AND COASTAL HAZARDS. SLR-XA is the combined exposure of the following three coastal hazards: coastal erosion, annual high wave flooding, and passive flooding[67].

C. Vulnerability Assessment Methods

1. Quantified Exposed Assets

This assessment looks at an overlay of the three SLR-XA hazards on existing assets, including infrastructure, building footprints, historical structures, agriculture, and natural and cultural resources that fall within the two projected SLR scenarios (1.1 feet and 3.2 feet). This geospatial intersection analysis was conducted with the results tabulated and interpreted. The databases of existing assets and their locations come from multiple federal, state, and county sources. Limitations of exposure estimates are related to inaccuracies in asset records and databases and uncertainties in SLR modeling results. Exposed assets were organized into the following categories: transportation, drainage, coastal properties, agriculture, cultural resources, and other infrastructure including schools, hospitals, police stations, fire departments, emergency shelters, civil defense sirens, levees, dams, wastewater utilities, on-site wastewater disposal systems, water utilities, electrical utilities, telecommunication towers, and economic facilities. An inventory including the measure of exposure for each asset in the overall project area and corresponding data sources is provided in *Chapter III, Inventory of Exposed Assets*.

Chapter IV, Community Profiles provides exposure inventories for each community, which includes the number of exposed coastal buildings and properties and their associated potential economic loss. Zoning data and building outlines were obtained from the County of Kauaʻi Geographic Information System (GIS) and were utilized to record the number of coastal buildings into the following three columns: 'Residential', 'Commercial', and 'All Remaining Buildings'.

Potential economic loss data for each community was also recorded. The data, which was produced by Tetra Tech, Inc., is based on the value of the land and structures from the county tax assessor's database that would be permanently lost in the projected SLR exposure area[68]. The calculated potential economic loss values are based on the following assumptions: 1) loss is permanent; 2) economic loss is based on the value in U.S. dollars in 2016 as future property values cannot be determined; 3) economic loss does not include infrastructure cost, such as roads, and water conveyance systems, therefore the calculated value is likely an underestimation; and 4) no adaptation measure are established to mitigate impacts in the SLR-XA[69]. This economic loss data can be considered a 'first cut' at determining vulnerability in West Kauaʻi. This assessment took the vulnerability analysis a step further by discussing exposure, sensitivity and adaptive capacity in depth with the community through background research, interviews and the VCAPS workshops.

2. Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS)

For this assessment, the team built a series of community workshops fashioned after the VCAPS participatory modeling process[70]. VCAPS supports structured discussions that document threats, assess vulnerability, and generate ideas for adaptation using a conceptual framework approach. It uses a causal structure of hazards that begins with the climate stressor and then looks at the outcomes and consequences[71]. During the VCAPS process, community members, asset and resource managers engaged in dialogue about current and future weather and climate threats, provide and summarize their specific local knowledge and experience about how the community could be impacted. During this process, participants learned about the details behind the latest climate data and helped identify gaps. And lastly, they thought strategically as a group about preventive measures by coming up with public and private actions. This participatory approach promoted learning amongst participants, supported learning across sectors through structured discussions, and encouraged the integration of climate science with local knowledge.

The facilitated conversations produced scenarios, represented by diagrams that link climate stressors to outcomes and consequences. Participants were also encouraged to consider how social and environmental contextual factors could affect the intensity and interaction of stressors. Contextual factors are behavioral, social, cultural, economic, institutional, and environmental characteristics of the local system that may impact an area's vulnerability and adaptation measures[72]. This scenario building work culminated in suggested public and private actions. Figure 10 below illustrates the template for a VCAPS causal diagram or scenario. Appendix A contains 7 causal diagrams created by the community during the workshops. VCAPS is open source technology and freely available, but trained facilitators are needed for its application. University of Hawai'i Sea Grant Coastal Land Use Extension Agent, Ruby Pap, facilitated all workshops.

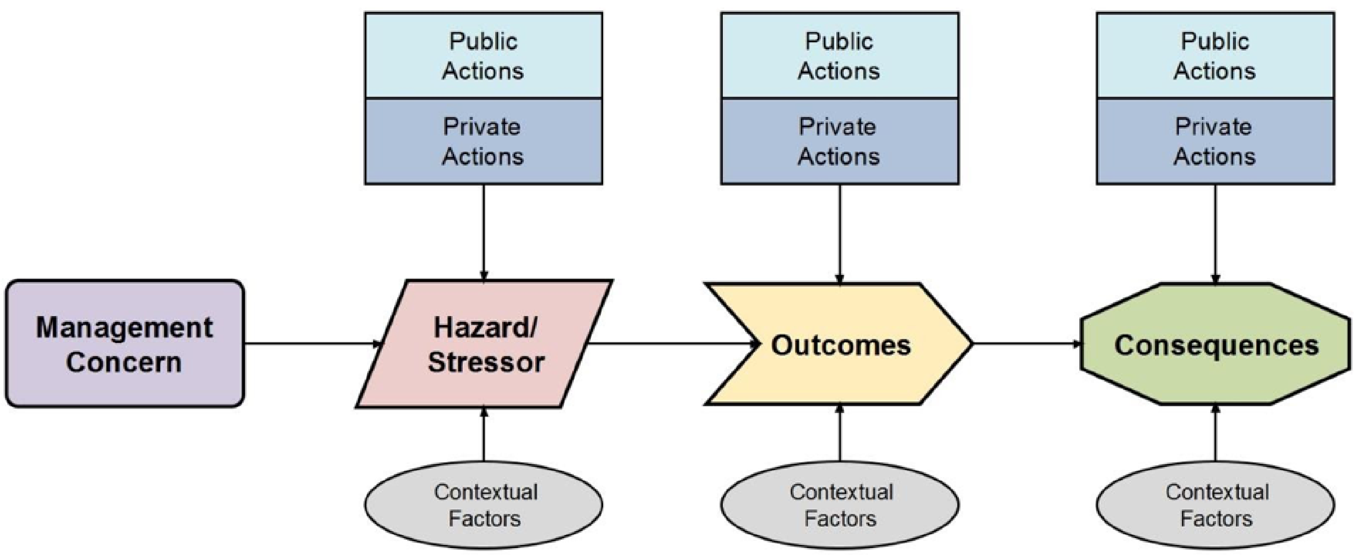


FIGURE 10. VCAPS TEMPLATE. The building blocks in VCAPS diagramming process, which begins with the climate stressor and then looks at the outcomes and consequences[73].

It is important to note that because the primary purpose and scope of the CVA is to identify and understand vulnerability, the project team has not undergone any separate analysis to vet adaptation actions discussed during the workshops utilizing the VCAPS decision support tool. This requires a separately funded analysis typically undertaken with the development of an adaptation plan or something similar. However, the actions provide a good first cut at adaptation options to be considered, either for immediate consideration (e.g., simple things) or for further analysis.

Several of the actions throughout this document refer to "trigger points." A trigger point is an identifiable change in environmental (or social) conditions that serves as a prompt for a particular action[74]. Examples could include, length of time for water ponding, a pre-determined beach width measurement as an indicator for erosion response, or a particular water table level detected during groundwater monitoring.

3. Community Engagement

The main goal of the community engagement process was to bring West Kaua'i community members and asset/resource managers together to discuss vulnerabilities and ideas about ways to adapt. The VCAPS framework was utilized (Figure 11). The community engagement process was divided into two phases - background research and community workshops. In Phase I of the project, the project team conducted background research and in-depth interviews to identify management concerns. In Phase II, the project team facilitated seven participatory scenario planning workshops that delved deeper into the various management concerns identified during Phase I of the project.

FIGURE 11. THREE PHASES OF VCAPS. The background, scenario building, and reporting phases of VCAPS[75].

a. *Phase 1: Background Research*

Phase 1 of the CVA was launched in February 2018 and involved in-depth interviews with community and asset managers, a literature review, and site visits[76]. The interviews helped to pinpoint community views and understandings of climate change risks, specific management concerns with respect to hazards exposure, and adaptation actions. This phase consisted of approximately one-hour semi-structured interviews with 33 public agency staff, infrastructure/asset managers, resource managers, community members, and business leaders who live or work in West Kaua‘i. Purposive sampling was used to recruit a cross-section of individuals either responsible for the management of assets, resources and facilities or community members and leaders across the four west Kaua‘i communities. Snowball sampling was also used to identify additional people who care about possible impacts of climate change in West Kaua‘i, and who might be willing to participate in the project. Interviewees were asked a set of semi-structured questions. They were also provided with maps of West Kaua‘i communities overlaid with 1.1’ and 3.2’ of SLR. The results of these interviews were used to generate a list of dominant management concerns to be discussed during Phase 2.

Once management concerns were identified from the interviews, a public meeting was held at the Waimea Theater on July 31, 2018 with over 50 community members from across West Kaua‘i. The goal of the meeting was to present the list of management concerns and refine the list with the attendees. The kick-off meeting, “Let’s Tackle Sea Level Rise,” included a screening of the film, Miss South Pacific[77], a presentation on climate change science from Hawai‘i Sea Grant extension faculty Dolan Eversole, and an introduction to the CVA and management concerns by Dr. Daniele Spirandelli. Participants were asked to vote and comment on the management concerns identified during Phase I. These were subsequently refined from the feedback.

b. *Phase 2: Community Vulnerability Assessment (CVA) Workshops*

Phase 2 involved eight facilitated four-hour community workshops utilizing VCAPS to discuss the topic of future SLR impacts on each of the broad management concerns. These meetings were open to all community members who live or work in West Kaua‘i, as well as County, State, and Federal Government staff responsible for infrastructure or assets (e.g., roads and drainage), and environment and cultural resources. Participants in the workshops ranged from 15 to 30, and depending on the topic, included resource managers, residents, farmers, cultural practitioners, engineers, planners, private landowners and businesses. Table 2 summarizes the dates and locations of each community workshop.

Table 2. CVA Workshop Dates and Locations

Management Concern	Meeting Date	Location
Transportation and evacuation	September 5, 2018	Hanapēpē Library
Drainage	October 3, 2018	Kekaha Neighborhood Center
Transportation Follow-up	October 10, 2018	Hanapēpē Library
Critical Infrastructure	November 26, 2018	Hanapēpē Library
Coastal Properties and Beaches	December 10, 2018	Hanapēpē Library
Agriculture	February 25, 2019	Waimea Technology Center
Cultural Resources	April 1, 2019	Waimea Technology Center
Critical Infrastructure follow-up: water & electricity	May 8, 2019	Waimea Technology Center

When and where the CVA workshops took place for each of the seven management concern topics.

The first hour of each CVA Workshop was dedicated to introductions and educational presentations. This included a climate expert giving an overview of the coastal exposure data and maps as they relate to the respective management concern[78].

The remaining time consisted of a facilitated scenario building session, where the VCAPS tool was utilized to collectively produce scenarios illustrating the impacts of climate stressors on the specified management concern. The project facilitator led the VCAPS diagramming process, while a scribe mapped the conversation in real-time using a freeware program called Visual Understanding Environment (VUE). In addition, at least one note-taker took notes throughout each workshop.

The final VCAPS scenario diagrams for each management concern can be found in Appendix A. The results of each workshop were used to characterize West Kauaʻi's vulnerability as described in the following chapters.

D. Project Team

The Principal Investigator (PI) for the CVA is Dr. Daniele Spirandelli, assistant professor of coastal policy and community development at the University of Hawaiʻi (UH) Department of Urban and Regional Planning and extension faculty with the Hawaiʻi Sea Grant College Program. Ruby Pap, Hawaiʻi Sea Grant coastal land use extension agent based on Kauaʻi, is the project coordinator. The Hawaiʻi Sea Grant graduate trainees are Erin "Bear" Braich and Alisha Summers. The project was conducted with support from the Kauaʻi County Planning Department, including Marie Williams, Alex Wong, Alan Clinton, Leanora Kaiaokamalie, Kaʻaina Hull, Marisa Valenciano, Nani Sadora, Jody Galinato, and Lee Steinmetz.

III. INVENTORY OF EXPOSED ASSETS

Table 3. Inventory of Exposed Assets to 1.1' Sea Level Rise

Exposed Assets	Sea Level Rise Scenario				Comment	Source
	1.1 ft (near-term)					
	Measure of Exposure within SLR-XA (count, miles, acres)	Coastal Hazard Layer				
		Measure of Exposure from Passive Flooding (count, miles, acres)	Measure of Exposure from Erosion (count, miles, acres)	Measure of Exposure from Annual High Waves (count, miles, acres)		Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2017.
1.0 Transportation						
1.1 State Roads	2.01 (miles)	0.16 (miles)	1.83 (miles)	0.32 (miles)		County of Kauai. March 2018.
1.2 County Roads	1.10 (miles)	0.22 (miles)	0.62 (miles)	0.40 (miles)		County of Kauai. March 2018.
1.3 Harbors	2	2	0	0	1.1 ft. exposure: Kikiaola Small Boat Harbor, Port Allen Small Boat Harbor	County of Kauai. March 2018.
1.4 Airports	1	0	1	1	1.1 ft exposure: Port Allen Airport	National Imagery and Mapping Agency (NIMA) of the United States Department of Defense (DOD).
2.0 Drainage						
2.1 Ditches	15.57 (miles)	14.98 (miles)	0.31 (miles)	2.99 (miles)		USGS Digital Line Graphs, 1983 version; DLNR Division of Aquatic Resources (DAR), 2004.
2.2 Outlets	8	8	6	7	Mill Drain, Second Ditch, First Ditch, Kawaiele Outlets (2), Nohili Outlet, Kikiaola Harbor Outlet	Water Resource Associates. June 2008.
3.0 Other Infrastructure						
3.1 Schools	0	0	0	0		Public Schools: State Department of Education (DOE) Private Schools: HAIS.org (Hawaii Association of Independent Schools, 2011.
3.2 Hospitals	0	0	0	0		Pacific Disaster Center. 2003.
3.3 Police Station	0	0	0	0		County of Kauai. March 2018.
3.4 Fire Department	0	0	0	0		County of Kauai
3.5 Lifeguard Stations	2	1	2	2	1.1 ft exposure: Kekaha Beach, Salt Pond Beach	County of Kauai
3.6 Emergency Shelters	0	0	0	0		County of Kauai
3.7 Civil Defense Sirens	0	0	0	0		County of Kauai
3.8 Levees	no data	no data	no data	no data	Not enough information	
3.9 Dams	0	0	0	0		County of Kauai
3.10 Sewage Mains	0.08 (miles)	0.06 (miles)	0 (miles)	0.03 (miles)		County of Kauai
3.11 Sewage Pump Stations	0	0	0	0		County of Kauai
3.12 Wastewater Treatment Plant	0	0	0	0		County of Kauai
3.13 On-Site Disposal Systems (OSDS)	22	1	20	1		Hawaii State Department of Health. May 2017.
3.14 Water Meters	24	no data	no data	no data	1.1 ft. exposure: 22 vulnerable in Kekaha and 2 in Waimea	Kauai County Department of Water
3. 15 Fire Hydrants	6	no data	no data	no data	1.1 ft. exposure: 4 vulnerable in Kekaha, 2 in Waimea	Kauai County Department of Water
3.16 Deep Wells	0	no data	no data	no data		Kauai County Department of Water
3.17 Valves	25	no data	no data	no data	1.1 ft. exposure: 18 vulnerable in Kekaha, 7 in Waimea	Kauai County Department of Water
3.18 Pipes	1.04 (miles)	0.18 (miles)	0.84 (miles)	0.06 (miles)		Kauai County Department of Water

Table 3. Inventory of Exposed Assets to 1.1' Sea Level Rise (continued)

Exposed Assets	Measure of Exposure within SLR-XA (count, miles, acres)	Measure of Exposure from Passive Flooding (count, miles, acres)	Measure of Exposure from Erosion (count, miles, acres)	Measure of Exposure from Annual High Waves (count, miles, acres)	Comment	Source
	Sea Level Rise Scenario *1.1 ft (near-term)*					
		Coastal Hazard Layer				Hawai'i Climate Change Mitigation and Adaptation Commission. 2017.
3.19 Electricity						
3.19.1 Electrical Poles	28	2	24	8		Kaua'i Island Utility Cooperative
3.19.2 Substation	N/A	N/A	N/A	N/A		Kaua'i Island Utility Cooperative
3.19.3 UG (Pullboxes and admounted transformers)	1	0	1	0		Kaua'i Island Utility Cooperative
3.19.4 UG wire	0.01 (miles)	0 (miles)	0.01 (miles)	0 (miles)		Kaua'i Island Utility Cooperative
3.20 Cell Towers	0	0	0	0		County of Kauai
3.21 Radio Towers	0	0	0	0		County of Kauai
3.22 Economic Facilities						
3.22.1 Financial Institutions	0	0	0	0		County of Kauai
3.22.2 Credit Unions	0	0	0	0		County of Kauai
4.0 Coastal Properties						
4.1 Coastal Buildings						
4.1.2 Residential	41	0	29	15		County of Kaua'i. 2012.
4.1.3 Commercial	2	2	0	0		County of Kaua'i. 2012.
4.1.4 Total (all zoning)	95	6	63	34		County of Kaua'i. 2012.
4.2 Hotels	1	0	0	1	1.1 ft. exposure: Waimea by the Sea (condo)	Hawaii Tourism Authority. April 2018.
4.3 Parks	141.14 (acres)	47.23 (acres)	120.95 (acres)	94.55 (acres)	Na Pali Coast State Park, Polihale State Park, Kekaha Beach Park, Waimea State Recreation Pier, Waimea River Park, Russian Fort Elizabeth State Park, Salt Pond Park	Office of Planning. 1998.
5.0 Agriculture						
5.1 State Land Use Agriculture	882.1 (acres)	854.23 (acres)	12.91 (acres)	202.73 (acres)		State Land Use Commission. February 2016.
5.2 State Designated Important Agricultural Lands (IAL)	11.64 (acres)	11.64 (acres)	0 (acres)	0 (acres)		State Land Use Commission. October 2016.
5.3 Pasture	7.26 (acres)	1.9 (acres)	4.20 (acres)	4.02 (acres)		State Department of Agriculture
5.4 Kaua'i Crops						
5.4.1 Aquaculture	2.3 (acres)	0.83 (acres)	1.63 (acres)	1.13 (acres)		State Department of Agriculture. 2015.
5.4.2 Banana	0 (acres)	0 (acres)	0 (acres)	0 (acres)		State Department of Agriculture. 2015.
5.4.3 Coffee	0 (acres)	0 (acres)	0 (acres)	0 (acres)		State Department of Agriculture. 2015.
5.4.4 Diversified Crop	0 (acres)	0 (acres)	0 (acres)	0 (acres)		State Department of Agriculture. 2015.
5.4.5 Agriculture Research & Development	438.01 (acres)	422.13 (acres)	4.56 (acres)	141.35 (acres)		State Department of Agriculture. 2015.
5.4.6 Taro	0 (acres)	0 (acres)	0 (acres)	0 (acres)		State Department of Agriculture. 2015.
5.4.7 Tropical Fruit	0 (acres)	0 (acres)	0 (acres)	0 (acres)		State Department of Agriculture
6.0 Cultural and Natural Resources						
6.1 Registered Historic Site	2	2	1	2	1.1 ft. exposure: Hanapepe Salt Pond, Cook Landing Site	County of Kauai. March 2018.
6.2 Cultural Features	16	3	12	11		County of Kauai. March 2018.
6.3 Traditional Cultivation Areas	566.44 (acres)	543.2 (acres)	9.55 (acres)	148.8 (acres)		Department of Urban and Regional Planning, University of Hawaii at Manoa. 2011.
6.4 Wetlands	1289.84 (acres)	1032.90 (acres)	322.86 (acres)	569.09 (acres)		National Wetlands Inventory (http://www.fws.gov/wetlands/)
6.5 Critical Habitats	250.62 (acres)	48.81 (acres)	215.33 (acres)	187.33 (acres		Office of Planning 2017; USFWS 2004

Assets within 1.1 ft. SLR-XA layer for the project area as well as within each hazard layer with the corresponding data sources. State and County roads were identified by selecting only public roads in the attribute table. The project team updated the OSDS data after consulting with Kaua'i County Wastewater Division. Kaua'i County DOW also provided water zone maps, which the project team georeferenced and digitized water pipes to measure the miles of exposed pipes. Due to limitations in digitizing the extent of water pipes, the exposed water pipes measurements are a rough estimate.

Table 4. Inventory of Exposed Assets to 3.2' Sea Level Rise

Exposed Assets	Sea Level Rise Scenario: 3.2 ft (mid-to-late century) — Measure of Exposure within SLR-XA (count, miles, acres)	Coastal Hazard Layer: Measure of Exposure from Passive Flooding (count, miles, acres)	Coastal Hazard Layer: Measure of Exposure from Erosion	Coastal Hazard Layer: Measure of Exposure from Annual High Waves	Comment	Source
						Hawai'i Climate Change Mitigation and Adaptation Commission. 2017.
1.0 Transportation						
1.1 State Roads	3.19 (miles)	0.17 (miles)	2.26 (miles)	2.40 (miles)		County of Kauai. March 2018.
1.2 County Roads	5.75 (miles)	1.81 (miles)	2.10 (miles)	2.56 (miles)		County of Kauai. March 2018.
1.3 Harbors	2	2	0	0	3.2 ft. exposure: Kikiaola Small Boat Harbor, Port Allen Small Boat Harbor	County of Kauai. March 2018.
1.4 Airports	2	1	2	2	3.2 ft. exposure: Barking Sands PMRF, Port Allen Airport	National Imagery and Mapping Agency (NIMA) of the United States Department of Defense (DOD).
2.0 Drainage						
2.1 Ditches	30.28 (miles)	28.09 (miles)	0.50 (miles)	12.95 (miles)		USGS Digital Line Graphs, 1983 version; DLNR Division of Aquatic Resources (DAR), 2004.
2.2 Outlets	8	8	6	7	3.2 ft. exposure: Cox Drain, Mill Drain, Second Ditch, First Ditch, Kawaiele Outlets (2), Nohili Outlet, Kikiaola Harbor Outlet	Water Resource Associates. June 2008.
3.0 Other Infrastructure						
3.1 Schools	1	0	1	1	3.2 ft. exposure: St. Teresa (Kekaha)	Public Schools: State Department of Education (DOE) Private Schools: HAIS.org (Hawaii Association of Independent Schools, 2011.
3.2 Hospitals	0	0	0	0		Pacific Disaster Center. 2003.
3.3 Police Station	1	0	0	1	3.2 ft. exposure: Waimea Police Substation	County of Kauai. March 2018.
3.4 Fire Department	1	0	0	1	3.2 ft. exposure: Waimea Fire Station	County of Kauai
3.5 Lifeguard Stations	2	1	2	2	3.2 ft exposure: Kekaha and Salt Pond Beach	County of Kauai
3.6 Emergency Shelters	0	0	0	0		County of Kauai
3.7 Civil Defense Sirens	0	0	0	0		County of Kauai
3.8 Levees	no data	no data	no data	no data	Not enough information	
3.9 Dams	0	0	0	0		County of Kauai
3.10 Sewage Mains	1.51(miles)	0.62 (miles)	0 (miles)	0.89 (miles)		County of Kauai
3.11 Sewage Pump Stations	3	1	0	2	3.2 ft. exposure: Two pump stations in Waimea and one pump station in Hanapepe-'Ele'ele (names unknown)	County of Kauai
3.12 Wastewater Treatment Plant	0	0	0	0		County of Kauai
3.13 On-Site Disposal Systems (OSDS)	110	5	80	52		Hawaii State Department of Health. May 2017.
3.14 Water Meters	202	no data	no data	no data	3.2 ft. exposure: 81 vulnerable in Kekaha, 97 in Waimea, 24 in Hanapepe-'Ele'ele	Kauai County Department of Water
3. 15 Fire Hydrants	27	no data	no data	no data	3.2 ft. exposure: 10 vulnerable in Kekaha, 15 in Waimea, 2 in Hanapepe	Kauai County Department of Water
3.16 Deep Wells	0	no data	no data	no data		Kauai County Department of Water
3.17 Valves	111	no data	no data	no data	3.2 ft. expsure: 58 vulnerable in Kekaha, 46 in Waimea, 7 in Hanapepe	Kauai County Department of Water
3.18 Pipes	3.75 (miles)	0.51 (miles)	1.88 (miles)	2.30 (miles)		Kauai County Department of Water

Table 4. Inventory of Exposed Assets to 3.2’ Sea Level Rise (continued)

Exposed Assets	Sea Level Rise Scenario: 3.2 ft (mid-to-late century) — Measure of Exposure within SLR-XA (count, miles, acres)	Coastal Hazard Layer: Measure of Exposure from Passive Flooding (count, miles, acres)	Coastal Hazard Layer: Measure of Exposure from Erosion (count, miles, acres)	Coastal Hazard Layer: Measure of Exposure from Annual High Waves (count, miles acres)	Comment	Source: Hawai‘i Climate Change Mitigation and Adaptation Commission. 2017.
3.19 Electricity						
3.19.1 Electrical Poles	234	44	75	148		Kaua'i Island Utility Cooperative
3.19.2 Substation	See Comment	N/A	N/A	See Comment	3.2 ft. exposure: In Kekaha from annual high waves	Kaua'i Island Utility Cooperative
3.19.3 UG (Pullboxes and admounted transformers)	15	0	13	2		Kaua'i Island Utility Cooperative
3.19.4 UG wire	0.12 (miles)	0 (miles)	0.12 (miles)	0.01 (miles)		Kaua'i Island Utility Cooperative
3.20 Cell Towers	0	0	0	0		County of Kauai
3.21 Radio Towers	0	0	0	0		County of Kauai
3.22 Economic Facilities						
3.22.1 Financial Institutions	3	0	0	3	3.2 ft. exposure: BOH, American Savings, and First Hawaiian in Waimea	County of Kauai
3.22.2 Credit Unions	1	0	0	1	3.2 ft. exposure: Kaua'i Community Federal Credit Union in Waimea	County of Kauai
4.0 Coastal Properties						
4.1 Coastal Buildings						
4.1.2 Residential	236	24	127	133		County of Kaua'i. 2012.
4.1.3 Commercial	62	15	0	47		County of Kaua'i. 2012.
4.1.4 Total (all zoning)	471	76	197	278		County of Kaua'i. 2012.
4.2 Hotels	2	0	0	2	3.2 ft. exposure: Waimea by the Sea, Waimea Plantation Cottages	Hawaii Tourism Authority. April 2018.
4.3 Parks	173.89 (acres)	53.64 (acres)	146.77 (acres)	116.3 (acres)	Na Pali Coast State Park, Polihale State Park, Kekaha Beach Park, Waimea State Recreation Pier, Waimea River Park, Russian Fort Elizabeth State Park, Salt Pond Park	Office of Planning. 1998.
5.0 Agriculture						
5.1 State Land Use Agriculture	2218.69 (acres)	2117.71 (acres)	35.55 (acres)	894.96 (acres)		State Land Use Commission. Feb. 2016
5.2 State Designated Important Agricultural Lands (IAL)	14.59 (acres)	14.59 (acres)	0 (acres)	0 (acres)		State Land Use Commission. Oct. 2016
5.3 Pasture	24.79 (acres)	3.27 (acres)	10.97 (acres)	16.82 (acres)		State Department of Agriculture
5.4 Kaua'i Crops						
5.4.1 Aquaculture	5.51 (acres)	1.29 (acres)	4.74 (acres)	2.63 (acres)		State Department of Agriculture. 2015.
5.4.2 Banana	0 (acres)	0 (acres)	0 (acres)	0 (acres)		State Department of Agriculture. 2015.
5.4.3 Coffee	0 (acres)	0 (acres)	0 (acres)	0 (acres)		State Department of Agriculture. 2015.
5.4.4 Diversified Crop	1.16 (acres)	1.16 (acres)	0 (acres)	0 (acres)		State Department of Agriculture. 2015.
5.4.5 Agriculture Research & Development	1214.85 (acres)	1164.37 (acres)	18.69 (acres)	468.97 (acres)		State Department of Agriculture. 2015.
5.4.6 Taro	0 (acres)	0 (acres)	0 (acres)	0 (acres)		State Department of Agriculture. 2015.
5.4.7 Tropical Fruit	0 (acres)	0 (acres)	0 (acres)	0 (acres)		State Department of Agriculture
6.0 Cultural and Natural Resources						
6.1 Registered Historic Site	5	2	1	5	3.2 ft. exposure: Hanapepe Salt Pond, Cook Landing Site, Yamase building, Bishop National Bank of Hawaii, Waimea Hawaiian Church	County of Kauai. March 2018.
6.2 Cultural Features	35	3	18	26		County of Kauai. March 2018.
6.3 Traditional Cultivation Areas	1526.99 (acres)	1457.51 (acres)	26.01 (acres)	465.61 (acres)		Dept. of Urban and Regional Planning, University of Hawaii at Mānoa. 2011.
6.4 Wetlands	2586.41 (acres)	2312.35 (acres)	324.21 (acres)	1247.00 (acres)		National Wetlands Inventory
6.5 Critical Habitats	297.56 (acres)	63.69 (acres)	253.96 (acres)	218.28 (acres)		Office of Planning 2017; USFWS 2004

Assets within 3.2 ft. SLR-XA layer for the project area as well as within each hazard layer with the corresponding data sources. State and County roads were identified by selecting only public roads in the attribute table. The project team updated the OSDS data after consulting with Kaua‘i County Wastewater Division. Kaua‘i County DOW also provided water zone maps, which the project team georeferenced and digitized water pipes to measure the miles of exposed pipes. Due to limitations in digitizing the extent of water pipes, the exposed water pipes measurements are a rough estimate.

FIGURE 12. HANAPĒPĒ-'ELE'ELE EXPOSED TO A 3.2' SLR SCENARIO. Aerial photo of Hanapēpē/'Ele'ele/ Port Allen exposed to a 3.2 ft. SLR-XA layer (in navy blue). The white lines depict State and County roads. Source: Hawai'i Office of Planning GIS Portal[79,80].

IV. COMMUNITY PROFILES

A. HANAPĒPĒ-'ELE'ELE

1. Overview of Area

Hanapēpē – 'Ele'ele, the "Gateway to the West Side," is the first community upon entering West Kaua'i from Kaumuali'i Highway and the uplands of Kalāheo. The area includes the waterfront community of Port Allen, an industrial, port, and commercial/tourism area containing the island's biggest power plant and harbor. A little further west, historic Hanapēpē Town is situated mauka around and along the banks of the Hanapēpē River. The neighborhoods of Hanapēpē Heights and Ele'ele flank and overlook the town, high up on ridges. The General Plan categorizes Hanapēpē – 'Ele'ele as a 'Small Town' with a peaceful, laid back, local style vibe[81].

The population of the area is approximately 5,028[82]. It is expected to grow in population, however, trends indicate a slowing growth rate[83]. The population is growing older, with a median age of 39.3 and 13.5 percent individuals over 65 years of age[84]. The racial composition of Hanapēpē-ʻEleʻele is majority Asian (48.6% and 58% respectively), and approximately 25% of the population in both towns identify as 2 or more races. Whites make up 16% in Hanapēpē and 12% in ʻEleʻele. Native Hawaiian/Pacific Islanders make up 8.5% and 5% respectively[85].

Hanapēpē – ʻEleʻele is experiencing a housing shortage, with 90% of the housing stock over twenty years old, and many households paying more than 30% of their annual housing income on housing. 4.2% of the population in Hanapēpē and 5.2% of the population in ʻEleʻele live below the poverty line [86]. West Kauaʻi has experienced an increase in homeless individuals and families overall [87].

The General Plan has strong incentives to support housing and economic growth, and assigns an ʻincremental' degree of change to this area with respect to future development. It also states that the area is vulnerable to natural hazards and there is a need to employ resiliency strategies in community siting, design, and relocation.

Historic Hanapēpē Town, which is characterized by its peaceful, laidback, small town atmosphere. Source: Chance Bukoski

2. Exposed Assets – Buildings and Economic Loss[88,89,90]

Table 5. Hanapēpē-'Ele'ele Exposed Assets – Buildings and Economic Loss.

SLR Scenario *Residential* *Commercial*			**Coastal Buildings**			**Potential Economic Loss**
			All Remaining Buildings			
1.1 ft. (near term)	Measure of Exposure within SLR-XA (count)		0	2	8	$37,154,936
	Coastal Hazard Layer	Passive Flooding (count)	0	2	4	
		Erosion (count)	0	0	2	
		Annual High Waves (count)	0	0	2	
3.2 ft. (mid-to-late century)	Measure of Exposure within SLR-XA (count)		16	15	39	$63,858,963
	Coastal Hazard Layer	Passive Flooding (count)	10	15	35	
		Erosion (count)	6	0	4	
		Annual High Waves (count)	0	0	2	
Note: 'All remaining buildings' includes all other coastal buildings that are located within other zoning districts.						

