Hawai´i Climate Change Mitigation & Adaptation
Pili Na Mea A Pau

Hawai´i Sea Level Rise Vulnerability and Adaptation Report

State of Hawaii 1959

Department of Land and Natural Resources State of Hawaii

State of Hawaii, Office of Planning

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Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report

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DISCLAIMER. *This report is a tool to estimate the scale and cost of potential flooding and erosion with sea level rise. The exact location of flooding and economic costs from damages are estimates. Flood maps are in the range of 80 percent probability. Damage estimate costs are conservative. The data, maps, and recommendations provided should be used only as a screening-level resource to support management decisions to address sea level rise. As with all remotely sensed data, all features should be verified with a site visit. The risk associated with use of the results is assumed by the user. This report should be used strictly as a planning reference tool and not for permitting, or other legal purposes.*

Acknowledgements

The Hawaiʻi Climate Change Mitigation and Adaptation Commission (Hawaiʻi Climate Commission) wishes to express its sincere appreciation to the many individuals from state, county, and federal agencies, nongovernmental organizations, private sector, universities, and the public for assisting in the development of this Report. This Report has been made possible through a broad collaboration between diverse stakeholders, including our State Legislature and Governors Ige and Abercrombie. This report was prepared by Tetra Tech, Inc. and the State of Hawaiʻi Department of Land and Natural Resources (DLNR), Office of Conservation and Coastal Lands (OCCL), under DNLR Contract No: 64064.

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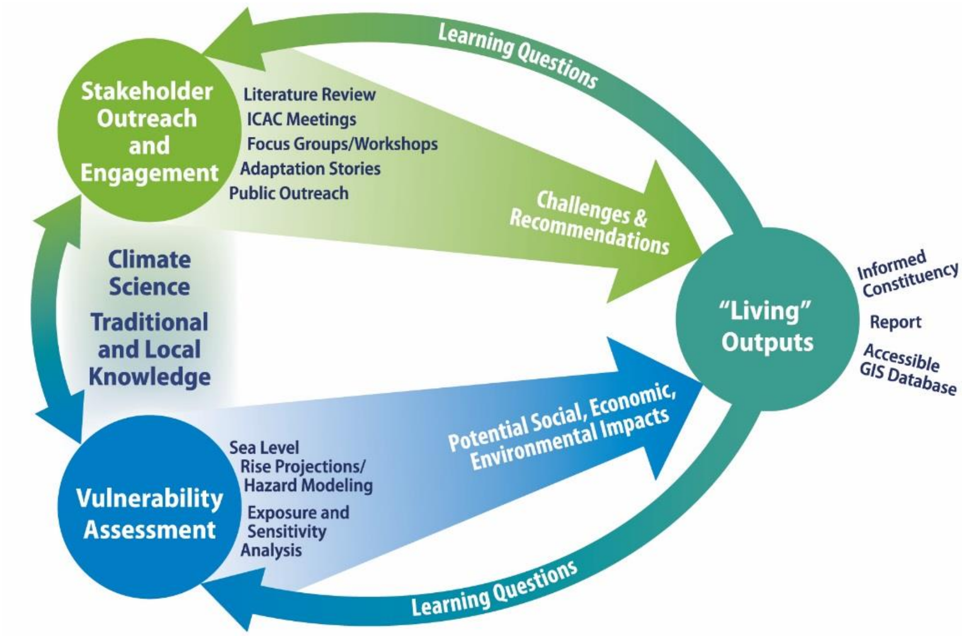
Queen's Beach, Waikīkī, O'ahu
Source: Hawai'i Sea Grant College Program, King Tide's Project

Executive Summary

Shorelines are one of our planet’s most dynamic physical features and Hawaii’s are no exception. Communities along our shores have flourished for centuries in harmony with the ebb and flow of the tides, punctuated by the occasional devastating hurricane or tsunami event. However, rapid warming of the atmosphere and oceans, caused by two centuries of unabated carbon emissions, is causing increasing rates of sea level rise, unprecedented in human history, that threatens natural environments and development on low-lying coasts.

Sea level rise is an inevitable outcome of global warming that will continue through many centuries even if human-generated global greenhouse gas (GHG) emissions were stopped today. However, much of what happens with future sea level rise will depend on our ability, or inability, to implement aggressive global carbon emissions reduction programs envisioned through the 2016 Paris Climate Accord.

This Sea Level Rise Vulnerability and Adaptation Report (Report), initially mandated by Act 83 in 2014 (Hawaii Climate Change Adaptation Initiative) and expanded by Act 32 in 2017 (Hawai‘i Climate Change Mitigation and Adaptation Initiative), provides the first state-wide assessment of Hawaii’s vulnerability to sea level rise and recommendations to reduce our exposure and sensitivity to sea level rise and increase our capacity to adapt. This Report combines the best available science on climate change and sea level rise from sources such as the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (IPCC 2014), more recent scientific reports from the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA), as well as the best-available peer-reviewed scientific research articles. The Report also provides recommendations based on emerging good practices and framed through extensive stakeholder consultations. The Report is considered a "living" output that will be updated as new information becomes available. The update process will be guided by learning questions crafted around the assumptions and limitations that need to be revisited over time as climate science evolves and new challenges appear on the horizon. While the Report focuses on sea level rise vulnerabilities and adaptation, it should also strengthen our State's resolve to do our part in reducing GHG emissions in line with Act 32 and the Paris Climate Accord. In addition, this report is intended to serve as a framework for identifying and managing other climate change threats facing Hawai'i.

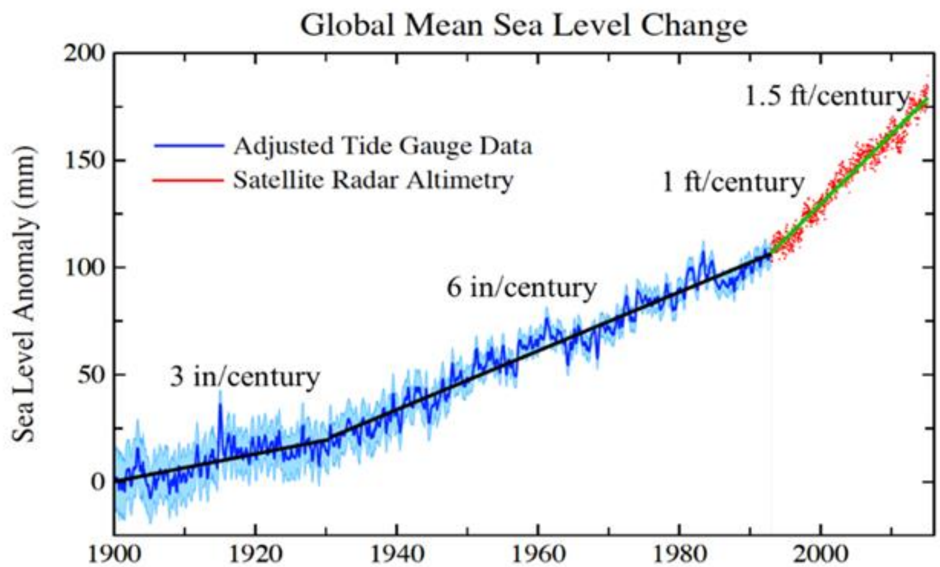


Hawai'i Climate Adaptation Initiative Framework Applied to Sea Level Rise

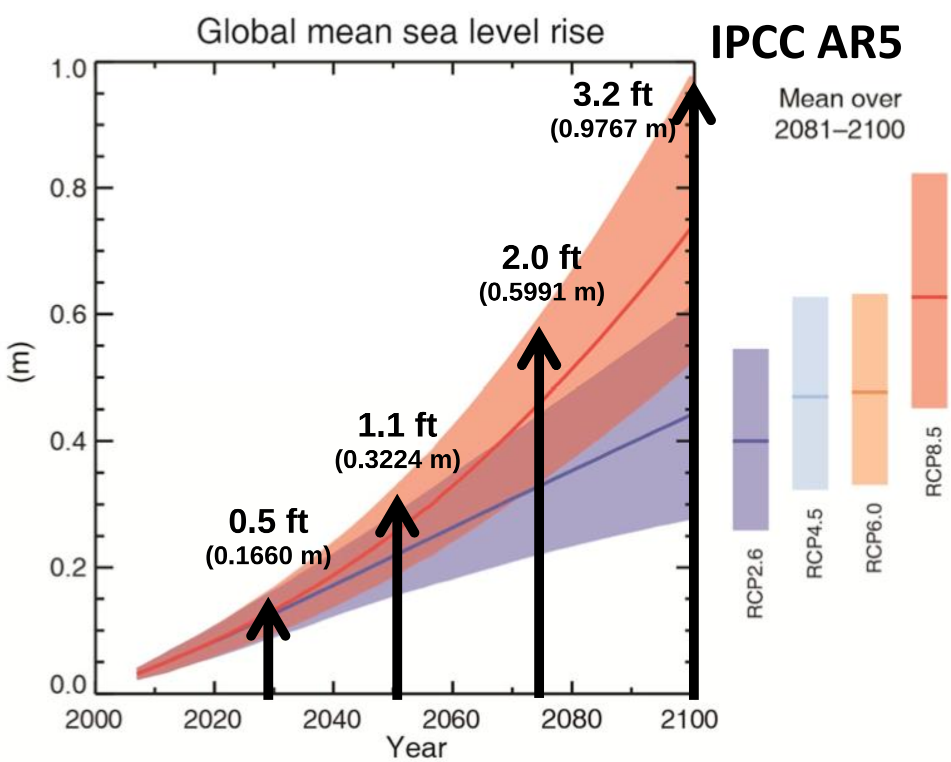
Sea Level Rise Outlook

While the Earth's climate experiences natural change and variability over geologic time, the changes that have occurred over the last century due to human input of GHGs into the atmosphere are unprecedented. The rapid build-up of GHGs, including carbon dioxide, methane, nitrous oxide, and fluorinated gases, from humans, is causing global warming and climate disruption. The concentration of carbon dioxide in the atmosphere is well outside the range of natural variability and is now approaching 410 parts per million (Scripps Institution of Oceanography 2015); about 40 percent (%) higher than pre-industrial levels and the highest in at least 800,000 years and probably as long as 3 million years.

Sea level is rising at increasing rates due to global warming of the atmosphere and oceans and melting of the glaciers and ice sheets. Rising sea level and projections of stronger and more frequent El Niño events and tropical cyclones in waters surrounding Hawai'i all indicate a growing vulnerability to coastal flooding and erosion. While the IPCC's "business as usual" scenario, where GHG emissions continue at the current rate of increase, predicts up to 3.2 feet of global sea level rise by year 2100 (IPCC 2014), recent observations and projections suggest that this magnitude of sea level rise could occur as early as year 2060 under more recently published highest-end scenarios (Sweet et al. 2017). As such, questions remain around the exact timing of that rise due largely to uncertainties around future behavior of Earth's cryosphere and global GHG emission trajectories. For this reason, it is vital that the magnitude and rate of sea level rise is tracked as new projections emerge, plan for 3.2 feet of sea level rise now, and be ready to adjust that projection upward. It is also important to recognize that global sea level rise will not stop at the year 2100, but will likely continue on for centuries.



Observed global mean sea level rise over the last century (Church and White 2011, Nerem et al. 2010, Yi et al. 2015, Hay et al. 2015, Hansen et al. 2016, Watson et al. 2015, Fasullo, Nerem, and Hamlington 2016)



Projected rate of global sea level rise under different GHG scenarios (IPCC 2014)

Methodology

Modeling, using the best available data and methods, was conducted to determine the potential future exposure of each island to multiple coastal hazards as a result of sea level rise. Three chronic flooding hazards were modeled: passive "bathtub" flooding, annual high wave flooding, and coastal erosion. The footprints of these three hazards were combined to define the projected extent of chronic flooding due to sea level rise, called the sea level rise exposure area (SLR-XA). Not all hazards were modeled for each island due to limited historical information and geospatial data. Each of these hazards were modeled for four future sea level rise scenarios: 0.5 feet, 1.1 feet, 2.0 feet and 3.2 feet based on the upper end of the IPCC, Assessment Report 5, representative concentration pathway 8.5, or "business as usual" sea level rise scenario.

Coverage of Hazard Modeling by Island			
	Sea Level Rise Exposure Area *(SLR-XA; Chronic Flooding with Sea Level Rise)*		
Island	*Passive Flooding*	*Annual High Wave Flooding*	*Coastal Erosion*
Kaua'i	√	√	√
O'ahu	√	√	√
Maui	√	√	√
Moloka'i	√	–	–
Lāna'i	√	–	–
Hawai'i	√	–	–

Using the outputs of this coastal hazard modeling, vulnerability was assessed for the main Hawaiian Islands. Vulnerability is the result of exposure to a hazard, sensitivity or susceptibility to harm, and lack of capacity to cope and adapt. A vulnerability assessment estimates the potential social, cultural, economic, and environmental impacts of this exposure and provides important information needed to design appropriate strategies and use the right tools to adapt to sea level rise. This assessment determined the vulnerability of valued assets such as land, homes, beaches, cultural sites, roads, and other critical infrastructure to sea level rise.

Results Overview

Vulnerability is assessed in terms of potential impacts to land use, people, property, cultural and natural resources, and critical infrastructure. As the only U.S. state that is an island, Hawai'i is highly vulnerable to the effects of sea level rise. Vulnerability to sea level rise is based on modeling chronic coastal flooding with sea level rise due to passive flooding, annual high wave flooding, and coastal erosion in the SLR-XA.

Although this Report provides a range of sea level rise projections and vulnerability scenarios, the SLR-XA with 3.2 feet of sea level rise was chosen to depict hazards that may occur in the mid to latter half of this century. Vulnerability to 1.1 feet of sea level rise in the SLR-XA is used to approximate current or near-term exposure to coastal hazards and sea level rise. All sea level rise results from both the hazard modeling and vulnerability assessment are available to view on the Hawai‘i Sea Level Rise Viewer (http://hawaiisealevelriseviewer.org/).

Summary of Key Terms, Assumptions, and Limitations in the Methodology Used to Assess Vulnerability in the Sea Level Rise Exposure Area (SLR-XA)

This summary is intended to help the reader become familiar with key terms, assumptions, and limitations in the modeling and vulnerability assessment methodology.

- The SLR-XA depicts the area exposed to potential chronic flooding and land loss based on modeling passive flooding, annual high wave flooding, and coastal erosion with sea level rise for the islands of Maui, O‘ahu, and Kaua‘i. The SLR-XA for the islands of Hawai‘i, Molokai, and Lāna‘i is based on modeling passive flooding only.
- Flooding in the SLR-XA is associated with long-term, chronic hazards punctuated by annual or more frequent flooding events. Over time, recurring flooding at the highest tides in low-lying areas leads to chronic flooding and then to permanent flooding, and permanent loss.
- Vulnerability in the SLR-XA is characterized as potential impacts to land use, people and property, critical infrastructure, Native Hawaiian communities, cultural resources, and coastal resources, including beaches.

Key assumptions and limitations of the vulnerability assessment include:

- Potential economic loss is based on present values of the land and structures from the county tax parcel database permanently lost in the SLR-XA.
- Economic (monetary) losses due to sea level rise on critical infrastructure (such as roads, airports, harbors, water, sewer and power, etc.) has not been considered, but many such structures or facilities that are located in the SLR-XA have been identified in this Report.
- A more detailed economic loss analysis of Oahu’s critical infrastructure, including harbor facilities, airport facilities, sewage treatment plants, and roads is needed. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.
- Macro-economic impacts (such as on tourism or the real estate market) resulting from potential chronic flooding over time caused by sea level rise are not analyzed.

Potential Impacts in the Sea Level Rise Exposure Area (SLR-XA)

Chronic flooding in the SLR-XA with 3.2 feet of sea level rise would render over 25,800 acres of land in the State unusable. Some of that land will have eroded into the ocean, some will become submerged by inches or feet of standing water, and some areas will be dry most of the year, but repeatedly washed over by seasonal high waves. State-wide, about 34% of that potentially lost land is designated for urban use, 25% is designated for agricultural use, and 40% is designated for conservation. The loss of urban land could put pressure on development of inland areas, including those designated as agricultural and conservation lands.

Across the state, over 6,500 structures located near the shoreline would be compromised or lost in the SLR-XA with 3.2 feet of sea level rise. Some of these vulnerable structures include hotels, shopping malls, and small businesses. The loss of these structures may result in the interruption, relocation, or even closure of those businesses. Other types of structures which may be impacted are churches, schools, and community centers. In addition, houses and apartment buildings are also vulnerable and the loss of these structures would result in over 20,000 displaced residents in need of new homes. The value of projected flooded structures, combined with the land value of the 25,800 acres projected to be flooded, amounts to over $19 billion across the State. Hotspots for potential economic loss across the State are centered in urban areas with the greatest potential loss in Honolulu on the Island of Oʻahu, with 66% of the total state-wide economic loss, due to the density and economic assets potentially exposed to sea level rise. As a result, the impacts of sea level rise on Oʻahu could generate substantial social, infrastructure, and economic impacts with ripple effects throughout the State.

It should be noted that the $19 billion in economic loss does not encompass the full loss potential in the State. Monetary losses that will occur from the chronic flooding of roads, utilities and other public infrastructure were not analyzed in this report and may amount to an order of magnitude greater than the potential economic losses from land and structures. For example, over 38 miles of major roads would be chronically flooded across the State with 3.2 feet of sea level rise, ranging from residential roads to sections of coastal highways such as Kūhiō Highway on Kauaʻi, Kamehameha Highway on Oʻahu, and Honoapiʻilani Highway on Maui. Utilities, such as water, wastewater and electrical systems often run parallel and underneath roadways, making lost road mileage a good indication of the extent of lost utilities. This chronically flooded infrastructure would have significant impacts on local communities as well as reverberating effects around each island through loss of commerce, loss of access to emergency services, and increased traffic on other roads and highways. Repair and relocation of vulnerable roadways are already costly efforts for the State and Counties, which will only worsen as sea level rises. In addition, many of our harbor and airport facilities are often located in low-lying coastal areas of the State and face the problem of chronic flooding. For this reason, the economic loss due to flooded critical infrastructure may be an order of magnitude greater than the potential economic loss from land and structures.

Summary of potential impacts in the SLR-XA with 3.2 feet of sea level rise (chronic flooding) in Hawai'i

The loss of invaluable natural and cultural resources across all islands is even harder to quantify, yet their loss would cost the State dearly due to their intrinsic value. Beaches that provide for recreation, wildlife habitat, and cultural tradition will erode, from iconic sites such as Sunset Beach on Oʻahu to neighborhood beach access points rarely visited by anyone except local residents. Some beaches could be lost entirely if their landward migration is blocked by roads, structures, shoreline armoring, or geology. The flooding of the over 2,000 on-site sewage disposal systems located in the SLR-XA with 3.2 feet of sea level rise could result in diminished water quality. The loss of and harm to native species and entire ecosystems will have implications for Hawaiian cultural traditions and practices, which are closely tied to the natural environment. Further, nearly 550 cultural sites in the State would be flooded and many Hawaiian Home Lands communities would be impacted by flooding. In some cases, these natural and cultural resources could be allowed to migrate inland or carefully relocated. In other cases, the resources are inextricably bound to place and would be permanently altered by flooding.

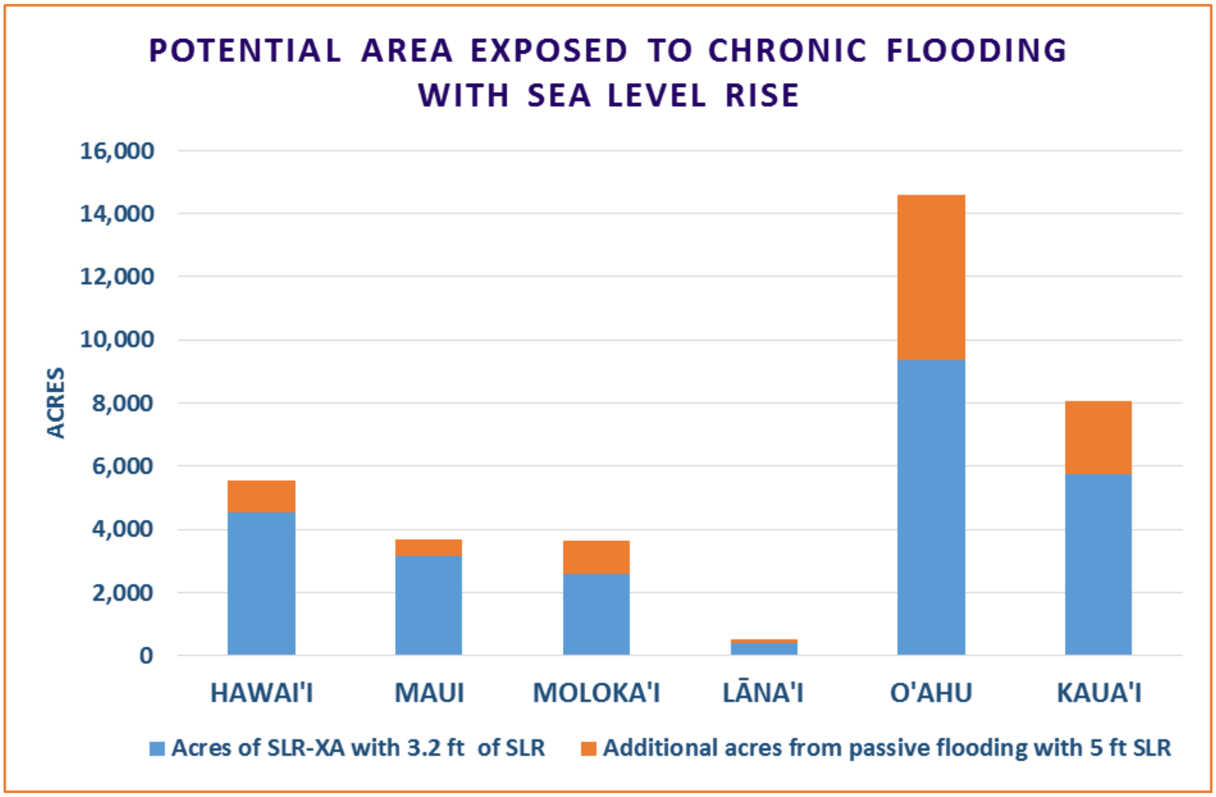
Opportunities and Challenges

Over the next 30 to 70 years, as sea level rises, homes and businesses located on or near the shoreline throughout the State will become exposed to chronic flooding. Portions of coastal roads may become flooded, eroded, impassible, and potentially irreparable, jeopardizing access to and from many communities. The flooding of hotels and transportation systems would impact the visitor economy and thus impact the people whose livelihoods depend on tourism. The impact of sea level rise on Oʻahu is greater than all of the other islands combined due to the size of the population and extensive urbanization of vulnerable coastal areas. Even more troubling is the fact that impacts from chronic flooding with sea level rise on Oʻahu can reverberate and translate into economic and social impacts for the other islands.

The added risk of coastal flooding from hurricanes and tropical cyclones from a warming planet poses a potential for loss of human life and property and for severe and long-term economic disruption. Tropical storms, hurricanes, and tsunamis create waves that flood low-lying coastal areas. This added risk from this "event-based" coastal flooding exacerbated by sea level rise is not included in this Report. It is important though that the reader understands that event-based coastal flooding with sea level rise would alter the extent of the area subject to flooding from such events.

The results of the vulnerability assessment highlight just a few of the very significant challenges the State faces under a scenario of 3.2 feet of sea level rise by the mid- to latter-part of the century. However, this may not be the worst of it. According to recent climate science, sea level rise greater than 6 feet is "physically plausible" by the end of the century (Le Bars, Drijfhout, and de Vries 2017, Sweet et al. 2017). While not modeled in this Report, additional feet of sea level rise would add thousands of acres to the SLR-XA on each island (Figure 2). A geographic information system (GIS) analysis using layers from the NOAA Sea Level Rise Viewer (NOAA 2017b), which only accounts for passive flooding, indicates that an additional 10,000 acres state-wide would be added to the SLR-XA with 5 feet of sea level rise. This would increase the total area exposed to chronic flooding State-wide to over 36,000 acres and the economic, environmental, cultural and societal impacts of which would be far greater than the results presented in this

Report. Each island's exposure to passive flooding with 5 feet of sea level varies due to its geomorphology with O'ahu having the highest additional exposure (36%) and Maui, the lowest additional exposure (15%) in terms of additional acres passively flooded with 5 feet of sea level rise.



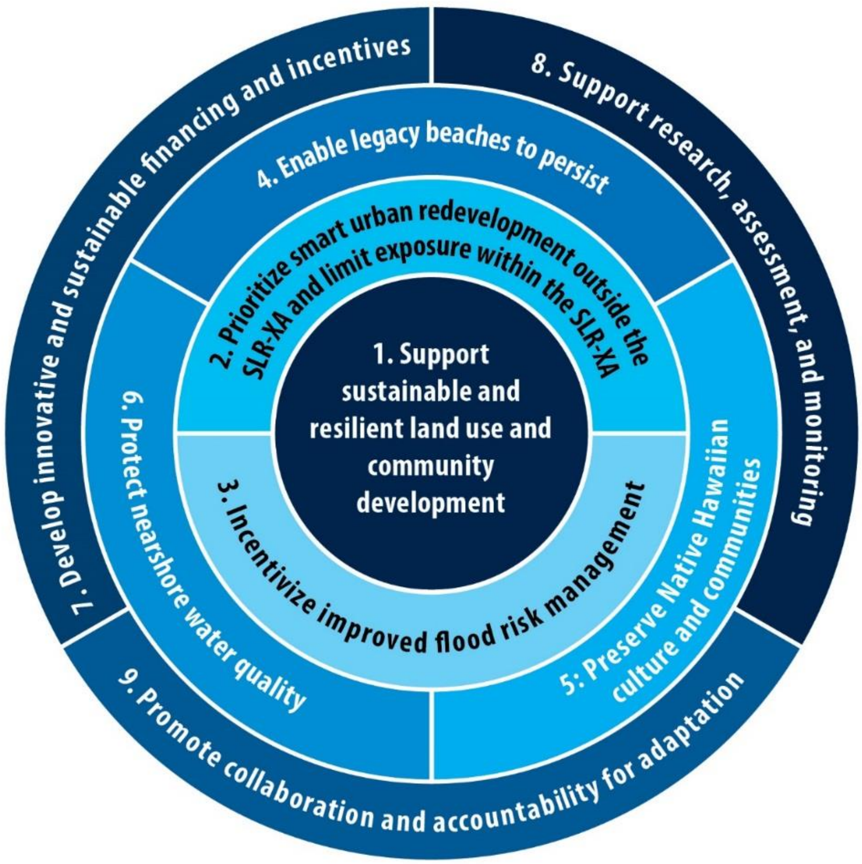
Potential additional area of chronic flooding with 5 feet of sea level rise

The threat of 3 feet or more of sea level rise in this century is real and is not likely to diminish given the overall trend in scientific research toward higher and more rapid scenarios of sea level rise in this century. This state-wide vulnerability assessment provides a framework for considering sea level rise threats in planning decisions by illustrating spatial flooding in this century and providing a framework for adaption. Invariably, adaption to sea level rise will require difficult decisions regarding when, where, and how to act on this information.

Recommendations

Recommendations were developed to provide guidance for State and County agencies, communities, and other stakeholders for improving our capacity to adapt to sea level rise. These recommendations were compiled through a comprehensive literature review; interviews, workshops, and meetings with a wide range of stakeholders; and quarterly consultations with the Hawai'i Climate Commission. The recommendations are designed to support a multi-sectoral and holistic response to adaptation building on existing efforts and considering challenges and new opportunities.

Recommendation 1, support sustainable and resilient land use and community development, focuses on the central role that land use and community development planning play in adapting to sea level rise. A Recommended Action under Recommendation 1 is to recognize the SLR-XA with 3.2 feet of sea level rise as a state-wide vulnerability zone for planning at state, county, and community levels. It is further recommended that a land inventory be conducted in each county to identify urban areas that could support a managed retreat strategy.



Recommendations to improve Hawaii's capacity to adapt to sea level rise

Recommendations 2 and 3 support Recommendation 1, through prioritizing smart redevelopment in areas outside the SLR-XA, limiting exposure inside the SLR-XA, and incentivizing improved flood risk management. In prioritizing smart redevelopment in areas outside the SLR-XA, under Recommendation 2, each county is encouraged to identify priority target areas for smart redevelopment. The State should consider developing design standards as best management practices for building in the SLR-XA with 3.2 feet of sea level rise. Also under Recommendation 2, the potential impacts of sea level rise provide new opportunities to use land more sustainably by identifying and prioritizing areas for smart redevelopment within existing urban land boundaries and to minimize pressure on agriculture and conservation lands. Further, the identification of shoreline protection, conservation, and restoration priorities are needed to make decisions on shoreline armoring. Finally, Recommendation 3 seeks to incentivize improved flood risk management through support to a state-wide Community Rating System program, encouraging property owners outside currently regulated flood zones to purchase flood insurance, and incorporate sea level rise in hazard mitigation plan updates and disaster recovery frameworks.

Recommendations 4, 5, and 6 address cultural and environmental vulnerabilities that underpin resilient and sustainable land use and community development. A state-wide assessment of legacy beach conservation priorities is suggested as a Recommended Action under Recommendation 4 for enabling beaches to persist with sea level rise. An inventory, protocols, and process are needed to preserve Native Hawaiian culture and communities with sea level rise as part of Recommendation 5. For Recommendation 6, a comprehensive review of environmental regulations that allow for the siting of environmental hazards, such as hazardous materials/waste storage facilities and onsite wastewater storage systems is needed to protect nearshore water quality with rising seas.

Finally, cross-cutting recommendations include developing funding sources and incentives for adaptation (Recommendation 7), supporting research, assessment, and monitoring of changing conditions (Recommendation 8), and promoting collaboration and accountability for adaptation (Recommendation 9). These cross-cutting recommendations highlight the need to engage diverse stakeholders in making complex decisions about addressing the impacts of sea level rise. Recommendation 7 highlights the very real need to address the cost of adaptation by exploring both funding sources and incentives while Recommendation 8 is fundamental to a learning approach to adaptation which involves conducting research, assessments, and monitoring needed to update the Report and other “living” outputs.

This Report should serve as a baseline for understanding the most probable impacts of sea level rise and should be used to as a tool by the decision makers of the State, the Counties, and community leaders. Recommendations to increase our capacity to adapt to sea level rise are described, but do not lay out a plan for implementation. The Hawai‘i Climate Commission provides a collaborative multisectoral forum for furthering discussions on how, when, and where to implement many of these recommendations. Some recommendations were identified through stakeholder consultations as priorities to be fast-tracked for discussion and action. In addition, sequencing considerations and synergies among the recommendations need to be recognized and planned for. Overall, we have enough information now to take action to address the inevitable near and medium-term rise of sea level.

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Sea Level Rise Vulnerability and Adaptation Report

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Acronyms and Abbreviations

°	Degrees
%	Percent
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
Act 32	Hawaiʻi Climate Mitigation and Adaptation Initiative, 2017
Act 83	Hawaiʻi Climate Adaptation Initiative Act, 2014
AR5	5th Assessment Report (of the IPCC), 2014
BCEGS	Building Code Effectiveness Grading Schedule
BMP	Best management practices
CCD	U.S. Census Bureau for Census County Division
CDBG-DR	Community Development Block Grant for Disaster Recovery
CRS	Community Rating System
CSSR	Climate Science Special Report
CZM	Coastal Zone Management
DEM	Digital elevation model
DHHL	Department of Hawaiian Home Lands
DLNR	Hawaiʻi Department of Land and Natural Resources
DOT	Department of Transportation
DPP	City & County of Honolulu Department of Planning and Permitting
ENSO	El Niño Southern Oscillation
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Maps
FMA	Flood Mitigation Assistance
GEV	Generalized extreme value
GHG	Greenhouse gases
GIS	Geographic information system
Hawaiʻi Climate Commission	Hawaiʻi Climate Change Mitigation and Adaptation Commission
Hazus	Hazards-U.S.
HMGP	Hazard Mitigation Grant Program
HRS	Hawaiʻi Revised Statutes
ICAC	Interagency Climate Adaptation Committee
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
KHM	Ka Honua Momona
KIRC	Kahoʻolawe Island Reserve Commission
LiDAR	Light detection and ranging
LiMWA	Limit of moderate wave action
LUC	Hawaiʻi State Land Use Commission

MHHW	Mean higher high water
MMPA	Marine Mammal Protection Act
NASA	National Aeronautics and Space Administration
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NWHI	Northwestern Hawaiian Islands
NYC	New York City
OCCL	Office of Conservation and Coastal Lands
OEQC	Office of Environmental Quality Control
OHA	State of Hawai‘i Office of Hawaiian Affairs
Office of Planning	State of Hawai‘i Office of Planning
ORMP	Hawai‘i Ocean Resources Management Plan
OSDS	On-site sewage disposal system
PacIOOS	Pacific Islands Ocean Observing System
PDO	Pacific Decadal Oscillation
PDM	Pre-Disaster Mitigation Grant Program
PDR	Purchase of development rights
PICCC	Pacific Islands Climate Change Cooperative
PMNM	Papahānaumokuākea Marine National Monument
RCP	Representative concentration pathway
Report	Sea Level Rise Vulnerability and Adaptation Report
RMSE 95%	Root mean square error at the 95% confidence interval
SCR	Senate Concurrent Resolution
SFHA	Special flood hazard area
SHPD	State of Hawai‘i Historic Preservation Division
SLH	Session Laws of Hawai‘i
SLR-XA	Sea level rise exposure area
SMA	Special Management Area
SWAN	Simulated WAves Nearshore
TAT	Transient Accommodations Tax
TDR	Transfer of development rights
Tetra Tech	Tetra Tech, Inc.
TOD	Transit-oriented development
UH SOEST	University of Hawai‘i School of Ocean, Earth Science and Technology
UNESCO site	United Nations Educational, Scientific, and Cultural Organizations site
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
UST	Underground storage tank

Introduction

ʻAʻohe puʻu kiʻekiʻe ke hoʻāʻo ʻia e piʻi. No cliff is so tall that it cannot be scaled. No problem is too great when one tries hard to solve it.

There is an ʻōlelo noʻeau, a Hawaiian proverb, that speaks of humans' relationship to the ʻāina, the land. He aliʻi ka ʻāina; he kauwā ke kanaka. "The land is chief; man is its servant." According to Hawaiian historian Mary Kawena Pukuʻi (Pukui 1983), "Land has no need for man, but man needs the land and works for its livelihood." To Hawaiians, land provides everything that is needed for man to survive. It is our responsibility to care for the land so that it continues to provide the necessary resources for survival such as food, water, and shelter. However, if we neglect the āina, then the āina will neglect us.

Call to Action

"We are all at-risk due to the limited sense of urgency to address sea level rise. We need a broad-based, multi-faceted education, talk story at all levels to ensure people know the issues, their risks and how to respond accordingly. A call to kuleana, E Ala E, a prepared community, Pili na mea apau."

Group message developed during the 1st Sea Level Rise Vulnerability and Adaptation Workshop
Oʻahu, January 2016

We are now facing the consequences of what happens when we neglect the āina on a global scale. Global anthropogenic impacts on the climate have potentially done irreparable harm to ecosystems around the world and now the earth is responding, showing us who truly is the chief. While natural disasters are not new to Hawaiʻi, their intensity and frequency have increased and will continue to increase. We have already begun to experience the effects of a rising sea inundating areas across the islands. The solutions to our forthcoming challenges will be complicated. It will require policymakers, engineers, residents, scientists, planners, and more, to adapt our current development practices and to build a network of solutions. If there is one take-away from our experience with climate change, we have proven that humans have the capacity to modify Earth's biosphere in ways that are harmful to life. It seems reasonable, therefore, that we have the capacity to undo the negative impacts of climate change on our society, but it will depend on our willingness and capability to embrace climate mitigation and adaptation strategies as early as possible.

The link between human greenhouse gas (GHG) emissions, climate warming, and sea level rise is clear and well documented both globally and in Hawaiʻi. Globally-averaged sea level is rising at increasing rates due to climate and ocean warming caused by increasing concentrations of GHGs (carbon dioxide, methane, nitrous oxide and fluorinated gases) in the atmosphere from human activity, particularly from burning of fossil fuels and land use changes. In addition, there is a large and growing body of scientific evidence that accelerated melting of the Antarctic and Greenland ice sheets may contribute to 3 feet or more of sea level rise before the end of this century. Despite the findings of the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5) (IPCC 2014), which projects 3.2 feet of sea level rise by the end of this century under the "business as usual" GHG emissions scenario (and which forms the basis of our sea level rise modeling effort), recent peer-reviewed publications indicate that 3.2 feet of sea level rise may be reached earlier in the second half of this century and that 6 feet of sea level rise or more is "physically plausible" by the end this century (Le Bars, Drijfhout, and de Vries 2017, NASA 2015, Sweet et al. 2017). Three feet of sea level rise within the latter half of this century appears increasingly likely, given the predominant trend of the research toward higher scenarios of sea level rise. Whether we see 3 or 6 feet of sea level rise in this century or next will depend primarily on humankind's ability to mitigate GHG emissions over the next few decades and the response of Earth's polar regions to warming. Impacts from climate change and sea level rise are occurring now and will inevitably increase over several generations. Planning for sea level rise must begin in earnest while we work in parallel to mitigate climate change. If no action is taken, these negative impacts will ripple through Hawaii's economy causing great social and economic disruption. Fortunately, we are in a position to anticipate and plan for sea level rise, thereby reducing, but not eliminating, its effects.

This Sea Level Rise Vulnerability and Adaptation Report (Report) provides, for the first time, a state-wide assessment of our exposure to sea level rise and its potential social, economic, and environmental impacts to our islands. While the focus of the assessment is on the main Hawaiian Islands, vulnerability and adaptation to sea level rise needs to be addressed for the archipelago as a whole (Figure 1). The Report fills in important data gaps in projected exposure and vulnerability to chronic coastal flooding from modeling passive marine and groundwater flooding, coastal erosion, and annual high wave flooding under higher sea level.

Vulnerability and Adaptation (IPCC 2007)

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes.

Adaptation (planned) is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

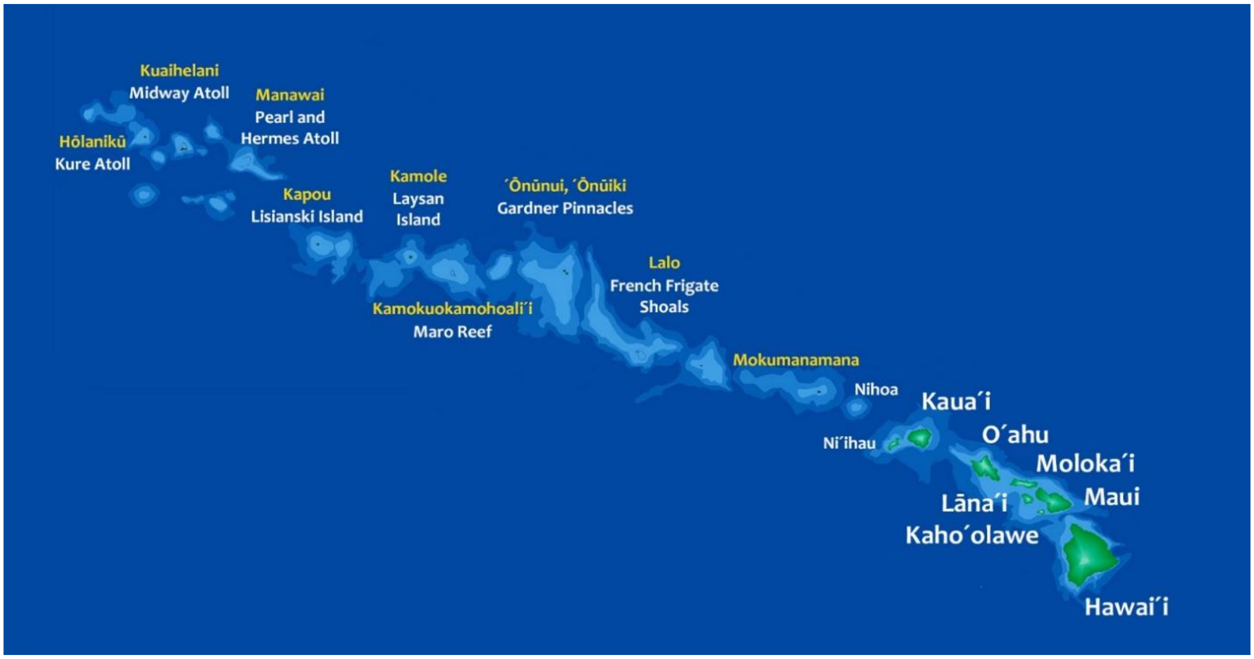


Figure 1. Islands, islets, and atolls of the Hawaiian archipelago

Our Kuleana as Stewards of the Future

Although sea level rise may alter Hawaii's future, we have the capacity to moderate its deleterious effects. We alone possess the human qualities that allow us to build a resilient future together.[1] Our Native Hawaiian community has taught us how to apply traditional cultural knowledge to solve problems of resource management. This includes the revitalization of the ahupua‘a land system which was a section of land that ran from mauka (inland) to makai (seaward) and the size of the ahupua‘a was dependent on the resources of the area. The ahupua‘a was thought of as the basic self-sustaining unit and emphasized the interrelationship of the elements (nature) and beings (humans). Further, Hawai‘i is often referred to as a "melting pot" of cultures which allows us access to the multicultural knowledge and heritage embodied in our residents. Our unique cultural heritage provides us a broader spectrum of ideas and possible solutions which makes us stronger and more resilient to face all crisis and challenges together.

This Report is intended to reach the wide range of stakeholders needed to envision, plan, and design a future with rising seas so we can all be stewards of the ‘āina. This Report is not a plan but a technical document that provides projections of areas along the coast that are vulnerable to sea level rise based on the latest available science and state of the art modeling. Recommendations to address risks from sea level rise focus on improving our capacity to adapt and build resilient communities. As this report is also considered a "living document," the results should provide a picture of our future with sea level rise, with the understanding that this "picture" is based on many assumptions and limitations that will need to be reviewed and updated as new science and modeling emerge and efforts to adapt are tried and tested.

Who Should Read this Report?	
State Legislators	Develop policies and laws that will strengthen Hawaii's capacity to adapt to sea level rise and support sustainable and resilient communities and the environment.
Scientists, Engineers, Planners, and Architects	Use the results to support planning and the design of innovative adaptation options and update the results based on the best available science.
Native Hawaiian Cultural Practitioners, Groups and Individuals	Develop plans and protocols to protect Native Hawaiian culture and restore cultural resources threatened by sea level rise.
State and County Government Staff	Examine, update, or change existing plans, rules and regulations, and the design and siting of capital improvement projects to increase resilience to sea level rise.
County Council Members	Craft and support a regulatory environment that protects human health and safety and the environment with sea level rise.
Businesses	Develop innovative solutions that promote good business, environmental sustainability, and resilience to sea level rise.
Teachers, Parents, and the General Public	Raise awareness about sea level rise impacts and adaptation at home and at school, and advocate for measures to protect future generations.

[1] Many of our unique island challenges and qualities were captured as messages in break-out groups during the State's first *Sea Level Rise Vulnerability and Adaptation Workshop* attended by 250 participants on January 26, 2016. Some of these messages are included in "Call to Action" text boxes at the beginning of each chapter of this Report.

Key Milestones in Hawaii's Climate Change Policy

The risks posed by climate change and sea level rise to Hawai‘i were recognized as early as 1984 by State Senate Resolution 137 that requested a study the worldwide greenhouse effect on Hawaii's coastal development. The resulting report, *Effects on Hawaii of a Worldwide Rise in Sea Level Induced by the Greenhouse Effect,* was released in 1985 by the Hawai‘i Coastal Zone Management (CZM) Program. This report, delivered to the State legislature, stated that the debate has shifted from questioning the possibility that the "Greenhouse Effect" would occur to whether the effect will be mild or severe as well as the timeframe for its imminent occurrence.

Hawaii's first iteration of a climate change action plan was completed in 1998. The *Hawai‘i Climate Change Action Plan* did not set specific goals, but was intended to be a catalyst for discussions by Hawaii's people about their involvement in future efforts to reduce GHG emissions and to adapt to climate change. The major recommendation of this first plan was to develop consensus as to Hawaii's goals for GHG emission reductions.

Hawaii's first sustainability plan was requested in 2005 through Act 8, Special Session Laws of Hawai‘i (SLH), to review the precepts of the Hawai‘i State Plan and other fundamental components of community planning. Specifically, many quality of life issues were addressed including water quality, air quality, land use, energy, and ocean resources for planning Hawaii's future. Act 8 also called the plan to be updated every ten years. The *Hawai‘i 2050 Sustainability Plan*, published in 2008, warned of global warming, rising sea levels, and that stronger, more frequent storms would impact Hawai‘i. The plan also established many goals and recommendations, including strategic actions to reduce reliance on fossil fuels; conserve water and ensure an adequate water supply; conduct research to strengthen management initiatives to respond to rising sea levels, coastal hazards, erosion, and other natural hazards; and develop a comprehensive environmental mapping and measurement system to evaluate the overall health and status of Hawaii's natural ecosystems. The plan set a 2020 target date to reduce the reliance on fossil fuels by benchmarking that 20 percent (%) of electricity be generated from renewable resources by the end of 2020.

In 2009, the multi-stakeholder Ocean Resources Management Plan (ORMP) Working Group, established by the Hawai‘i CZM Program, developed a *Framework for Climate Change Adaptation in Hawai‘i* as part of the ORMP implementation (State of Hawaii's ORMP Working Group 2009). Core values for adaptation to climate change were established to provide a:

- *Safe* environment for residents and visitors;
- *Healthy* environment that promotes human well-being and sustainable ecosystem services;
- *Productive* environment that enables residents to thrive; and
- *Resilient* environment that is able to withstand shocks to the system

This framework provided initial guidelines on how the State could plan for adaptation to the impacts of climate change (State of Hawaii's ORMP Working Group 2009). Building on this effort, a policy toolkit was developed in 2011 for state and local governments to address sea level rise and coastal land use in Hawai‘i

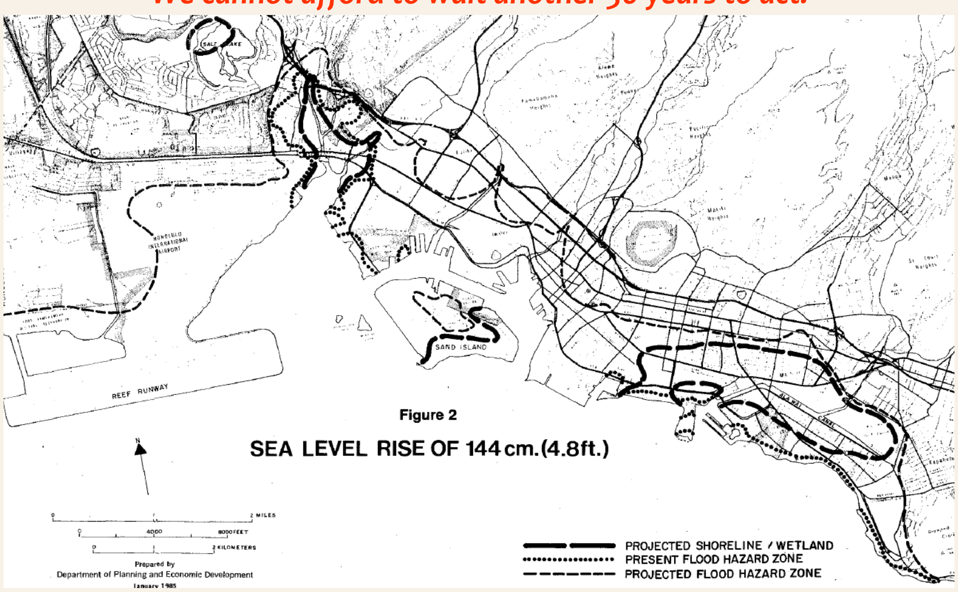
(Codiga and Wager 2011). In addition, the ORMP, a state-wide plan updated every 5 years which sets forth the State's ocean and coastal resource management priorities, identified "appropriate coastal development" and "managing coastal hazards" as the top two management priorities in its 2013 update (Hawai'i CZM Program 2013).

BACK TO THE FUTURE

Over 30 years ago, the Hawaiʻi CZM Program submitted the report, *Effects on Hawaiʻi of a Worldwide Rise in Sea Level Induced by the Greenhouse Effect* (Hawai'i CZM Program 1985), to the State legislature. Maps showed estimated projections of sea level rise in Honolulu and highlighted the uncertainty regarding the magnitude and rate of sea level rise. While at the time, the report concluded there was insufficient basis for formulating a long-range plan, the recommendations below are still valid today.

1. Adopt sea level rise projections for planning purposes based upon the best data and scientific predictions available;
2. Review and revise the adopted sea level projections at regular intervals;
3. Plot the approximate locations of shorelines and coastal hazards based on the adopted or amended sea level projections;
4. Use the projected shoreline and coastal hazard maps in the design and location of new public facilities and in the improvement and alteration of existing facilities, based on their lifespan and safety features;
5. Locate new infrastructural facilities as a means to attract development to "safe" areas away from zones of projected hazard. Considerations may include the maintenance or non-maintenance of the existing infrastructure;
6. Adopt more innovative uses of the economic incentives of the National Flood Insurance Program to encourage appropriate changes in existing patterns of development;
7. Require stricter adherence to existing prohibitions against shoreline development (e.g., shoreline setback, special management permits, and conservation district uses) by approving fewer variances, waivers, and exemptions; and
8. Consider more seriously the viability of replacing structures lost to natural forces and situated within areas subject to impact from rising sea levels.

The impacts of sea level rise are already being felt in Hawaiʻi.
We cannot afford to wait another 30 years to act!



The Hawaiʻi State Planning Act (Hawaiʻi Revised Statutes (HRS), Chapter 226) was amended in 2011 to include *Sustainability Priority Guidelines and Principals* (Act 181, SLH 2011). These guidelines were created to encourage collaboration needed to promote and implement sustainability through economic, social, community, and environmental priorities, through planning that respects and promotes living within the natural resources and limits of the State, by promoting decisions based on meeting the needs of the present without compromising the needs of the future, considering the principles of the ahupuaʻa system and emphasizing that everyone has the responsibility for achieving a sustainable Hawaiʻi.

The Hawaiʻi State Planning Act was again amended in 2012 with the addition of the *Climate Change Adaptation Priority Guidelines* (Act 286) (Box 1). These guidelines were created to encourage the collaboration needed to address climate change by recognizing that impacts will occur in multiple sectors including agriculture, conservation lands, coastal and nearshore marine areas, natural and cultural resources, education, energy, higher education, health, historic preservation, water resources, the built environment, and the economy (State of Hawaiʻi Senate 2012).

In 2013, Hawaiʻi became the first sub-national signatory of the *International Majuro Declaration for Climate Leadership* after then-Governor Neil Abercrombie became one of eight governors appointed by the U.S. President to the *State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience*.

The 2014 Hawaiʻi State Legislature unanimously passed Senate Concurrent Resolution 69 (SCR 69), "Endorsing and Supporting the Aloha+ Challenge." The Aloha+ Challenge, He Nohona ʻAeʻoia - A Culture of Sustainability, is guided by and builds upon the sustainability definition, goals, and principles (Box 2) which established sustainability as a State priority.

In 2014, the Hawaiʻi State Legislature also passed Act 83, which formally established *The Hawaiʻi Climate Adaptation Initiative* to enable a coordinated approach among all agencies at all levels of government to plan for and address the effects of climate change to protect the State's economy, health, environment, and way of life. Act 83 established a coordinating body to carry out this mission known as the Interagency Climate Adaptation Committee (ICAC) composed of State and County government representatives. Their first task was to develop this Report to address the state-wide impacts of sea level rise. In addition, they were also tasked to develop plans and policy recommendations for action, and with the coordination of the State of Hawaiʻi Office of Planning (Office of Planning), to then use this Report as a model framework for addressing other climate threats and priorities.

Box 1. Hawaiʻi Climate Adaptation Priority Guidelines (Hawaiʻi State Planning Act)

1. Ensure that Hawaii's people are educated, informed, and aware of the impacts climate change may have on their communities;
2. Encourage community stewardship groups and local stakeholders to participate in planning and implementation of climate change policies;
3. Invest in continued monitoring and research of Hawaii's climate and the impacts of climate change on the State;
4. Consider Native Hawaiian traditional knowledge and practices in planning for the impacts of climate change;
5. Encourage the preservation and restoration of natural landscape features, such as coral reefs, beaches and dunes, forests, streams, floodplains, and wetlands, that have the inherent capacity to avoid, minimize, or mitigate the impacts of climate change;
6. Explore adaptation strategies that moderate harm or exploit beneficial opportunities in response to actual or expected climate change impacts to the natural and built environments;
7. Promote sector resilience in areas such as water, roads, airports, and public health, by encouraging the identification of climate change threats, assessment of potential consequences, and evaluation of adaptation options;
8. Foster cross-jurisdictional collaboration between county, state, and federal agencies and partnerships between government and private entities and other nongovernmental entities, including nonprofit entities;
9. Use management and implementation approaches that encourage the continual collection, evaluation, and integration of new information and strategies into new and existing practices, policies, and plans; and
10. Encourage planning and management of the natural and built environments that effectively integrate climate

Box 2. Aloha+ Challenge Sustainable Development Goals

- **Clean Energy:** 70% clean energy, including 40% from renewables and 30% from efficiency
- **Local Food:** At least double local food production with a goal of 20 to 30% of food consumed grown locally
- **Natural Resource Management:** Reverse the trend of natural resource loss mauka to makai by increasing freshwater security, watershed protection, community- based marine management, invasive species prevention, and native species restoration
- **Waste Reduction:** Reduce the solid waste stream prior to disposal by 70% through rough source reduction, recycling, bioconversion, and landfill diversion methods
- **Smart Sustainable Communities:** Increase livability and resilience in the built environment through planning and implementation at the state and county levels
- **Green Workforce and Education:** Increase local green jobs and education to implement these targets

In 2015, Hawaiʻi became the first state to require 100% renewable power supply by year 2045 (Act 97, SLH 2015). This included other climate mitigation measures passed by the State legislature such as Act 99, SLH 2015 and Act 176, SLH 2016 which directed all public schools and university campuses to become energy net-zero by year 2035. Other measures established a community-based renewable energy program to allow condominium dwellers and others who have been largely unable to participate in Hawaii's clean energy transformation to purchase electricity generated at an off-site renewable energy facility (Act 100, SLH 2015), and designated a state hydrogen implementation coordinator to promote fuel cell technology (Act 98, SLH 2015).

In 2017, *The Hawaiʻi Climate Adaptation Initiative* (Act 83, SLH 2014), was strengthened through the passing of Act 32, *The Hawaiʻi Climate Change Mitigation and Adaptation Initiative* which expanded the ICAC into the Hawaiʻi Climate Change Mitigation and Adaptation Commission (Hawaiʻi Climate Commission) (Box 3). The Hawaiʻi Climate Commission was assigned various tasks related to climate change mitigation and adaptation including systematically reducing GHG emissions and improving Hawaii's resiliency to climate change aligned with the principals and contributing to the goals established by the 2014 Paris Accord (Act 32, SLH 2017). Through all these efforts, Hawaiʻi has laid a solid foundation for adapting to climate change, reducing GHG emissions, and charting a new course to protect the State's economy, health, environment, and way of life.

Box 3. Members of the Hawaiʻi Climate Change Mitigation and Adaptation Commission established by Act 32

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

The Hawai'i Climate Change Mitigation and Adaptation Initiative (Act 32)

The *Hawai'i Climate Change Mitigation and Adaptation Initiative* (Act 32, SLH 2017) strengthens support for the creation of a framework to address climate threats. The framework begins with an initial focus on sea level rise (this Report) and allows that framework to be used to address other climate impacts such as changes in rainfall patterns that will affect our water supply, agriculture, invasive species, and ecosystems. Other impacts might include increasing air temperature and incidence of heat waves which will result in human health impacts such as increased respiratory and mosquito-borne diseases, increased ocean temperatures and acidity which will reduce the health and resilience of our coral reefs and ocean resources, and more frequent natural disasters which could pose significant risk for the islands.

Act 32 also establishes the following tasks for the Hawai'i Climate Commission as related to climate change mitigation and adaptation:

- Provide policy direction, facilitation, coordination, and planning among state and county agencies, federal agencies, and other partners as appropriate;
- Establish climate change mitigation and adaptation goals to help guide planning and implementation state-wide using the latest scientific analysis and risk assessment to monitor and forecast climate change related impacts at the regional, state, and local level, including any additional information deemed necessary;
- Identify vulnerable people, communities, industries, ecosystems, and the potential economic ramifications for climate change related impacts;
- Identify existing climate change mitigation and adaptation efforts at the federal, state, and local levels and make recommendations for how to meet or exceed Hawaii's state mitigation goals and adopt a liberal approach in preparation, so as to minimize future risk to the people and environment of Hawai'i;
- Assess the capacity and availability of existing resources and identify new source of revenue necessary to address climate change mitigation and adaptation and advise the governor, legislature, and counties on the economic and budgetary ramifications of climate change impacts, mitigation, and adaptation;
- Identify information necessary to track progress in implementing climate change mitigation and adaptation efforts and submit an annual report to the governor and legislature;
- Maintain a website that includes a mission statement as well as access to climate change related actions, plans, policies, and results; and
- Conduct a comprehensive review of the implementation as required by the Act.

Hawai'i Climate Adaptation Framework

The Hawai'i Climate Adaptation Framework was developed as a process for science-driven and stakeholder-informed analysis of sea level rise and other climate change-related issues. The key components of this framework are: (1) stakeholder outreach and engagement, (2) vulnerability assessment, and (3) "living" outputs which are informed by the climate science and traditional and local knowledge and revised through a learning process (Figure 2). Emphasis is placed on the use of the best available science combined with traditional and local knowledge and practices to assess our vulnerability and to increase our capacity to adapt by applying an integrated learning approach. This framework was used to guide the development of this Report (Figure 3). A summary of each component of the framework is described in this section together with specific activities and outputs conducted as part of the development of the Report.