Hanapēpē-'Ele'ele buildings exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets within the overall SLR-XA and within each hazard (passive flooding, erosion, annual high waves) was recorded in ArcGIS. Potential economic loss is shown in the last column. Economic loss is based on based on the value of the land and structures from the county tax parcel database permanently lost in the SLR-XA for each projected SLR height.

3. Vulnerability[91]

The Hawai'i SLR and Vulnerability Report provided a preliminary glimpse at vulnerability through an economic lens. Looking specifically at property and building loss within the SLR-XA, this data shows that in the near term SLR scenario Hanapēpē -'Ele'ele can expect a loss of $37,154,936. In the mid-to-late century, this number jumps to $63,858,963 (Table 5). This is likely an underestimation since it does not take into account the economic loss of infrastructure. This CVA took the analysis to the local level by asking local experts to talk with one another about vulnerability. While the CVA workshops did not focus on vulnerability at the town level, the seven 'management concerns' workshops described in *Chapter V, Management Concerns,* helped to illuminate particular aspects about each town that are vulnerable to climate change and natural hazards.

Hanapēpē River and Bridges

The Hanapēpē River is a dominant feature for this region, and has historic, cultural, and environmental significance for the town. The river cuts through Hanapēpē Town before it enters the sea. Therefore its two bridges, the historic Hanapēpē Road Bridge and the Kaumuali'i Highway Bridge, are extremely important for community resilience. The loss of these bridges would result in complete loss of access for the entire west side, cutting off Waimea, Kekaha, and the Pacific Missile Range Facility.

Aerial view of Hanapepe town, Kaumualii Highway Bridge, and the historic town bridge located mauka. Source: imagery c 2020 EagleView

Workshop participants pointed out that the Kaumuali'i Highway Bridge is sensitive to large storm events due to its low-lying location and that it could 'act as a dam' during a large rainstorm event by catching heavy debris that is carried down the fast-moving river. SLR could compound the situation and possibly overwhelm the bridge. The bridge is currently being re-constructed but SLR has not been taken into account in its design, therefore this 'dam' effect may be exacerbated.

Hanapēpē is protected from flooding by a levee on the banks of their river. The levee in Hanapēpē discontinues between Hanapēpē road and the mouth of the river, a low-lying area that is prone to flooding[92]. The levee has been decertified by FEMA and the Army Corps of Engineers as not having appropriate height (or freeboard) above the 100-year storm height. As a result more properties will be put into the flood zone and subject to flood insurance and other building requirements. Workshop participants expressed concern that future SLR plus heavy rainfall could erode the levee walls, or sediment could build up in the river due to SLR pushing sand up the mouth and low river flow.

The levee that is built along the banks of the river in Hanapēpē. The levee protects the town from flooding. Source: Ruby Pap

<u>Salt Pond</u>

Salt Pond beach is eroding and with SLR it will be exposed to increased flooding, erosion, and wave inundation. The loʻi paʻakai of ʻUkula at Hanapēpē (Hanapēpē Salt Pond) is very vulnerable to SLR in the near-term and latter half of the century. Outcomes include: wave runup, passive flooding, erosion of the beach and dune, and rising groundwater. All result in flooding of the salt pans, which can destroy a salt crop. If the pond is not able to drain quickly enough, an entire salt making season can be cut short.

The *loʻi paʻakai* of ʻUkula at Hanapēpē (Hanapēpē Salt Pond) which is very vulnerable to sea level rise in the near-term and latter half of the century. Source: Ruby Pap

River Valley Agriculture

Important small-scale river valley agriculture also occurs in Hanapēpē, where there are "truck farms" that rely on irrigation, and grazing that rely on rainfall. Large storms that lead to flooding could wash away the topsoil of small farms, destroy crops, increase the amount and distribution of invasive species, and lead to a long recovery time for farmers and families.

4. Adaptive Capacity/Opportunities

Because much of historic downtown Hanapēpē is located mauka of the shoreline, it may be safer from SLR impacts in the near to midterm. This is an opportunity to continually monitor the town as well as the latest science and projections as community awareness grows. Six or more feet of SLR is physically plausible by the end of the century according to the Hawaiʻi SLR Vulnerability and Adaptation Report, and under that scenario the downtown area would be subject to permanent flooding.

The safest areas for development with respect to SLR and flooding appear to be ʻEleʻele, Hanapēpē Heights, and Port Allen. However, knowing that revitalizing the downtown is important to the community, increased flood mitigation measures would be prudent such as elevating existing development, implementing freeboard standards through ordinance, low impact development (LID) measures and green infrastructure, and preserving and increasing floodable areas. Implementing these actions also provides an opportunity for the County to join the FEMA Community Rating System (CRS), which would provide discounts on flood insurance.

Passive flooding with 3' SLR scenario could impact the Hanapēpē communities makai of the highway and east of the river in the mid to the latter half of the century. Groundwater impacts are expected to be felt in advance of above ground impacts. Areas makai of downtown are not protected by levee at all and most are in the FEMA Special Flood Hazard Area (SFHA). Implementing the measures described above may help mitigate these impacts, as well as continuing to monitor SLR impacts over time, identifying triggers for relocation and providing options and programs for relocation in the future. These are all ideas that are meant to be explored further in a follow up adaptation plan or through the community planning process.

The Hanapēpē Bay beach situated between the river mouth and Port Allen small boat harbor would be subject to increased erosion and passive flooding under a 3.2' SLR scenario. The area is relatively undeveloped, and contains agricultural uses and structures. This might be a good area to explore whether enhancement as a water storage or wetland would help control flooding in surrounding areas.

Communities makai of the highway and east of the river, as well as Hanapēpē Bay and Beach, and Port Allen. Mauka are the communities of Hanapēpē Heights and 'Ele'ele. Source: Chance Bukoski

The threat of tropical storms and other events still looms large beyond the chronic SLR and coastal hazards threats. It is important that the community and relevant agencies maintain and increase their preparedness and stay up to date with response plans, including collaboration with each other. The Hanapēpē – 'Ele'ele Community has a strong and active community focused on resiliency as evidenced by the Hanapēpē 'Ele'ele Neighborhood Association's participation in the State's Hawai'i Hazards Awareness and Resilience Program (HHARP). They are in the process of formulating a community – based emergency disaster response plan and have actively participated in this CVA.

One workshop participant pointed out, on the positive side, that West Kaua'i is less isolated than places like the north shore. West Kaua'i does have the benefit of major stores, police, fire, and hospital services. Although, it is also important to note, some of these same critical services are threatened by future SLR (see *Chapter III, Inventory of Exposed Assets*).

Last but not least, there were several adaptation ideas raised with reference to the bridges, roads, drainage, levees, cultural resources (i.e. Salt Pond, River Valleys), and agriculture. Rather than duplicating them here, please see the respective sections in *Chapter V, Management Concerns*.

New elevated home construction in Hanapēpē River Valley. Photo was taken after Kona rainstorm on 3/19/20. Source: Ruby Pap

FIGURE 13. AERIAL PHOTO OF PĀKALĀ VILLAGE EXPOSED TO A 3.2 FT. SLR-XA layer (in navy blue). The white lines depict private roads[93,94,95].

B. PĀKALĀ VILLAGE

1. Overview of Area

Pākalā Village is a small, rural shorefront community east of Waimea adjacent to Kapalawai. It is a historic remnant of a former sugar plantation housing camp abutting a white sand beach and reef system that creates the iconic waves of the Pākalā surf break. The land and homes are still owned by the Robinson family, and its 294 residents rent their homes.[96] As such, village infrastructure is privately owned and maintained. Many families living in this village are descendants of plantation workers that lived here and identify with the ahupua'a of Makaweli. Kaumakani, a neighboring plantation village to the southeast was not included in this assessment due to its higher elevation, distance from the shoreline, and lack of chronic SLR exposure (although arguably a hurricane could affect this area).

Unlike the surrounding communities, with a current population of about 294, Pākalā Village has shrunk in population by about 15% since the 2000 census. The median age is 44, with 26% of residents aged 65 or older, 54% between the ages of 18 and 64 years of age, and the remaining 20% less than 18[97,98]. The majority of Pākalā residents identify as Asian (32%) with two or more races (26%), a strong second. 24% are Native Hawaiian/Pacific Islander and 18% are white[99].

The median income in Pākalā Village is $44,583 and 11.8% live below the poverty line[100]. Pākalā families for the most part rent aging homes that were built for the families of plantation workers. Over 90% of the housing units (161) were built prior to 1960[101].

The General Plan characterizes Pākalā Village as a 'plantation camp' defined as a cluster of houses with little or no retail or service uses. It would not be considered as a future area of potential growth due to its single-use nature that is primarily auto-oriented with little to no services. The area is zoned Agriculture.

2. Exposed Assets – Buildings and Economic Loss[102,103,104]

Table 6. Pākalā Village Exposed Assets – Buildings and Economic Loss.

SLR Scenario *Residential* *Commercial*			**Coastal Buildings**			**Potential Economic Loss**
			All Remaining Buildings			
1.1 ft. (near term)	Measure of Exposure within SLR-XA (count)		1	0	0	$1,079,763
	Coastal Hazard Layer	Passive Flooding (count)	0	0	0	
		Erosion (count)	1	0	0	
		Annual High Waves (count)	0	0	0	
3.2 ft. (mid-to-late century)	Measure of Exposure within SLR-XA (count)		23	0	0	$20,882,090
	Coastal Hazard Layer	Passive Flooding (count)	0	0	0	
		Erosion (count)	17	0	0	
		Annual High Waves (count)	6	0	0	
Note: All buildings are located in the agricultural zoning district, but they are residential homes.						

Pākalā Village buildings exposed to two SLR scenarios: A near-term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets within the overall SLR-XA and within each hazard (passive flooding, erosion, annual high waves) was recorded in ArcGIS. Potential economic loss is shown in the last column. Economic loss is based on the value of the land and structures from the county tax parcel database permanently lost in the SLR-XA for each projected SLR height.

3. Vulnerability

The Hawai'i SLR and Vulnerability Report provides a preliminary glimpse at vulnerability through an economic lens. Looking specifically at property and building loss within the SLR-XA, this data shows that in the near term SLR scenario Pākalā Village can expect a loss of $1,079,763 with only one building exposed. In the mid-to-late century, this number jumps to $20,882,090, with 23 buildings exposed, the majority (17) due to shoreline erosion. These numbers do not take into account the loss of infrastructure such as roads, wastewater, drainage, and water. As the village is privately owned, it is recommended that the property owner conduct an assessment of this vulnerability.

One shortcoming of the CVA workshops is that there was not much discussion focused on this small community. The data appears to indicate that this population will become more and more vulnerable, given coastal erosion, the low numbers of alternative housing options on the west side, and the low income levels in the village. However, this viewpoint does not include analysis of social cohesion and family ties that can lift a community's resiliency. This community, along with its single property owner, would certainly benefit from further discussions about the future of Pākalā Village as well as the rest of Makaweli in light of SLR and other climate related hazards.

Aerial view of Pākalā Village. Source: imagery c 2020 EagleView

FIGURE 14. WAIMEA TOWN EXPOSED TO A 3.2' SLR SCENARIO. Aerial photograph of Waimea exposed to a mid-to-late century scenario of 3.2' SLR (in navy blue). The white lines depict State and County roads[105,106,107].

C. WAIMEA

1. Overview of Area

The low-lying historic town of Waimea is flanked by Waimea Canyon and the beautiful black sands of Waimea Beach. Its rich plantation history has shaped the land use and the historic buildings we see today. It is home to many of the civic facilities of West Kauaʻi, including the high school and hospital. Waimea residents have a strong sense of community pride.

According to 2010 U.S. Census, the population of Waimea is approximately 1,855[108]. It is expected to experience some growth but trends indicate a slowing growth rate[109]. Waimea residents are aging. In 2010, Waimea had the highest median age of West Kauaʻi, at 44 years and 18% over the age of 65[110]. The majority of Waimea residents identify with two or more races (35%), with Asian a close second (34%). Hawaiian and Pacific Islanders make up 12% and whites make up 18%[111].

Waimea is experiencing a shortage in housing. Over 89% of the housing stock is over twenty years old while over 50% percent of households are paying more than 30% of their annual income on housing. 13.9% of the population lives below the poverty line[112]. Homelessness is also a concern[113].

The General Plan has strong incentives to support housing and economic growth and assigns an 'incremental' degree of change to this area with respect to future development. It also points out that much of the town lies within flood, tsunami, and SLR inundation areas, a consideration to take into account for future land use and development[114].

2. Exposed Assets – Buildings and Economic Loss[115,116,117]

Table 7. Waimea Exposed Assets – Buildings and Economic Loss.

SLR Scenario			**Coastal Buildings**			**Potential Economic Loss**
	Residential	*Commercial*	*All Remaining Buildings*			
1.1 ft. (near term)	Measure of Exposure within SLR-XA (count)		12	0	3	$5,356,163
	Coastal Hazard Layer	Passive Flooding (count)	0	0	0	
		Erosion (count)	0	0	0	
		Annual High Waves (count)	12	0	3	
3.2 ft. (mid-to-late century)	Measure of Exposure within SLR-XA (count)		65	47	45	$215,019,704
	Coastal Hazard Layer	Passive Flooding (count)	14	0	2	
		Erosion (count)	0	0	0	
		Annual High Waves (count)	51	47	43	
Note: 'All remaining buildings' includes all other coastal buildings that are located within other zoning districts.						

Waimea buildings exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets within the overall SLR-XA and within each hazard (passive flooding, erosion, annual high waves) was recorded in ArcGIS. Potential economic loss is shown in the last column. Economic loss is based on based on the value of the land and structures from the county tax parcel database permanently lost in the SLR-XA for each projected SLR height.

3. Vulnerability

Downtown Waimea, especially makai of the highway and west of the levee, will become increasingly exposed to SLR by the latter half of the century. Based on the exposure data, annual high wave runup would be the dominant hazard, but a higher groundwater level due to SLR will become an increasing concern. Both the Waimea Fire Station and Police Substation would be exposed to annual high wave flooding under the 3.2' scenario, which has implications for public safety in the future if adaptation is not put in place. Both are already within the tsunami evacuation zone.

The Hawai'i SLR and Vulnerability Report provided a preliminary glimpse at vulnerability across Kaua'i through an economic lens. Property and building loss is estimated for coastal lands in Waimea within the SLR-XA 1.1' scenario and is estimated at approximately

$5,356,163. In the mid-to-late century, this number jumps to $215,019,704. This is likely an underestimation since it does not take into account loss of infrastructure. On the other hand, data assumes permanent loss of properties with SLR exposure, which isn't always the case.

The CVA workshops further examined the vulnerability question from the community perspective using VCAPS. The following is highlighted for Waimea.

An oblique view of Waimea town, which is characterized by its rich plantation history and is considered the civic center of the West Side. Source: Chance Bukoski

<u>Roads</u>

Kaumualiʻi Highway and County Roads in Waimea will be increasingly vulnerable to annual high wave flooding or storm surge. Waimea Valley roads are also vulnerable due to problems that arise between the drainage ditch and its exit point through the Waimea River levee (see *Chapter V, Management Concerns*, Section B Levees). Even on a sunny day, the Waimea Valley roads can flood. The vulnerability of the Waimea River Bridge is also of concern due to the level of silt build up in the river. Increased SLR combined with heavy rainfall could overwhelm the bridge. There are no alternatives to the main highway for emergency access or evacuation, besides improving the ford crossing across the Waimea River.

Drainage

Waimea has limited drainage structures and may be in need of updating. Drainage/ stormwater relies on drainage ditches and canals inherited from the plantation days and some underground drainage pipes. By the end of the century, groundwater inundation (GWI) will likely be an increasing concern for the town, especially makai of the highway. This means there will likely be drainage concerns for roads and utilities, including inundation of underground infrastructure.

Waimea River Levee

The Waimea River levee protects the town from riverine flooding. However, it is questionable whether the levee can protect against a 1% chance annual storm, and the height does not meet Federal freeboard standards. As a result, the levee was decertified and portions of Waimea Valley will be placed in the FEMA Special Flood Hazard Area (SFHA), adding an additional layer of flood regulation and insurance requirements for homeowners. Menehune Ditch, which diverts stormwater to the Waimea River, is fitted with a flap and sluice gate valve at the levy. This is meant to prevent back-flow into the town when the water levels are high. However, the flap is not fully sealed and can leak back into the ditch. This happens when the river mouth is blocked due to sand build up. The State Department of Land and Natural Resources and County are responsible for clearing the river mouth, which has turned into a regular and expensive activity. Both the State and County are looking for solutions to this ongoing maintenance problem, which could be exacerbated by increasing SLR.

Waimea River, bridge, levee, and flap gate A. The ditches will back up and may overflow if the river rises above the flap gates in the levy. Source: Ruby Pap

Waimea River mouth, which can become blocked due to sand buildup. Source: Ruby Pap

Flooding at Menehune Ditch and Menehune Road due to malfunctioning flap and sluice gates on the Waimea levee. Source: Klayton Kubo

Coastal Properties

Waimea's coastal neighborhoods will become more and more vulnerable to erosion. While much of the area east of Kikiaola Harbor in front of Waimea Town is accreting, the SLR exposure data shows that by the latter half of the century the beach will become more and more erosional, threatening the first block of homes.

Wastewater

Waimea has a centralized publicly owned wastewater (sewage) system and secondary (R-2) treatment plant. As sea level and the groundwater table[118] continue to rise wastewater pipes will become submerged. Due to structural defects or deterioration, pipes with cracks and leaky joints are prone to groundwater infiltration (GWI)[119]. Waimea also has a few properties with on-site disposal systems (mostly cesspools), which are vulnerable to SLR and GWI in low-lying areas (see *Chapter V, Management Concerns*, Section C.1 Wastewater).

4. Adaptive Capacity/Opportunities

Areas mauka of the highway and west of Waimea Town are the least exposed to hazards, therefore are more appropriate for additional development or as retreat areas. In downtown Waimea makai of the highway, wave runup is expected to increase over time, at times extending to the highway. However, runup depths could be as low as 4" and may happen only at the highest wave of the year[120]. This points to SLR accommodation opportunities in this area such as elevating existing buildings, adding 'freeboard' standards to the floodplain ordinance and implementing LID design principles. It is also recommended that the County join the FEMA flood program's Community Rating System (CRS), which incentivizes increased flood mitigation practices and can result in reductions in flood insurance premiums. Individual properties and renters living in the 1.1 SLR-XA or within the river floodplain should consider purchasing flood insurance even outside of regulated FEMA flood zones. Partnering with the scientific community to create a 2D or 3D wave runup model would be an important next step to better understand wave runup impacts. Alternative alignments and access points for the highway and roads also deserve further study to help improve community resilience.

Groundwater studies taking into account SLR would help understand the nature of this hazard, and help inform adaptation actions. Existing underground infrastructure, such as sewer lines and water lines should be assessed carefully. Upgrades that take into account GWI will be important for these critical infrastructure to continue serving existing and future population. Adaptive capacity may also increase makai of the highway if new development or density increases were limited and directed in more elevated areas. Less density provides more room to shift around and less buildings in harm's way, especially since new construction typically last for at least 75 years[121]. If there are significant investments in new construction in this area, it might be harder to convince property owners to move to safer areas.

By the latter half of the century, erosion will be an increasingly important factor for properties adjacent to the beach. If seawalls are constructed, beach width will likely diminish. The buildup of sand at the river mouth may provide future opportunities to nourish the beach and avoid hard armoring. The existing County shoreline setback policy contributes to sufficient setbacks along the shoreline, however they should be updated to incorporate SLR data. The project team recommends that in order to preserve beaches for as long as possible, avoid armoring as much as feasible. This should involve working with shoreline property owners and infrastructure managers on a comprehensive and reasonable response plan for when erosion becomes a dominant threat or when a large storm destroys a neighborhood. This plan should include trigger points for action (e.g., width of beach or distance of development to shoreline), a thorough analysis of alternatives such as relocation, elevation, beach nourishment, dune restoration, temporary sandbag protection, and hard armoring.

A large rainfall combined with SLR will result in drainage issues for the town. Waimea Valley is particularly vulnerable, as described above. The County continues to work with its Federal partners to access funding to raise the levee walls and address dysfunctional flap and sluice gates. This is an opportunity to study the levy's capacity for flood protection under a 1% chance annual storm combined with SLR. To aid with resiliency in the surrounding neighborhoods, flood accommodation measures for homes as described above would be prudent. In addition, there will be an increased need to dredge the river or address the chronically low flows examining the mauka water diversion facility.

The threat of tropical storms and tsunamis loom large beyond the chronic SLR and coastal hazards threats. There are always more opportunities for the community and relevant agencies to increase their preparedness and stay up to date with response plans. Collaboration and communication is key. We are not aware of any Waimea specific community groups involved with resiliency training activities, however there are groups in Hanapēpē and Kekaha. It is never too late for Waimea residents to come together on their own or join forces with these other groups.

Last but not least, there were several adaptation ideas raised with reference to the bridges, roads, drainage, levees, cultural resources, agriculture, and critical infrastructure. Rather than duplicating them here, please see the respective sections in *Chapter V, Management Concerns*.

FIGURE 15. TOWN OF KEKAHA EXPOSED TO A 3.2' SLR SCENARIO. Aerial photograph of the town of Kekaha exposed to a 3.2 ft. SLR-XA layer (in navy blue). The white lines depict State and County roads[122,123,124].

D. KEKAHA

1. Overview of Area

The small town of Kekaha, situated west of Waimea, is surrounded by low-lying agricultural lands, Kekaha State Beach, and beach front properties. Kekaha has a proud agricultural identity and is also searching for new industries that will revitalize the town, while maintaining its relaxed country-living atmosphere[125]. Kekaha State Beach is one of the most dynamic beaches in the state. From one season to the next (summer to winter), the beach can erode dramatically, only to return several months later. Adjacent to Kekaha is Kikiaola Harbor and the neighborhood to the west, which is fronted by a black sand beach that is connected to the Waimea river sand source.

In 2010, the population of Kekaha was approximately 3,537, up from 3,175 from the 2000 census. During this time, Kekaha also gained more households[126,127]. At the same time, Kekaha residents are aging. In 2010, Kekaha had a median age of 39.9 years with 15.9 percent over the age of 65. The majority of Kekaha residents identify with two or more races (32%), with Asian a close second (31%). Hawaiians and Pacific Islanders make up 15% and whites make up 18%.[128] Many houses are old with over a quarter (27%) built in 1969 or earlier. The average household earns $66,890 and 5.4% of Kekaha's population lives below the poverty level.

The General Plan emphasizes the revitalization of the Kekaha Neighborhood Center with commercial and community activities clustered next to existing businesses along Kekaha Road[129]. However, much of the town lies within flood, tsunami, and SLR inundation areas. Kekaha is vulnerable to flooding due to its low-lying elevation and the surrounding flood-prone agricultural areas. These areas rely upon ditches, canals and the regular pumping of ground water to keep them dry, which likely helps to reduce flood risk in the town. Kekaha is also dependent upon a revetment to protect the highway and coastal properties from erosion and wave inundation. The high water table in much of East Kekaha renders the roads and underground infrastructure vulnerable to groundwater inundation. Kekaha does not have a central wastewater treatment system and relies upon individual onsite disposal systems, most of which are cesspools.

2. Exposed Assets – Buildings and Economic Loss[130,131,132]

Table 8. Kekaha Exposed Assets – Buildings and Economic Loss

<table>
<tr><th colspan="3" rowspan="2">**SLR Scenario**
Residential
Commercial</th><th colspan="3">**Coastal Buildings**</th><th rowspan="2">**Potential Economic Loss**</th></tr>
<tr><th>*All Remaining Buildings*</th><th></th><th></th></tr>
<tr><td rowspan="4">*1.1 ft. (near term)*</td><td colspan="2">Measure of Exposure within SLR-XA (count)</td><td>28</td><td>0</td><td>23</td><td rowspan="4">$43,272,401</td></tr>
<tr><td rowspan="3">Coastal Hazard Layer</td><td>Passive Flooding (count)</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Erosion (count)</td><td>28</td><td>0</td><td>23</td></tr>
<tr><td>Annual High Waves (count)</td><td>3</td><td>0</td><td>4</td></tr>
<tr><td rowspan="4">*3.2 ft. (mid-to-late century)*</td><td colspan="2">Measure of Exposure within SLR-XA (count)</td><td>132</td><td>0</td><td>44</td><td rowspan="4">$123,685,171</td></tr>
<tr><td rowspan="3">Coastal Hazard Layer</td><td>Passive Flooding (count)</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>Erosion (count)</td><td>104</td><td>0</td><td>42</td></tr>
<tr><td>Annual High Waves (count)</td><td>76</td><td>0</td><td>22</td></tr>
</table>

Kekaha buildings exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets within the overall SLR-XA and within each hazard (passive flooding, erosion, annual high waves) was recorded in ArcGIS. Potential economic loss is shown in the last column. Economic loss is based on the value of the land and structures from the county tax parcel database permanently lost in the SLR-XA for each projected SLR height.

3. Vulnerability

Kekaha Town will become increasingly exposed to SLR by the latter half of the century. Based on the exposure data, erosion and annual high wave runup are expected to be the dominant hazards. Data from the Hawai'i SLR and Vulnerability Report (Table 8) provides a preliminary glimpse at vulnerability in Kekaha through an economic lens. The economic loss for Kekaha buildings and land within the SLR-XA area is estimated at $43,272,401 in the near term and $123,685,171 by the mid-to-late century. This is likely an underestimation since it does not take into account loss of infrastructure. On the other hand, data assumes permanent loss of properties with SLR exposure, which isn't always the case. In addition, the data does not take into account the existence of the highway revetment.

The CVA 'management' concerns workshops further examined vulnerability from the community perspective. The following describes highlighted concerns for Kekaha.

<u>Roads</u>

Kaumuali'i Highway between Kekaha and PMRF will become increasingly vulnerable to SLR by mid-to-late century given its location along the coast and low-lying position. This is of concern because the highway serves as an important corridor connecting Kekaha and all of West Kauai to PMRF, a major employer for the island. Loss of the highway and local roads would have long-term consequences for the community. It could isolate Kekaha from the rest of West Kaua'i and cut off evacuation routes, resulting in loss of access to social services, jobs, etc.

Revetment along the Kaumuali'i Highway in Kekaha. Source: Ruby Pap

The highway has a rip rap revetment and a drilled pier wall which serves to protect the roads and the town from erosion and wave inundation. It is important to note that the projections for future erosion and annual high wave flooding do not take this revetment into account so the SLR exposure area (SLR-XA) could be an overestimate of impacts. However, currently high waves do breach the wall and splash onto the highway. This could get worse in the future. Thus, despite being partially protected, the roads and town are still vulnerable to erosion and wave over-wash particularly. Relying on seawalls to protect the town requires government commitment to maintaining and upgrading the wall. Absent this or relocation of homes and infrastructure, erosion will be a serious issue for parts of the town and the highway. Also, further expanding the seawall could accelerate erosion at either end through a process called, "flanking erosion". Lastly, relying on the revetment for protection from SLR impacts may help slow erosion and waves for some time, however, mauka of the highway, groundwater will continue to rise with flooding impacts to roads and potentially impeding road access.

Drainage

In the near-term, Kekaha might experience more frequent flooding events in the form of nuisance flooding, but by mid-to-late century, low-lying areas will become permanently inundated. This will impact local roads, underground infrastructure, and individual properties with potentially, at a minimum, $125 million dollars in economic loss. Groundwater inundation is expected to become an increasing concern, especially to onsite disposal systems (OSDS) and underground infrastructure. At 3.2 feet of SLR, areas east of the town will passively flood and groundwater will break the land surface. This implies groundwater impacts will likely be felt by many properties a lot sooner, especially those with underground infrastructure. This is of concern because, according to DOH, OSDS require 3' of vertical separation either below the absorption area (for an absorption bed) and the seasonal high groundwater or below a vessel (for a seepage pit or cesspool)[133].

Drainage in Kekaha relies upon drainage ditches, canals, and ocean outlets inherited from the sugar plantations, as well as a number of pumps in the surrounding agricultural lands to keep the groundwater level low and area dry. The Kekaha Agricultural Association (KAA) and the Agribusiness Development Corporation (ADC) run and maintain these pumps year round. Drainage ditches and outlets will become increasingly vulnerable to future flooding, erosion and high wave action from SLR. Keeping the ocean outlets clear is expected to become more challenging with SLR as more frequent high tides and sand build up is expected to block the outlets. Groundwater inundation in surrounding areas is also expected to increase although SLR modeling does not reflect the current pumping regime. The pumping could help in the near-term but it is unknown how long this can be sustained.

Pumps in Kekaha keep the groundwater level low and the area dry. Source: Daniele Spirandelli

Beaches and Coastal Properties

With SLR, Kekaha coastal properties will become more and more vulnerable to erosion and wave inundation. While properties rely upon the highway and rip-rap to protect it, the shoreline armoring also increases the rate of beach erosion.

Along the small coastline west of Kikiaola Small Boat Harbor, the beach is starved of sediment due to the presence of the harbor which blocks sand from the Waimea River mouth. This situation is compounded by waves and tides that cause high rates of erosion, and with future SLR, these rates are expected to increase further threatening homes, property values, and the Japanese and Chinese cemeteries. SLR could also impact Kikiaola Small Boat Harbor, which could have negative consequences for the fishing industry.

Construction of a 300 foot drilled pier wall to mitigate coastal erosion impacts to Kaumualii Highway in 2012.
Source: Ruby Pap

Aerial view of Kikiaola Harbor. West of Kikiaola Harbor there are high rates of coastal erosion, which threatens homes, property values, and the Japanese and Chinese cemeteries.
Source: imagery c 2020 EagleView

A sandbag and rock revetment, which were constructed in an attempt to mitigate coastal erosion west of Kikiaola Harbor near Mamo Road. Source: Ruby Pap

Critical infrastructure: Wastewater, water, and electricity

At 3.2 feet of SLR, areas east of town will passively flood and groundwater will break the land surface. While exposure maps (See Appendix B) show Kekaha town safe from passive flooding, these maps do not reflect areas where the groundwater is very high but has not broken the land surface. Rising groundwater is expected to render underground infrastructure vulnerable first in the form of wetting with occasional nuisance flooding, then with higher sea levels, permanent inundation impacting cesspools, an electrical substation and underground electrical assets in Kekaha leading to possible power outages. Cesspools are also vulnerable to future erosion and wave impacts, although the seawall if maintained might protect them from these hazards for some time. Despite the seawall, groundwater is still a threat to cesspools which require unsaturated space underneath them to function properly. This could have major consequences for human and environmental health in the near-term.

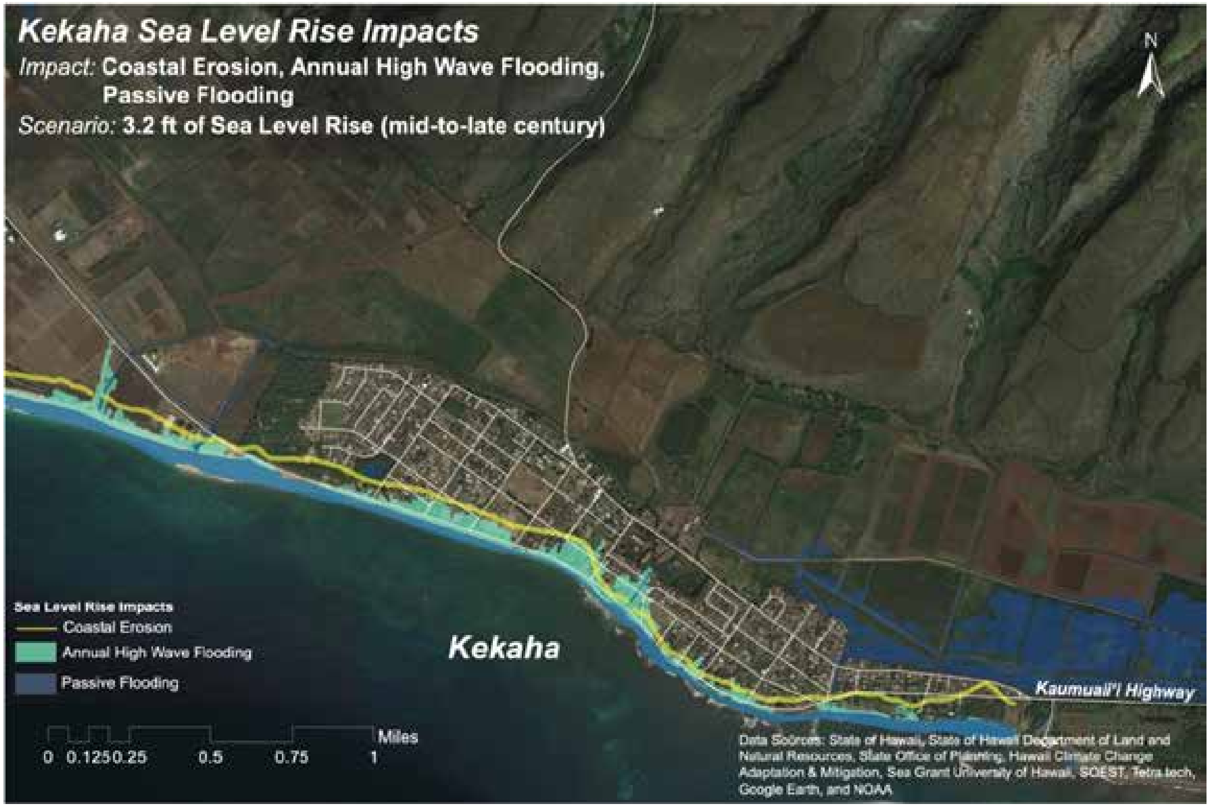


FIGURE 16. 3.2' SLR HAZARD SCENARIO IN KEKAHA TOWN. Aerial photo of Kekaha Town exposed to a mid-to-late century scenario of 3.2' SLR hazards (passive flooding, erosion, and high wave inundation). The navy blue shading depicts passive flooding, the yellow line depicts erosion, and the cyan shading depicts high wave inundation[134,135].