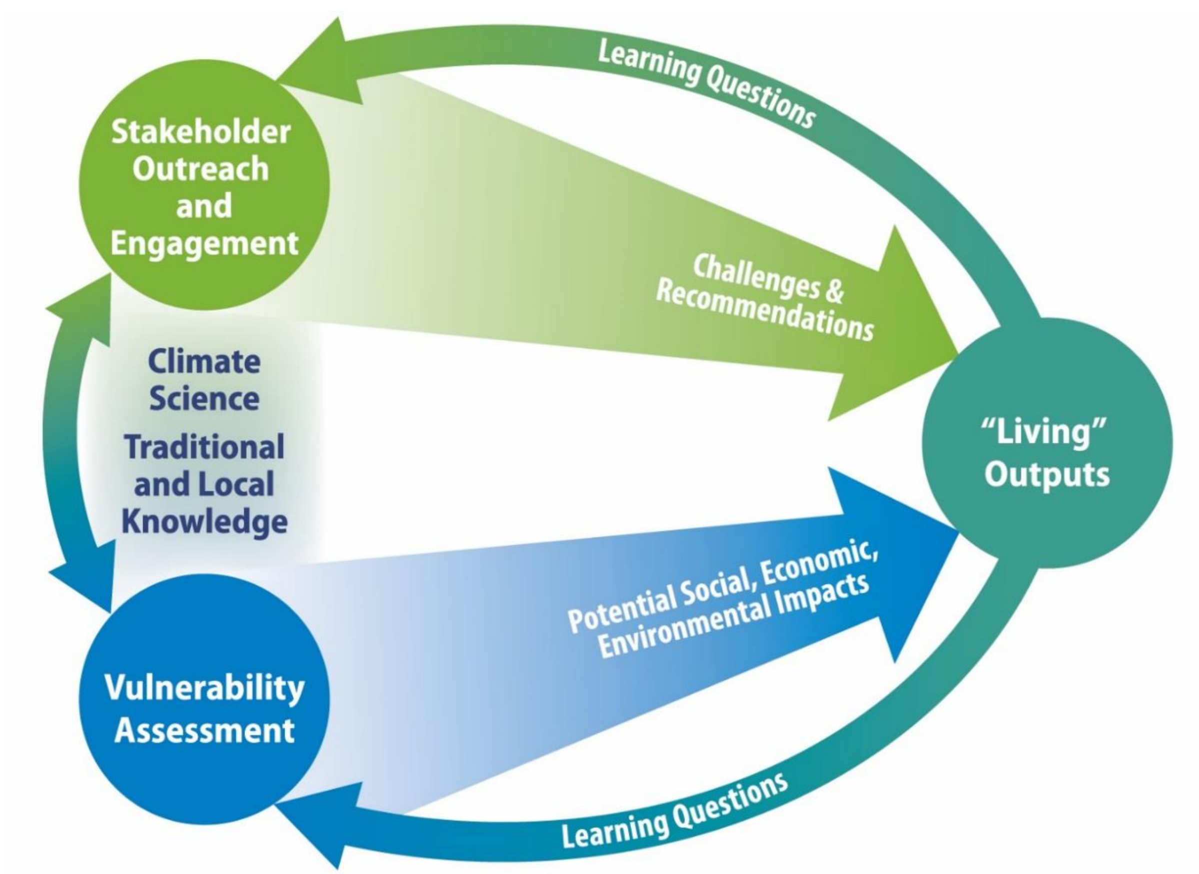


Figure 2. Hawai'i Climate Adaptation Framework

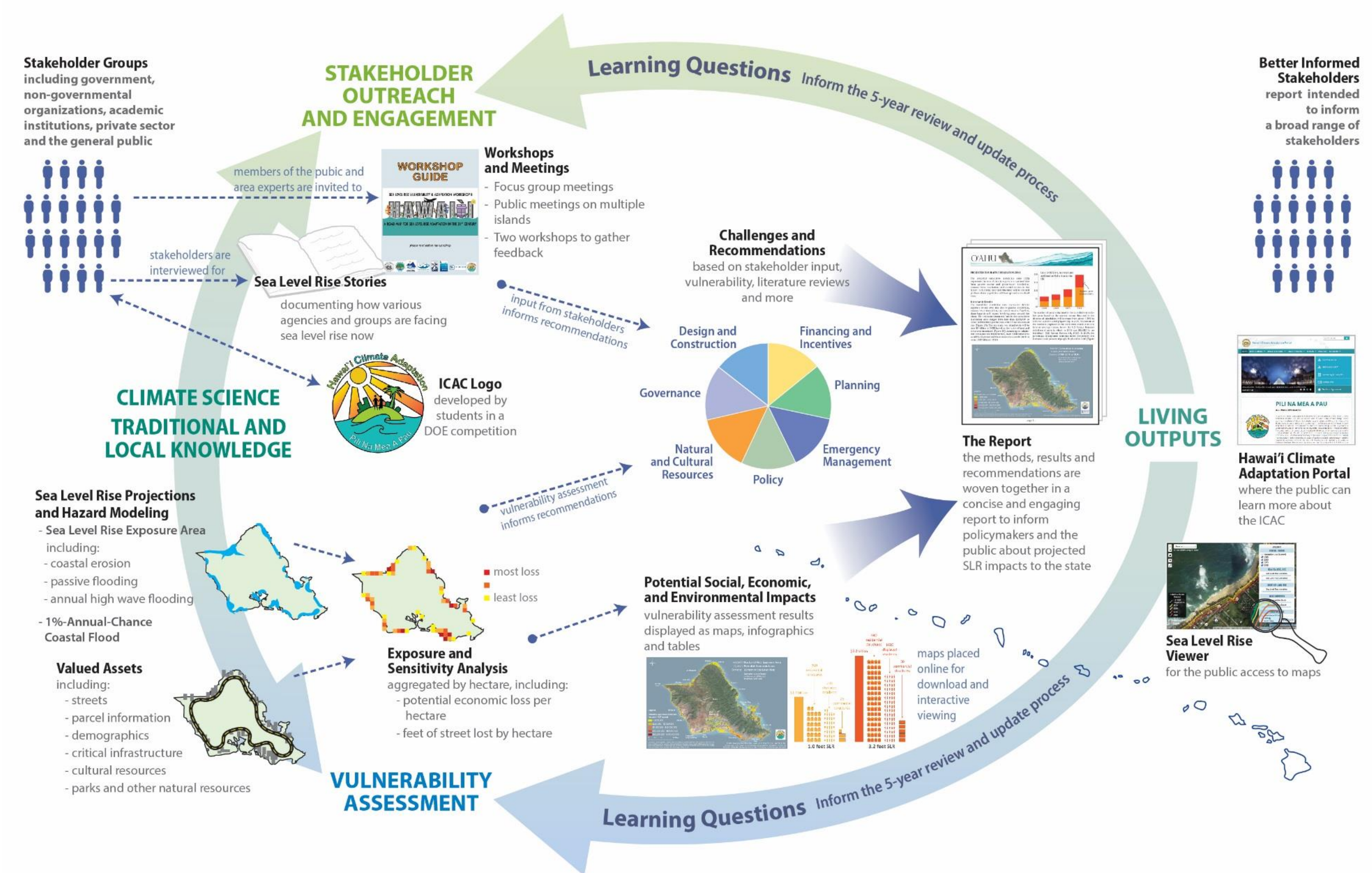


Figure 3. The Hawai'i Climate Adaptation Framework applied to sea level rise

Stakeholder Outreach and Engagement

Stakeholder outreach and engagement are designed to inform a broad constituency of the current and projected threats from climate change and sea level rise and work together to develop adaptation responses. Multiple forums, such as focus groups, workshops, and storytelling, are used to seek input on adaptation challenges and recommendations that can be used to inform the other components of the framework. Key questions addressed through these forums included:

- What climate variables (e.g., sea level rise, changing rainfall, rising atmospheric and ocean temperature) should we focus on?
- What are the issues and concerns related to those climate variables?
- What lessons can be used to address these issues and concerns?
- What are “no regrets” strategies that should be adopted?
- What we are doing now that we should stop doing?
- What we are not doing that we should be doing?

The following is a brief summary of stakeholder outreach and engagement conducted as a part of this Report.

Quarterly public meetings of the ICAC (now called the Hawai‘i Climate Commission) were held to educate the Committee regarding the science behind the Report and bring in others from different sectors to educate the Committee about their current, ongoing work in dealing with climate change. The meetings were also used to update the Committee members on the progress to date of the Report and to solicit their input, as well as the public’s input, on various aspects of the approach being used to develop the Report.

The State of Hawai‘i Department of Land and Natural Resources (DLNR), in partnership with the ICAC, teamed up with the Department of Education’s Career and Technical Education to have students participating in their Graphic Design Program of Study design a logo for the Hawai‘i Climate Adaptation Initiative. The students were asked to design a creative, innovative, and professional logo that expressed the student’s perspective on climate adaptation and how it related to the State of Hawai‘i. In preparation for the assignment, the students were also required to write a short paper on climate adaptation. All logos were given to the DLNR to review and the top five logos were presented to the ICAC at their May 10, 2016 Meeting where a winner was selected. The winning logo was designed by Ms. Britney Van Winkle and Ms. Tymberlyn Tugaoen of Leilehua High School.

Focus group meetings were held with State and County agencies and nongovernmental organizations to identify specific issues or concerns. From these meetings and other contacts, storytellers were identified to capture issues and ongoing efforts in addressing shoreline problems and loss. These adaptation stories document key lessons that can be used to address sea level rise and are included throughout the Report.

Two stakeholder workshops were held. The first workshop, held in January 2016, was open to the public and attended by 250 people. The focus of this workshop was to communicate the latest science on climate change and sea level rise, provide an overview of the process that would be used to develop the Report, solicit issues and concerns about sea level rise, and develop call-to-action messages which are captured throughout the Report. The second workshop, held in February 2017, was attended by 150 multidisciplinary stakeholders from government, private sector, and nongovernmental organizations. As in the previous workshop, the latest climate science was communicated along with preliminary hazard modeling, vulnerability assessment results, and draft recommendations. The primary objective of this workshop was to solicit input on the suite of proposed recommendations and to identify priority recommendations

A series of informational meetings were held for County government officials and the public for the islands of O'ahu, Kaua'i, Maui, Hawai'i (Hilo and Kona), and Moloka'i to educate people about the impacts of sea level rise and gather comments and input about key issues and concerns regarding preparedness and adaptation to sea level rise.

The Hawai'i Climate Adaptation Portal (http://climateadaptation.hawaii.gov/) was developed to serve as a repository of news and resources on climate change. The website was also used as a forum to disseminate information regarding upcoming public events and meetings as well as host videos and summaries from past ICAC meetings as well as the workshops held.

Vulnerability Assessment

A vulnerability assessment quantifies (where possible) the potential social, economic, and environmental impacts of climate change. Vulnerability is a result of exposure to a hazard, degree of sensitivity or susceptibility to harm. Capacity or inability to cope or adapt (sensitivity) to hazards is the critical link between understanding hazards and doing something about it. Key questions addressed in developing the vulnerability assessment include:

- What are key climate change variables and projections of change?
- How do these climate change variables increase existing hazards or create new hazards now and in the future?
- What is our spatial and temporal exposure to these hazards? When and where will they occur?
- What are the potential social, cultural, economic, and environmental impacts of climate change?

The vulnerability assessment in this Report utilizes the IPCC sea level rise projections (1.1 feet of sea level rise as the setting for demonstrating present-day or near-term flooding and erosion hazards and 3.2 feet of sea level rise as the setting for current sea level rise planning efforts) to create a model of exposure to passive flooding, coastal erosion, annual high wave flooding. Under the guidance of the Hawai'i Climate Commission, the University of Hawai'i School of Ocean, Earth Sciences, and Technology (UH SOEST), and Tetra Tech, Inc. (Tetra Tech), a decision was made to aggregate these three hazards into a combined Sea Level Rise Exposure Area (SLR-XA) for the vulnerability assessment. A thorough description of the methodology and assumptions are provided in Chapter 3 to support more localized assessment of exposure and vulnerability and to support update of the Report results as part of the living outputs process.

Living Outputs

The “living outputs” process recognizes the evolving nature of climate science, technology, and innovation that must be considered as we adapt to climate change. This Report is the first output of the living outputs process. As required under Act 32, this Report will be updated every 5 years. It should not be used or viewed as a final, definitive analysis of sea level rise vulnerability, particularly at a site level. Key questions addressed through the living outputs approach include:

- How is the science evolving on climate change and sea level rise?
- How can we improve model projections?
- What can we do to increase our capacity to adapt to climate change?
- Where are our successes and shortcomings toward adaptation and resilience?
- How do we set priorities in terms of where, when, and how to adapt?
- Are the assumptions made still valid?
- What have we learned from our assumptions? What has changed?

Sea level rise will not stop at 3.2 feet. The effects of carbon dioxide are long-lived and there is a large degree of “inertia” in the climate system. Over the next few centuries, seas will continue to rise, although the rate of increase and timing are uncertain. This Report provides a framework for assessing climate change within dynamic physical and social systems so we can continually adapt its use to new information and circumstances. Thus, the results of the vulnerability assessment and recommendations require updating based on the best available science and the lessons learned through implementation and trial. This Report also includes learning questions designed to help us re-think critical elements of a sea level rise adaptation strategy, as well as scientific and modeling assumptions. Learning questions define an important element of the living outputs process by highlighting issues that require further investigation, uncertainties in our knowledge, and known trends that need to be monitored.

In addition, this Report incorporates an accessible online Hawai‘i Sea Level Rise Viewer (http://hawaiisealevelriseviewer.org/), which can also be considered as another “living” output. The Hawai‘i Sea Level Rise Viewer provides detailed high-resolution maps of exposure and vulnerability to coastal hazards with sea level rise, and thus supports planning at community, county, and state levels. However, the Hawai‘i Sea Level Rise Viewer should be updated as new climate science and improved sea level rise hazard modeling approaches become available.

Sea Level Rise Outlook: Global and Local Observations and Projections

Pua aʻe la ka uwahi o ka moe. The smoke seen in the dream now rises. The trouble of which we were forewarned is here.

Located at the center of the North Pacific basin, Hawaiʻi is one of the most remote, beautiful, and threatened places on the planet. While threats of active volcanoes, tropical storms, hurricanes, earthquakes, tsunamis, and floods are a constant reminder to islanders of the risks of natural hazards, sea level rise threatens to permanently reshape Hawaii's landscape and future. If we continue along the current trajectory of GHG emissions in our atmosphere, the long-term sea level rise outlook for Hawaiʻi and the world is grim. Global observations from tide gauges and satellite data show increasing rates of sea level rise over the past century throughout the oceans. The high end "business as usual" scenario put forth by the IPCC, which is the United Nations body of leading climate scientists, projects up to 3.2 feet of sea level rise by the end of the century (IPCC 2014). However, there is a growing body of scientific evidence since the release of the 2014 IPCC AR5 that accelerated melting of the Antarctic and Greenland ice sheets may contribute to more than 3 feet of sea level rise before the end of this century. Scientists in Hawaiʻi and around the world are working to understand how global changes impact local conditions. We must keep abreast of the latest science in order to inform our efforts to adapt to sea level rise.

Call to Action

"We believe future generations have a right to live in a Hawai'i that is safe, healthy, and prosperous. We hope that Hawai'i will take a leadership role in sea level rise adaptation, using sound science and active participation and empowerment of the whole community with a long-term perspective. By doing so, we will have developed effective community driven strategies to mitigate effects of sea level rise."

Group message developed during the 1st Sea Level Rise Vulnerability and Adaptation Workshop, Oʻahu January 2016

Key Take-Aways

- Rapid build-up of GHGs, including carbon dioxide, methane, nitrous oxide, and fluorinated gases, due to humans, is causing global warming and climate disruption.
- Carbon dioxide concentration in the atmosphere is of particular concern because of its effects on the global climate system can last for centuries.
- The concentration of carbon dioxide in the atmosphere is well outside the range of natural variability and is now approaching 410 parts per million, which is about 40% higher than pre-industrial levels and the highest in at least last 800,000 years and probably as long as 3 million years.
- Globally-averaged sea level is rising at increasing rates due to global warming of the atmosphere and oceans.

- Global atmosphere and ocean warming is leading to sea level rise that results from the thermal expansion of the oceans and melting of land-based ice including glaciers and polar ice sheets.
- While the high-end IPCC scenario projects up to 3.2 feet (1 meter) of sea level rise by the year 2100, more recent studies indicate that over 6 feet of sea level rise is "physically plausible" by the end of the century based on the potential for accelerated melting of the Antarctic and Greenland ice sheets.
- Coastal flooding and erosion hazards from high waves and storms are increasing with sea level rise.
- Computer model projections of tropical cyclone activity and El Niño patterns in the central North Pacific indicate increasing risk of hurricanes for Hawai'i.
- Ongoing global and local scientific observations and projections continue to improve our understanding of the magnitude and timing of these impacts to our islands.

Observations

While the Earth's climate has experienced change and variability over geologic time, global climate change occurring over the last century due to human input of GHGs into the atmosphere is unprecedented over the period of human civilization. This rapid build-up in GHGs, including carbon dioxide, methane, nitrous oxide, and fluorinated gases, from humans, is causing global warming and climate disruption.

While climate science continues to evolve, the consensus that humans are causing these changes in our climate is shared by over 97% of climate scientists globally (Cook et al. 2016). Nearly 200 worldwide scientific organizations hold an official position that climate change is caused by human activity, including diverse groups such as the U.S. National Academy of Sciences, American Geophysical Union, American Meteorological Society, American Chemical Society, American Society of Civil Engineers, and American Medical Association (State of California 2011, NASA 2017c). Most recently, the U.S, Global Change Research Program (USGCRP), under the administrative lead of NOAA, released its 4th National Climate Assessment. As part of this assessment, a Climate Science Special Report (CSSR) was prepared as a stand-alone document to report the state of science relating to climate change and its physical impacts. The CSSR is designed to be an authoritative assessment of the science of climate change, with a focus on the United States, to serve as a foundation for efforts to assess climate-related risks and inform decision-making about responses. In this report, the USGCRP concluded

Climate Change and Variability (IPCC 2007)

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

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

that "it is extremely likely that human activities, especially GHGs, are the dominant cause of the observed warming since the mid-20th century" (USGCRP 2017).

Atmospheric Carbon Dioxide

Hawaiʻi's Mauna Loa Observatory is one of the world's leading scientific stations for monitoring the atmospheric concentration of carbon dioxide. The plot, often referred to as the Keeling Curve (which was named after the atmospheric chemist), shows the concentration of carbon dioxide in the atmosphere since 1958 and is the longest continuous direct measurement of atmospheric carbon dioxide (Scripps Institution of Oceanography 2015) (Figure 4). These measurements show that the carbon dioxide concentration in the atmosphere now exceeds 400 parts per million, about 40% above pre-industrial levels. About half of the man-made carbon dioxide produced since the industrial revolution (Ballantyne et al. 2012) and about 93% of the excess heat caused by GHG warming since the mid-20th century has been absorbed by the world's oceans (Rhein 2013). While this may have moderated the warming of the atmosphere, changes to ocean chemistry and warming resulting from this uptake of carbon dioxide and heat is resulting in negative impacts to marine ecosystems.

The concentration of carbon dioxide in our atmosphere exceeds 400 parts per million. Known as the Keeling Curve, these measurements, made at the Mauna Loa Observatory since 1958, are the longest running measurement in the world. The green line shows the concentration measure as of October 25, 2017. What is the concentration today? [Visit the Keeling Curve](https://scripps.ucsd.edu/programs/keelingcurve/)

(https://scripps.ucsd.edu/programs/keelingcurve/)

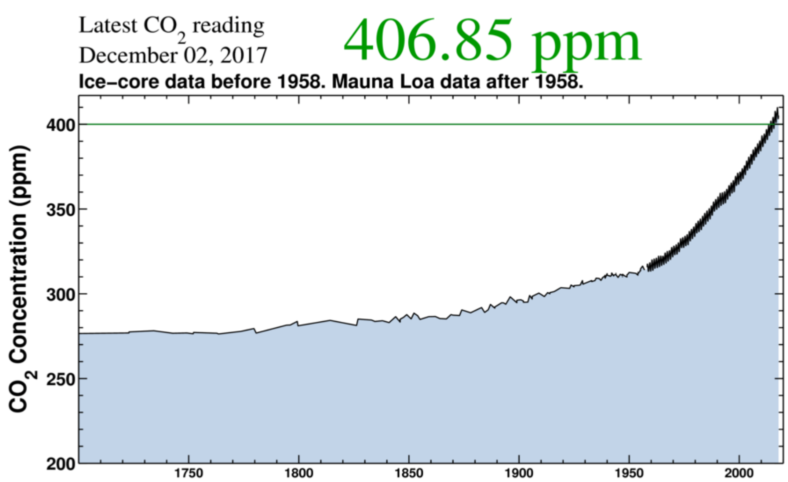


Figure 4. Concentration of carbon dioxide in the atmosphere since 1958 measured at Mauna Loa Observatory (the Keeling Curve) (Scripps Institution of Oceanography 2015).

Measurements from air bubbles trapped in ice cores taken from the Antarctic and Greenland ice sheets indicate that the carbon dioxide content of the atmosphere has varied between about 180 and 280 parts per million over the past 800,000 years with the coming and going of ice ages on an approximately 100,000-year cycle (Tripati, Roberts, and Eagle 2009) (Figure 5). In 2018, atmospheric carbon dioxide concentrations will likely exceed 410 parts per million several months out of the year. The only explanation for this rapid and unprecedented increase is due to human activity.

The concentration of carbon dioxide in our atmosphere today is higher than at any time in the last 800,000 years of Earth's history

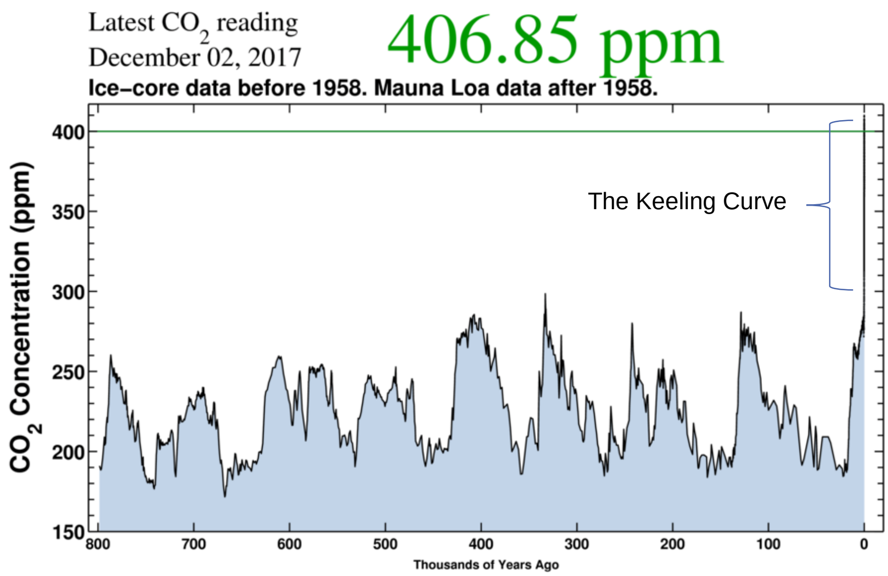


Figure 5. Carbon dioxide concentration in the atmosphere over the last 800,000 years (Scripps Institution of Oceanography 2015). Data before 1958 is from ice cores and data after 1958 are measurements taken from the Mauna Loa Observatory (the Keeling Curve) (Scripps Institution of Oceanography 2015).

Hawaiʻi is doing our part to reduce greenhouse gas emissions by working toward a 100% renewable power supply by 2045

Hawaiʻi established a goal of 100% renewable electric utility sales of power by 2045. The Hawaiʻi Public Utilities Commission issued a landmark "post-net-metering" ruling, ending the State's net energy metering policy for rooftop solar in favor of two (2) new programs called "self-supply" and "grid-supply." "Self-supply" is intended for solar installations that are designed to not export any electricity to the grid and customers are not compensated for any export of energy. "Grid-supply" customers receive a PUC-approved credit for electricity sent to the grid and are billed at the retail rate for electricity they use from the grid. More than 10% of the State's homes are now powered by solar energy with 16% on Oʻahu. Further on December 12, 2017, Hawaii's mayors committed to 100% renewable ground transportation. We can all do our part by purchasing energy-efficient vehicles and going solar on every rooftop!

For more information visit the *Hawaiʻi Clean Energy Initiative.*

Atmospheric and Ocean Temperatures

Measurements made by multiple scientific agencies around the world over the past century reveal that global atmospheric temperature is increasing and has been accelerating since about 1980 (Figure 6). Global warming is the unusually rapid increase in Earth's average surface temperature over the past century primarily due to the GHGs released as people burn fossil fuels. These temperature data are collected from weather stations, ships, and marine buoys located around the world. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 (IPCC 2014). Sixteen of the 17 warmest years in the span of the 136-year temperature record have all occurred since 2001, with the exception of 1998 which saw one of the most powerful El Niños on record (NASA 2017c). The year 2016 ranks as the warmest on record, seconded by 2015, and then 2014. While shorter-term (inter-annual) variability in global temperature is also visible in the records, there is a clear, long-term trend that Earth's climate is getting warmer (NASA 2016, USGCRP 2017, NASA 2017c). This rising atmospheric temperature also coincides with rising temperatures of the earth's oceans.

The Paris Agreement, which entered into force on November 4, 2016, aims to strengthen the global response to the threat of climate change by keeping global temperature rise well below 2° Celsius this century, above pre-industrial levels, and to pursue efforts to limit the temperature increase even further to 1.5° Celsius. The temperature anomaly is the change in global surface temperature relative to 1951-1980 average temperatures

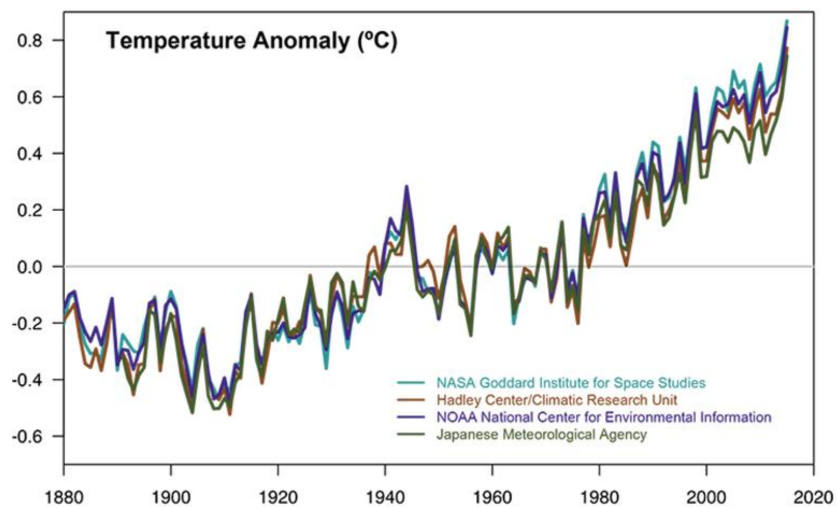


Figure 6. Global atmospheric temperature anomalies (NASA

Sea surface temperatures have also increased during the 20th century and will continue to rise. From 1901 to 2015, sea surface temperatures rose at an average rate of 0.13 degrees (°) Fahrenheit per decade (Figure 7). Similar to atmospheric temperature, sea surface temperature has been consistently higher during the past three decades. It should be noted, however, that changes in sea surface temperature vary regionally. While most parts of the world's oceans have seen an increase in temperature, there are a few areas that have actually experienced cooling, such as in the North Atlantic (Figure 8).

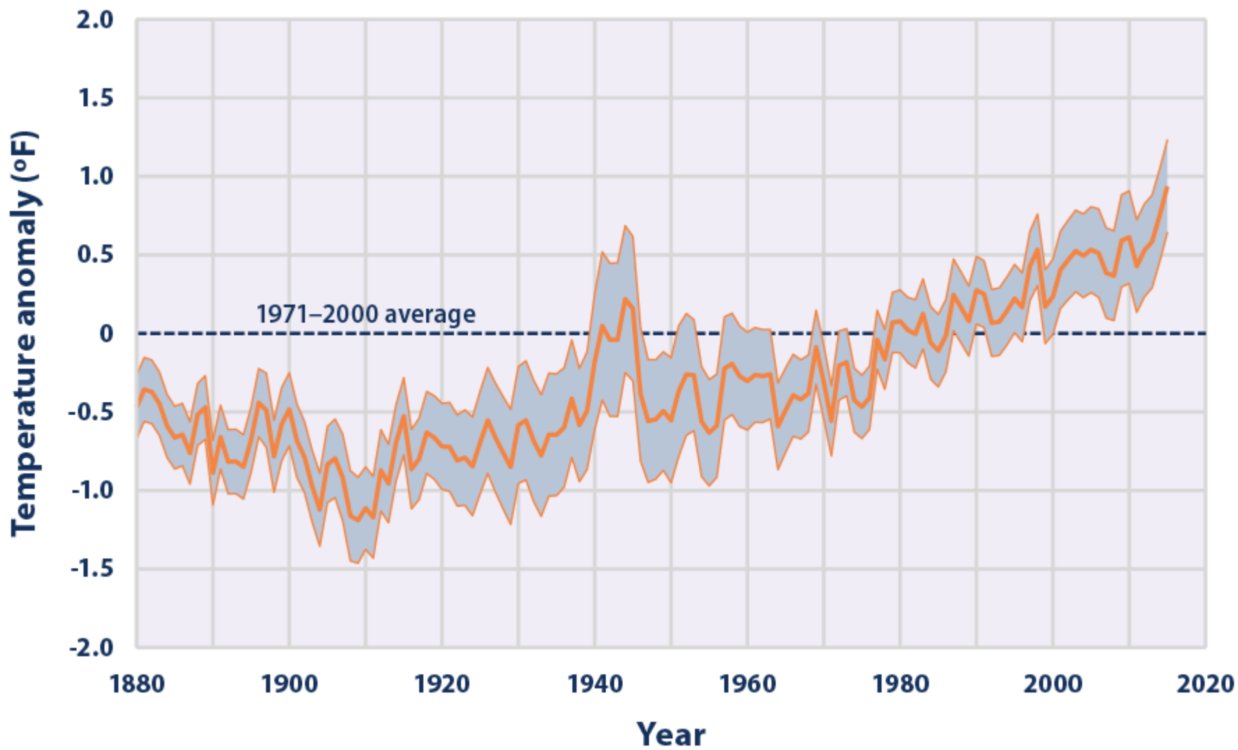


Figure 7. Global change in average sea surface temperature over time (NOAA 2016a)

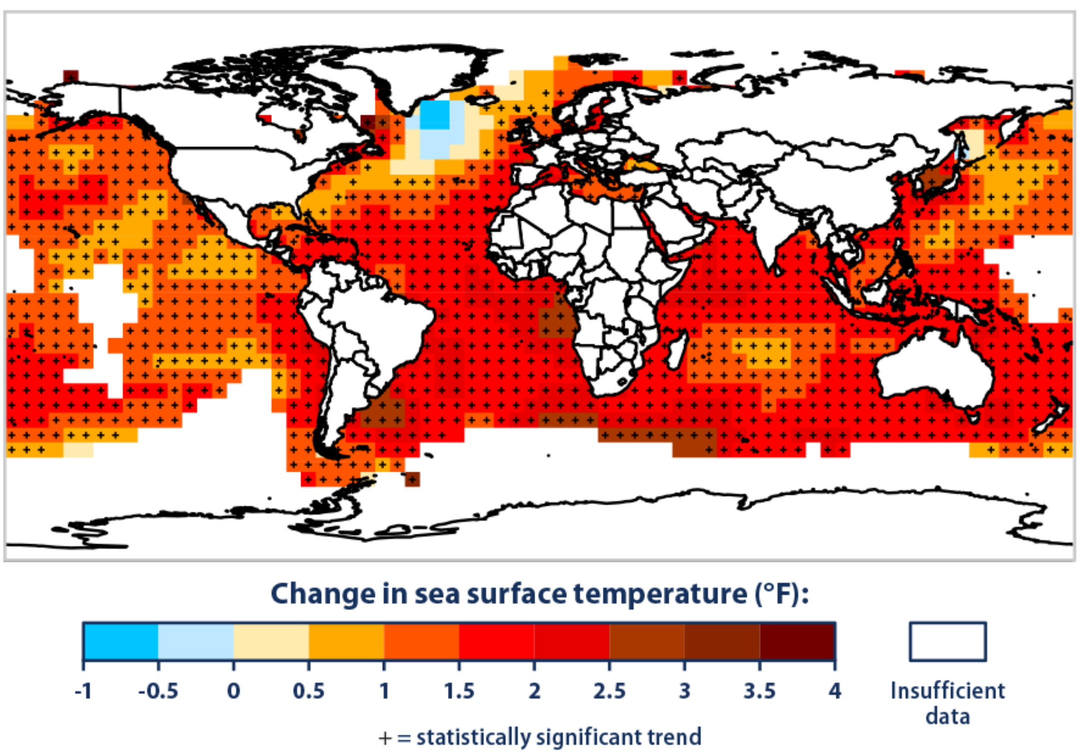


Figure 8. Change in average sea surface temperature over the period 1901 to 2015 by geographic location (IPCC 2013, NOAA 2016b)

Global Mean Sea Level

This warming of the atmosphere and the oceans is causing global mean sea level to rise. This has been observed over the last century in tide station data from around the world and, more recently, in satellite-based ocean height measurements. The rate of sea level rise has accelerated over the past century (Figure 9) (Fasullo, Nerem, and Hamlington 2016) and global mean sea level has risen by 8 to 9 inches (21 to 24 centimeters) since 1880, with a third of that rise occurring since 1993 (Church and White 2011, Hay et al. 2015, Nerem et al. 2010). This conicides with a key finding of the CSSR (USGCRP 2017) which found that global mean sea level has risen by about 7 to 8 inches (about 16 to 21 cm) since 1900, with about 3 of those inches (about 7 cm) occurring since 1993.

The rate of globally-averaged sea level rise is increasing. This acceleration is expected to continue due to accelerating melting of the Greenland and Antarctic glaciers and ice sheets

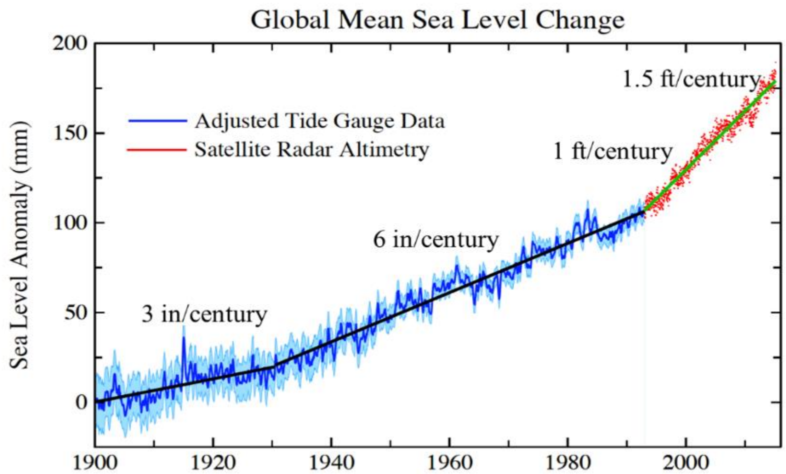


Figure 9. Observed global mean sea level rise over the last century (Church and White 2011, Nerem et al. 2010, Yi et al. 2015, Hay et al. 2015, Hansen et al. 2016, Watson et al. 2015, Fasullo, Nerem, and Hamlington 2016)

Global mean sea level is rising from two primary contributions; thermal expansion of ocean waters and melting of land-based glaciers and ice sheets (Church 2013). Heating of the ocean surface causes the water to expand while the melting of the glaciers and ice sheets from continents (i.e. Greenland and Antarctica) transfer water mass from the continents to the ocean also causing the ocean to rise. Up to the early 2000s, expansion and ice melt contributed similar amounts of water, however, ice melt now contributes about twice the amount than that of thermal expansion (Figure 10). The global loss of glaciers in the 21st century is unprecedented (Zemp et al. 2015). Multiple data sets and models were used in a recent reassessment of the mass balance of Earth's polar ice sheets (Shepherd et al. 2012). The melting of Greenland and Antarctic glaciers and ice sheets alone is estimated to contribute approximately 34% of the rise in sea level globally. Between 2002 and 2016, the ice sheets of Greenland and Antarctica decreased in volume contributing, on average, 0.05 inches (1.15 millimeters) per year to the rate of global sea level rise (NASA 2017a) (Figure 11). Glaciers and ice sheets have contributed approximately 0.06 inches (1.63 millimeters) per year to the rate of sea level rise in Hawai'i (NASA 2017b).

As global atmosphere and ocean temperatures rise, sea level also rises due to thermal expansion of the water and melting of glaciers and ice sheets.

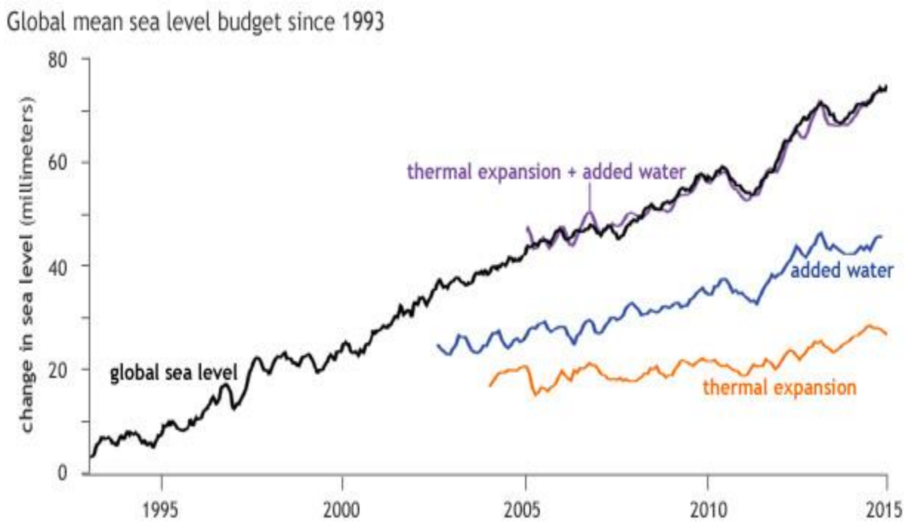


Figure 10. Contribution of thermal expansion and added water from glacier and ice sheet melting to sea level rise (Thompson et al. 2017)

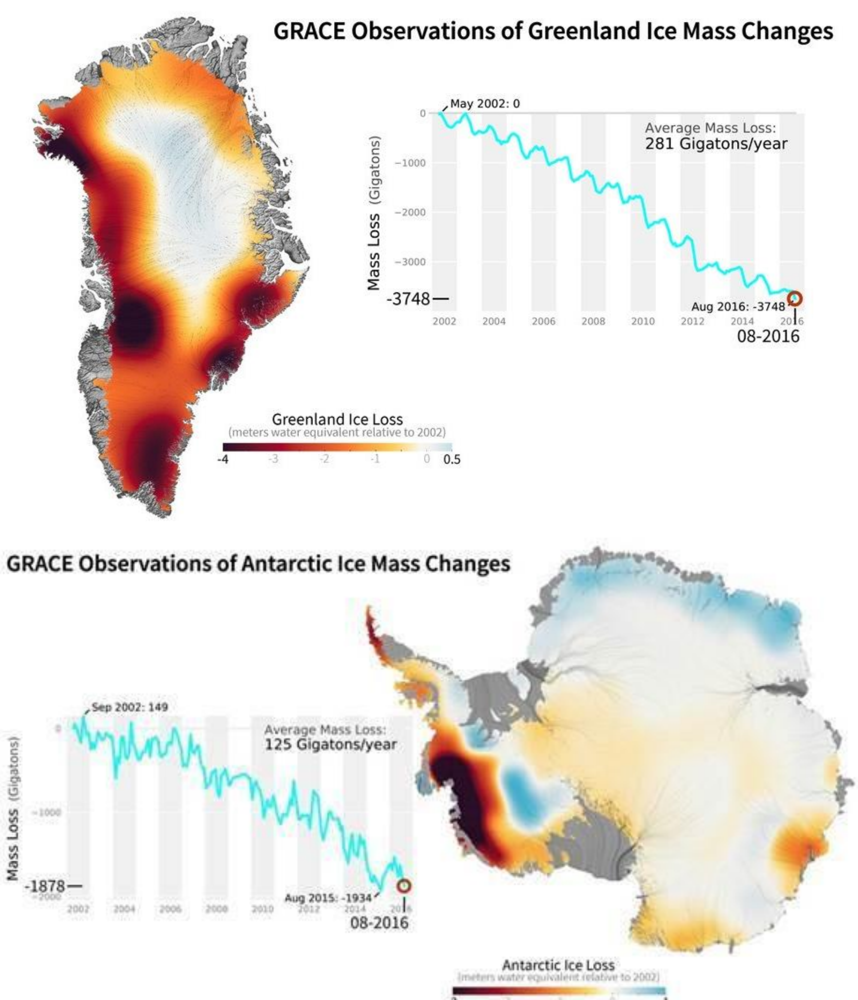


Figure 11. Ice mass loss in gigatons per year from Greenland and Antarctica (NASA 2017a)

Long-term records from tide stations around Hawai'i show that sea level is rising around the islands (Figure 12). However, it should be noted that local relative rates of sea level rise vary among the islands due to varying rates of subsidence along the volcanic island chain and possibly, in part, due to oceanic variability. The relative rate of sea level rise on the Island of Hawai'i is almost twice the rate on the Island of Kaua'i (NOAA 2017c). This is due to the fact that the Island of Hawai'i is slowly subsiding as it gains mass from active volcanoes resulting in a higher relative rate of sea level rise (Figure 12) while the islands of Kaua'i and O'ahu, which are the older islands in the chain, are relatively stable.

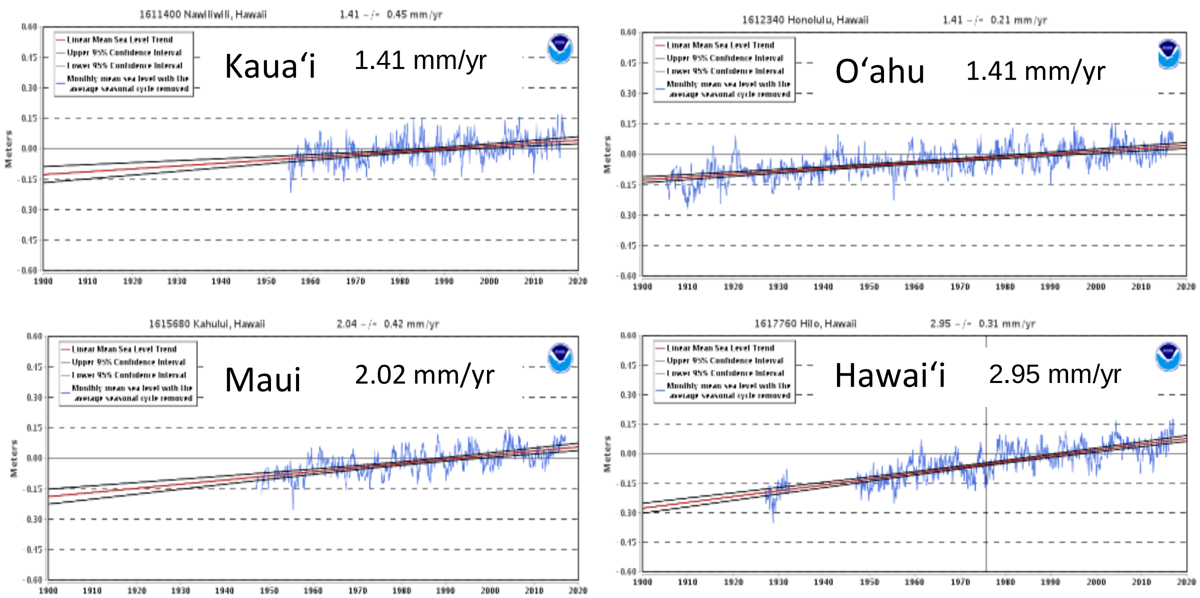


Figure 12. Observed mean sea level trends and rates of sea level rise in the Hawaiian Islands (NOAA 2017c)

It has been observed that sea level rise resulting from global warming exacerbates temporary high sea level events caused by natural climate and oceanic variability in the Pacific Ocean related to: (1) transiting elevated water masses called "mesoscale eddies", (2) El Niño events, (3) longer term (multi-decade) fluctuations called the Pacific Decadal Oscillation (PDO), and (4) wind stress. This natural variability is visible in the blue monthly mean sea level lines shown in Figure 12 and can result in fluctuations of 6 inches or more from the long-term average trend (Marra, Merrifield, and Sweet 2012, NOAA 2014). Sea level rise has also caused an increase in "sunny day" or tidal flooding. Tidal flooding occurs when tides are exceptionally high in combination with high waves and/or other oceanic and atmospheric phenomena (Moftakhari et al. 2017). Tidal flooding can have major impacts such as road overwash and backed-up storm drains in low-lying areas. On the Island of O'ahu, the city of Honolulu experienced the greatest number of tidal flooding days in 2002 and 2003, as illustrated in Figure 13 compared to 35 days in 2016 (Marra et al. 2017).

Tidal flooding is becoming increasingly common along low-lying shorelines throughout the world even in the absence of storm effects (Sweet et al. 2014). This coincides with a key finding of the recently released CSSR (USGCRP 2017) which projects that tidal flooding will continue increasing in depth, frequency, and extent this century based on observations of several U.S. coastal cities in which the number of tidal floods each year has increased 5- to 10-fold since the 1960s due to sea level rise.

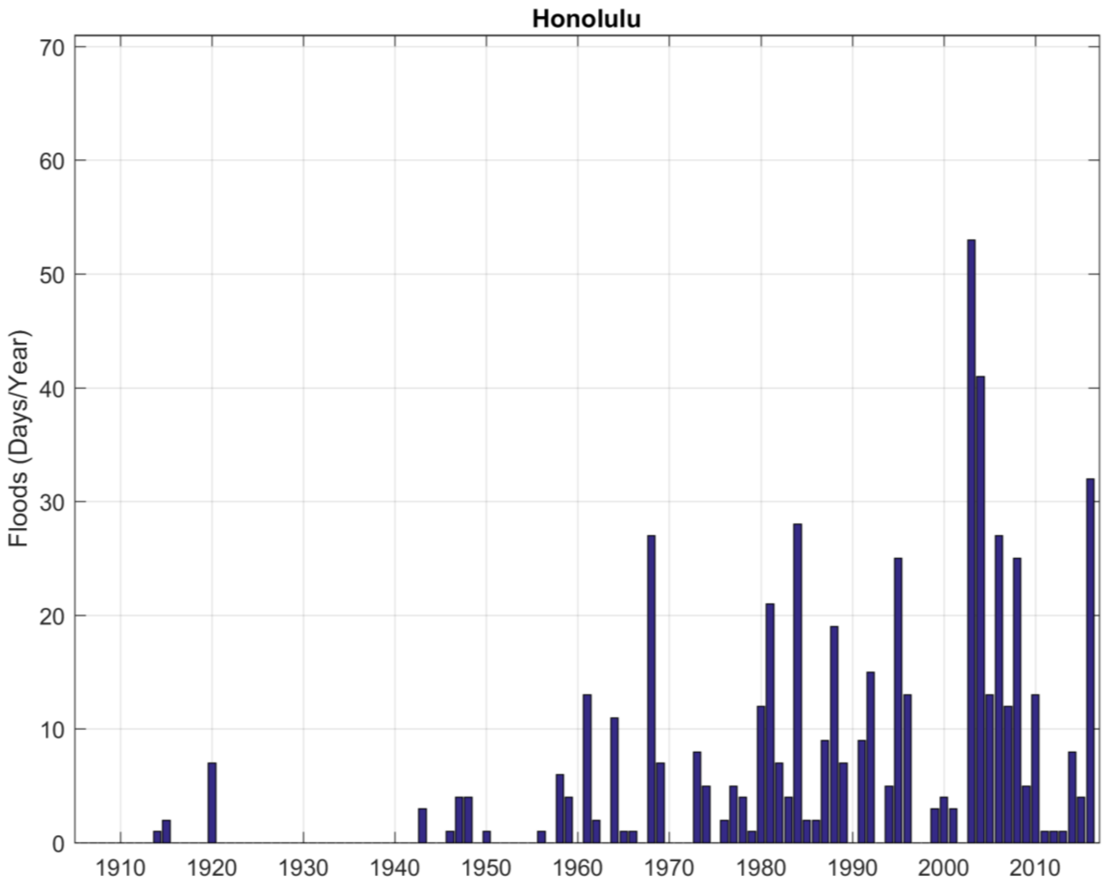


Figure 13. Number of tidal flood days per year for the observed record per calendar year for Honolulu, Hawai'i (Marra et al. 2017)

TIDAL FLOODING 2017 – A GLIMPSE INTO OUR NEAR FUTURE

Elevated water levels in spring and summer of 2017 provided a glimpse of our near future when coastal flooding events will occur more frequently and severely with continued sea level rise. The University of Hawaiʻi Sea Level Center found that the 2017 anomalously high water levels resulted from an unprecedented combination of Pacific-wide climate and ocean variability, ocean eddies with elevated centers moving through the islands, and global sea level rise on top of "king tides" (the highest astronomical tides of the year). This extraordinary combination resulted in record-high water levels on the Honolulu tide gauge and caused localized flooding and coastal erosion throughout the islands in the spring and summer of 2017. Impacts included beach overwash and erosion at Waikīkī and flooding of roads and businesses in the Mapunapuna area of Oʻahu. "Citizen scientists" helped document flooding impacts around the islands as part of the University of Hawaiʻi Sea Grant program's Hawaiʻi and Pacific Islands King Tides Project, which utilizes a free publicly available mobile application and photo database. The program and images collected are helping decision-makers and the public to better understand and visualize Hawaiʻi's vulnerability to sea level rise as well as enabling researchers to validate models of sea level rise and flooding impacts. For more information please visit: Hawai'i and Pacific Islands Project.

Modified Trade Winds (El Niño Events)

The east to west trade winds play a large role in the climate of the equatorial Pacific Ocean. These winds can vary in response to El Niño Southern Oscillation (ENSO) and PDO phases. During El Niño events, the relaxation of the trade winds causes water levels to rise in the eastern tropical Pacific. During La Niña events, enhanced trade winds "drive" water near the equator to the west resulting in lower sea levels in the eastern Pacific. El Niño events in the tropical Pacific can cause sea levels to rise 6 to 12 inches above mean conditions in some areas (Marra, Merrifield, and Sweet 2012).

Tropical Cyclones

Tropical cyclones are weather events generated in tropical latitudes characterized by very heavy rainfall and strong and damaging winds that can generate storm surge and extremely high waves. A good example of this is Hurricane Iniki, which hit the Island of Kauai as a Category 4 hurricane on September 11, 1992 causing almost $2 billion in damage. In 2015 (an El Niño year), the Central Pacific saw a historic number of tropical cyclones, with 15 named storms (Figure 14), 8 hurricanes, and 5 major hurricanes, making 2015 the most active season since reliable record-keeping began in 1970 (NOAA National Centers for Environmental Information 2016). The tropical cyclone activity, heavily influenced by a strong El Niño and widespread ocean warming across the central Pacific basin, started in early July and continued non-stop through October. Three Category 4 hurricanes, Ignacio, Kilo and Jimena, lined up across the Central and Eastern Pacific Ocean on August 29, 2015. On Sunday, August 30, from west to east, Hurricane Kilo was located 1,200 miles west-southwest of Honolulu, Hawai'i, Hurricane Ignacio was located 515 miles east-southeast of Hilo, Hawai'i, and Hurricane Jimena was located 1,815 miles east-southeast of Hilo, Hawai'i. Although none of them made landfall, this was the first time this level of hurricane activity had been observed (Figure 15). There were direct impacts to Johnston Island and portions of the Northwestern Hawaiian Islands (NWHI), and caused the evacuation of research staff on Kamole or Laysan Island.

Roof blown off during Hurricane Iniki, Kaua'i iki.
Source: FEMA News Photo - Aug 31, 1992

The number of tropical cyclones in the central Pacific is highly variable from year to year. More tropical cyclone activity is generally correlated with El Niño events. A doubling of El Niño events is projected in response to greenhouse warming (Cai et al. 2014).

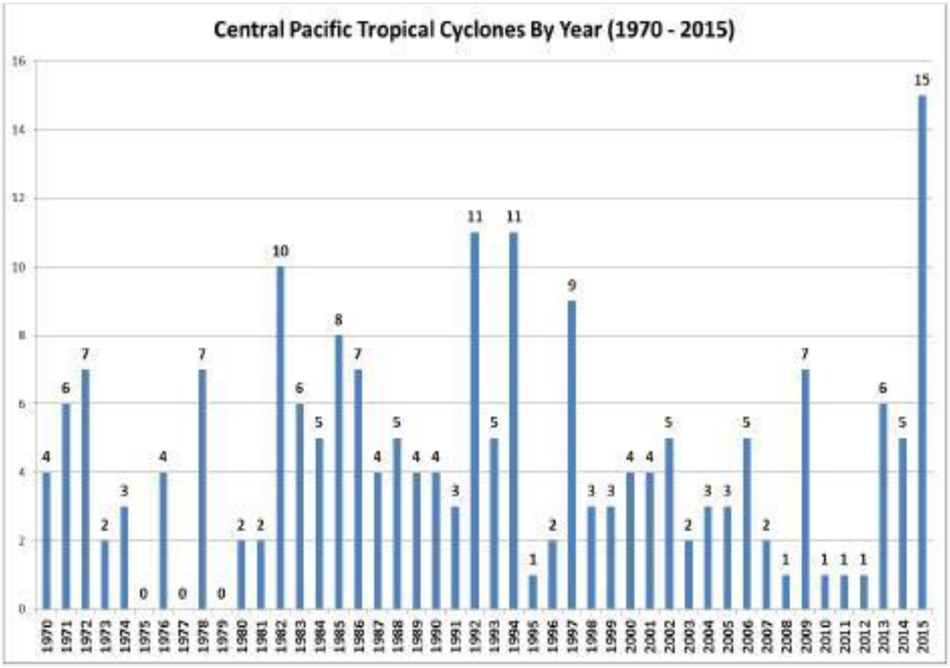


Figure 14. Number of tropical cyclones in the Central Pacific from 1970 to 2015 (NOAA 2015)

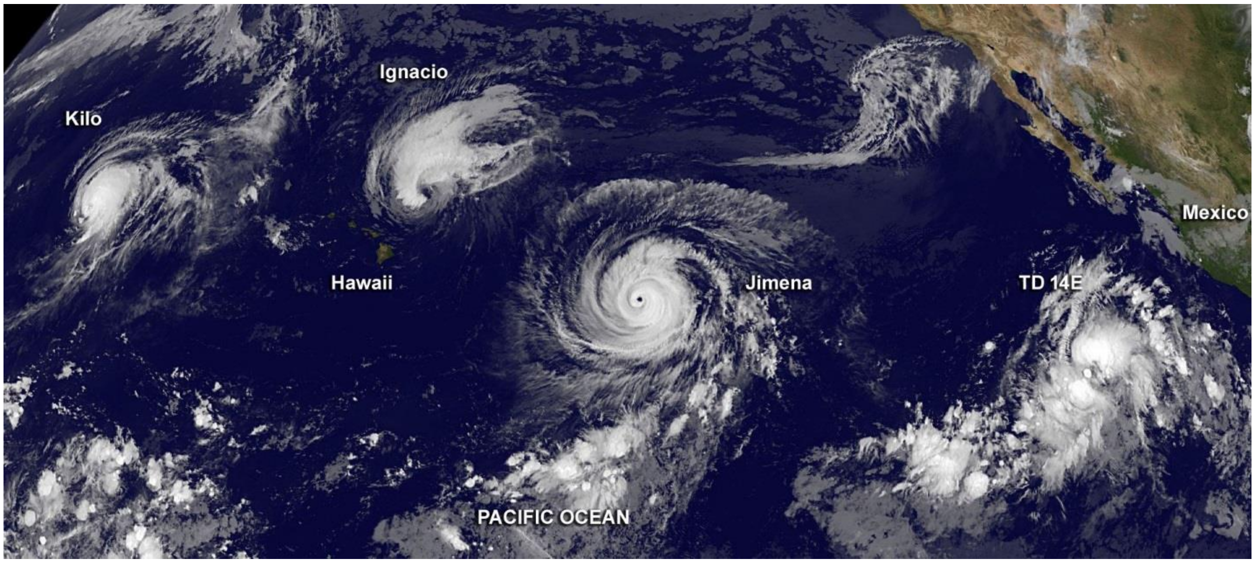


Figure 15. Hurricanes Kilo, Ignacio, and Jimena in late August 2015 (Photo: NASA)

Projections

Projections of global and local sea level rise are critical for adapting to climate change. The IPCC projections, based on a synthesis of the published literature, represent the scientific consensus on climate change. The IPCC climate and sea level forecasts represent the inputs and analyses of thousands of scientists and a broad consensus of an international group of authors and reviewers. The IPCC AR5 provides projections of global mean sea level rise for four GHG emissions scenarios (IPCC 2014).These scenarios are called representative concentration pathways (RCPs).

The RCPs describe possible climate futures based on how much GHGs are emitted. The four scenarios, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 watts per square meter). A radiative forcing is a change in the balance of incoming and outgoing energy in the Earth-atmosphere system. Sea level rise projections for the high GHG emissions scenario (RCP8.5) and the low GHG emissions scenario (RCP2.6) are shown in Figure 16.

The upper boundary of this IPCC scenario (RCP8.5) was used in modeling coastal hazards with sea level rise in this Report. This upper boundary of the business-as-usual scenario of 3.2 feet is the likely scenario because ice sheets and glaciers are melting at rates greater than accounted for in the IPCC report (NASA 2015).

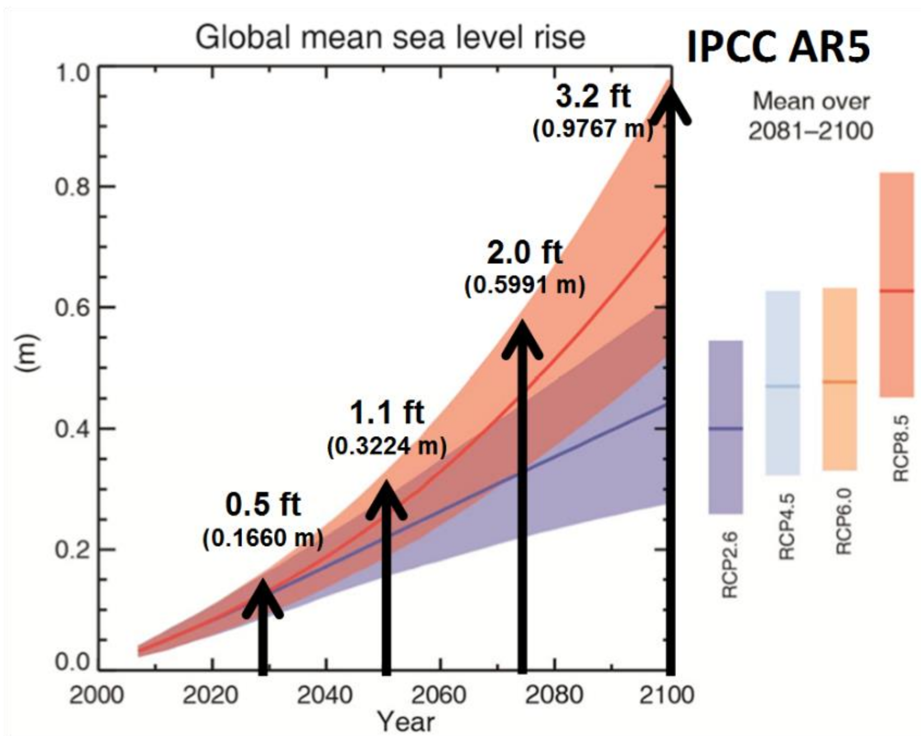


Figure 16. Projected rate of global mean sea level rise under different GHG scenarios (IPCC 2014)

On the high end, “business as usual” scenario, RCP8.5 assumes that no reduction in GHGs will occur over the period modeled (Figure 16). Uncertainty of the projections increases with time as indicated by the increasing width of the projection after the year 2050. The RCP8.5 scenario was used in the Report to model exposure to sea level rise at 0.5 feet in 2030, 1.1 feet in 2050, 2.0 feet in 2075, and 3.2 feet in 2100. The decision to use the upper limit of the IPCC projections was initially made out of precaution—to assess what is potentially vulnerable to sea level rise. Climate science and sea level rise projections have continued to evolve since the IPCC AR5 and throughout the development of this Report. Sea level observations and trends in the latest scientific literature suggest that 1.1 feet of sea level rise could be reached intermittently in Hawai‘i over the next couple of decades and sustained before mid-century. Local projections of sea level rise for Honolulu using the IPCC model but incorporating regional and local factors that influence sea level, suggest a slightly higher range of mean sea level rise of 2.0 feet (0.6 meters) to 3.6 feet (1.1 meters) in 2100 using the RCP 8.5 scenario (Kopp et al. 2014).

The recently released CSSR (USGCRP 2017) reports that relative to the year 2000, global mean sea level is very likely to rise 0.3 to 0.6 feet (9 to 18 cm) by 2030, 0.5 to 1.2 feet (15 to 38 cm) by 2050, and 1.0 to 4.3 feet (30 to 130 cm) by 2100 with very high confidence in lower bounds; medium confidence in upper bounds for 2030 and 2050; and low confidence in upper bounds for 2100. Future pathways have little effect on projected global mean sea level rise in the first half of the century, but significantly affect projections for the second half of the century (high confidence). Emerging science regarding Antarctic ice sheet stability suggests that, for high emission scenarios, a global mean sea level rise exceeding 7.9 feet (2.4 m) by 2100 is” physically plausible”, although the probability of such an extreme outcome cannot currently be assessed. Regardless of pathway, it is extremely likely that global mean sea level rise will continue beyond 2100 (high confidence).

The IPCC is currently working toward its 6th Assessment Report (AR6) which will be finalized in 2021; although a special report on climate change and the oceans and the cryosphere is expected to be released by the IPCC before the next assessment report. In the meantime, new scientific research continues to emerge providing insights into climate change and sea level rise. Antarctica, alone, has the potential to contribute more than 3.0 feet (1.0 meter) of sea level rise by 2100 if emissions continue unabated (Figure 11). Atmospheric warming will become the dominant driver of ice loss but prolonged ocean warming will delay recovery of ice sheets and glaciers for thousands of years (DeConto and Pollard 2016).

According to a recent National Oceanic and Atmospheric Administration (NOAA) report (Sweet et al. 2017) looking at the most up-to-date scientific literature on sea level rise projections, global mean sea level rise in the range of 6.4 feet (2.0 meters) to 8.8 feet (2.7 meters) is “physically plausible” by the end of this century (Sweet et al. 2017), which is much higher than the worst case IPCC AR5 projections shown in Figure 16. These high-end projections are based on observations and models of potential rapid ice melt in Greenland and Antarctica. Further, the NOAA 2017 report indicates that sea level rise in the area around Hawai‘i and other “far-field” areas in the tropical oceans will exceed projections of global mean sea level rise due to mass and gravitational changes with the melting of the Greenland and Antarctic ice sheets (Figure 17) (Sweet et al. 2017).

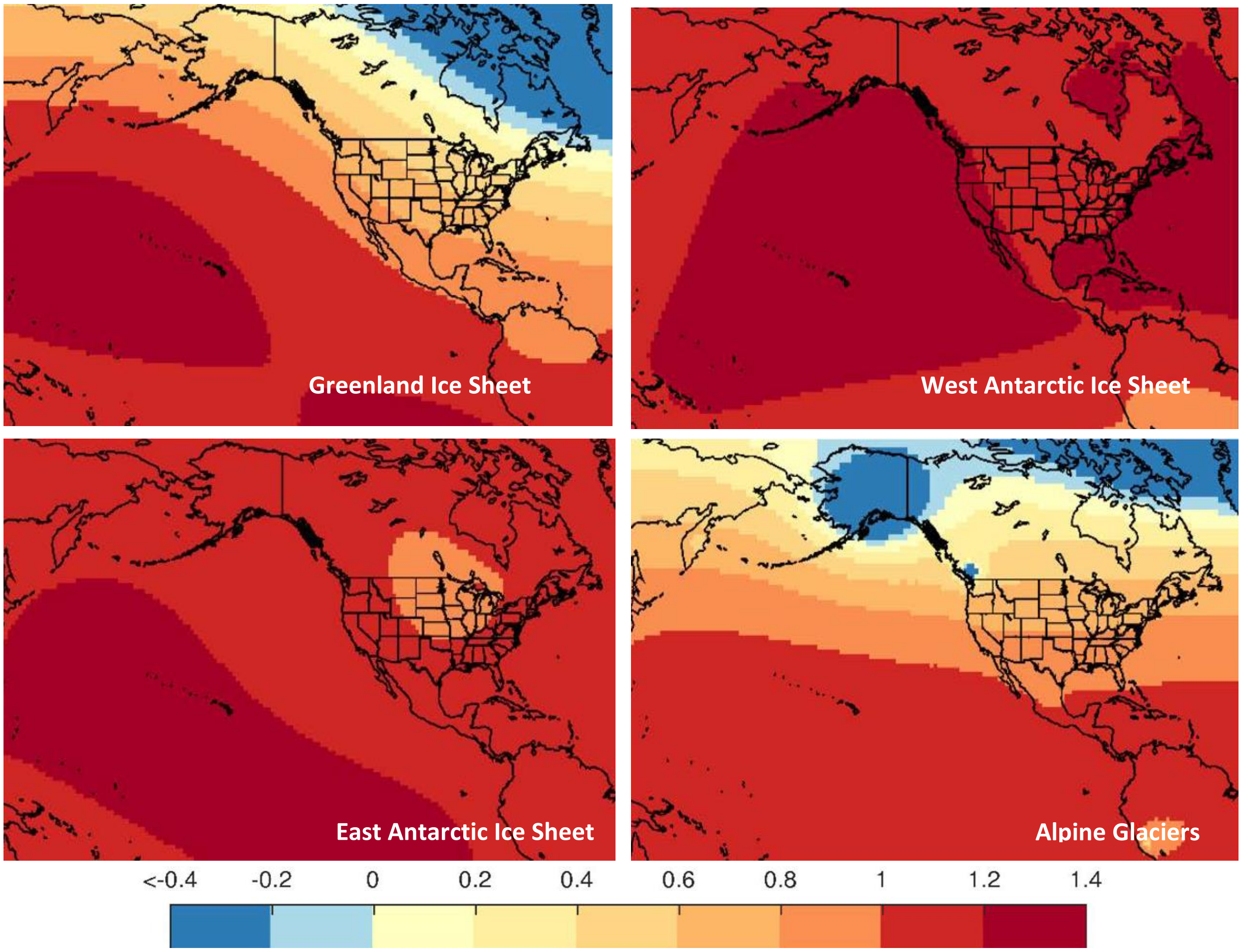


Figure 17. Ratio of projected relative sea level rise to global mean sea level rise attributed to mass loss from specific land-ice sources. Values more than 1 indicate areas with projected relative sea level rise greater than the global average sea level rise (Sweet et al. 2017)

> "*Given what we know now about how the ocean expands as it warms and how ice sheets and glaciers are adding water to the seas, it's pretty certain we are locked into at least 3.0 feet [0.9 meters] of sea level rise and probably more.*" (NASA 2015)
>
> *"Humanity faces near certainty of eventual sea level rise of 16.4 to 29.5 feet (5.0 to 9.0 meters) if fossil fuel emissions continue on a business-as-usual course."* (Hansen et al. 2015)

The recently released CSSR (USGCRP 2017) states that assuming storm characteristics do not change, sea level rise will increase the frequency and extent of extreme flooding associated with coastal storms, such as hurricanes. In addition to global sea level rise, global projections of tropical cyclone activity indicate an increase in average cyclone intensity, precipitation rates, and in the overall number and occurrence-days of very intense category 4-5 storms (Knutson et al. 2015). Further, projections depict a global average migration of tropical cyclone activity away from the tropics at a rate of about one degree of latitude per decade (Kossin, Emanuel, and Vecchi 2014) and increased frequency of occurrence of tropical cyclones in the Central Pacific (Murakami et al. 2013). Waves and storm surge from nearby tropical cyclones and swell from more distant cyclones would also be expected to increase coastal flooding and erosion which would be further worsened by sea level rise. A doubling of the occurrence of El Niño events is also projected (Cai et al. 2014) which can sustain more tropical cyclone activity and corresponding wave action, flooding, and erosion.

THE BOTTOM LINE

Rising sea level and projections of stronger and more frequent El Niño events and tropical cyclones in waters surrounding Hawaiʻi, all indicate a growing vulnerability to coastal flooding and erosion. While the IPCC's business-as-usual scenario predicts up to 3.2 feet of global sea level rise by 2100, recent observations and projections suggest that this magnitude of sea level rise could occur as early as year 2060 (Sweet et al. 2017). For this reason, it is vital that we track the magnitude and rate of sea level rise as new projections emerge, plan for 3.2 feet of sea level rise now, and be ready to adjust that projection upward. It is also important to recognize that global sea level rise does not stop at 2100 but will very likely continue for centuries.

Learning Questions for the 5-Year Report Update

Learning questions for this chapter are driven by the understanding that climate science is evolving and sea level rise projections will be updated. New sea level rise projections incorporating the latest climate science will be available in the in the IPCC A6 report due in 2021. This assessment and future National Climate Assessments should serve as milestones for the evaluation of sea level rise projections for Hawaiʻi.

Learning questions that should be considered for the 5-year report update include:

1. What are the observations of change in sea level in the vicinity of the Hawaiian Islands, and how do they correspond with the recent global acceleration in mean sea level rise?
2. To what extent has the magnitude and timing of the sea level rise projections from IPCC AR5 changed with new projections from the IPCC AR6?
3. What are the observations and projections of the frequency and intensity of tropical cyclones and El Niño events and their effects on coastal water levels and tidal flooding?

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Methodology

E nānā ana i ka ʻōpua o ka ʻāina. Observing the horizon clouds of the land. Seeking to discover future events by observing the cloud omens.

Our understanding of Hawaii's vulnerability to coastal hazards has largely been grounded in observations of the past. In a changing climate, projections of future conditions must be combined with historical trends to assess the social, cultural, economic, and environmental vulnerabilities to sea level rise. Modeling, using the best available science and methods, was conducted to determine the potential future exposure of each island to multiple coastal hazards as a result of sea level rise. Using the outputs of this coastal hazard modeling, vulnerability was assessed to provide information and data needed to support efforts to encourage Hawaii's adaptation to sea level rise.

Call to Action

"Sea level rise will force us to address existing and prevent future private development along shorelines. Multiple planning and regulatory strategies are needed to both incentivize and criminally discourage reckless, unfettered coastal development over short and long terms. These strategies will result in reduction in environment, property and human losses, possible gains in public spaces, and better usage of public funds."

Group message developed during the 1st Sea Level Rise Vulnerability and Adaptation Workshop, Oʻahu January 2016

Key Take-Aways

- Exposure to multiple coastal hazards was modeled using the best available historical data and projections of sea level rise derived from the upper boundaries of the IPCC's AR5 "business-as-usual", RCP8.5 scenario.
- Previous studies of sea level rise hazard exposure for Hawai'i and elsewhere have typically relied on "bathtub" models of passive flooding with sea level rise (e.g., raising static water levels over digital topographic maps), which does not account for the effects of more landward seasonal wave inundation and higher erosion rates along our coasts due to rising seas.
- A more thorough assessment of sea level rise impacts and hazard exposure was produced in this study by modeling three types of hazards: passive flooding, annual high wave flooding (average annual high wave over-wash at the shoreline), and coastal erosion (shoreline recession and land loss).
- Chronic flooding with sea level rise is depicted as the SLR-XA based on the combined outputs of modeling passive flooding, annual high wave flooding, and coastal erosion.
- Data on the social, economic, and environmental valued assets that were used in the vulnerability assessment were obtained from existing federal, state, and county databases.
- Vulnerability to sea level rise was assessed in terms of the potential impacts to people, structures, land, infrastructure, beaches, cultural resources, and other assets vulnerable to sea

level rise using a geographic information system (GIS) and Federal Emergency Management Agency (FEMA) software, Hazards-U.S. (Hazus).

- Vulnerability to chronic flooding in the SLR-XA (e.g., the combined effects of high wave flooding, passive flooding, and erosion) was assessed in terms of the potential permanent loss of structures, land, and other valued assets.
- The added risk of event-based coastal flooding with sea level rise resulting from hurricanes, tropical cyclones, and tsunamis is not included in this Report.
- Assumptions and limitations of the methodology are articulated to support the monitoring and evaluation of learning questions as part of the 5-year Report update.

Coastal Hazards Modeling with Sea Level Rise

Hawai'i experiences coastal flooding and erosion due to high waves and tides, and infrequent events such as storm surges and tsunamis (Figure 18). With higher sea level, waves and tides will reach farther inland and with greater velocity resulting in increased coastal erosion, flooding, and overall damage to coastal communities. Previous studies of sea level rise hazard exposure for Hawai'i and elsewhere typically rely on "bathtub" models to estimate passive flooding with sea level rise (NOAA 2017b). The bathtub model provides a good first look at sea level rise hazards by identifying low-lying coastal areas and employing a static digital elevation model (DEM) to raise water levels over existing topography. However, the model does not account for potentially significant damage from higher sea level rise when annual (e.g., typical seasonal wave set-up) high waves, erosion, and storms are added to the model mix. To provide a more thorough assessment of sea level rise hazard exposure and vulnerability, this study assesses three types of hazards: passive flooding, annual high wave flooding (average annual high wave over-wash at the shoreline), and coastal erosion (shoreline recession and land loss).

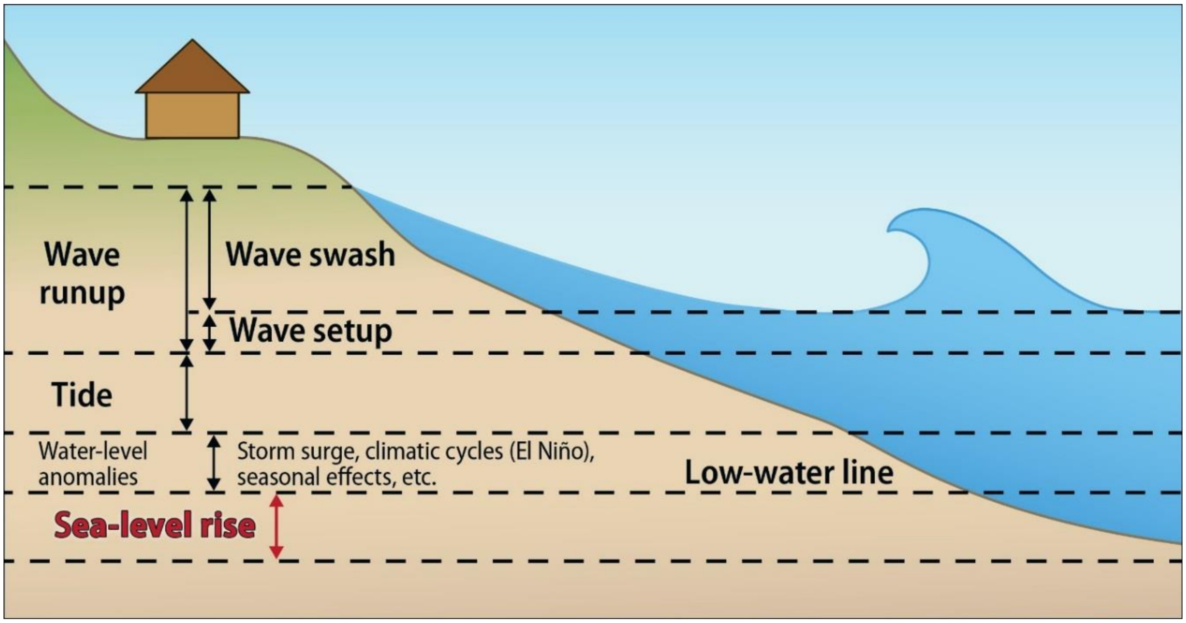


Figure 18. Water level components that contribute to coastal flooding (Vitousek et al. 2017)

Coastal hazards modeling was conducted by two teams: The Coastal Geology Group at UH SOEST who modeled (1) passive groundwater, drainage, and marine flooding, (2) coastal erosion, and (3) annual high wave flooding with sea level rise (Table 1) and Tetra Tech who developed the combined exposure to these three hazards referred to as the SLR-XA. Not all hazards were modeled for each island due to limited historical information and geospatial (map) data (Table 1). As such, the SLR-XA for the islands of Molokaʻi, Lānaʻi, and Hawaiʻi are based on modeling for passive flooding only.

Table 1. Coverage of hazard modeling by island

Island	Sea Level Rise Exposure Area (SLR-XA; Chronic Flooding)		
	Passive Flooding	Coastal Erosion	Annual High Wave Flooding
Kauaʻi	√	√	√
Oʻahu	√	√	√
Maui	√	√	√
Molokaʻi	√	–	–
Lānaʻi	√	–	–
Hawaiʻi	√	–	–

Global Sea Level Rise Projections

Coastal hazards were modeled using the IPCC global sea level rise projections. The IPCC AR5 identified four sea level rise scenarios based on RCPs (IPCC 2014). The "business-as-usual" scenario, RCP8.5, was used in coastal hazard modeling for this Report. For passive flooding and annual high wave flooding, the upper boundary of the RCP8.5 scenario was used to model coastal hazards in the future (Table 2; see also Figure 16). In modeling coastal erosion, the uncertainty (upper and lower bounds) of the RCP8.5 sea level rise projection was used (Figure 16).

Assumptions and Limitations. The IPCC AR5 "business-as-usual" GHG emissions scenario, RCP8.5, which predicts as much as 3.2 feet of sea level rise by the year 2100, was used as the basis of our modeling effort. For the Report, the decision to use the upper limit of the IPCC projections was initially made "out of an abundance of precaution." Since the release of the IPCC AR5, leading climate scientists and organizations, such as NOAA, are reporting that higher scenarios of sea level rise in this century are more likely than previously thought primarily due to improving understanding of the Antarctic and Greenland ice sheet instability (see discussion in previous SLR Outlook chapter). As noted throughout this Report, climate science and sea level rise projections have continued to evolve since the IPCC AR5 report and will continue to do so after this Report is completed.

Table 2. Upper boundaries of global sea level rise projections used in modeling coastal hazard exposure based on IPCC AR5 RCP8.5 (IPCC 2014)

Year	Global Sea Level Projection (feet)	Global Sea Level Projection (meters)
2030	0.5	0.1660
2050	1.1	0.3224
2075	2.0	0.5991
2100	3.2	0.9767

Notes:
IPCC Intergovernmental Panel on Climate Change
AR5 Assessment Report 5 (of the IPCC), 2014
RCP Representative Concentration Pathway

Passive Flooding

Passive flooding, also known as hydrostatic flooding, is depicted by bathtub modeling. Passive flooding includes marine flooding over the shoreline by stillwater flow into the lands that lie below the water level. It also depicts low-lying areas indirectly flooded by sea level rise through water table rise. Passive flooding is exacerbated by rainfall as it prevents drainage and as such, runoff and marine waters combine to produce larger impacts. Passive flooding was modeled by UH SOEST using a modified "bathtub" approach that accounts for both regional tidal variability and hydrological connectivity (Cooper et al. 2013). Passive flooding represents the simplest projection and provides an initial assessment of low-lying areas susceptible to flooding by sea level rise. Passive flooding includes areas that are hydrologically connected to the ocean (marine flooding) and low-lying areas that are not hydrologically connected to the ocean (groundwater) (Figure 19).

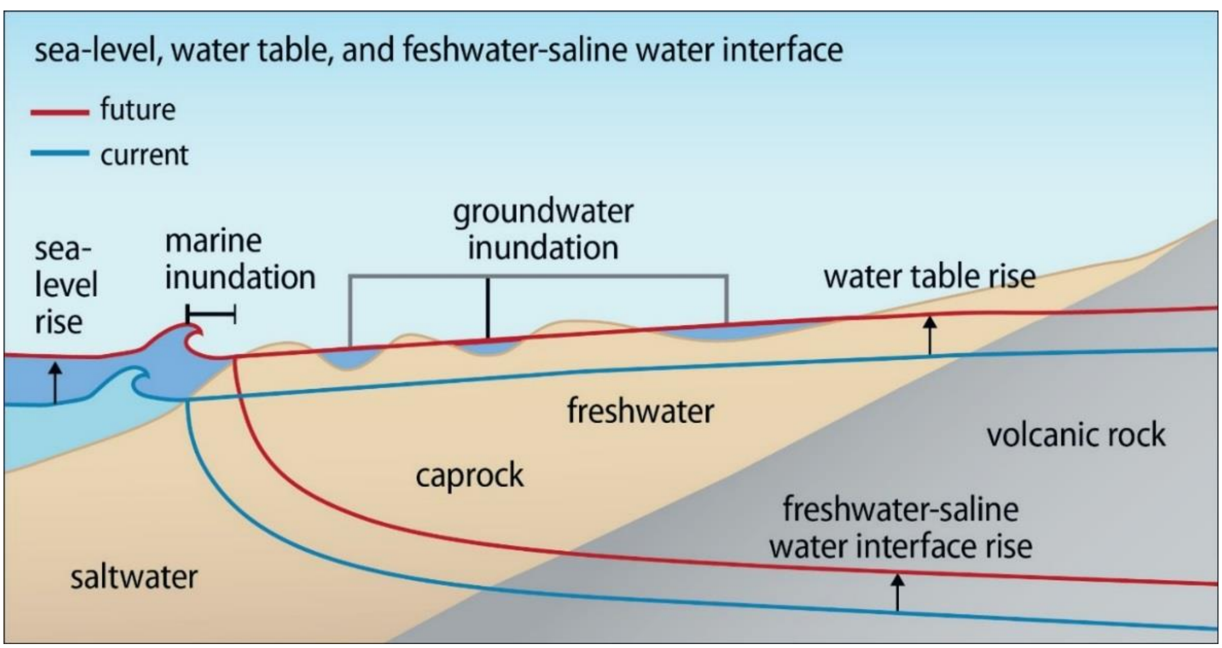


Figure 19. Schematic diagram showing passive marine and groundwater flooding from current sea level (blue) to future sea level (red) (Rotzoll and Fletcher 2013)

Data Inputs. Data used in modeling passive flooding included the global sea level rise projections discussed above, DEMs, and the mean higher high water (MHHW) datum. A DEM is a three-dimensional (3D) representation of a terrain surface. DEMs are derived from aerial light detection and ranging (LiDAR) data. DEMs used in this study are freely available from NOAA and the U.S. Army Corps of Engineers (USACE) and include nearshore bathymetry.

Hazard modeling for passive flooding used DEMs with either 1-meter (i.e.1x1 meter) or 3-meter grid cells in order to capture the full extent of flooding for 3.2 feet of sea level rise for all islands (Figure 20). The 1-meter resolution DEM was compiled by the Coastal Geology Group at UH SOEST and derived from USACE 2013, 1999-2003Topo/Bathy LiDAR data surveys and UH SOEST multi-beam and side-scan sonar data. This dataset includes both terrain and bathymetric LiDAR returns. The horizontal positional (locational) accuracy root mean square error at the 95% confidence interval (RMSE 95%) of the DEM is better than 1.0 meter while the vertical positional accuracy is 0.09 meters (9 centimeters) for the terrain LiDAR, 0.125 meters (12.5 centimeters) for shallow bathymetric returns, and 0.20 meters (20 centimeters) for deeper water returns. The NOAA 3-meter DEM incorporates LiDAR data sets collected between 2003 and 2007 from NOAA, FEMA, the State of Hawai'i Emergency Management Agency, and the USACE (NOAA National Centers for Environmental Information 2017). The high-resolution DEM (1-meter), which covers terrain near the shoreline, was combined with the lower-resolution DEM (3-meter), which covers more inland terrain, to expand the overall coverage of the DEM for modeling passive flooding. All DEMs were processed using a smoothing algorithm to remove buildings, trees, and other features to create a "bare-earth" topographic surface.

The horizontal and vertical positional accuracies of the DEMs conform to FEMA flood hazard mapping standards (FEMA 2012). Those standards specify a maximum horizontal (location) accuracy of 3.3 feet (1.0 meter) and a vertical (elevation) accuracy of no more than 1.0 feet (0.3 meters) based on the RMSE 95%. The DEMs used in this study were adjusted vertically from ellipsoid heights to match a local tidal datum based on local mean sea level using a single offset value calculated by NOAA and derived from tidal benchmarks for each island (NOAA 2017a).

The MHHW datum was used as a reference (base-level) height for modeling sea level rise. The MHHW datum is the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch (1983 to 2001).

Modeling Approach. Passive flooding was modeled using the DEMs in GIS software to identify areas below a certain sea level height (flooded by sea level rise) when raising water levels above current MHHW tidal datum. Water levels are shown as they would appear during MHHW, or the average higher high water height of each tidal day (NOAA 2013). The area flooded was derived by subtracting a tidal surface model from the DEM. For more information on the methods employed refer to Cooper et al. (2012) and Cooper et al. (2013). For quality control, modeled flooded areas were compared against known elevations. Example maps of modeled passive flooding for Punalu'u, O'ahu with 1.1 and 3.2 feet of sea level rise are provided in Figure 21.

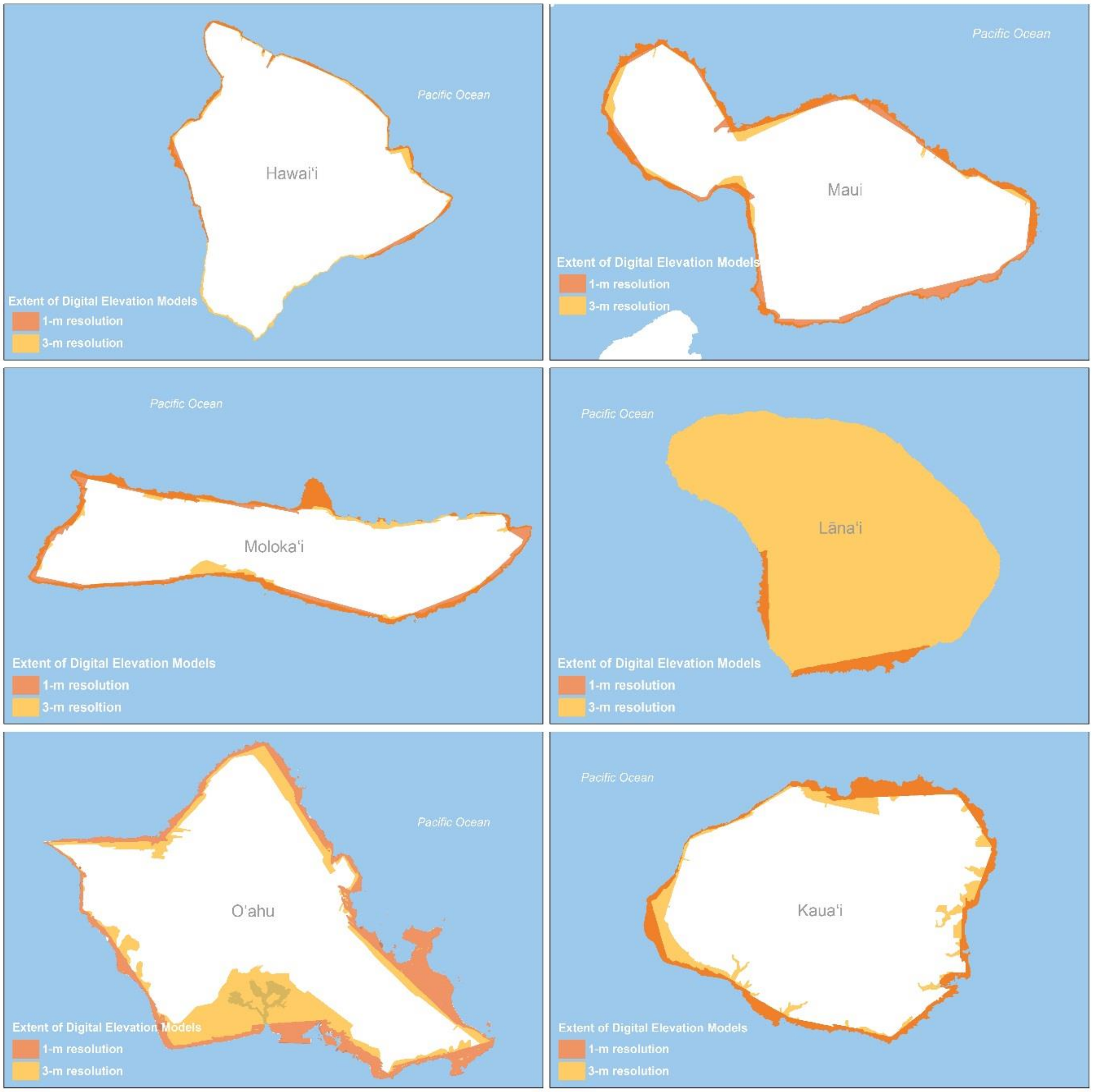
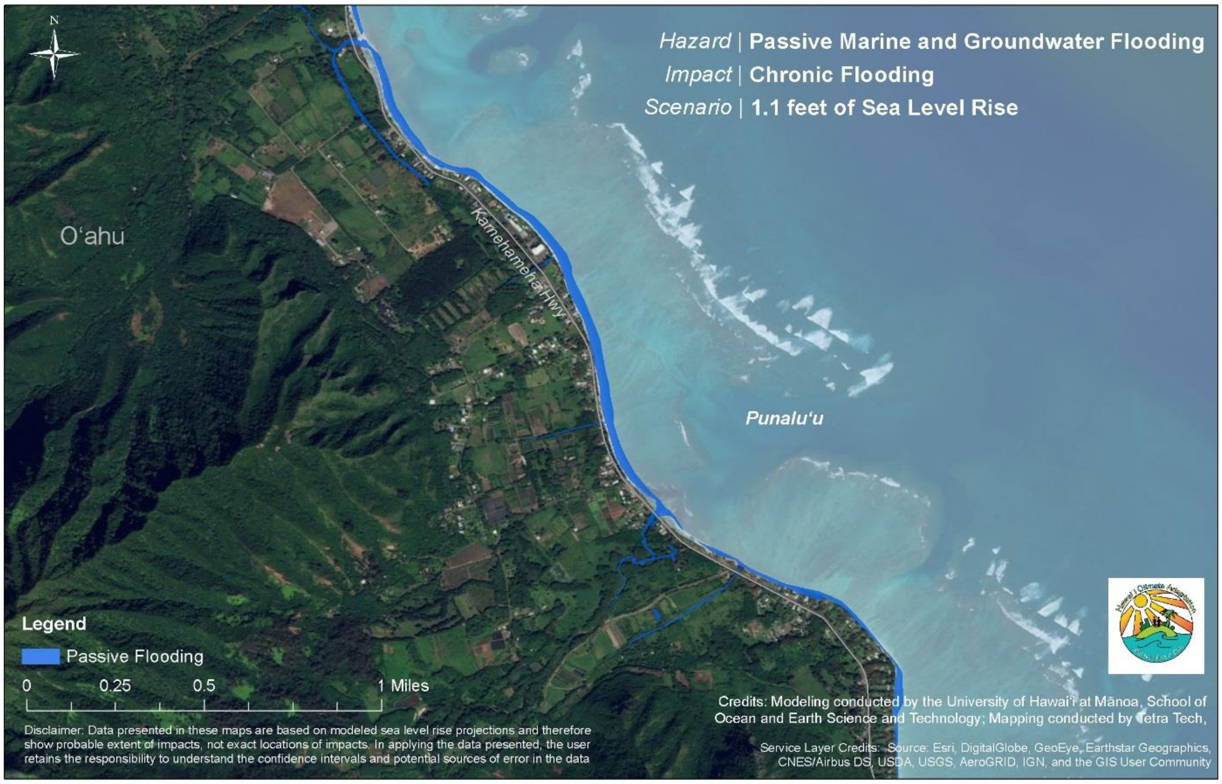


Figure 20. Extent of 1-meter and 3-meter resolution digital elevation models for the main Hawaiian Islands



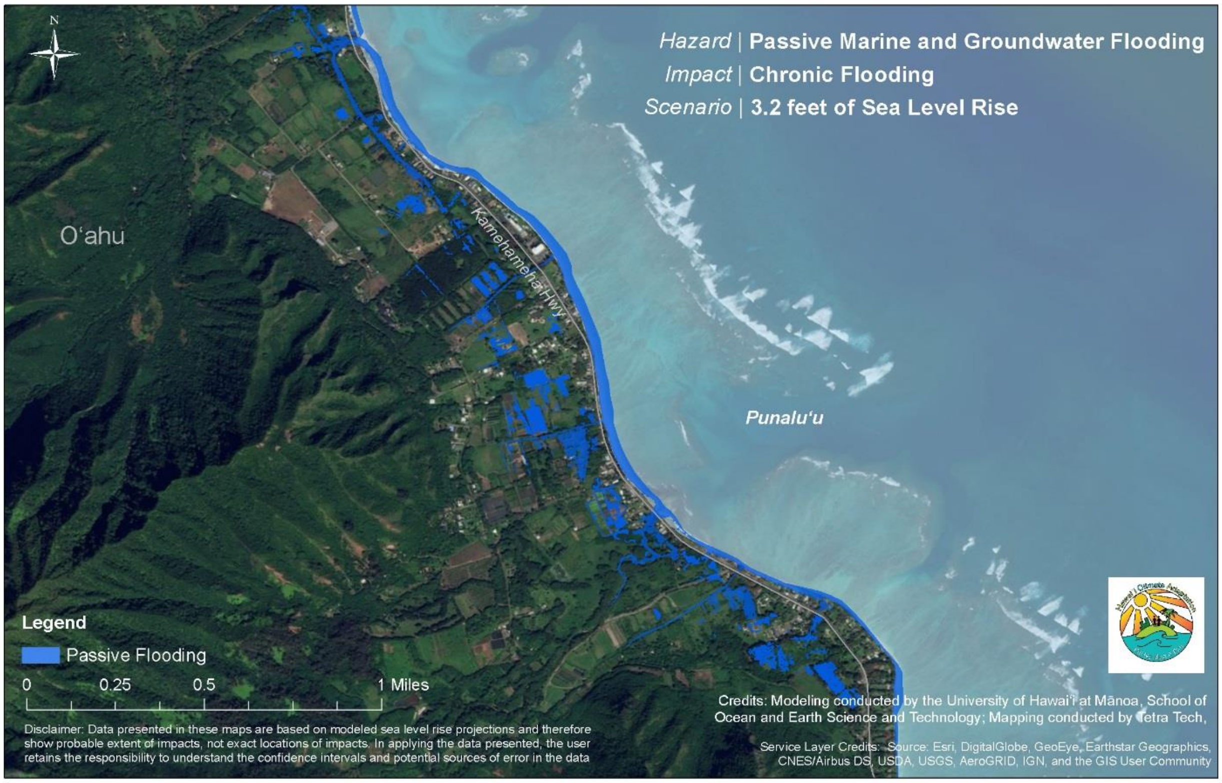


Figure 21. Example maps showing results of modeling passive marine flooding (blue) and groundwater flooding (green) with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise at Punalu'u, O'ahu

Assumptions and Limitations. In many areas around the State, representing sea level rise from passive marine flooding will likely produce an underestimate of the area inundated or permanently submerged because the model does not account for waves and coastal erosion, important processes along Hawaii's highly dynamic coasts that increase the extent of potential hazards and damages along our shores. For this reason, coastal erosion and annual high wave flooding are also modeled to provide a more comprehensive picture of the extent of hazard exposure with sea level rise in Hawaiʻi.

The passive flooding model does not explicitly include flooding through storm drain systems and other underground infrastructure, which will contribute to flooding in many low-lying areas identified in the model. The DEMs used in modeling depict a smoothed topographic surface and do not identify basements, parking garages, and other development below ground that will be affected by marine and groundwater flooding with sea level rise. As with the other models in this Report, the passive flooding model is intended to provide an initial screening tool for sea level rise vulnerability. More detailed hydrologic and engineering modelling may be necessary to fully assess passive marine flooding hazards at the scale of individual properties.

Hanapepe salt pond, Kauaʻi during tidal flooding event in 2017
Source: Ruby Pap

Annual High Wave Flooding

The distance over which waves run-up and wash across the shoreline will increase with sea level rise. As water levels increase, less wave energy will be dissipated through breaking on nearshore reefs and waves will arrive at a higher elevation at the shoreline. Hawai'i is exposed to large waves annually on all open coasts due to our location in the Central North Pacific Ocean. High wave events generated by distant and localized storms, combined with extreme high tides, frequently cause damaging overwash and flooding. High waves arrive at Hawaii's shores from four primary sources: swell from North Pacific storms in winter months, swell from distant southern hemisphere storms in summer months, easterly trade wind waves year round, and infrequent southerly "Kona" storm waves, found typically during the winter months (Figure 22) (Vitousek and Fletcher 2008). Key inputs and outputs of modeling annual high wave flooding are illustrated in Figure 23.

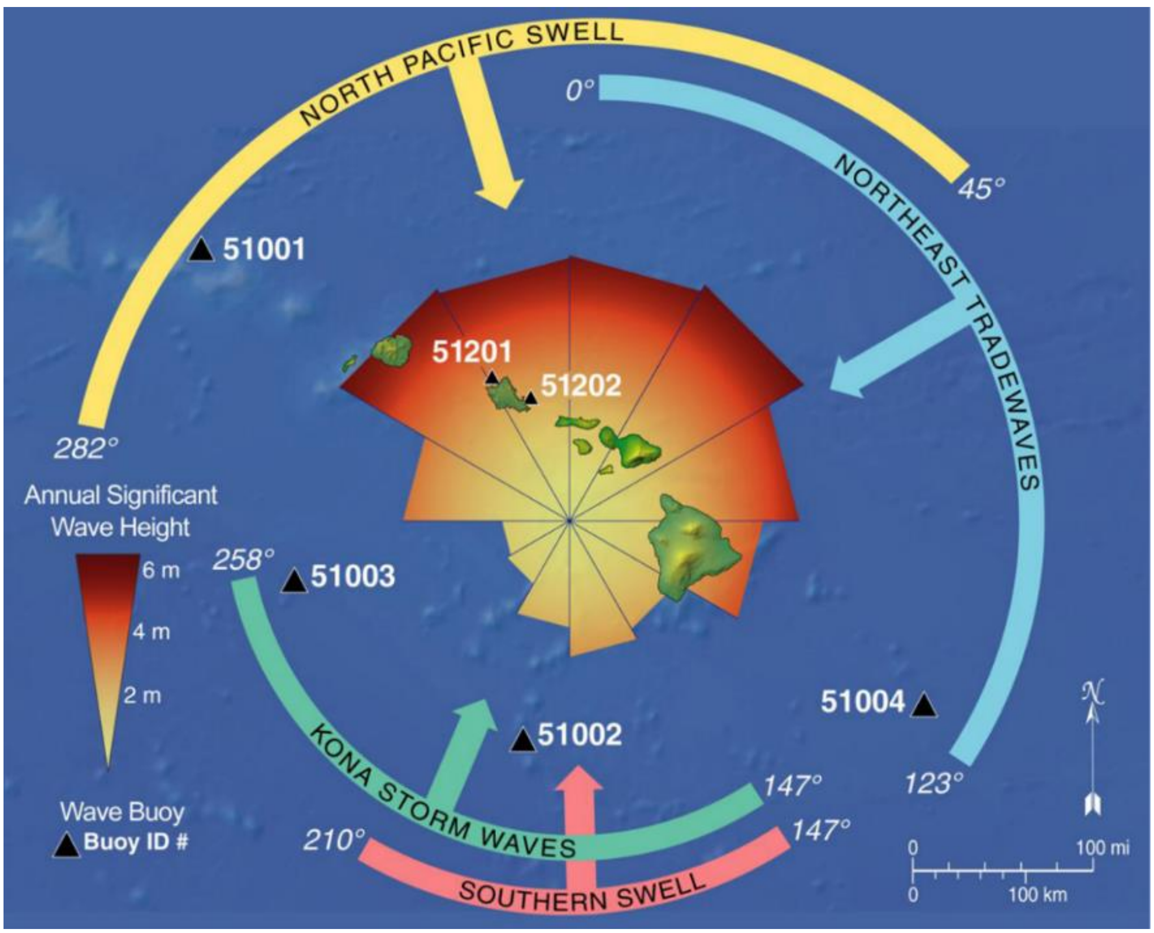


Figure 22. Dominant swell regimes and wave-monitoring buoy locations in Hawai'i (Vitousek and Fletcher 2008)

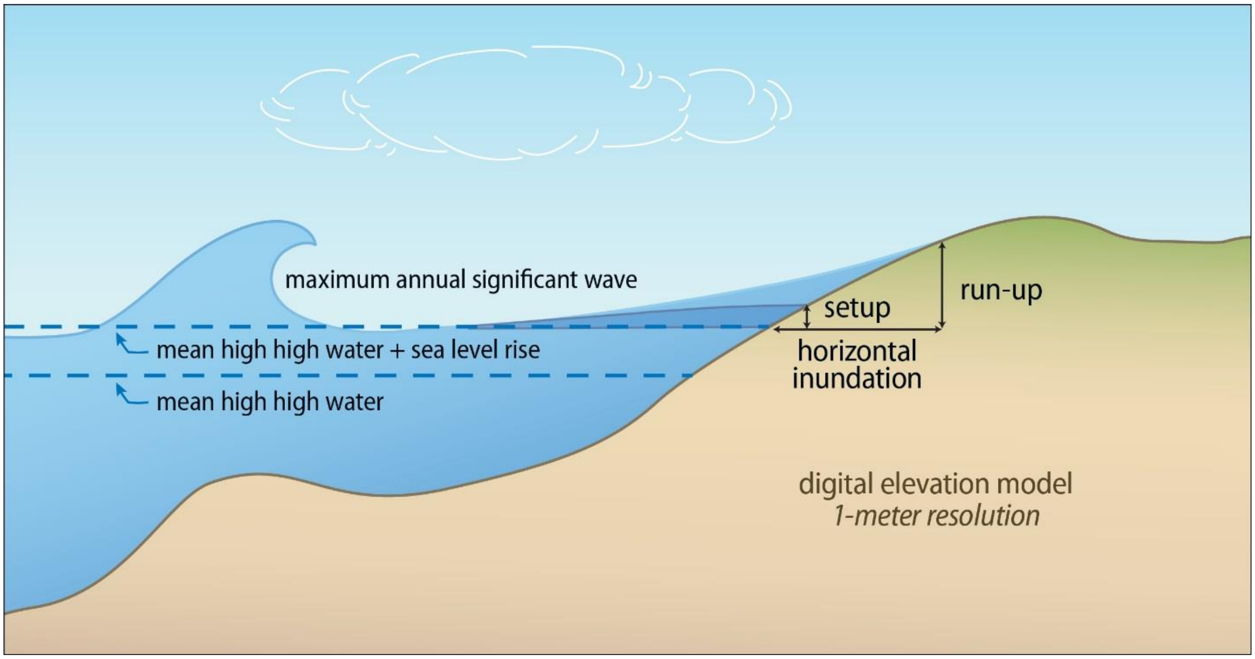


Figure 23. Schematic diagram of showing key inputs and outputs of modeling annual high wave flooding

Data Inputs. Historical data used to model annual high wave flooding consisted of modeled hourly measurements of significant wave height, peak wave period, and peak wave direction, acquired from offshore wave buoy data from the Pacific Islands Ocean Observing System (PacIOOS) (PacIOOS 2017). Offshore waves for coasts around Oʻahu, Kauaʻi, and Maui islands were modeled from the buoy data by PacIOOS beginning June 2010, using the Simulated WAves Nearshore (SWAN) model developed by researchers at Delft University of Technology in the Netherlands (SWAN 2017). The incoming wave conditions used at the outer geographic boundaries for the regional SWAN models were provided by the WaveWatch III model, as developed by NOAA (NOAA 2016c). Modeled SWAN estimates were preferred over wave buoy records because the model provides nearshore wave parameters for all locations at roughly 500-meter resolution, which also incorporates the effects of nearshore coastal dynamics such as refraction, shoaling, and island shadowing.

The maximum annually recurring wave parameters (significant wave height, peak wave period, and peak wave direction) from the historical modeled wave record were used to model annual high wave flooding exposure. Maximum wave parameters were determined at offshore locations spaced roughly 1.5 kilometers apart along the coast and in about 20 to 35 meters of water depth. At each location, the maximum annually recurring significant wave height was determined by performing a generalized extreme value (GEV) analysis on the historical wave record, following the method presented in Vitousek and Fletcher (2008).

Annual peak wave periods are the median of all wave periods corresponding to extreme wave heights within one standard deviation of the annual maximum significant wave height from the GEV analysis. To determine the annual peak wave direction, the above procedure was repeated on subsets of historical wave heights, where each subset only included waves that approached from a prescribed 30° directional window with 15° overlap between windows. For example, one subset contained only waves whose hourly peak directions were between 0-30°N, while another window contained waves whose hourly peak directions were between 15-45°N.

The maximum peak direction was defined as the center of the directional window with the largest significant wave height and peak wave period, which typically coincided with waves arriving parallel to the shore. On occasion, the largest significant wave height and peak wave period were not in the same directional window; in these circumstances, expert elicitation was used to determine the appropriate window.

Hazard modeling for annual high wave flooding used the higher resolution, but narrower landward-extent, 1-meter DEM.

Modeling Approach. Annual high wave flood modeling was conducted only for Maui, Oʻahu, and Kauaʻi and did not cover all shorelines (Figure 24). Computer model simulations of future annual high wave flooding were conducted by UH SOEST using the XBeach (for eXtreme Beach behavior) numerical model developed by a consortium of research institutions (Deltares 2017). Key inputs and outputs of the model are shown in a simplified schematic diagram in Figure 23. The model propagates the maximum annually recurring wave from roughly 15 to 35 meter water depth, over the reef, and to the shore, along one-dimensional (1D) cross-shore profiles extracted from a 1-meter DEM. Profiles are spaced 20 meters apart along the coast. This approach was used to model the transformation of the wave as it breaks across the reef and includes shallow water wave processes such as wave set-up and overtopping.

Maximum surface elevation and depth of the annual high wave flooding is calculated from the mean of the five highest modeled water elevations at each model location along each profile. Output from the simulations is interpolated between transects and compiled in a 5-meter map grid. Depth grid cells with values less than 10 centimeters are not included in the impact assessment. This was done to remove very thin layers of water excursions that (1) are beyond the accuracy of the model and (2) might not constitute a significant impact to land and resources when only occurring once annually. Any low-lying flooded areas that are not connected to the ocean are also removed. Example maps of modeled high annual high wave flooding for 1.1 and 3.2 feet of sea level rise are shown in Figure 25.

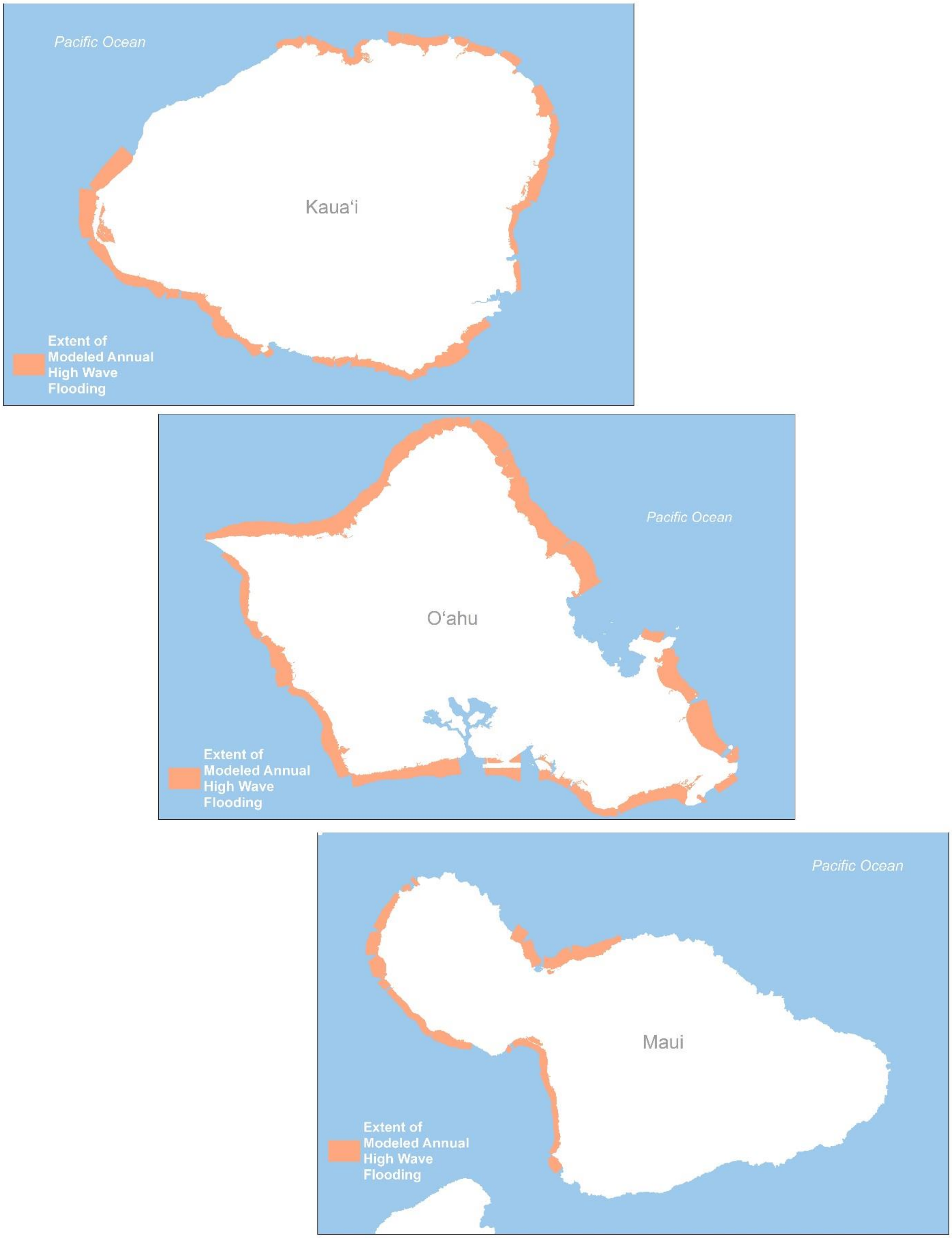


Figure 24. Extent of annual high wave modeling on Kaua'i, O'ahu, and Maui

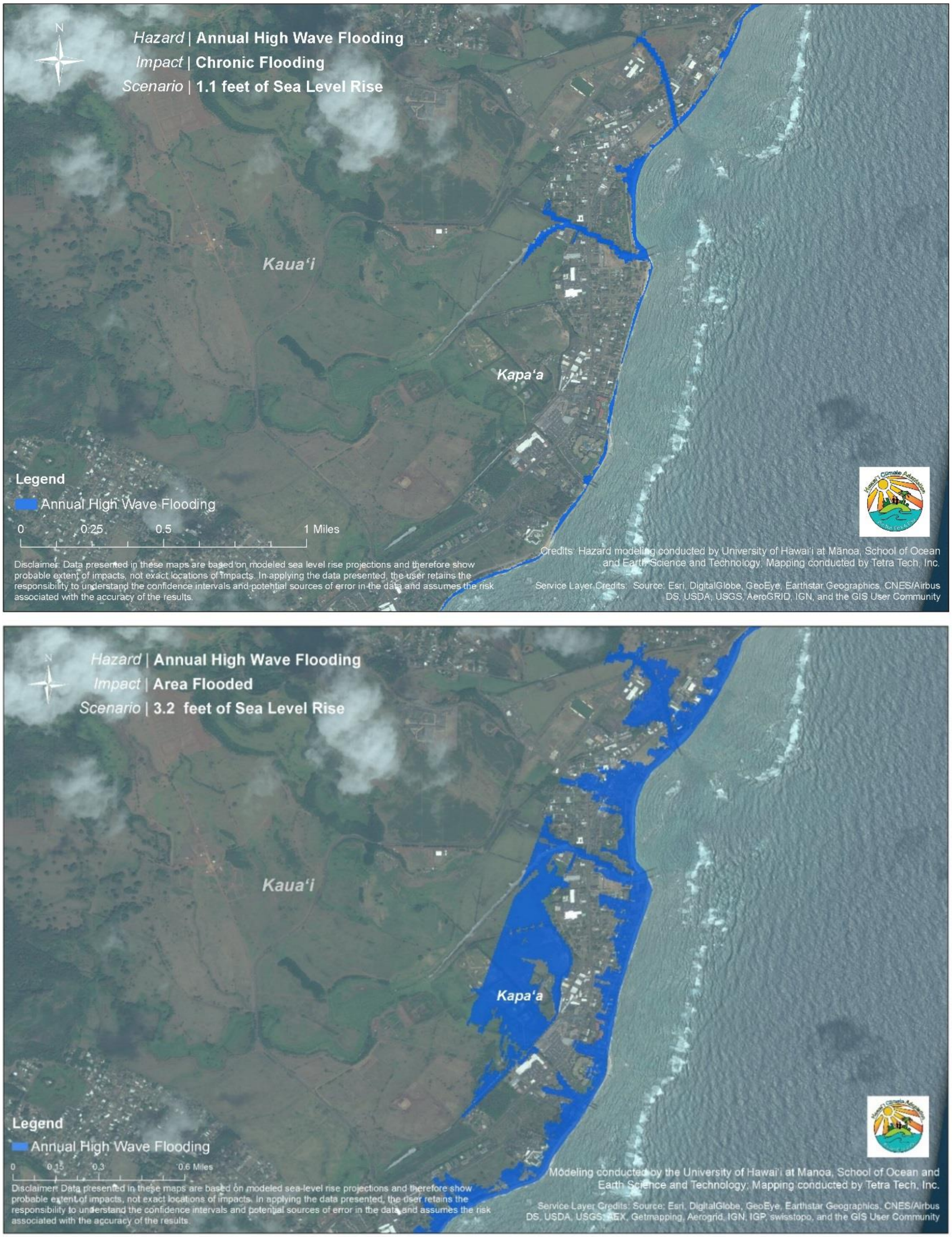


Figure 25. Example maps showing results of annual high wave flood modeling with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise for Kapa‘a, Kaua‘i

Assumptions and Limitations. The historical wave parameters used to model annual high wave flooding do not include possible changes to future wave characteristics related to climate change. The historical wave records used in this study only extend back to the year 2010; annual wave statistics would be improved with a longer time series of wave data. However, tests (using data from a wave buoy) that compared annual wave statistics over a 30-year time span with annual wave statistics over several truncated, 6-year time spans showed that the significant wave heights differed by only about 5%.

Annual high wave flood modeling did not cover all shorelines (Figure 24). The maximum annually recurring wave parameters (significant wave height, period, direction) were statistically determined using historical wave climate records and do not include potential changes in future wave climate or the effects of storm surge. In addition, in some cases the extent of the 1-meter DEM limited the extent of flooding modeled as is reflected in a straight edge of landward results from 3.2 feet of sea level rise in Figure 25. The maximum annual wave heights (and periods) do not account for less-frequently occurring wave events that can take place in any given year. For example, a 1-in-10 year wave event would not be included in this wave modeling.

Changes in shoreline location due to coastal erosion are not included in this modeling. As shown in Anderson et al. (2015) and this Report, the vast majority of beaches are expected to undergo increasing erosion and shoreline retreat with increasing sea level rise. As shorelines retreat, annual high wave flooding will reach farther inland along retreating shorelines. Waves are propagated along a “bare earth” DEM which is void of shoreline structures, buildings, and vegetation, and therefore depicts the potential of wave flooding. Waves are assumed to flow over an impermeable surface. The DEM represents a land surface at one particular time, and may not be representative of the beach shape during the season of most severe wave impact, particularly for highly variable north and west-exposed beaches.

The 1D wave modeling used in this study will be less accurate in areas where the reef shape and depth is highly variable along the coast. Two-dimensional (2D) models that account for alongshore movement in waves and run-up are available, but require extensive manpower to set up, long computer processing times, and are less tested. Harbors and other unexposed coasts (e.g., Kāneʻohe Bay) are generally not modeled because the 1D model cannot account for circulation patterns and surges that would require 2D modeling. Undesirable artifacts of 1D modeling also include over-predicted flooding along transects with deep, shore-perpendicular indentations in the sea bottom such as nearshore reef channels. The 1D modeling does not account for the presence of nearby shallow reef which refracts and dissipates some of the wave energy traveling through the channel toward the shore. Benthic habitat (reef) maps of Hawaiʻi were used to estimate bottom roughness (BAE Systems Sensor Solutions Identification & Surveillance 2007). However, the wave flooding model may be improved in future efforts through local field experiments to validate effects of bottom roughness on water flow across the reef.

Coastal Erosion

Studies of historical shoreline change using aerial photographs and survey maps show that 70% of beaches on Kaua‘i, O‘ahu, and Maui shoreline are eroding (receding landward) (Fletcher et al. 2012). Sea level rise has been shown to be an important driver in the predominant trend of coastal erosion around the Hawaiian Islands (Romine et al. 2013). Anderson et al. (2015) found that shoreline recession (erosion) along Hawaii's beaches will double by mid-century under rising sea level, compared to historical extrapolations.

Beaches exist in a delicate balance between existing water levels, wave energy, and sand supply. A small rise in sea level can lead to the loss of a much larger amount of land. Observational and theoretical studies of beach response to sea level rise show that beaches recede by a factor of 10 to 100 times the rise in sea level height as the beach slope re-equilibrates to a new water level (Zhang, Douglas, and Leatherman 2004, Leatherman, Zhang, and Douglas 2000, Bruun 1962). The modeling used to simulate the impact of sea level rise on coastal erosion is shown schematically in Figure 26.

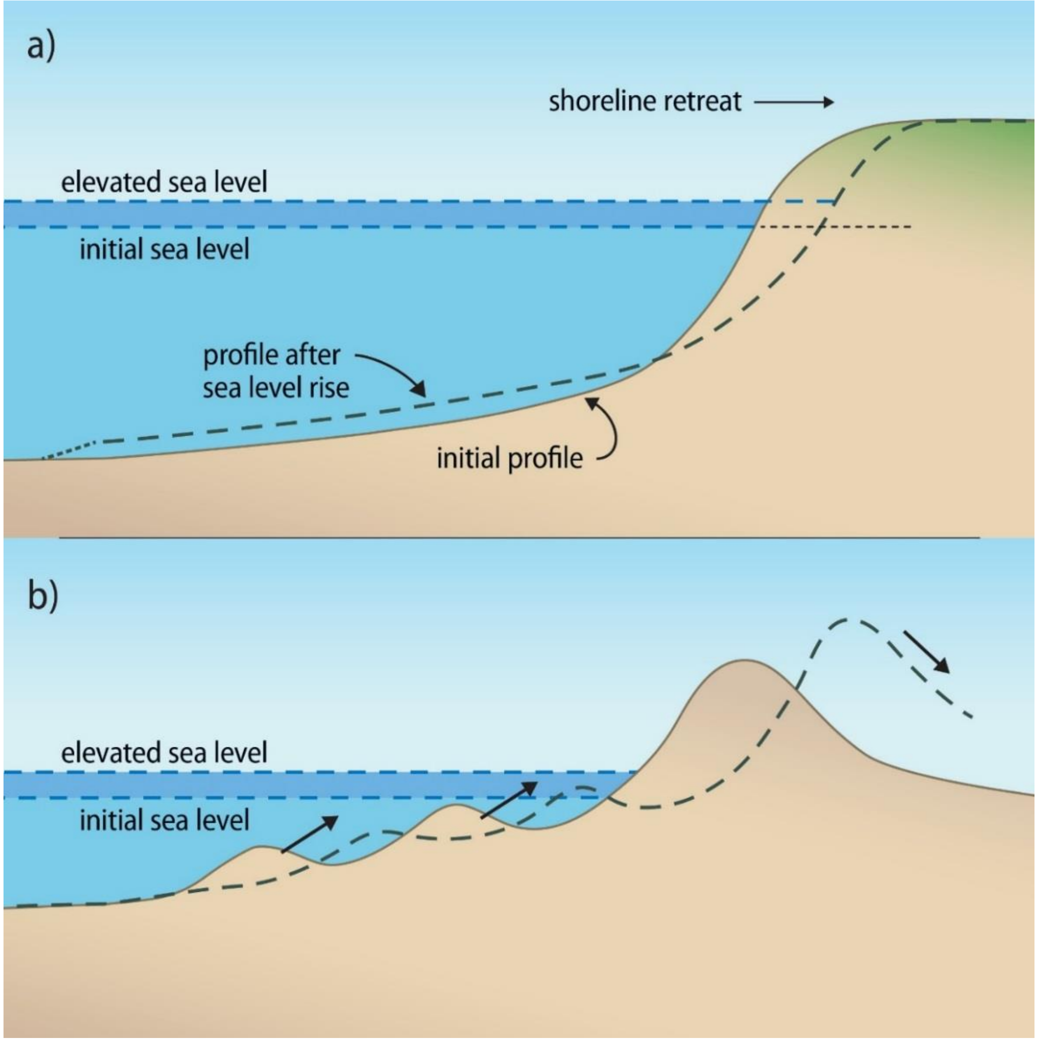


Figure 26. Schematic diagram of showing key inputs and outputs of modeling coastal erosion (a) and the change in shoreline profiles with sea level rise (b)

Data Inputs. Historical data used to model coastal erosion consisted of: (1) historical shoreline positions and erosion rates measured from high-resolution (0.5 meters) ortho-rectified aerial photographs and NOAA topographic charts dating back to the early 1900s (Fletcher et al. 2012, Romine et al. 2013), and (2) beach profile field surveys data collected between 1994 and 2008 by UH, initially for the U.S. Geological Survey (USGS) (Gibbs et al. 2001, Fletcher et al. 2012). The vegetation line was identified in the most recent aerial photography dating from 2006 to 2008.

Modeling Approach. Coastal erosion modeling was conducted for sandy shorelines of Maui, Kauaʻi, and Oʻahu (Figure 27). Modeling was conducted by UH SOEST by combining historical shoreline change trends with the Davidson-Arnott profile model of beach response to sea level rise (Davidson-Arnott 2005) in order to estimate probabilities of future exposure to erosion at transects (shore-perpendicular measurement locations) spaced approximately 20 meters apart along the shoreline (Anderson et al. 2015). Coastal erosion modeling was not conducted for the islands of Molokaʻi, Lānaʻi, and Hawaiʻi due to the lack of historical erosion data (Figure 26).

While Hawaiʻi has an overall trend of beach erosion, shoreline trends are highly variable at the scale of individual beaches. It is not uncommon to find a long-term trend of erosion in one section of beach with accretion (beach growth) in an adjoining area due to localized waves and sand transport. The model from Anderson et al. (2015) accounts for localized alongshore variability in shoreline change by incorporating trends from historical erosion mapping studies.

The output of the modeling is the estimated exposure zone to future erosion hazards. The exposure zones extend landward from the current-day shoreline (vegetation line) up to the 80% cumulative probability contour for each of the four sea level rise scenarios. Based on the model and sea level rise scenario, there is an 80% probability that land that will be impacted by erosion will be confined within the exposure zone at that particular time. Example maps of flooding due to coastal erosion with 1.1 and 3.2 feet of sea level rise are shown in Figure 28.