4. Adaptive Capacity/Opportunities

Critical for planning purposes, studies on the drainage system and its ability to handle future SLR are needed. The ADC and other partners currently pump the agricultural land in the Mānā Plain and this likely helps reduce flood risk in Kekaha. However, we do not understand the full geographic influence of the groundwater pumping. In addition, the SLR exposure data does not reflect this pumping. As a result, the pumping could reduce projected SLR-flooding, although there is uncertainty how long it will help. There needs to be a specific study on the capacity of both the ditch system and the pumping to control flooding with future SLR. Also, a detailed 3-D groundwater study with SLR would be helpful to understand the full geographic extent of the high-water table in Kekaha. These sorts of studies will be important to help inform the location of infrastructure and buildings, as well as where to site appropriate levels of density.

The project team recommends that if new development or additional density is planned in Kekaha prior to these studies, limit it to those areas that are highest in elevation (e.g., the west side of town). In addition, it is recommended that flood accommodation measures be implemented for existing development or redevelopment in Kekaha. These include elevation of buildings, low impact development (LID) design standards such as permeable surfaces, and adding 'freeboard' standards to the floodplain ordinance. These measures may better enable the County to join the Federal Emergency Management Agency's (FEMA) flood program's Community Rating System (CRS), which incentivizes flood mitigation strategies and can result in reductions in flood insurance premiums. To help increase resiliency in the town, individual properties and renters living in the 1.1 SLR-XA should consider purchasing flood insurance even outside of regulated FEMA flood zones.

Conversion of cesspools in Kekaha is paramount, and requires an additional assessment of wastewater treatment alternatives, such as extending the sewer to Kekaha or alternative OSDS. These alternatives should be explored with DOH, community members and other stakeholders. Relocation of critical underground infrastructure will depend upon the relocation of both the highway and development. A DOT cost benefit analysis would be warranted for Kaumualiʻi Highway comparing the cost-benefits of keeping the revetment, raising the road, relocating (retreating) the road, or any other alternative.

The threat of tropical storms and tsunamis loom large beyond the chronic SLR and coastal hazards threats. There are always more opportunities for the community and relevant agencies to increase their preparedness and stay up to date with response plans. Kekaha has two active community groups, E Ola Mau and the Kekaha Emergency Response Team that work to build emergency response and community resilience.

Last but not least, there were several adaptation ideas raised with reference to the bridges, roads, drainage, levees, cultural resources, and agriculture, and critical infrastructure. Rather than duplicating them here, please see the respective sections in *Chapter V, Management Concerns*.

Kekaha Road flooded after a Kona rain storm, 3/19/2020. Source: Ruby Pap

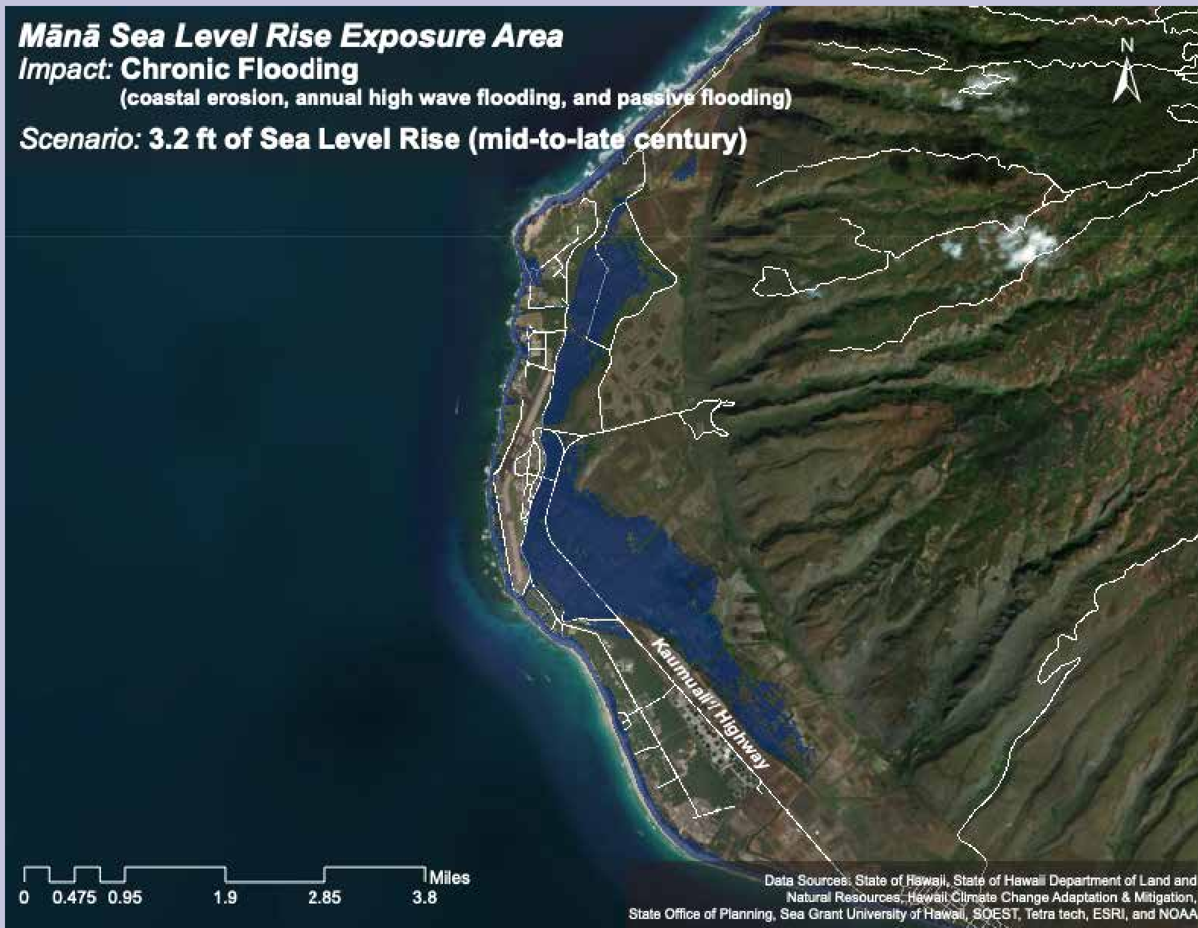


FIGURE 17. MĀNĀ-POLIHALE EXPOSED TO A 3.2' SLR SCENARIO. Aerial photograph of Mānā-Polihale exposed to a mid-to-late century scenario of 3.2' SLR (in navy blue). The white lines depict State and County roads[136,137,138].

E. MĀNĀ- POLIHALE

1. Overview of Area

The broad Mānā Plain extends over 16km along the west coast of Kaua'i and is bordered by a long sandy beach that begins at Polihale and extends to Kekaha. Some of the Mānā shoreline is backed by a large system of sand dunes, known as the Nohili sand dunes or Barking Sands. This area is rich in history and culture, in particular in iwi kūpuna (native Hawaiian burials), whose preservation is dependent partially upon the restoration of the sand dunes, as well as the protection and maintenance by PMRF[139].

Mānā no longer maintains a population center. The nearest town is Kekaha[140]. The Mānā plain hosts agricultural lands and the PMRF military base. PMRF employs approximately 900 civilian jobs in addition to active duty members and provides opportunities to support businesses and entrepreneurs, particularly those in the area of green technologies[141]. The agricultural lands in the Mānā plains is primarily made up of agricultural research crops.

Aerial photo showing portion of Mānā Plain including Nohili dunes and agricultural lands, which were formally a large wetland. Source: imagery c 2020 EagleView

The agricultural lands of Mānā were formerly comprised of a large wetland. The sugar plantations installed ditches and canals with ocean outlets to drain the wetland, as well as pumps to drawdown the groundwater and make the land farmable. Today, two pumps, one of which is on PMRF land, are critical to keep the land dry and viable for agriculture. Detailed storm and response procedures are performed by the Kekaha Agricultural Association (KAA) and coordinated across County, State and Federal entities, including Agribusiness Development Corporation (ADC), PMRF, and others.

2. Exposed Assets – Buildings and Economic Loss[142,143]

Table 9. Mānā-Polihale Exposed Assets – Buildings and Economic Loss.

SLR Scenario *Residential* *Commercial*			**Coastal Buildings**				**Potential Economic Loss**
			Military	*Agriculture*			
1.1 ft. (near term)	Measure of Exposure within SLR-XA (count)		0	0	15	3	$3,251,513
	Coastal Hazard Layer	Passive Flooding (count)	0	0	0	0	
		Erosion (count)	0	0	6	3	
		Annual High Waves (count)	0	0	10	0	
3.2 ft. (mid-to-late century)	Measure of Exposure within SLR-XA (count)		0	0	39	6	$6,520,670
	Coastal Hazard Layer	Passive Flooding (count)	0	0	0	0	
		Erosion(count)	0	0	18	6	
		Annual High Waves (count)	0	0	26	5	

Mānā-Polihale buildings exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets within the overall SLR-XA and within each hazard (passive flooding, erosion, annual high waves) was recorded in ArcGIS. Potential economic loss is shown in the last column. Economic loss is based on based on the value of the land and structures from the county tax parcel database permanently lost in the SLR-XA for each projected SLR height.

3. Vulnerability

The Hawai'i SLR and Vulnerability Report provided a preliminary glimpse at vulnerability across Kaua'i through an economic lens. There are fifteen buildings that are documented as being threatened by SLR in the near-term, primarily from future erosion and inundation from high wave action. Most of these buildings are military buildings and the total loss from all buildings would be $3,251,513. By mid-to-late century, the estimated loss doubles and the number of buildings threatened almost triples. Based on the exposure data of 3.2 feet of SLR, erosion and the annual high wave runup are expected to be the dominant hazard.

The CVA workshops further examined the vulnerability question from the community perspective using VCAPS. The following are highlighted for Mānā.

<u>Roads</u>
Kaumuali'i Highway leading to PMRF and a number of county roads that give access to the surrounding agricultural lands are at risk of passive flooding from 1.1 foot of SLR in the near term. These roads become increasingly threatened by 3.2 feet of SLR. In addition, erosion and annual high wave runup are compounding hazards that threaten county roads along the coastline. As the portion of the highway between Kekaha and PMRF becomes increasingly threatened by SLR[144], this area will become more isolated and vulnerable, possibly cut off in the event of a large storm or disaster.

Drainage

Drainage in the Mānā Plain is entirely reliant upon agricultural ditches, canals, ocean outlets, and regular pumping of the groundwater. According to the exposure data, many of these ditches and canals become vulnerable to flooding with SLR both in the near-term and increasingly later in the century. It is important to note that the SLR exposure does not reflect current pumping activity. Therefore, pumping could mitigate the flooding in the near-term, although it is expected that the amount of pumping would need to increase and there is uncertainty how long this can be sustained by ADC, KAA, and PMRF.

Agriculture

Agriculture on the Mānā Plain will become increasingly exposed to flooding with 1.1' of SLR in the near term and 3.2' of SLR later mid-to-late century. Much of this agricultural land is used for agricultural research and development. Flooding is expected to be the dominant hazard, although salt water intrusion is also expected to impact crops and crop yields[145]. This could lead to loss of jobs and reduce opportunities for local food production. Current pumping of groundwater might serve as a mitigation strategy for the near-term, but it is unclear how long this can be maintained. Compounding the stress upon local agricultural production, rising temperatures and drought is also expected to impact agriculture negatively.

Dunes and Iwi Kūpuna

Nohili Dunes on PMRF land is one of the largest functioning sand dune systems in the state. These dunes will be exposed to annual high wave flooding under both near term and long-term SLR with the likely outcome of dune erosion. In addition, salt spray from wave overwash as sea levels rise will also impact dune native plants. This die back of native vegetation will in turn increase erosion. The loss of these dunes could have devastating impacts on iwi kūpuna and their extended families, as well as wildlife that rely on these remaining dunes for habitat. The Pacific Missile Range Facility (PMRF) manages the land and dunes, and through an MOU works with families to address burial exposure[146].

4. Adaptive Capacity/Opportunities

PMRF could become restricted from the rest of the west side primarily through loss of road access. This could prove to be a big problem mid-to-late century since PMRF is one of the larger employers in the region. It will be prudent for DOT and the county to address Kaumuali'i Highway either by relocating it or elevating it in certain low lying area. However, this will not address road access from and to PMRF on local roads, as well as to and from the agricultural lands mauka. If these lands are to remain viable and accessible, long-term drainage will need to be addressed, either by increasing pumping or re-designing the agricultural system (for e.g., the polder systems in the Netherlands)[147].

Maintaining connection to people's ancestors, or iwi, and the land they are buried in is critical for the emotional and community well-being of West Kaua'i families and residents. The decision of what to do about the exposure of iwi is a case by case decision undertaken by the family. Respecting each family, their unique needs, concerns and approach is paramount and requires a carefully crafted consultation process. In the case of iwi kūpuna in Nohili Dunes, a Memorandum of Understanding (MOU) has been established between

PMRF and the families to address burial exposure with the support from the State Historic Preservation Department (SHPD), who helped put agreements in place. Workshop participants looked to this MOU as a model for developing agreements between land owners with iwi sites and Hawaiian families in other areas in West Kaua'i with iwi kūpuna threatened by SLR[148].

Last but not least, there were several adaptation ideas raised with reference to the roads, drainage, agriculture, and critical infrastructure. Rather than duplicating them here, please see the respective sections in *Chapter V, Management Concerns*.

Sand dunes at Polihale. 6/11/18. Source: Ruby Pap

Waimea Bridge, a key component of the West Kauai transportation system. Source: imagery c 2020 EagleView

V. MANAGEMENT CONCERNS

A. TRANSPORTATION AND EVACUATION

The West Kauaʻi transportation system consists of one state highway (Kaumualiʻi), county collector roads, a series of state and county bridges, ports and harbors. There is also a small air strip in Port Allen (Burn's Field) and an airstrip at the Pacific Missile Range Facility (PMRF) in Kekaha. Evacuation of the population from a major storm is dependent in large part on access to roads and bridges. During emergencies the community is also dependent on the Ports, harbors and air strips for fuel, food, supplies, etc.

1. Key Takeaways

- The West Kauaʻi transportation system is vulnerable to SLR (i.e. erosion, passive flooding, wave inundation), heavy rainfall, and storm events. Due to a lack of alternative access and evacuation routes, the West Kauaʻi community could become isolated.
- Several sections of roadway along West Kauaʻi are particularly vulnerable and deserve specific study with regard to SLR impacts and alternative options. These are referred to as 'choke points.'
- The Pacific Missile Range Facility (PMRF) could become isolated from the rest of West Kauaʻi due to the highway's vulnerability in Kekaha. This would have a myriad of economic and social consequences for the community.

- There are many actions that can be taken to address short-term nuisance flooding on roads and highways, including developing cane haul roads as alternative access or evacuation routes and developing maintenance and response plans for water ponding.
- Long-term options for roadways include relocation, raising, and armoring, each with its own set of impacts and feasibility issues. Detailed feasibility studies of these options are needed.
- There are some sections of the highway that have more apparent relocation options. The highway in Kekaha is one such example because there are several alternative routes behind the town. However, questions remain about the costs and benefits of relocation and the long-term future of the existing revetment and Kekaha Town.
- Ports, harbors, and airports are also vulnerable because they could be isolated if the roadway transportation system is not addressed

2. Inventory of Exposed Transportation Infrastructure

A complete set of transportation SLR exposure maps can be found in Appendix B.

Table 10. Inventory of Exposed Transportation Infrastructure within SLR-XA[149,150,151]

	Measure of Exposure within SLR-XA with 1.1 ft. SLR (near-term) (count, miles)	Measure of Exposure within SLR-XA with 3.2 ft. SLR (mid-to-late century) (count, miles)
State Roads	2.01 (miles)	3.19 (miles)
County Roads	1.1 (miles)	5.75 (miles)
Harbors	2 (Kikiaola and Port Allen Small Boat Harbor)	2 (Port Allen and Kikiaola Small Boat Harbor)
Airports**	1 (Port Allen (Burns Field))	2 (Port Allen & Barking Sands)

An inventory of transportation infrastructure exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2 feet. Exposed assets within the overall SLR-XA was recorded in ArcGIS. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report. With respect to SLR impacts on West Kaua'i bridges, the CVA team did some additional research into the exposure data. Specific studies of SLR exposure for bridges and their footing elevations as well as rivers needs to be done. Bridges were not taken into account when mapping present day ground level with the digital elevation model (DEM) used in the SLR exposure data. *For the harbors, the jetties' exposure at 1.1' is milder, and for both scenarios they would not be completely inundated. **For the airports, only portions of the runways closest to the shoreline are exposed.

Table 11. Inventory of Exposed Transportation Infrastructure to Passive Flooding, Erosion, and Wave Inundation[152]

	Measure of Exposure from Hazards with 1.1 ft. SLR (near-term) (count, miles)			Measure of Exposure from Hazards with 3.2 ft. SLR (mid-to-late century) (count, miles)		
	Passive flooding	Erosion	High Wave Inundation	Passive flooding	Erosion	High Wave Inundation
State Roads	0.16 (miles)	1.83 (miles)	0.32 (miles)	0.17 (miles)	2.26 (miles)	2.40 (miles)
County Roads	0.22 (miles)	0.62 (miles)	0.4 (miles)	1.81 (miles)	2.1 (miles)	2.56 (miles)
Harbors*	2(Kikiaola Harbor and Port Allen Small Boat)	0	0	2 (Kikiaola Harbor and Port Allen Small Boat)	0	0
Airports**	0	1	1	1	2	2

An inventory of transportation infrastructure exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets affected by each SLR hazard (passive flooding, erosion, and high wave inundation) was recorded in ArcGIS. In most cases, infrastructure is impacted by multiple hazards. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report. With respect to SLR impacts on West Kaua'i bridges the CVA team did some additional research into the exposure data and spoke with the modelers from UH Coastal Geology Group. Specific studies of SLR exposure for bridges and their footing elevations as well as rivers needs to be done. Bridges were not taken into account when mapping present day ground level with the digital elevation model (DEM) used in the SLR exposure data. *For the harbors, the jetties' exposure at 1.1' is milder, and for both scenarios they would not be completely inundated. High wave inundation was not modeled at the harbors, so wave impacts at harbors are unknown. **For the airports, only portions of the runways closest to the shoreline are exposed.

3. Vulnerability and Potential Adaptation Actions

The project team conducted a community workshop focusing on the vulnerabilities of transportation and evacuation on September 5, 2018 at the Hanapēpē Public Library. Participants discussed two main climate stressors: SLR, heavy rainfall, and the intersection of the two (see Appendix A for the VCAPS diagram). SLR impacts to the highway and low lying collector roads will increase over time starting with nuisance flooding. In the longer term, beach erosion and flooding are expected to become a chronic concern, with the eventual outcome of major flooding and loss of roads, especially if combined with a heavy rainfall event. If this occurs, access to whole communities, evacuation routes, and employment centers could be lost, resulting in the isolation of individual communities. Consequences would include major loss of community resources, economic resources, and dramatic increases in public expenditures, as well as impacts on community health and well-being.

Short-Term Outcomes and Consequences to All Roads

With chronic SLR, it is expected that near-term impacts will be of the nuisance variety. This includes water ponding on the roads, soil softening underneath and adjacent to the roads, and shoulder flooding. Sea water ponding on the roads due to wave overwash could damage vehicles, potentially overwhelming towing and landfill capacity, and contribute toward ocean pollution. Continual inundation and flooding will make the pavement weak. This will increase road and drainage system maintenance. The drainage system (pumps, ditches, and canals) is discussed in detail in the following section.

Increased erosion due to SLR will also occur over time. Expected short-term outcomes include loss of beaches and the undercutting of roads, eventually leading to total loss of access. For more information on beach erosion see Section D of this chapter.

Potential Adaptation Actions

To address near term water ponding on roads, it was suggested that transportation agencies respond by monitoring, identifying trigger points or benchmarks in advance, and setting a schedule for responsive actions. This includes the drainage system in which the roads are highly dependent upon. See Section B Drainage for details on the drainage system.

Short-term actions discussed for erosion included monitoring the seasonal erosion patterns, continuing to conduct the sand bypass project in Waimea, and installing and/or maintaining revetments in areas where erosion threatens the roads. However, it was acknowledged that if revetments or other types of hard structures are built, further beach loss would likely be a consequence. As one participant explained, "Kekaha beach used to have over 100 yards of sand from road to water"[153]. See Section D, Beaches and Coastal Properties, for further details on beach erosion.

Longer term Outcomes and Consequences to All Roads

Major flooding of the highway (or local collector roads) due to mid-century SLR projections, either combined with heavy rain, or by itself was a topic of much discussion among workshop participants. Major flooding could also occur sooner with a major rain event, tropical cyclone, or tsunami. Potential consequences include loss of access to communities/ job centers, loss of emergency services, loss of life, economic loss, and isolation of PMRF, a major employer for the area. Loss of vehicular access to the landfill would have consequences for waste management island wide, although it's unlikely that the landfill will remain in its current location long-term. Permanent isolation could lead to negative consequences for community, including impacts to mental health as well as major financial costs to government.

Special concerns were discussed with regard to community mental health, in particular impacts on current vulnerable populations, such as the elderly and the poor. West Kauaʻi in general has an aging population and substantial populations living under the poverty line (for more information see *Chapter IV, Community Profiles*). In addition, participants expressed concern over a general lack of awareness and education regarding how to personally prepare for natural hazards. Concern was also expressed about an increase in tourism. Participants in the workshop viewed tourists as a particularly vulnerable group, since according to their observations, they generally don't understand what to do or where to go during an emergency. According to County fire/ocean safety officials, safety call volume on the westside has increased with the increase of in-fill housing, additional visitor traffic to Port Allen/Koke'e, and additional ocean recreational use.

Potential Adaptation Actions

Workshop participants came up with a list of potential actions to address the major flooding of the roads with a focus on the logistics of the infrastructure itself. More details are provided with specific roadway choke points below. Actions include armoring roads but with the caveat that it would require continual funding and could impact coastal dynamics and lead to further loss of beaches. Relocation of roads mauka was also discussed. Elevating the highway was mentioned but raises questions about feasibility due to impacts on the surrounding areas. All of these options would require a feasibility and cost-benefit analysis to determine the best option. Better floodplain management, ditch management, watershed management (including no logging upstream) was emphasized, as well as river dredging to promote stream flow. Lastly, asset managers pointed to the need to have SLR exposure maps with shorter 20 year timeframes to help with adaptation strategies. This is an immediate action the scientific community could work toward.

Roadway Choke Points

Workshop participants discussed several highway choke points that make West Kaua'i particularly vulnerable to SLR and high rain events. If these areas were to flood, either chronically or in an extreme event, West Kaua'i would be isolated posing problems with respect to evacuation, access to social services, access to jobs, etc. More specific studies are needed for all of these choke points[154].

Kaumuali'i Highway between Kekaha and MacArthur Park

The Kaumuali'i Highway located between Kekaha and MacArthur Park is low-lying, immediately adjacent to the ocean, and partly protected by a revetment. It already experiences wave overwash and erosion. Kekaha beach in front of the revetment is highly dynamic. In 2012, it experienced severe erosion near MacArthur Park, threatening the road. Under a 1.1' or 3.2' SLR scenario, the highway is exposed to erosion and annual high wave flooding. However, it is important to note that the exposure data does not take into account the existence of manmade structures (i.e., the existing revetment or the drilled pier wall). It is reasonable to think that if the shoreline armoring in this area is not continually monitored, maintained, and upgraded, the road will be impacted by erosion and wave overwash. Groundwater flooding will be a concern with or without the armoring.

Kaumuali'i Highway located between Kekaha and MacArthur Park, which was threatened by episodic erosion in 2012. Source: Ruby Pap

<ins>Potential Adaptation Actions</ins>

As short-term public actions, participants discussed the need for a clear monitoring and maintenance plan for the road that identifies trigger points and responsive actions for flooding. A hydrology study evaluating the drainage system in the face of SLR is also needed as well as feasibility studies for raising and/or relocating the highway. Ensuring that the road revetment is adequately maintained is also advised by the project team. Participants also pointed to the need to maintain, re-grade or dredge the canal/ditch system in Kekaha. This could be done with collaboration between the private and public sector.

Longer term public actions discussed included raising or relocating the highway. There are several alternative location options behind town, either on Kekaha road, old cane haul roads within the agricultural fields or along the pali. However, questions remain about the costs and benefits of relocation and the long-term future of the existing revetment and homes fronting the highway. The revetment protecting the highway (and by default, the homes) is continually maintained by the State with federal aid. If the highway were to be relocated, decisions need to be made about the use of the 'old highway,' and agreements would need to be put in place regarding who is responsible for maintenance of the revetment, or if removed, whether and how homes would need to be relocated. A thorough cost-benefit and feasibility study is needed to address these questions, drawing on other examples of roadway relocation.

Case Study: California Highway 1 Realignment at Devil's Slide

Located just south of the City of Pacifica in California, Devil's Slide is a treacherous coastal landslide feature. Highway 1 was built on a former railway bench in 1937 and every decade since, the roadway has suffered massive slides and closures that isolated the communities to the south, causing economic hardships for businesses and families. The state first began planning a bypass for the slide in 1958 to avoid the long-term maintenance costs of rebuilding the road repeatedly in its existing location. San Mateo County voters passed a local ordinance in the 1990s to provide a tunnel for motorized vehicles behind Devil's Slide through San Pedro Mountain. The ordinance required the old highway to be repurposed as a trail for pedestrians and bicycles. The project cost $439 million to construct and was funded entirely with Federal Highway Administration (FHWA) Emergency Relief Funding. Construction began in January 2007 and was completed in 2013. The existing highway right of way was relinquished to the County of San Mateo. Strong-interagency partnerships, political support, and negotiations towards a shared vision were key ingredients in bringing this project to fruition.


Highway 1 at Devil's Slide before (left) and after (right) relocation. Source: California Department of Transportation.

References:
Associated Press. 2013. Devil's Slide Tunnel Project Facts
Email from Tami Grove, Caltrans Liaison, California Coastal Commission, 8/28/19

Kaumuali'i Highway through Waimea Town and Local County Roads

The highway through Waimea town leading to Waimea Bridge is low lying. With 3.2' of SLR, this portion of the highway as well as county roads located makai could be impacted by annual high wave flooding. Towards the end of the century, rising groundwater in areas makai of the highway is also expected to undermine drainage and cause permanent flooding[155]. This will pose additional challenges to the roads, the neighborhood, and underground infrastructure. The highway needs an alternative route mauka of the highway for evacuation purposes. It might be more difficult to implement a retreat alignment along existing roads. This deserves further study. There is a ford crossing across the Waimea River that needs improving. It may not be feasible to raise the highway through town due to the fact that the surrounding town would be at a lower elevation. Elevating the roads but not the private properties could inadvertently increase flood risk to the private lands, especially on the mauka side of the road. One participant pointed out that many existing houses are on slab.

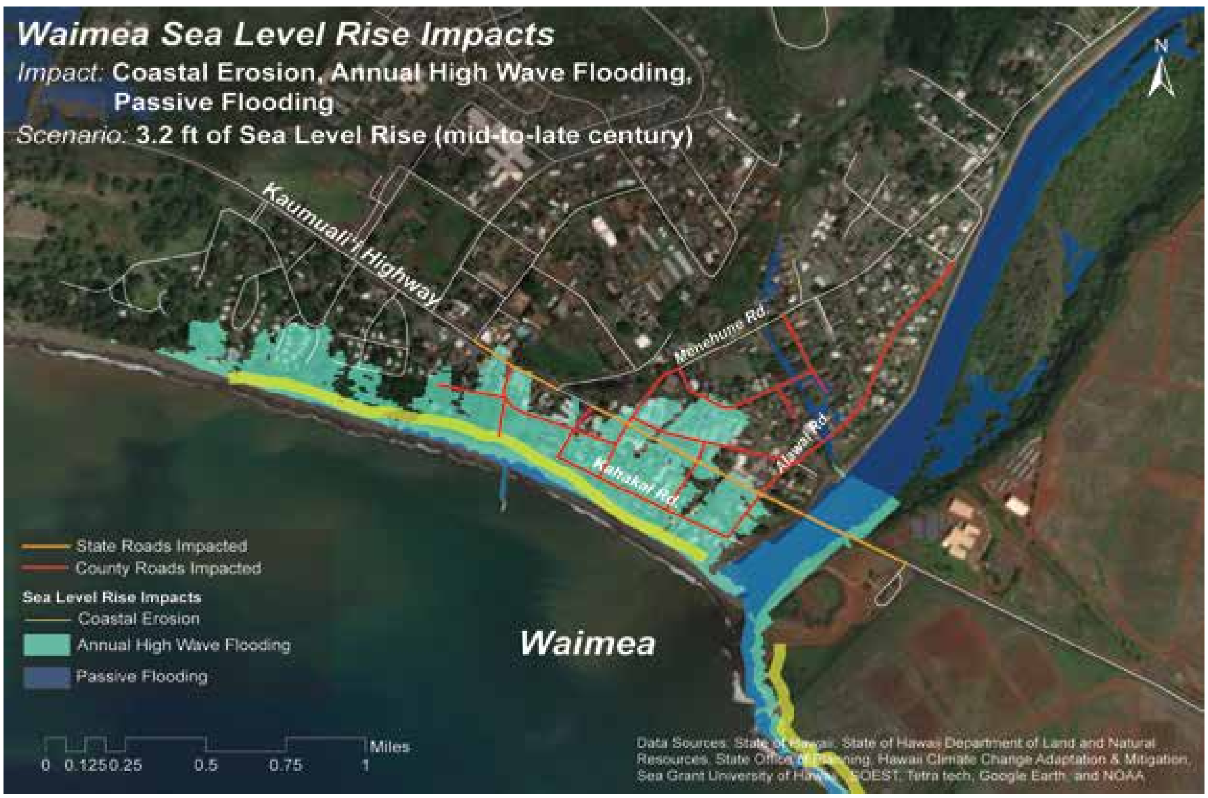


FIGURE 18. ROADWAYS IN WAIMEA TOWN EXPOSED TO A 3.2' SLR SCENARIO. The highway through Waimea Town, Kaumuali'i Highway, and county roads which will be exposed to 3.2' of SLR. Exposed assets are affected by one or more of the following SLR hazards: passive flooding, erosion, or annual high wave inundation. The exposed highway is indicated in orange and the exposed county roads are indicated in red.

Potential Adaptation Actions

As a short-term public action, participants emphasized that there needs to be an alternative evacuation route for the highway in case the highway or bridge is damaged. One option for evacuation in the short-term could be to improve the river ford crossing. It was also suggested that alternative mauka highway routes be studied including sites for bridge locations. Because there could be negative consequences economically if the highway is moved mauka, the highway through town could remain a 'main street' until maintenance is no longer feasible.

Since roads are a critical link for homes, businesses, and neighborhoods, several actions relating to private developments and neighborhoods were emphasized. On the public side, it was suggested that all construction permits for homes, infrastructure, etc. should consider SLR; starting a relocation program for homes/ businesses; and studying the feasibility of building a large dike or similar armoring along the shoreline. Private actions included consideration of SLR in all home improvements, elevating homes, and relocating homes and businesses to higher ground.