Figure 27. Extent of modeled coastal erosion on Kaua'i, O'ahu, and Maui

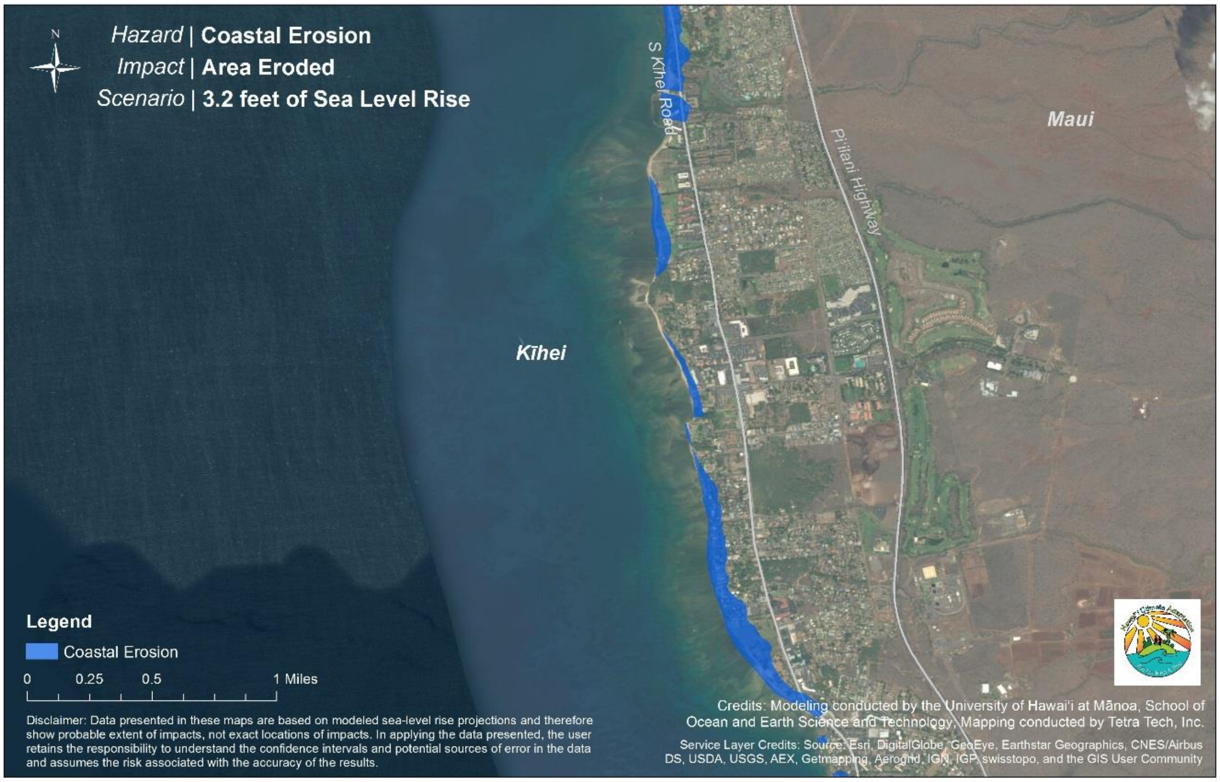


Figure 28. Example maps showing the results of coastal erosion modeling with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise for Kīhei, Maui

Assumptions and Limitations. Historical beach erosion rates do not consider potential changes in sediment supply. Sediment supply is influenced by changes in coastal processes and human impacts from shoreline hardening and other coastal engineering. The decline of coral reefs from ocean warming, acidification, and other impacts also has potential to affect coastal processes and sediment supply.

Historical beach profiles needed to model coastal erosion were available for the islands of Kaua'i, O'ahu, and Maui. Future coastal erosion was modeled where historical shoreline measurements were available on sandy shorelines (Figure 27). Exposure was not modeled for less-erodible rocky coasts and bluffs, though the latter can be prone to sudden failure in some areas. In addition, modeling <u>did not</u> account for:

- Existing seawalls or other coastal armoring in the backshore;
- Increasing wave energy across the fringing reef with sea level rise;
- Possible changes in reef accretion and nearshore sediment processes with sea level rise; and
- Possible changes to sediment supply from future shoreline development and engineering, such as construction or removal of coastal armoring or other coastal engineering.

The calculation of the 80% probability contour (landward boundary) of the erosion hazard zone incorporates the uncertainty (upper and lower bounds) of the IPCC RCP8.5 sea level rise projection. This is in contrast to the other coastal hazard exposure layers in this study, which use only the upper bound of the RCP8.5 sea level rise projection.

Sea Level Rise Exposure Area (SLR-XA)

The SLR-XA represents the projected area of chronic (e.g., permanent) exposure to sea level rise based on modeling (1) passive flooding, (2) annual high wave flooding, and (3) coastal erosion (Figure 29). Each model floods the shoreline in a different way—at different stretches of the shoreline or to greater inland extents. There are some areas that are flooded by all three hazards. These areas represent a "triple" threat of exposure to sea level rise. Other areas with higher elevation topography are only affected by single or double hazard threats. It is important that multiple sea level rise hazards are modeled rather than just the single "bathtub" hazard, which has been the norm, in order to perceive actual exposure of coastal land and infrastructure to sea level rise. An example of the SLR-XA with 3.2 feet of sea level rise for Hale'iwa, O'ahu is shown in Figure 30 along with the individual hazards that were used to develop the combined map.

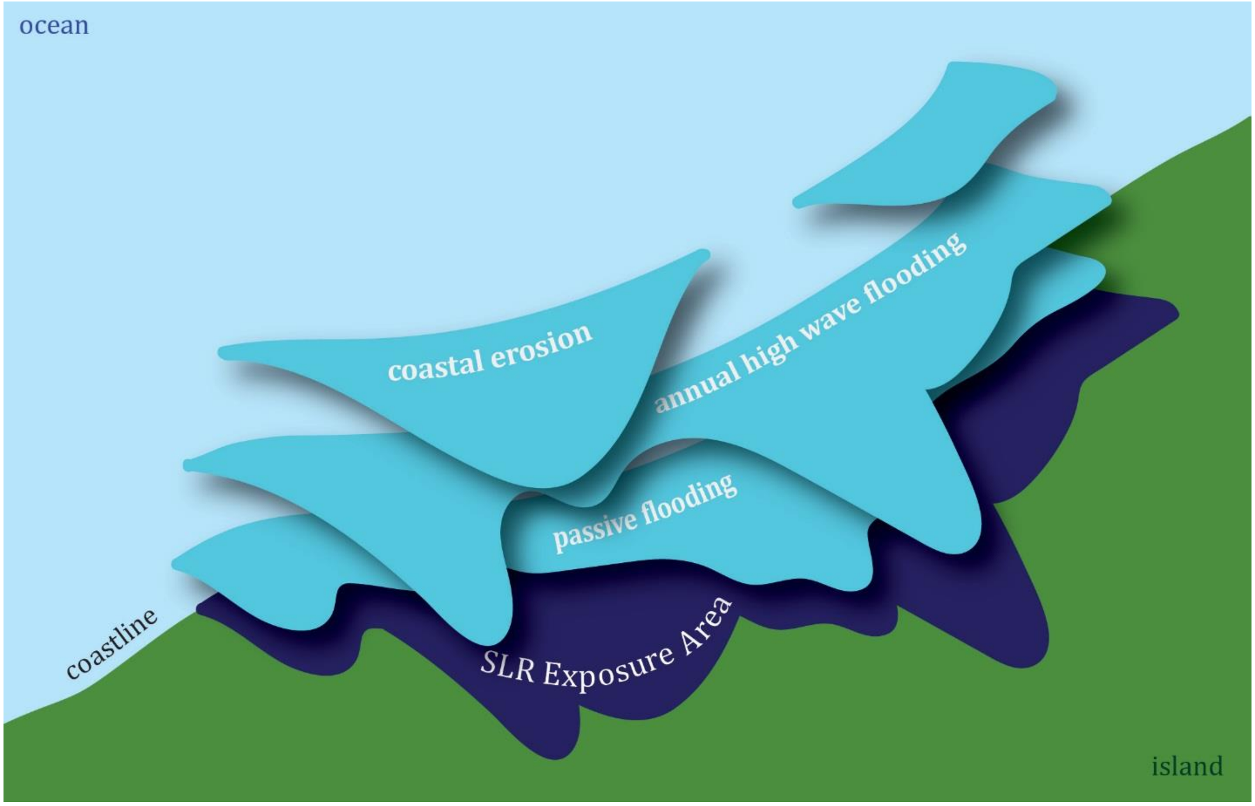


Figure 29. Schematic diagram of the SLR-XA as the combined exposure to sea level rise from passive flooding, annual high wave flooding, and coastal erosion

Assumptions and Limitations. The assumptions and limitations described previously for the individual hazards apply to the SLR-XA. In addition, it should be noted that for the islands of Lāna‘i, Moloka‘i, and Hawai‘i, the SLR-XA represents only one hazard, passive flooding, due to the lack of historical data needed to model the other two hazards. Additional studies would be needed to include the annual high wave flooding and coastal erosion in the SLR-XA. The SLR-XA is an overlay of three hazards and does not account for interactive nature of these hazards as would be expected by natural processes. As with the individual exposure models, the SLR-XA maps hazard exposure on the present landscape. The modeling does not account for future (unknown) land use changes, including any adaptation measures. The SLR-XA does not include impacts from less frequent high wave events (e.g., 1%-annual-chance coastal flood events) from hurricanes, tropical cyclones, and tsunamis with sea level rise. These hazards are not addressed in this Report. Further, the frequency and severity of storms, high waves, and water level hazards in the Pacific as modulated by ENSO-related variability and process, other climatic cycles, and additional factors associated with trends and variability resulting from climate change are not modeled in this Report.

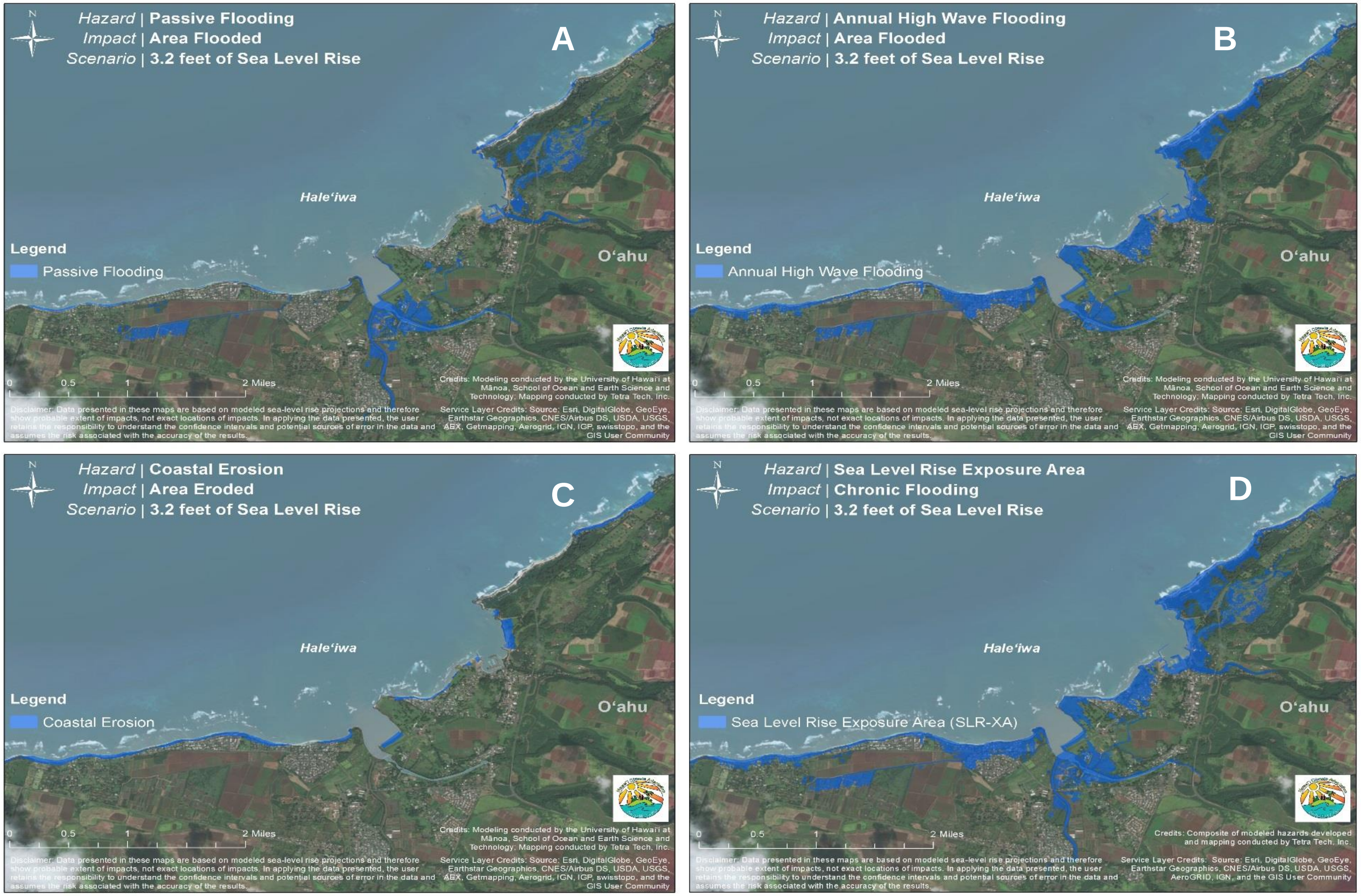
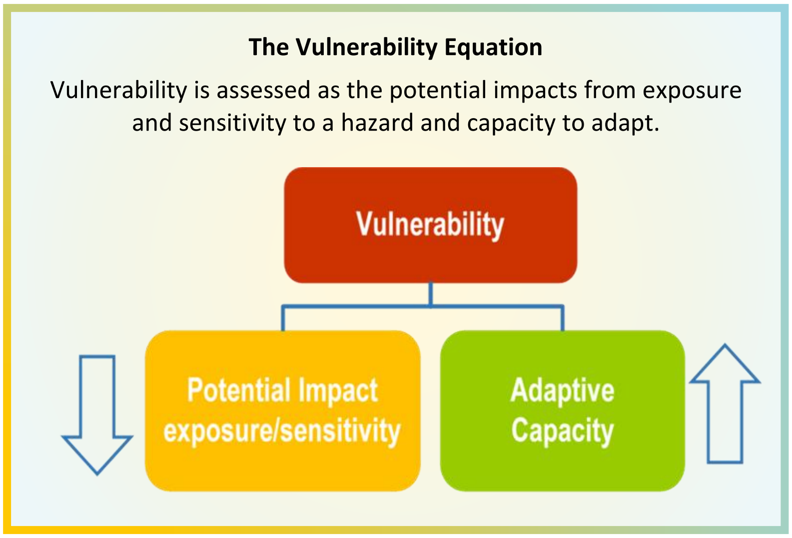


Figure 30. Example maps showing the SLR-XA (D, lower right) with 3.2 feet of sea level rise as the composite of passive flooding (A), annual high wave flooding (B), and coastal erosion (C) for Hale'iwa, O'ahu

Vulnerability Assessment

Coastal hazards modeling provides the projected future exposure of our coasts to multiple hazards. A vulnerability assessment estimates the potential social, cultural, economic, and environmental impacts of this exposure and provides important information needed to design appropriate strategies and tools to adapt to sea level rise. Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC 2007). Vulnerability in the SLR-XA is assessed as the estimated potential permanent loss of land and structures and displaced people from the exposure to sea level rise. GIS analysis was used to estimate the potential economic loss, number of displaced people, and length of roads, area of parks, and other infrastructure and ecological features flooded.



Assessment of Potential Economic, Social, Environmental, and Cultural Impacts in the Sea Level Rise Exposure Area

The vulnerability assessment for the SLR-XA uses GIS data collected from federal, state, and county agencies including county tax parcel and building footprint data. Data on valued assets is compiled and analyzed at the parcel level (individual property level). The most recent county tax parcel data provided by each county was used to obtain information on the value of land and structure by parcel. The datasets from the counties also provided information such as the footprint, type of structure (e.g., commercial, residential) and construction of buildings (e.g., building materials, structure height), public utilities (e.g., power, water, wastewater), and critical facilities (e.g., hospitals, police and fire stations, and evacuation centers). Data layers from the State GIS database were used to augment the valued assets for environmental and cultural data, land use zones, and other relevant information needed to show the impacts of sea level rise. Census data was used to determine the number of people displaced by sea level rise.

This approach to assessing vulnerability highlights the value of modeling multiple hazards in defining the SLR-XA. As shown in schematic diagram in Figure 29, the combination of passive flooding, annual high wave flooding, and erosion is used to define the SLR-XA. In doing so, some areas of the SLR-XA are covered by multiple (2 or 3) hazards and some areas are covered by only one of the three hazards. The area covered by only one of the three hazards on each island modeled is significant, accounting for 50% to 65% of the area in the SLR-XA (Figure 31). Passive flooding accounts for the majority of the unique area contribution whereas flooding from waves and erosion account for the majority of unique economic loss.

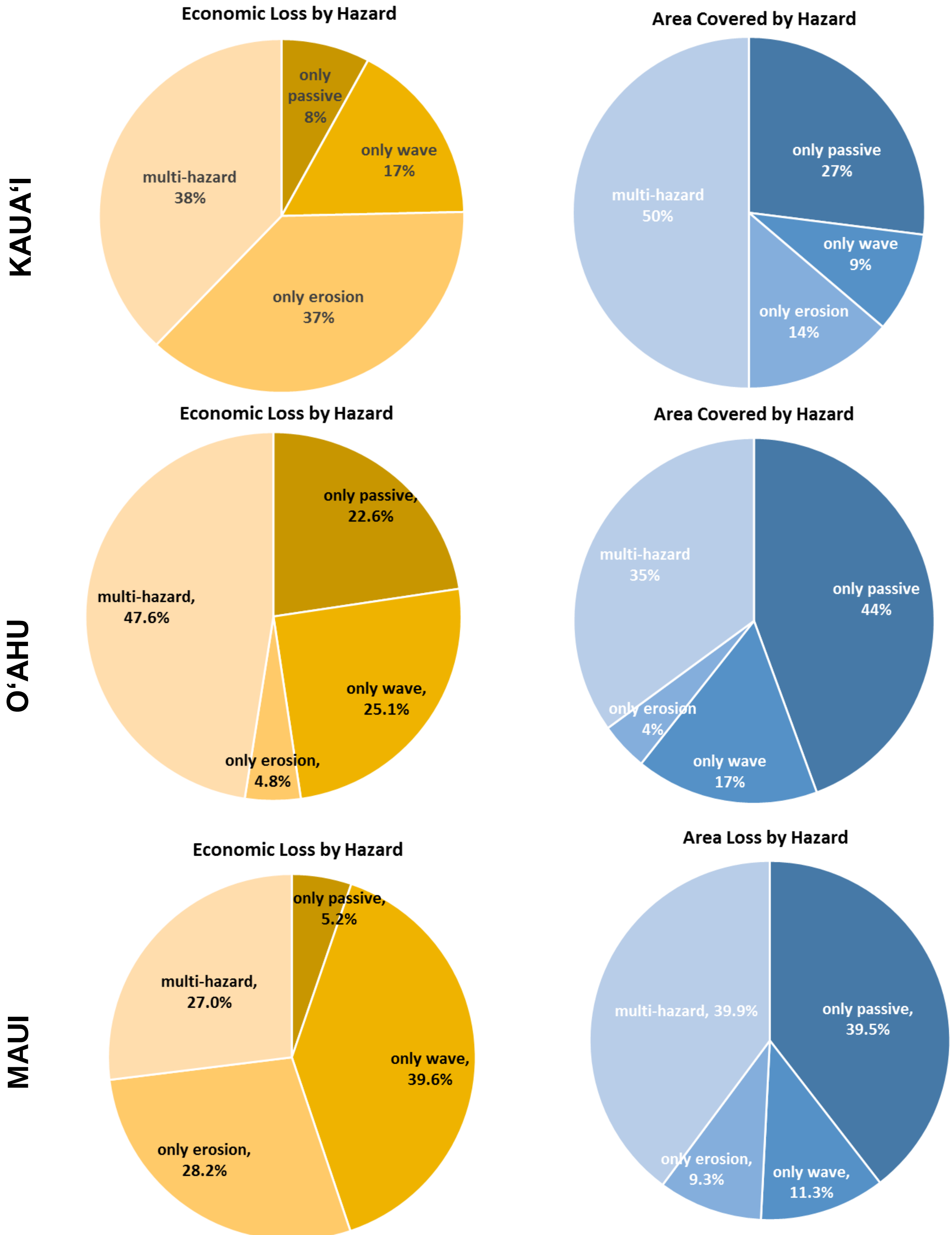


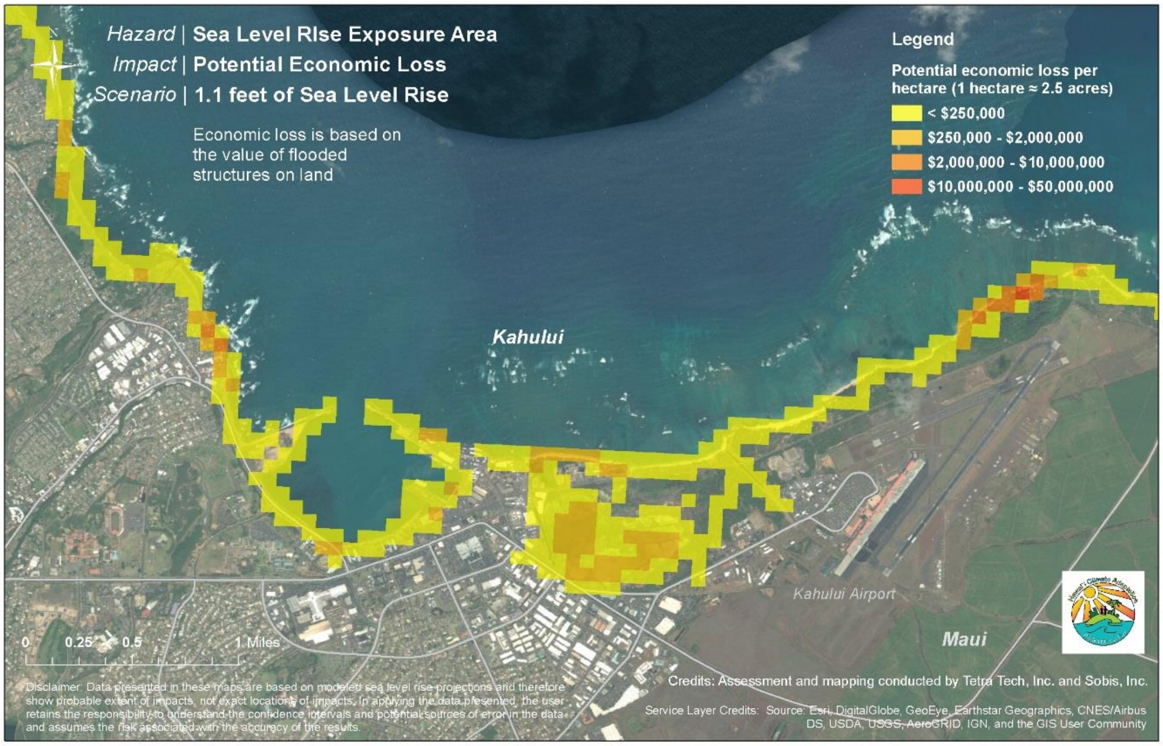
Figure 31. Unique area and economic contributions attributable to modeling multiple hazards in SLR-XA with 3.2 feet of sea level rise for Kauaʻi, Oʻahu, and Maui

This kind of unique contribution analysis[2] helps to compare the extent and nature of each hazard's potential harm and underscores the importance of multi-hazard modeling compared to single hazard modeling (e.g., bathtub alone), which would severely underestimate actual land and economic losses form a multi-faceted hazard such as sea level rise. Further, this approach helps to address some of the gaps in the horizontal extent (e.g., shoreline coverage for coastal erosion and annual high waves) and vertical extent (e.g., landward coverage of DEMs) of coastal hazards modeling noted earlier.

Potential 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 sea level rise height. The area exposed to each coastal hazard modeled (passive flooding, annual high wave flooding, and coastal erosion) is overlaid with the tax parcel data to determine the number, type, and value of structures, and value of land in each individual hazard area. Potential economic loss is analyzed individually for each hazard at the parcel level and subsequently aggregated and reported by sector (agricultural, commercial, industrial, residential, educational, and religious) in 1-hectare (100 square meter or 1,076 square foot) grids. Potential economic loss in the SLR-XA area is determined from the highest loss value in each sector of any one hazard within the 1-hectare grid, thus avoiding double counting a loss of a particular asset from multiple hazards. Those maximum values for each sector are then summed to determined the total economic loss to property in each grid. Example maps of the potential economic loss in the SLR-XA at 1.1 and 3.2 feet of sea level rise in Kahalui, Maui are shown in Figure 32.

The number of people displaced in the SLR-XA was estimated by structure type (single-family residence, condominium, and high rise) based on census data. For each census block, the total block population was divided by the total number of households based on the 2010 U.S. Census. This resulted in a different estimate for number of people per household for each census block, the average of which was around 3 people per household across the state. These estimates were used to assign a number of residents to each residential structure, for example, a single-family home might be assigned 3 people per structure while a duplex would be assigned 6 people per structure (e.g., two 3-person households). For apartments and condominiums, several real estate sites such as Zillow, were used to determine the average apartment size across the state. A value of 400 square feet per person was assigned for apartment- and condominium-type structures. This value was used for all apartment buildings in the state. For example, a 1,200 square foot apartment would be assigned three people. The total square footage for each apartment building exposed to the hazard was calculated from the property database and divided by 400 to determine the number of people displaced.

[2] The "unique contribution" of a hazard to the SLR-XA is the area or economic loss that is attributable to only one of the three coastal hazards modeled. By depicting the SLR-XA as a composite of passive flooding, annual high wave flooding, and coastal erosion, additional exposure is identified in terms of area and economic loss. It should be noted that there were breaks in modeling annual high wave flooding and coastal erosion which also affected the absolute value of the unique contribution.



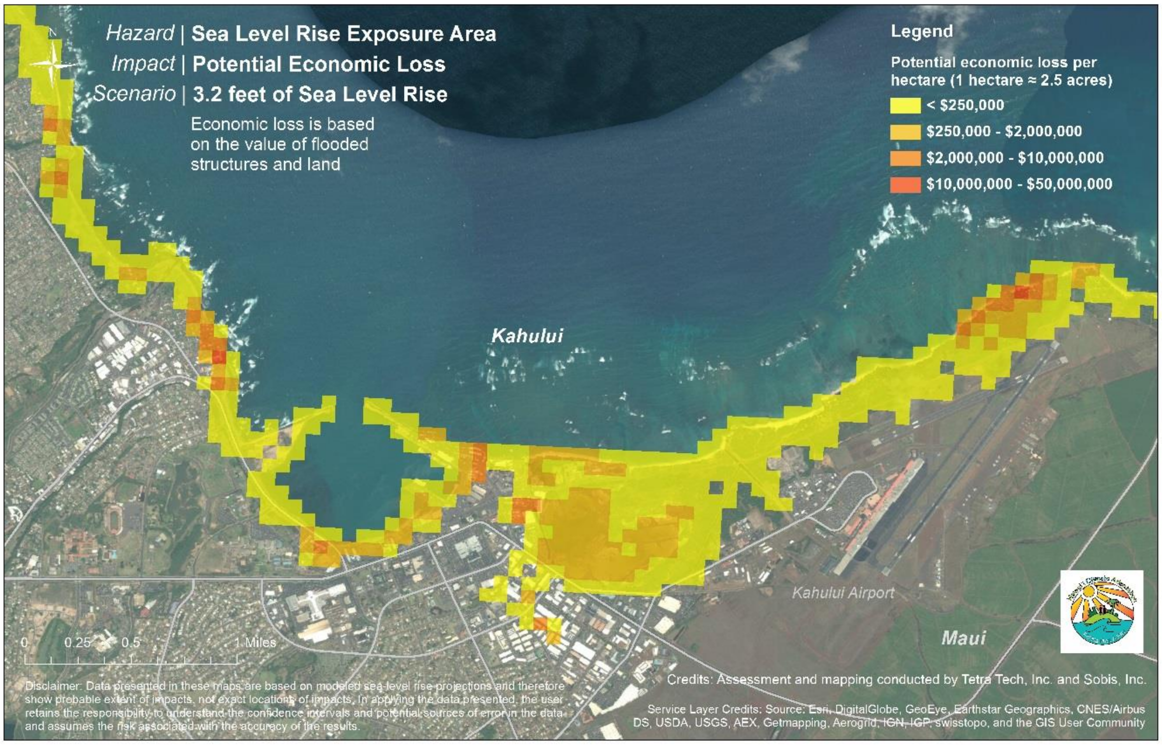


Figure 32. Example maps showing results of economic loss per hectare in the SLR-XA with 1.1 foot (top) and 3.2 feet (bottom) of sea level rise for Kahului, Maui

Potential impacts to roads, water/wastewater conveyance systems, parks, cultural resources, and other valued assets are assessed in terms of exposure to chronic flooding in the SLR-XA, but were not monetized. The SLR-XA is overlaid with these assets to determine the miles, numbers, or area extent in acres of assets impacted by chronic flooding with sea level rise.

Assumptions and Limitations. The vulnerability assessment was based on modeling chronic flooding using the IPCC AR5, RCP8.5 sea level rise scenario, which predicts as much as 3.2 feet of sea level rise by the year 2100. Climate science and sea level rise projections have continued to evolve since the IPCC AR5 and throughout the development of this Report suggesting that 3.2 feet of sea level rise may be reached earlier in the second half of this century and sea level rise of 6.0 feet or more by the end this century is "physically plausible." As such, vulnerability to sea level rise could possibly occur earlier and have greater impacts than projected in this Report.

The vulnerability assessment addresses primarily exposure toe chronic flooding with sea level rise. Key assumptions of the economic analysis for the SLR-XA include: (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.

Economic value data was not available for length of roads, water and wastewater lines, and other public infrastructure due to the variable cost of such infrastructure depending on location, and the complexity and uncertainty involved in design, siting, and construction. Additionally, environmental assets such as beaches and wetlands were not assessed economically due to the complexity in valuing ecosystem services. The loss of both public infrastructure and environmental assets from flooding will result in significant economic loss. Therefore, the total potential economic loss figures estimated in this Report are likely an underestimate. Building footprints were not available with county tax parcel data for Hawai'i County so building locations in the SLR-XA and floodplain were approximated manually using publically available satellite imagery from Google Earth.

Assessment of Potential Future Shoreline Hardening and Beach Loss in the SLR-XA

Over 13 miles of beach on Kaua‘i, O‘ahu, and Maui have been completely eroded away in areas fronted by seawalls, revetments, and other types of shoreline hardening (Fletcher et al., 2012). Historically, shoreline hardening was the typical response to protect beachfront property from erosion and flooding. The State and Counties have policies restricting new shoreline hardening with a focus on conserving public beach resources and shoreline access. In addition, Kaua‘i and Maui Counties have adopted setback policies based on historical erosion rates to move new development out of hazard areas. However, regulatory agencies tasked with managing coastal resources and shoreline development are facing increasing pressure to allow shoreline hardening to protect private and public development. This pressure will continue to grow in the coming years as coastal flooding and erosion due to sea level rise impact more and more beachfront properties.

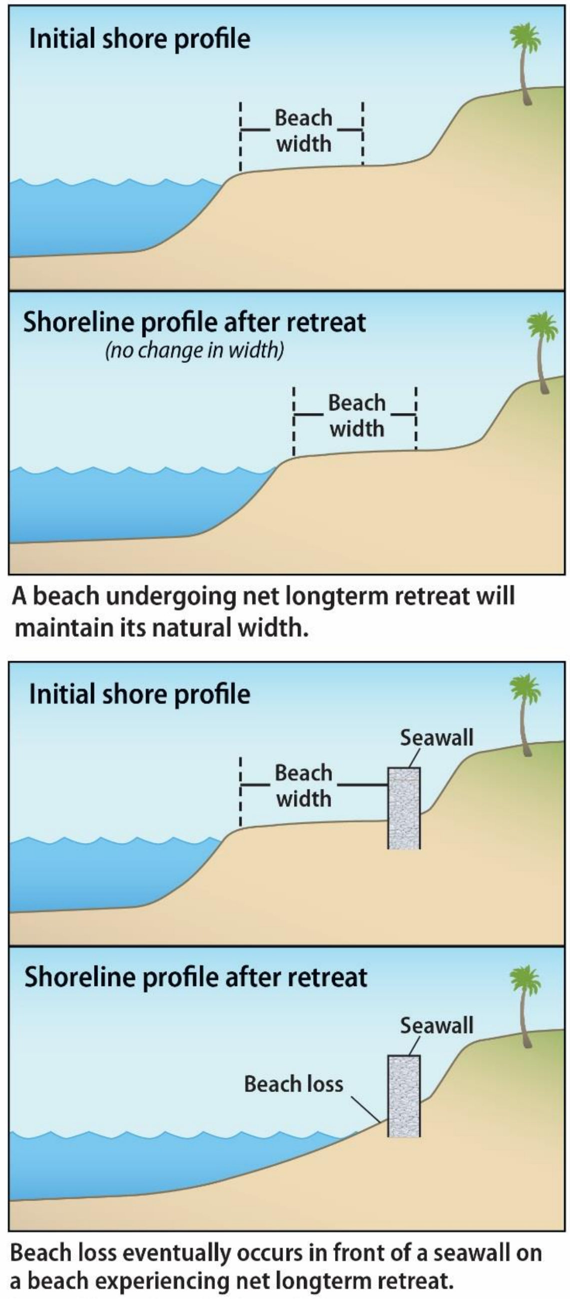


Figure 33. Shoreline hardening on chronically-eroding beaches leads to beach narrowing and loss (Griggs et al. 1997)

Shoreline hardening has been shown to lead to beach narrowing and loss when installed on the backshore of a sandy beach that is undergoing chronic erosion (Fletcher, Mullane, and Richmond 1997, Romine and Fletcher 2012, Griggs et al. 1997) (Figure 33). Seawalls and other hardening structures impound beach sediment in the backshore that would otherwise be available to nourish an eroding beach. The beach continues to narrow as sand is eroded away fronting the wall, ultimately leading to complete beach loss in many locations. This process of beach narrowing and loss is accelerated when waves begin to impact the wall on a regular basis. Shoreline hardening also typically leads to accelerated erosion on adjoining unprotected shorelines as waves and currents bend around the end of the structure in a process known as “end scour” or “flanking erosion,” which in turn prompts requests for additional shoreline protection on neighboring properties.

Hawai‘i Sea Grant conducted a GIS-based assessment of potential future shoreline hardening and potential for beach loss with 1.1 feet and 3.2 feet of sea level rise for Kaua‘i, O‘ahu, and Maui using hazard exposure and other map data layers from this report including the SLR-XAs, building footprints, and roads. In addition, map layers of existing shoreline hardening were acquired for Kaua‘i (Bezore, Pap, and Milnes 2013), O‘ahu (Romine and Fletcher 2013), and Maui (County of Maui Department of Planning, unpublished). Extents of historical beach loss are available from Fletcher et al. (2012). Areas of beach and backshore sediment deposits were verified using satellite imagery and geology map layers from the USGS (Sherrod et al. 2007). Beachfront buildings and beachfront sections of coastal roads within the SLR-XA were identified using a standard intersect tool in ArcGIS software. Areas of potential future shoreline hardening and beach loss were delineated along the shoreline based on the buildings and highway segments identified within the SLR-XA (Figure 34). Sections of overlap among the lines were removed to ensure that portions of shoreline were not counted multiple times.

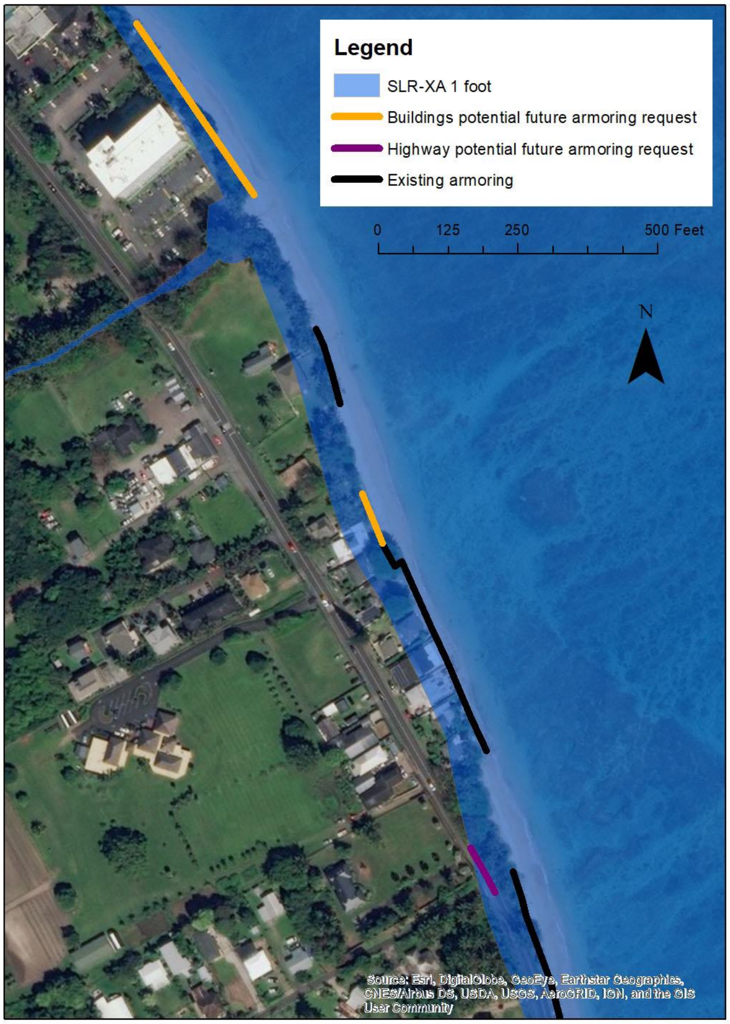
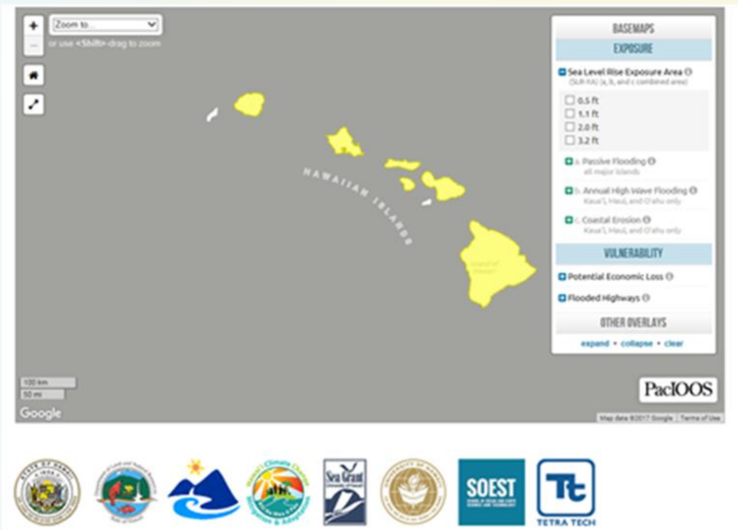


Figure 34. Example map of existing shoreline hardening (black) and potential future shoreline hardening and beach loss based on the SLR-XA with 1 foot of sea level rise for exposed beachfront properties (orange) and coastal roads (purple) for a section of Punalu‘u, O‘ahu

Assumptions and Limitations. This assessment is intended to be a first look at potential future impacts to beachfront development and beach resources in the state with sea level rise. More research is needed to improve understanding and projections of localized vulnerability of beach and coastal environments to combined impacts of poorly sited beachfront development and erosion and flooding with sea level rise. This assessment looks at an overlay of the SLR-XA on existing beachfront development (building footprints and roads), but does not account for accelerated erosion that often occurs fronting and adjacent to shoreline structures when waves interact with the structure. The database of existing shoreline hardening comes from multiple sources developed using aerial photography and verified by site visits in some locations, and may not include all shoreline hardening. This assessment also focuses on active open-coast beach systems and does not include back-bay shorelines (e.g., Kāne'ohe Bay) and beaches perched atop rocky shorelines. Miles of beach exposed to potential loss provided in this Report are based on a hypothetical scenario where widespread shoreline hardening is permitted along impacted beachfront property and does not consider other adaptation scenarios such as managed retreat of existing development from impacted areas, increased setbacks for new development, or beach nourishment, which would help to conserve beaches.



HAWAI'I SEA LEVEL RISE VIEWER

Visit the [Hawai'i Sea Level Rise Viewer] to see the modeling and vulnerability assessment results and zoom in to areas of interest. (http://hawaiisealevelriseviewer.org/)

Learning Questions for the 5-Year Report Update

Learning questions for this chapter are driven by the assumption that sea level rise projections will be modified based on new climate science, and new approaches will be tested and applied to coastal hazard modeling and vulnerability assessment. There are many ongoing efforts in the United States and around the world to better characterize vulnerability to sea level rise using different models and approaches (USGS 2017). As such, learning questions for the 5-year Report update include:

1. To what extent do new global sea level rise projections differ from those used in this hazard modeling?
2. To what extent have data and coastal hazard modeling improved to warrant updating this hazard modeling?
3. To what extent have property values, population, and other development trajectories changed from the baseline data used in this report?
4. Is the SLR-XA for 3.2 feet of sea level rise modeled in the Report still valid as the exposure overlay for the mid to latter half of this century?

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Results

Ka manu kaʻupu hālō ʻale o ka moana. The kaʻupu, the bird that observes the ocean. Said of a careful observer.

As the only U.S. state that is made up of islands, Hawaiʻi is highly vulnerable to the effects of sea level rise. In this chapter, we present the Report's findings from a state-wide perspective.

Vulnerability to sea level rise is based on modeling chronic coastal flooding with sea level rise due to passive flooding, annual high wave flooding, and coastal erosion in the SLR-XA with 3.2 feet of sea level rise and depicts flood hazards that may occur in the mid- to latter-half of this century (Box 4). Vulnerability to 1.1 feet of sea level rise in the SLR-XA is used to approximate current or near-term exposure to coastal hazards and sea level rise. Vulnerability is assessed in terms of potential impacts to land use, people, property, cultural and natural resources, and critical infrastructure.

The reader is urged to exercise caution in interpreting the results, which could be to a greater or lesser extent depending on actual observed future sea level rise, technological innovations in climate change mitigation and adaptation, unknown economic variables, as well as future societal choices which cannot be known today. Further, the reader should visit the Hawaiʻi Sea Level Rise Viewer to explore the full extent of the vulnerability maps for each island.

Call to Action

"We have the science, the vision, and the leadership to take up the challenge that sea level rise poses to our communities and economy. Our kuleana is to act to preserve our environment, culture and lifestyle in the inevitable change. These actions include using public education to explain the risks and opportunities and create a groundswell of support for action and forming coalitions and cross agency collaborations to develop proactive options to be enacted by state and county governments and supported by the public. As a result, we will produce integrated and long-term plans that address sea level risk holistically across multiple sectors."

Group message developed during the 1st Sea Level Rise Vulnerability and Adaptation Workshop
Oʻahu, January 2016

Box 4. Summary of Key Terms, Assumptions, and Limitations in the Methodology Used to Assess Vulnerability in the Sea Level Rise Exposure Area (SLR-XA)

This summary is intended to help the reader become familiar with key terms, assumptions, and limitations in the modeling and vulnerability assessment methodology. The reader is encouraged to revisit the Methodology chapter for further details.

- The SLR-XA depicts the area exposed to potential chronic flooding and land loss based on modeling passive flooding, annual high wave flooding, and coastal erosion with sea level rise for the Islands of Maui, Oʻahu, and Kauaʻi,. The SLR-XA for the Islands of Hawaiʻi, Molokaʻi, and Lānaʻi is based on modeling passive flooding only.
- Flooding in the SLR-XA is associated with long-term, chronic hazards punctuated by annual or more frequent flooding events. Over time, recurring flooding at the highest tides in low-lying areas leads to chronic flooding and then to permanent flooding, and permanent loss.
- Vulnerability in the SLR-XA is characterized as potential impacts to land use, people and property, critical infrastructure, Native Hawaiian communities, cultural resources, and coastal resources, including beaches.

Key assumptions and limitations of the vulnerability assessment include:

- Potential economic loss is based on present values of the land and structures from the county tax parcel database permanently lost in the SLR-XA.
- Economic (monetary) losses due to sea level rise on critical infrastructure (such as roads, airports, harbors, water, sewer and power, etc.) has not been considered, but many such structures or facilities that are located in the SLR-XA have been identified in this Report.
- A more detailed economic loss analysis is needed of Oahu's critical infrastructure, including harbor facilities, airport facilities, sewage treatment plants, and roads. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.
- Macro-economic impacts (such as on tourism or the real estate market) resulting from potential chronic flooding over time caused by sea level rise are not analyzed.

Honolulu, Oʻahu
Source: Catherine Courtney

State-wide Summary

Although sea level rise is analyzed at the individual island level in the Report, it is important to understand its state-wide impacts. This section quantifies some of the assets across the State that could be lost to chronic flooding in the SLR-XA.

Key Take Aways

- Chronic coastal flooding is occurring now. The SLR-XA with 1.1 feet of sea level rise approximates this current or near-term exposure to chronic coastal flooding.
- Over the next 30 to 70 years, chronic flooding with sea level rise will increase, impacting homes and businesses located near the shoreline. Approximately 6,500 structures and 19,800 people state-wide would be exposed to chronic flooding in the SLR-XA with 3.2 feet of sea level rise.
- State-wide, the SLR-XA with 3.2 feet of sea level rise covers an area of approximately 25,800 acres, one third of which is designated for urban use.
- An estimated $19 billion of economic loss would result from chronic flooding of land and structures located within the SLR-XA with 3.2 feet of sea level rise.

- Approximately 38 miles of coastal roads would be chronically flooded within the SLR-XA with 3.2 feet of sea level rise and become potentially impassible, jeopardizing critical access to many communities.
- Approximately 550 cultural sites would become chronically flooded within the SLR-XA with 3.2 feet of sea level rise.
- More than 13 miles of beaches have been lost on Kaua'i, O'ahu, and Maui to erosion fronting seawalls and other shoreline armoring. Many more miles of beach could be lost with sea level rise, if widespread armoring is allowed.
- Flooding, hurricanes, and tropical cyclones could occur at any time and would be exacerbated by sea level rise.
- Actions are needed now to increase Hawaii's capacity to adapt to sea level rise.

Potential Impacts in Sea Level Rise Exposure Area

When sea level rises another 3.2 feet over the 21st century, the State of Hawai'i stands to lose over 25,800 acres of coastal and low-lying land to chronic flooding (Figure 35). This loss will take the form of incrementally eroding beaches, waterfront property inundated by increasingly high tides and by seasonal waves that reach father inland, and low-lying areas becoming wetlands because of rising water tables and reduced drainage. O'ahu, with its expansive coastal plains, will lose the most land, followed by Kaua'i and Hawai'i. While the total amount of land loss will amount to less than 1% of the State's total land, much of this land encompasses high density urban, commercial, and industrial districts.

State-wide, approximately 6,500 structures would be chronically flooded with 3.2 feet of sea level rise resulting in the displacement of more than 19,800 residents. The projected total value of land and structures that would be lost amounts to over $19 billion. Approximately 38 miles of road would be chronically flooded across the State with 3.2 feet of sea level rise, ranging from residential roads to sections of coastal highways such as Kūhiō Highway on Kaua'i, Kamehameha Highway on O'ahu, and Honoapi'ilani Highway on Maui. Utilities, such as water, wastewater, and electrical systems, that often run parallel underneath roadways, would also be significantly impacted. However, the reader should note that the $19 billion in economic loss does not encompass the full extent of potential losses in the State. As stated in Chapter 3 (Methodology), economic value data were not available for length of roads, water and wastewater lines, and other public infrastructure due to the variable cost of such infrastructure and the complexity and uncertainty involved in design, siting, and construction of such facilities. Thus, the total potential economic loss figures throughout the State are likely an underestimate.

Figure 35. State-wide summary of potential impacts in the SLR-XA with 3.2 feet of sea level rise

The loss of natural and cultural resources across all islands is also difficult to quantify—yet their loss would cost the State dearly. Sea level rise would take its toll on Hawaii's world famous beaches, including such iconic stretches of beaches such as North Shore Oahu's "Seven Mile Miracle," the beaches of Kauai's North Shore, and West Maui beaches, unless drastic measures are taken to curb the practice of shoreline armoring. Many Native Hawaiian cultural resources would be impacted as nearly 550 cultural sites in the State would be chronically flooded in the SLR-XA with 3.2 feet of sea level rise and cultural practices including fishing, gathering, and other practices that require shoreline access would be impacted. Further, coastal portions of Hawaiian Home Lands could be impacted by chronic flooding.

Sea level rise also has the potential to impact facilities that could release wastewater or hazardous materials and waste to nearshore waters and coastal habitats. Septic tanks, cesspools, and other on-site sewage disposal systems (OSDS) as well as other hazard materials/waste storage and disposal sites are located along the coast. Approximately 2,100 OSDSs would be exposed to chronic flooding in the SLR-XA with 3.2 feet of sea level rise state-wide that would not only result in the failure of these systems to operate properly but degrade nearshore water quality.

Challenges and Opportunities

Over the next 30 to 70 years, as sea level rises, homes and businesses located on or near the shoreline throughout the State will become exposed to chronic flooding. Portions of coastal roads may become flooded, eroded, impassible, and potentially irreparable, jeopardizing access to and from many communities. The flooding of hotels and transportation systems would impact the visitor economy and thus impact the people whose livelihoods depend on the tourism industry. The added risk of flooding from hurricanes and tropical cyclones from a warming planet poses a potential for loss of human life and property and for severe and long-term economic disruption.

The impact of sea level rise on O'ahu is greater than all of the other islands combined due to the size of the population and extensive urbanization of vulnerable coastal areas. Even more troubling is the fact that impacts from chronic flooding with sea level rise on O'ahu can reverberate and translate into economic and social impacts for the other islands.

In addition to chronic coastal flooding from sea level rise, tropical storms, hurricanes, and tsunamis create waves that flood low-lying coastal areas. However, the added risk from event-based coastal flooding exacerbated by sea level rise is not included in this Report. Flood risk zones subject to inundation from the 1%-annual chance flood are designated as special flood hazard areas (SFHAs) on the Federal Insurance Rate Maps (FIRMs) produced by FEMA. It is important though that the reader understands that event-based coastal flooding with sea level rise would expand the landward extent of these SFHAs.

The results of the vulnerability assessment highlight just a few of the very significant challenges the State faces under a scenario of 3.2 feet of sea level rise by the mid- to latter-part of the century. However, this may not be the worst of it. According to recent climate science, sea level rise greater than 6 feet is "physically plausible" by the end of the century (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017).

While not modeled in this Report, additional feet of sea level rise would add thousands of acres to the SLR-XA on each island (Figure 36). A GIS analysis using layers from the NOAA Sea Level Rise Viewer (NOAA 2017b), which only accounts for passive flooding, indicates that an additional 10,000 acres state-wide would be added to the SLR-XA with 5 feet of sea level rise. This would increase the total area exposed to chronic flooding state-wide to over 36,000 acres and the economic, environmental, cultural and societal impacts of which would be far greater than the results presented in this Report. Each island's exposure to passive flooding with 5 feet of sea level varies due to its geomorphology, with Oʻahu having the highest additional exposure (36%) and Maui, having the lowest additional exposure (15%) in terms of additional acres passively flooded.

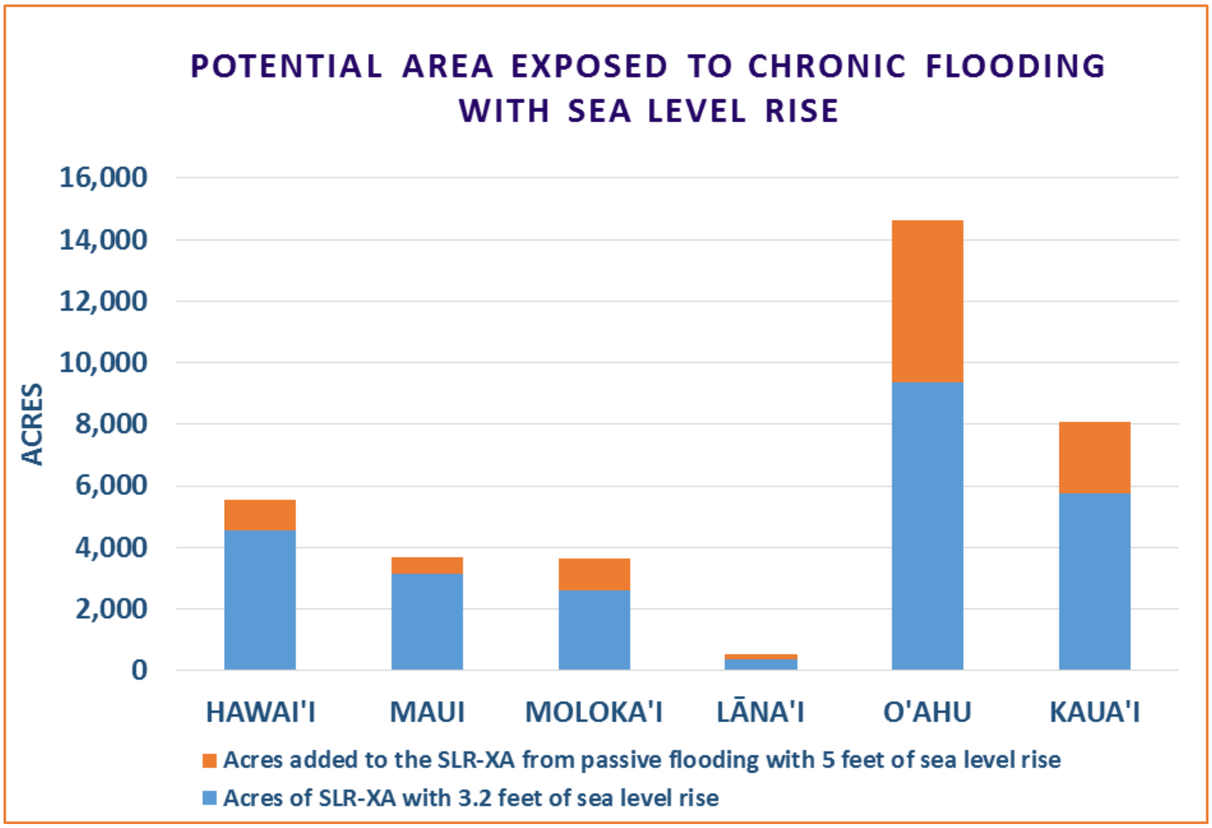

Figure 36. Potential additional area of chronic flooding with 5 feet of sea level rise

The threat of 3 feet or more of sea level rise in this century is real and is not likely to diminish given the overall trend in scientific research toward higher and more rapid scenarios of sea level rise in this century. This state-wide vulnerability assessment provides the information needed to consider the potential impacts of sea level rise in planning future land use decisions by depicting the areas exposed to flooding in this century and providing a framework for adaption. Invariably, adaption to sea level rise will require difficult decisions regarding when, where, and how to act on this information.

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Kapoho, Hawai'i
Source: Reid Sirat

Hawai'i

The Island of Hawai'i, with an area of more than 2.5 million acres, is the largest island in the Hawaiian archipelago. With a population of 189,382 residents (State of Hawai'i 2015), the Island of Hawai'i accounts for only 14% of the State's total population. However, an almost tripling of Hawai'i Island's population over the last 50 years, coupled with a growing tourism industry—over 1.5 million visitors came to Hawai'i Island in 2016 (State of Hawai'i 2016)—has placed ever increasing demands on the island's housing market, natural resources, critical infrastructure, and basic services. Be that as it may, Hawaii's large size, relatively low population, and unique geography/geology makes it the least vulnerable of the main Hawaiian Islands to sea level rise impacts. Nonetheless, the Island of Hawai'i faces serious flooding threats in some of its main urban areas, including low-lying areas in Kona, Puakō, and Hilo Bay.

Key Take Aways

- Over the next 30 to 70 years, homes and businesses located near the shoreline will be impacted by sea level rise. Approximately 130 structures would be chronically flooded with 3.2 feet of sea level rise.
- Of the 4,500 acres of land located within the SLR-XA, approximately 20% is designated for urban land uses.
- A more detailed economic loss analysis is needed of Hawaii's critical infrastructure, including harbor facilities, airport facilities, sewage treatment plants, and roads.
- State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.

This section provides a picture of the future of the Island of Hawai'i with sea level rise and the potential impacts if no action is taken. The results are based on modeling coastal flooding with sea level rise due to passive flooding, annual high wave flooding, and coastal erosion in the SLR-XA with up to 3.2 feet of sea level rise, and depicts flood hazards that may occur in the mid- to latter-half of this century. This timeframe is within the expected lifespan of most new construction and much of our existing development. It should be noted that sea level rise projections greater than 3.2 feet are "physically plausible" by the end of the century, based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). Vulnerability to 1.1 feet of sea level rise in the SLR-XA is used to approximate current or near-term exposure to coastal hazards and sea level rise. Vulnerability is assessed in terms of potential impacts to land use, people, property, cultural and natural resources, and critical infrastructure (only land and structures are monetized, not infrastructure).

The reader is urged to exercise caution in interpreting the results, which could be to a greater or lesser extent depending on actual observed future sea level rise, technological innovations in climate change mitigation and adaptation, unknown economic variables, as well as future societal choices which cannot be known today. Further, the reader should visit the Hawai'i Sea Level Rise Viewer to explore the full extent of the vulnerability maps for each island.

Potential Impacts in the Sea Level Rise Exposure Area

The SLR-XA depicts the area of potential chronic flooding from exposure to passive flooding with sea level rise. For the purposes of exposure and planning, we focus mainly on a scenario with 3.2 feet of sea level rise.

With 3.2 feet of sea level rise, low-lying coastal areas around the island within the SLR-XA may become chronically flooded within the mid- to latter-half of this century (Figure 37). This land will become submerged by coastal erosion, direct marine flooding from tides and waves, or become new wetlands behind the shoreline from rising water tables and reduced drainage. Approximately 4,550 acres of land on the Island of Hawaiʻi is estimated to be located in the SLR-XA with 3.2 feet of sea level rise. Some examples of areas that would be exposed to chronic flooding, including Kaʻūpūlehu , Waimea, South Point, and the Hawaiian Beaches subdivision, are illustrated on Figure 38. Portions of the Huālalai Resort in Kaʻūpūlehu, an economically important tourist destination in North Kona, would be permanently flooded with 3.2 feet of sea level rise. In Waimea, new and expanding wetland areas would form around the historical, agricultural areas and the black sand beaches may begin to erode. In South Point, existing Hawaiian farmsteads, coastal resources and recreation areas are already experiencing recurring flooding during high tides without rainfall because of rising seas. At the Hawaiian Beaches subdivision, as the shoreline erodes with rising seas, properties along the shoreline would become increasingly vulnerable to flooding and the beach would eventually be lost if structures, such as seawalls impede the landward migration of the beach. In addition, along the Hāmākua coast, bluff erosion and potentially catastrophic bluff failures would increase with higher sea level.

Over time, as sea level continues to rise, low-lying, populated coastal communities such as the small residential village of Puakō in South Kohala, would experience increased frequency and extent of flooding (Figure 39). This flooding could possibly lead to permanent inundation, especially given the high water table in the area (County of Hawai'i 2005), ultimately making some areas of the coast impassible or uninhabitable. Decisions about where to use coastal armoring and when to retreat will need to be made carefully. It should be noted that seawalls may not be effective at preventing flooding with sea level rise in many low-lying areas as rising groundwater can infiltrate through porous geology. While specific responses to sea level rise would need to be place-based, larger regional issues should also be considered, such as whether to armor in place or whether to relocate roads and other critical infrastructure inland. In the case of the town of Puakō, where seasonal wave overtopping and flooding are already an issue, there may be opportunities to consider a managed retreat strategy as there are ample vacant lands immediately mauka (landward) and outside of the SLR-XA with 3.2 feet of sea level rise. However, as discussed in the Recommendations Chapter of this Report (Chapter 5), and as with other populated coastal areas with adjacent vacant lands, large-scale boundary amendments should be predicated on appropriate state policies and guidelines (e.g., within Chapter 205, State Land Use Act) to provide the supportive legal basis for major land use changes.

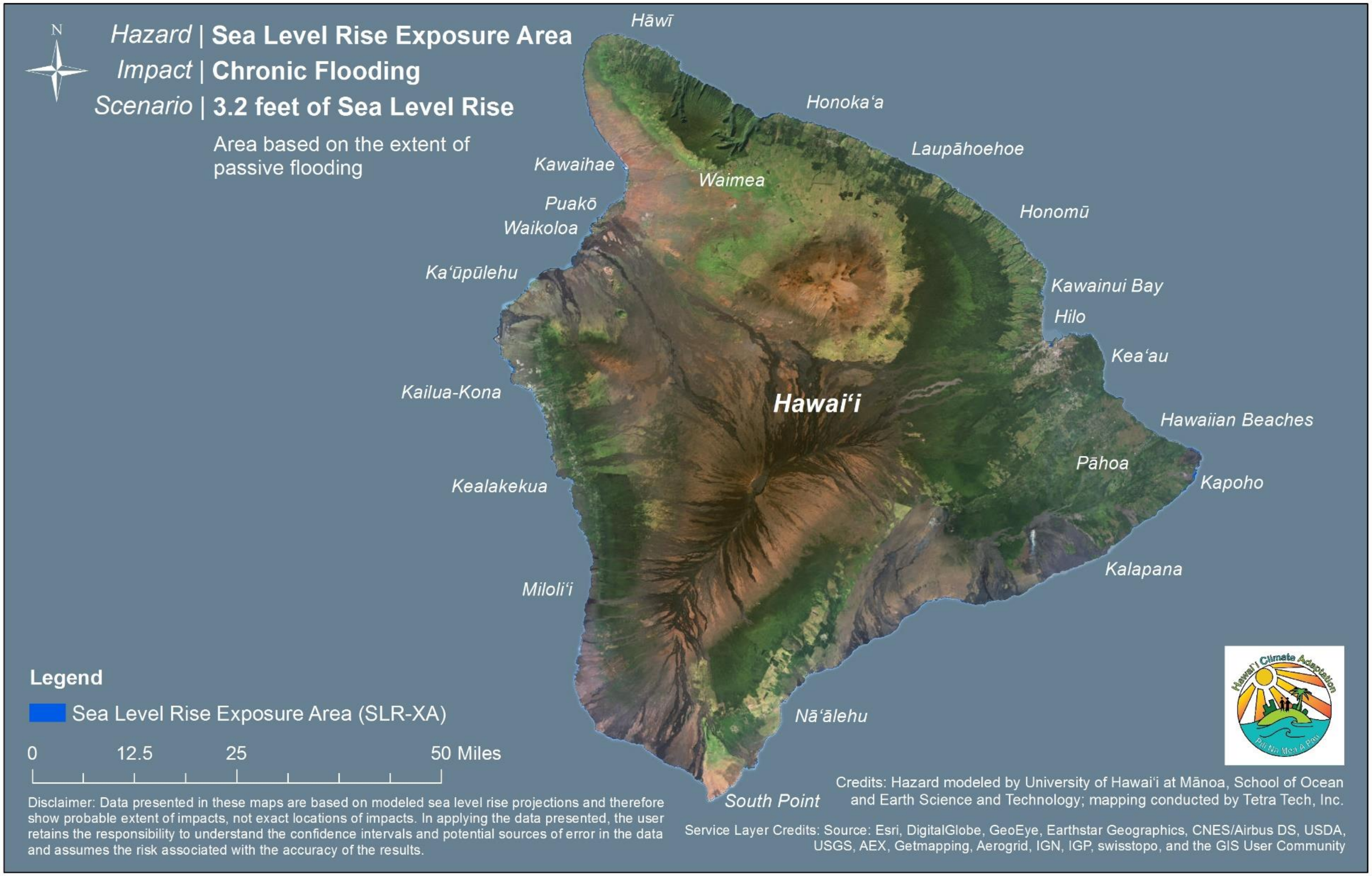


Figure 37. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise (a thin, barely visible blue line) for the Island of Hawai'i

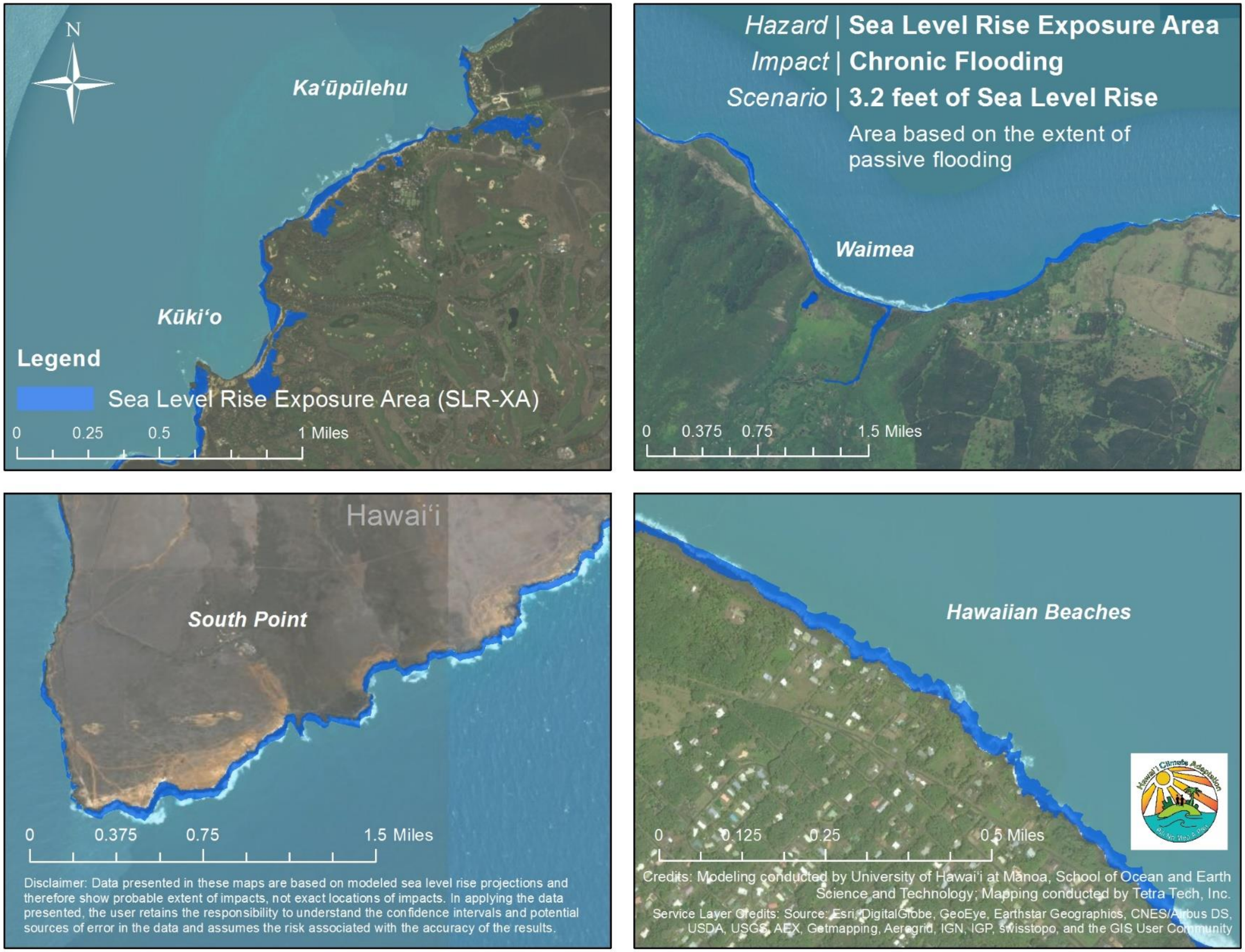
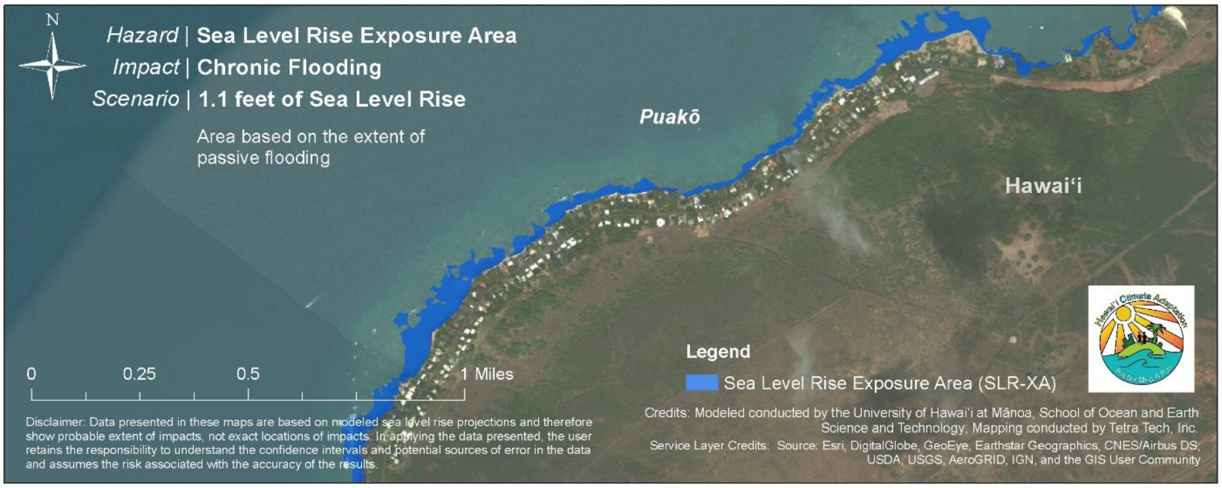
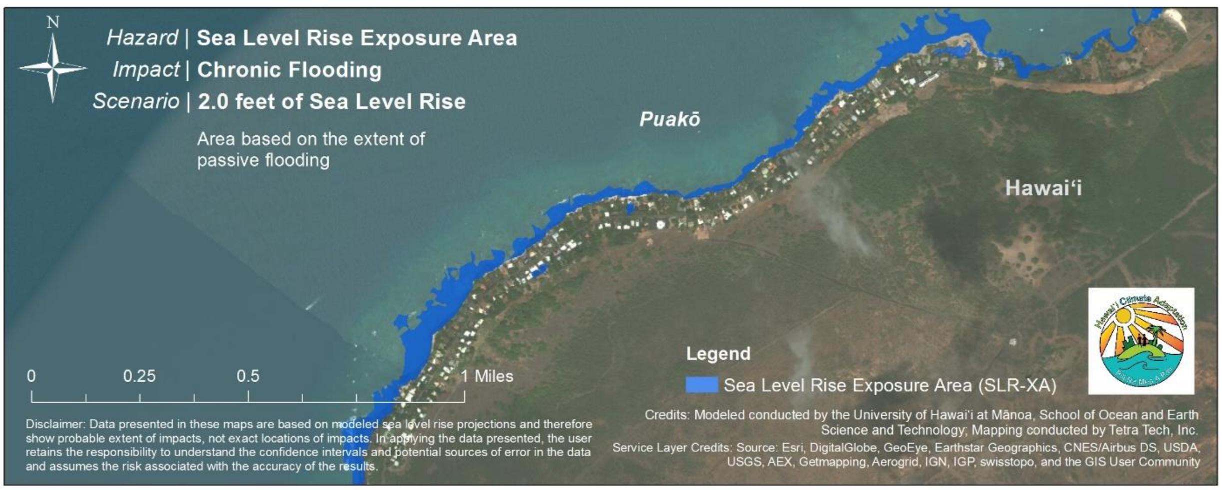


Figure 38. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise in four areas on the Island of Hawai'i





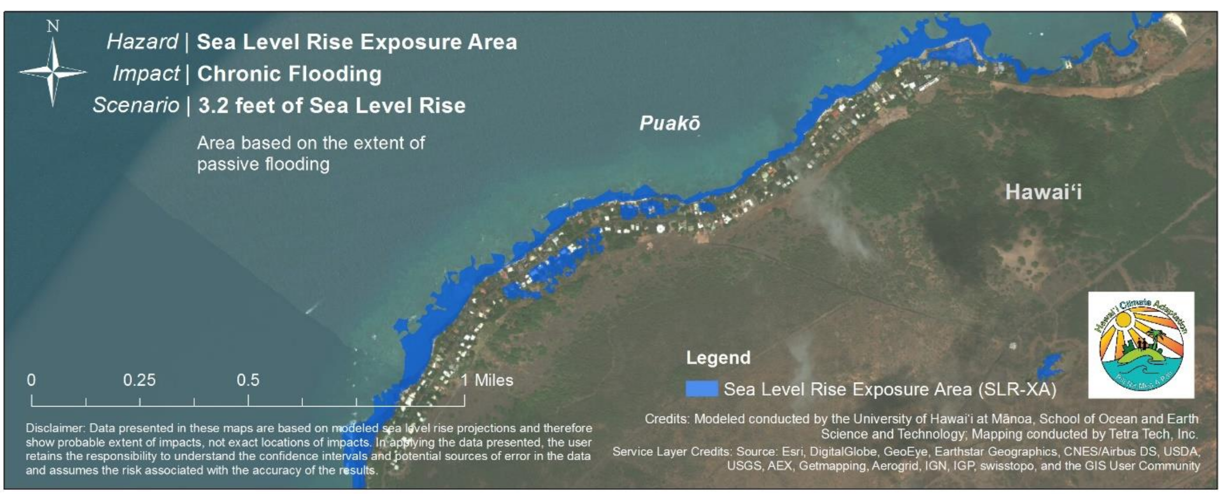


Figure 39. Potential chronic flooding in the SLR-XA with 1.1, 2.0, and 3.2 feet of sea level rise in Puakō, Hawai'i

POTENTIAL IMPACTS TO LAND USE

While sea level rise would result in impacts within the State Urban, Agricultural, and Conservation Land Use Districts around the island, Conservation District lands would experience the greatest extent of chronic flooding (Figure 40). While approximately 76% of the lands located within the SLR-XA are designated as Conservation District lands, only 20% of the lands located within the SLR-XA with 3.2 feet of sea level rise are located in the Urban District. However, considering that only 2% of the island's more than 2.5 million acres is in the Urban Land Use District (State of Hawai'i 2015), it's likely that new Urban District land would need to be designated to respond to shifts in coastal infrastructure and population away from the shoreline.

While the State Land Use Law (Hawai'i Revised Statutes Chapter 205) could be used to sort out major land changes as part of a managed retreat strategy, County General Plan and Community Plan updates provide important opportunities to address land use issues with rising seas at the local level. Revised and updated Special Management Areas (SMA) policies, objectives, and requirements offer additional opportunities at the local level to prepare for sea level rise. Additional controls on development along the coast may be necessary to protect Native Hawaiian traditional and customary practices; iwi kūpuna (ancestral bones); archaeological/historical, and cultural resources; to ensure public access; and to mitigate the impacts of coastal hazards.

RECOMMENDATION HIGHLIGHTS

- Recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone in the County General Plan and Community Plan updates.
- Strive to balance managed retreat strategies from vulnerable urban areas with preservation of agriculture and conservation lands.
- Seek opportunities to plan new development outside of the SLR-XA, wherever possible, under a long-term comprehensive adaptation strategy.

POTENTIAL IMPACTS TO PEOPLE AND PROPERTY

People living and working within the SLR-XA would be displaced when homes, condominiums, and businesses become flooded due to sea level rise. The potential number of people displaced is calculated by assigning an estimated occupancy for each type of structure in the SLR-XA. Potential economic loss in the SLR-XA is estimated based on the value of land and structures flooded. Loss estimates are assessed at the parcel level and aggregated into 1-hectare grids. The potential economic loss associated with flooded roads, water/wastewater facilities, and other critical infrastructure is not accounted for in the assessment of economic impacts and would add significant increases in losses.

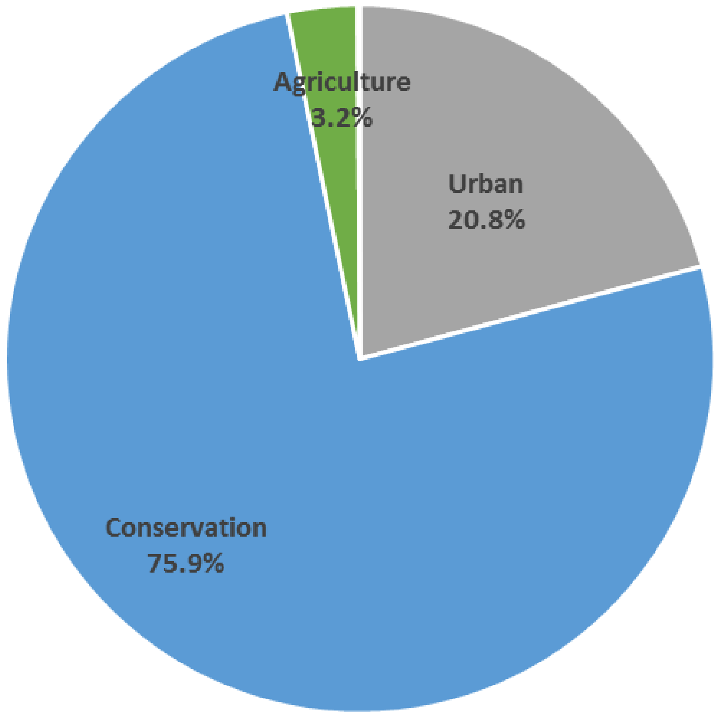


Figure 40. Estimated percentage of Land Use Districts impacted in the 3.2 feet sea level rise exposure area on the Island of Hawai'i

The potential number of displaced people island-wide could rise from 452 residents with 1.1 feet of sea level rise to over 1,000 residents with 3.2 feet of sea level rise (Figure 41). The people displaced would include a range of income levels and living arrangements. Approximately 34% of the occupied housing units on the Island of Hawai'i are occupied by renters (U.S. Census Bureau 2015a), so both homeowners and renters would be affected island-wide.

Potential economic losses (all structures and land) island-wide would increase from an estimated $195 million with 1.1 feet of sea level rise to $426 million with 3.2 feet of sea level rise (Figure 41). Approximately 63% of the potential economic loss with 3.2 feet of sea level rise is attributed to the loss of residential structures and land. The potential economic loss across all sectors results from loss of 132 structures and approximately 4,550 acres of land in the SLR-XA with 3.2 feet of sea level rise.

With 3.2 feet of sea level rise, potential economic loss would occur in low-lying coastal areas island-wide, with the greatest loss along the northeastern shore from Puakō to Kailua-Kona due to the concentration of high-value residential, commercial and resort land and structures (Figure 42). Over time, as sea level continues to rise, coastal communities and resort areas, such as those between Waikōloa and Puakō in the South Kohala Community Planning District (Figure 43), would experience increasing potential economic loss.

RECOMMENDATION HIGHLIGHTS

- Require mandatory disclosure for vulnerable properties and consider acquisition to protect valuable coastal resources.
- Develop design standards to increase flood resiliency for existing and new development within the SLR-XA that cannot be relocated.
- Seek opportunities to plan new development well landward of the SLR-XA with 3.2 feet of sea level rise under a long-term, comprehensive adaptation strategy.
- Develop a multi-pronged financing strategy at federal, state, county, private sector, and philanthropic levels to address costs of adaptation to sea level rise.

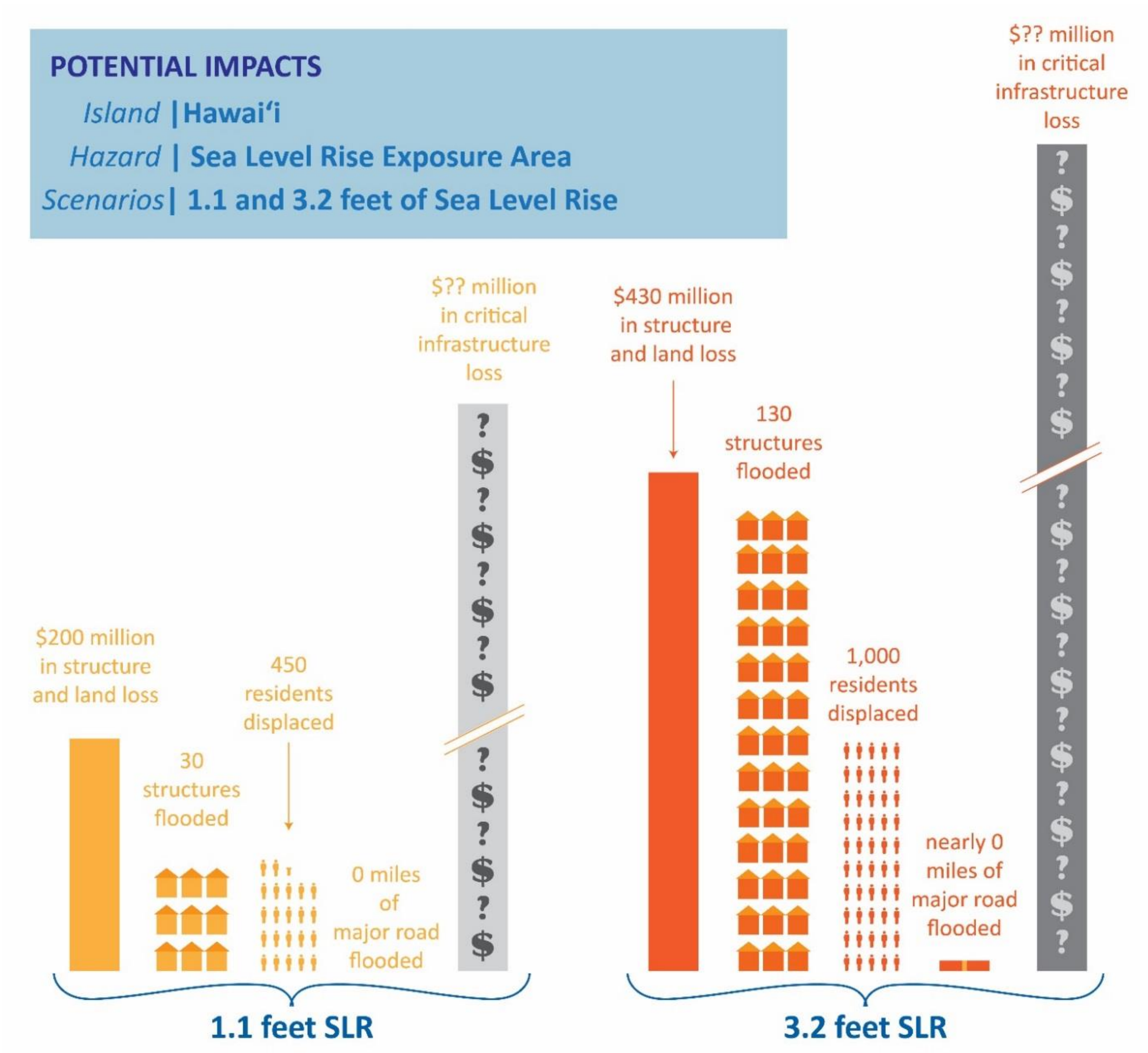


Figure 41**. Summary of potential impacts in the SLR-XA with 1.1 feet and 3.2 feet of sea level rise on the Island of Hawaiʻi**

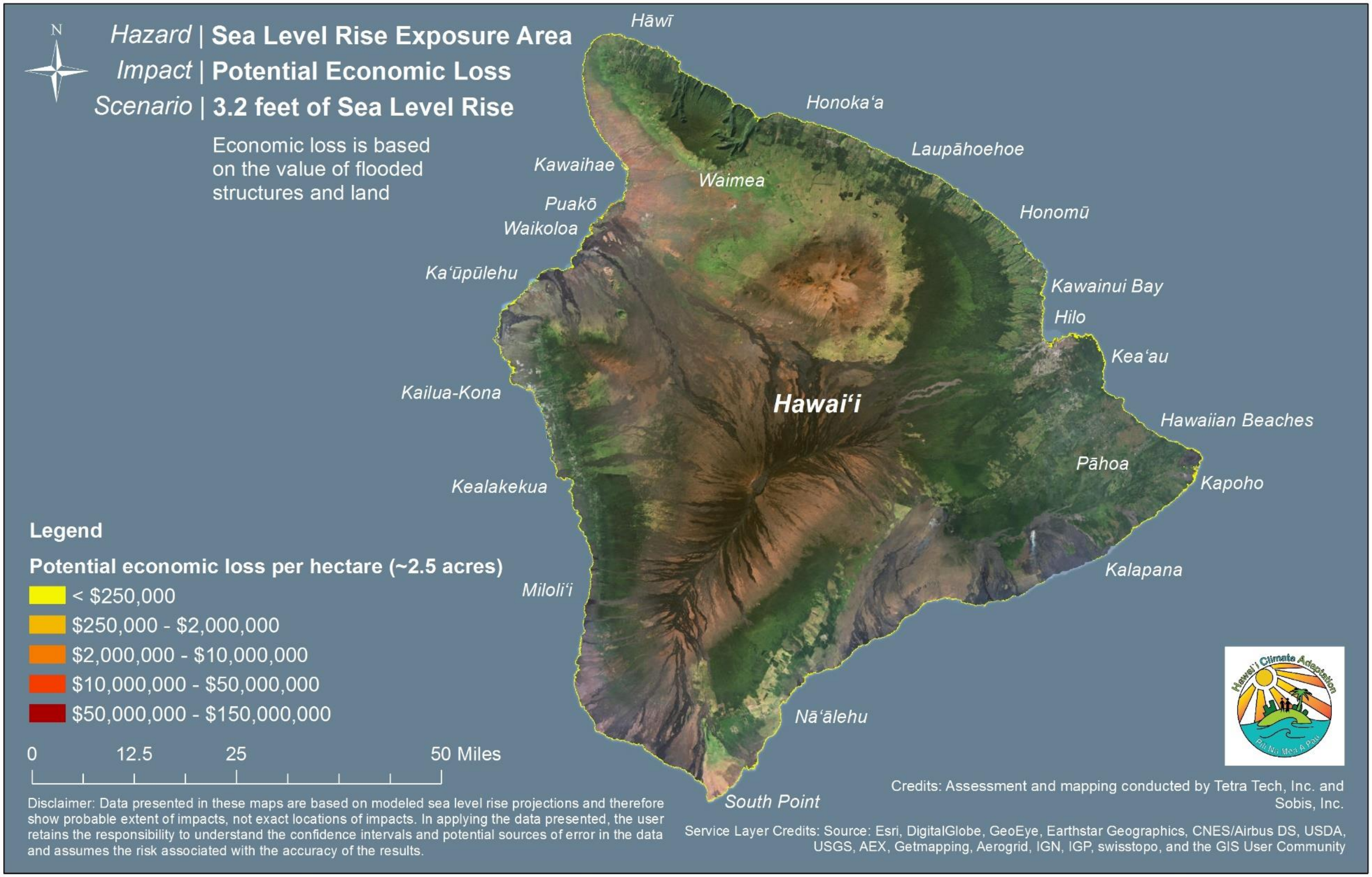
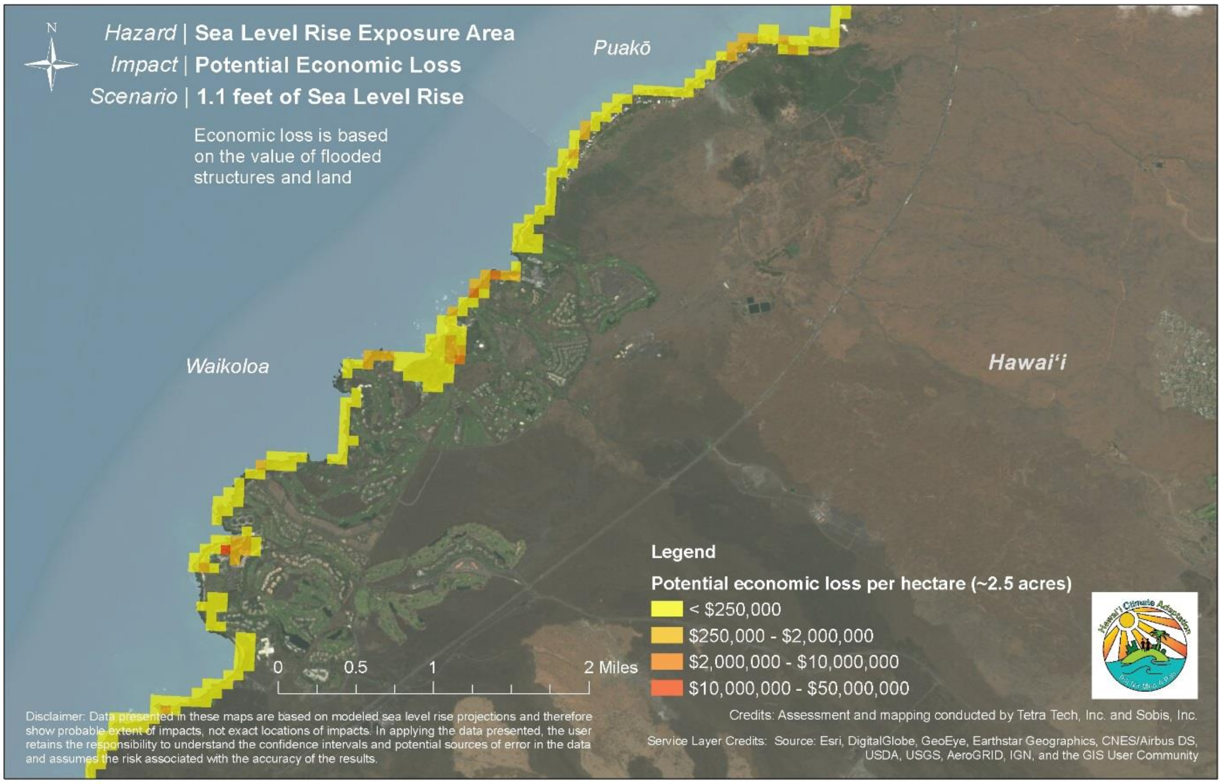


Figure 42. Potential economic loss in the SLR-XA with 3.2 feet of sea level rise (a thin barely visible yellow-orange line) on the Island of Hawai'i



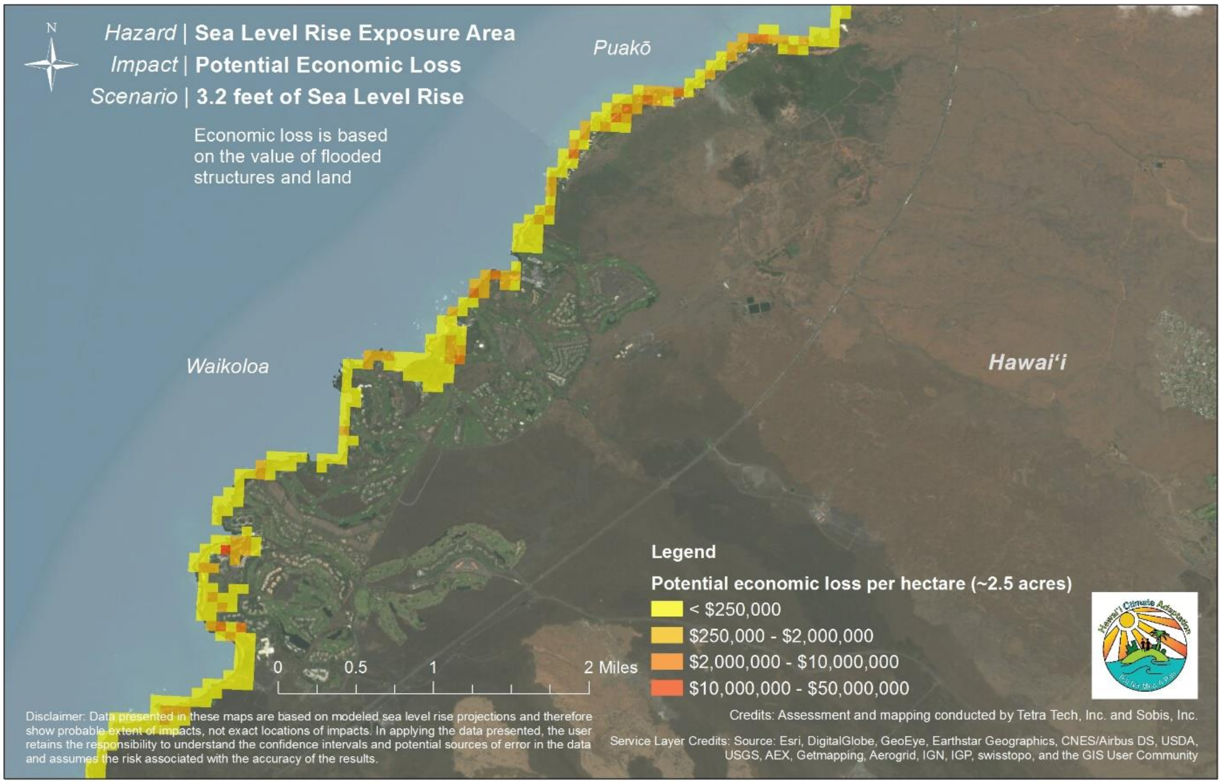


Figure 43. Potential economic loss in the SLR-XA with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise in Waikōloa and Puakō, Hawai'i

POTENTIAL IMPACTS TO CRITICAL INFRASTRUCTURE

Sea level rise would result in significant impacts to roads, airports, harbors, electrical and telecommunications, water/wastewater facilities and conveyance systems, and other public service facilities (i.e. schools, fire stations, police stations, medical facilities) on the Island of Hawaiʻi. Following the trends of private development, portions of the island's critical public infrastructure is concentrated along low-lying shores and is vulnerable to flooding and erosion in the SLR-XA. No major highways would be flooded in the SLR-XA with 1.1 feet of sea level rise and only 0.05 miles would be flooded with 3.2 feet of sea level rise. Portions of coastal roads, such as Kalanianaʻole Avenue in Hilo, would become chronically flooded (Figure 44) and result in regional issues such as loss of commerce, loss of access to emergency services, and increased traffic on other roads and highways, some of which serve as the only access in and out of many communities. Electric and telecommunication transmission lines commonly follow roads and those located underground in the SLR-XA may be impacted by sea level rise resulting in service disruptions.

Three of the islands four airports, Hilo International, Kona International, and ʻUpolu Airport, lie along the coast, but are located on higher ground outside of the SLR-XA (Figure 45). However, operations at the island's two commercial harbors, Hilo (Figure 45) and Kawaihae (Figure 46), may be impacted and could experience disruption of more than 4,000 tons of cargo (based on the amount of cargo that passed through the harbors in 2014) (State of Hawai'i 2015). In addition, disruption can also be expected to cruise ships and their passengers that pass through these harbors as well as at the Kailua-Kona Wharf. Further, interruption to interisland and transoceanic shipping and travel would impact residents, visitors, and all forms of economic activity. No schools, fire stations, police stations, hospitals or wastewater treatment plants are located within the SLR-XA with 3.2 feet of sea level rise.

More detailed analyses of vulnerability and adaptation options for critical infrastructure are needed to evaluate adaptation options such as retrofitting or relocating the Island of Hawaii's critical infrastructure. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., flood proofing and relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years. The reader should visit the online Hawaiʻi Sea Level Rise Viewer to determine if any infrastructure or public facilities of interest are located within the SLR-XA. Please keep in mind that infrastructure losses have not been monetized. However, it should be noted that these costs could be an order of magnitude greater than the potential economic losses estimated from land and structures.

RECOMMENDATION HIGHLIGHTS

- Conduct in-depth vulnerability assessments and evaluation of adaptation strategies for existing critical infrastructure throughout the County.
- Consider long-term cost savings from implementing sea level rise adaption measures now (e.g., major flood proofing or relocation) compared to the cost of maintaining and repairing chronically threatened public infrastructure over the next 30 to 70 years.
- Require the design and siting of new development and capital improvement projects to include an in-depth analysis of sea level rise impacts based on elevation, tolerance for risk, and lifetime of the structure.

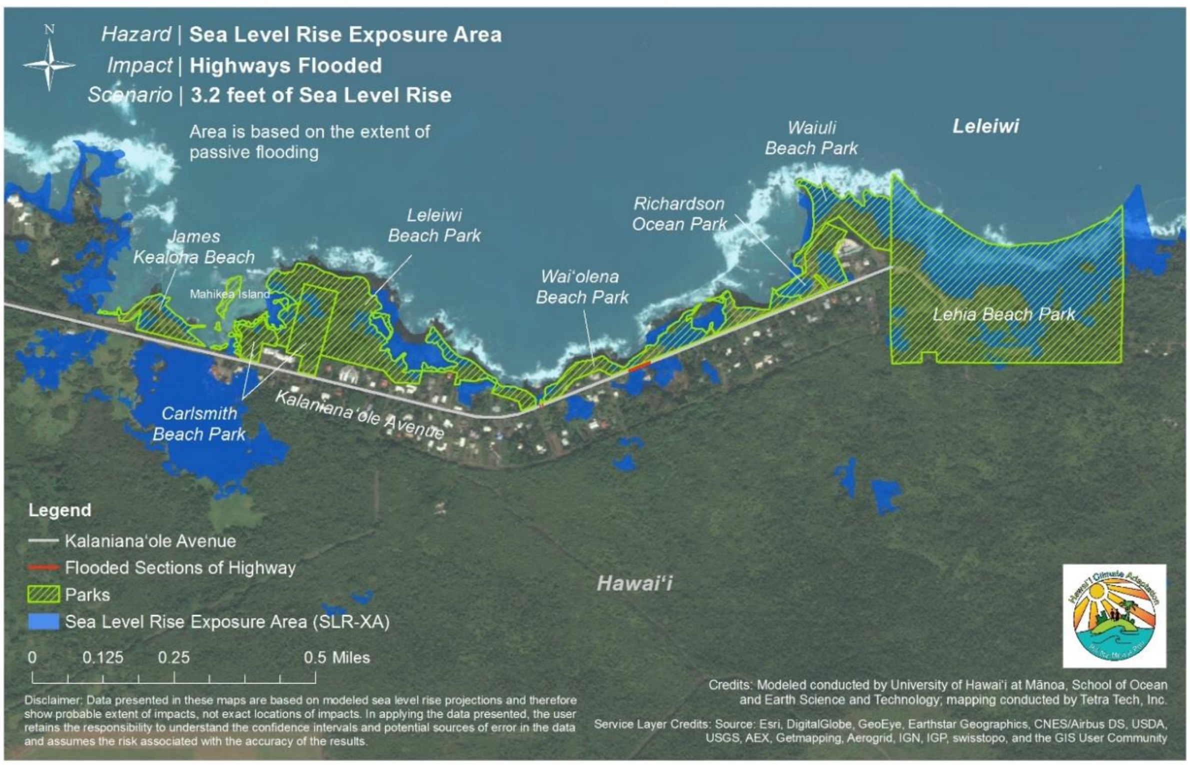


Figure 44. Sections of Kalaniana'ole Avenue extending to the west of Hilo in the SLR-XA (red) with 3.2 feet of sea level rise on the Island of Hawai'i

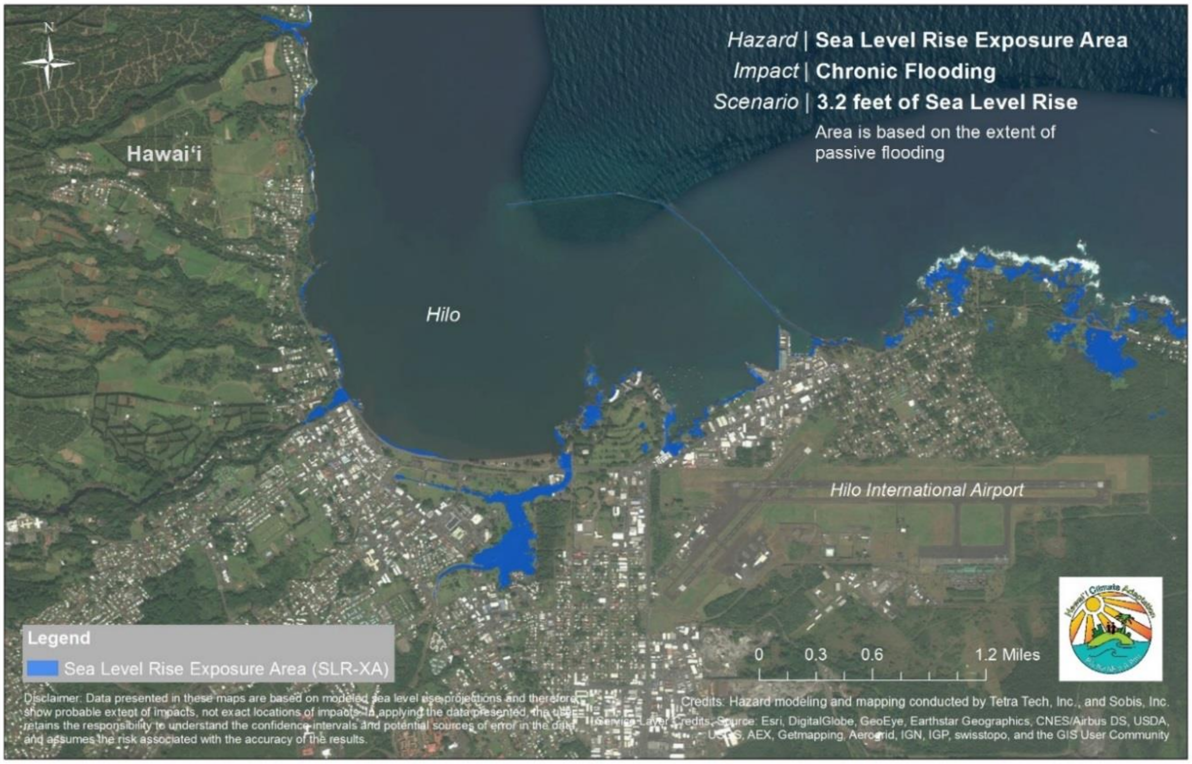


Figure 45. Key transportation facility, Hilo Harbor, in the SLR-XA with 3.2 feet of sea level rise on the Island of Hawaiʻi

POTENTIAL IMPACTS TO NATIVE HAWAIIAN COMMUNITIES AND CULTURAL RESOURCES

Hawaiian Home Lands are intended to provide for the economic self-sufficiency of Native Hawaiians through a homesteading program (University of Hawaiʻi 2015). Consistent with Native Hawaiian culture, Hawaiian Home Lands include areas from mauka to makai (from the mountain to the sea). Coastal portions of Hawaiian Home Lands, such as in Kawaihae in South Kohala (Figure 46), would be flooded with sea level rise displacing Native Hawaiian families that live in this area. In addition, fishing and cultural practices taking place along the shore would be impacted as beaches erode. In a recent study of multiple coastal hazards, three of the 27 Hawaiian Home Lands homesteads on the Island of Hawaiʻi—Keaukaha, Maku'u, and Kawaihae—are estimated to have the greatest potential for people to be displaced by tsunamis, waves, and sea level rise (University of Hawaiʻi 2015).

In addition to Native Hawaiian communities, many Native Hawaiian cultural and historical resources are located near the shoreline and are threatened by sea level rise. Coastal erosion already threatens areas that serve as burial grounds, home sites, fishponds, and other places of cultural significance (Kane et al. 2012). The number of cultural sites on the Island of Hawaiʻi in the SLR-XA is projected to increase from 131 sites with 1.1 feet of sea level rise to 132 sites with 3.2 feet of sea level rise. This includes a number of cultural sites such as historic trails, heiau, and petroglyphs located along the shoreline of Pōhue Bay that may be flooded as a result of sea level rise (Figure 47). Rising seas would also impact loko iʻa (ancient Hawaiian fishponds) such as the loko iʻa of Kaloko and ʻAimakapā located on Honokōhau Bay (Figure 48) (Marrack and O'Grady 2014). A case study on sea level rise impacts on Kaloko fishpond within the Kaloko-

Honokōhau National Historical Park indicated that the area of the pond would expand under different sea level rise scenarios and would expand beyond the current park boundary with approximately 3.3 feet of sea level rise. Rising seas may also impact the Ala Kahakai National Historic Trail. A recent coastal hazard analysis report of the Puʻukoholā Heiau National Historic Site and Kaloko Honokōhau Historical Park projects a higher frequency of coastal flooding in the area due to sea level rise (Vitousek et al. 2009).

RECOMMENDATION HIGHLIGHTS

- Develop an inventory of Native Hawaiian cultural resources and practices impacted by sea level rise.
- Work with Native Hawaiian communities to determine steps they want to take regarding climate impacts.
- Develop adaption plans to preserve access to coastal lands and water within Native Hawaiian communities.

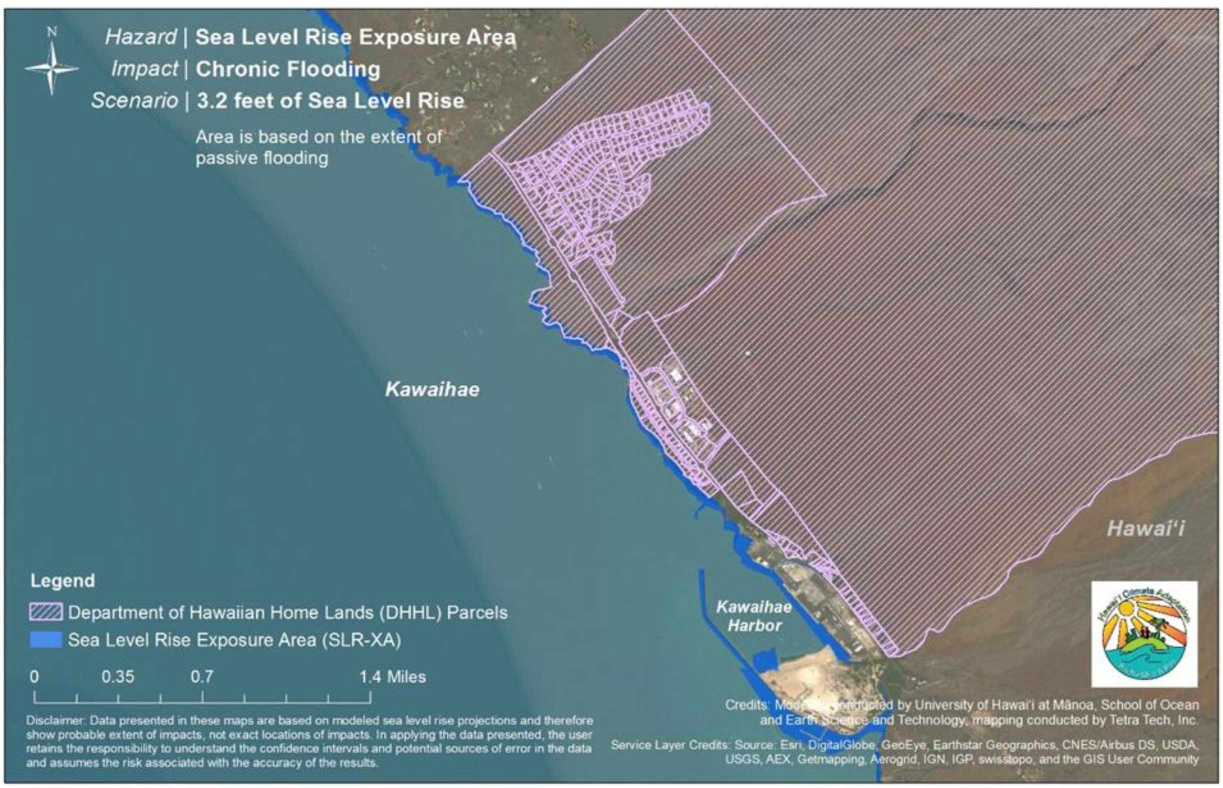


Figure 46. Potential chronic flooding of the Kawaihae Hawaiian Home Lands on the Island of Hawai‘i (hatched pink) in the SLR-XA (blue) with 3.2 feet of sea level rise

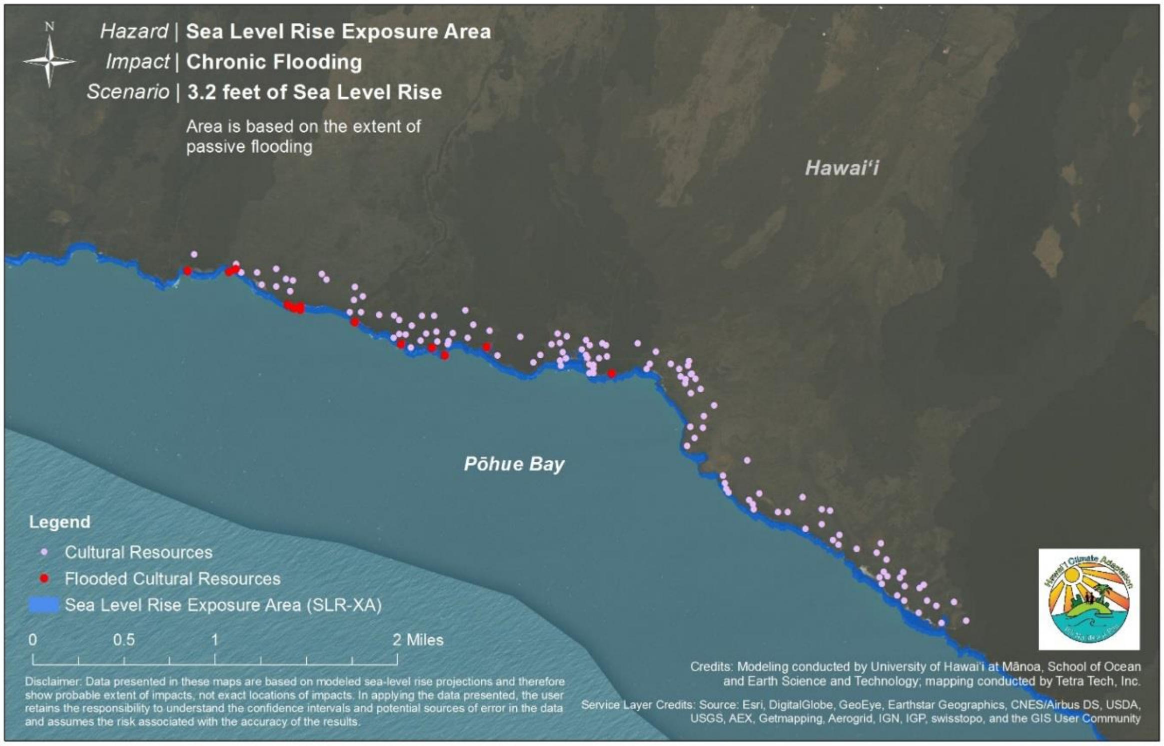


Figure 47. Cultural resource sites (light and dark pink) located in the SLR-XA (blue) with 3.2 feet of sea level rise along the shoreline of Pōhue Bay, Hawai'i

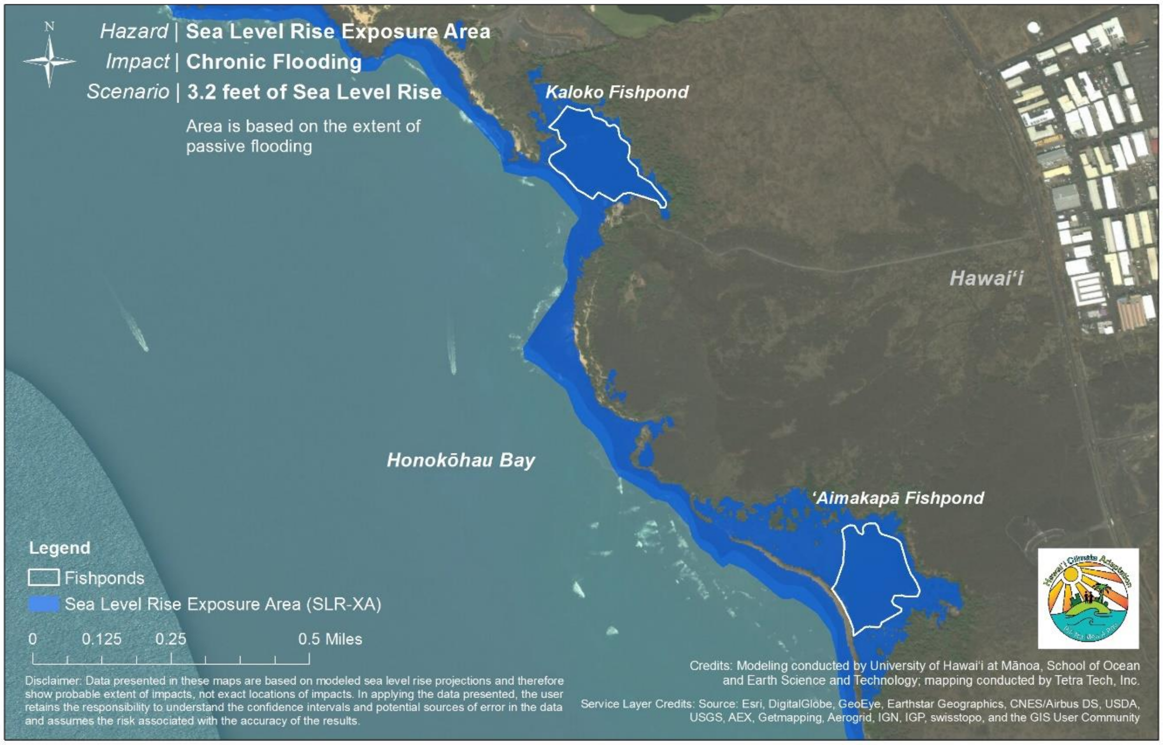


Figure 48. Loko i'a located in the SLR-XA with 3.2 feet of sea level rise along the shoreline of Honokōhau Bay, Hawai'i

POTENTIAL IMPACTS TO COASTAL RESOURCES AND PUBLIC ACCESS

The Island of Hawaiʻi has more than 305 miles of coastline, but approximately 75% of it is made up of cliffs of varying heights (County of Hawai'i 2005). While only 25% of its coastline is beaches, these beaches play a critical role in recreation for residents and the overall economy.

Approximately 692 acres of public beaches and parks (inclusive of city, state and federal parks) on the Island of Hawaiʻi are located within the SLR-XA with 3.2 feet of sea level rise. Many of these parks, such as Hōnaunau County Park and Pu'uohonua o Hōnaunau National Historical Park (Figure 49) are located on the seaward side of major roads, and demonstrate how lightly-developed parkland can provide a buffer between erosion and flood-prone shorelines and development for many decades.

Besides recreational areas, a variety of coastal habitats vital to aquatic organisms and wildlife would become flooded with sea level rise, changing the nature of such habitats and the organisms that rely on them. Estuarine habitats, where freshwater from rivers and streams, and saltwater from the sea meet and mix, would become increasingly marine with rising seas. This dynamic would impact areas such as Hakalua Stream and Beach Park located in South Hilo (Figure 50). Hawaiian anchialine pools, land-locked bodies of water of varying salinity that are adjacent to the ocean (The Nature Conservancy 2012), are occupied by small endemic red shrimp (*Halocaridina* and others) called ʻōpaeʻula and the endangered shrimp, *Procaris hawaiana* (Fish and Wildlife Service 2016). These pools have indirect, underground connections to the sea, and show tidal fluctuations in water level. Other species, restricted to the surface waters of the pools, include a few fish species, crustaceans and other invertebrates.Two endangered waterbirds (Hawaiian Stilt and Hawaiian Coot), and several species of migratory waterfowl also use these pools (The Nature Conservancy 2012). A study of anchialine pools in Kaloko-Honokōhau National Historical Park, found that 53% of the ponds would be inundated with 3.3 feet (1.0 meter) of sea level rise and 97% of the ponds would be inundated with 6.2 feet (1.9 meters) of sea level rise (Marrack and O'Grady 2014). However, the study also indicated that new pools could form if the areas were protected as open space to allow for such emergence.

Sea level rise also has the potential to impact facilities that release wastewater or hazardous materials to nearshore waters and coastal habitats. Septic tanks, cesspools and other OSDS, as well as hazardous materials storage and disposal sites could become flooded and release wastewater or contaminants to nearshore waters. On the Island of Hawaiʻi, OSDS are located along many urban and rural shoreline areas, such as along the shoreline of Kapoho (Figure 51). Releases from these OSDS may change disease risk for coral reefs and negatively impacting nearby coral resources, such as those off the coast of Puakō (Kim et al. 2014). Island-wide, there are approximately 94 OSDS within the SLR-XA with 3.2 feet of sea level rise. The reader should visit the online Hawaiʻi Sea Level Rise Viewer to determine if infrastructure of interest is located in the SLR-XA.

RECOMMENDATION HIGHLIGHTS

- Amend the State Legacy Lands Act to set aside funding for preserving priority coastal lands and use of a variety of practices and tools to enable legacy beaches to persist.
- Develop shoreline conservation and restoration priorities and guidelines to support adaptation to sea level rise.
- Expand the area of national, state, and county parks and wildlife refuges on the main Hawaiian Islands to preserve wetlands and wildlife.
- Protect nearshore water quality by identifying hazard mitigation measures to address coastal flooding of hazardous material/waste storage facilities and OSDSs vulnerable to sea level rise.