Hanapēpē Bridge

Workshop participants also pointed out that Hanapēpē Bridge is sensitive to large storm events due to its low lying position and the fact that it could 'act as a dam' from debris and the high velocity of the water. Concern was also expressed that SLR combined with heavy rainfall could overwhelm the bridge.

Waimea River Bridge

While the Waimea River Bridge is higher and more inland than the Hanapēpē Bridge, vulnerability of the bridge was of concern because the level of silt that builds up in the river and the fear that future SLR combined with heavy rainfall could overwhelm the bridge. If that were to occur, Waimea to Polihale would be isolated as there is no alternative road for access.

Potential Adaptation Actions

Public actions discussed for the bridges included regular dredging of the rivers, raising the bridge and levy walls, and conducting a risk assessment study of the bridges based on a combined scenario of large rainfall with SLR. In addition, it was noted that better coordination between agencies, organizations, and the public is needed to address flood prevention.

Waimea Valley Roads

Waimea valley roads are vulnerable due to the nature of their location and the complicated factors with how the river and its levies are managed. These include Ala Wai, Ape, and Menehune Roads. This area is located west of the Waimea River levy in an area that is a former floodplain. Even on a sunny day the Waimea Valley roads can flood. The river rises regularly due to the blockage of the river mouth by sand, which is influenced by the swells and tides. If the river rises above a broken flap gate in the levy, the ditches in Waimea Valley back up and often overflow because they are unable to drain to the river. In addition, the ditches and underground drainage pipes in this neighborhood are poorly maintained. The result is flooding on the valley roads, also affecting homes, businesses, and infrastructure. With SLR this situation is expected to worsen due to the river's diminished ability to drain.

Potential Adaptation Actions

Participants suggested several actions to address flooding on Waimea Valley Roads. However, a large part of the flooding problem has to do with the levee and river interactions. Section C, Critical Infrastructure describes specific actions. Additional public actions discussed include designating areas needed to channel water, avoiding new home construction, and utilizing existing unused canals to help channel the water.

Kekaha Road
Another chronically flooded area is Kekaha Road due to drainage issues. This issue is connected to *Chapter V Sectiont B: Drainage*.

Ports and Harbors
SLR could impact Port Allen Harbor, Port Allen Small Boat Harbor, and Kikiaola Small Boat Harbor in Waimea. Road access to the ports and harbors could also become compromised. A direct consequence could be loss of fuel and electricity for the community because Port Allen's fuel for energy gets delivered to the Port Allen Harbor.

While the SLR exposure data shows Port Allen breakwaters and docks to be exposed to 3.2' of SLR, it is unclear how compromised they would be. According to DOT officials, the state hopes to upgrade or build a new port in the near future. The Mahinauli Boat Harbor in Pākalā can be used as an alternative to Port Allen if unusable, but this is also vulnerable to SLR. If the small boat harbors in Port Allen or Kikiaola are damaged or destroyed, the fishing industry could diminish or disappear.

FIGURE 19. 3.2' SLR PORT ALLEN SMALL BOAT HARBOR. Port Allen Small Boat Harbor exposed to passive flooding under a mid-to-late century scenario of 3.2' SLR.

FIGURE 20. 3.2' SLR EXPOSURE AREA AT KIKIAOLA SMALL BOAT HARBOR.

<u>Potential Adaptation Actions</u>

Public actions discussed include conducting specific SLR studies on the ports and reengineering existing breakwaters, ramps, and piers. It was also suggested that floating docks are an alternative to fixed docks that allow for change in sea levels, and that creating response plans in specific facilities for high water level events would be beneficial. Lastly, boat harbor managers need better, short-term predictions for SLR and a fiscal analysis of the impacts.

<u>Addressing Financial Costs</u>

How will the government and community deal with the high costs of adaptation? Workshop participants mentioned higher property taxes for those in vulnerable areas, revisiting "environmental regulations" that pose high cost to government, a feasibility study addressing realignment of current state road by the Department of Transportation, toll roads, and re-developing communities outside the SLR hazard zone. Participants also emphasized the need to change zoning to avoid/restrict development in future hazardous areas and create an inventory of prioritized lands for retreat.

<u>Addressing Personal Preparation for SLR and Natural Disasters</u>
Providing education on personal preparation, and investment in early warning systems is a major priority for the community. Also, since tourists are one of the most vulnerable populations due to their lack of knowledge of the area, it was suggested that limiting tourism during times of emergency is something the public sector should explore.

B. DRAINAGE AND LEVEES

Cox drainage canal located in Kekaha. Source: Daniele Spirandelli

Drainage in West Kaua'i is comprised of a network of rivers, streams, levees, canals, remnant sugar cane ditches, grassy swales, some limited underground stormwater pipes, and impervious surfaces that direct river and stormwater mauka to makai. Many streets in older developments have grassy shoulders with roadside swales and they have no underground drainage pipes. Storm runoff flows through roadside swales to streets with curbs, gutters and sidewalks and an underground drainage system, or to a location where the street crosses a man-made ditch or natural drainageway. Newer subdivisions have a combination of roadside swales and underground drainage pipes or curbs, gutters and sidewalks with underground drainage systems[156].

In Kekaha and the Mānā Plain, water pumps keep the groundwater level low to support agriculture production and prevent flooding in the town of Kekaha. Several community members describe the area mauka of Kekaha as formerly a wetland. One interviewee explained, "When the sugar plantations came to Hawai'i, they installed these drains and canals so the land would be farmable. Before the land was settled you were able to canoe from Waimea to Mānā"[157]. The Kekaha Agricultural Association (KAA) and Agribusiness Development Corporation (ADC) perform storm preparation and response procedures for a number of drainage facilities in Kekaha and its agricultural lands to minimize flooding impacts to crops and adjacent residential areas. These facilities include pump stations, ditches, and outlets that drain to the ocean. These procedures are performed in coordination with county and state entities, including Kauai Emergency Management Agency (KEMA), and the Hawai'i Department of Health Clean Water Branch.

> "When the sugar plantations came to Hawai'i, they installed these drains and canals so the land would be farmable. Before the land was settled you were able to canoe from Waimea to Mānā."

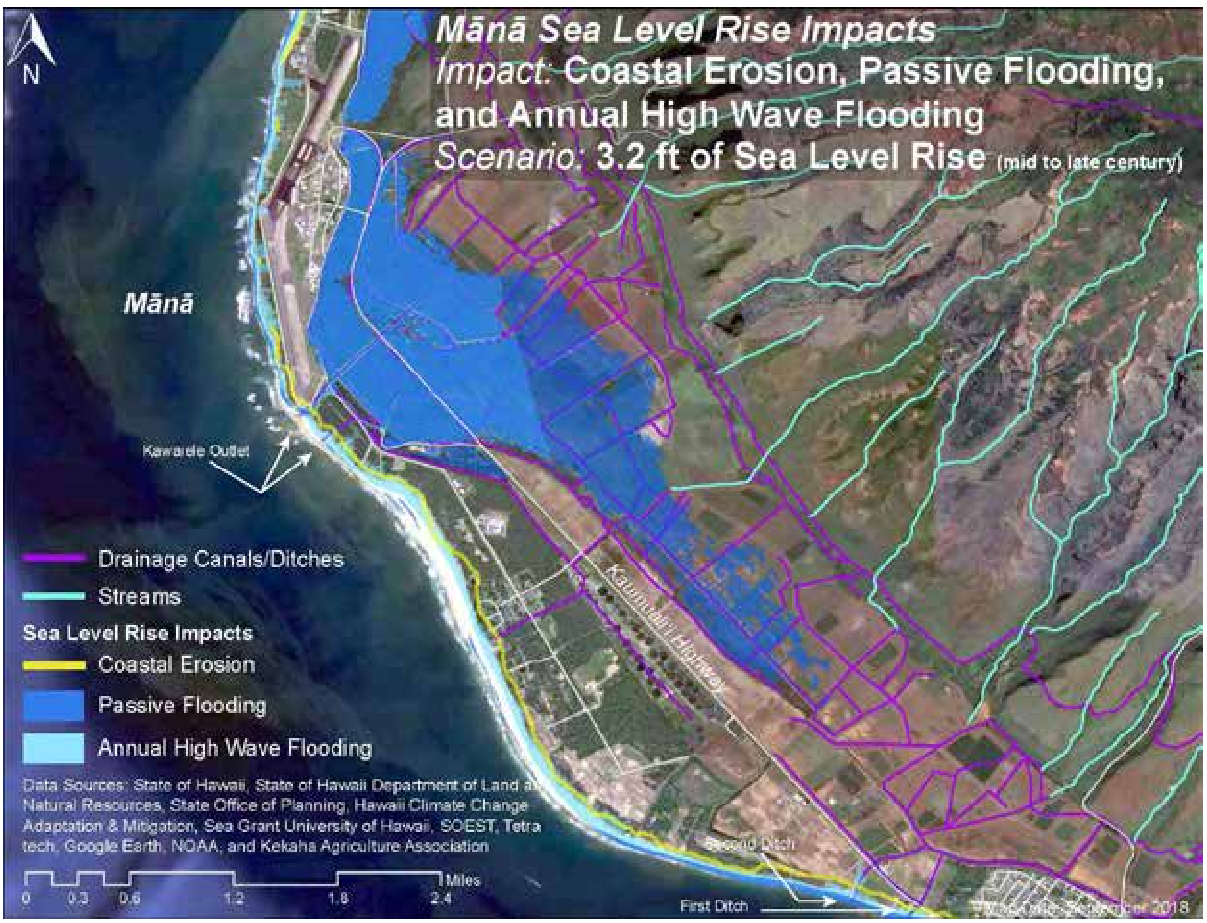


FIGURE 21. MĀNĀ-POLIHALE DRAINAGE EXPOSED TO A 3.2' SLR SCENARIO. Drainage assets which will be exposed under a 3.2' SLR scenario. Exposed assets are affected by one or more of the following SLR hazards: passive flooding, erosion, or high wave inundation. Drainage canals/ditches are indicated in purple.

1. Key Takeaways

- Drainage is insufficient for present day large rain events leading to flooding. These conditions will be exacerbated with future SLR. In Hanapēpē, workshop participants felt that flooding occurs in town due to inadequate stormwater infrastructure. The drainage system needs to be studied in detail to better understand the combined risks caused by SLR and changing rainfall patterns.
- The expected groundwater rise due to SLR will exacerbate drainage issues.
- Present day drainage infrastructure is old, under capacity and poorly maintained. Workshop participants discussed the need for better coordination across responsible parties, improved maintenance, updating of infrastructure, and its redesign for larger storms.
- The river levees provide critical flood protection services to the towns of Waimea and Hanapēpē.
- The current height of levees are most likely inadequate to protect both towns from future SLR, heavy rainfall, and a combination of both.
- Sediment build up in the Hanapepe and Waimea rivers and a sandbar at the river mouth of Waimea further reduce the capacity of the levees and increase the town's vulnerability to flooding.
- Flap and sluice gates on the Waimea levee that help drain the town need to be addressed; they can leak and cause river flooding into the Waimea Valley neighborhood. With SLR and a permanent higher river, their placement could prevent drainage into the river.
- In Kekaha, coordination and knowledge sharing does occur between responsible parties regarding drainage needs, maintenance, and storm procedures for ditches, canals, existing pumps and outfalls. These efforts are critical to preventing flooding in the area. Participants expressed the need for more publicly available information about drainage and that having this knowledge would help the community be more resilient.
- Flooding from inadequate drainage can impact sewer pipes, cesspools, roads, and homes. In Kekaha, this is especially of concern where these is no central sewer system.
- Participation in the National Flood Insurance Program's (NFIP) Community Rating System would incentivize flood mitigation measures on both private and public lands and reduce flood insurance costs for the community.

Green infrastructure

A bioswale, which slow and filter stormwater from areas with impervious surfaces. Source: Daniele Spirandelli

Green infrastructure encompasses a range of strategically planned natural and semi-natural areas that include environmental features to deliver a broad range of ecosystem services. Green infrastructure strategies and projects are implemented at multiple scales, including regional ecological networks (e.g., wetlands), green space networks (e.g., network of parks and open spaces), and local stormwater control measures to mitigate stormwater run-off (e.g., flood control basins, bioretention basins, swales, green roofs, and other low impact development strategies). Low Impact Development (LID) refers to a system of small, on-site storm water control measures designed to mimic natural processes that infiltrate, transpire or reuse stormwater on the site where it is generated. Municipalities and counties have been incorporating LID into their ordinances as either incentives with new construction or mandating them all together. A green infrastructure approach can also be used as a natural barrier along a coast with plants, dunes and wetlands. In contrast to hard structures such as sea walls and bulkheads, a "living shoreline" helps reduce erosion, wave impacts, and flooding associate with sea level rise while providing other benefits such as improved water quality, aquatic habitat, and carbon sequestration.

More information:
https://www.epa.gov/green-infrastructure/what-green-infrastructure
https://www.epa.gov/sites/production/files/2015-10/documents/climate_res_fs.pdf
https://www.georgetownclimate.org/adaptation/toolkits/green-infrastructure-toolkit/regulatory-tools.html
http://seagrant.soest.hawaii.edu/sbcd-stormwater-practices/

2. Inventory of Exposed Drainage Infrastructure[158,159]

A complete set of drainage SLR exposure maps can be found in Appendix B.

Table 12. Inventory of Exposed Drainage Infrastructure within SLR-XA

	Measure of Exposure within SLR-XA with 1.1 ft. SLR (near-term) (count, miles)	Measure of Expoure within SLR-XA with 3.2 ft. SLR(mid-to-late century) (count, miles)
Ditches	15.57 (miles)	30.28 (miles)
Outlets	8	8

An inventory of drainage infrastructure exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2 feet. Exposed assets within the overall SLR-XA was recorded in ArcGIS. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report. There is not enough data on the levees or streams to assess their exposure to SLR.

Table 13. Inventory of Exposed Drainage Infrastructure to Passive Flooding, Erosion, and Wave Inundation

	Measure of Exposure from Hazards with 1.1 ft. SLR (near-term) (count, miles)			Measure of Exposure from Hazards with 3.2 ft. SLR (mid-to-late century) (count, miles)		
	Passive flooding	Erosion	High Wave Inundation	Passive flooding	Erosion	High Wave Inundation
Ditches	14.98(miles)	0.31(miles)	2.99(miles)	28.09(miles)	0.5(miles)	12.95(miles)
Outlets	8	6	7	8	6	7

An inventory of drainage infrastructure exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets affected by each SLR hazard (passive flooding, erosion, and high wave inundation) was recorded in ArcGIS. In most cases, infrastructure is impacted by multiple hazards. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report. There is not enough data on the levees or streams to assess their exposure to SLR.

3. Vulnerability and Potential Adaptation Actions

On October 3, 2018, the project team held a community workshop with community members and asset managers to characterize the drainage system's vulnerability to climate change and coastal hazards. Two climate stressors were discussed during the workshop: SLR and heavy rainfall, as well as the combination of these two stressors. In a separate workshop on November 26, 2018, community and asset managers discussed West Kaua'i's vulnerability with respect to levees. In this workshop participants also focused their discussion on SLR and heavy rainfall, as well as a combination of both. Participants agreed that, across all towns, the drainage infrastructure requires better maintenance, re-design and upgrade. (See Appendix A, VCAPS diagram]).

Waimea and Hanapēpē Drainage System and Levees

The Waimea and Hanapēpē levees were designed to protect the towns from a 1 percent annual chance flood event (100 year storm). However, according to the Army Corps of Engineers, the levees do not meet the Federal freeboard standard and therefore fail Federal certification requirements. As a result, properties in the valleys will soon be identified as being in the Federal Emergency Management Agency's (FEMA) Special Flood Hazard Area (SFHA), triggering additional National Flood Insurance Program's (NFIP's) floodplain management regulations and insurance requirements for homeowners[160]. Workshop participants expressed that low-lying areas are prone to flooding both behind the levees and where the levees discontinue (i.e. between Hanapēpē Road and the river mouth). Workshop participants also expressed concern about the shallow grassy swales in Hanapēpē Heights as being insufficient to handle storm flows and enter Hanapēpē town. This situation is expected to worsen with SLR and a rising water table.

The levee that is built along the banks of the river in Hanapēpē. The levee protects the town from flooding.
Source: Ruby Pap

Waimea and Hanapēpē rivers can get blocked with boulders, rocks, and other debris during a rain storm. Workshop participants expect SLR with the addition of large storm events to exacerbate debris blockages. The group also discussed the Waimea and Hanapēpē bridges acting as a potential dam and thus increasing flood risk. The state DOT is not incorporating SLR into bridge design (e.g., height) and thus the bridge may act as a choke point or dam for the river. SLR will push saltwater further upstream the river and may also reduce sediment movement.

With heavy rainfall higher river levels could potentially overtop the levees. A higher river level could also impact the flap gates on the levee as they will not open when river level is high. Heavy rainfall also increases bank erosion on the levees. For both rivers, a combination of SLR and heavy rainfall leading to more bank erosion could add to sediment build-up in the river, which will reduce the flow capacity of the river. Flow diversions upstream already reduce river flow and thus sediment does not readily move out of streams.

In both towns drainage ditches flow toward the rivers, and when they reach the levees they are fitted with flap gates and manual sluice gates. The purpose is to prevent back flow into the towns when the river flow or ocean tides are high. However, there is an issue in Waimea when the river mouth is blocked due to sand build up at the river mouth. This raises the river water levels above the flap gates (Gate A). In addition flap gate A has been damaged and does not fully seal. As a result, river water leaks back into the drainage ditch in Waimea Valley causing flooding on the roads and neighborhood. Hanapēpē has a lift pump station which can be activated when the water elevation in town outside of the river is high enough to create a flood situation, but this is not the case in Waimea. Poor drainage ditch maintenance in Waimea also contributes to the problem. The DLNR and County are responsible for opening the Waimea river mouth when required via an on call state contractor, which has turned into a regular and expensive activity. Both the State and County are looking for solutions to this ongoing maintenance problem, which could be exacerbated by increasing SLR.

Flap gate A on the Waimea River Levee. Source: Ruby Pap

Sluice gate A on the Waimea levee. Source: Ruby Pap

Waimea River mouth, which can become blocked due to sand built up. Source: Ruby Pap

Potential Adaptation Actions

In Waimea, there is a critical need to repair flap gate A to ensure it does not leak river water into Waimea Valley or prevent drainage into the river. In addition, the drainage need to be cleaned out and maintained.

Several specific studies are needed on the combined risks of SLR and rainfall events to the drainage systems and the levees. Detailed hydrologic studies of these levees are needed to assess their capacity for flood protection under 1% chance annual storm combined with 3.2 feet of SLR. These studies would help inform the feasibility and need for raising the levee walls under future conditions. Workshop participants emphasized the need for levees to be designed for such conditions, as well as for bridges to have a 50-year design life.

Participants also discussed the need to update flood insurance maps to reflect more recent rainfall events and data, and a more accurate flood hazard area. They discussed ideas for how to mitigate new flood risk to homes by elevating homes in the river valleys and regulate buildings and development to a higher standard in flood risk areas. Kauai's participation in FEMA's Community Rating System would help to incentivize flood mitigation measures on both private and public lands, and to reduce flood insurance rates.

This is also an opportunity to improve stormwater management, adding green infrastructure and more pervious surfaces. The infrastructure should be designed to mitigate large rainfall events and future SLR.

National Flood Insurance Program's Community Rating System

The National Flood Insurance Program's (NFIP) Community Rating System (CRS) is a voluntary incentive program that recognizes and encourages community floodplain management activities that exceed the minimum NFIP requirements.

Under the CRS, flood insurance premium rates are discounted to reward community actions. The CRS has three goals: (1) to reduce flood damage to insurable property; (2) to strengthen and support the insurance aspects of the NFIP; and (3) to encourage a comprehensive approach to floodplain management.

The CRS uses a Class rating system to determine flood insurance premium reductions for residents. CRS Classes are rated from 9 to 1. If Kaua'i County were to enter the CRS program at a CRS Class 9, this would entitle residents in Special Flood Hazard Areas (SFHAs) to a 5 percent discount on their flood insurance premiums. As the communities engage in additional mitigation activities, Kaua'i residents would become eligible for increased NFIP policy premium discounts. There are 19 creditable activities, organized under four categories:

- Public information
- Mapping and regulations
- Flood damage reduction
- Warning and response.

As a participating community in the CRS with a class 7 rating, Maui County residents receive 15% off of their flood insurance premiums, which FEMA estimates saves the county approximately $1 million dollars in premiums. Hawai'i County also participates in the program at a class 8 rating, which provides homeowners in the SFHA up to 10% savings on their flood insurance.

More information:
https://www.fema.gov/national-flood-insurance-program-community-rating-system
https://waihalana.hawaii.gov/2019/02/02/what-is-the-national-flood-insurance-programs-crs/

Kekaha Drainage

The system of canals and ditches in Kekaha are poorly maintained resulting in overgrown vegetation, trash, and other obstructions that block flow, further increasing the risk of flooding. There is confusion and uncertainty in the community over who is responsible for ditch or canal maintenance. In addition, oftentimes, local residents do not know which public entity is responsible for what drainage structure during an emergency.

Two pumps and pumping outfalls (Kawaiele and Nohili) are critical for Kekaha. These pumps, including one on PMRF land, are maintained by KAA and ADC and currently prevent flooding into agricultural lands and Kekaha town. Groundwater inundation in surrounding areas is expected to increase with SLR, although the projected flooding on the exposure maps at 1.1 or 3.2 feet of SLR does not reflect current pumping activity. The pumping could help in the near-term, but it is unknown how long this can be sustained.

Potential Adaptation Actions

Participants expressed the need to increase coordination among public agencies and private landowners regarding the maintenance of the ditch and canal systems in all of the towns. As part of this coordination, improved communication between responsible parties is needed, as well as clear information on who to contact when there is a problem with a canal or ditch. More education and outreach programs are needed to help educate homeowners on the importance of keeping ditches and canals clear of debris, vegetation, and trash.

More studies are needed to better understand how the drainage system functions in Kekaha, how SLR will impact the drainage and pumping regime, how the system will function under a combined scenario of heavy rainfall plus 3.2' of SLR, and how this will affect KAA & ADC's capacity to keep up with pumping, storm procedures, as well as ditch-outlet maintenance requirements. A 3-D groundwater study with SLR is needed to understand the full geographic extent of the high water table and how pumping impacts groundwater in Kekaha.

As with Waimea and Hanapēpē, this is also an opportunity to improve stormwater management, adding green infrastructure and more pervious surfaces. The infrastructure should be designed to mitigate large rainfall events and future SLR.

Wastewater Impacts

Excess run-off (during large storms) and rising water table with high tides can enter wastewater sewer pipes (in the form of inflow and infiltration) and exceed the capacity of the wastewater treatment plant, causing possible sewage overflows (see more details in Section C.1 Wastewater Infrastructure). These same conditions can inundate cesspools. There is concern over the long-term impacts of sea-level rise on current wastewater treatment systems, namely inundated cesspools with implications for human and environmental health.

Potential Adaptation Actions

Workshop participants discussed the need to convert cesspools to septic or another onsite wastewater technology, or if possible, to fund a new wastewater treatment plant in Kekaha. See Section C.1 Wastewater Infrastructure for more details.

C. CRITICAL INFRASTRUCTURE

The research project team defined critical infrastructure as all critical assets and infrastructure that are vital to the communities of West Kaua'i. The loss and destruction of these assets would have a debilitating effect on security, public health, and safety. A full list of critical infrastructures assessed for potential exposure to SLR is provided in *Chapter III, Inventory of Exposed Assets*. For the purposes of this CVA, the critical infrastructures assessed in more depth during individual workshops were wastewater infrastructure, electricity, and water supply. Other critical infrastructure such as drainage, levees, and roads are discussed in their own respective chapters.

1. Wastewater Infrastructure

The wastewater treatment plant in Waimea. Source: imagery c 2020 EagleView

The towns of Hanapēpē, 'Ele'ele, Port Allen, and Waimea contain centralized wastewater (sewage) systems consisting of gravity pipelines, manholes, pump stations, force mains, and wastewater treatment plants. There are two publicly owned and maintained wastewater treatment systems in Waimea and 'Ele'ele. There is also a private wastewater treatment system in Mānā at the Pacific Missile Range Facility (PMRF). Kekaha is not connected to a central sewer system. Individual homes and businesses in Kekaha process their wastewater with onsite disposal system (OSDS), primarily with cesspools, many on the coast and in areas with a high water table. A high water level impacts the effluent in a cesspool pit or absorption (leachfield), potentially leading to surface flows and contamination above ground and/or backing up into the house. There are also properties in Hanapēpē, Port Allen, 'Ele'ele, and Waimea, as well as in the rural communities in between that are not on central sewage, but instead on OSDS.

a. *Key Takeaways*

- Flooding from SLR and heavy rainfall can impact both sewer pipes and cesspools. In Kekaha, this is especially of concern where there is no central sewer system, mostly cesspools.
- In both the near-term and long-term, wastewater treatment plants appear to be safe from the impacts of SLR. However, two pump stations in Waimea could be impacted by high wave inundation with the increase of 3.2 feet of SLR.
- In the near-term, higher rates of erosion associated with SLR could compromise OSDS, and in the long-term, SLR will most likely impact over 100 OSDS, much of this due to future erosion and high wave inundation.
- Mid-to-late century, groundwater is expected to rise with sea level with consequences for wastewater infrastructure, although a more detailed study is needed to assess areas at risk with future groundwater rising.
- Conversion of cesspools is paramount, particularly those at risk of flooding in areas with a high water table and/or directly on the coast. A feasibility analysis is needed to assess the best alternative: septic systems, other onsite systems, or extending municipal sewer to homes.
- There is a need for pre-disaster planning for post disaster recovery/reconstruction of the public sewer system and OSDS in the event of a large flood.
- Long-term public actions discussed include upgrading sewage pipes and fittings by lining pipes to reduce cracks, and raising manholes, which would require raising the streets.

Wastewater Treatment Alternatives

Aerobic Treatment Unit: An onsite disposal system (OSDS) that is designed to retain solids, aerobically decompose organic matter over a period of time, and allow effluent to discharge into an approved disposal system.

Cesspools: Generally large, cylindrical, lined excavations used to receive untreated wastewater from a home or building. Solids are retained and the liquid percolates into the surrounding soil. In 2016, Hawai'i State legislature banned the construction of new cesspools, and in 2017, passed Act 125, which requires that all cesspools be upgraded by 2050.

Composting toilet: Receives human waste and stabilizes it through natural degradation. The waste is mixed with starting mulch, and generally sterilizes the waste when allowed to degrade and dehydrate for a period of up to 12 months, depending on usage. The compost from a composting toilet can be used to grow plant life, but is never used to grow food.

Constructed Wetland: A man-made, large, marsh-like system that employs natural processes, like sedimentation, filtration, and plant uptake to treat wastewater.

Onsite Disposal System (OSDS): A system relying on natural processes and/or mechanical components that is used to collect, treat, and disperse/discharge wastewater from single dwellings or buildings. The disposal system can be any seepage pit, cesspool, injection well, soil absorption system, or other facility used in the disposal of wastewater or wastewater sludge.

Septic Tank with Drainfield Treatment: A tank that serves as both a settling and skimming tank, and is used as pretreatment for biological treatment through a drainfield or absorption trenches.

Wastewater treatment with primary treatment: A central sewer system which transports all sewage to a treatment plant via a conveyance system. The system includes building and street sewer laterals or connections from individual properties, interceptor sewers, sewage pump stations, and force mains. Primary treatment uses sedimentation to remove floating and settleable materials found in wastewater.

Wastewater treatment plant with secondary treatment: A central sewer system which transports all sewage to a treatment plant via a conveyance system, and uses a biological treatment process to remove biodegradable organic material, and suspended solids. Disinfection is also typically included in secondary treatment.

More information:
http://seagrant.soest.hawaii.edu/cesspools-in-paradise/
University of Hawai'i Water Resources Research Center 2008. Onsite Wastewater Treatment Survey and Assessment.

b. *Inventory of Exposed Wastewater Infrastructure*[161,162]

A complete set of wastewater SLR exposure maps can be found in Appendix B.

Table 14. Inventory of Exposed Wastewater Infrastructure within SLR-XA

	Measure of Exposure within SLR-XA with 1.1 ft. SLR (near-term) (count, miles)	Measure of Expoure within SLR-XA with 3.2 ft. SLR (mid-to-late century) (count, miles)
Sewage mains	0.08 (miles)	1.51 (miles)
Sewage pump stations	0	3 (2 in Waimea, 1 in Hanapēpē-'Ele'ele)
Wastewater treatment plant	0	0
Onsite disposal systems (OSDS)	22	110

An inventory of wastewater infrastructure exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2 feet. Exposed assets within the overall SLR-XA was recorded in ArcGIS. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report.

Sewage spill warning at Kikiaola Harbor after a heavy rain overwhelmed the system, 3/20/20. Source: Ruby Pap

Table 15. Inventory of Exposed Wastewater Infrastructure to Passive Flooding, Erosion, and Wave Inundation

	Measure of Exposure from Hazards with 1.1 ft. SLR (near-term) (count, miles)			Measure of Exposure from Hazards with 3.2 ft. SLR (mid-to-late century) (count, miles)		
	Passive flooding	Erosion	High Wave Inundation	Passive flooding	Erosion	High Wave Inundation
Sewage mains	0.06(miles)	0	0.03(miles)	0.62(miles)	0	0.89(miles)
Sewage pump stations	0	0	0	1 (in Hanapēpē)	0	2 (in Waimea)
Wastewater treatment plant	0	0	0	0	0	0
Onsite disposal systems (OSDS)	1	20	1	5	80	52

An inventory of wastewater infrastructure exposed to two SLR scenarios: A near-term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets affected by each SLR hazard (passive flooding, erosion, and high wave inundation) was recorded in ArcGIS. In most cases, infrastructure is impacted by multiple hazards. SLR exposure data was obtained from the Hawaiʻi SLR Vulnerability and Adaptation Report.

c. *Vulnerability and Potential Adaptation Actions*

On November 26, 2018, the project team held a community workshop where residents and asset managers came together to characterize West Kauaʻi's vulnerability to climate change and coastal hazards with respect to wastewater infrastructure. The workshop took place at the Hanapēpē Public Library. Several climate stressors were discussed during the workshop: SLR including groundwater inundation, heavy rainfall, extreme events/storms, and the combination of these stressors.

Based on the SLR exposure data, erosion and annual high wave runup are expected to be the dominant hazards putting sewer mains and many OSDS at risk, particularly by mid-to-late century (Table 14). Many of these systems are located in Waimea and Kekaha. In Kekaha, the number of OSDS at risk could be an overestimate since the exposure data does not take into account the rip rap revetment along edge of Kaumualiʻi Highway and the coastline. However, while the revetment serves as protection from SLR impacts by helping to slow erosion and waves for some time mauka of the highway, groundwater is expected to rise with SLR with consequences for all underground infrastructure.