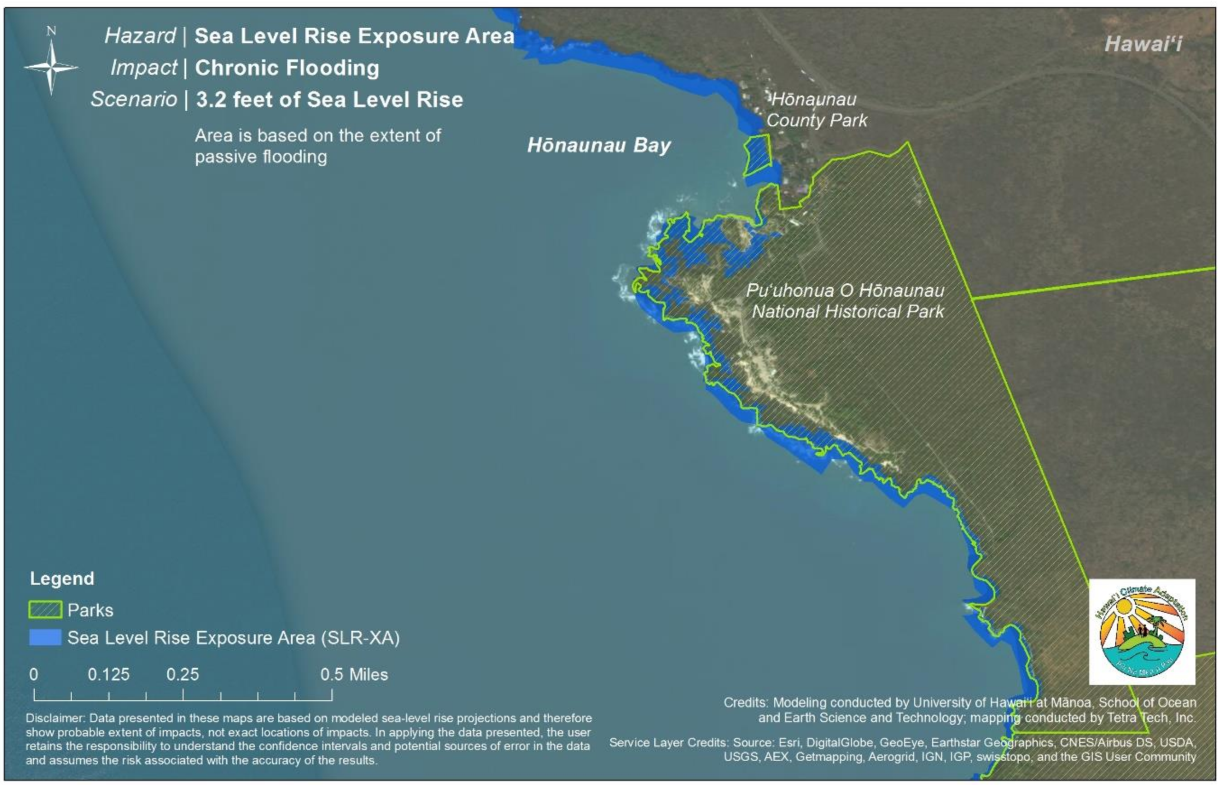


Figure 49. Potential chronic flooding of Hōnaunau County Park and Pu'uohonua o Hōnaunau National Historical Park in the SLR-XA with 3.2 feet of sea level rise along Hōnaunau Bay, Hawaiʻi

Figure 50. Hakalau Stream and Beach Park in the SLR-XA with 3.2 feet of sea level rise in South Hilo, Hawai'i

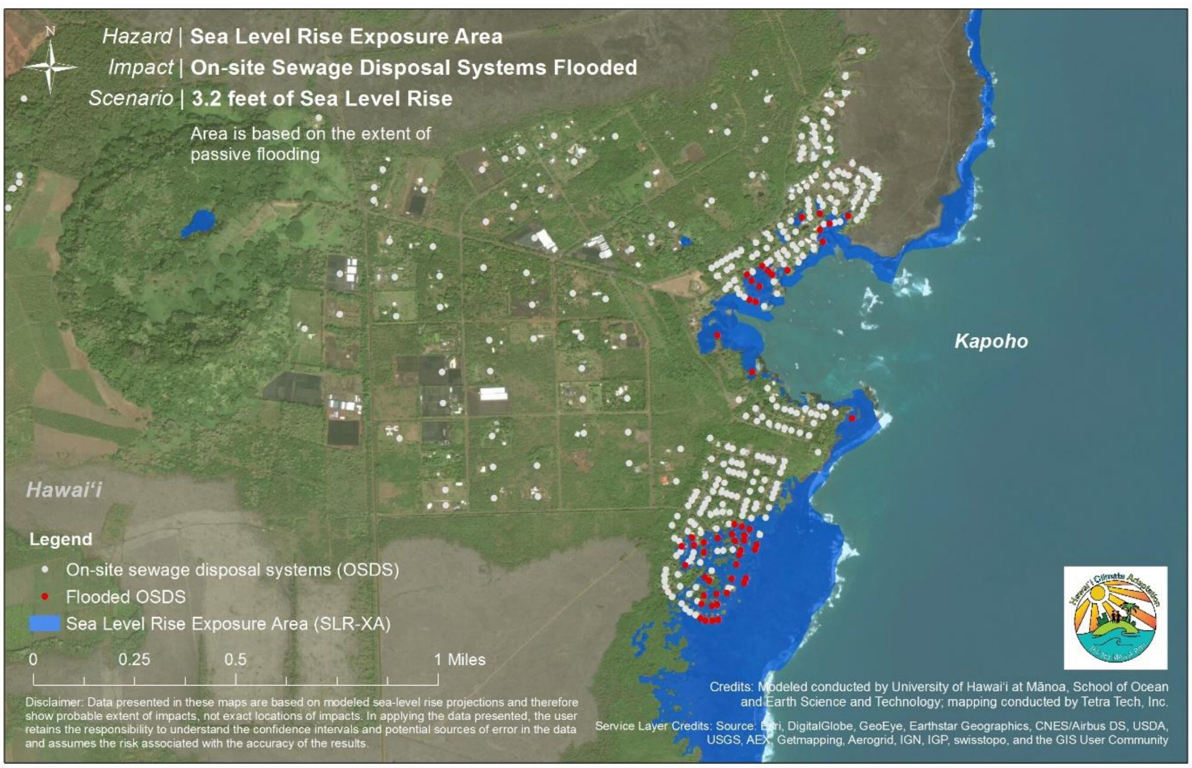


Figure 51. On-site sewage disposal systems flooded in the SLR-XA with 3.2 feet of sea level rise near Kapoho, Hawai'i

Challenges and Opportunities

Over the next 30 to 70 years, properties located on or near the Island of Hawaii's shorelines will increasingly be flooded, eroded, or completely lost to the sea. Portions of coastal roads will also become flooded, eroded, impassible, and irreparable, jeopardizing access to and from many communities. Beaches, such as those between Kailua-Kona and Kawaihae, will increasingly be eroded and permanently lost if hard structures such as roads and seawalls impede their landward migration. The flooding of hotels and transportation systems, along with the loss of beaches, would impact not only the people whose livelihoods depend on it, but the State's economy which relies heavily on revenues from the tourism industry. This Results section highlights just a few of the very real challenges on the Island of Hawai‘i with a scenario of 3.2 feet of sea level rise by the mid- to the latter-part of the century.

Sea level rise will not stop at the middle or end of the century. As highlighted throughout this Report, higher sea level rise projections are considered physically plausible by the end of the century based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). While this Report models sea level rise up to 3.2 feet, it should be noted that NOAA has modeled passive flooding scenarios with up to 6 feet of sea level rise in their Sea Level Rise Viewer (NOAA 2017b). To illustrate potential impacts from higher sea level scenarios, we incorporated the 5-foot passive flood layer from NOAA into our vulnerability assessment which increases the area of the SLR-XA for the Island of Hawai‘i by 18%. Figure 52 shows the potential extent of 5 feet of passive flooding with sea level rise in Kailua-Kona. While there is uncertainty over when the islands might experience such extreme sea level rise, the information is provided to remind readers that sea level rise is going to continue for the remainder of the century and beyond.

With abundant land outside of the SLR-XA, the Island of Hawai‘i has opportunities to plan for sea level rise now by considering County General Plan and Community Plan updates that recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone and to plan for future land use now. In addition to chronic coastal flooding from sea level rise, tropical storms, hurricanes, and tsunamis create waves that flood low-lying coastal areas. The added risk from event-based coastal flooding exacerbated by sea level rise is not included in this Report. However, these events pose a potential for loss of human life and property, and for severe and long-term economic disruption. Communities should consider planning new development to reduce exposure from severe events by recognizing that the coastal floodplain will migrate landward with increased sea level rise. Hazard mitigation and disaster recovery projects should be reviewed and revised to address chronic and event-based flooding and consider the additive effects of accelerating sea level rise.

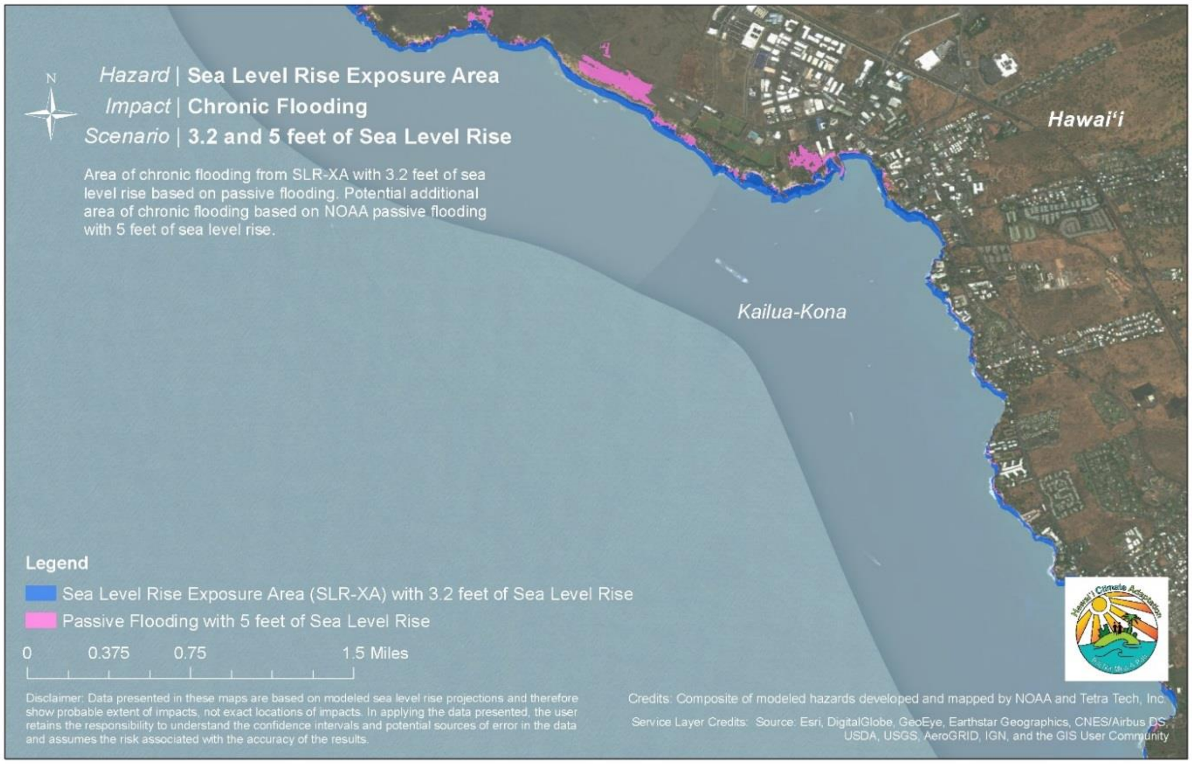


Figure 52. Potential additional area of chronic flooding with 5 feet of sea level rise in Kailua-Kona on the Island of Hawai‘i

SEA LEVEL RISE STORIES

County of Hawaiʻi

CONSIDERING SEA LEVEL RISE IN SUSTAINABLE COMMUNITIES AND DEVELOPMENT PLANS

The coastline of the Island of Hawaiʻi is long and diverse, with mostly basalt rock shoreline interrupted by pockets of sandy beach. This geology lends itself to coastal hazards that differ from other islands where beach erosion, for instance, is more prevalent. Instead, low-lying areas of the Island of Hawaiʻi are susceptible to other impacts associated with sea level rise, such as flooding of inland areas at high tides and episodic events, such as storm surge and tsunamis, which pose a less frequent but more severe concern. The County of Hawaiʻi is working to protect and manage their coastal development through research, planning, and policy.

Having studies to inform action, Bethany Morrison from the Hawaiʻi County Planning Department explained, is crucial to implementing good policy. For example, a study was conducted in Kapoho, in the district of Puna, on the eastern tip of the Island of Hawaiʻi, to determine the rate of subsidence—a geologic phenomenon where the land gradually sinks in elevation. "We have been able to successfully use that subsidence rate to increase the base flood elevation requirements for some structures being built in the Special Management Area [SMA]," said Morrison.

The lesson from this, Morrison explained, is that sea level rise can be treated much in the same way as subsidence in coastal areas within the SMA. Areas near the coast at risk of subsidence that contain valuable natural resources are protected by additional regulations and permits. SMA, defined in Act 176, SLH 1975, refers to the land extending not less than one hundred yards inland from the "shoreline" including the surrounding area extending one hundred yards from the border of any body of surface water subject to salinity intrusion or tidal influences and the waters themselves. SMA permits are issued by counties to regulate appropriate land use.

"The SMA has been a good tool. It allows for a little more dialogue," said Morrison in regards to using SMA permits to require coastal development to consider coastal hazards in their plan. "Because otherwise if [landowners] meet the code requirements, they can develop, but in the SMA we can mitigate for any impacts."

"Sea level rise as a coastal hazard is one of many," Morrison said, which means that it can be treated and managed like other coastal hazards such as subsidence. By using existing regulatory frameworks such as the SMA, the County of Hawaiʻi could require coastal development to factor in sea level rise alongside other coastal hazards. In order to employ this useful tool, the County of Hawaii's next step will need to be acquiring island-specific data on how sea level rise will impact the coastline.

You can read more of this story at
climateadaptation.hawaii.gov/climate stories


Honoapi'ilani Highway Olowalu, Maui
Source: Asa Ellison

Maui

The Island of Maui, known as "The Valley Isle," is the largest and most populous island in Maui County. Maui boasts a varied geography with coastal communities and mountainous areas in West Maui, small towns and agricultural communities in Upcountry and East Maui, and the more urbanized areas of Central Maui (County of Maui 2012). With 148,403 residents (State of Hawai'i 2015), the Island of Maui accounts for 10.6% of the State's population. Since the 1970s, Maui has experienced significant growth in both resident and visitor populations. A near tripling of Maui's population over the last 50 years, coupled with a growing tourism industry—over 2.6 million visitors came to Maui in 2016 (State of Hawai'i 2016) —has placed ever increasing demands on natural resources, critical infrastructure, and basic services.

Key Take Aways

- Over the next 30 to 70 years, homes and businesses located near the shoreline will be severely impacted by sea level rise. Nearly 300 structures would be chronically flooded with 3.2 feet of sea level rise.
- Of the 3,130 acres of land located within the SLR-XA, approximately a third of those lands are designated for urban land uses.
- With 3.2 feet of sea level rise, more than 11 miles of major coastal roads would become impassible jeopardizing critical access to and from many communities.
- Maui has lost more than 4 miles of beaches to coastal erosion fronting seawalls and other shoreline armoring. Many more miles of beach could be lost with sea level rise, if widespread armoring is allowed.

- A more detailed economic loss analysis is needed of Maui's critical infrastructure, including harbor facilities, airport facilities, sewage treatment plants, and roads. State and Counties should consider potential benefits in terms of long-term cost savings from implementing sea level rise adaption measures now (e.g., major flood proofing or relocation) compared to the cost of maintaining and repairing chronically threatened public infrastructure over the next 30 to 70 years.

This section provides a picture of the future of the sland of Maui with sea level rise and the potential impacts from chronic flooding. The results are based on modeling coastal flooding with sea level rise due to passive flooding, annual high wave flooding, and coastal erosion in the SLR-XA with up to 3.2 feet of sea level rise, and depicts flood hazards that may occur in the mid- to latter-half of this century. This timeframe is within the expected lifespan of most new construction and much of our existing development. It should be noted that sea level rise projections greater than 3.2 feet are "physically plausible" by the end of the century, based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). Vulnerability to 1.1 feet of sea level rise in the SLR-XA is used to approximate current or near-term exposure to coastal hazards and sea level rise. Vulnerability is assessed in terms of potential impacts to land use, people, property, cultural and natural resources, and critical infrastructure (only land and structures are monetized, not infrastructure).

The reader is urged to exercise caution in interpreting the results, which could be to a greater or lesser extent depending on actual observed future sea level rise, technological innovations in climate change mitigation and adaptation, unknown economic variables, as well as future societal choices which cannot be known today. Further, as not all parts of the island can be shown in detail, the reader should also visit the Hawaiʻi Sea Level Rise Viewer to explore the full extent of the vulnerability maps for each island.

Potential Impacts in the Sea Level Rise Exposure Area

The SLR-XA depicts the area of potential chronic flooding from the combined exposure to passive flooding, annual high wave flooding, and coastal erosion with sea level rise. With 3.2 feet of sea level rise, low-lying coastal areas around the island within the SLR-XA would become chronically flooded within the mid- to latter-half of this century (Figure 53). This land will become submerged as a result of coastal erosion, coastal flooding from tides and waves, or become new wetlands behind the shoreline from rising water tables and reduced drainage. Approximately 3,130 acres of land on Maui is estimated to be located in the SLR-XA, with one third of that located in the Urban District.

Towns such as Waiheʻe, Hana, Lāhainā, Kīhei, and others, that are vulnerable to the effects of sea level rise are shown in Figure 54. Waiheʻe is a small rural town located on the northwest side of the island where portions of the Waiheʻe Coastal Dune and Wetlands Refuge would be permanently flooded with 3.2 feet of sea level rise. In the town of Hana, higher sea levels would form new wetlands that would impact rural homeowners. Lāhainā, the former capital of the State of Hawaiʻi and an important seaport, is an urban settlement in West Maui backed by agricultural lands and the West Maui Mountains. With 3.2 feet of sea level rise, Lāhainā's historic district would be exposed to chronic flooding, along with portions of the town itself which is West Maui's visitor, service, commercial and residential center. Kīhei is the residential and commercial center of Southwest Maui. It has been identified as a planned growth area in the County due to the existing opportunities to expand outward from current settlement areas (County of Maui 2010). However, many areas in Kīhei may succumb to flooding from sea level rise. Thoughtful planning about where and how this expansion could occur is important to ensure new development is resilient to sea level rise.

Over time, as sea level continues to rise, low-lying, populated coastal communities such as Spreckelsville would experience increased frequency and severity of flooding, ultimately making some areas of the coast impassible or uninhabitable (Figure 55). Decisions about where to use coastal armoring and when to retreat will need to be made carefully. It should be noted that seawalls may not be effective at preventing flooding with sea level rise in many low-lying areas as rising groundwater can infiltrate through porous geology. While specific responses to sea level rise would need to be place-based, larger regional issues should also be considered, such as whether to armor in place or whether to relocate roads and other critical infrastructure inland. In the case of Spreckelsville and similar coastal communities, there may be opportunities for managed retreat inland, as there are ample vacant lands immediately mauka (landward) and outside of the SLR-XA. However, as discussed in the Recommendations Chapter of this Report (Chapter 5), and as with other populated coastal areas with adjacent vacant lands, large-scale boundary amendments should be predicated on appropriate state policies and guidelines (e.g., within Chapter 205, State Land Use Act) to provide the supportive legal basis for major land use changes.

Kaanapali Beach, west Maui, Hawaiʻi
Source: Andrew D. Short

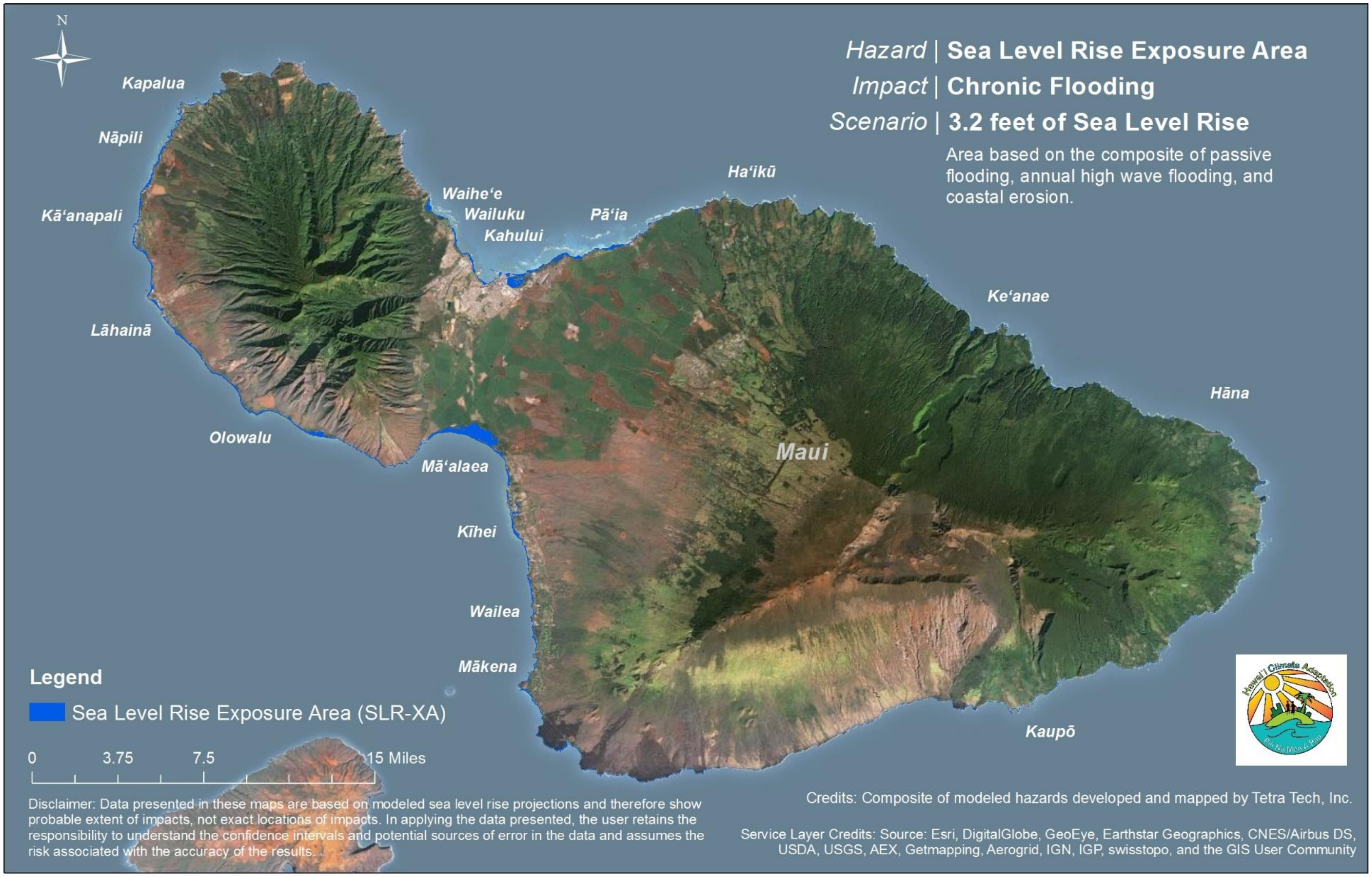


Figure 53. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise for Maui

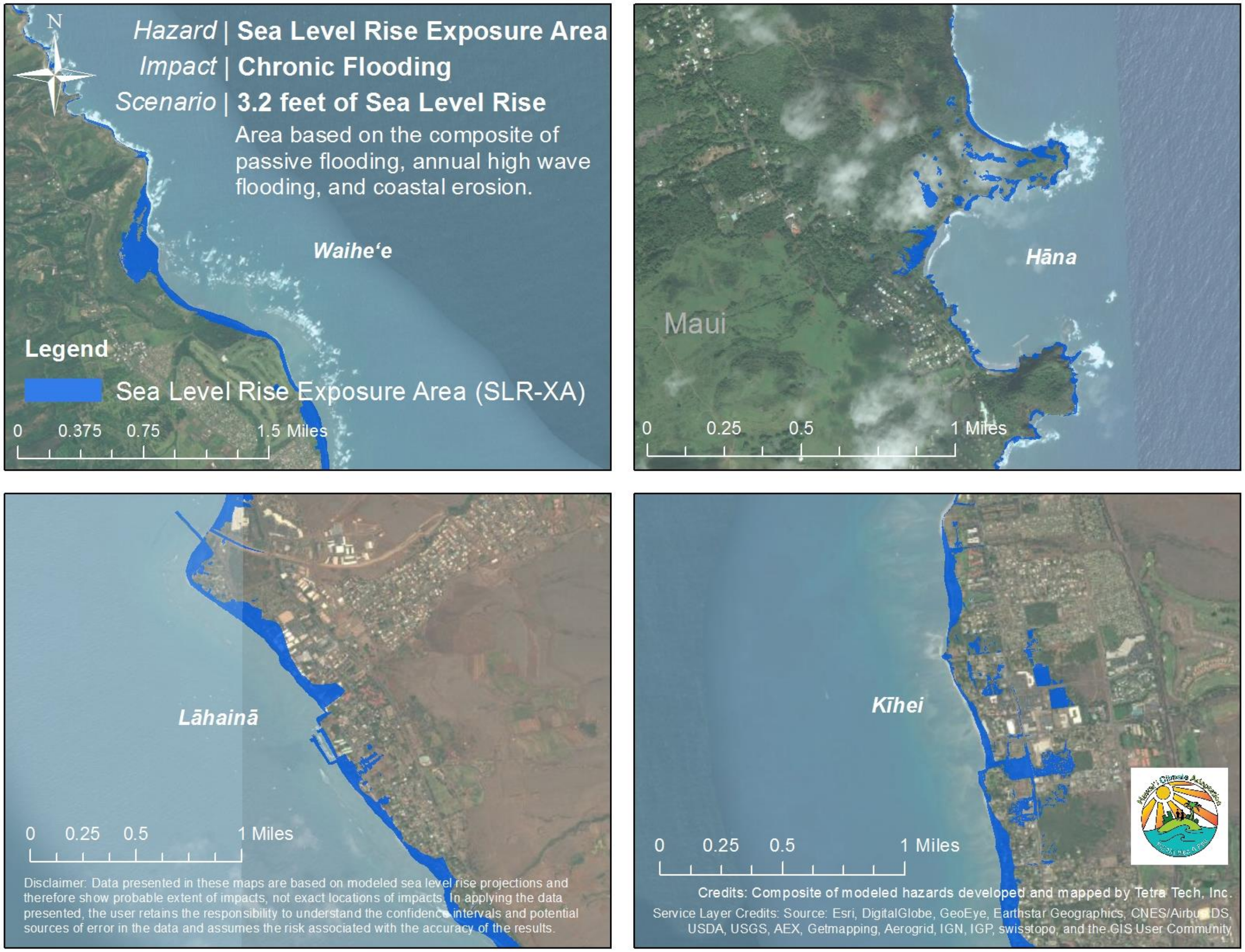


Figure 54. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise in four areas on Maui

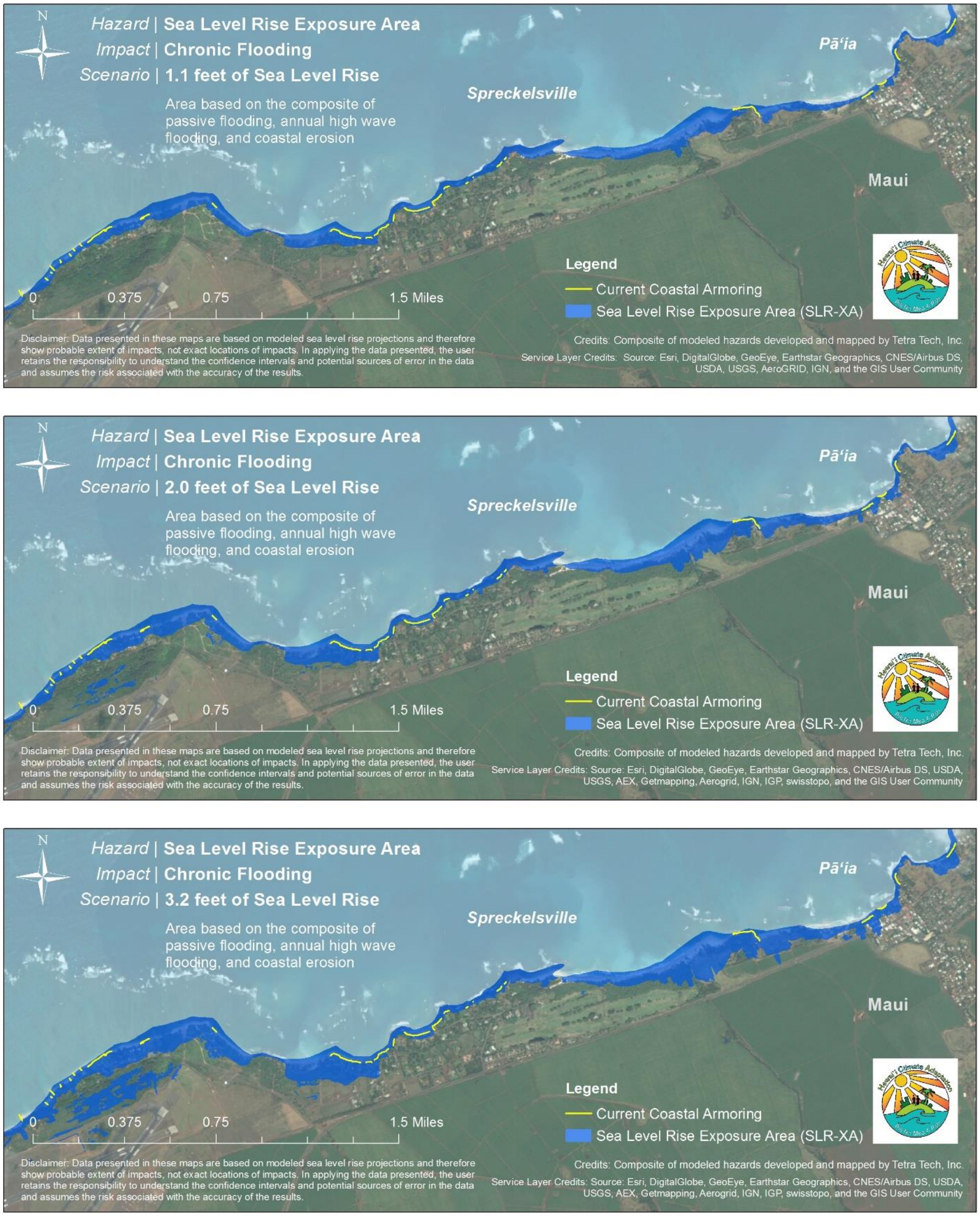


Figure 55. Potential chronic flooding in the sea level rise exposure area with 1.1, 2.0, and 3.2 feet of sea level rise in Spreckelsville, Maui

POTENTIAL IMPACTS TO LAND USE

While sea level rise would affect lands within the State Urban, Agricultural, Conservation, and Rural Land Use Districts around the island, Conservation District lands would experience the greatest extent of chronic flooding, followed by Urban District lands (Figure 56). Over half of the 3,130 acres located in the SLR-XA are designated as Conservation while almost a third is designated for Urban use. Thus, it can be expected that new Urban District lands would need to be designated to accommodate redevelopment away from the shoreline. However, the island of Maui is unique in that agricultural land is the "default" district designation for any lands not formally designated as Urban, Rural, or Conservation. Many of these "default" lands frequently border more urbanized areas (County of Maui 2012) which would allow for the potential expansion of the adjacent urban areas. This concept coincides with The Maui Island Plan which identifies lands abutting Kahului, Waikapū, Lāhainā, and northeast Kīhei as areas that could provide such opportunities for conversion and expansion (County of Maui 2012).

While the State Land Use Law (Hawai'i Revised Statutes Chapter 205) could be used to address major land changes as part of a managed retreat strategy, County General Plan and Community Plan updates provide important opportunities to address land use issues with rising seas at the local level. Revised and updated SMA policies, objectives, and requirements offer additional opportunities at the local level to prepare for sea level rise. Moreover, if the County of Maui chooses to recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone (one of the recommendations in Chapter 5), it might be prudent to consider adjusting SMA boundaries to coincide with the SLR-XA so that new subdivisions, commercial areas, hotels, and other development activities could undergo a higher level of review in light of sea level rise constraints. Figure 57 illustrates the partial overlap of SMA boundaries with the SLR-XA along portions of Ukumehame which is the southernmost settlement in the West Maui Community Plan region. It is a low-density agricultural region that still contains vacant undeveloped lots. The community is surrounded by fallow sugarcane fields and significant cultural resources. The County may want to consider adjusting SMA boundaries to incorporate areas vulnerable to sea level rise throughout this region.

RECOMMENDATION HIGHLIGHTS

- Recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone in the County General Plan and Community Plan updates.
- Strive to balance managed retreat strategies from vulnerable urban areas with preservation of agriculture and conservation lands.
- Seek opportunities to plan new development outside of the SLR-XA, wherever possible, under a long-term comprehensive adaptation strategy.
- Develop design standards to increase flood resiliency within the SLR-XA.

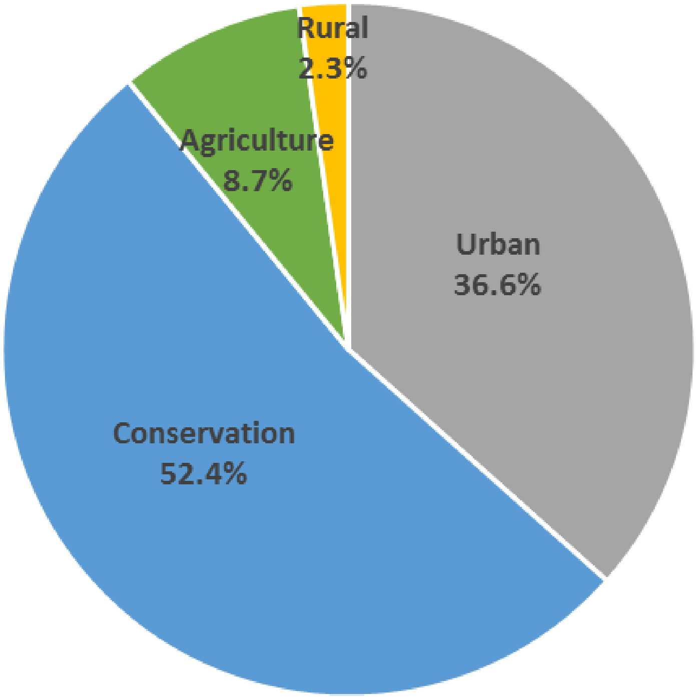


Figure 56. Estimated percentage of Land Use Districts impacted in the 3.2 feet sea level rise exposure area on Maui

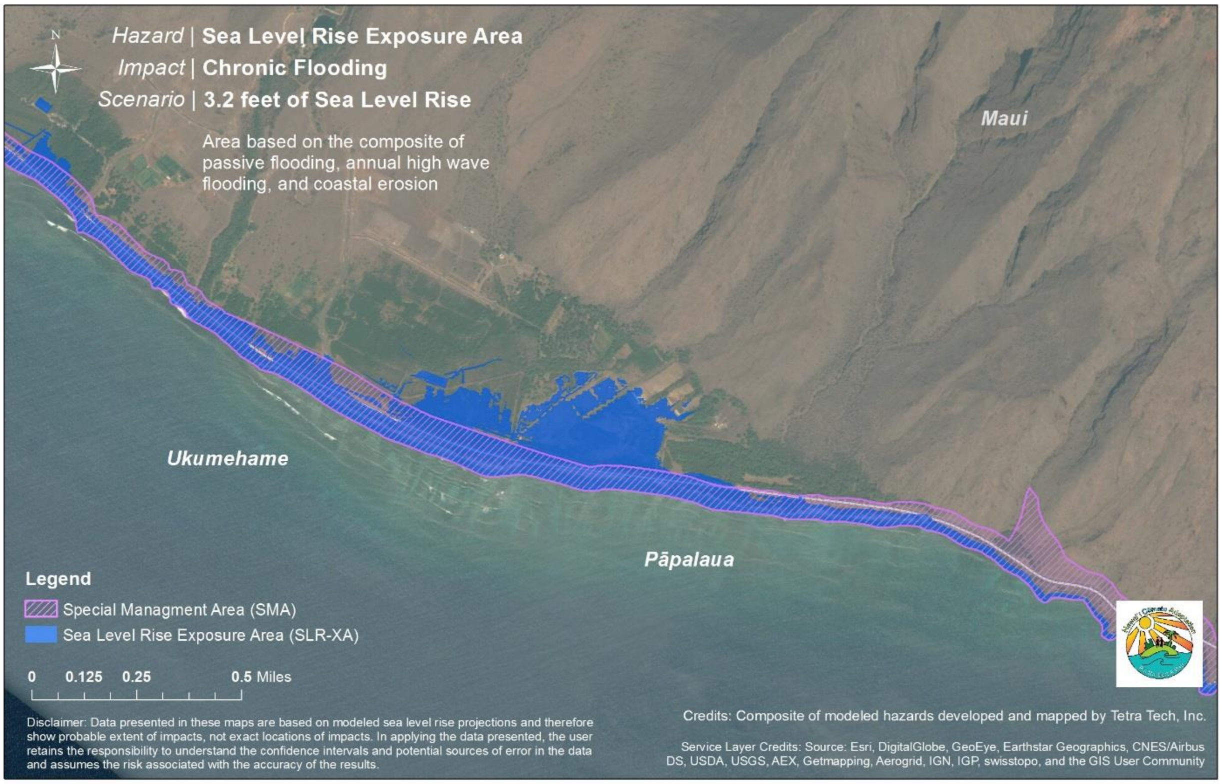


Figure 57. Portions of the 3.2 feet SLR-XA (blue) around Ukumehame extending beyond the Special Management Area (SMA) boundary (pink hatched area) that would not be subject to SMA permitting requirements

POTENTIAL IMPACTS TO PEOPLE AND PROPERTY

People living and working within the SLR-XA would be displaced when homes, condominiums, and business become flooded due to sea level rise. The potential number of people displaced is calculated by assigning an estimated occupancy for each type of structure in the SLR-XA. Potential economic loss in the SLR-XA is estimated based on the value of land and structures flooded. Loss estimates are assessed at the parcel level and aggregated into 1-hectare grids. The potential economic loss associated with flooded roads, water/wastewater facilities, and other critical infrastructure is not accounted for in the assessment of economic impacts, and would add significant increases in losses.

The potential number of displaced people island-wide could rise from 730 residents with 1.1 feet of sea level rise to over 1,590 residents with 3.2 feet of sea level rise (Figure 58). The people displaced would include a range of income levels and living arrangements. In addition, both homeowners and renters are expected to be affected based on the housing census data provided by the U.S. Census Bureau for Census County Divisions (CCDs) (U.S. Census Bureau 2015d). CCDs are areas delineated by the U.S. Census Bureau in cooperation with state, tribal, and local officials for statistical purposes. CCD boundaries usually follow visible features and usually coincide with Census Tract boundaries. For the Island of Maui, the island is divided into 11 CCDs: Haʻikū-Paʻuwela, Hana, Kahului, Kīhei, Kula, Lahaina, Makawao-Paia, Puʻunēnē, Spreckelsville, Waiheʻe-Waikapū, and Wailuku. In taking the average for the percentage of the occupied housing units that are owner- and renter-occupied, approximately 58% are owner-occupied while approximately 42% are renter-occupied.

Potential economic losses (all structures and land) island-wide would increase from an estimated $1.7 billion with 1.1 feet of sea level rise to $3.2 billion with 3.2 feet of sea level rise (Figure 58). Approximately 79% of the potential economic loss with 3.2 feet of sea level rise is attributed to the loss of residential structures and land. The potential economic loss across all sectors is associated with approximately 760 structures in the SLR-XA with 3.2 feet of sea level rise and approximately 3,130 acres of land. A number of the potentially flooded structures are hotels located in important visitor destination areas in West Maui as shown in Figure 59.

With 3.2 feet of sea level rise, potential economic loss would occur in low-lying coastal areas island-wide, with the greatest loss in West Maui due to the concentration of high-value residential and commercial land and structures (Figure 60). Over time, as sea level continues to rise, communities such as Lāhainā (Figure 61) would experience increasing potential economic loss as it serves as the region's visitor, service, commercial, and residential center.

RECOMMENDATION HIGHLIGHTS

- Require mandatory disclosure for vulnerable properties and consider acquisition to protect valuable coastal resources.
- Seek opportunities to plan new development well landward of the SLR-XA with 3.2 feet of sea level rise under a long-term, comprehensive strategy.
- Develop design standards to increase flood resiliency for existing and new development within the SLR-XA that cannot be relocated.
- Develop a multi-pronged financing strategy at federal, state, county, private sector, and philanthropic levels to address costs of adaptation to sea level rise.

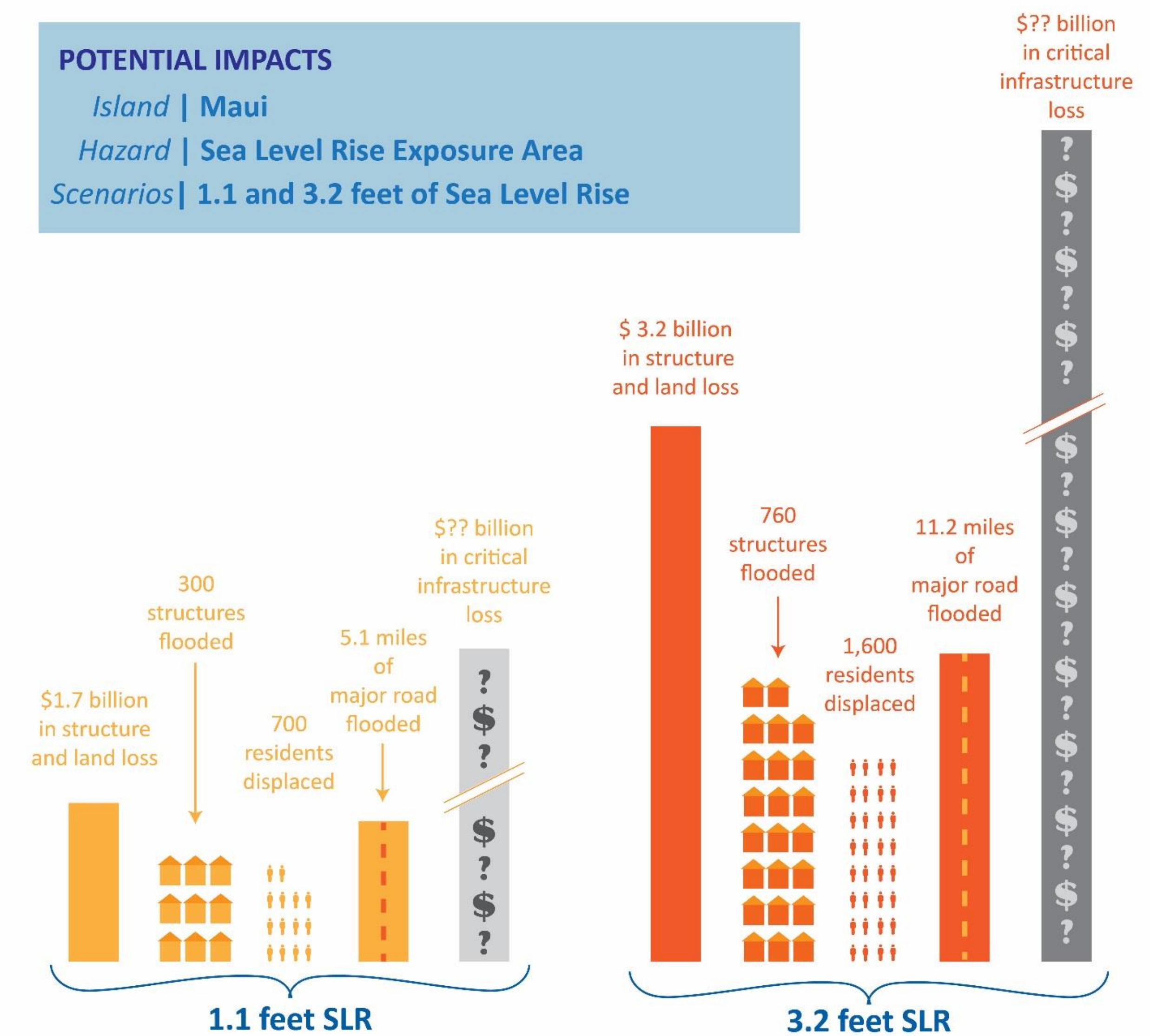


Figure 58. Summary of potential impacts in the SLR-XA with 1.1 feet and 3.2 feet of sea level rise on Maui

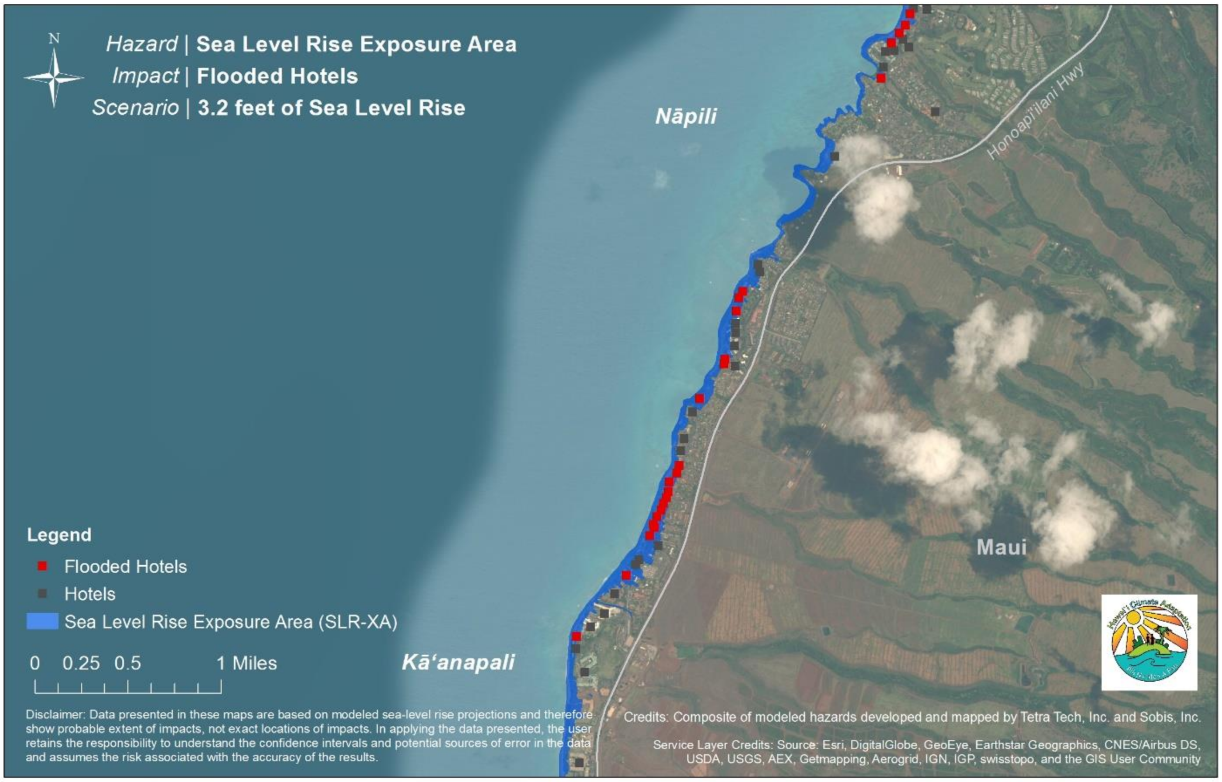


Figure 59. Potential chronic flooding of hotels with 3.2 feet of sea level rise between Kāʻanapali and Nāpili, Maui

POTENTIAL IMPACTS TO CRITICAL INFRASTRUCTURE

Sea level rise would result in significant impacts to roads, harbors, airports, electrical and telecommunication infrastructure, water/wastewater facilities and conveyance systems, and other public service facilities (i.e. schools, fire stations, police stations, medical facilities) on Maui. Following the trends of private development, Maui's critical infrastructure is concentrated along low-lying shores and is highly vulnerable to flooding and erosion in the SLR-XA. An estimated 5.1 miles of major roads in Maui would be flooded in the SLR-XA with 1.1 feet of sea level rise, increasing to 11.2 miles with 3.2 feet of sea level rise (Figure 58). Portions of many coastal roads, such as Honoapiʻilani Highway, which connects West Maui and Central Maui, would become chronically flooded (Figure 62). This could result in wide-spread regional issues such as loss of commerce, loss of access to emergency services and increased traffic on other roads and highways, some of which serve as the only access in and out of many communities. Electric and telecommunication transmission lines commonly follow roads and those located underground in the SLR-XA may be impacted by sea level rise resulting in service disruptions.

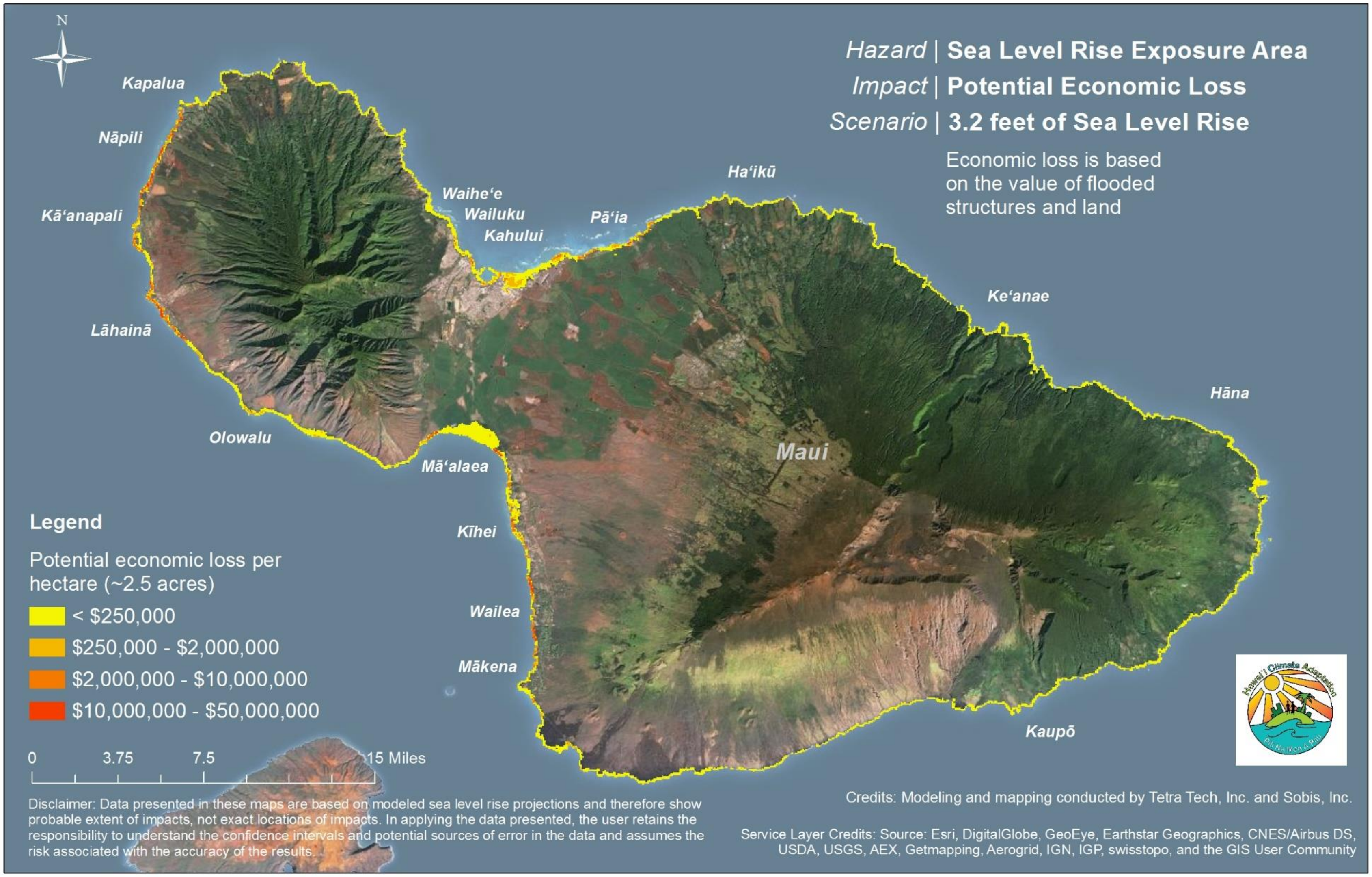
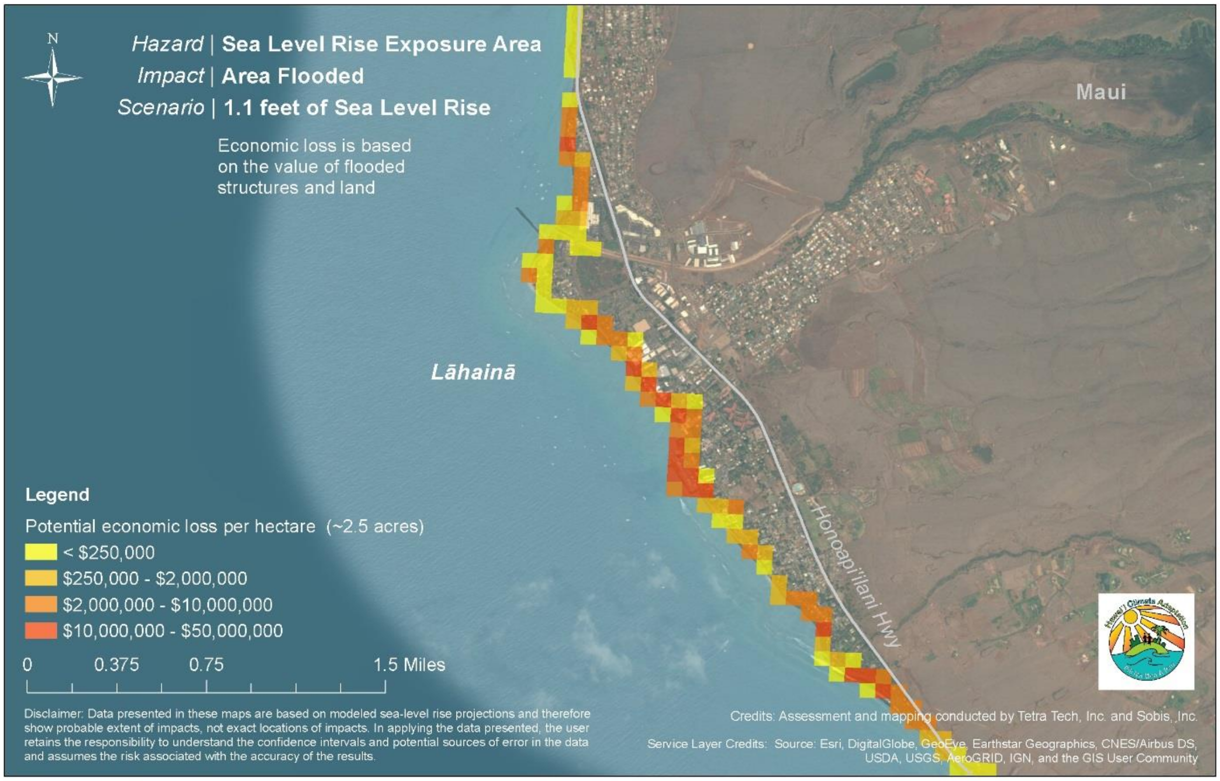


Figure 60. Potential economic loss in the SLR-XA with 3.2 feet of sea level rise on Maui



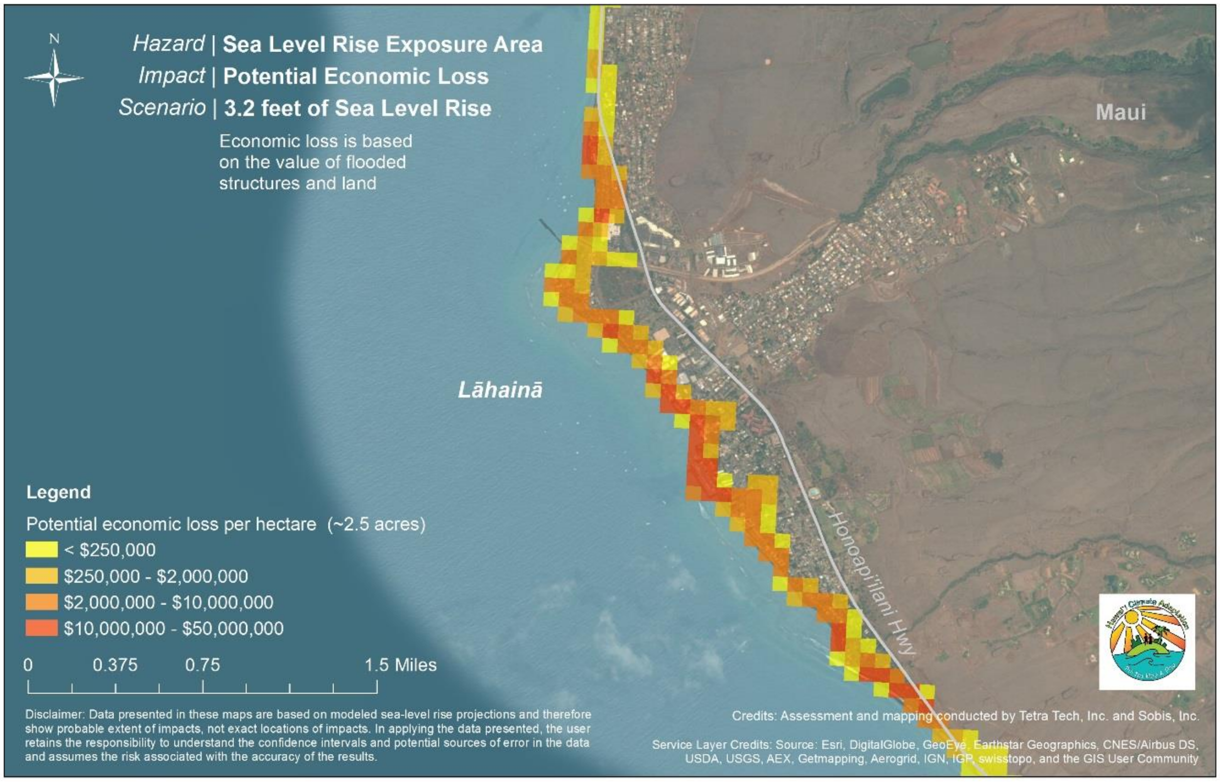
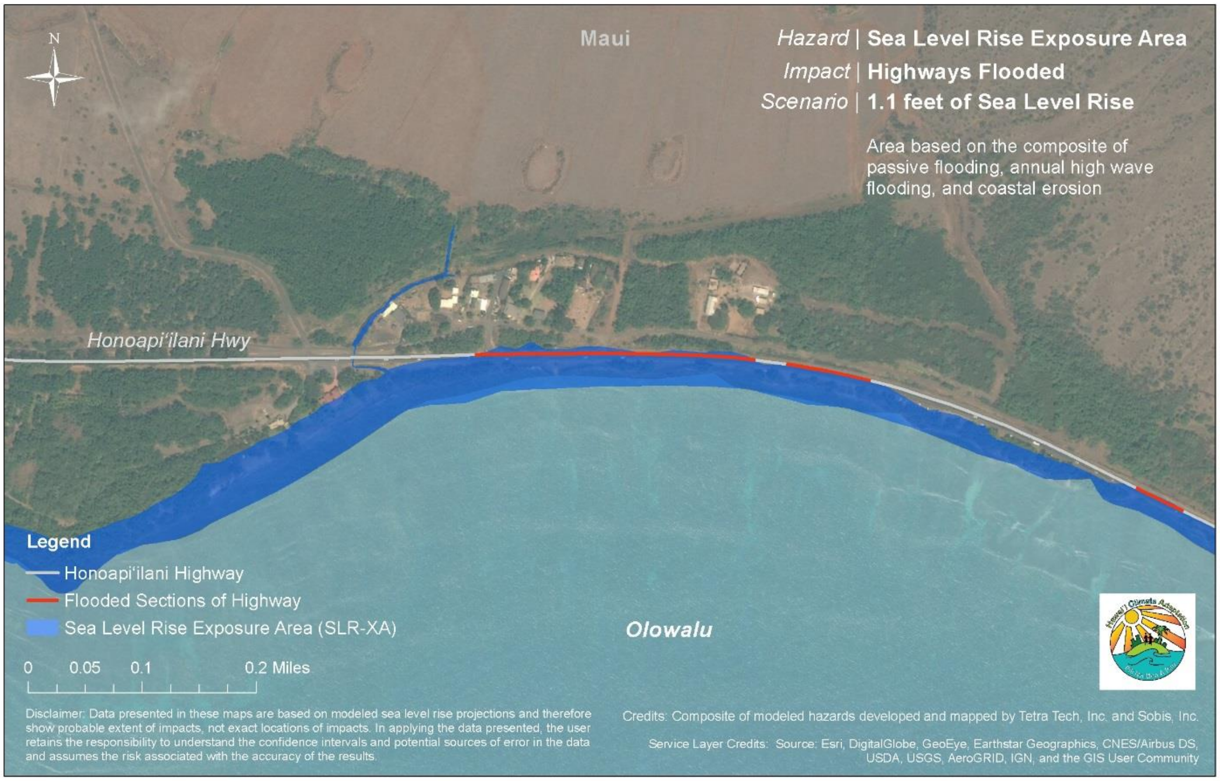


Figure 61. Potential economic loss in the SLR-XA with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise in Lāhainā, Maui



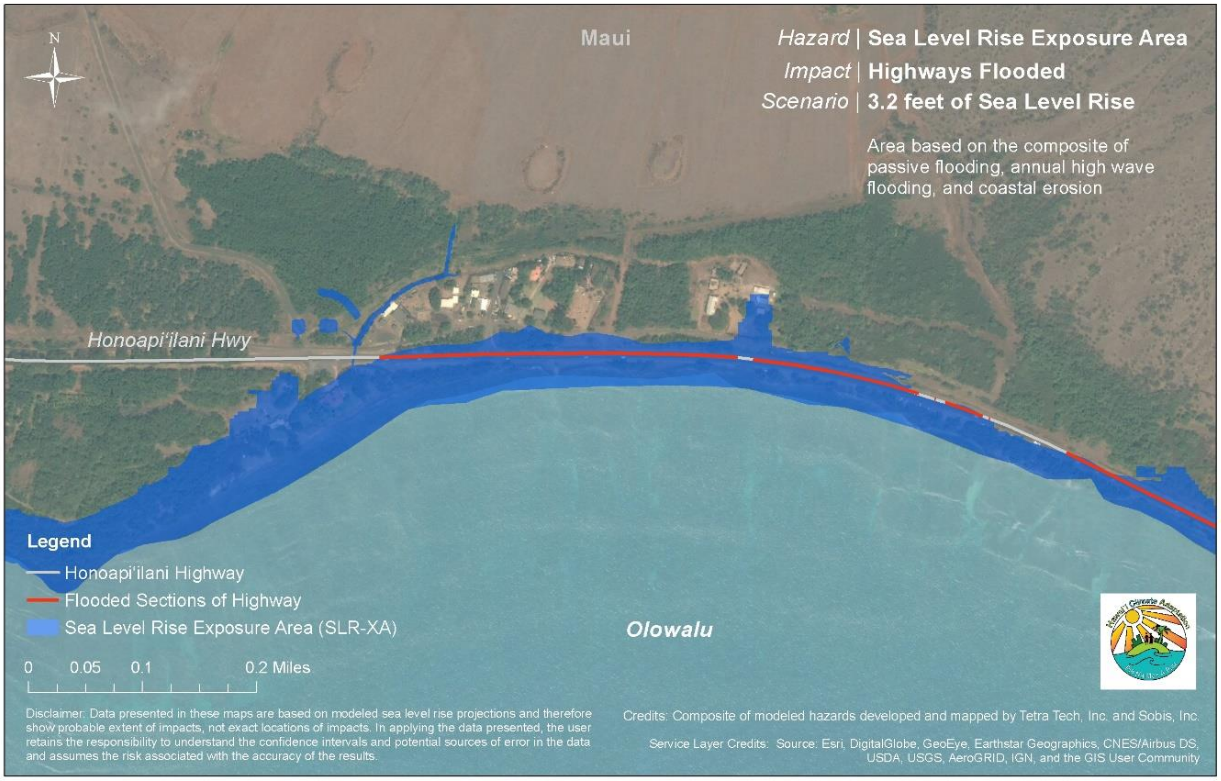


Figure 62. Projected chronic flooding of Honoapi'ilani Highway in the SLR-XA (red) with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise road flood in Olowalu, Maui

Maui's three commercial harbors and three airports are all located in the SLR-XA with 3.2 feet of sea level rise. The busiest and most significant facilities are located in Kahului in Central Maui (Figure 63). According to the Maui Island Plan (County of Maui 2012) "all business activities on the island are either directly or indirectly dependent on operations at Kahului Harbor" (State of Hawai'i 2015). More than 22,500 tons of cargo enter the island via the airport annually (based on the amount of cargo that passed through the harbors in 2014) (State of Hawai'i 2015). Kahului Airport, the second busiest airport in the State, serves more than 6.2 million passengers a year. These critical transportation hubs and other critical infrastructure would become increasingly exposed to chronic flooding from sea level rise. Further, interruption to interisland and transoceanic shipping and travel would impact residents, visitors, and all forms of economic activity.