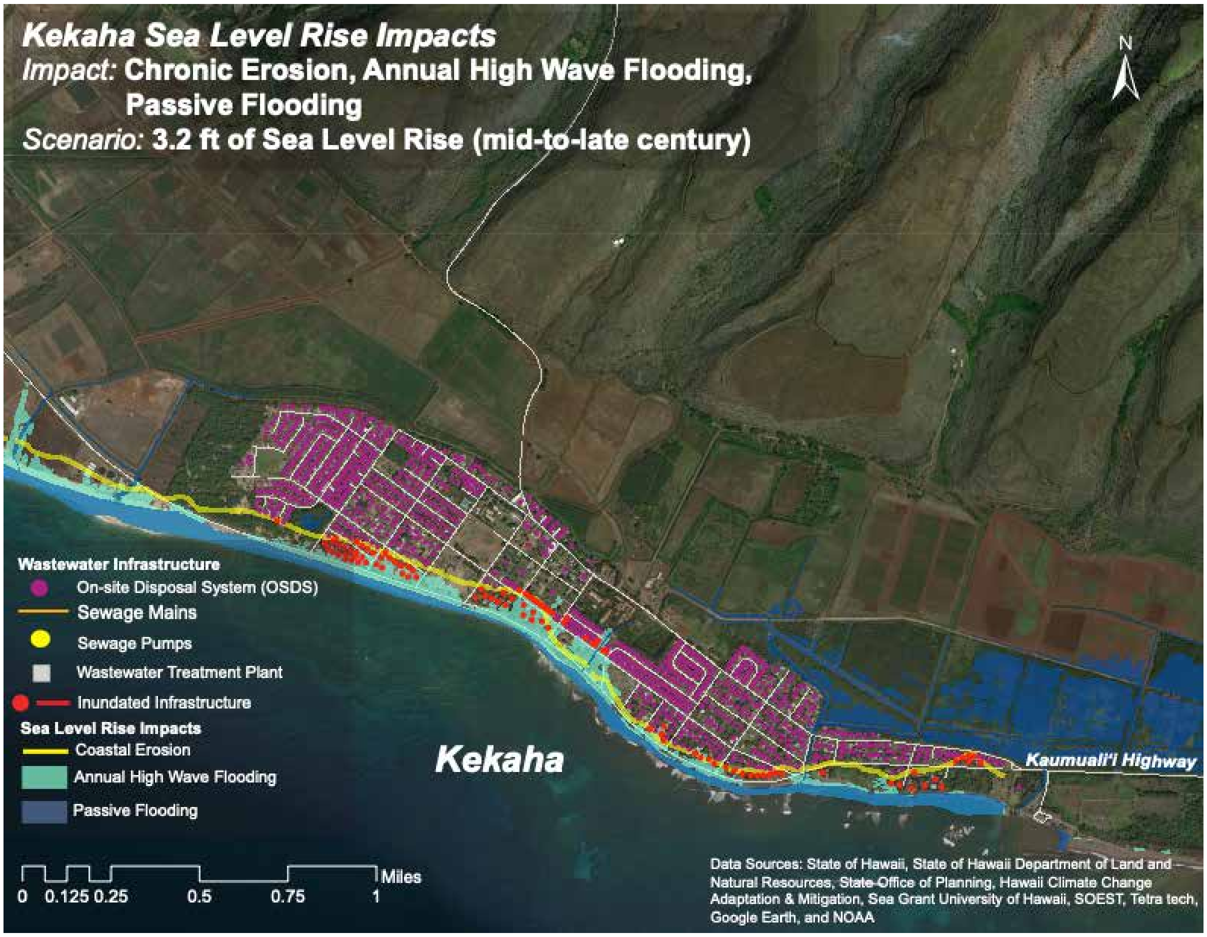


FIGURE 22. ON-SITE DISPOSAL SYSTEMS (OSDS) IN KEKAHA EXPOSED TO A 3.2' SLR SCENARIO (described on the following page). OSDS which will be exposed under a 3.2' SLR scenario. Exposed assets affected are affected by one or more of the following SLR hazards: passive flooding, erosion, or annaul high wave inundation. Exposed infrastructure is indicated in red.

Centralized Wastewater System: Sea Level Rise Vulnerability

Workshop participants focused much of their discussion on the consequences of a higher water table on wastewater. As sea level and the groundwater table continue to rise, wastewater pipes will become submerged[163]. Due to structural defects or deterioration, pipes with cracks and leaky joints are prone to groundwater infiltration (GWI). A higher water table will increase the amount of groundwater that will infiltrate sewer pipes. Sewer pipes and treatment plants are designed to allow for 10 to 25 percent (%) of wastewater sewage flow as GWI[164]. However, this value may underestimate the actual amount of GWI and this percent is expected to increase with SLR. This could overwhelm the treatment plant and lead to spills raising the risk of human and environmental exposure to pollutants.

GWI into wastewater main pipes and laterals will depend on the amount and severity of cracks and watertight sealing of pipe joints. An important contextual factor is that sewer mains are managed by the County, but sewer laterals are the responsibility of the homeowner. Thus, upgrades that are funded with public resources will only improve sewer mains, but improvements to laterals come at the cost of the homeowner. GWI can also enter the wastewater system via manholes however, this will depend on the elevation of manholes. Manholes above sea level will keep groundwater out from entering through the cover, but the joints within the manhole need to be sealed sufficiently (similar to pipe joints) in order to keep groundwater out.

Potential Adaptation Actions

Public actions discussed include developing regulatory mechanisms to permit greywater reuse in private homes (e.g., rainwater catchment and reuse) to reduce flows to the wastewater treatment plant. To address GWI into pipes, there is a need for more condition assessments of sewage pipes that will be exposed to SLR and a higher water table. A detailed needs assessment of old sewer pipes, fittings, and manhole covers taking into account SLR is needed, as well as an assessment of options for lining pipes to protect from GWI, and options for raising manholes. Private actions discussed include reducing water usage and water conservation (to reduce flows to treatment plant), installing grease traps in businesses, and replacing old sewer laterals connected to homes or businesses to reduce GWI into laterals.

On-Site Disposal Systems (OSDS): Sea Level Rise Vulnerability

Higher groundwater could also impact cesspools because raising the water level impacts the effluent in the cesspool pit leading to above ground contamination and/or backing up into the house. High water tables will also impact the performance of the absorption or leach field, or seepage pit downstream of the septic tank because the ground will be saturated. Similar to cesspools, this will cause surface overflows and/or wastewater backing up into homes. Operational failures from heavy rains and flooding could exacerbate the situation. Workshop participants expressed concern over untreated effluent because it could possibly contaminate agriculture and drinking wells causing human and environmental health risks. Whether drinking wells, which are typically located at higher elevations, are at direct risk of contamination would require further analysis. In the Mānā plain, groundwater is actively pumped to lower its level for a few hours every day. This might reduce the exposure of underground infrastructure to groundwater inundation in Kekaha, although further studies are needed to better understand the drainage system (see Section B Drainage).

Potential Adaptation Actions

For Kekaha and other areas where there is no municipal sewer, a detailed assessment of OSDS exposure to SLR is needed. In the near-term and possibly longer, continued pumping of groundwater in the Mānā Plain as sea levels rise is a possible option, although this could lead to land subsidence. Additional study on the feasibility of pumping and its potential consequences are needed to fully understand this action. Ultimately, there is a need to convert cesspools to alternative systems or extend the sewer system to Kekaha. Feasibility of onsite alternative systems will depend on the space/ treatment capacity of properties (for septics) and the density of homes, which influences cost of conversion to sewage pipes.

Extreme Storm Vulnerability

An extreme storm scenario can have immediate impacts on OSDS and municipal wastewater systems, including loss of power at wastewater treatment plants and pump stations. West Kauaʻi has 7 sewage pump stations which convey raw wastewater to 2 wastewater treatment plants. If a pump station is damaged, additional manpower is required to get back up running. This is critical because a pump station conveys raw sewage to the wastewater treatment plant. In addition, with a large storm, there is the potential for collateral damage to generators and buildings, for instance, if an electricity pole falls on a generator or a building. If roads are blocked by flooding, this limits access to wastewater systems, and can delay response and restoration of the system.

Potential Adaptation Actions

It was suggested that the County develop contingency response plans (also known as an Emergency Response Plan - ERP) for the wastewater facilities to prepare for the potential impact of an extreme storm. An ERP describes strategies, resources, plans, and procedures the utility can use to prepare for and respond to an incident, natural or man-made, that threatens life, property, or the environment[165]. In addition, participants emphasized the need to coordinate among and between public utilities (water, electricity, and wastewater) to practice spill response, formalize existing partnerships, and establish new public-private partnerships. And finally, there is a need to install an early warning systems for the wastewater utility. Early warning systems (EWSs) have been developed to coordinate and systematize activities to detect and control the release of contaminants from the system. These systems involve real-time sensors, monitoring, and communications, which would require identifying additional funding and resources for its development and implementation.

The workshop participants discussed several actions to support pre-disaster planning. A critical need is current and updated maps of all public and private on-site wastewater treatment systems in Geographic Information Systems (GIS) that are easily accessible during a disaster. Early disaster declarations are critical when a disaster strikes to quickly waive the permits/rules to release funds and support a rapid response. Part of this might be a full assessment of all OSDS and whether reconstruction might include upgrades of current cesspools to alternative OSDS or a central sewer system. Lastly, to help increase manpower and knowledge sharing across public and private entities, there is a need to strengthen the Community Emergency Response Team (CERT) program and establish formal documentation of recovery through Standard Operating Procedures between agencies.

2. Electricity

The major power plant that generates and transmits electricity to West Kaua'i and the rest of the island is located on a bluff in Port Allen. The Kaua'i Island Utility Cooperative (KIUC) runs and maintains the electric generation assets, which include diesel, steam turbines, combustion turbines and 6 megawatts (MW) of solar on land adjacent to the plant[166]. The plant sends electricity out to three major substations that serve West Kaua'i communities. A number of pull-boxes and mounted transformers also distribute energy. Electricity is distributed via transmission lines overhead attached to poles located along the highway and roads. Since Hurricane Iniki, significant hardening of the infrastructure has helped increase the resilience of electricity island-wide. In addition, KIUC with partner AES Distributed Energy is building an additional solar farm plus battery storage facility on 140 acres of land leased from the US Navy at the Pacific Missile Range Facility (PMRF) at Barking Sands, Kekaha (slated to be completed by end of year 2019). KIUC is also planning a 25 MW solar photo voltaic (PV) and pumped storage hydro plant, to be located in Mānā, near the existing Mānā Reservoir at an approximate elevation of 60' above sea level.

Kaua'i Island Utility Cooperative (KIUC) electrical facilities in Port Allen, which includes diesel, steam turbines, combustion turbines and 6 megawatts of solar on land adjacent to the plant. Source: Kaua'i Island Utility Cooperative

a. *Key Takeaways*

- Power lines, substations and underground electricity assets will likely be more vulnerable to inundation by mid-century with 3.2 feet of SLR. Many of these facilities are already vulnerable to a major storm event.
- Relocation of energy and electricity related assets may be necessary in the long-term but will depend upon the relocation of highways, communities, and other critical infrastructure.
- KIUC is working on and should continue to work on distributed energy generation. However, they should also conduct a detailed vulnerability assessment of planned future projects to SLR.
- More education and training is required to increase awareness and understanding of how to conserve energy, reduce use, and become self-sufficient in the event of a large storm hitting West Kaua'i.
- Additional and alternative forms of communication besides cell-phones is needed to support coordination, recovery, and community resilience.

b. *Inventory of Exposed Eletricity Infrastructure and Assets*[167],[168]

A complete set of electricity SLR exposure maps can be found in Appendix B.

Table 16. Inventory of Exposed Electricity Infrastructure within SLR-XA

	Measure of Exposure within SLR-XA with 1.1 ft. SLR (near-term) (count, miles)	Measure of Expoure within SLR-XA with 3.2 ft. SLR (mid-to-late century) (count, miles)
Substations	0	1 (in Kekaha)
Underground assets (pull boxes & mounted transformers)	1	15
Underground wires	0.01(miles)	0.12 (miles)

An inventory of electricity assets exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2 feet. Exposed assets within the overall SLR-XA was recorded in ArcGIS. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report.

Table 17. Inventory of Exposed Electricity Infrastructure to Passive Flooding, Erosion, and Wave Inundation

	Measure of Exposure from Hazards with 1.1 ft. SLR (near-term) (count, miles)			Measure of Exposure from Hazards with 3.2 ft. SLR (mid-to-late century) (count, miles)		
	Passive flooding	Erosion	High Wave Inundation	Passive flooding	Erosion	High Wave Inundation
Substations	0	0	0	0	0	1 (in Kekaha)
Underground assets (pull boxes & mounted transformers)	0	1	0	0	13	2
Underground wires	0 (miles)	0.01 (miles)	0 (miles)	0 (miles)	0.12 (miles)	0.01 (miles)

An inventory of electricity assets exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets affected by each SLR hazard (passive flooding, erosion, and high wave inundation) was recorded in ArcGIS. In most cases, infrastructure is impacted by multiple hazards. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report.

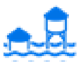
c. *Vulnerability and Potential Adaptation Actions*

On May 8, 2019, the project team held a workshop at the Waimea Technology Center with community members and asset managers to characterize the West Kaua'i electrical system's vulnerability to climate change and coastal hazards. The workshop participants focused the discussion on two main climate stressors, SLR and a major hurricane, and included a short discussion on a third: Extreme heat (see Appendix A [VCAPS diagram]).

Vulnerability of Electricity Infrastructure to Sea Level Rise

In the near-term, SLR is expected to produce nuisance flooding during high tide events resulting in water ponding and wetting of electricity poles and underground infrastructure. High tide nuisance flooding could also impact substations, particularly those in low lying areas such as, Kekaha and Mānā, resulting in occasional loss of power.

Major flooding of substations (in Kekaha and Mānā) and permanent inundation of underground electrical assets due to SLR by mid-to-late century was a major focus of the discussion. Permanent inundation of critical electricity assets from the groundwater rising could result in complete loss of power to the community. It is noteworthy that SLR exposure maps point to future erosion as a major stressor to underground assets (see Table 16), although outcomes of this hazard were not discussed during the workshop. Instead, flooding remained the focus of concern.



Potential Adaptation Actions

Relocation of electricity related assets may be necessary in the long-term but will depend upon the relocation of highways, communities, and other critical infrastructure. KIUC is working on, and should continue to work on, distributed energy generation. It has a number of energy projects planned and funded. A SLR vulnerability assessment and/or adaptation plan is advised to ensure the resiliency of these projects. It is important to note, however, that KIUC typically does not site projects in low-elevation areas or close to the shore.

Vulnerability of Electricity Infrastructure to Extreme Storms

High winds and a large storm surge are two immediate outcomes of a major hurricane that can impact electricity and energy assets. Strong winds can bring down power lines, trees, and potentially impact solar panels. The invasive Albizia tree in particular is vulnerable to strong winds and has been found to be a major disruptor and cause of damages in Hawai'i[169]. In addition, one pole can bring down numerous poles leading to power line failure and total loss of electricity with cascading impacts, such as loss of water (since water pumps rely on power) and electrocution. In response, people cut power lines after a storm out of safety concern, however this adds time to recovery. Households and entire communities are impacted severely when people unnecessarily cut poles. Downed poles can still be used. Further, untrained cutting of lines under tension is a risk to the public. In addition, experience has shown with downed lines post hurricane, individuals hook up generators and risk feeding back into the system causing a great risk for the community. No electricity for up to weeks and months has large ramifications, such as loss of water. Loss of electricity over a long period of time could have larger social ramifications, such as the community experiencing frustration, health and safety issues. For instance, some people rely upon electricity for their medical needs (e.g., for oxygen).

Major hurricanes also increase the risk of a large storm surge. Participants discussed at length the risk that a storm surge poses to electricity and related assets, both above and underground. A storm surge could flood substations, cut off access to roads, and impact KIUC's ability to restore power. A large storm surge can also cut off boat access to the port, which reduces the ability to bring in emergency supplies. A storm surge may also impact fuel tanks at Port Allen in addition to other objects. (Tanks serve as back-up fuel source). Fuel tanks and debris could enter and pollute the ocean. The tanks, however have containment berms that help reduce the risk of a spill. Lastly, a major concern and consequence discussed was the potential impact of flooding from a large storm (as well as high winds) on communications and coordination between emergency response and private citizens. The group expressed particular concern over cell towers since most use cell phones as primary means of communication, and less use landlines or radios to retrieve information.

Potential Adaptation Actions

A number of public and private actions were discussed to address a major storm event. A major point of discussion was improving communication & coordination by creating alternate means of communication (e.g., hand held radios). Several ideas emerged such as designating one public radio station, Kauai Emergency Management Agency (KEMA) or several stations as the source(s) of public information during disasters. One participant offered that KEMA might make sense since they already coordinate with Hawaii Emergency Management Agency (HEMA) to bring in resources.

Increasing awareness and education was a major theme while discussing adaptation. The group suggested that more training is needed to inform citizens how to prepare and what to do in the event of a disaster. The Hanapēpē Neighborhood Association has helped to organize CERT trainings in the area. Related to this, more education is needed regarding how to treat downed powerlines, how to avoid electrocution, and not to cut power lines. Lastly, the group discussed the importance of building more education and outreach around energy conservation, and the idea of living without energy.

In the event of a large disaster, post disaster, KIUC will review its generation, transmission, and distribution assets, and strategically prioritize rebuilding efforts. This possibly means building micro- grids across the island. KIUC is already working on developing this capacity. For instance, KIUC has "micro gridded" Lihue in the sense that they can get central Kaua'i up and running fairly quickly and then focus on outlying areas more quickly. In addition, the group discussed the need for hospitals to have a back-up energy source, as well as communities and individual properties.

Vulnerability of Electricity Infrastructure to Extreme Heat

The group discussed extreme heat as a third stressor. With more heat, it is anticipated that more air conditioning will be used, increasing overall energy usage.

3. Potable Water Supply Infrastructure

There are 9 water systems across the island. In West Kaua'i there are two water systems with corresponding service areas in Kekaha-Waimea and Hanapēpē-Ele'ele[170]. Potable water in West Kaua'i comes from deep well sources. The majority of wells that tap the aquifer are located at higher elevations and closer to the mountains. The pipe system that distributes the water to households is a closed pressurized system, and therefore more resilient to groundwater or saltwater intrusion. In 2001, the Department of Water (DOW) documented that up to 23% of their pipes island wide were built prior to 1960, needing upgrade and repair[171]. DOW maintains approximately 63 miles of public water supply mains in West Kaua'i. The resilience of pipes depends upon their material and age; some pipes are built out of cast iron, some galvanized steel, some built with asbestos cement. More current pipes are ductile iron, which is the industry standard, unless the pipes are near the coast in which case they should be polyvinyl chloride (PVC). The DOW maintains an active pipe replacement program. The water system is also dependent upon constant electricity to pump water from deep wells. The DOW maintains generators at its Lihue base yard, which can be mobilized to remote sites, and also has permanent generators located at key deep well sites to ensure power can be provided as reliably as possible.

Paua Valley Well and Steel Tank. Source: Kaua'i Department of Water

a. *Key Takeaways*

- No deep wells appear to be at risk from SLR, however, several other water supply assets such as water meters, valves, and pipes are vulnerable in the near-term (15-20 years), and their exposure increases exponentially by mid-century.
- The risk of future droughts may also put strain on the future supply of potable water.
- Increasing water conservation strategies will be key to protecting West Kaua'i sources of water.
- There is a need to incorporate SLR into prioritization of pipe upgrades and replacements.
- A coordinated approach/assessment is needed when considering relocation between water infrastructure and roads.

b. *Inventory of Exposed Potable Water Supply Infrastructure*[172,173]

A complete set of potable water supply SLR exposure maps can be found in Appendix B.

Table 18. Inventory of Exposed Potable Water Supply Infrastructure within SLR-XA

	Measure of Exposure within SLR-XA with 1.1 ft SLR (near-term) (count, miles)	Measure of Exposure within SLR-XA with 3.2 ft SLR (mid-to-late century) (count, miles)
Water meters	24	202
Deep wells	0	0
Valves	25	111
Pipes	1.04 (miles)	3.75 (miles)

An inventory of potable water supply infrastructure exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2 feet. Exposed assets within the overall SLR-XA was recorded in ArcGIS. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report. With respect to SLR impacts on West Kaua'i pipes, the CVA team georeferenced and digitized water zone maps provided by Kaua'i County DOW. Due to limitations in digitizing the extent of water pipes, the exposed water pipes measurements are a rough estimate.

Table 19. Inventory of Exposed Potable Water Supply Infrastructure to Passive Flooding, Erosion, and Wave Inundation

	1.1 ft. SLR (near-term)			3.2 ft. SLR (mid-to-late century)		
	Passive flooding	Erosion	High Wave Inundation	Passive flooding	Erosion	High Wave Inundation
Water meters	no data	no data	no data	no data	no data	no data
Deep wells	no data	no data	no data	no data	no data	no data
Valves	no data	no data	no data	no data	no data	no data
Pipes	0.18 (miles)	0.84 (miles)	0.06 (miles)	0.51 (miles)	1.88 (miles)	2.30 (miles)

An inventory of potable water supply infrastructure exposed to two SLR scenarios: A near-term 1.1 foot scenario, and a mid-to-late century scenario of 3.2’. Exposed assets affected by each SLR hazard (passive flooding, erosion, and high wave inundation) was recorded in ArcGIS. In most cases, infrastructure is impacted by multiple hazards. SLR exposure data was obtained from the Hawaiʻi SLR Vulnerability and Adaptation Report. With respect to SLR impacts on West Kauaʻi pipes, the CVA team georeferenced and digitized water zone maps provided by Kauaʻi County DOW. Due to limitations in digitizing the extent of water pipes, the exposed water pipes measurements are a rough estimate.

c. *Vulnerability and Potential Adaptation Actions*

On May 8, 2019, the project team held a workshop with community members and asset managers to characterize West Kauaʻi’s vulnerability to climate change and coastal hazards with respect to potable water supply. Participants discussed three climate stressors: drought, increased frequency and intensity of storms, and SLR (see Appendix A [VCAPS diagram]).

<u>Vulnerability of Potable Water Supply to Drought</u>

Droughts increase the risk of wildfires and impact crops. The group discussed the increase in water demand as a consequence for both fire suppression and irrigation. Concern was expressed that this would add stress to the water system by reducing the supply of potable water for drinking and public use. The potential long-term consequence of reduced water supply could be higher water fees for both residential and commercial uses, and increased conflict between water resource users, such as farmers and households. Farmers currently receive a discount in water rates, although DOW is revisiting the rate structure that will reflect a more typical industry rate structure. The DOW plans for the next 5-10 years and not necessarily for 20 years or for future droughts, although they are part of a Drought Committee, which looks at predicted weather over the next 30 years.

<u>Potential Adaptation Actions</u>

The group stressed the importance of watershed protection, restoring stream flow, protecting native vegetation, and other strategies to increase infiltration and replenish aquifers. Several household level conservation practices were discussed, including rainwater catchment, the use of onsite non-potable water reuse, and personal wells for irrigation. As increasing pressures on water resources lead to water scarcity, rainwater catchment and onsite water reuse are solutions that households and businesses can adopt to help reclaim, recycle, and reuse water for irrigation and indoor non-potable water purposes, such as toilet flushing, clothes washing, and ornamental plant irrigation [174]. However, there is a need to design and implement clear regulations to incentivize and increase the use of these solutions. This includes updating plumbing codes.

Several studies or detailed analyses are needed, including understanding the social, economic, and regulatory barriers to water conservation practices and the use of catchment and greywater systems. A scenario-planning study is needed to examine the possible impact of future drought on water demand and different strategies to reduce demand and increase supply (for e.g., water pricing, desalination, and water recycling/reuse.)

Vulnerability of Potable Water Supply to Extreme Storms

Large storm events can damage both water and electricity networks (see section C.2 electricity details). In particular, loss of electricity impacts water pumps at deep well sites, as well as homes and pump stations that rely upon energy to pump water from their source along the pipe network. In the event of a water disruption, DOW focuses its response on restoring power to pumps at deep wells first, and is working toward building more permanent generators and generator shelters at critical site. The immediate consequences of water loss includes increased stress on DOW workers to restore water, and the increased cost to DOW for additional workers to support recovery efforts. DOW maintains a partnership with neighbor islands to bring in additional workers during an emergency response. In the event of water disruption, the DOW has four "water buffalos" which are 500-gallon tankers for potable water supply. Prolonged power outages could slow down recovery efforts and result in loss of water access to residents and the community over a longer period of time.

Potential Adaptation Actions

In the event of a large hurricane disaster, residents need to be prepared and self-reliant for 14 days minimum, including potable water for drinking and other uses. More awareness and community education on how to prepare is needed. One immediate action that is already being planned by DOW is to establish more permanent, hardened generator shelters at critical sites.

Vulnerability of Potable Water Supply to Sea Level Rise

SLR will raise the water table and increase the risk of both groundwater infiltration (GWI) and saltwater intrusion. This could cause corrosion to underground pipes that are not made of PVC (PVC pipes are resilient to saltwater). However, since the network of pipes is pressurized and closed, the system is more protected against intrusion, except for those pipes that are cracked.

Potential Adaptation Actions

To reduce the risk of GWI or saltwater entering pipes, it would be prudent to replace non-PVC pipes with PVC, especially in high risk SLR exposure areas. DOW's long-range Water Plan 2020 assessed these existing old pipes, and prioritizes pipes to replace. This plan should consider the impacts of SLR.

In some areas, SLR will cause the permanent inundation of pipes. This is a problem in the case of a main break that needs to be repaired or replaced. This would also cause roadway encroachments and prompt actions to protect or relocate road infrastructure.

Potential Adaptation Actions

The group learned that DOW probably would not relocate water infrastructure by itself until DOT or the county decides to relocate roads. In the long-term, it would be prudent for DOW, as well as KIUC, to coordinate with DOT and the County on potential relocation of highways, roads, electricity, and water infrastructure. A feasibility study is needed to assess relocation options, and the feasibility of moving infrastructure to potential designated receiving areas.

Critical infrastructure, such as water or sewer pipes, are often co-located with roads and bridges.
Source: Erin Braich

D. BEACHES AND COASTAL PROPERTIES

A home in Kekaha that is threatened by erosion. A sandbag revetment was built in front the home to help control erosion. Source: Ruby Pap

Many West Kaua'i neighborhoods, particularly in Kekaha and Waimea, abut sandy beaches and contain valuable coastal property. Kaua'i's beaches and coastal properties are particularly vulnerable to SLR. Beaches buffer the land from waves and tides. As sea levels rise, West Kaua'i's beaches will erode and/or become permanently inundated. In rare cases where the beach is not backed by hard structures and the geologic substrate is sand or dune materials, the beach will be able to migrate inland for some time.

Kaua'i's carbonate beach sand sources, over 5,000 years old, are a limited resource. Kekaha State Beach, north of O'omanu Point, is one of the most dynamic seasonal beaches in the state. Seasonal beaches add complexity to determining SLR impacts[175]. West Kaua'i also contains the Island's only black sand beaches, situated at the mouths of the Waimea and Hanapēpē Rivers, where they draw their terrigenous sand source. According to geologist Charles Blay, Waimea contains the state's largest volcanic beach sand reservoir extending 2.5 miles from the river west to O'omano Point near Kekaha. Hanapēpē Bay Beach today is a remnant of a large beach that used to extend west of the river mouth across the Bay. The majority of the shoreline here is protected by a revetment.

1. Key Takeaways

- Many of West Kauaʻi's beaches are currently threatened by erosion, and SLR will result in increased erosion and flooding of beaches.
- Seawalls on chronically eroding beaches lead to beach loss.
- Shoreline properties and infrastructure are vulnerable to erosion and beach loss. As erosion increases, the pressure for seawall development increases. Seawall construction can protect structures for some time, but they also cause erosion on neighboring properties resulting in overall beach loss.
- As properties are lost or unbuildable due to erosion, the community loses a source of income due to reduced property taxes from reduced property values.
- The loss of shoreline homes in West Kauaʻi can contribute to housing shortages.
- Beaches are very important to West Kauaʻi's lifestyle and livelihood. Beach loss has consequences to cultural resources and practices, wildlife habitat, public access to the shoreline, recreation, reduced property values, economic loss, social impacts, and the eventual need to for shoreline dwellers to move.
- A number of actions were discussed to address these outcomes including: dune restoration; elevation of threatened structures; relocation of threatened structures; protection of threatened structures; and land acquisition (i.e. buyouts).

2. Inventory of Exposed Coastal Properties[176,177]

A complete set of beaches/coastal properties SLR exposure maps can be found in Appendix B.

Table 20. Inventory of Exposed Coastal Properties within SLR-XA

	Measure of Exposure within SLR-XA with 1.1 ft. SLR (near-term) (count, acres)	Measure of Exposure within SLR-XA with 3.2 ft. SLR (mid-to-late century) (count, acres)
Coastal Buildings:		
Residential	41	236
Commercial	2	62
Hotels	1 (Waimea by the Sea)	2 (Waimea by the Sea, Waimea Plantation Cottages)
Parks	141.14 (acres)	173.89 (acres)

An inventory of coastal properties exposed to two SLR scenarios: A near-term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets within the overall SLR-XA was recorded in ArcGIS. SLR exposure data was obtained from the Hawaiʻi SLR Vulnerability and Adaptation Report.

Table 21. Inventory of Exposed Coastal Properties to Passive Flooding, Erosion, and Wave Inundation

	Measure of Exposure from Hazards with 1.1 ft. SLR (near-term) (count, acres)			Measure of Exposure from Hazards with 3.2 ft. SLR (mid-to-late century) (count, acres)		
Coastal Buildings:	Passive flooding	Erosion	High Wave Inundation	Passive flooding	Erosion	High Wave Inundation
Residential	0	29	15	24	127	133
Commercial	2	0	0	15	0	47
Hotels	0	0	1	0	0	2
Parks	47.23 (acres)	120.95 (acres)	94.55 (acres)	53.64 (acres)	146.77 (acres)	116.3 (acres)

An inventory of coastal properties exposed to two SLR scenarios: A near-term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets affected by each SLR hazard (passive flooding, erosion, and high wave inundation) was recorded in ArcGIS. In most cases, infrastructure is impacted by multiple hazards. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report.

Table 22. Economic Loss from SLR Exposure[178]

SLR-XA	Hanapēpē-Ele'ele	Pākalā	Waimea	Kekaha	Mānā
1.1 ft.	$37,154,936	$1,079,763	$5,356,163	$43,272,401	$3,251,513
3.2 ft.	$63,858,963	$20,882,090	$215,019,704	$123,685,171	$6,520,670

Potential economic loss per community based on the value of the land and structures from the county tax parcel database permanently lost in the SLR-XA for each projected SLR height. Key assumptions of the economic analysis for the SLR-XA included: (a) loss is permanent; (b) economic loss is based on the value in U.S. dollars in 2016 as property values in the future are unknown; (c) economic loss is based on the value of the land and structures exposed to flooding in the SLR-XA excluding the contents of the property and does not include the economic loss or cost to replace roads, water conveyance systems and other critical infrastructure; and (d) no adaptation measures are put in place that could reduce impacts in the SLR-XA.

3. Vulnerability and Potential Adaptation Actions

The project team conducted a community workshop on beaches and coastal properties on December 10, 2018 at the Hanapēpē Public Library. Coastal geologists Dr. Chuck Blay, Dr. Chip Fletcher, and Dr. Bradley Romine served as resources. Participants learned that as sea levels rise, the rate of erosion will increase, leading to beach movement, beach narrowing, and eventually beach loss. In addition, SLR will increase wave runup, dune wetting, landward deposition of sand, and eventual landward migration of the beach. Erosion and release of sand from the backshore is an important part of this process. If there is a hard structure in the way, such as a seawall, road, or harder land formations (i.e., basalt), the beach will eventually be lost.

West Kauaʻi Beaches and Coastal Properties Overall

Due to the exposure of West Kauaʻi's beaches to SLR, coastal properties and structures along the shoreline are vulnerable. Estimates from the Hawaiʻi Sea Level Rise Report indicate that SLR exposure of 3.2' could result in $430 million in economic loss on the west side due to potential loss of land, residential and commercial structures (See Table 22). This could lead to increased economic vulnerability for the community as a portion of the County's revenue stems from property taxes. Additional revenue loss is expected due to lost or damaged infrastructure.

In addition to residential and commercial properties, approximately 141 acres of parks (seaward portions) are exposed in the 1.1' SLR scenario (near-term scenario) and 174 acres under the mid-to-late century scenario (3.2 SLR) (Table 20). These parks include, Nā Pali Coast State Park, Polihale State Park, Kekaha Beach Park, Waimea State Recreation Pier, Waimea River Park, Russian Fort Elizabeth State Park, and Salt Pond Park. Lifeguard Towers at County Beach Parks are also vulnerable.

Consequences discussed by participants included loss of cultural resources, wildlife habitat, public access and recreation. This loss could result in reduced property values, economic loss, social impacts, and the eventual need to for shoreline dwellers to move.

The other consequence for coastal properties in particular is increased pressure for seawall construction. Seawalls and revetments contribute to erosion and beach loss[179]. Coastal armoring is generally prohibited under current State and County law, but many older structures still exist, and emergency situations have permitted armoring as well. The cycle of beach loss, seawall construction, and further beach loss as a result of that seawall construction is one that Kauaʻi experiences currently and will be exacerbated by SLR.

Potential Adaptation Actions

Participants discussed the following public and private actions with regard to all vulnerable beach areas and abutting private properties in West Kauaʻi: Implementing beach and dune restoration projects, elevating and/or relocating structures along the shoreline, and protecting the shoreline with shoreline armoring. For this last option, it was recognized that shoreline armoring could lead to further beach loss and erosion problems. As a public action to help facilitate relocation, it was suggested that a land acquisition program be instituted (or similar land swapping program). Subsequent comments from County ocean safety officials suggested relocation of beach park lifeguard towers as they become threatened by erosion, and implementation of roving patrol units to supplement the towers.

Each beach has a set of unique factors that lends to unique planning or adaptation strategies. These factors include the backshore geology (i.e. behind the beach) and the amount and type of shoreline development (i.e., homes, roads, etc.). For instance, if a beach is backed by an undeveloped area of sandy substrate, it is conceivable that beach could migrate landward as sea levels rise. Beach parks provide the best opportunities for conserving eroding, migrating beaches. However, in the absence of a beach, other strategies for adaptation should be explored. Workshop participants divided the assessment into three locations: Kekaha Beach, Waimea Beach, and Hanapēpē Beaches.

Kekaha Beach

Kekaha Beach Park and MacArthur Park. Source: Ruby Pap

Kekaha Beach is a popular beach fronting the town of Kekaha. The beach is actually part of a continuous strand of carbonate beach extending from O'omanu Point to Polihale (13 miles). Situated on the Mānā Plain, the land in this area is mostly comprised of older beach and sand dune deposits. This would be an area where, as sea levels rise, and in the absence of coastal armoring and development, the beach could migrate back towards the pali. Sand is transported along shore north-south in the winter, and south to north in the summer. The seasonal beach changes can be dramatic with some summers at MacArthur Park showing a loss of approximately 400 feet, with the beach returning in the winter[180].

In the town of Kekaha, the back of the beach is fixed by a revetment protecting the highway. The backshore geology where the town is developed is all sand. Erosion is expected to be the dominant hazard caused by 1.1' and 3.2' of SLR. According to the exposure data, the highway could erode, as well as the first few rows of adjacent properties. Waves already wash onto the highway during high surf. Data shows annual high waves extending further inland onto the first two rows of coastal properties (Figure 23). It is important to note that the exposure data does not take into account manmade structures (i.e. the revetment), so in this respect the impacts may be overestimated. But it is also important to remember that SLR could reach higher levels by the end of the century, with some predictions reaching 6-8 feet[181], and this high SLR scenario has not been modeled for erosion or annual high wave runup.

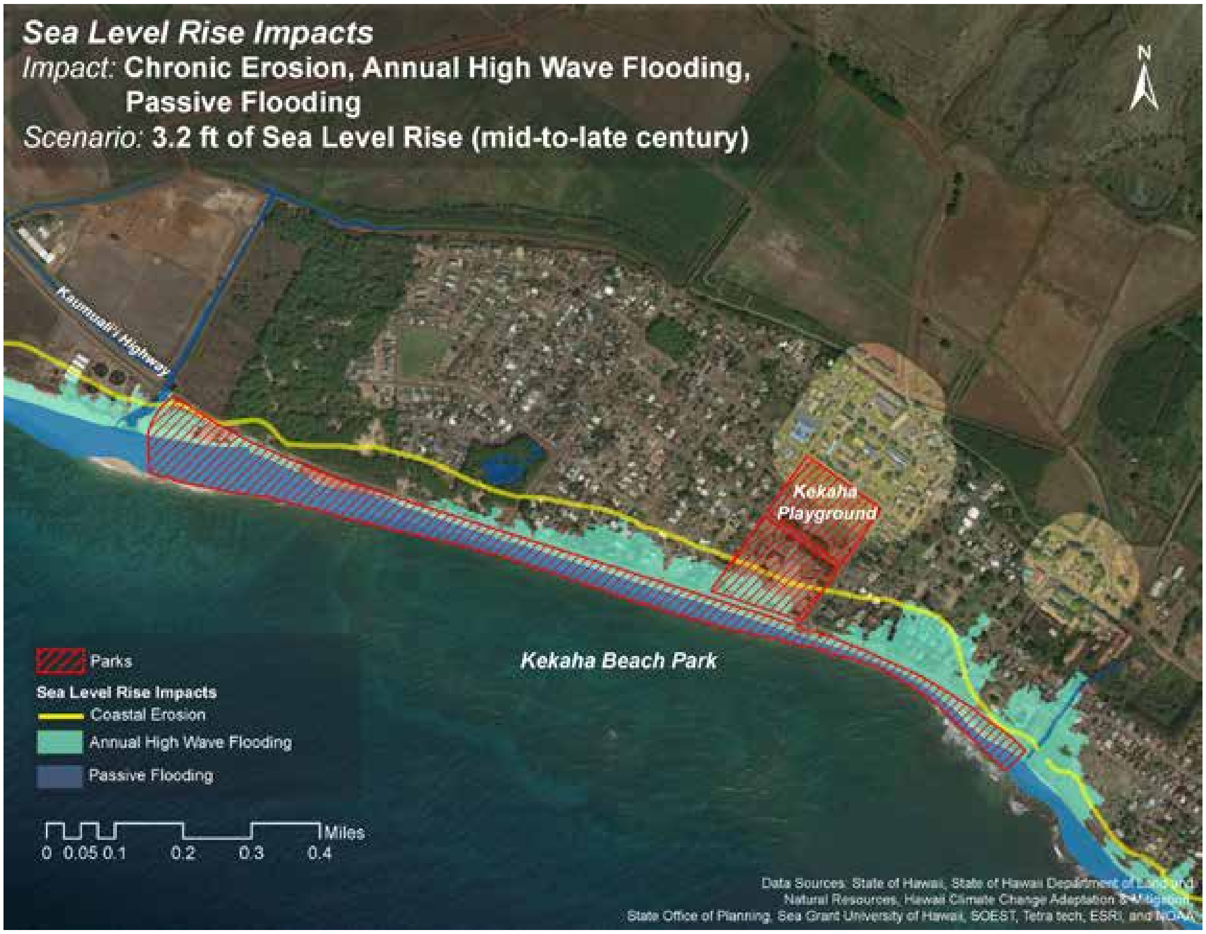


FIGURE 23. KEKAHA BEACH PARK EXPOSED TO A 3.2' SLR SCENARIO. Kekaha Beach Park and Kekaha town affected by each SLR hazard (passive flooding, erosion, and high wave inundation) under the 3.2' mid-to-late century SLR scenario.

Workshop participants categorized Kekaha Beach (MacArthur Beach Park, Intersection Park) and the surrounding coastal properties as vulnerable to SLR, with major consequences being the loss of the highway and homes, and loss of access (See previous Transportation and Evacuation section for more details). Other potential consequences discussed include impacts to the shrimp farm, and recreational and fishing impacts due to beach loss.

<u>Adaptation Actions</u>

For Kekaha Beach, short-term public actions discussed included elevating the highway and revetment, protecting other infrastructure, and collecting data on the groundwater table (see section B, Drainage for more details). Participants at the transportation workshop in September 2018 also discussed the need to monitor seasonal erosion patterns, and studying the feasibility for raising and/or relocating the highway.

<u>Waimea Beach</u>

While most of Kauai's beaches contain white carbonate sand derived from coral reefs, Waimea's greenish-gray sand is terrigenous, derived from weathered lava rock from Waimea Canyon and carried to the shore by the Waimea River.

Waimea Beach can be divided into two sections, east and west of Kikiaola Small Boat Harbor (Figure 24). The harbor was constructed in 1959, approximately half way down the beach. Prior to its construction a relatively uniform beach extended over the entire stretch. Over the last 60 years it became lopsided, leaving a wide beach on the east side of the harbor and a narrow one on the west side. The harbor blocks the westward shore currents that distribute sand from the river mouth to the rest of the beach. As a result, this sand is unable to move west starving down drift areas of sediment. This, combined with waves and tides, has caused high rates of coastal erosion to the west, threatening homes, property values, and the Japanese and Chinese cemeteries. SLR is expected to exacerbate this situation.

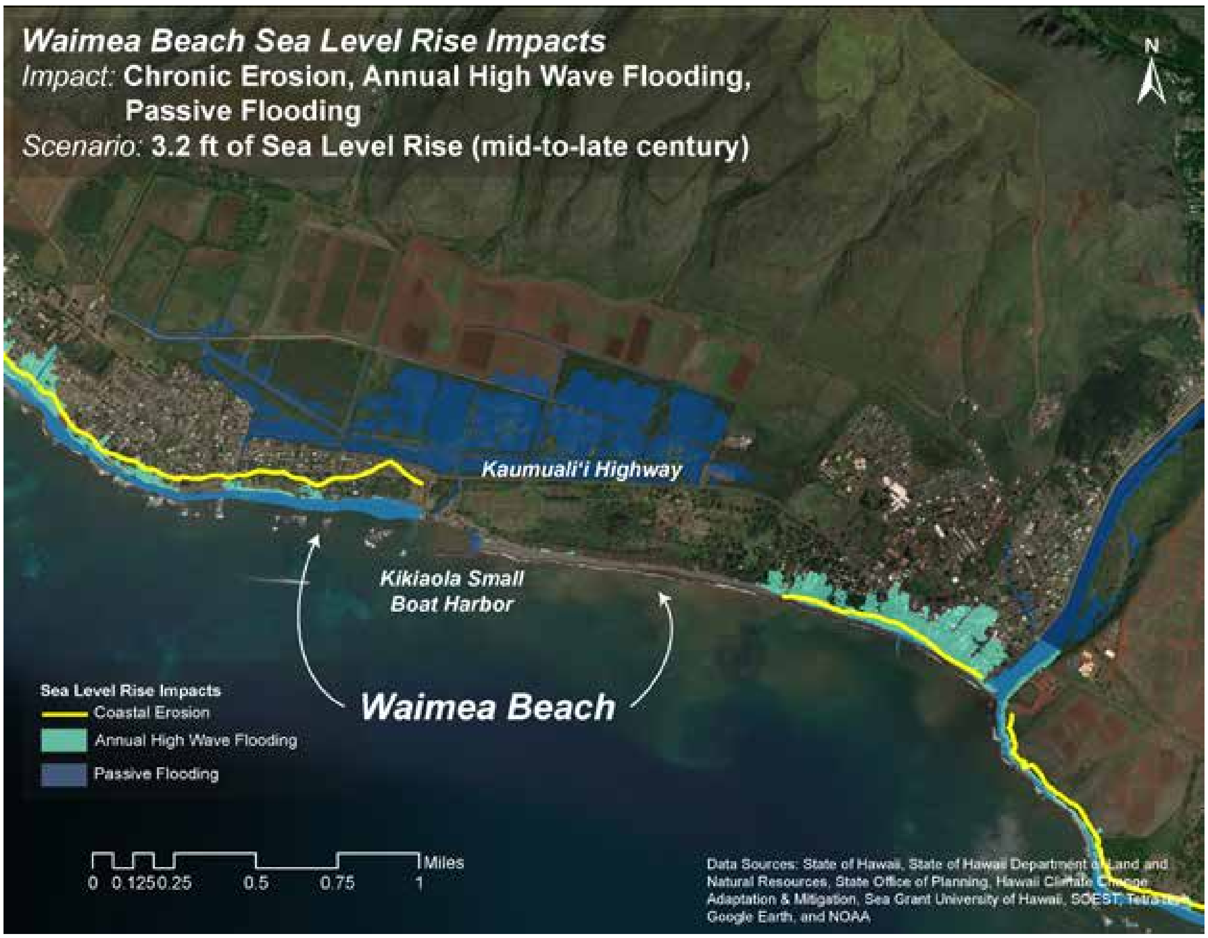


FIGURE 24. WAIMEA BEACH PARK. Aerial photo east and west of Kikiaola Small Boat Harbor exposed to mid-to-late century 3.2' SLR hazards (passive flooding, erosion, and high wave inundation). The navy-blue shading depicts passive flooding, the yellow line depicts erosion, and the cyan shading depicts high wave inundation.

The area east of the Harbor provides a unique perspective on vulnerability. Because the harbor acts like a dam for sand, the beach has been accreting on that side. The SLR exposure data shows minimal impacts as a result. The question came up whether the harbor is protecting Waimea town and whether it would continue to do so into the future. The project team consulted further with the data modelers from the UH Coastal Geology Group. According to their assessment, the harbor has artificially caused the beach to accrete, however, a large storm could damage the harbor and quickly change this situation.

Workshop participants also discussed how SLR will affect the interactions between Waimea River and the beach. As sea levels rise, one outcome will be that the channel mouth will lose velocity and sand will be deposited further up river, with a buildup of sand at the river mouth. This may result in riverine flooding to surrounding communities, due in part to a malfunctioning levee (see section B Levees of this chapter). The buildup of sand at the river mouth may also have implications for future sand availability on the beach.

Potential Adaptation Actions

Public actions discussed to address the erosion west of Kikiaola Harbor include continuing the sand bypass project from the east to the west side, previously completed by the Department of Boating and Recreation (DOBOR). Armoring the beach with a seawall and revetment are also options, however this would need to be weighed against the consequence of beach erosion and narrowing. Relocation of homes in this area is another option, which could be phased over time. Public funding is a requirement for all these options.

In terms of private actions, it was recommended that property owners and residents start planning for relocation and consider elevating buildings to mitigate flood impacts. Mortgage contingent financing was a new, untested option mentioned to help facilitate this. This is a loan where the property owner gives their property to the government in exchange for a loan that is tied to the value of their home (rather than their income), which can be used to buy property elsewhere[182].

Hanapēpē: Salt Pond Beach Park

Hanapēpē Salt Pond Beach Park, which is vulnerable to 1.1' and 3.2' of SLR. Source: Ruby Pap

Salt Pond Beach Park has historically been eroding at a rate of 1 foot/year, and with SLR it will be exposed to increased flooding, erosion, and wave inundation. Under 1.1' SLR scenario, the beach will likely erode as far back as the park lawn facilities, and under 3.2' SLR, as far back as the salt pond. Passive flooding, combined with high wave flooding will also likely affect the area. Wave runup and erosion may also inundate park structures, the salt pans, and possibly inundate parts of the Burns Field Air Strip south of the beach park.

The backshore geology of Hanapēpē Beach Park is alluvium (volcanic soil and sediment), so beach migration may be a challenge. However, there are no structures in the way (the salt pond and beach park are on public land). As the land erodes, accommodation space could be provided for a migrating beach, assuming there is available sand in the system.

Vehicle compaction of the dunes has exacerbated erosion, allowing wave runup over the berm and into the salt pond area (see section F of this chapter, Cultural Resources). Vehicular access to the beach is now mostly blocked by recent County placement of a boulder barrier. It will be important to monitor the area in the near term to document any beach berm recovery.

Wave runup will also lead to flooding of Salt Pond (lo'i pa'akai), cutting off of the ability to make salt, which is an important Hawaiian cultural practice and major community concern. This problem is discussed at length in section F, Cultural Resources.

Potential Adaptation Actions

Beach parks provide the best opportunities for conserving eroding, migrating beaches. Participants discussed dune restoration at Salt Pond that, in the short-term, would most likely prevent wave runup into the salt pans and help mitigate beach erosion. Additional public actions discussed include relocating the air strip, acquiring (or setting aside) lands for land bank ,and expansion of Salt Pond Beach Park mauka and westward. These actions could be delineated in a County Park Master Plan. It was noted that SLR should be studied more specifically and monitored in this location to inform future public actions.

There are several other beaches on the west side that also deserve attention, but due to time constraints they were not discussed during the workshop. These include Hanapēpē Bay Beach, Makaweli, Pākalā, and Polihale.

E. AGRICULTURE

West Kaua'i has a long history of agriculture, from pre-contact traditional Hawaiian taro cultivation to the sugar plantation economy that helped define the land and water use we see today. Indeed, the agricultural land from Mānā to Waimea was drained for sugar cultivation (see section B Drainage). Current agriculture in West Kaua'i is primarily made up of crops used for research and development, much of this in the Mānā Plain. However, there are also small "truck farms" primarily in the river valleys that are crucial for food, resources, and economic sustainability, as well as to the cultural heritage and identity of the island. Agriculture in the Mānā Plain depends upon a carefully managed drainage and pumping system by the State Agricultural Development Corporation (ADC) and the Kekaha Agricultural Association (KAA), as well as other partners (see also section B, Drainage of this chapter for additional details). Without the pumping of groundwater, the current crops would not be viable.

Kalo farming in Waimea Valley. Source: imagery c 2020 EagleView

1. Key Takeaways

- By the latter half of the century, over 2000 acres of state zoned agricultural lands are potentially exposed to SLR. Approximately 14.5 acres of these exposed lands are identified as Important Agricultural Lands (IAL) and consist of soils of the highest quality. The main types of agriculture that are threatened are aquaculture, diversified crops, taro, and land used for agriculture research and development (Table 23).
- Many of these crops are threatened by passive flooding. With rising sea level, salt water intrusion is a likely impact on crops.
- More research is needed on salt-tolerant plants and alternative types of agricultural methods (e.g., aquaponics, greenhouses) that could be viable for West Kaua'i.

- Several feasibility studies were discussed: the relocation of agriculture to higher ground and the possibility of returning portions of Mānā lands to its former/natural wetlands, as well as a managed dike system to reduce risk of flooding into Kekaha town.
- Many small truck farmers are vulnerable to extreme storm events in the river valleys. These farms are so small that their location is unknown, which can make recovery planning difficult post-disaster.
- Public and private actions discussed include: develop post-disaster readiness and planning for small taro farmers (look to on-going North Shore recovery), collaborate with OHA, DHHL, and other sectors to develop a response for small farmers, and map small farms.
- Increasing temperatures and drought is also expected to impact agriculture negatively. Several public and private actions were suggested, including: planting drought resistant crops and shade crops, add water storage, increase efficient irrigation systems for farms, and identify additional sources of water supply.

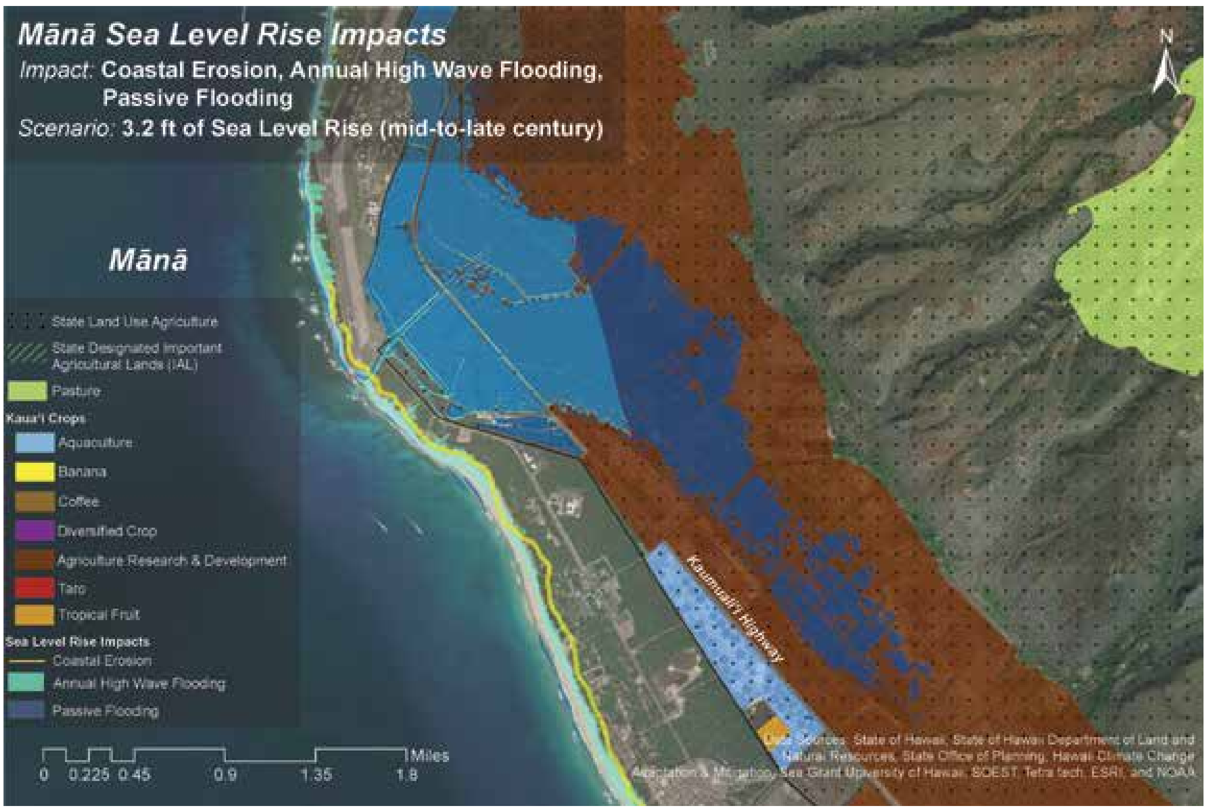


FIGURE 25. MĀNĀ AGRICULTURE EXPOSED TO A 3.2' SLR SCENARIO. Agriculture on the Mana Plain exposed to 3.2' of SLR. Exposed agriculture is mainly affected by passive flooding.

2. Inventory of Exposed Agriculture[183,184]

A complete set of agriculture SLR exposure maps can be found in Appendix B.

Table 23. Inventory of Exposed Agriculture within SLR-XA

	Measure of Exposure within SLR-XA with 1.1 ft. SLR (near-term) (acres)	Measure of Exposure within SLR-XA with 3.2 ft. SLR (mid-to-late century) (acres)
State Land Use Zoned Agriculture	882.1	2218.69
State Designated Important Agricultural Lands (IAL)	11.64	14.59
Pasture	7.26	24.79
Kaua'i Crops:		
Aquaculture	2.3	5.51
Banana	0	0
Coffee	0	0
Diversified Crop	0	1.16
Agriculture Research & Development	438.01	1214.85
Taro	0	0
Tropical Fruit	0	0

An inventory of agriculture exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2 feet. Exposed agriculture within the overall SLR-XA was recorded in ArcGIS. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report.

Table 24. Inventory of Exposed Agriculture to Passive Flooding, Erosion, and Wave Inundation

	Measure of Exposure from Hazards with 1.1 ft. SLR (near-term) (acres)			Measure of Exposure from Hazards with 3.2 ft. SLR (mid-to-late century) (acres)		
	Passive flooding	Erosion	High Wave Inundation	Passive flooding	Erosion	High Wave Inundation
State Land Use Zoned Agriculture	854.23	12.91	202.73	2117.71	35.55	894.96
State Designated Important Agricultural Lands (IAL)	11.64	0	0	14.59	0	0
Pasture	1.9	4.20	4.02	3.27	10.97	16.82
Kaua‘i Crops:						
Aquaculture	0.83	1.63	1.13	1.29	4.74	2.63
Banana	0	0	0	0	0	0
Coffee	0	0	0	0	0	0
Diversified Crop	0	0	0	1.16	0	0
Agriculture Research & Development	422.13	4.56	141.35	1164.37	18.69	468.97
Taro	0	0	0	0	0	0
Tropical Fruit	0	0	0	0	0	0

An inventory of agriculture exposed to two SLR scenarios: A near term 1.1 foot scenario, and a mid-to-late century scenario of 3.2’. Exposed agriculture affected by each SLR hazard (passive flooding, erosion, and high wave inundation) was recorded in ArcGIS. In most cases, infrastructure is impacted by multiple hazards. SLR exposure data was obtained from the Hawai‘i SLR Vulnerability and Adaptation Report.

3. Vulnerability and Potential Adaptation Actions

On February 25, 2019, the project team held a workshop with residents and members of the agricultural community to characterize West Kaua‘i’s vulnerability to climate change and coastal hazards with respect to agriculture. Due to the nature of the drainage system and location of agriculture, vulnerability was examined by: (1) agriculture in the Mānā Plain (Waimea to Polihale), (2) agriculture in the river valleys, and (3) all agriculture in West Kaua‘i. It was assumed that different climate stressors would impact agriculture differently in these areas. Several climate scenarios were raised as having potential impacts on agriculture, however due to limited time, the workshop participants discussed three in depth, including SLR, extreme storm events, and droughts. See Appendix A for the VCAPS diagram.

Mānā Plain

The primary climate stressor to agriculture in the Mānā Plain is SLR. This area is low-lying, and as a result, much of it is threatened by SLR induced passive flooding in the near-term. The majority of the area at risk is land designated as being used for Agricultural Research and Development (see Table 23). By mid-to-late century, the area threatened by SLR nearly doubles. These estimates could be conservative since they do not take into account groundwater rising. However, they also do not take into account current pumping of the groundwater which lowers the groundwater table (see section B, Drainage for more details). This pumping regime was inherited from the plantation era. When sugarcane was the dominant crop, most of the area would be pumped down to -3 feet. Today, it is pumped down between -1.5 to -2 feet[185].

SLR could lead to passive flooding and saltwater intrusion. Saltwater intrusion impacts crop yield or can kill crops all together. This could lead to loss of farming jobs and reduce opportunities for local food production. Although there are no crops in the area dedicated to food production, some participants expressed the desire to increase local food production[186]. The plants or crops that are currently planted in the area are not salt-water tolerant. Flooding could also impact the existing infrastructure, namely drainage and roads, and reduce access to these lands, which in turn could lead to isolation and economic loss.

Potential Adaptation Actions

Actions discussed among workshop participants include researching salt-tolerant plants and alternative types of agricultural methods (e.g., aquaponics, greenhouses) to improve resilience of local agriculture to saltwater intrusion. Participants also discussed the need to study the Dutch polder systems as a potential strategy to adapt to higher groundwater. The Dutch polder systems in the Netherlands is an approach that has been used by farmers for centuries to adapt their agricultural systems to rising sea and river levels[187]. Part of this study should assess the feasibility of relocating agriculture to higher ground and return portions of land in Mānā to natural wetlands. Since higher groundwater could impact Kekaha town as well, participants also discussed the need to assess the feasibility of a managed dike system in the area to reduce the risk of flooding into Kekaha town.

River Valley Agriculture

River valley agriculture, mainly taro, occurs in both Waimea and Hanapēpē. These are predominantly small "truck farms" that support local families and communities, and are critical to their cultural heritage and identity. These farms rely completely on irrigation. Grazing also takes place in the upper valleys and relies on rainfall to keep the food source healthy.

The major climate stressor for river valley agriculture are large, intense storms that cause flooding. Large storms are a problem for small farms because they can wash away nutrient-rich top soil, damage crops, and lead to an increase in invasive species. As a result, there can be very long recovery times for farmers and the families that depend upon them for food and income. Further, according to workshop participants, these farms are too small to be eligible for crop insurance. Farms are not mapped, making it hard to locate them in the event of a disaster. In addition, an extreme storm can negatively impact water quality. Flooding can also impact existing infrastructure, and recovery without pre-disaster planning can induce unwanted infrastructure, such as hardening of river drainages or new diversions.

Potential Adaptation Actions

Workshop participants discussed the need to educate farmers on best management practices (BMPs) to prevent impacts from flooding and mitigate polluted runoff. One such example is the use of vegetated buffers around farms. The Natural Resources Conservation Service (NRCS) would be a good partner to develop an outreach program.

There is also a need to develop post-disaster readiness and planning for small taro farmers. As a precedent, participants mentioned farmers and organizations can look to the on-going North Shore recovery efforts to learn from and help design post-disaster plans. There is a need for the county and communities to engage in community resilience planning. As part of this, west-side farmers and organizations should collaborate with OHA, DHHL and other sectors to develop a response for small farmers, in addition to map the location of small farms in the area.

All West Kauaʻi Agriculture

Increasing temperatures and drought is a third climate stressor impacting all agriculture in West Kauaʻi. Drought decreases river flows, lowers the groundwater table, increases rates of evapotranspiration, and increases the risk of wildfires. As a result, crops can burn and produce lower yield for wetland taro and other agriculture, which results in the downsizing of crops. Crops and vegetation also get stressed from rising temperatures with farmers needing to irrigate more. The long-term consequences could lead to loss of local food production, economic sustainability, and overall loss of food security.

Potential Adaptation Actions

Workshop participants discussed several actions to address rising temperatures and the impacts of increased droughts on agriculture. These include planting more drought resistant crops (i.e., dry taro vs wet) and shade crops. There is also a need to build additional water storage (i.e., storage tanks, rainwater catchment) and to design an incentive program to increase the installation of private water storage and efficient irrigation systems (e.g., pipes or drip instead of ditches). Alternative sources of water could mitigate the impacts of drought such as wastewater recycling and reuse for agriculture, and the increased use of deep wells, although this should be a last resort option. All of this would require additional studies on the cost and feasibility of increasing irrigation as part of a drought water use policy or plan, as a public action.

F. CULTURAL AND NATURAL RESOURCES

The *loʻi paʻakai* of ʻUkula at Hanapēpē (Hanapēpē Salt Pond) which is very vulnerable to sea level rise in the near-term and latter half of the century. Source: Ruby Pap

Cultural resources (defined as part of Heritage Resources in the Kauaʻi General Plan) symbolize Kauaʻi's history, showcasing a diversity that perpetuates a unique sense of place. West Kauaʻi has a rich concentration of cultural resources including historic buildings, structures, experiences, *wahi pana (famous places)*, cultural sites, landmarks, and scenic resources. Natural resources include wetlands, wildlife habitat, beaches, and dunes (also discussed in Section D). As stated in the General Plan, as time progresses these resources will require more attention to ensure their persistence[188]. The inherent high value and irreplaceability of cultural and natural resources make them particularly vulnerable to coastal hazards and SLR, particularly in low lying locations and/or in close proximity to the shoreline.

1. Key Takeaways

- Due to West Kauaʻi's exposure to SLR, and the inherent sensitivity of cultural resources, various types of cultural resources are vulnerable. These include, historically registered buildings/sites, cultural features such as burials, and traditional cultivation areas such as loʻi kalo and loʻi paʻakai.
- Iwi kūpuna, Hawaiian burials typically in sand dunes, are highly sensitive to beach erosion and high wave runup. It is paramount that property owners work with family members on adaptation actions through existing processes, such as the SHPD consultation process.

- The loʻi paʻakai of ʻUkula at Hanapēpē (Hanapēpē Salt Pond) is very vulnerable to SLR both in the near- and long-term. Outcomes include: wave runup, passive flooding, erosion of the beach and dune, and rising groundwater. All result in flooding of the salt pans, which can destroy a salt crop. If the pond is not able to drain quickly enough, an entire salt making season can be cut short. Hydrologic studies, drainage measures, keeping vehicles off the beach, and beach berm restoration were all discussed as potential adaptation actions.
- Traditional cultivation of kalo is vulnerable in the river valleys to riverine floods; and in the lowlands to increased saltwater intrusion. Loss of this practice equates to a loss of a key component of the West Kauaʻi cultural landscape. Potential adaptation actions discussed by participants include planting a diversity of salt tolerant crops and regulating building in former loʻi areas to allow for expansion/relocation of farming outside of vulnerable areas.

2. Inventory of Exposed Cultural Resources[189,190]

A complete set of cultural resources SLR exposure maps can be found in Appendix B.

Table 25. Inventory of Exposed Cultural and Natural Resources within SLR-XA

	Measure of Exposure within SLR-XA with 1.1 ft. SLR (near-term) (count, acres)	Measure of Exposure within SLR-XA with 3.2 ft. SLR (mid-to-late century) (count, acres)
Registered Historic Sites[191]	2	5
Cultural Features	16	35
Traditional Cultivation Areas	566.44 (acres)	1526.99 (acres)
Wetlands 1	1289.84 (acres)	2586.41 (acres)
Critical Habitats	250.62 (acres)	297.56 (acres)

An inventory of cultural resources and natural exposed to two SLR scenarios: A near-term 1.1 foot scenario, and a mid-to-late century scenario of 3.2’. Exposed assets within the overall SLR-XA was recorded in ArcGIS. SLR exposure data was obtained from the Hawaiʻi SLR Vulnerability and Adaptation Report.

Table 26. Inventory of Exposed Cultural and Natural Resources to Passive Flooding, Erosion, and Wave Inundation

	Measure of Exposure from Hazards with 1.1 ft. SLR (near-term) (count, acres)			Measure of Exposure from Hazards with 3.2 ft. SLR (mid-to-late century) (count, acres)		
	Passive flooding	Erosion	High Wave Inundation	Passive flooding	Erosion	High Wave Inundation
Registered Historic Sites	2	1	2	2	1	5
Cultural Features	3	12	11	3	18	26
Traditional Cultivation Areas	543.2 (acres)	9.55 (acres)	148.8 (acres)	1457.51 (acres)	26.01 (acres)	465.61 (acres)
Wetlands	1032.90 (acres)	322.86 (acres)	569.09 (acres)	2312.35 (acres)	324.21 (acres)	1247.00 (acres)
Critical Habitats	48.81 (acres)	215.33 (acres)	187.33 (acres	63.69 (acres)	253.96 (acres)	218.28 (acres)

An inventory of cultural and natural resources exposed to two SLR scenarios: A near-term 1.1 foot scenario, and a mid-to-late century scenario of 3.2'. Exposed assets affected by each SLR hazard (passive flooding, erosion, and high wave inundation) was recorded in ArcGIS. In most cases, infrastructure is impacted by multiple hazards. SLR exposure data was obtained from the Hawai'i SLR Vulnerability and Adaptation Report.

3. Vulnerability and Potential Adaptation Actions

On April 1, 2019, the project team held a community workshop to characterize West Kaua'i's vulnerability to climate change and coastal hazards with respect to cultural resources. (See Appendix A for the full VCAPs diagram).