Island-wide, no schools, fire stations, police stations, or hospitals are located within the SLR-XA with 3.2 feet of sea level rise; however, the Wailuku-Kahului Wastewater Reclamation Facility may experience chronic flooding from 3.2 feet of sea level rise. A more detailed analyses of vulnerability and adaptation options for critical infrastructure are needed to evaluate adaptation options such as retrofitting or relocation. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., flood proofing and relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.

Please keep in mind that the economic loss resulting from critical infrastructure was not estimated due to the complexity and uncertainties involved in design, siting, and construction (Figure 58). However, it should be noted that these costs could be an order of magnitude greater than the potential economic losses estimated from land and structures.

RECOMMENDATION HIGHLIGHTS

- State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., flood proofing and relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.
- Require the design and siting of new development and capital improvement projects to include an in-depth analysis of sea level rise impacts based on elevation, tolerance for risk, and lifetime of the structure.

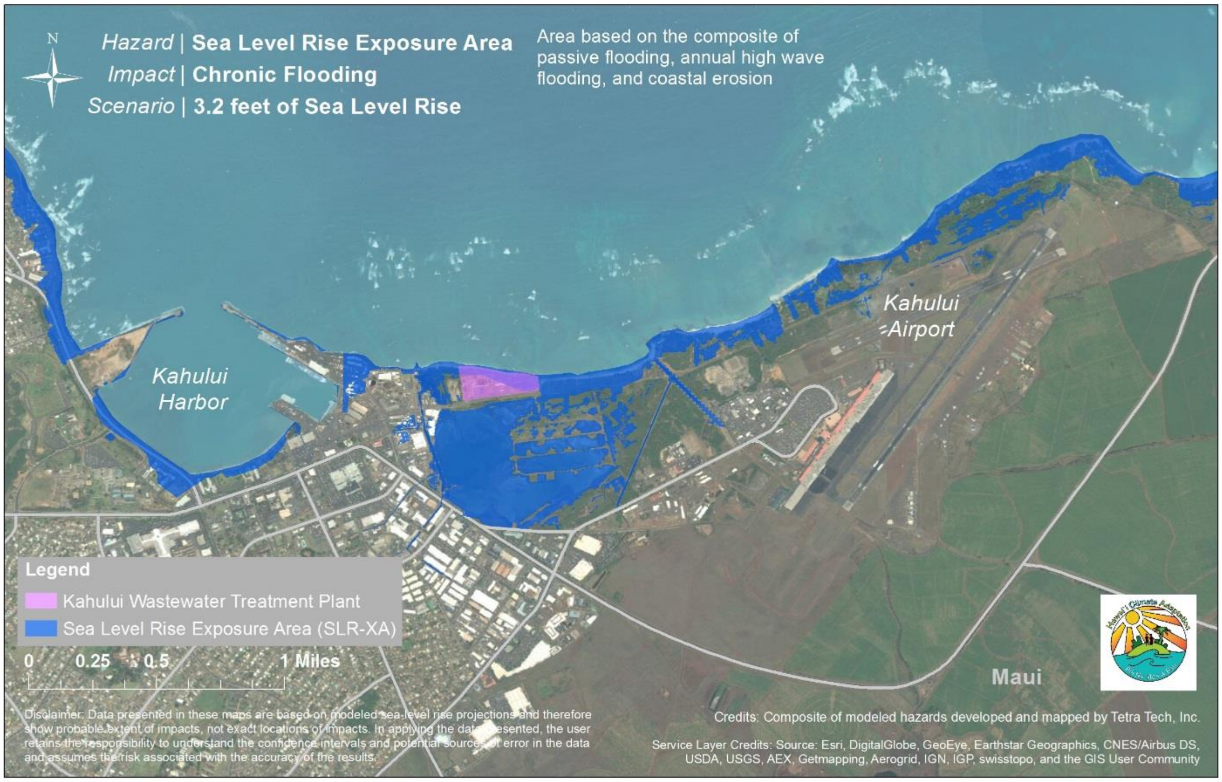


Figure 63. Kahului Harbor and Kahului Airport in the SLR-XA with 3.2 feet of sea level rise on Maui

POTENTIAL IMPACTS TO NATIVE HAWAIIAN COMMUNITIES AND CULTURAL RESOURCES

Hawaiian Home Lands are intended to provide for the economic self-sufficiency of Native Hawaiians through a homesteading program (University of Hawai‘i 2015). Consistent with Native Hawaiian culture, Hawaiian Home Lands include areas from mauka to makai (from the mountain to the sea). Coastal portions of Hawaiian Home Lands, such as in the East Maui communities of Ke’anae and Wailua (Figure 64), would be flooded with sea level rise displacing Native Hawaiian families that live in this area. In addition, fishing and cultural practices taking place along the shore would be impacted as beaches erode. In a recent study of multiple coastal hazards, 3 of the 11 Hawaiian Home Lands homesteads on Maui—Waiehu, Leiali’i, and Kahikinui—are estimated to have the greatest potential for people to be displaced by tsunamis, waves, and sea level rise (University of Hawai‘i 2015).

In addition to Native Hawaiian communities, many Native Hawaiian cultural and historical resources are located near the shoreline and are threatened by sea level rise. Coastal erosion already threatens areas that have served as burial grounds, home sites, fish ponds, and other places of cultural significance (Kane et al. 2012). The number of cultural sites on Maui in the SLR-XA is projected to increase from 33 sites with 1.1 feet of sea level rise, to 48 with 3.2 feet of sea level rise. This includes an unnamed resource located along the coast in Ke‘anae (Figure 64).

RECOMMENDATION HIGHLIGHTS

- Develop an inventory of Native Hawaiian cultural resources and practices impacted by sea level rise.
- Work with Native Hawaiian communities to determine steps they want to take regarding climate impacts.
- Develop adaption plans to preserve access to coastal lands and water within Native Hawaiian communities.

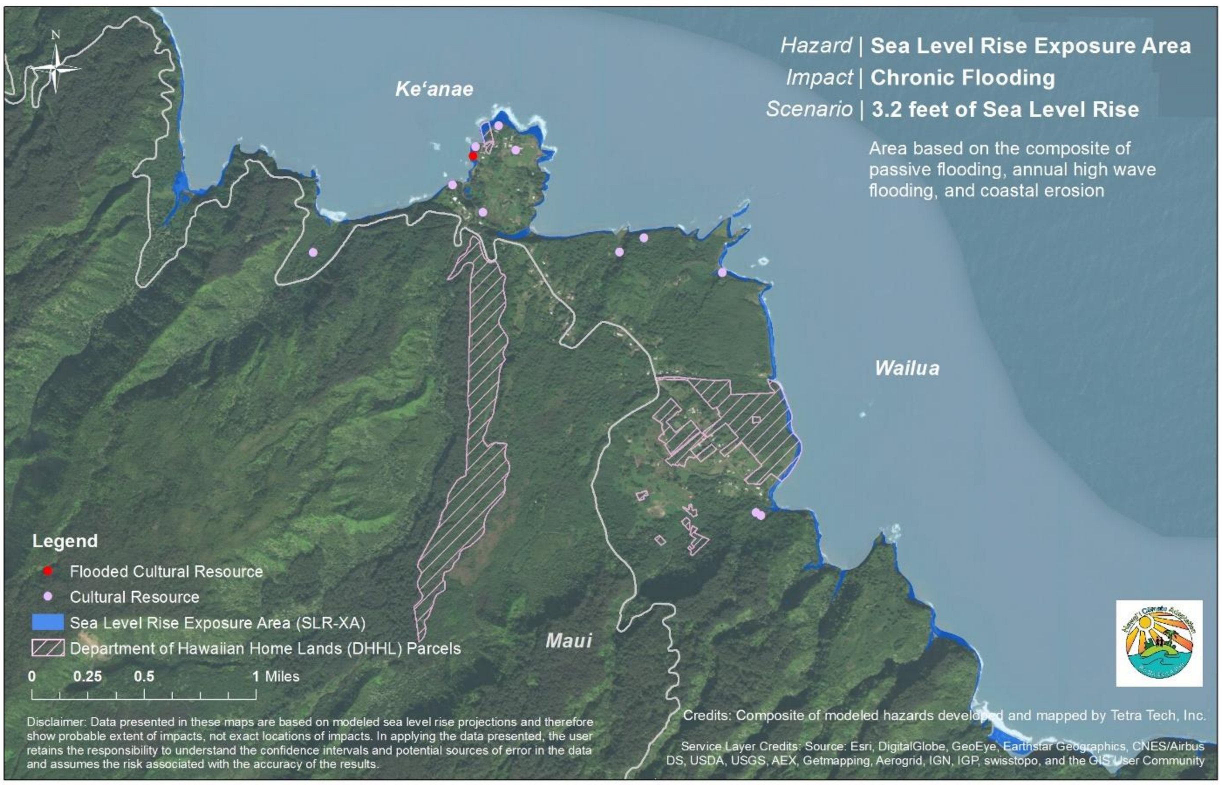


Figure 64. Potential chronic flooding of Ke'anae and Wailua Hawaiian Home Lands on Maui (pink) and cultural resources (red) in the SLR-XA (blue) with 3.2 feet of sea level rise

Kahoʻolawe

Kahoʻolawe, part of Maui County, is the 8th largest island in Hawaiʻi, with an area of 45 square miles. The island was not analyzed in this Report, largely due to the lack of built infrastructure and population upon which to conduct a vulnerability assessment. However, the island is home to significant natural and cultural resources which could be vulnerable to sea level rise which should be investigated further.

The island is best known in recent history as "The Target Isle" for its use as a bombing range and other military training for half of the 20th century. Known also as the piko (navel, center) of the Hawaiian archipelago, the island has widespread cultural significance for fishing, voyaging and navigation. Owned by the State of Hawaiʻi, the island is managed by the Kahoʻolawe Island Reserve Commission (KIRC). Kahoʻolawe currently has no resident population, however KIRC volunteers, staff, and other visitors stay on the island in a cluster of buildings on the southeast coast at Honokanaiʻa. Vegetation on the island is defined by the minimal rainfall the island receives, as well as the impact of widespread former ranching on the island. KIRC works to restore native species on the island such as native grass planting in coastal dunes.

Historically, the island has been home to modest settlement due to limited resources such as freshwater. Kahoʻolawe is designated as an Archeological District and is on the National Register of Historic Places. Many sacred places are found on the island, including heiau (shrines), koʻa (fishing shrines), and locations of navigational significance. Kahoʻolawe is a traditional point of embarkation for voyaging canoes sailing to Tahiti and there is a navigational platform located right on the shoreline at the western-most point of the island, called Kealaikahiki (the road to Tahiti).

Most of Kahoʻolawe's coastline is rocky with some sandy beaches located in protected bays. The island has experienced extensive land-based erosion due to the large populations of cattle, goats, and sheep that were ranched on the island in the 19th and 20th centuries. With 3.2 feet of sea level rise, some of the cultural sites and ecosystems on the coast are likely to be exposed to chronic flooding.

POTENTIAL IMPACTS TO COASTAL RESOURCES AND PUBLIC ACCESS

Maui's beaches play a critical role in recreation for our residents and Hawaii's overall economy (Cristini et al. 2013). Approximately 110 acres of public beaches and parks on Maui are located within the SLR-XA with 3.2 feet of sea level rise. Many of these parks, such as Hoʻokipa Beach Park (Figure 65), are located on the seaward side of major roads, and demonstrate how lightly-developed parkland can provide a buffer between eroding shorelines and development for many decades. Sea level rise will lead to extensive beach loss if widespread shoreline hardening is permitted and beach systems are not allowed to migrate landward. Many beaches on Maui, particularly along the north and southwest coasts, are backed by deposits of older beach and dune sand (Sherrod et al. 2007) which are crucial sources of sediment along eroding coasts. In a natural state, a beach can be maintained as it migrates landward if there is sufficient sand available in the backshore to nourish the beach as it erodes. Shoreline hardening locks up this backshore sediment source leading to narrowing and loss of chronically eroding beaches.

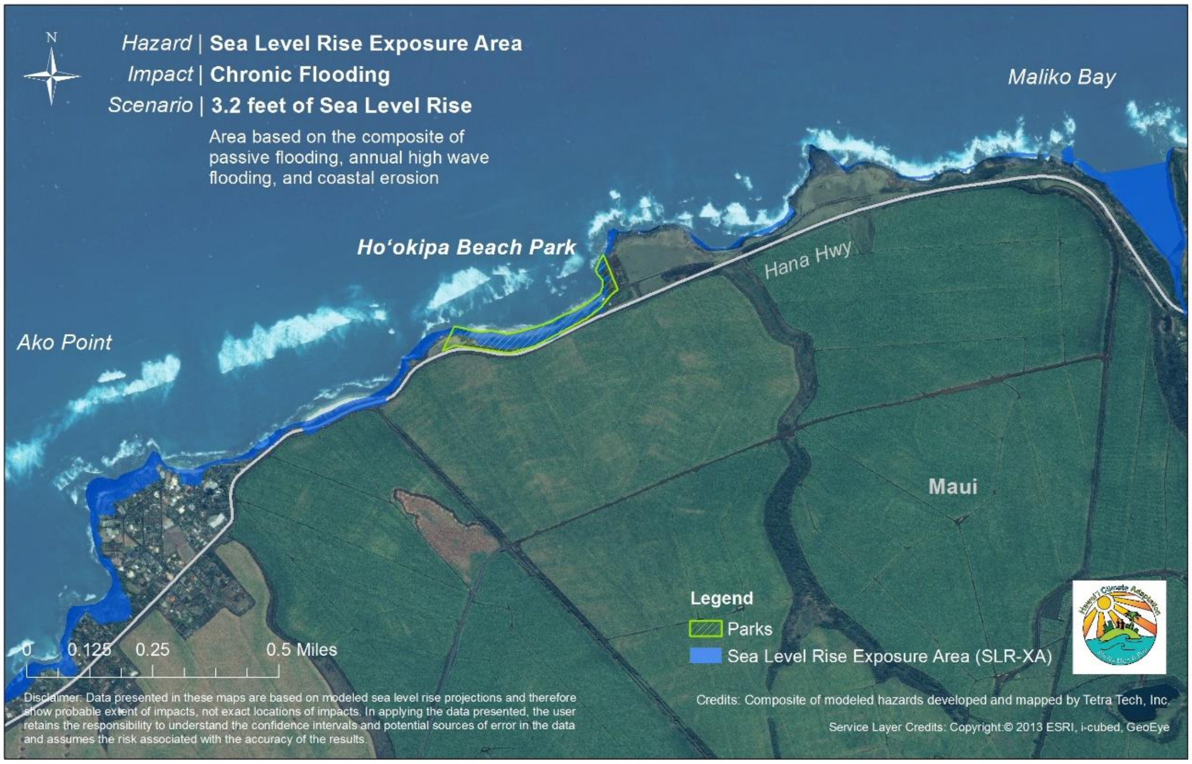


Figure 65. Potential chronic flooding of Hoʻokipa Beach Park in the SLR-XA with 3.2 feet of sea level rise along Maliko Bay, Maui

A study of historical shoreline changes in Hawaiʻi by the U.S. Geological Survey and the University of Hawaiʻi (Fletcher et al. 2012) found that 85% of Maui beaches are chronically eroding, the highest among the three islands studied (Kauaʻi, Oʻahu, and Maui). Over the past century, shoreline hardening was the typical response throughout Hawaiʻi when beachfront property was threatened by erosion or flooding. As a result, approximately 11 miles of Maui beaches are backed by seawalls and other shoreline hardening structures. Over 4 miles of beach fronting those structures have already been completely eroded away.

Looking at the future, sea level rise presents a serious threat to Maui beach environments and public shoreline access. At present, 7 miles of beach remains with shoreline hardening on the backshore (11 miles minus the 4 already lost). These 7 miles of beach has a very high risk of being inundated and eroded away in coming decades with sea level rise. With 1.1 feet of sea level rise, an additional 8 miles of unprotected beachfront development will be exposed to erosion and flooding (i.e. within the SLR-XA). These 8 miles include 4 miles of homes and buildings and 4 miles of coastal highway. With 3.2 feet of sea level rise, 16 miles of unprotected beachfront development will be exposed to erosion and flooding, including 7 miles of homes and buildings, and 9 miles of roads. Beaches fronting these areas of exposed development face a high risk of loss if widespread shoreline hardening is allowed rather than allowing beaches to migrate landward with sea level rise. As described in the Methods section, this analysis considers a scenario where widespread armoring is permitted and does not consider other adaptation scenarios such as managed retreat from impacted areas or beach nourishment, which could help extend the life of beaches such as Kāʻanapali. This analysis also does not account for effects of accelerated erosion that typically occurs fronting and adjacent to coastal armoring, leading to more widespread impacts. More research is needed to improve the understanding and projections of localized vulnerability of beach and environments to the combined impacts of encroaching beachfront development and erosion and flooding with sea level rise.

Maui's Erosion-based Shoreline Building Setbacks with Rising Seas

As the State CZM program delegates authority to administer the CZM law to each of the various counties, Maui County, through the Maui Planning Commission, has adopted an erosion-rate-based shoreline building setback rule (which holds the same power as a State Administrative Rule). This shoreline building setback rule requires that all lots have a shoreline setback line that is the greater of the distances from the shoreline calculated by one of the following methods:

1. Twenty-five feet plus a distance of 50 times the annual erosion hazard rate from the shoreline, or;
2. Based on the lot's depth in the following table:

Average Lot Depth	Setback Line
Less than 100 feet	25 feet from the shoreline
100 feet to 160 feet	40 feet from the shoreline
Greater than 160 feet	25% of the average lot depth, but no more than 150 feet

For irregularly shaped lots, or where cliff, bluffs, or other topographic features inhibit the safe measurement of the boundaries and/or the shoreline, the shoreline setback will be equivalent to 25% of the lot's depth (to be determined by the Planning Director) to a maximum of 150 feet from the shoreline.

This will help to protect Maui's beaches and new development threatened by sea level rise. However, like the other islands, Maui faces the challenge of addressing increasing erosion and flooding impacts to older, existing beachfront development sited without sufficient setbacks. While this ordinance will go a long way in the short-term to protect beaches and new development threatened by sea level rise, like the other islands, Maui faces the challenge of addressing potential erosion and flooding impacts to older, existing beachfront development sited without sufficient setbacks. In addition, erosion rates will accelerate with sea level rise. As depicted in this Report as the SLR-XA, chronic flooding due to sea level rise is a composite of passive flooding, annual high wave flooding, and coastal erosion.

Besides recreational areas, a variety of coastal habitats, vital to aquatic organisms and wildlife, would become flooded with sea level rise changing the nature of such habitats and the organisms that rely on themt. Estuarine habitats, where freshwater from rivers and streams, and saltwater from the sea meet and mix, would become increasingly marine with rising seas. This dynamic would impact areas such as Kanahā Pond State Wildlife Sanctuary (Aloha-Hawaii.com 2017), which provides habitat for endangered, native water birds (Figure 66), that could potentially be altered by flooding as the sea level rises. Hawaiian anchialine pools, land-locked bodies of water of varying salinity that are adjacent to the ocean (The Nature Conservancy 2012), are occupied by small endemic red shrimp (*Halocaridina* and others) called ʻōpaeʻula and the endangered shrimp, *Procaris hawaiana* (Fish and Wildlife Service 2016). These pools have indirect, underground connections to the sea, and show tidal fluctuations in water level. Other species, restricted to the surface waters of the pools, include a few fish species, crustaceans and other invertebrates. Two endangered waterbirds (Hawaiian Stilt and Hawaiian Coot), and several species of migratory waterfowl also use these pools (The Nature Conservancy 2012).

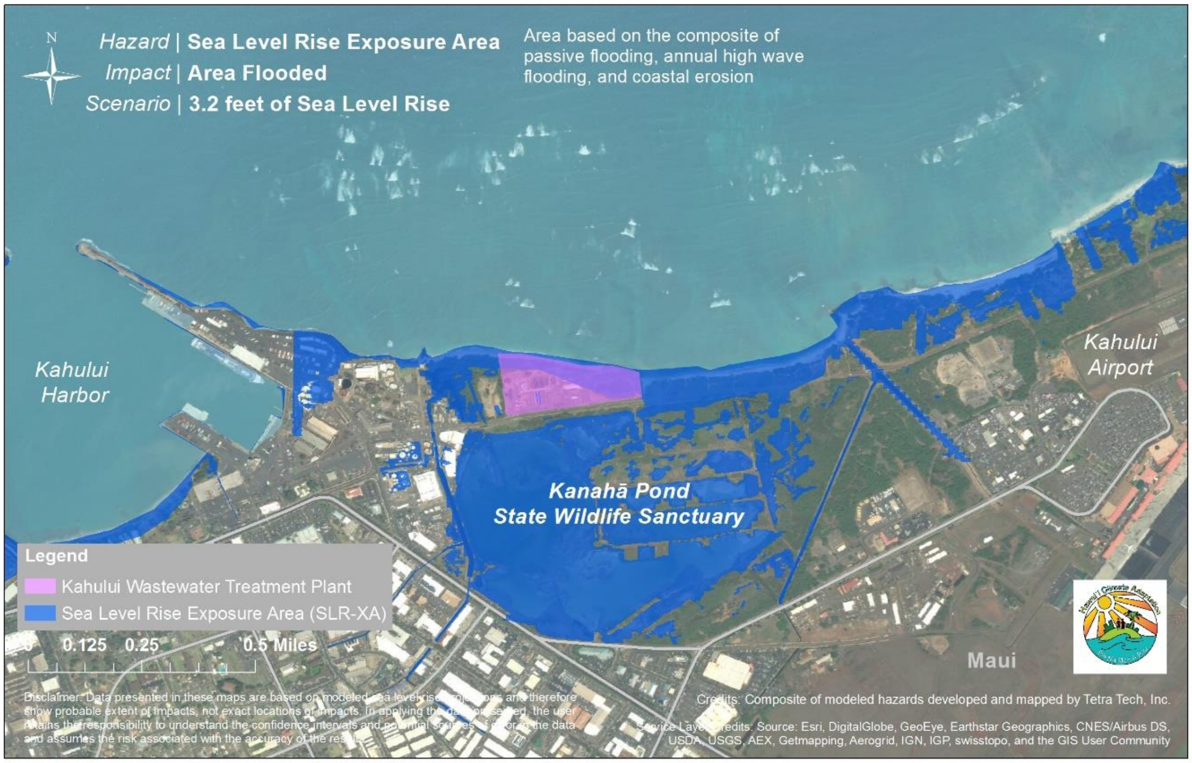


Figure 66. Kanahā Pond State Wildlife Sanctuary in the SLR-XA with 3.2 feet of sea level rise in Kahului, Maui

Sea level rise also has the potential to impact facilities that release wastewater or hazardous materials to nearshore waters and coastal habitats. For example, on Maui where there are approximately 100 OSDS within the SLR-XA with 3.2 feet of sea level rise, 12 of those OSDS are located along Māʻalaea Bay in Central Maui (Figure 67) which is in relatively close proximity to Keālia Pond National Wildlife Refuge. This wildlife refuge is one of the few remaining natural wetlands on Maui and home to endangered wetland birds (U.S. Fish & Wildlife Service 2013). The flooding of such systems in addition to septic tanks, cesspools, and other hazardous materials storage and disposal sites could release wastewater or contaminants to nearshore waters. The reader should visit the online Hawai‘i Sea Level Rise Viewer to determine if infrastructure of interest is located in the SLR-XA.

RECOMMENDATION HIGHLIGHTS

- Amend the State Legacy Lands Act to set aside funding for preserving priority coastal lands and use of a variety of practices and tools to enable legacy beaches to persist.
- Develop shoreline conservation and restoration priorities and guidelines to support adaptation to sea level rise.
- Expand the area of national, state, and county parks and wildlife refuges on the main Hawaiian Islands to preserve wetlands and wildlife.
- Protect nearshore water quality by identifying hazard mitigation measures to address coastal flooding of hazardous material/waste storage facilities and OSDSs vulnerable to sea level rise.

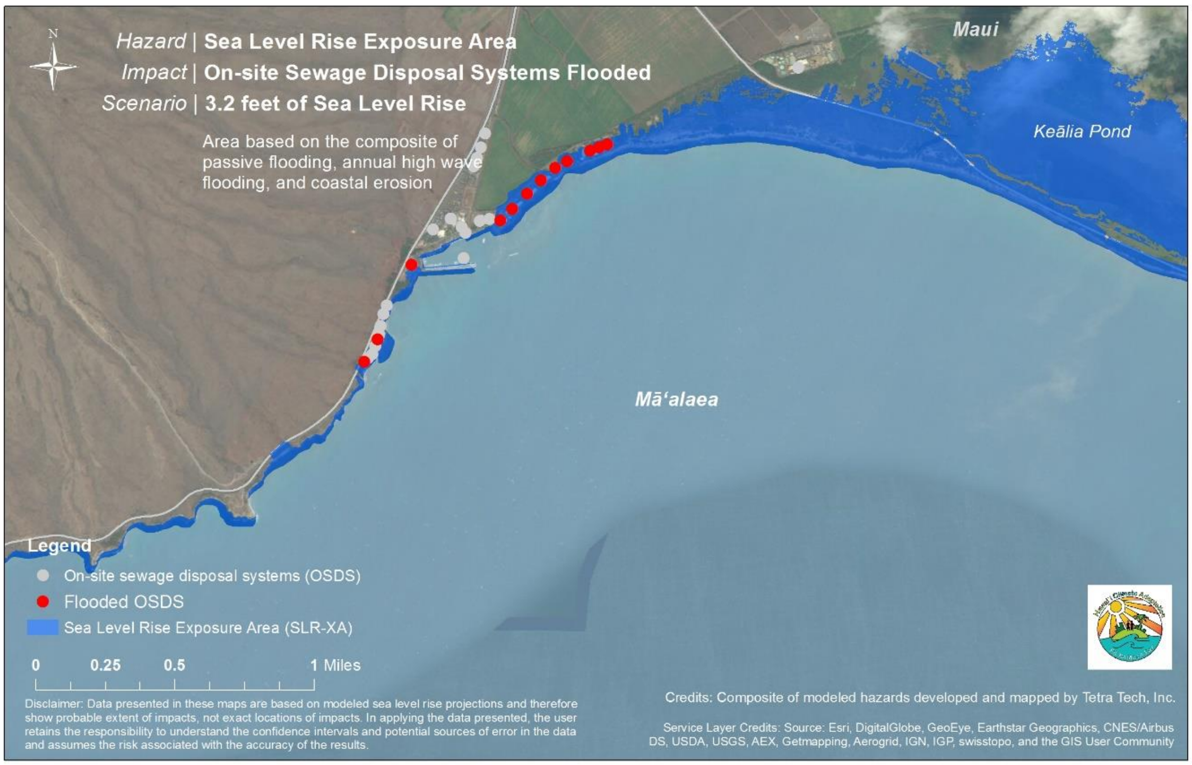


Figure 67. On-site sewage disposal systems flooded in the SLR-XA with 3.2 feet of sea level rise along Mā'alaea, Maui

Challenges and Opportunities

Over the next 30 to 70 years, properties located on or near Maui's shorelines will increasingly be flooded, eroded, or completely lost to the sea. Portions of coastal roads will also become flooded, eroded, impassible and irreparable, jeopardizing access to and from many communities. Maui's famous beaches will increasingly be eroded and permanently lost if hard structures such as roads and seawalls impede their landward migration. The flooding of hotels and transportation systems, along with the loss of beaches, would impact the tourism economy and thus impact the people whose livelihoods depend on it.

This Results section highlights just a few of the very real challenges on Maui with a scenario of 3.2 feet of sea level rise by the mid- to latter-part of the century. However, sea level rise will not stop at the middle or end of the century. As highlighted throughout this Report, higher sea level rise projections are considered "physically plausible" by the end of the century based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). While this Report models sea level rise up to 3.2 feet, it should be noted that NOAA has modeled passive flooding scenarios with up to 6 feet of sea level rise in their Sea Level Rise Viewer (NOAA 2017b). To illustrate potential impacts from higher sea level scenarios, the 5-foot passive flood layer from NOAA was incorporated into the vulnerability assessment which increases the area of the SLR-XA on Maui by 15%. Figure 68 shows the potential extent of 5 feet of sea level rise in Kahului. While there is uncertainty over when the islands might experience such extreme sea level rise, the information provided illustrates the likely scenario of continued sea level rise over the next century.

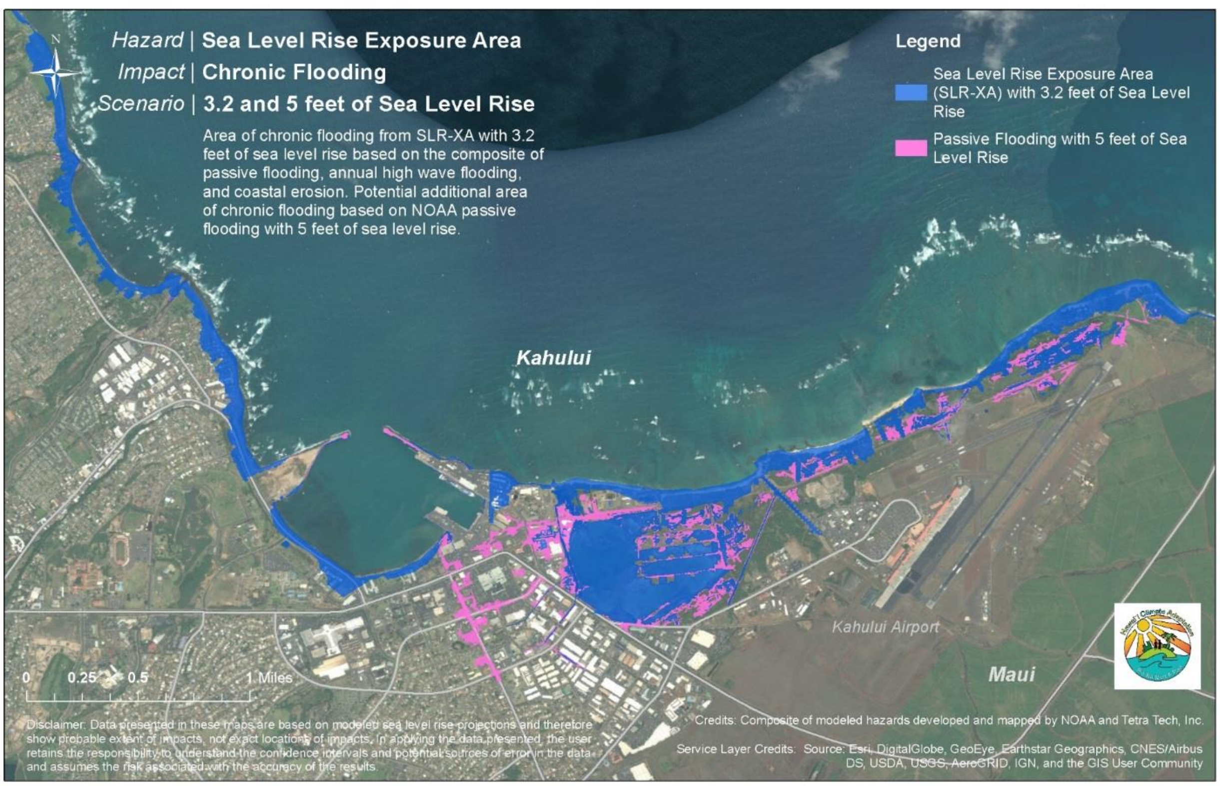


Figure 68. Potential additional area of chronic flooding with 5 feet of sea level rise in Kahului, Maui

Maui has opportunities to plan for sea level rise now by considering the recommendations for adaptation presented in Chapter 5 of this Report. Another threat that we will have to face in a world with climate change is increased coastal flooding from tropical storms, hurricanes, and tsunamis. The added risk from event-based coastal flooding exacerbated by sea level rise is not included in this Report. However, these events pose a potential for loss of human life and property and for severe and long-term economic disruption. Communities should consider planning new development to reduce exposure from severe events by recognizing that the coastal floodplain will migrate landward with increased sea levels. Hazard mitigation and disaster recovery projects should be reviewed and revised to address chronic and event-based flooding and consider the additive effects of accelerating sea level rise.

SEA LEVEL RISE STORIES

Maui County

POST-DISASTER RECONSTRUCTION FOR SEA LEVEL RISE ADAPTATION

One way in which Maui County is addressing the problem of non-conforming structures on the coastline is through resilient reconstruction after damage from a disaster. The Maui County Planning Department recognized that, in the rush to rebuild structures that were damaged in a storm or flood event, building codes and coastal management priorities are often disregarded in favor of quick recovery. In response to that, the Planning Department led a planning process to develop a set of guidelines and protocols to build back “safer, stronger and smarter” after a damaging coastal event. To develop these tools, the Planning Department held a series of workshops in communities across the County to understand priorities for each community in rebuilding (County of Maui 2015b). These workshops were intended to fulfill several objectives, including making communities more resilient to sea level rise.

The Planning Department held community meetings in which participants weighed the costs and hazards of rebuilding post-disaster in order to come up with a set of protocols for the County to employ post-disaster. The Planning Department compiled these protocols into a set of messages which they can release post-disaster as public service announcements. These messages can guide landowners in what steps they need to take to recover from the damage incurred. This public guidance aims to minimize potentially harmful short-term solutions such as constructing a cement wall to protect beachfront property and instead encourages long-term hazard mitigation and sea level rise adaption strategies. “So we don’t want to necessarily build back in the same site in the exact same way because we want to increase our resilience in our communities,” said Tara Owens, Coastal Hazards Specialist with University of Hawai‘i Sea Grant Program partnering with the Maui County Planning Department. Some strategies the Planning Department has identified for rebuilding to mitigate hazards to coastal structures are: retrofitting structural components, rebuilding to code, armoring (when appropriate), and elevating structures. Strategies to adapt to sea level rise include reconfiguring arrangement of structures on a plot, relocating structures or retreating, restoring beach ecosystems such as dunes, and demolishing or retiring structures where necessary.

You can read more of this story at
climateadaptation.hawaii.gov/climate stories

Kepuhi Bay, Molokaʻi
Source. Tara Owens

Molokaʻi

Molokaʻi, the State's fifth largest island, is known as the "friendly isle." For those who live there, they characterize the island as a mokupuni kuaʻāina, a country island, in both culture and geography (County of Maui 2001). While the word kuaʻāina translates literally as "back land" or "back country," in the context of the Native Hawaiian cultural renaissance of the late twentieth century, kuaʻāina refers to those who actively live Hawaiian culture and kept the spirit of the land alive.

Kaunakakai located along the south coast, is the island's major population and commercial center (County of Maui 2001). The island is home to 6,958 residents (State of Hawai'i 2015) accounting for less than 1% of the State's population. Molokaʻi is the second largest island, in terms of population and land area, of the five islands (three inhabited) that make up Maui County. It should be noted that Kalaupapa, a peninsula on the north coast of Molokaʻi is a separate county, Kalawao County, and is not a part of Maui County. The population of Molokaʻi has grown by 32% over the last 50 years, but has not seen the population booms impacting other islands, such as Maui (State of Hawai'i 2015). Nonetheless, this population growth coupled with a growing tourism industry—almost 59,000 visitors came to Molokaʻi in 2016 (State of Hawai'i 2016)—has placed ever increasing demands on natural resources, critical infrastructure, and basic services.

Key Take Aways

- Over the next 30 to 70 years, homes and businesses located near the shoreline will be impacted by sea level rise. Over 400 structures would be chronically flooded with 3.2 feet of sea level rise.
- Of the 2,600 acres of land located within the SLR-XA, approximately 50% is designated as Conservation District lands.
- With 3.2 feet of sea level rise, approximately 2 miles of Molokai's coastal roads would become impassible jeopardizing critical access to many communities.
- A more detailed analysis of the vulnerability of Molokai's critical infrastructure, including the Kalaupapa Airport and Kaunakakai Harbor, is needed. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.

This section provides a picture of the future of the Island of Moloka'i with sea level rise and the potential impacts if no action is taken. The results are based on modeling coastal flooding with sea level rise due to passive flooding, annual high wave flooding, and coastal erosion in the SLR-XA with up to 3.2 feet of sea level rise, and depicts flood hazards that may occur in the mid- to latter-half of this century. This timeframe is within the expected lifespan of most new construction and much of our existing development. It should be noted that sea level rise projections greater than 3.2 feet are "physically plausible" by the end of the century, based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). Vulnerability to 1.1 feet of sea level rise in the SLR-XA is used to approximate current or near-term exposure to coastal hazards and sea level rise. Vulnerability is assessed in terms of potential impacts to land use, people, property, cultural and natural resources, and critical infrastructure (only land and structures are monetized, not infrastructure).

The reader is urged to exercise caution in interpreting the results, which could be to a greater or lesser extent depending on actual observed future sea level rise, technological innovations in climate change mitigation and adaptation, unknown economic variables, as well as future societal choices which cannot be known today. Further, the reader should also visit the Hawai'i Sea Level Rise Viewer to explore the full extent of the vulnerability maps for each island.

Potential Impacts in the Sea Level Rise Exposure Area

The SLR-XA depicts the area of potential chronic flooding from exposure to passive flooding with sea level rise. For the purposes of exposure and planning, we focus mainly on a scenario with 3.2 feet of sea level rise.

With 3.2 feet of sea level rise, low-lying coastal areas around the island within the SLR-XA may become chronically flooded within the mid- to latter- half of this century (Figure 69). This land will be submerged by coastal erosion, direct marine flooding from tides and waves, or become new wetlands behind the shoreline from rising water tables and reduced drainage. Approximately 2,590 acres of land are estimated to be in the SLR-XA with 3.2 feet of sea level rise. Some examples of areas that would be exposed to chronic flooding include Moʻomomi, Kalaupapa, Hale o Lono Harbor, and Kapaʻakea as illustrated on Figure 70. These areas include a wide variety of communities and assets such as portions of the Moʻomomi Preserve, which is located in northwest Molokaʻi and home to rare native and endangered species; the Kalaupapa Peninsula, which includes the Kalaupapa National Historic Park and the administratively distinct settlement of Kalawao; Hale o Lono Harbor, a manmade harbor on the southwestern coast of the island that hosts two annual outrigger canoe competitions; and Kapaʻakea, a Hawaiian Homelands community near Kaunakakai. These areas would all become flooded with 3.2 feet of sea level rise.

Over time, as sea level continues to rise, low-lying, populated coastal communities such as Kapaʻakea would experience increased frequency and severity of flooding ultimately leading to permanent inundation, making some areas of the coast impassable or uninhabitable (Figure 71). Decisions about where to use coastal armoring and when to retreat will need to be made carefully. It should be noted that seawalls may not be effective at preventing flooding with sea level rise in many low-lying areas as rising groundwater can infiltrate through porous geology. While specific responses to sea level rise will need to be place-based, larger regional issues should be considered, such as whether to armor in place or whether to relocate roads and other critical infrastructure inland. In the case of Kapaʻakea where there may be opportunities to consider a managed retreat strategy as there are ample vacant lands immediately mauka (landward) and outside of the SLR-XA with 3.2 feet of sea level rise. However, as discussed in the Recommendations Chapter of this Report (Chapter 5), and as with other populated coastal areas with adjacent vacant lands, large-scale boundary amendments should be predicated on appropriate state policies and guidelines (e.g., within Chapter 205, State Land Use Act) to provide the supportive legal basis for major land use changes.

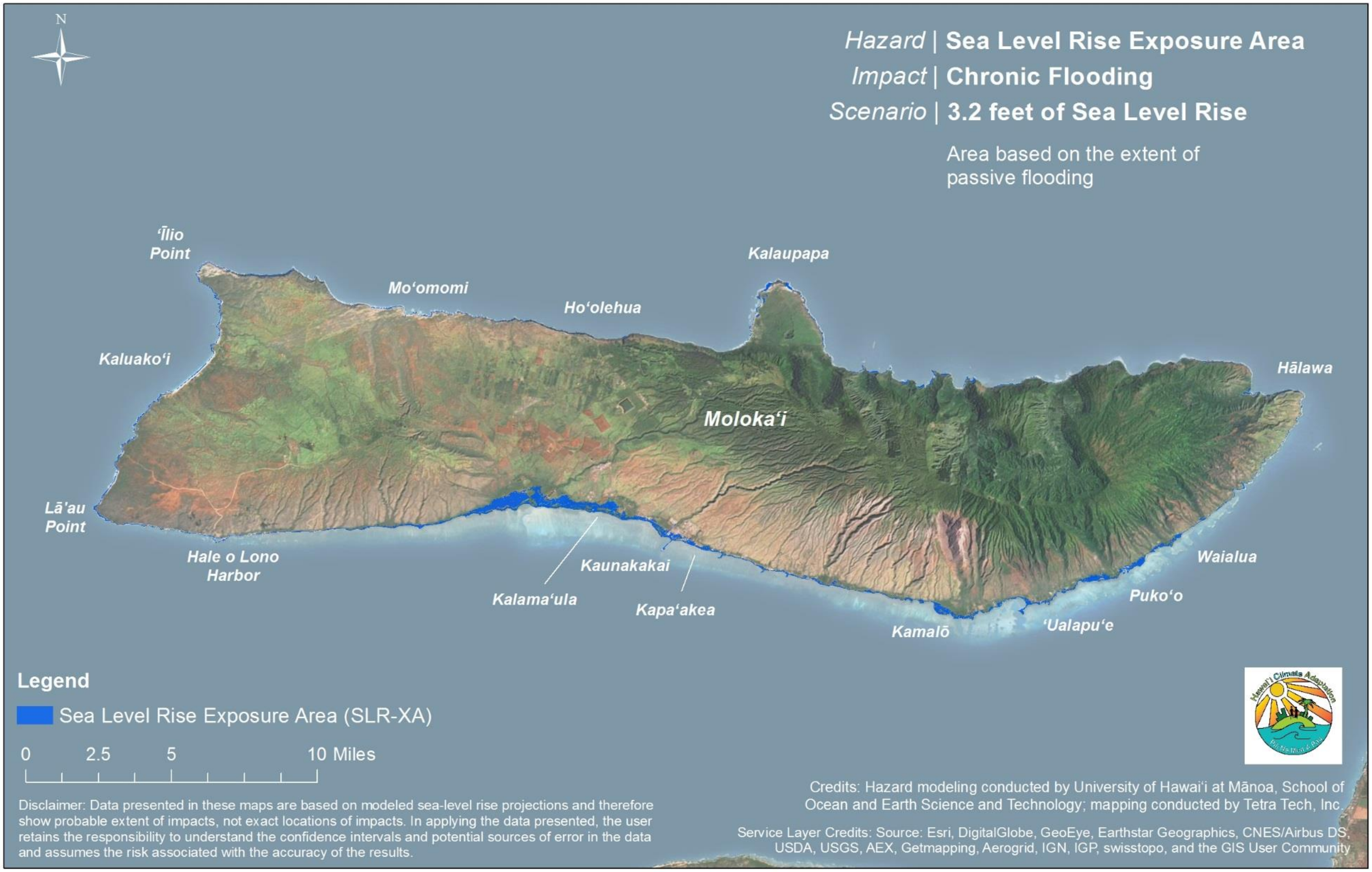


Figure 69. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise for Molokaʻi

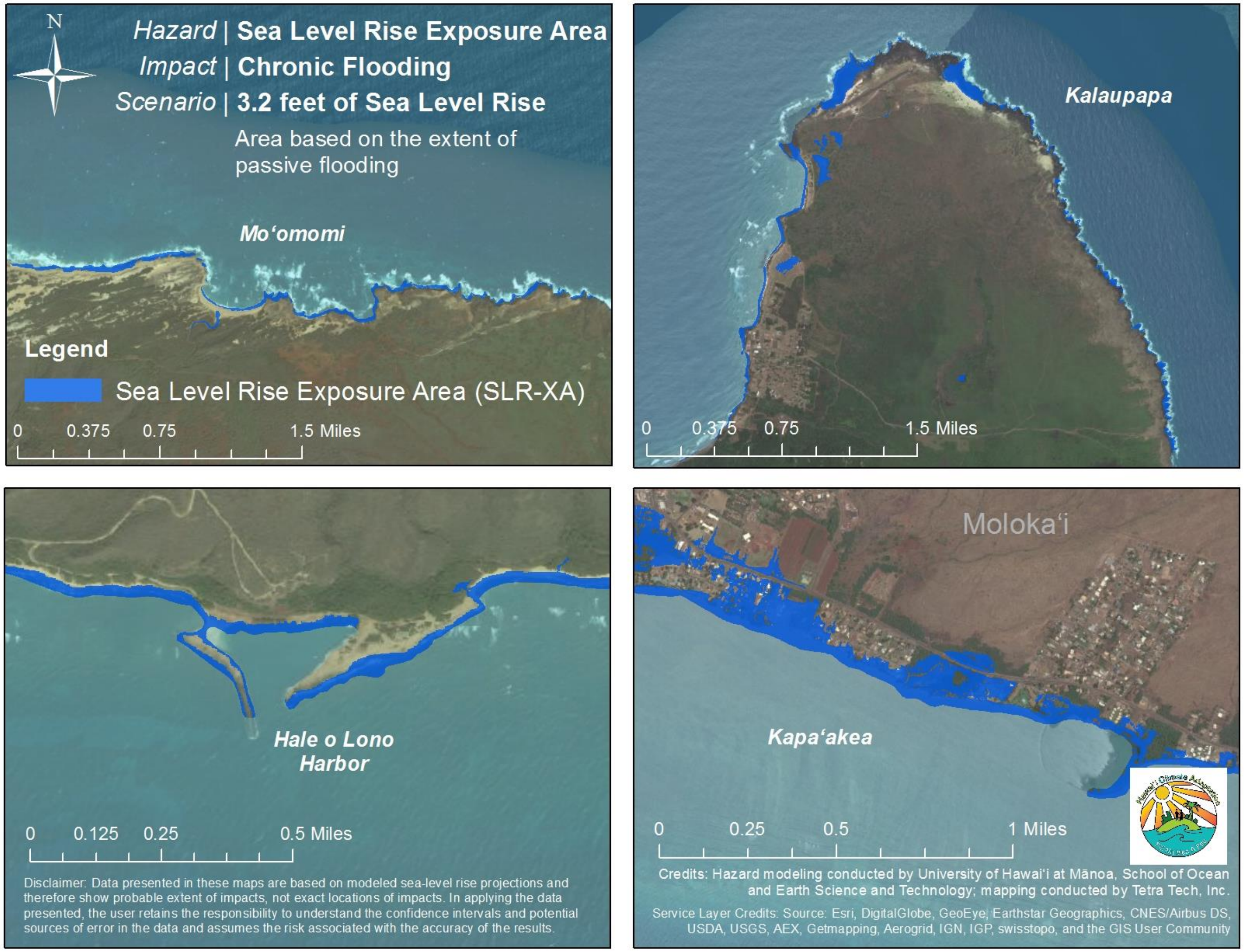
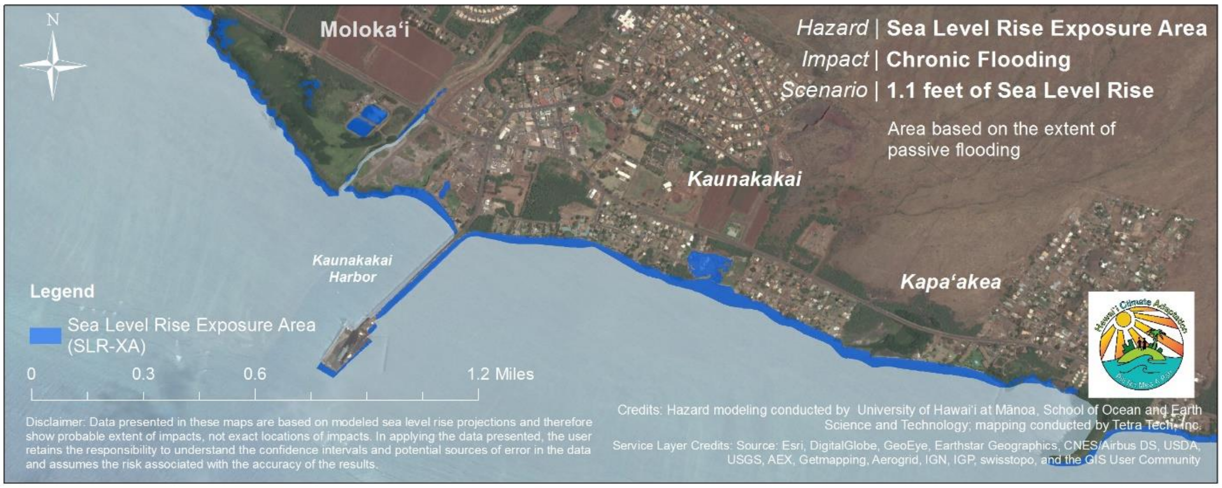
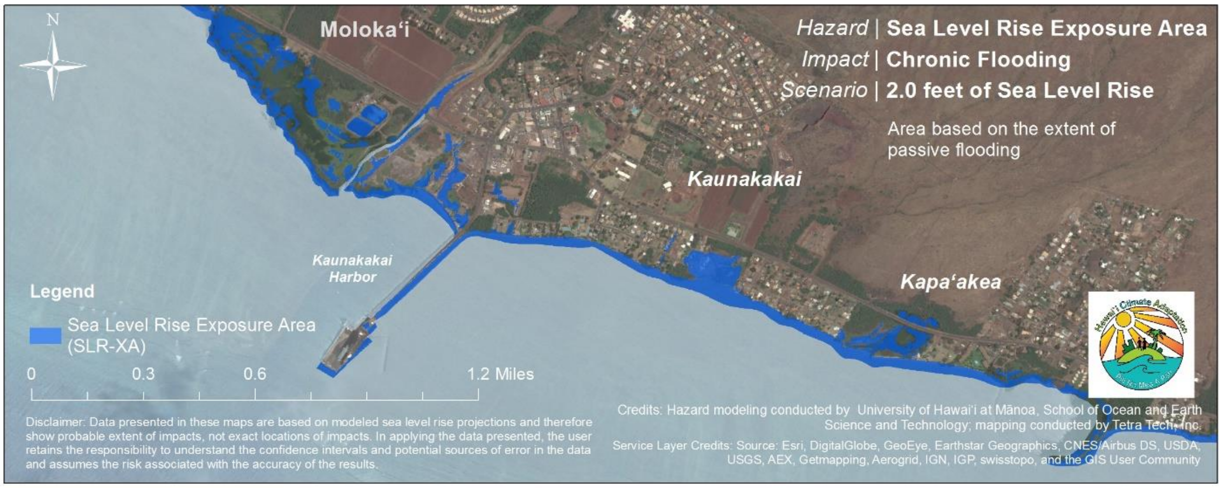


Figure 70. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise in four areas on Moloka'i





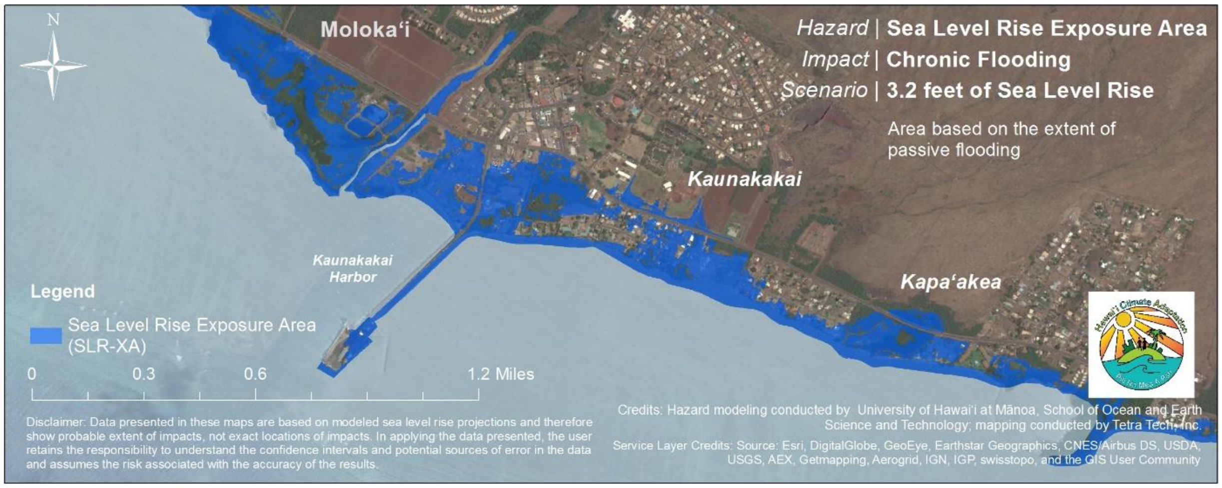


Figure 71. Potential chronic flooding in the SLR-XA with 1.1, 2.0, and 3.2 feet of sea level rise in Kaunakakai and Kapa'akea, Moloka'i

POTENTIAL IMPACTS TO LAND USE

While sea level rise would result in impacts within the State Urban, Rural, Agricultural, and Conservation Land Use Districts around the island, Conservation District lands would experience the greatest extent of chronic flooding (Figure 72). More than 51% of the 2,590 acres in the SLR-XA with 3.2 feet of sea level rise is designated as Conservation District land while only approximately 8% of the land located within the SLR-XA is located in the Urban District. However, considering that currently only about 2% of Molokai's 165,800 acres is located in an Urban Land Use District (State of Hawai'i 2015), it can be expected that new Urban District land would need to be designated to accommodate (re)development away from the shoreline.

While the State Land Use District Boundary Amendment process could be used to sort out major land changes as part of a managed retreat strategy, County General Plan and Community Plan updates provide important opportunities to address land use issues with rising seas at the local level. Revised and updated SMA policies, objectives, and requirements offer additional opportunities at the local level to prepare for sea level rise. Moreover, if the County of Maui chooses to recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone (one of the recommendations in Chapter 5), it might be prudent to consider adjusting SMA boundaries to coincide with the SLR-XA so that new subdivisions, commercial areas, hotels, and other development activities could undergo a higher level of review in light of sea level rise constraints. Figure 73 illustrates the partial overlap of SMA boundaries with the SLR-XA near Kamalō located on the southeast side of Moloka'i.

RECOMMENDATION HIGHLIGHTS

- Recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone in the County General Plan and Community Plan updates.
- Strive to balance managed retreat strategies from vulnerable urban areas with preservation of agriculture and conservation lands.
- Seek opportunities to plan new development outside of the SLR-XA, wherever possible, under a long-term comprehensive adaptation strategy.
- Develop design standards to increase flood resiliency within the SLR-XA.

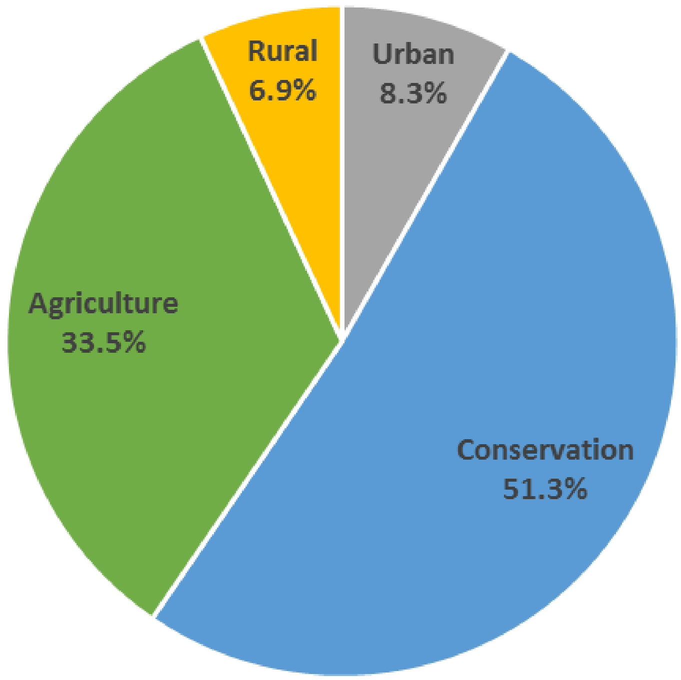


Figure 72. Estimated percentage of Land Use Districts impacted in the 3.2 feet of sea level rise exposure area on Moloka'i

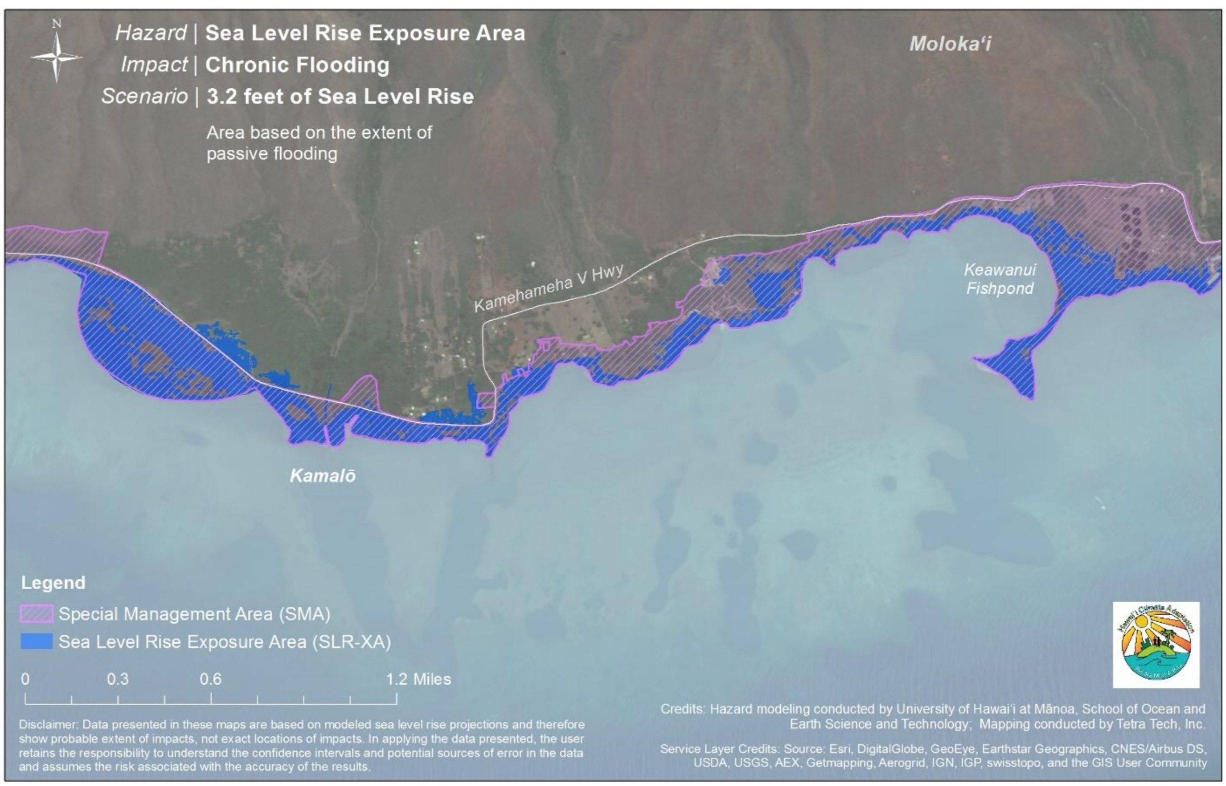


Figure 73. Portions of the SLR-XA (blue) near Kamalō, Moloka'i extending beyond the Special Management Area (SMA) boundary (pink hatched area) that would not be subject to SMA permitting requirements

POTENTIAL IMPACTS TO PEOPLE AND PROPERTY

People living and working within the SLR-XA would be displaced when homes, condominiums, and businesses become flooded due to sea level rise. The potential number of people displaced is calculated by assigning an estimated occupancy for each type of structure in the SLR-XA. Potential economic loss in the SLR-XA is estimated based on the value of land and structures flooded. Loss estimates are assessed at the parcel level and aggregated into 1-hectare grids. The potential economic loss associated with flooded roads, water/wastewater facilities, and other critical infrastructure is not accounted for and would add significant increases in losses.