According to the SLR exposure assessment (Table 25), in the near term (1.1') scenario, two registered historic sites are exposed to SLR. This includes the Hanapēpē salt pans and the Cook landing site. For the mid-to-late century scenario, 3 more sites are exposed: Yamase Building, Bishop National Bank of Hawai'i and the Waimea Hawaiian Church. Sixteen (16) sensitive 'cultural features' are exposed to SLR under a near term scenario, with the number jumping to thirty-five (35) in the mid-to-late century. Cultural features include things like salt pans, burial sites, and cemeteries. Traditional cultivation areas are lands that were historically farmed by Hawaiians for subsistence. There is some overlap in location with the agricultural research crops today in the Mānā Plain (see Section E Agriculture). For these areas as a whole, 566 acres would be exposed in the near term. Under the mid-late century scenario, the number jumps to 1,457 acres.

Workshop participants focused their discussion on the vulnerability of native Hawaiian burials (iwi kūpuna), the salt pans in Hanapēpē, and lowland kalo cultivation.

Iwi Kūpuna

The vulnerability of iwi kūpuna across West Kaua'i was discussed at length. Participants chose to discuss in detail the vulnerability of Nohili dunes as an example for other iwi kūpuna burials as well as vulnerable cemeteries. Nohili dunes is one of the last healthy dune systems in the state. These dunes are exposed to flooding from annual high wave runup under both near term and long-term scenarios, which will likely cause dune erosion and lead to the eventual exposure of iwi. The increased salt spray from wave overwash as sea levels rise will also impact dune native plants. This die back of native vegetation can in turn increase erosion and impact wildlife habitat (as well as iwi kūpuna).

The exposure of iwi, or people's bones, is a highly sensitive and emotional issue to many members of the West Kaua'i community. The vulnerability of this cultural connection to 'ohana cannot be overstated and is illustrated by the following statement by a workshop participant, "It hurts. It feels like you are not taking care of them." What to do about exposure of iwi is a case by case decision undertaken by each individual family. In the case of Nohili dunes, the Pacific Missile Range Facility (PMRF), a Federal entity, manages the land and dunes. A Memorandum of Understanding (MOU) has been established between PMRF and the families to address burial exposure. This MOU came about through the established consultation process with the State Historic Preservation Department (SHPD), who helps put agreements in place. This MOU provides a good example and precedent that could be used in planning for SLR and exposure of iwi elsewhere in West Kaua'i.

> It hurts. It feels like you are not taking care of them.

Potential Adaptation Actions

The potential exposure and inadvertent discovery of iwi kūpuna is a highly sensitive matter, requiring careful review and evaluation in considering family needs and desires. Participants discussed at length the successful use of the Memorandum of Understanding (MOU) during the SHPD consultation process and the construction of a burial crypt to address the eventual exposure of iwi to SLR, instead of reacting to "inadvertent exposure" from, for example, a sudden erosional event. Educating families and landowners about SLR impacts is another important action to help facilitate this planning. One advantage of the West Kauai landscape is that there are only a few large land owners to work with. The same consultation process could be used for other burial areas, including stable cemeteries such as the Chinese and Japanese Cemeteries in Kekaha. Actions to respond to exposure include relocation, reinternment, or (irresponsibly) allowing the bones to wash away (a very sensitive topic). This is first and foremost a family decision. As a general rule, it is important to consult Native Hawaiian families and SHPD early, and consult often.

Dune restoration, including out planting of native plants is a public action that can be undertaken in advance to help prevent or slow the process of erosion and exposure. It is important to note that iwi can be inadvertently exposed during restoration so consultation through the SHPD process is key[192]. It was also suggested that, in the long-term, the road and ditch at Nohili and Polihale could be relocated to allow the dunes to migrate. This would require monitoring of the dune. Also, vehicles on the dunes should be prohibited and prohibition enforced.

Hanapēpē Salt Pond

The Hawaiian practice of creating salt is one of Hawaiʻi's oldest traditions. For generations Hawaiian families have been harvesting sea salt at the loʻi paʻakai of ʻUkula at Hanapēpē (Salt Pond) through an intricate system of ancient hand-dug wells (waipuna) and hand-sculpted loʻi (salt pans/beds) within the low-lying volcanic red clay area mauka of Salt Pond Beach. The area and practice is highly treasured and protected by the community. Over the years this cultural practice has been threatened by a myriad of factors including user conflicts, nonpoint-source pollution, and wave inundation and flooding.

Specific hazards from SLR at Salt Pond include passive flooding, high wave inundation, erosion of the beach and dune, and groundwater rise. Flooding of Salt Pond and the salt pans can destroy a salt crop and if the pond does not drain quickly enough, an entire salt making season can be cut short. One extreme storm with storm surge and rainfall could dramatically impact salt making for one or multiple seasons. The loss of this practice of farming salt can also lead to the loss of traditional cultural practices that are based on Hawaiian salt: Protocol, medicine, and food preservation.

Unfortunately, even under a near-term 1.1' SLR scenario, passive flooding is expected to inundate the salt ponds, which signals flooding being a relatively permanent situation unless drainage or other measures are undertaken. A hydrological study and groundwater model is currently being undertaken by UH Sea Grant to better understand the subsurface geomorphology and drainage patterns of the pond. It is very important that this, and any future studies, be conducted in consultation with the Hui Hāna Paʻakai and the use of non-invasive study techniques.

The current threat of wave runup over the beach and into the pond during the summer salt making season is also an imminent threat to the practice. It is believed that vehicles driving and parking on the beach has contributed to the compaction and erosion of the beach berm. The vehicles were recently stopped by the County placement of boulders with the hope that the beach berm elevation will be restored, in part, by natural wave action. However, active restoration of the beach berm may be necessary in the future.

Vehicles parked on the beach at Salt Pond Beach Park. Source: Ruby Pap

Potential Adaptation Actions

For all actions, it was emphasized that this is a hui/salt maker decision and there is an existing decision making structure in place amongst the traditional salt making families, the Hui Hāna Paʻakai.

Public actions discussed include restoring the beach berm and adding native dune plantings, monitoring the berm/erosion, and prohibiting vehicles from the beach. In addition, implementing the Salt Pond Hydrologic Study that is underway and monitoring flooding and erosion over time will help address what to do in the long-term.

Pending results of the Hydrologic Study, suggested private/public drainage measures include diverting water away from the salt making area, constructing barriers, and/or creating detention basins outside the salt making area. Another action could be to identify wells on the other side of Kaalani road for potential relocation of salt making. This private/public action would need to be done in direct consultation with the Hui Hāna Paʻakai. It was also suggested that as a public/private action, the ʻusefulness' of Kaalani Road which divides the two sides of the pond be studied, examining whether it should be kept in place or removed. One option would be to leave the berm/road, but remove its asphalt and plant with native vegetation.

Traditional Agricultural Practices

Traditional agricultural practice in the river valleys is a key component of the West Kauaʻi cultural landscape, and this landscape is vulnerable to climate related hazards particularly heavy rainfall events. See Section E, Agriculture for the vulnerability discussion and suggested adaptation actions.

Lowland traditional kalo farming is also at risk. More brackish water in streams would increase salinity in the loʻi over time and traditional varieties are not well adapted to salinity. There are also areas that are unfarmed now, with hopes to expand kalo. These potential farming areas are also at risk in low lying areas. Consequently, West Kauaʻi is at risk of losing kalo farming and its cultural practices, as well as these important cultural landscapes that define these areas.

There is a concern about saltwater intrusion upstream of the West Kauaʻi rivers and streams, namely Waimea and Hanapēpē. The rivers are expected to be saltwater influenced up to a new point, but the exposure maps should not be taken literally as to where that point is. Specific studies of SLR exposure for rivers using good bathymetry data are needed[193].

Potential Adaptation Actions

Private actions discussed for lowland loʻi kalo include planting a diversity of crops including salt tolerant taro and experiment with floating rafts like the ʻfloating loʻi of Mānā plain' that are known to have existed in the past. As public actions, it was suggested to regulate/prohibit building in former Hawaiian loʻi areas to allow for expansion/relocation of farming outside of vulnerable areas[194,195].

Kikiaola Harbor sand bypass to address erosion on the west side of the harbor. Source: Ruby Pap

VI. RECOMMENDATIONS

In this section, the project team synthesizes all the project information into succinct recommendations based on the seven management concerns. We also specify recommendations that are pertinent to the individual communities. At the end of each recommendation, we indicate whether it is a public or private action, or both. While the scope of the CVA did not include a prioritization exercise, there are certain recommendations that clearly rise to the top as necessary next steps to move forward in the adaptation process or are 'low hanging fruit' that could easily be done with minimal expenditure. The (priority) and (low hanging fruit) symbols are used below to identify these important actions.

1. Based on the results of this CVA, develop an 'adaptation plan' or similar type analysis that (a) thoroughly vets the suggested actions, including the costs and benefits of actions, and incorporates equity into the analysis; (b) identifies how and where to use adaptation strategies such as relocation, accommodation, and protection; (c) inventories available lands for retreat[196, 197].
2. Incorporate relevant recommendations of the CVA into the update of the Kaua'i Multi-Hazard Mitigation Plan in order to leverage potential hazard mitigation grant funding for recommended studies and actions. (public)
3. Implement actions of the Kaua'i County General Plan's Watershed, Public Safety and Hazards Resiliency, and Energy Sustainability and Climate Change Mitigation Sectors[198]. (public/private)

4. Kaumuali'i Highway in Kekaha:
    a. Develop a strategic plan to respond to near term impacts from SLR to the highway, revetment, and drilled pier wall, which includes a monitoring and maintenance plan. Identify trigger points that identify changed conditions or need for different actions, including actions described below. (public)
    b. Evaluate the costs and benefits, and feasibility of relocating the highway behind (mauka) town. (public)
    c. Evaluate the costs, benefits and feasibility of continuing to armor and maintain the road in place, taking into account SLR projections and how these will impact armoring over time and the need to upgrade the wall. In this evaluation consider the long term impacts to the beach and coastal processes. (public)
    d. Continue to monitor the best available science and modeling on hazard exposure and SLR projections. (public)
    e. Identify cane haul roads as potential alternative access routes for evacuation purposes. (public)
5. Kaumuali'i Highway in Waimea including Waimea Bridge:
    a. Evaluate potential wave runup impacts on the highway and establish maintenance and response actions. (public)
    b. Study potential realignment locations and emergency access/evacuation routes in the event of major damage of the road or the bridge. (public)
    c. Continue to monitor the best available science and modeling of hazard exposure and SLR projections. (public)
    d. Conduct specific study on SLR exposure to the bridge, evaluate bridge height and design to withstand SLR plus heavy rainfall. (public)
    e. Address river flow and siltation concerns, including the need for more frequent dredging and examine whether the mauka diversion needs to be adjusted. (public)
6. Waimea Makai County Roads:
    a. Evaluate potential wave runup and erosion impacts on County roads and establish maintenance and response actions. (public)
    b. Study potential realignment locations and evaluate trigger points for relocation/removal (such as # of days flooded or a specified width of beach). (public)
    c. Conduct cost benefit analysis of adaptation actions (relocation, armoring, elevation, and beach nourishment) for short term and long term. (public)
    d. Continue to monitor the best available science and modeling on hazard exposure and SLR projections. (public)

7. Hanapēpē Bridges:

    a. Partner with scientists/engineers to conduct specific assessment of SLR exposure to the bridge, and evaluate appropriate bridge height and designs to withstand SLR combined with heavy rainfall. (public)

    b. Address river flow and siltation concerns, including the need for more frequent dredging and examine whether the mauka diversion needs to be adjusted. (public)

8. Ports and Harbors:

    a. Re-engineer breakwaters, ramps, and piers to address SLR. Evaluate the long term viability of Kikiaola Harbor with SLR and its impact on alongshore transport of sediment on Waimea Beach. (public)

9. Drainage:

    a. Partner with scientists to conduct a focused hydrological assessment of West Kauaʻi drainage system, including pumps, ditches, canals, pipes and outfalls to handle various projections of SLR in the short term and long term. (public)

    b. Partner with scientists to conduct groundwater studies and mapping for various SLR scenarios in low-lying areas of Kekaha, Waimea, and Hanapēpē. (public)

    c. Use the results of these assessments to inform future adaptation actions of the drainage system and/or adaptation actions within the communities affected (i.e. homes, cesspools, etc.) (public/private)

    d. Consider wetland restoration on the Mānā Plain and elsewhere, as appropriate, as a technique to store floodwaters. (public)

    e. Improve coordination across drainage system responsible parties and improve communication with the public. (public/private)

    f. Update mapping of the West Kauaʻi drainage system in Geographic Information Systems (GIS). (public/private)

10. Wastewater:

    a. Reduce water usage and install grease traps in businesses.

    b. Work with EPA/ State DOH to identify low interest loans for home owners and businesses to replace old sewer laterals to reduce GWI into laterals. (public/private)

    c. Conduct focused study of all impacts to the municipal wastewater system and use results of the assessment to schedule future adaptation actions to line pipes, relocate pipes, raise manholes, etc. (public)

    d. Conduct a feasibility study of wastewater treatment alternatives in Kekaha that would consider replacing cesspools by: (a) extending municipal wastewater system to the town of Kekaha; (b) replacing with alternative onsite disposal systems that are resilient to SLR and compatible with the environment. (public)

e. Conduct pre-disaster planning for post-disaster reconstruction of the wastewater system, a full assessment of all OSDS, and whether reconstruction might include upgrades of current cesspools to alternative OSDS or a central sewer system. (public/private)

f. Update mapping of all private and public wastewater treatment facilities in GIS. (public)

g. Assess power resilience at County of Kaua‘i Wastewater Management Department and increase power resilience measures in areas where needed, including communication, power assessments, emergency/standby generators, fuel, energy efficiency, on-site power, black sky planning, and funding.

Eight areas in which water/wastewater utility sectors can increase power resilience:

Communication – Establish capability to communicate with electric providers, local agencies and the public to help water or wastewater utility respond more quickly and efficiently to a power loss.

Power Assessments – Conduct a power assessment to understand utility's essential equipment energy needs.

Emergency/Standby Generators –Select, maintain and register requirements for a fixed or portable emergency generator needed in the event of a power outage.

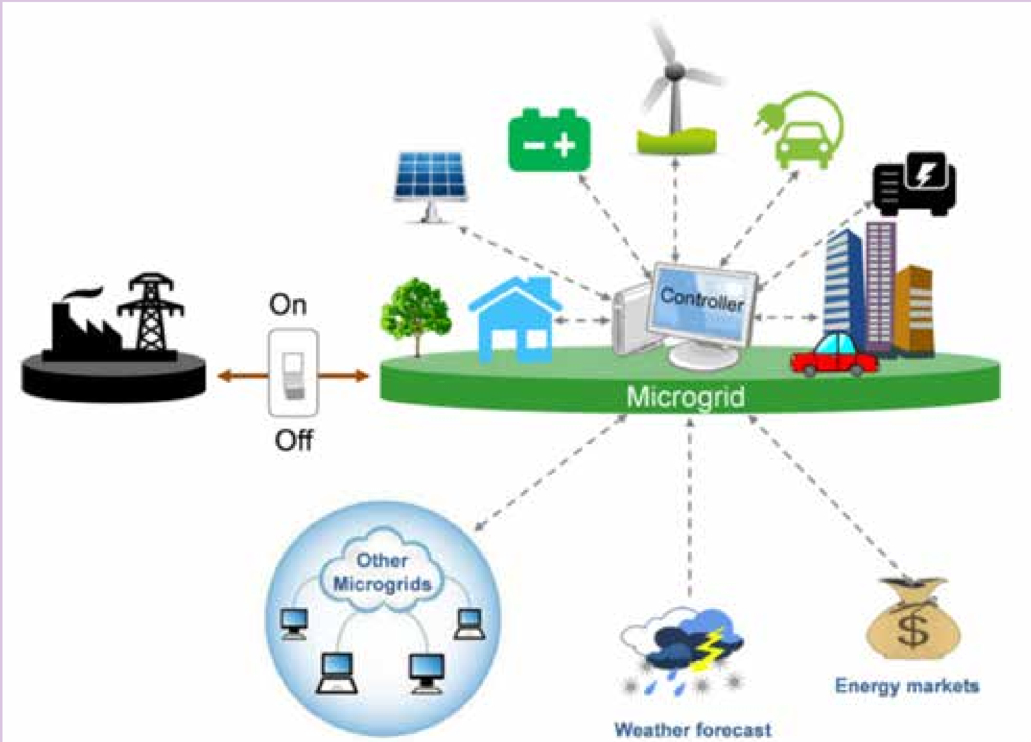
Fuel – Develop plans to ensure that the utility has enough fuel for generator(s) during a power outage emergency.

Energy Efficiency – Increase energy efficiency to allow operation on back-up power to run longer during emergencies and to reduce your electricity bills during normal operations.

On-site Power – Use options for generating own power to allow utility to function during grid outages, including off-grid power generations such as distributed energy resources and microgrids. A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.

Black Sky Planning – Prepare for long-duration, widespread power outages.

Funding – Learn about possible funding sources for resilience measures.



A microgrid, which is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. Source: EPA

11. Water:

a. Conduct focused study of all SLR impacts to the water system and use results of the assessment to schedule future adaptation actions to replace pipes with PVC, relocate pipes, etc. Coordinate with the Department of Transportation on relocation options. (public)

b. Implement back-up generators to deep wells. (public)

c. Establish generator shelters at critical water sites in the event of a large hurricane. (public)

d. Assess power resilience at Department of Water and increase power resilience measures in areas where needed.

e. Protect and restore the watershed including protecting native vegetation, restoring flow to rivers. (public/private)

f. Conduct household water conservation practices. (private)

g. Design and implement clear regulations, including the plumbing code, to incentivize and increase the use of greywater and rainwater catchment. (public)

h. Encourage personal preparedness for hurricanes, tsunamis, and other storm events, including having a 14-day supply of food and water. (public/private)

i. Conduct a study to examine the impact of potential increased drought on water demand and different strategies to reduce demand and increase supply (e.g. water pricing, desalination, and water recycling/reuse). (public)

12. Electricity:

a. A focused study of all SLR impacts to the electrical system and potential adaptation strategies is recommended. (public)

b. Conduct focused study of potential SLR impacts to future KIUC projects on books. (public)

c. Continue to build and expand energy distribution projects. (public)

13. Levees:

a. Partner with scientists to conduct specific hydrological analysis of a rainfall event combined with SLR (various short term and long scenarios) and evaluate the levees' abilities to protect the towns of Waimea and Hanapēpē. (public)

b. Pursue funding to raise and upgrade the levees consistent with above findings and requirements of the Federal freeboard standard. (public)

c. Repair flap and sluice gates and maintain drainage ditches to prevent flooding in surrounding neighborhoods (i.e. Waimea Valley). (public)

d. Continue dredging at the Waimea River mouth, and explore longer term solutions to reduce sediment buildup. Use compatible sand to nourish Waimea Beach in critically eroding areas. (public)

e. Address flooding in Waimea Valley by exploring feasibility of designating areas to channel water to undeveloped areas, unused drainage canals, or a constructed flood storage/wetland area; provide incentives to raise homes/ infrastructure. (public)

14. Beaches and coastal properties:

a. Conduct seasonal beach monitoring at Waimea (both sides of harbor and at river mouth), Kekaha, Pākalā, and Salt Pond Beaches. (public/private)

b. Continue the Kikiaola sand bypass program from east to west of the harbor and continue the monitoring in (a). When beach areas east of the harbor (Waimea Town) experience erosion, consider utilizing sand built up at the river mouth to nourish the beach. (Also see policy 5(a) above [Kikiaola Harbor). (public)

c. Partner with scientists to upgrade the SLR erosion model to incorporate the presence of manmade structures and to better understand the erosion hazard to the community. (public)

d. In order to preserve beaches for as long as possible, avoid armoring as much as feasible. Work with shoreline property owners and infrastructure managers on a comprehensive and reasonable response plan for when erosion becomes a dominant threat or when a large storm destroys a neighborhood. This plan should include trigger points for action (e.g. width of beach or distance of development to shoreline), a thorough analysis of alternatives such as relocation, elevation, beach nourishment, dune restoration, temporary sandbag protection, and hard armoring. (public/private)

e. Work with State and County Park Managers to identify adaptation options for beach parks. (public)

f. Conduct dune restoration at Salt Pond Beach park in consultation/collaboration with the Hui Hāna Pa`akai. (public)

g. Acquire or set aside lands for land bank and expansion of Salt Pond Beach Park mauka and westward. (public)

h. Individual property owners and renters living within the 1.1 SLR-XA should consider purchasing flood insurance even if outside of regulated FEMA flood zones. (private)

i. Implement incentives and regulations to implement flood accommodation measures such as elevating homes and low impact development (LID) practices, and incentives for voluntary relocation of homes in flood prone areas (see Waimea, Hanapēpē-Eleele, and Kekaha below). (private)

j. Join the FEMA Community Rating System (CRS) to incentivize the above. (public)

k. Include analysis of SLR impacts in all land use/building permitting decisions in SLR exposure areas. (public)

15. Agriculture:

a. Conduct focused agricultural study of climate change impacts to crops at various time intervals and different scenarios, and use the results of analysis to schedule and inform different adaptation actions. (private/public)

b. Conduct specific studies of SLR exposure to rivers and streams, using bathymetry, to determine the extent of saltwater intrusion to rivers and streams. (public or private)

c. Pursue alternative, salt tolerant and/or drought tolerant crops and shade crops. (private/public)

d. Relocate crops out of exposure areas. (private/public)

e. Consider wetland restoration/enhancement on the Mānā Plain as a technique to store floodwaters and carbon. (public)

f. Encourage local food crops to increase food security and community resilience. (private/public)

g. Educate farmers on best management practices to prevent impacts from flooding and mitigate polluted runoff (for e.g., with the use of vegetation buffers around farms). (public/private)

h. Map all small farms and make available to public in the event of a disaster for enhanced response and recovery to farmers. (private/public)

i. Develop disaster response and recovery plans to help farmers in the event of heavy rain. (private)

j. Pursue rainwater catchment or other water storage to ensure resiliency in the face of drought. Design incentive program to increase installation of private storage, efficient irrigation systems, and use of alternative irrigation sources (e.g., wastewater recycling). (public/private)

16. Cultural Resources:

a. Conduct focused education campaign on impacts of SLR for coastal property owners and families of iwi kūpuna who are faced with SLR exposure. (public)

b. Start the State Historic Preservation Department (SHPD) consultation process with property owners and families early, in advance of iwi exposure, to make action plans in advance of the exposure. (public/private)

c. Always consult with families early and consult often before any actions are taken. (private/public)

d. Actively consult with the Hui Hāna Pa'akai on SLR concerns and planning efforts at Hanapēpē Salt Pond. (public)

e. Conduct hydrological assessment at Hanapēpē Salt Pond that evaluates various scenarios of SLR and recommends adaptation actions to preserve and enhance this important cultural practice. (public)

17. Waimea Town Land Use:

a. Limit new development and/or density increases in the downtown area makai of Kaumuali'i Highway. (public)

b. Reserve areas mauka of the highway and west side of the town for additional development or as future retreat areas. (public)

c. Implement flooding accommodation measures for existing development or redevelopment in the downtown area makai of Kaumuali'i Highway. These include elevation of buildings, low impact development (LID) design standards such as permeable surfaces, and adding 'freeboard' standards to the floodplain ordinance. (public/private)

d. Join the FEMA flood program's Community Rating System (CRS), which incentivizes increased flood mitigation practices and can result in reductions in flood insurance premiums. (public)

e. Individual properties and renters living in the 1.1 SLR-XA or within the river floodplain should consider purchasing flood insurance even outside of regulated FEMA flood zones. (private)

f. Partner with scientists to develop next generation 2D or 3D wave runup models and groundwater inundation mapping with various scenarios of SLR. (public)

g. Continue to implement and update the shoreline setback ordinance with SLR data to ensure that any new development, major repairs and rebuilds along the shoreline are set back a safe distance from the shoreline. (public)

h. Avoid armoring as erosion control as much as feasible. Identify erosion hotspots and work with property owners and infrastructure managers on a comprehensive and reasonable response plan for when erosion becomes a dominant threat or when a large storm destroys a neighborhood. This plan should include a thorough analysis of all alternatives, including relocation, beach and dune restoration, groins, etc. (public/private)

18. Kekaha Town Land Use:

a. Prior to significant density increases in Kekaha, partner with scientists to conduct focused hydrological assessment of West Kaua‘i drainage system and a 3D groundwater study, consistent with Recommendation 5(a) and (b). Such an assessment should also evaluate groundwater interactions with cesspools and other underground infrastructure. (public)

b. If new development or additional density is planned prior to the above, limit it to those areas that are highest in elevation (e.g. the west side of town). (public)

c. Implement flood accommodation measures for existing development or redevelopment in Kekaha. These include elevation of buildings, low impact development (LID) design standards such as permeable surfaces, and adding ‘freeboard’ standards to the floodplain ordinance. (public/private)

d. Join the FEMA flood program’s Community Rating System (CRS), which incentivizes flood mitigation strategies and can result in reductions in flood insurance premiums. (public)

e. Individual properties and renters living in the 1.1 SLR-XA should consider purchasing flood insurance even outside of regulated FEMA flood zones. (private action)

f. See Recommendation 10

19. Hanapēpē – ‘Ele‘ele Land Use:

a. Consider placing new development or density increases in high elevation neighborhoods in ‘Ele‘ele, Hanapēpē Heights, and Port Allen. (public/private)

b. If revitalization and redevelopment of Hanapēpē town or low – lying areas makai of the highway within the SLR-XA or within the river floodplain, implement flood accommodation measures. These include elevation of buildings, low impact development (LID) design standards such as permeable surfaces, and adding 'freeboard' standards to the floodplain ordinance. (public)

c. Join the FEMA flood program's Community Rating System (CRS), which incentivizes increased flood mitigation practices and can result in reductions in flood insurance premiums. (public)

d. Individual properties and renters living in the 1.1 SLR-XA or within the river floodplain should consider purchasing flood insurance even outside of regulated FEMA flood zones. (private)

e. Partner with scientists to develop 3D groundwater inundation modeling with various scenarios of SLR. (public/private)

f. For other infrastructure and levee recommendations see # 10.

20. Community Disaster Recovery Preparedness:

a. Consider utilizing a disaster recovery preparedness planning process as a means to implement climate adaptation measures and become more resilient after a natural disaster occurs on West Kaua'i[199]. (public)

b. Consider relocating fire and police stations out of the SLR-XA and tsunami evacuation zone. (public)

21. Personal Disaster Preparedness:

a. Increase awareness and education within communities on how to prepare and what to do in the event of a disaster. (public/private)

22. SLR Outreach and Education:

a. Provide continued outreach and information to the West Kaua'i community regarding SLR vulnerability. (public)

BIBLIOGRAPHY

Anderson. C.M. 1978. “Coastal Residential Structures Life Time Determination”. Prepared for The Federal Insurance Administration. Department of Housing and Urban Development.

Anderson, Tiffany R., Charles H. Fletcher, Matthew M. Barbee, Bradley M. Romine, Sam Lemmo, and Jade M.S. Delevaux. 2018. “Modeling Multiple Sea Level Rise Stresses Reveals Up to Twice the Land at Risk Compared To Strictly Passive Flooding Methods”. *Scientific Reports* 8 (1). doi:10.1038/s41598-018-32658-x.

Bassiouni, Maoya, and Delwyn S. Oki. 2012. “Trends and Shifts in Streamflow in Hawai’i, 1913-2008”. *Hydrological Processes* 27 (10): 1484-1500. doi:10.1002/hyp.9298.

Blay, Charles. 2016. “West Kaua’i PMRF/Kekaha Mānā Coastal Plain Beach System Monitoring And Modeling”. TEOK Investigations.

Church, John A., and Neil J. White. 2011. “Sea-Level Rise from the Late 19th to the Early 21st Century”. *Surveys In Geophysics* 32 (4-5): 585-602. doi:10.1007/s10712-011-9119-1.

Cooper, Hannah M., Charles H. Fletcher, Qi Chen, and Matthew M. Barbee. 2013. “Sea-Level Rise Vulnerability Mapping for Adaptation Decisions Using Lidar Dems”. *Progress In Physical Geography: Earth And Environment* 37 (6): 745-766. doi:10.1177/0309133313496835.

County of Kaua’i. 2018. “Kaua’i Kakou, Kaua’i County General Plan”. 2018 Final Version Approved by the County Council.

Courtney, C.A., K. Gelino, B.M. Romine, K.D. Hintzen, C. Addonizio-Bianco, T.M. Owens, M. Lander, and J. Buika. 2019. “Guidance for Disaster Recovery Preparedness in Hawai’i”. Prepared by Tetra Tech, Inc. for the University of Hawai’i Sea Grant College Program and State of Hawai’i Department of Land and Natural Resources and Office of Planning, with funding from National Oceanic and Atmospheric Administration Office for Coastal Management award no. NA16NOS4730016

C. Peraro Consulting, LLC. 2017. “Hawai’i Statewide Point in Time Count”.

Dobes, L., and B. Chapman. 2011. “Financing Adaptation To Climate-Induced Retreat From Coastal Inundation And Erosion”. CCEP Working Paper 1113. Canberra: Centre for Climate Economics & Policy, Crawford School of Economics and Government, The Australian National University.

Fasullo, J. T., R. S. Nerem, and B. Hamlington. 2016. “Is the Detection of Accelerated Sea Level Rise Imminent?”. *Scientific Reports* 6 (1). doi:10.1038/srep31245.

Habel, Shellie, Charles H Fletcher, Kolja Rotzoll, Aly I El-Kadi, and Delwyn S Oki. 2019. "Comparison of a Simple Hydrostatic and a Data-Intensive 3D Numerical Modeling Method of Simulating Sea-Level Rise Induced Groundwater Inundation for Honolulu, Hawai'i, USA". *Environmental Research Communications* 1 (4): 041005. doi:10.1088/2515-7620/ab21fe.

Habel, Shellie, Charles H. Fletcher, Kolja Rotzoll, and Aly I. El-Kadi. 2017. "Development of a Model to Simulate Groundwater Inundation Induced by Sea-Level Rise and High Tides in Honolulu, Hawai'i". *Water Research* 114: 122-134. doi:10.1016/j.watres.2017.02.035.

Hansen, James, Makiko Sato, Paul Hearty, Reto Ruedy, Maxwell Kelley, Valerie Masson-Delmotte, and Gary Russell et al. 2016. "Ice Melt, Sea Level Rise and Superstorms: Evidence From Paleoclimate Data, Climate Modeling, And Modern Observations That 2 °C Global Warming Could Be Dangerous". *Atmospheric Chemistry and Physics* 16 (6): 3761-3812. doi:10.5194/acp-16-3761-2016.

Hawaii Administrative Rules, Title 11. Chapter 62, Wastewater Systems. 2004.

Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. "Hawai'i SLR Vulnerability and Adaptation Report". Prepared By Tetra Tech, Inc. and The State Of Hawai'i Department Of Land And Natural Resources, Office Of Conservation And Coastal Lands. under the State of Hawai'i under the State of Hawai'i under the State of Hawaiʻi Department of Land and Natural Resources Contract No: 64064.i Department of Land and Natural Resources Contract No: 64064.i Department of Land and Natural Resources Contract No: 64064.

Hawaiʻi State Office of Planning. 2019. *GIS Portal*. http://planning.hawaii.gov/gis/.

Hay, C.C., E. Morrow, R.E. Kopp, and J.X. Mitrovica. 2015. "Probabilistic Reanalysis of Twentieth-Century Sea-Level Rise." *Nature* 517 (7535):481-484. doi: 10.1038/nature14093

Hayhoe, K., D.J. Wuebbles, D.R. Easterling, D.W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner. 2018. "Our Changing Climate." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 72–144. doi: 10.7930/NCA4.2018.CH2

Hazards, Climate, & Environment Program, University of Hawaiʻi Social Science Research Institute and Disaster Resilience LLC. 2015. "County of Kauaʻi Multi-Hazard Mitigation and Resilience Plan, 2015 Update." Prepared for Kauaʻi County Civil Defense Agency and the County of Kauaʻi.

IPCC (Intergovernmental Panel on Climate Change). 2001. "IPCC Third Assessment Report: Climate change 2001: Impacts, Adaptation and Vulnerability." By IPCC Working Group II. Cambridge, UK: Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change). 2007. "IPCC Fourth Assessment Report: Climate Change 2007: Impacts, Adaptation and Vulnerability." By IPCC Working Group II. New York, NY: Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change). 2014. "IPCC Fifth Assessment Report: Climate Change 2014: Impacts, Adaptation and Vulnerability Part B: Regional Aspects." By IPCC Working Group II. New York, NY: Cambridge University Press.

Kauai Department of Water. 2001. "WaterPlan 2020." http://www.kauaiwater.org/ce_waterplan2020app.asp.

Keener, V., D. Helweg, S. Asam, S. Balwani, M. Burkett, C. Fletcher, T. Giambelluca, Z. Grecni, M. Nobrega-Olivera, J. Polovina, and G. Tribble. 2018. "Hawai'i and U.S.-Affiliated Pacific Islands." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1242–1308. doi: 10.7930/NCA4.2018.CH27

Kettle, Nathan P., Kirstin Dow, Seth Tuler, Thomas Webler, Jessica Whitehead, and Karly M Miller. 2014. "Integrating Scientific and Local Knowledge to Inform Risk-Based Management Approaches for Climate Adaptation". *Climate Risk Management* 4-5, 1 (2014): 17-31. doi: 10.1016/j.crm.2014.07.001

Kim, Karl E., Pradip Pant, and Eric Y. Yamashita. 2015. "Disasters, Drones, and Crowd-Sourced Damage Assessment." In *Computers in Urban Planning and Urban Management Conference*. Cambridge, MA.

KIUC. 2017. "KIUC Annual Report, In the Spotlight." Accessed on-line June 12, 2019.

Marra, J. J., M. A. Merrifield, and W. V. Sweet. 2012. "Sea Level and Coastal Inundation on Pacific Islands in Climate Change and Pacific Islands: Indicators and Impacts." Report for the 2012 Pacific Islands Regional Climate Assessment (PIRCA). edited by J. J. Marra V. W. Keener, M. L. Finucane, D. Spooner, & M. H. Smith. Washington, DC: Island Press.

Moser, S.C. 2005. "Impact Assessments and Policy Responses to Sea-Level Rise in Three US States: An Exploration of Human-Dimension Uncertainties". *Global Environmental Change* 15: 353-369. doi: 10.1016/j.gloenvcha.2005.08.002.

Nerem, R.S., D.P. Chambers, C. Choe, and G.T. Mitchum. 2010. "Estimating Mean Sea Level Change from the TOPEX and Jason Altimeter Missions". Marine Geodesy 33 (sup1):435- 446. doi: 10.1080/01490419.2010.491031.

NOAA. 2014. "SLR and Nuisance Flood Frequency Changes around the United States". NOAA Technical Report NOS CO-OPS 073.

NOAA Earth System Research Laboratory and Scripps Institution of Oceanography. 2019. "Monthly Average Mauna Loa CO2." https://www.esrl.noaa. gov/gmd/ccgg/trends/mlo.html. Accessed 7/3/19.

NOAA National Ocean Service. 2019. "Tides and Water Levels" website. Last Revised 8/8/18: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=1611400. Accessed on 7/3/19.

NOAA Research News. June 4, 2019. "Carbon Dioxide Levels Hit Record Peak in May"

Pacific Islands Ocean Observing System. 2018. "SLR: Hawai'i SLR Viewer." Accessed February, 2018. https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

R.M. Towill Corporation. 2015. "General Plan Update Kaua'i Infrastructure Analysis."

Romine, Bradley M., Charles H. Fletcher, Matthew M. Barbee, Tiffany R. Anderson, and L. Neil Frazer. 2013. "Are Beach Erosion Rates and Sea-Level Rise Related in Hawaii?" Global and Planetary Change 108 (September): 149–57. doi: 10.1016/j. gloplacha.2013.06.009.

Rotzoll, Kolja, and Charles H. Fletcher. "Assessment of Groundwater Inundation as a Consequence of Sea-Level Rise." *Nature Climate Change* 3 (November 11, 2012): 477.

Schoubroeck, Frank van. 2010. "The Remarkable History of Polder Systems in The Netherlands." White Paper. Rome: FAO. http://www.fao.org/fileadmin/templates/giahs/ PDF/Dutch-Polder-System_2010.pdf. Accessed June 26, 2019.

SMS Research and Marketing Services 2014. General Plan Socioeconomic Analysis and Forecasts. Prepared for the County of Kaua'i Department of Planning and Permitting.

Summers, Alisha, Charles H. Fletcher, Daniele Spirandelli, Kristian McDonald, Jin-Si Over, Tiffany Anderson, Matthew Barbee, and Bradley M. Romine. 2018. "Failure to Protect Beaches under Slowly Rising Sea Level." *Climatic Change* 151 (3): 427–43. doi: 10.1007/s10584-018-2327-7.

Susskind, Lawrence, Danya Rumore, Carri Hulet, and Patrick Field. 2015. *Managing Climate Risks in Coastal Communities*. Anthem Press. doi: 10.2307/j.ctt1gxp7qz.

Sweet, W.V., et al. 2018. "Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold." NOAA Technical Report NOS CO-OPS 086

Sweet, W.V., R.E. Kopp, R.E. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas. 2017. Global and Regional SLR Scenarios for the United States. Silver Spring, MD: NOAA Technical Report NOS CO-OPS 083.

Tico, Teresa. "Miss South Pacific: Beauty and the Sea." 2011. Video, https://www. misssouthpacificthemovie.com/

Tuler, Seth, Thomas Webler, Kristin Dow, Jessica Whitehead, and Nathan Kettle. 2013. "Diagramming Climate Change-Related Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS): A facilitation guide and tutorial." By Social and Environmental Research Institute, University of South Carolina, South Carolina Sea Grant Consortium, and Carolinas Integrated Sciences and Assessments.

Tuler, Seth. 2018. "Assessment of Adaptation, Policy, and Capacity Building Outcomes from Fourteen Community Vulnerability, Consequences, Adaptation Scenario (VCAPS) Processes." By Social and Environmental Research Institute, University of South Carolina, South Carolina Sea Grant Consortium, and Carolinas Integrated Sciences and Assessments.

UH Sea Grant. 2014a. "Kaua'i Climate Change and Coastal Hazards Assessment. Kaua'i General Plan Update Technical Study".

UH Sea Grant. 2014b. "Climate Change Impacts in Hawai'i - A Summary of Climate Change and its Impacts to Hawai'i's Ecosystems and Communities".

U.S. Census Bureau. 2000. Census Demographic Profile Data; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).

U.S. Census Bureau. 2010. Census Demographic Profile Data; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).

U.S. Census Bureau; American Community Survey. 2017. American Community Survey 5-Year Estimates; generated by Daniele Spirandelli; using American FactFinder; <http:// factfinder.census.gov> (June 26 2019).

USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018

Watson, C.S., N.J. White, J.A. Church, M.A. King, R.J. Burgette, and B. Legresy. 2015. "Unabated global mean sea-level rise over the satellite altimeter era." *Nature Climate Change* 5 (6):565-568. doi: 10.1038/nclimate2635.

Wittenberg, H., and H. Aksoy. 2010. "Groundwater Intrusion into Leaky Sewer Systems." *Water Science and Technology* 62 (1): 92–98. doi: 10.2166/wst.2010.287.

Yi, S., W. Sun, K. Heki, and A. Qian. 2015. "An Increase in the Rate of Global Mean SLR since 2010." *Geophysical Research Letters* 42 (10):3998-4006. doi: 10.1002/2015GL063902.

APPENDIX A: VCAPS CAUSAL DIAGRAMS

Go to: https://seagrant.soest.hawaii.edu/coastal-and-climate-science-and-resilience/ccs-projects/wkcva-report-appendix-a/

APPENDIX B: SLR EXPOSURE MAPS

Go to: https://seagrant.soest.hawaii.edu/coastal-and-climate-science-and-resilience/ccs-projects/wkcva-report-appendix-b/

ENDNOTES

1 NOAA National Ocean Service. 2019. "Tides and Water Levels" website. Last Revised 8/8/18: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=1611400. Accessed on 7/3/19.

2 Hayhoe, K., D.J. Wuebbles, D.R. Easterling, D.W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner. 2018. "Our Changing Climate." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 72–144. doi: 10.7930/NCA4.2018.CH2

3 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report*.; Pacific Islands Ocean Observing System. 2018. "Sea Level Rise: Hawai'i Sea Level Rise Viewer." Accessed February, 2018. https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

4 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *Hawai'i Sea Level Rise Vulnerability and Adaptation Report*. Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064.

5 Interview with community member, March 2018

6 Keener, V., D. Helweg, S. Asam, S. Balwani, M. Burkett, C. Fletcher, T. Giambelluca, Z. Grecni, M. Nobrega-Olivera, J. Polovina, and G. Tribble. 2018. "Hawai'i and U.S.-Affiliated Pacific Islands." In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1242–1308. doi: 10.7930/NCA4.2018.CH27

7 Hawai'i Climate Mitigation and Adaptation Commission. *HI SLR Report*. 2017

8 Hawai'i State Office of Planning. 2019. *GIS Portal*. http://planning.hawaii.gov/gis/.

9 NOAA Research News. June 4, 2019. Carbon Dioxide Levels Hit Record Peak in May

10 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. "Hawai'i Sea Level Rise Vulnerability and Adaptation Report." Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064.

11 NOAA Earth System Research Laboratory and Scripps Institution of Oceanography. 2019. "Monthly Average Mauna Loa CO_2." Last Modified June 2019. https://www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html. Accessed on 7/3/19.

12 Keener et al. 2018. *Chapter 27 of the 4th National Climate Assessment*

13 Keener et al. 2018. *Chapter 27 of the 4th National Climate Assessment*

14 Hawai'i Climate Change Mitigation and Adaptation Commission. *HI SLR Report.* 2017.

15 Church, J.A., and N.J. White. 2011. "Sea-Level Rise from the Late 19th to the Early 21st Century."
Surveys in Geophysics 32 (4-5):585-602. doi: 10.1007/s10712-011-9119-1.

16 Hay, C.C., E. Morrow, R.E. Kopp, and J.X. Mitrovica. 2015. "Probabilistic reanalysis of twentieth-century sea-level rise." Nature 517 (7535):481-484. doi: 10.1038/nature14093

17 Nerem, R.S., D.P. Chambers, C. Choe, and G.T. Mitchum. 2010. "Estimating Mean Sea Level Change from the TOPEX and Jason Altimeter Missions." Marine Geodesy 33 (sup1):435-446. doi: 10.1080/01490419.2010.491031.

18 Church & White. 2011. *Sea Level Rise from late 19th to 21st century*

19 Narem et al 2010. *Estimating Mean Sea Level Change*

20 Hay et al 2015. *Probabilistic Reanalysis of SLR*

21 Yi, S., W. Sun, K. Heki, and A. Qian. 2015. "An increase in the rate of global mean sea level rise since
2010." *Geophysical Research Letters* 42 (10):3998-4006. doi: 10.1002/2015GL063902.

22 Hansen, J., M. Sato, P. Hearty, R. Ruedy, M. Kelley, V. Masson-Delmotte, G. Russell, G. Tselioudis, J.
Cao, E. Rignot, I. Velicogna, B. Tormey, B. Donovan, E. Kandiano, K. von Schuckmann, P. Kharecha, A.N. Legrande, M. Bauer, and K.-W. Lo. 2016. "Ice melt, sea level rise and superstorms: evidence from paleoclimate data, climate modeling, and modern observations that 2 °C global warming could be dangerous.» *Atmospheric Chemistry and Physics* 16 (6):3761-3812. doi: 10.5194/acp-16-3761-2016.

23 Watson, C.S., N.J. White, J.A. Church, M.A. King, R.J. Burgette, and B. Legresy. 2015. "Unabated global mean sea-level rise over the satellite altimeter era." *Nature Climate Change* 5 (6):565-568. doi: 10.1038/nclimate2635.

24 Fasullo, J.T., R.S. Nerem, and B. Hamlington. 2016. "Is the detection of accelerated sea level rise
imminent?" *Scientific Reports* 6:31245. doi: 10.1038/srep31245.

25 Romine, Bradley M., Charles H. Fletcher, Matthew M. Barbee, Tiffany R. Anderson, and L. Neil Frazer. 2013. "Are Beach Erosion Rates and Sea-Level Rise Related in Hawaii?" Global and Planetary Change 108 (September): 149–57. https://doi.org/10.1016/j.gloplacha.2013.06.009.

26 NOAA National Ocean Service. 2019. "Tides and Water Levels" website. Last Revised 8/8/18: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=1611400. Accessed on 7/3/19.

27 Marra, J. J., M. A. Merrifield, and W. V. Sweet. 2012. "Sea Level and Coastal Inundation on Pacific
Islands In Climate Change and Pacific Islands: Indicators and Impacts." Report for the 2012 Pacific Islands Regional Climate Assessment (PIRCA). edited by J. J. Marra V. W. Keener, M. L. Finucane, D. Spooner, & M. H. Smith. Washington, DC: Island Press.

28 NOAA. 2014. "Sea Level Rise and Nuisance Flood Frequency Changes around the United States." NOAA
Technical Report NOS CO-OPS 073.

29 NOAA National Ocean Service. 2019. *Tides and Water Levels*. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=1611400. Accessed on 7/3/19.

30 UH Sea Grant 2014a. "Kaua'i Climate Change and Coastal Hazards Assessment. Kaua'i General Plan Update Technical Study."

31 Hazards, Climate, & Environment Program, University of Hawai'i Social Science Research Institute and
Disaster Resilience LLC. 2015. "County of Kaua'i Multi-Hazard Mitigation and Resilience Plan, 2015 Update." Prepared for Kaua'i County Civil Defense Agency and the County of Kaua'i.

32 Keener et al. 2018. *Chapter 27 of the 4th National Climate Assessment*

33 USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018

34 UH Sea Grant 2014b. Climate Change Impacts in Hawai'i - A summary of climate change and its impacts to Hawai'i's ecosystems and communities.

35 Bassiouni, M., and D. S. Oki, 2013: Trends and shifts in streamflow in Hawai'i, 1913–2008. Hydrological Processes, 27 (10), 1484–1500. doi:10.1002/hyp.9298

36 UH Sea Grant 2014a

37 County of Kaua'i 2015.

38 Keener et al. 2018. *Chapter 27 of the 4th National Climate Assessment*

39 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report*.

40 County of Kaua'i. 2018. "Kaua'i Kakou Kaua'i County General Plan." 2018 Final Version Approved by the County Council. pp 197-199

41 Hayhoe, K., D.J. Wuebbles, D.R. Easterling, D.W. Fahey, S. Doherty, J. Kossin, W. Sweet, R. Vose, and M. Wehner. 2018. "Our Changing Climate." In *Impacts, Risks, and Adaptation in the United*

States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 72–144. doi: 10.7930/NCA4.2018.CH2

42 Sweet, W.V., R.E. Kopp, R.E. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas. 2017.
Global and Regional Sea Level Rise Scenarios for the United States. Silver Spring, MD: NOAA Technical Report NOS CO-OPS 083.

43 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report*.

44 Sweet et al. 2017. *Global and Regional Sea Level Rise Scenarios*

45 Hayhoe et al. 2018. *Our Changing Climate*. pp. 72–144.

46 Pacific Islands Ocean Observing System. 2018. "Sea Level Rise: Hawai'i Sea Level Rise Viewer." Accessed February, 2018. https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

47 Habel, Shellie Linn. "Comparison of a simple hydrostatic and a data-intensive 3D numerical modeling method of simulating sea-level rise induced groundwater inundation for Honolulu, Hawai'i, USA." Environ. Res. Commun. in press https://doi.org/10.1088/2515-7620/ab21fe

48 Rotzoll, Kolja, and Charles H. Fletcher. "Assessment of Groundwater Inundation as a Consequence of Sea-Level Rise." *Nature Climate Change* 3 (November 11, 2012): 477, 35.

49 Sweet, W.V., et al. 2018. "Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold." NOAA Technical Report NOS CO-OPS 086

50 Ibid

51 Dr. Bradley Romine, personal communication, August 22, 2019.

52 Ibid

53 Keener et al. 2018. *Chapter 27 of the 4th National Climate Assessment*

54 IPCC (Intergovernmental Panel on Climate Change). 2007. "IPCC Fourth Assessment Report: Climate Change 2007: Impacts, Adaptation and Vulnerability." By IPCC Working Group II. New York, NY: Cambridge University Press. 7-22.

55 Ibid, 21.

56 IPCC (Intergovernmental Panel on Climate Change). 2001. "IPCC Third Assessment Report: Climate change 2001: Impacts, Adaptation and Vulnerability." By IPCC Working Group II. Cambridge, UK: Cambridge University Press, 995.

57 Ibid, 987.

58 IPCC (Intergovernmental Panel on Climate Change). 2014. "IPCC Fifth Assessment Report: Climate Change 2014: Impacts, Adaptation and Vulnerability Part B: Regional Aspects." By IPCC Working Group II. New York, NY: Cambridge University Press, 1772.

59 IPCC 2007. "Climate Change 2007: Impacts, Adaptation and Vulnerability.", 869.

60 IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland.

61 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. "Sea Level Rise Vulnerability and Adaptation Report." By Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064.

62 Susskind, Lawrence, Danya Rumore, Carri Hulet, and Patrick Field. 2015. *Managing Climate Risks in Coastal Communities*. Anthem Press. https://doi.org/10.2307/j.ctt1gxp7qz.

63 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report*.; Pacific Islands Ocean Observing System. 2018. "Sea Level Rise: Hawai'i Sea Level Rise Viewer." Accessed February, 2018. https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

64 Anderson, Tiffany R., Charles H. Fletcher, Matthew M. Barbee, Bradley M. Romine, Sam Lemmo, and Jade M.S. Delevaux. 2018. "Modeling Multiple Sea Level Rise Stresses Reveals up to Twice the Land at Risk Compared to Strictly Passive Flooding Methods." *Scientific Reports* 8, no. 1 (September): 14484. https://doi.org/10.1038/s41598-018-32658-x.

65 Cooper, Hannah M., Charles H. Fletcher, Qi Chen, and Matthew M. Barbee. 2013. "Sea-Level Rise Vulnerability Mapping for Adaptation Decisions Using LiDAR DEMs." Progress in Physical Geography: Earth and Environment 37, no. 6 (December): 745–66. doi:10.1177/0309133313496835.
66 Anderson et al. 2018. *Scientific Reports*.
67 Pacific Islands Ocean Observing System. 2018. "Sea Level Rise: Hawai'i Sea Level Rise Viewer." Accessed February, 2018. https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/
68 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report*.
69 Pacific Islands Ocean Observing System. 2018. "Sea Level Rise: Hawai'i Sea Level Rise Viewer." Accessed February, 2018. https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/
70 Kettle, Nathan P., Kirstin Dow, Seth Tuler, Thomas Webler, Jessica Whitehead, and Karly M Miller. 2014. "Integrating scientific and local knowledge to inform risk-based management approaches for climate adaptation" *Climate Risk Management* 4-5, 1 (2014): 17-31. doi: 10.1016/j.crm.2014.07.001
71 Tuler, Seth, Thomas Webler, Kristin Dow, Jessica Whitehead, and Nathan Kettle. 2013. "Diagramming Climate Change-Related Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS): A facilitation guide and tutorial." By Social and Environmental Research Institute, University of South Carolina, South Carolina Sea Grant Consortium, and Carolinas Integrated Sciences and Assessments.
72 Tuler, Seth. 2018. "Assessment of Adaptation, Policy, and Capacity Building Outcomes from Fourteen Community Vulnerability, Consequences, Adaptation Scenario (VCAPS) Processes." By Social and Environmental Research Institute.
73 Tuler, Seth, Thomas Webler, Kristin Dow, Jessica Whitehead, and Nathan Kettle. 2013. "Diagramming Climate Change-Related Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS): A facilitation guide and tutorial." By Social and Environmental Research Institute, University of South Carolina, South Carolina Sea Grant Consortium, and Carolinas Integrated Sciences and Assessments.
74 Barnett, Jon, Sonia Graham, Colette Mortreux, Ruth Fincher, Elissa Waters, and Anna Hurlimann. 2014 "A local coastal adaptation pathway." *Nature Climate Change* 4, no. 12: 1103.
75 Tuler, Seth. 2018. "Assessment of Adaptation, Policy, and Capacity Building Outcomes from Fourteen Community Vulnerability, Consequences, Adaptation Scenario (VCAPS) Processes." By Social and Environmental Research Institute, 4.
76 Susskind, Lawrence, Danya Rumore, Carri Hulet, and Patrick Field. 2015. *Managing Climate Risks in Coastal Communities*. Anthem Press. https://doi.org/10.2307/j.ctt1gxp7qz.
77 Tico, Teresa. "Miss South Pacific: Beauty and the Sea." 2011. Video, https://www.misssouthpacificthemovie.com/
78 These presentations were given by Dr. Daniele Spirandelli, Dr. Chip Fletcher, and Dr. Chuck Blay.
79 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*
80 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.
81 County of Kaua'i 2018. "Kaua'i Kakou Kaua'i County General Plan." 2018 Final Version Approved by the County Council.
82 U.S. Census Bureau 2010 Census Demographic Profile Data; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).
83 SMS Research and Marketing Services 2014. General Plan Socioeconomic Analysis and Forecasts. Prepared for the County of Kaua'i Department of Planning and Permitting.
84 U.S. Census Bureau; American Community Survey 2017 American Community Survey 5-Year Estimates; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).
85 U.S. Census Bureau 2010 Census Demographic Profile Data; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).
86 U.S. Census Bureau; American Community Survey 2017 American Community Survey 5-Year

Estimates; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).
87 C Peraro Consulting, LLC 2017. Hawai'i Statewide Point in Time Count
88 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*
89 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.
90 The 'All Remaining Buildings' column includes all other coastal buildings that are located within other zoning districts.
91 West Kaua'i Community Vulnerability Assessment (CVA) 2018-2019 Drainage, Transportation, Infrastructure, Agriculture, Cultural Resources, and Beaches/Coastal Properties Public Workshops
92 R.M. Towill Corporation 2015. General Plan Update Kaua'i Infrastructure Analysis.
93 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*
94 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.
95 Google maps
96 U.S. Census Bureau 2010 Census Demographic Profile Data; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).
97 U.S. Census 2010
98 U.S. Census Bureau 2000 Census Demographic Profile Data; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).
99 US Census 2010
100 American Community Survey 2013-2017 5 Year Estimates
101 ibid
102 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*
103 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.
104 The 'All Remaining Buildings' column includes all other coastal buildings that are located within other zoning districts. The 'Residential' column consists of the total number of exposed coastal buildings within lands zoned as 'Residential.' In the community of Pākalā, all exposed coastal buildings are located in the agricultural zoning district but are being used as residential homes; therefore, the exposed coastal buildings within this region were categorized in the 'Residential' column. The 'Commercial' column consists of the total number of exposed coastal buildings within lands zoned as 'Commercial'.
105 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*
106 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.
107 Google maps
108 U.S. Census Bureau 2010 Census Demographic Profile Data; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).
109 SMS Research and Marketing Services 2014. General Plan Socioeconomic Analysis and Forecasts. Prepared for the County of Kaua'i Department of Planning and Permitting.
110 US Census 2010
111 US Census 2010
112 U.S. Census Bureau; American Community Survey 2017 American Community Survey 5-Year Estimates; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).
113 C Peraro Consulting, LLC 2017. Hawai'i Statewide Point in Time Count
114 County of Kaua'i 2018. "Kaua'i Kakou Kaua'i County General Plan." 2018 Final Version Approved by the County Council.
115 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*
116 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.
117 The 'All Remaining Buildings' column includes all other coastal buildings that are located within other zoning districts.
118 Habel et al., 2017. Development of a model to simulate groundwater inundation induced by sea-level rise and high tides in Honolulu, Hawaii. Water Research, 114, pp.122–134.

119 West Kauaʻi Community Vulnerability Assessment 2018. Critical Infrastructure Workshop. November 26, 2018

120 Communication with Tiffany Anderson, UH Coastal Geology Group, May 2019.

121 Anderson, C.M. 1978. "Final Report – Coastal Residential Structures Life Time Determination, Federal Insurance Administration Department of Housing and Urban Development." P. 87 and Appendices

122 Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*

123 Hawaiʻi State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.

124 Google maps

125 County of Kauaʻi 2018. "Kauaʻi Kakou Kauaʻi County General Plan." 2018 Final Version Approved by the County Council.

126 U.S. Census Bureau 2010 Census Demographic Profile Data; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).

127 U.S. Census Bureau 2000 Census Demographic Profile Data; generated by Daniele Spirandelli; using American FactFinder; <http://factfinder.census.gov> (June 26 2019).

128 US Census 2010

129 County of Kauaʻi 2018. "Kauaʻi Kakou Kauaʻi County General Plan." 2018 Final Version Approved by the County Council.

130 Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*

131 Hawaiʻi State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.

132 The 'All Remaining Buildings' column includes all other coastal buildings that are located within other zoning districts.

133 Department of Health, 2016. Hawaii Administrative Rules, Title 11. Department of Health, Chapter 62, "Wastewater Systems."

134 Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2017. HI SLR Report.

135 Hawaiʻi State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.

136 Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*

137 Hawaiʻi State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.

138 Google maps

139 See Section F Cultural Resources.

140 See Chapter IV. Section D. Kekaha for details on housing and demographics.

141 Kauaʻi General Plan, 2018.

142 Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2017. Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawaiʻi Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawaiʻi Department of Land and Natural Resources Contract No: 64064.

143 For the Mānā-Polihale community inventory, the 'Military' column includes all buildings that are located in the conservation zoning district but are being utilized for military purposes. The remaining exposed coastal buildings within the Mānā-Polihale region were located in the Agriculture district and accounted for in the 'Agriculture' column.

144 See Chapter IV Section D. Kekaha Vulnerabilities for more details.

145 See Chapter V Section F Agricultural vulnerabilities.

146 See Chapter V Section F Cultural Resources.

147 Chapter V Section E Agriculture.

148 Chapter V Section F Cultural Resources.

149 Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2017. Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawaiʻi Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawaiʻi Department of Land and Natural Resources Contract No: 64064.

150 Hawaiʻi State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.

151 Anderson, T.R., C.H. Fletcher, M.M. Barbee, B.R. Romine, S. Lemmo, and J.M.S. Delevaux. Modeling multiple sea level rise stresses reveals up to twice the land at risk of flooding compared to strictly passive flooding methods, *Nature Scientific Reports*, 8:14484, doi:10.1038/s41598-018-32658-x
152 ibid
153 Workshop participant, 10/10/18
154 However, on the positive side, it was pointed out that the west side is less isolated than places like the north shore - there are major stores, police, fire, and hospital services already located on the west side.
155 Email communication with Dr. Tiffany Anderson, UH Coastal Geology Group, 10/2/19.
156 R.M. Towill Corporation. 2015. "General Plan Update Kaua'i Infrastructure Analysis."
157 Interview with community member, March 2018.
158 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. Hawai'i Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064.
159 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.
160 https://www.fema.gov/special-flood-hazard-area.
161 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. Hawai'i Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064.
162 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/
163 Habel, Shellie, Charles H. Fletcher, Kolja Rotzoll, and Aly I. El-Kadi. 2017. "Development of a Model to Simulate Groundwater Inundation Induced by Sea-Level Rise and High Tides in Honolulu, Hawaii." *Water Research* 114 (May): 122–34. https://doi.org/10.1016/j.watres.2017.02.035.
164 Wittenberg, H., and H. Aksoy. 2010. "Groundwater Intrusion into Leaky Sewer Systems." *Water Science and Technology* 62 (1): 92–98. https://doi.org/10.2166/wst.2010.287.
165 EPA, https://www.epa.gov/waterutilityresponse/develop-or-update-drinking-water-utility-emergency-response-plan
166 KIUC. 2017. "KIUC Annual Report, In the Spotlight." Accessed on-line June 12, 2019.
167 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. Hawai'i Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064
168 Kaua'i Island Utility Cooperative. 2019
169 Kim, Karl E., Pradip Pant, and Eric Y. Yamashita. 2015. "Disasters, Drones, and Crowd-Sourced Damage Assessment." In *Computers in Urban Planning and Urban Management Conference*. Cambridge, Mass.
170 Kauai Department of Water. 2001. "WaterPlan 2020." http://www.kauaiwater.org/ce_waterplan2020app.asp.
171 Kauai Department of Water. 2001. "WaterPlan 2020." http://www.kauaiwater.org/ce_waterplan2020app.asp.
172 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. Hawai'i Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064
173 Kaua'i County Department of Water. 2019
174 https://www.epa.gov/water-research/onsite-non-potable-water-reuse-research
175 Anderson, Tiffany R., Charles H. Fletcher, Matthew M. Barbee, L. Neil Frazer, and Bradley M. Romine. 2015. "Doubling of Coastal Erosion under Rising Sea Level by Mid-Century in Hawaii." *Natural Hazards* 78 (1): 75–103. https://doi.org/10.1007/s11069-015-1698-6.

176 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. Hawai'i Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064.
177 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.
178 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017
179 Summers, Alisha, Charles H. Fletcher, Daniele Spirandelli, Kristian McDonald, Jin-Si Over, Tiffany Anderson, Matthew Barbee, and Bradley M. Romine. 2018. "Failure to Protect Beaches under Slowly Rising Sea Level." *Climatic Change* 151 (3): 427–43. https://doi.org/10.1007/s10584-018-2327-7.
180 Blay, Charles T. 2016. "West Kaua'i PMRF/Kekaha Mānā Coastal Plain Beach System Monitoring and Modeling." TEOK Investigations.
181 Sweet, W.V., R.E. Kopp, R.E. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas. 2017. Global and Regional SLR Scenarios for the United States. Silver Spring, MD: NOAA Technical Report NOS CO-OPS 083.
182 Dobes, L. and B. Chapman. 2011. "Financing adaptation to climate-induced retreat from coastal inundation and erosion." CCEP Working Paper 1113, Centre for Climate Economics & Policy, Crawford School of Economics and Government, The Australian National University, Canberra.
183 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. Hawai'i Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawai'i Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai'i Department of Land and Natural Resources Contract No: 64064.
184 Hawaii Office of Planning. GIS Portal. http://planning.hawaii.gov/gis, Accessed on-line February 15, 2018.
185 Workshop participant, February 25, 2019.
186 Policy 11 of the Kaua'i General Plan (2018) states, "Support economic diversification and access to locally produced food by increasing the productivity and profitability of all forms of agriculture. Nurture small-scale farms, promote crop diversity, and form stronger public/private partnerships with farmers."
187 Schoubroeck, Frank van. 2010. "The Remarkable History of Polder Systems in The Netherlands." White Paper. Rome: FAO. http://www.fao.org/fileadmin/templates/giahs/PDF/Dutch-Polder-System_2010.pdf. Accessed June 26, 2019.
188 County of Kaua'i 2018. "Kaua'i Kakou Kaua'i County General Plan." 2018 Final Version Approved by the County Council.
189 Hawai'i Climate Change Mitigation and Adaptation Commission. 2017. *HI SLR Report.*
190 Hawai'i State Office of Planning. 2019. GIS Portal http://planning.hawaii.gov/gis/.
191 1.1 ft. exposure: Hanapepe Salt Pond, Cook Landing Site
3.2 ft. exposure: Hanapepe Salt Pond, Cook Landing Site, Yamase building, Bishop National Bank of Hawaii
192 Potential hindrances to out planting is that this process takes a great deal of time, for example removing the invasive kiawe, which keeps the dunes lower and crowds out native plants.
193 The project team consulted directly with the modelers from UH Coastal Geology Group (UHCGG) on this question. UHCGG clarified that the digital elevation model (DEM) used to estimate exposure did not have river bathymetry data, and the elevations of rivers was simply estimated as negative to the surrounding land elevations.
194 Handy, E.S. Craighill and Elizabeth G. Handy. 1972. Native Planters in Old Hawaii: Their Life, Lore, and Environment. Bishop Museum Bulletin 233. Bishop Museum Press, Honolulu.
195 Pukui, Mary Kawena 1983. 'Ōlelo No'eau: Hawaiian Proverbs and Poetical Sayings. Bishop

Museum Special Publication No.71. Bishop Museum Press, Honolulu
196 McDermott, M., S. Mahanty & K. Schreckenberg. 2013. Examining equity: a multidimensional framework for assessing equity in payments for ecosystem services. Environ. Sci. Policy 33: 416–427.
197 Foster, S., R. Leichenko, K. H. Nguyen, R. Blake, H. Kunreuther, M. Madajewicz, E. P. Petkova et al. "New York City Panel on Climate Change 2019 Report Chapter 6: Community-Based Assessments of Adaptation and Equity." Ann. NY Acad. Sci 40 (2019): 1-48.
198 County of Kaua'i. 2018. *General Plan.*
199 Courtney, C.A; Gelino, K; Romine, B.M.; Hintzen, K.D.; Addonizio-Bianco, C.; Owens, T.M.; Lander, M.; and Buika, J. 2019. Guidance for Disaster Recovery Preparedness in Hawai'i. Prepared by Tetra Tech, Inc. for the University of Hawai'i Sea Grant College Program and State of Hawai'i Department of Land and Natural Resources and Office of Planning, with funding from National
Oceanic and Atmospheric Administration Office for Coastal Management award no. NA16NOS4730016