The potential number of displaced people island-wide could rise from around 10 residents with 1.1 feet of sea level rise, to over 550 residents with 3.2 feet of sea level rise (Figure 74). The people displaced would include a range of income levels and living arrangements. In addition, both homeowners and renters are expected to be affected based on the housing census data provided by the CCDs. CCDs are areas delineated by the U.S. Census Bureau in cooperation with state, tribal, and local officials for statistical purposes. CCD boundaries usually follow visible features and usually coincide with Census Tract boundaries. For Molokaʻi, the island is divided into three CCDs: East Molokaʻi, West Molokaʻi CCD, and Kalawa. In taking the average for the percentage of the occupied housing units that are owner- and renter-occupied, 44% are owner-occupied while 56% are renter-occupied.

Potential economic losses (all structures and land) island-wide would increase from an estimated $131 million with 1.1 feet of sea level rise, to $285 million with 3.2 feet of sea level rise (Figure 74). Approximately 65% of the potential economic loss with 3.2 feet of sea level rise is attributed to the loss of residential structures and land. The potential economic loss across all sectors is associated with approximately 780 structures in the SLR-XA with 3.2 feet of sea level rise and approximately 2,590 acres of land.

With 3.2 feet of sea level rise, potential economic loss would occur in low-lying coastal areas island-wide, with the greatest loss along the southern shore between Kaunakakai and Kamalō due to the concentration of residential and commercial land and structures in these areas (Figure 75). Over time, as the sea level continues to rise, communities such as Kaunakakai and Kapaʻakea (Figure 76), would experience increasing potential economic loss.

RECOMMENDATION HIGHLIGHTS

- Require mandatory disclosure for vulnerable properties and consider acquisition to protect valuable coastal resources.
- Seek opportunities to plan new development well landward of the SLR-XA with 3.2 feet of sea level rise under a long-term, comprehensive adaptation strategy.
- Develop design standards to increase flood resiliency for existing and new development within the SLR-XA that cannot be relocated.
- Develop a multi-pronged financing strategy at federal, state, county, private sector, and philanthropic levels to address costs of adaptation to sea level rise.

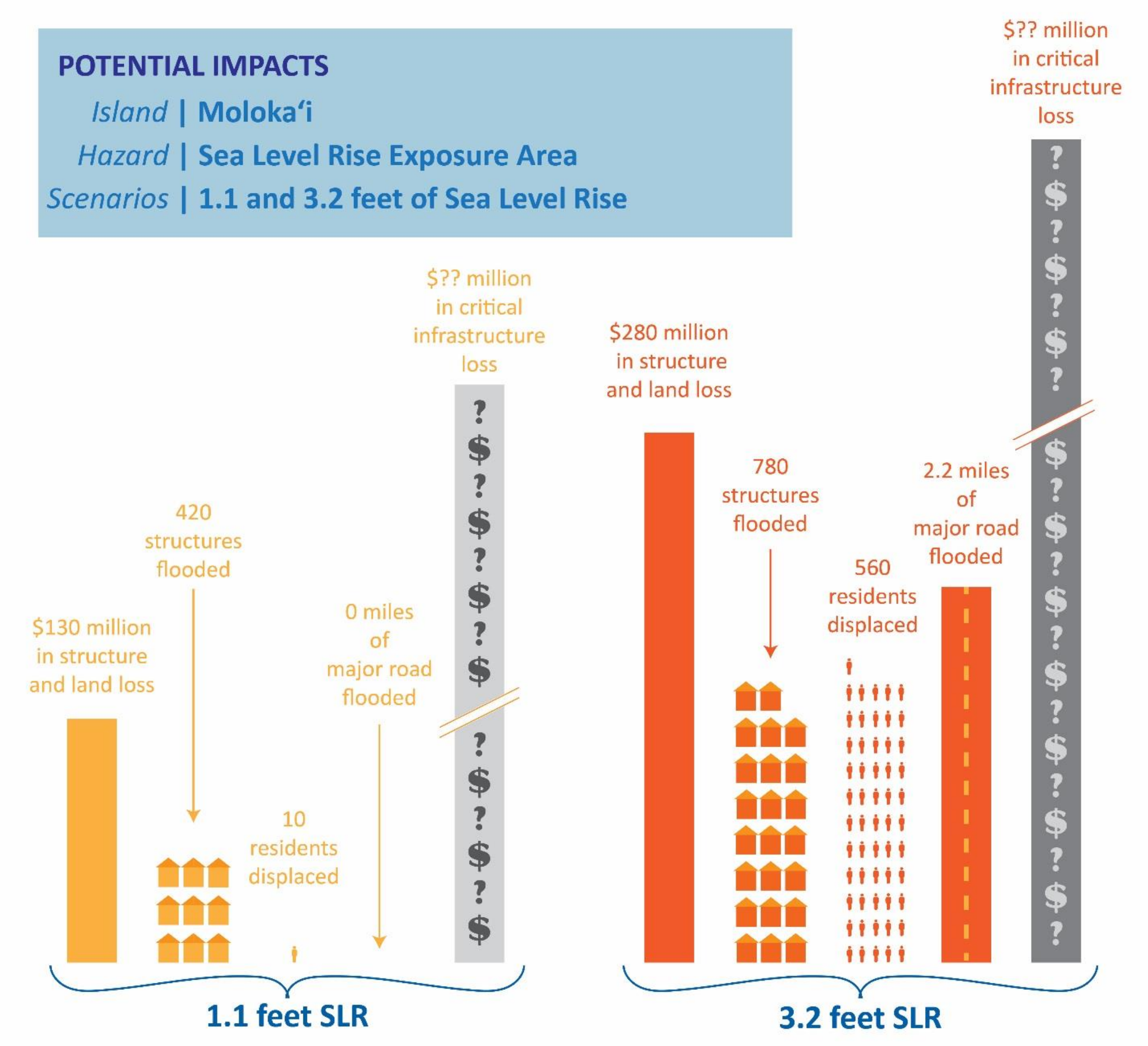


Figure 74. Summary of potential impacts in the SLR-XA with 1.1 feet and 3.2 feet of sea level rise on Moloka'i

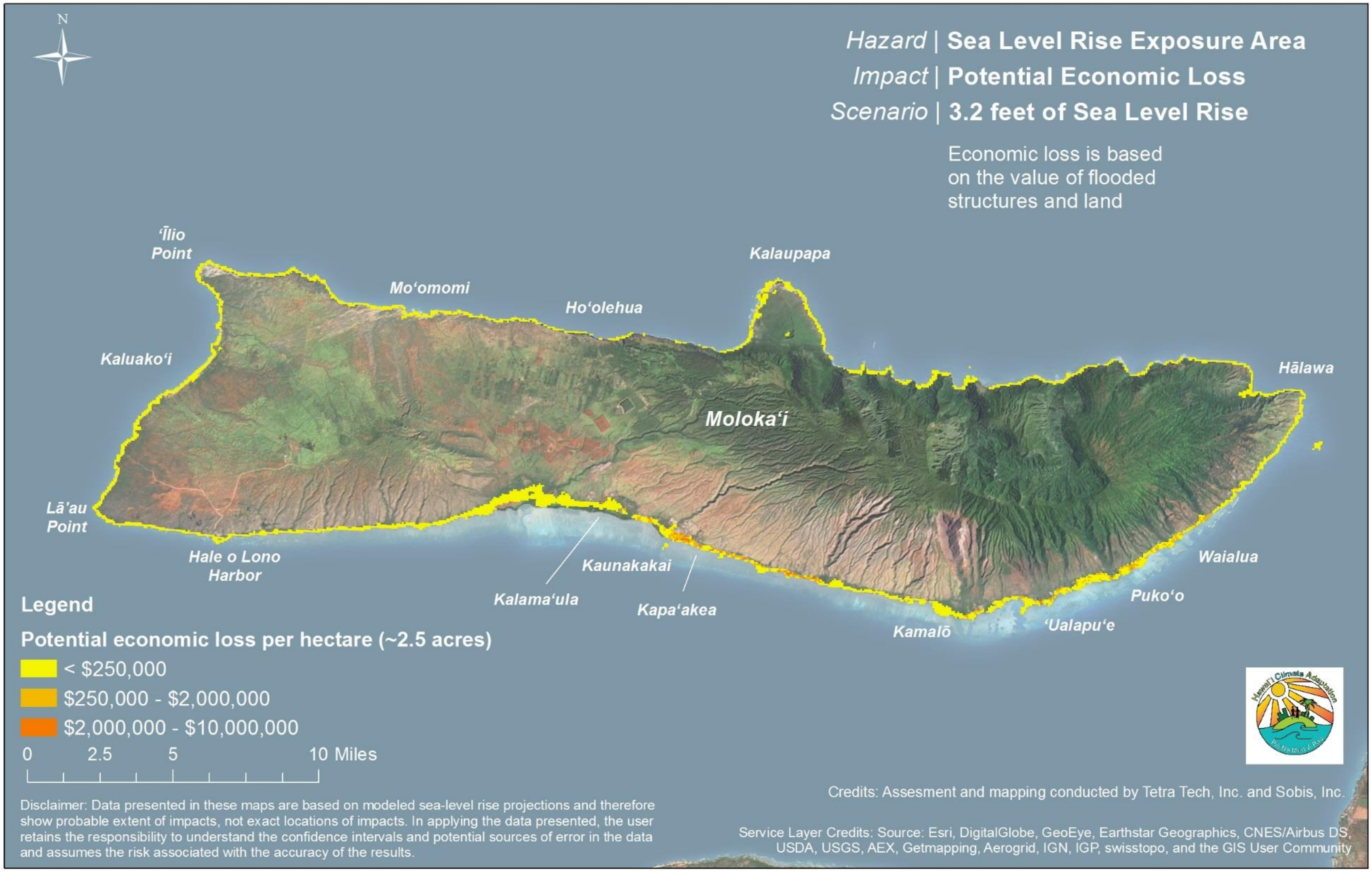
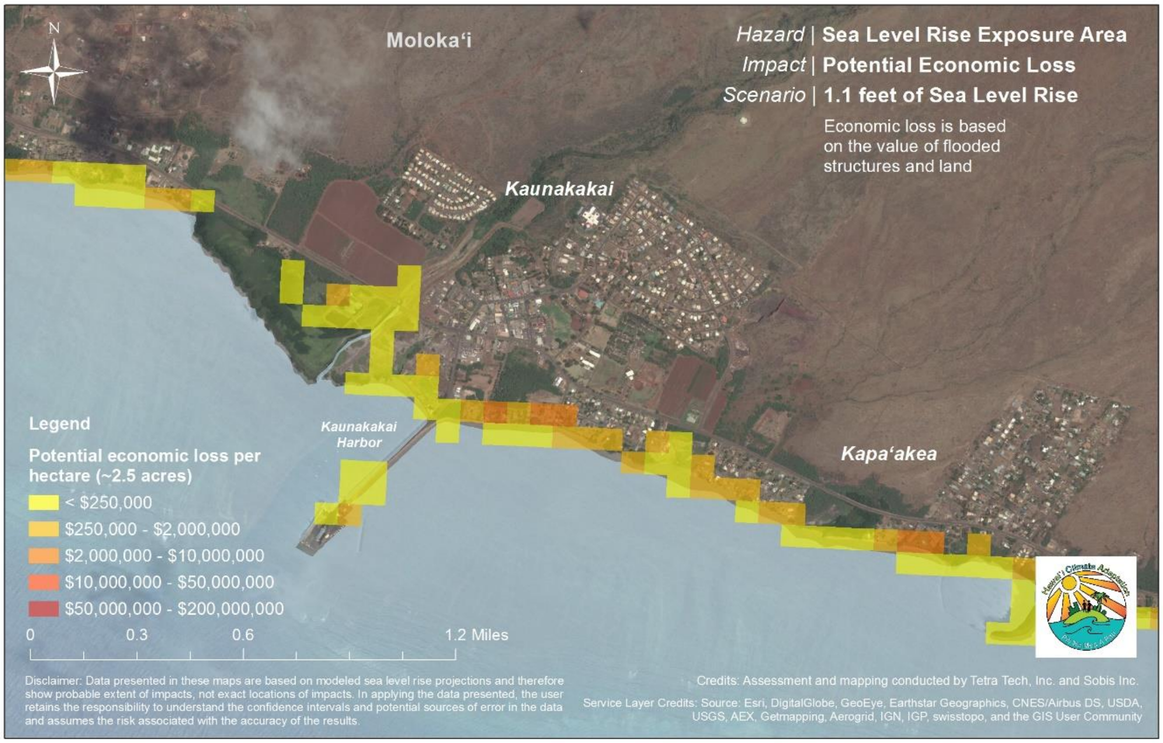


Figure 75. Potential economic loss in the SLR-XA with 3.2 feet of sea level rise on Moloka'i



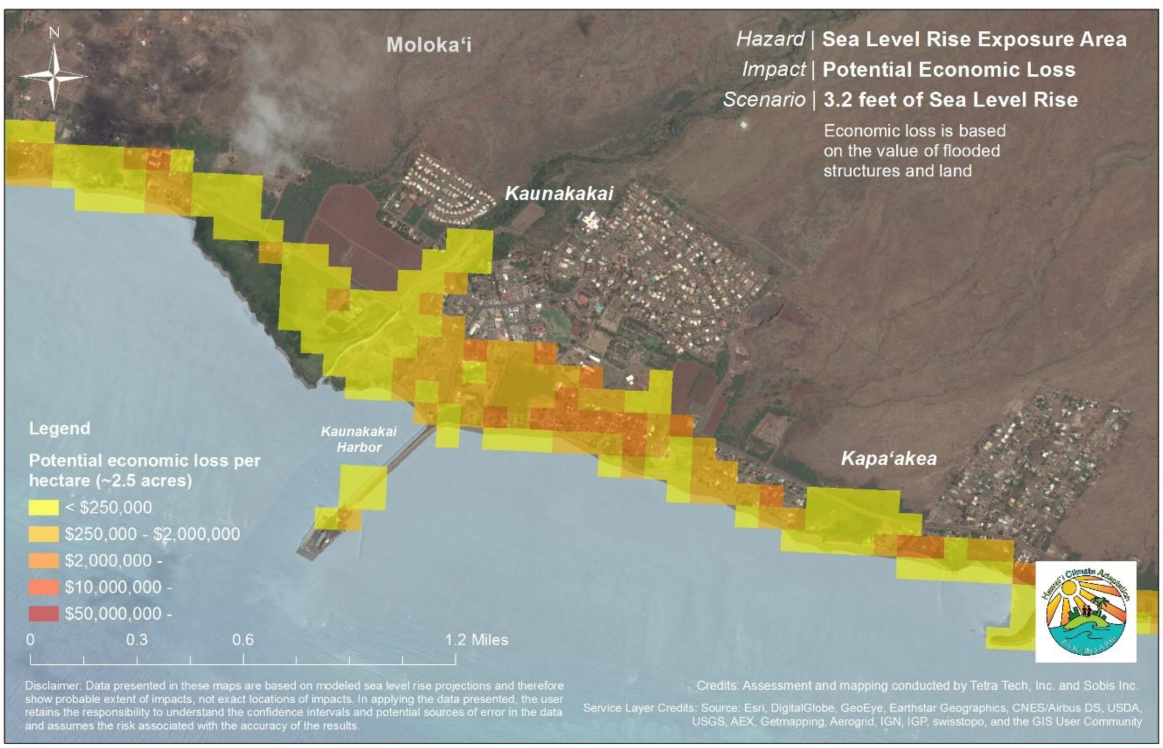


Figure 76. Potential economic loss in the SLR-XA with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise in Kaunakakai and Kapa'akea, Moloka'i

POTENTIAL IMPACTS TO CRITICAL INFRASTRUCTURE

Sea level rise would result in significant impacts to roads, airports, harbors, electrical and telecommunication infrastructure, water/wastewater facilities and conveyance systems, and other public service facilities (i.e. schools, fire stations, police stations, medical facilities) on Molokaʻi. Following the trends of private development, much of Molokai's critical public infrastructure is concentrated on low-lying shores and is highly vulnerable to flooding in the SLR-XA. No major roads would be flooded in the SLR-XA with 1.1 feet of sea level rise; however, more than 2 miles would be flooded with 3.2 feet of sea level rise (Figure 74). Portions of many coastal roads, such as Kamehameha V Highway, would become chronically flooded (Figure 77) and result in regional issues such as loss of commerce, loss of access to emergency services, and increased traffic on other roads and highways, some of which, serve as the only access in and out of many communities and inundation could result in isolation. As there are a limited number of roads on Molokaʻi, with only about 124 miles of paved roads, even limited flooding could have significant impacts. Electric and telecommunication transmission lines commonly follow roads and those located underground in the SLR-XA may be impacted by sea level rise resulting in service disruptions.

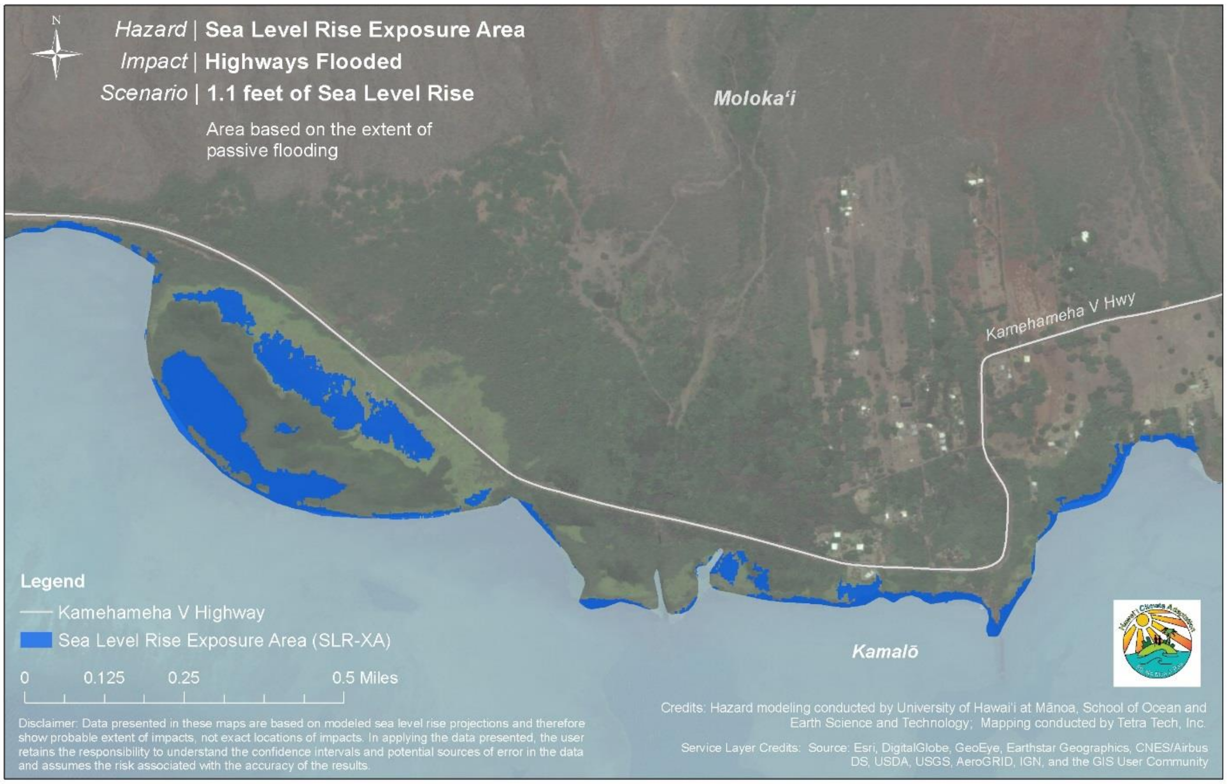
Molokaʻi has two small airports, Molokaʻi Airport located in the central plateau and Kalaupapa Airport located on the Kalaupapa Peninsula. These two airports are critical points of entry for people and goods to Molokaʻi. In 2014, the Molokaʻi Airport served 119,981 passengers and handled 825 tons of incoming cargo, while the Kalaupapa Airport served 6,408 passengers and handled 92 tons of incoming cargo (State of Hawai'i 2015). While Molokaʻi Airport is located on high ground away from the shore and would not be impacted by sea level rise, Kalaupapa Airport is located on lower ground near the coast (Figure 78) and portions of the airport would be located within the SLR-XA with 3.2 feet of sea level rise. The main harbor on Molokaʻi, Kaunakakai Harbor, is used for cargo, recreation, and commercial purposes and would experience chronic flooding as a result of 3.2 feet of sea level rise. Interruption to interisland shipping and travel would impact residents, visitors, and economic activity.

No schools, fire stations, police stations, or hospitals are located within the SLR-XA with 3.2 feet of sea level rise, however, the Kaunakakai Wastewater Treatment Plant is located within the SLR-XA with 3.2 feet of sea level rise. When flooded, this facility has the potential to release wastewater or contaminants to nearshore waters. More detailed analyses of vulnerability and adaptation options for critical infrastructure are needed to evaluate adaptation options such as retrofitting or relocation. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., flood proofing and relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years. The reader should visit the online [Hawaiʻi Sea Level Rise Viewer] to determine if any infrastructure or public facilities of interest are located within the SLR-XA.

Please keep in mind that infrastructure losses have not been monetized. However, it should be noted that these costs could be an order of magnitude greater than the potential economic losses estimated from land and structures.

RECOMMENDATION HIGHLIGHTS

- Conduct in-depth vulnerability assessments and evaluation of adaptation strategies for existing critical infrastructure throughout the County.
- Consider long-term cost savings from implementing sea level rise adaption measures now (e.g., major flood proofing or relocation) compared to the cost of maintaining and repairing chronically threatened public infrastructure over the next 30 to 70 years.
- Require the design and siting of new development and capital improvement projects to include an in-depth analysis of sea level rise impacts based on elevation, tolerance for risk, and lifetime of the structure.



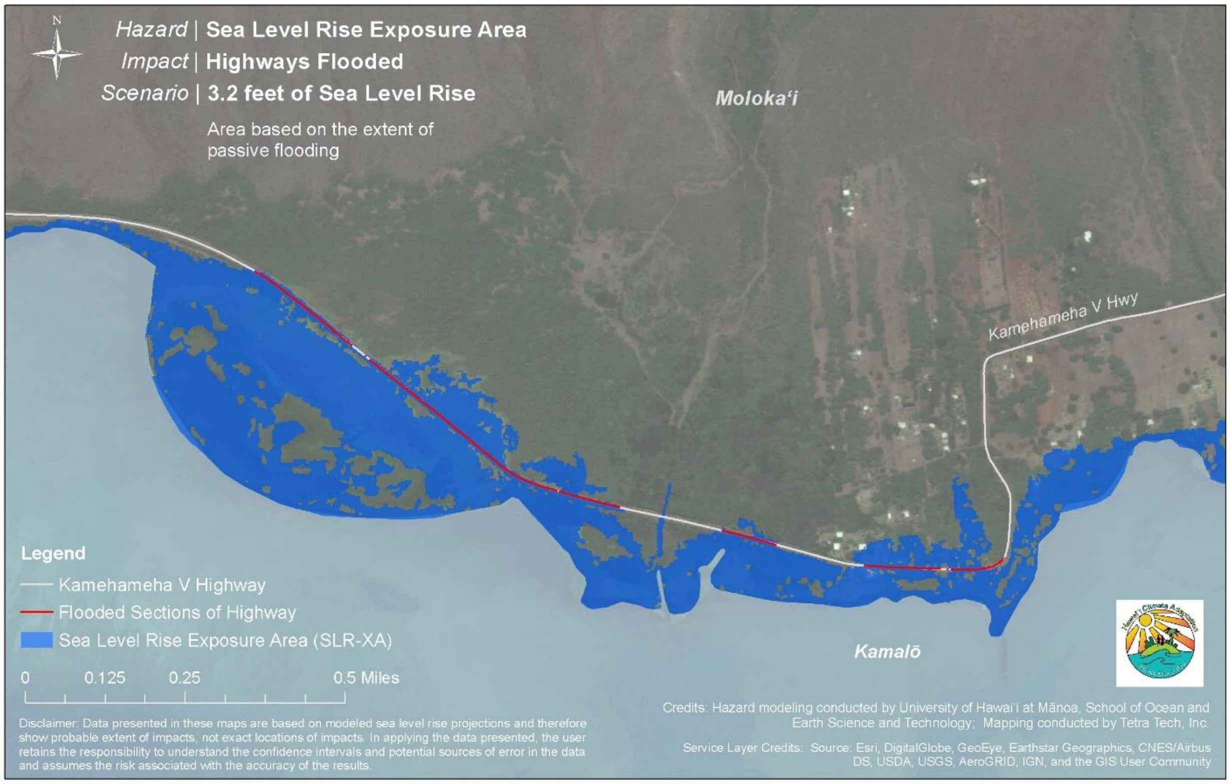


Figure 77. Sections of Kamehameha V Highway that would flood in the SLR-XA (red) with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise in Kamalō, Molokaʻi

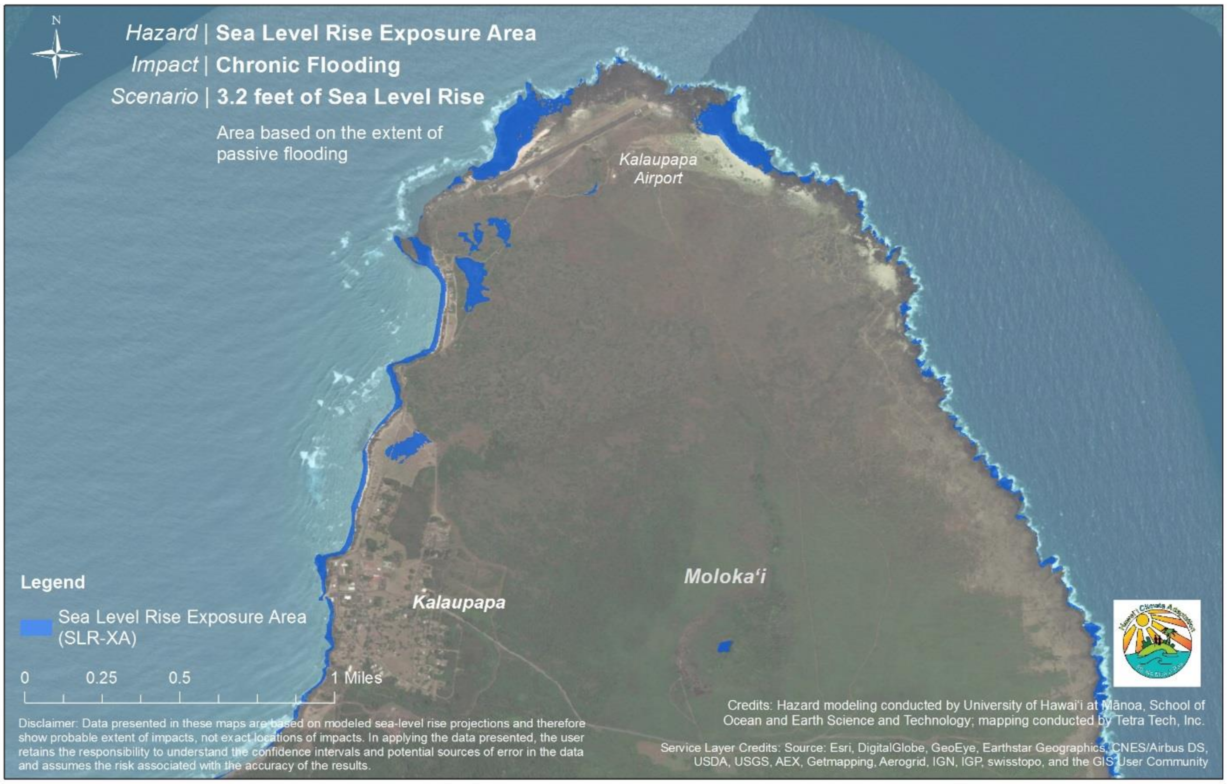


Figure 78. Portions of the Kalaupapa Airport in the SLR-XA with 3.2 feet of sea level rise on Molokaʻi

POTENTIAL IMPACTS TO NATIVE HAWAIIAN COMMUNITIES AND CULTURAL RESOURCES

Hawaiian Home Lands are intended to provide for the economic self-sufficiency of Native Hawaiians through a homesteading program (University of Hawaiʻi 2015). Consistent with Native Hawaiian culture, Hawaiian Home Lands include areas from mauka to makai *(*from the mountain to the sea*)*. Coastal portions of Hawaiian Home Lands, such as in Kalamaʻula (Figure 79), would be flooded with sea level rise displacing Native Hawaiian families that live in this areas. In addition, fishing and cultural practices taking place along the shore would be impacted as beaches erode. In a recent study of multiple coastal hazards, four of the six Hawaiian Home Lands on Molokaʻi, Kamiloloa-Makakupaʻia (assessed together due to proximate geography), Hoʻolehua-Pālāʻau, and Kalamaʻula, are estimated to have the greatest potential for people to be displaced by tsunamis, waves, and sea level rise (University of Hawaiʻi 2015).

In addition to Native Hawaiian communities themselves, many Native Hawaiian cultural and historical resources are located near the shoreline and are threatened by sea level rise. Coastal erosion already threatens areas that have served as burial grounds, home sites, fishponds, and other places of cultural significance (Kane et al. 2012). The number of cultural sites on Molokaʻi in the SLR-XA is projected to increase from 17 sites with 1.1 feet of sea level rise, to 26 with 3.2 feet of sea level rise. This includes cultural sites on Lāʻau Point that may be flooded as a result of sea level rise (Figure 80). Rising seas would also impact the many loko iʻa *(*ancient Hawaiian fishponds) located on Molokaʻi.

RECOMMENDATION HIGHLIGHTS

- Develop an inventory of Native Hawaiian cultural resources and practices that may be impacted by sea level rise.
- Work with Native Hawaiian communities to determine steps they want to take regarding climate impacts.
- Develop adaptation plans to preserve access to coastal land and water within Native Hawaiian communities.

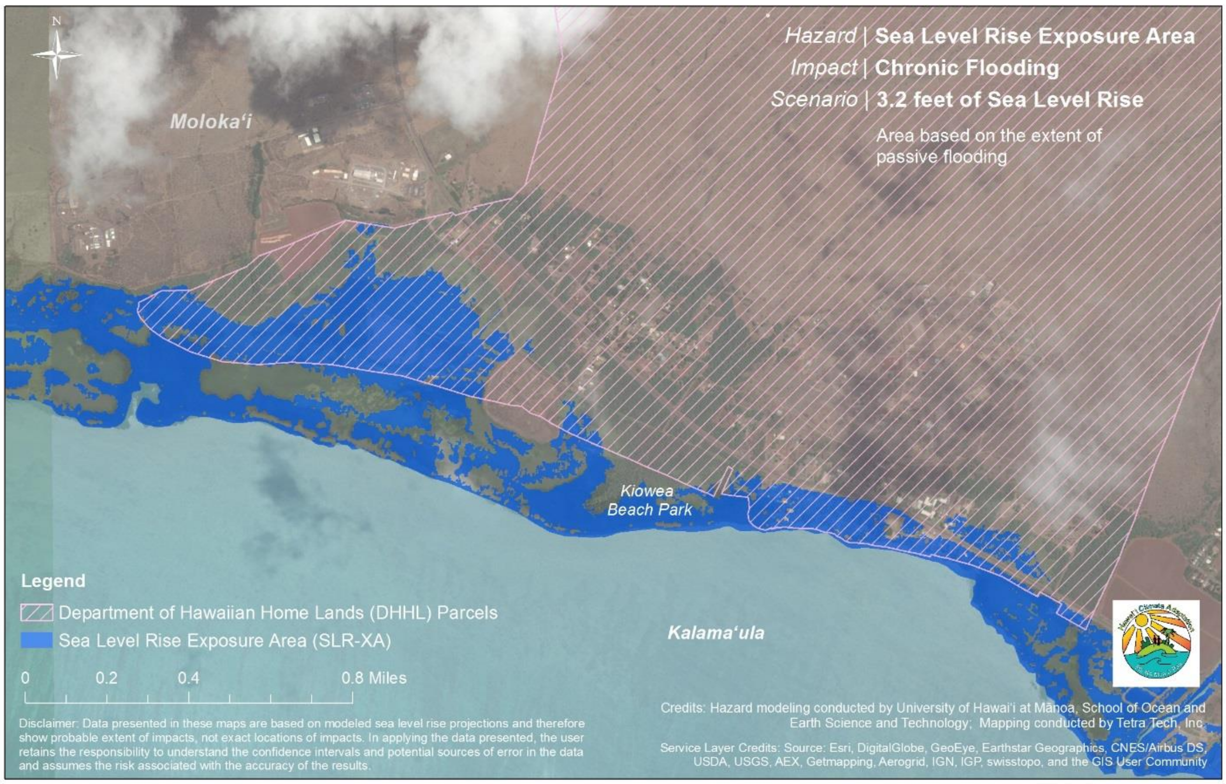


Figure 79. Potential chronic flooding of the Kalamaʻula Hawaiian Home Lands on Molokaʻi (pink hatched area) in the SLR-XA (blue) with 3.2 feet of sea level rise

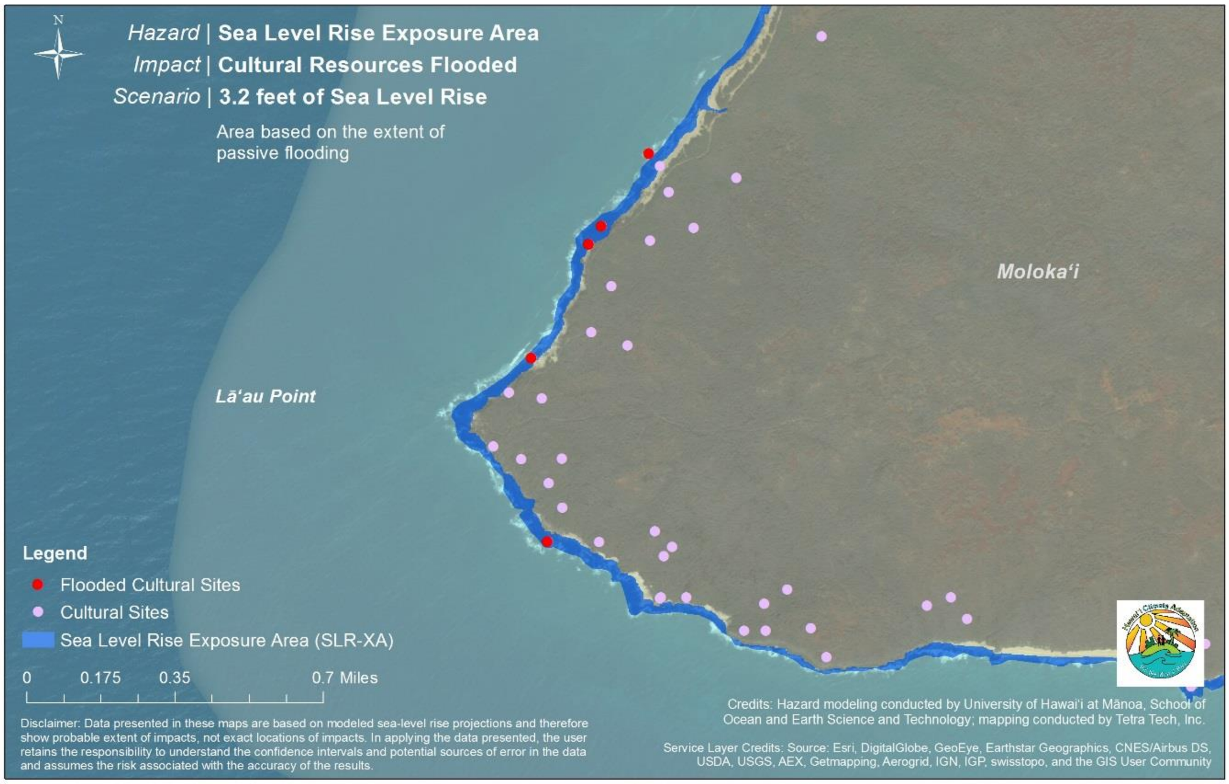


Figure 80. Cultural resource sites located in the SLR-XA with 3.2 feet of sea level rise along the shoreline of Laʻau Point, Molokaʻi

POTENTIAL IMPACTS TO COASTAL RESOURCES AND PUBLIC ACCESS

Molokai's beaches play a critical role in recreation for residents and Hawaii's overall economy (Cristini et al. 2013). An assessment of public beaches and parks was not conducted for Molokaʻi because of a lack of available GIS data; however, public parks located near the coast, such as Papohaku Beach Park, Mālama Cultural Park, Duke Maliu Regional Park, One Aliʻi Beach Park, Kakahaiʻa Beach Park, and Hālawa Beach Park, may be impacted by 3.2 feet of sea level rise. Some public beaches, such as Kepuhi Beach (Figure 81), are located on the seaward side of major roads, and demonstrate how lightly-developed parkland can provide a buffer between eroding shorelines and development for many decades.

Besides recreational areas, a variety of coastal habitats, vital to aquatic organisms and wildlife would become flooded with sea level rise, changing the nature of such habitats and the organisms that rely on them. Estuarine habitats, where freshwater from rivers and streams, and saltwater from the sea meet and mix, would become increasingly marine with rising seas. This dynamic would impact areas such as Hālawa Beach Park, on the eastern shore of Molokaʻi, where water from the Hālawa Stream mixes with ocean waters (Figure 82). Some of the earliest known settlements in Hawaiʻi are located in Hālawa Valley and remnants of irrigation systems supporting taro cultivation remain (County of Maui 2001). Hawaiian anchialine pools, land-locked bodies of water of varying salinity that are adjacent to the ocean (The Nature Conservancy 2012), are occupied by small endemic red shrimp (*Halocaridina* and others) called ʻōpaeʻula and the endangered shrimp, *Procaris hawaiana* (Fish and Wildlife Service 2016). These pools have indirect, underground connections to the sea, and show tidal fluctuations in water level. Other species, restricted to the surface waters of the pools, include a few fish species, crustaceans and other invertebrates. Two endangered waterbirds (Hawaiian Stilt and Hawaiian Coot), and several species of migratory waterfowl also use these pools (The Nature Conservancy 2012).

Sea level rise also has the potential to impact facilities that release wastewater or hazardous materials to nearshore waters and coastal habitats. Septic tanks, cesspools and other OSDS, as well as hazardous materials storage and disposal sites could become flooded and release wastewater or contaminants to nearshore waters. OSDS are of particular concern for Moloka'i as island-wide there are approximately 131 OSDS within the SLR-XA with 3.2 feet of sea level rise. Puko'o, located on the east shore of the island, is a good example of an area where the release of wastewater or contaminants from OSDS could impact nearshore waters and several fishponds (Figure 83).

RECOMMENDATION HIGHLIGHTS

- Amend the State Legacy Lands Act to set aside funding for preserving priority coastal lands and use of a variety of practices and tools to enable legacy beaches to persist.
- Develop shoreline conservation and restoration priorities and guidelines to support adaptation to sea level rise.
- Expand the area of national, state, and county parks and wildlife refuges on the main Hawaiian Islands to preserve wetlands and wildlife.
- Protect nearshore water quality by identifying hazard mitigation measures to address coastal flooding of hazardous material/waste storage facilities and OSDSs vulnerable to sea level rise.

Hawaiian monk seal, western tip of Moloka'i
Source: Randolph Femmer, USGS

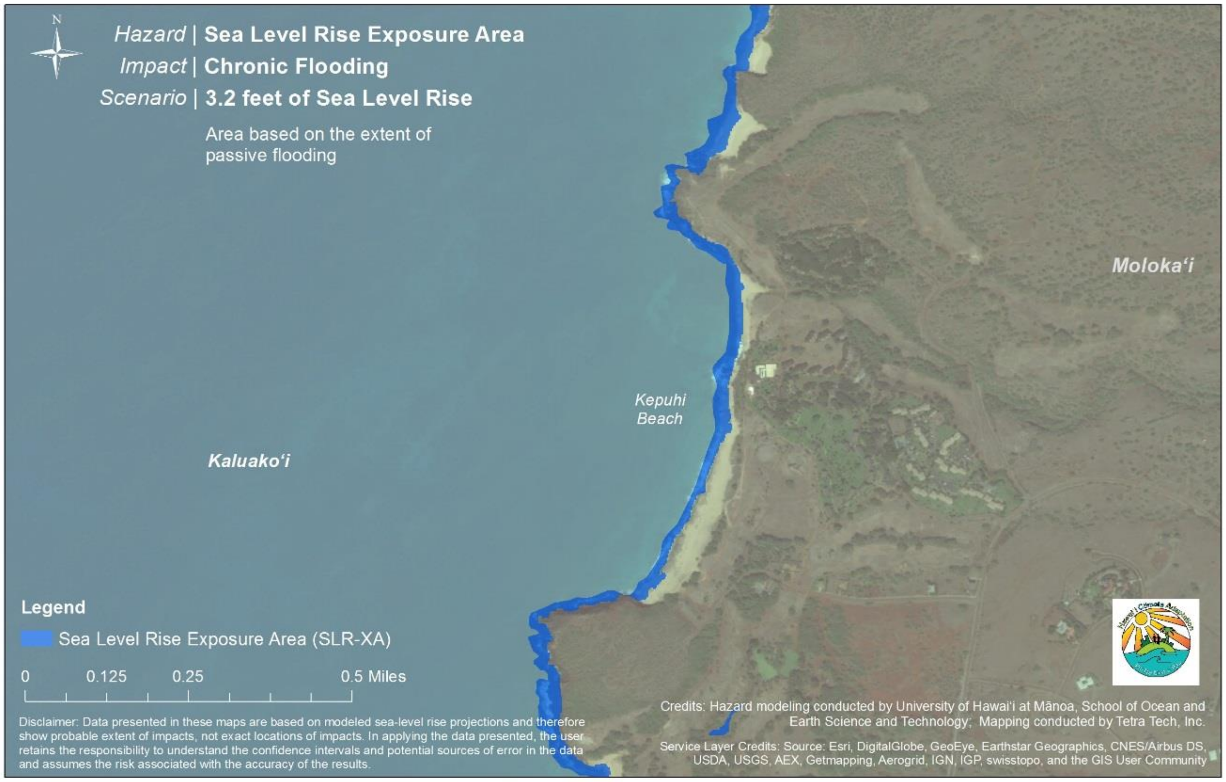


Figure 81. Potential chronic flooding of Kepuhi Beach in the SLR-XA with 3.2 feet of sea level rise along the Kaluakoʻi Coast, Molokaʻi

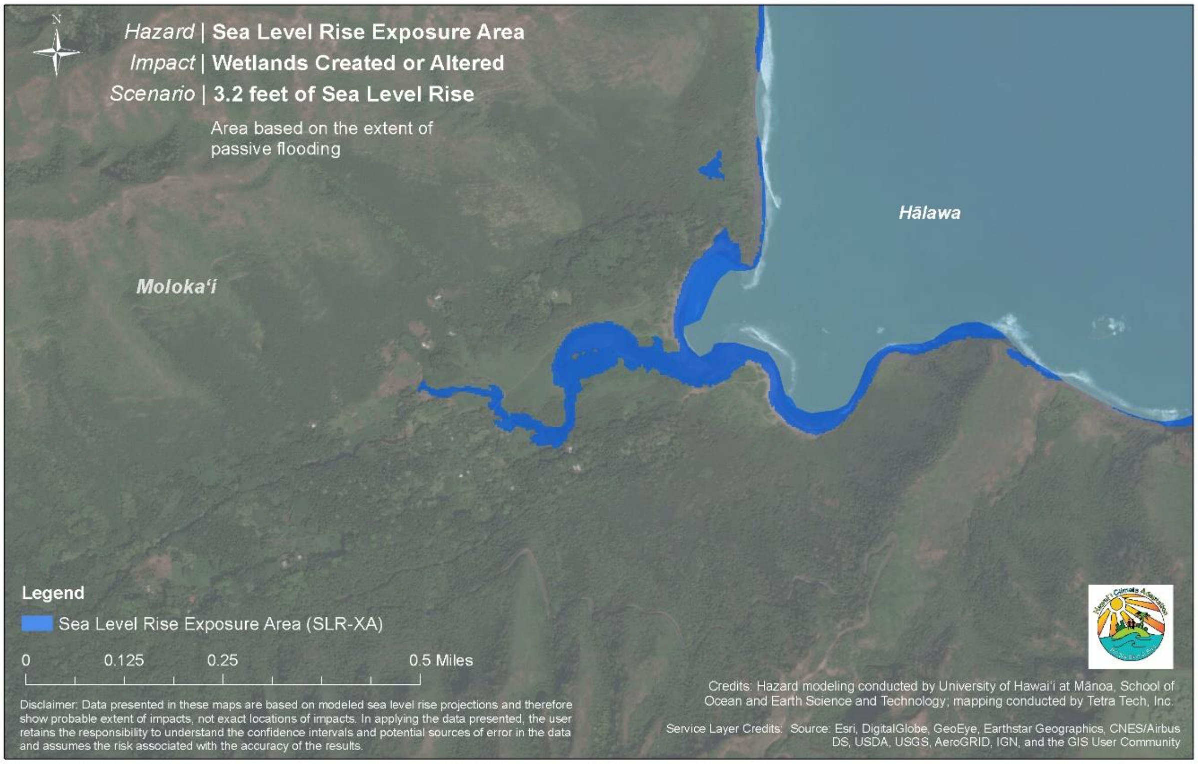


Figure 82. Wetlands created or altered in the SLR-XA with 3.2 feet of sea level rise in Hālawa Bay, Molokaʻi

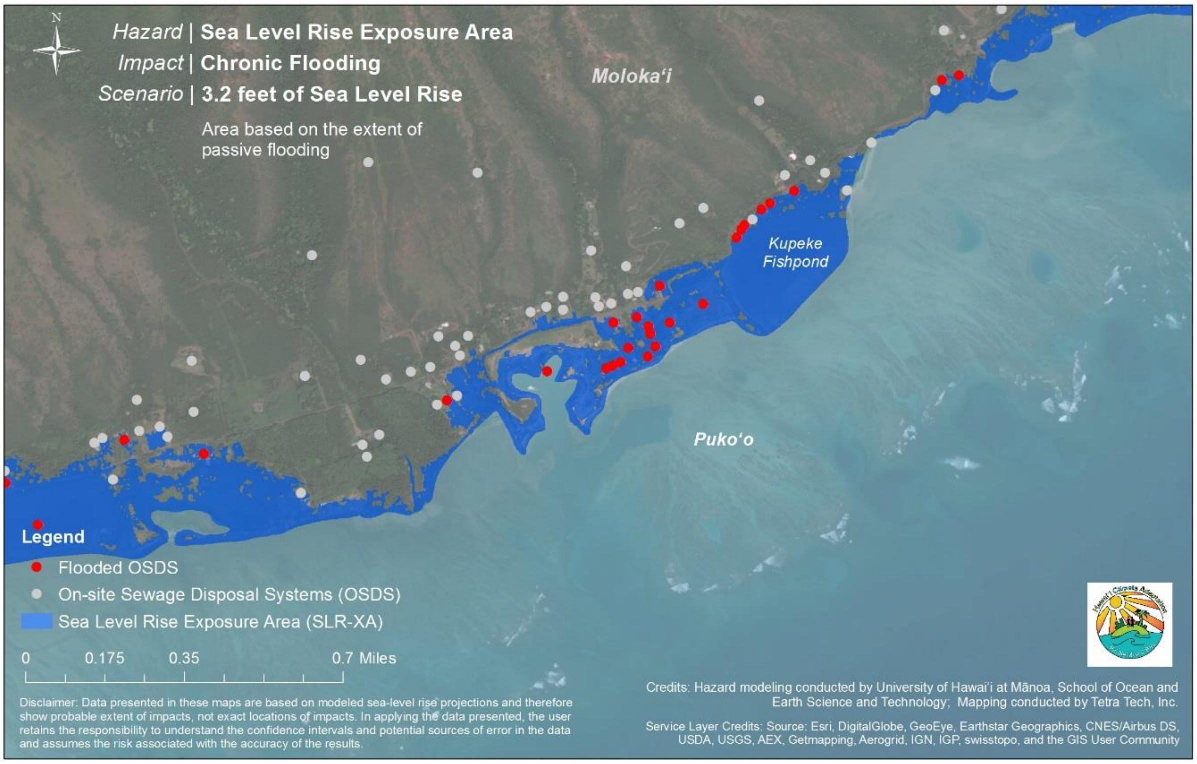


Figure 83. On-site sewage disposal systems flooded in the SLR-XA with 3.2 feet of sea level rise along the Puko’o Shore of Moloka‘i

Challenges and Opportunities

Over the next 30 to 70 years, properties located on or near Molokai’s shorelines will increasingly be flooded, eroded, or completely lost to the sea. Portions of coastal roads will also become flooded, eroded, impassible and irreparable, jeopardizing access to and from many communities. Beaches will increasingly be eroded and permanently lost if hard structures such as roads and seawalls impede their landward migration.

This Results section highlights just a few of the very real challenges on Moloka‘i with a scenario of 3.2 feet of sea level rise by the mid- to the latter-part of the century. Sea level rise will not stop at the middle or end of the century. As highlighted throughout this Report, higher sea level rise projections are considered “physically plausible” by the end of the century based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). While this Report models sea level rise up to 3.2 feet, it should be noted that NOAA has modeled passive flooding scenarios with up to 6 feet of sea level rise in their Sea Level Rise Viewer (NOAA 2017b). To illustrate potential impacts from higher sea level scenarios, the 5-foot passive flood layer from NOAA was incorporated into the vulnerability assessment which increases the area of the SLR-XA of Moloka‘i by 29%. Figure 84 shows the potential extent of 5 feet of passive flooding with sea level rise for the communities of Kaunakakai, Kekaha, and Kapa‘akea. While there is uncertainty over when the islands might experience such extreme sea level rise, the information is provided merely to remind readers that sea level rise is going to continue for the remainder of the century and beyond.

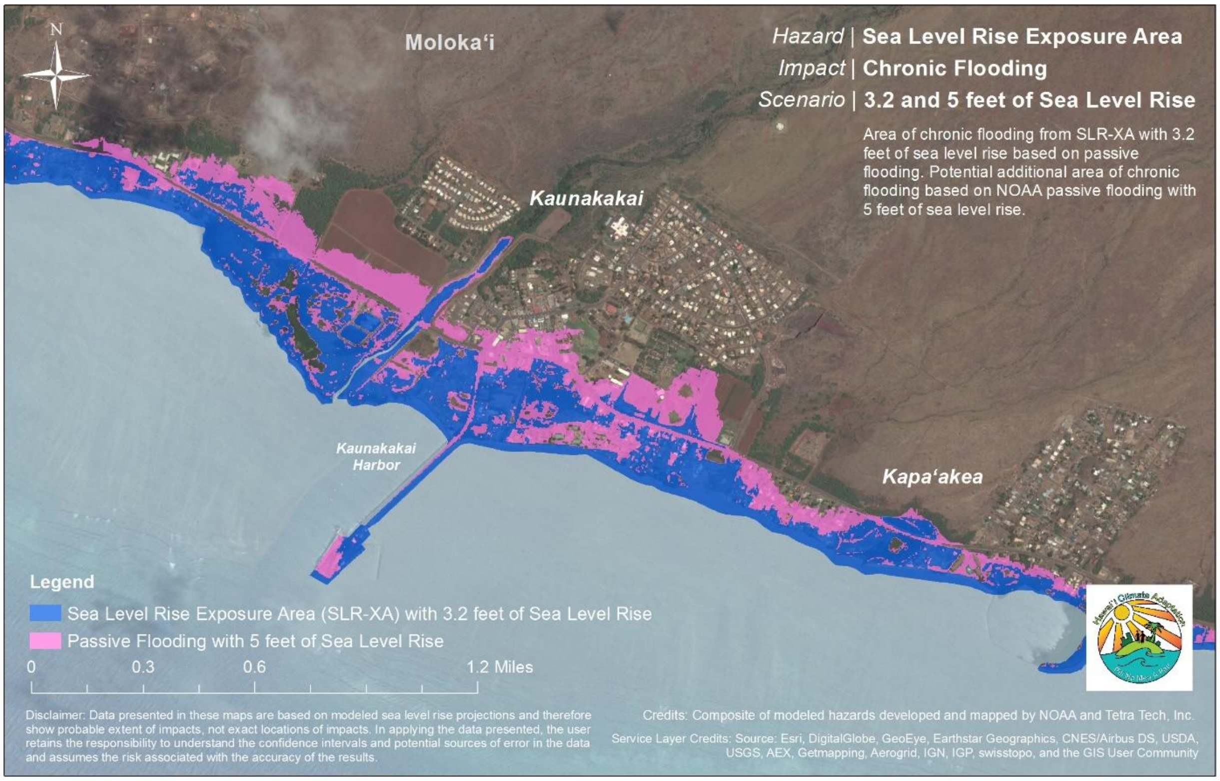
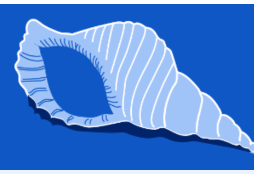


Figure 84. Potential additional area of chronic flooding with 5 feet of sea level rise in Kaunakakai, Kekaha, and Kapa‘akea on Moloka‘i

Regardless, these uncertainties should catalyze not paralyze action. With abundant land outside of the SLR-XA, Moloka‘i has opportunities to plan for sea level rise now by considering County General Plan and Community Plan updates that recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone and to plan for future land use now. In addition to chronic coastal flooding from sea level rise, tropical storms, hurricanes, and tsunamis create waves that flood low-lying coastal areas. The added risk from event-based coastal flooding exacerbated by sea level rise is not included in this Report. However, these events pose a potential for loss of human life and property, and for severe and long-term economic disruption. Communities should consider planning new development to reduce exposure from severe events by recognizing that the coastal floodplain will migrate landward with increased sea level . Hazard mitigation and disaster recovery projects should be reviewed and revised to address chronic and event-based flooding and consider the additive effects of accelerating sea level rise.

SEA LEVEL RISE STORIES

Protecting Molokai's Fishponds



WEAVING TRADITIONAL VALUES AND MODERN CLIMATE SCIENCE TO PROTECT MOLOKAI'S FISHPONDS AND OTHER VALUED RESOURCES

"I think what brought us to this point was that we were starting to observe changes and our kupuna were starting to observe changes to the landscape," said Kauwila Hanchett, Co-Executive Director of Ka Honua Momona (KHM), a nonprofit founded to restore and care for two 15th century, traditional fishponds on Molokaʻi. "We'd been hearing this buzz about climate change but we recognized that we didn't know a lot about it."

It was the threat of changes to the fishponds as well as the natural and cultural resources on Molokaʻi that inspired KHM to apply for a grant from the Pacific Islands Climate Change Cooperative (PICCC). This grant funded workshops and other projects aimed at bridging traditional values and practices with modern climate science.

Though KHM's focus is on coastal issues that would impact fishponds, such as coastal erosion and changing rain patterns and runoff, the group is concerned with the whole spectrum of climate impacts. "Part of our whole approach is looking at the ahupuaʻa [watershed] as a whole, the island as a whole," said Hanchett. By looking at all the potential impacts to the whole island ecosystem, the community can determine how climate change could impact their way of life and the resources on which it depends. One of the Task Force's first priorities is to improve education on Molokaʻi about these potential lifestyle changes to Molokai's subsistence lifestyle and connection to more traditional Hawaiian practices.

The workshops were so successful that the attendees decided to form an "Interim Task Force" continuing the climate change conversation at a grassroots level. "The dialogue was really rich. We felt like it was too precious to have that end," said Hanchett. The group made a list of action items to pursue, including holding climate science trainings, collecting local data points such as rain gauge measurements, and documenting landscape change through historical photographs. Those on Molokaʻi have tried to meet monthly since then to continue their work to increase awareness within the Molokaʻi community about climate change. The visiting scientists have continued to provide support and several returned to present at a recent community meeting.

You can read more of this story at
climateadaptation.hawaii.gov/climate stories

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Lānaʻi shoreline
Source: Four Seasons Resort Lānaʻi

Lānaʻi

The Island of Lānaʻi, the State's smallest publicly accessible inhabited island, is also known as the "Pineapple Island" due to its past as an island-wide pineapple plantation. Lānaʻi is a part of Maui County and is home to 3,526 residents (State of Hawai'i 2015), accounting for only 0.2% of the State's population. While the population has grown by 31% since 1970, it has not seen the population booms impacting other islands, such as Maui. Nonetheless, this population growth coupled with a growing tourism industry—over 63,000 visitors came to Lānaʻi in 2016 (State of Hawai'i 2016)—has placed ever increasing demands on natural resources, critical infrastructure, and basic services. It should be noted that majority of the population and the primary commerce center on Lānaʻi is located in the center of the island at higher elevations. Due to this and the rural nature of the island, Lānaʻi has significantly less development exposed to sea level rise impacts compared to the other islands in the State. However, sea level rise will still have impacts on the people, economy, and environment of Lānaʻi.

Key Take Aways

- Over the next 30 to 70 years, structures located near the shoreline will be impacted by sea level rise. Around a dozen structures would be chronically flooded by 3.2 feet of sea level rise.
- Of the 380 acres of land located within the SLR-XA, over 50% is designated as Conservation District lands.
- A more detailed analysis of the vulnerability of Lānai's critical infrastructure, including Kaumālapaʻu Harbor, is needed. State and County agencies should consider potential long-term cost savings

from implementing sea level rise adaption measures as early as possible (e.g., relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.

This section provides a picture of the future of the Island of Lānaʻi with sea level rise and the potential impacts if no action is taken. The results are based on modeling coastal flooding with sea level rise due to passive flooding, annual high wave flooding, and coastal erosion in the SLR-XA with up to 3.2 feet of sea level rise, and depicts flood hazards that may occur in the mid- to latter-half of this century. This timeframe is within the expected lifespan of most new construction and much of our existing development. It should be noted that sea level rise projections greater than 3.2 feet are "physically plausible" by the end of the century, based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). Vulnerability to 1.1 feet of sea level rise in the SLR-XA is used to approximate current or near-term exposure to coastal hazards and sea level rise. Vulnerability is assessed in terms of potential impacts to land use, people, property, cultural and natural resources, and critical infrastructure (only land and structures are monetized, not infrastructure).

The reader is urged to exercise caution in interpreting the results, which could be to a greater or lesser extent depending on actual observed future sea level rise, technological innovations in climate change mitigation and adaptation, unknown economic variables, as well as future societal choices which cannot be known today. Further, as not all parts of the island can be shown in detail, the reader should also visit the Hawaiʻi Sea Level Rise Viewer to explore the full extent of the vulnerability maps for each island.

Potential Impacts in the Sea Level Rise Exposure Area

The SLR-XA depicts the area of potential chronic flooding from exposure to passive flooding with sea level rise. For the purposes of exposure and planning, we focus mainly on a scenario with 3.2 feet of sea level rise.

With 3.2 feet of sea level rise, low-lying coastal areas around the island within the SLR-XA may become chronically flooded within the mid- to latter-half of this century (Figure 85). This land will become submerged by coastal erosion, direct marine flooding from tides and waves, or become new wetlands behind the shoreline from rising water tables and reduced drainage. Approximately 380 acres of land on Lānaʻi are estimated to be located in the SLR-XA with 3.2 feet of sea level rise. As mentioned previously, the topography and development patterns of Lānaʻi lend themselves to less exposure to the impacts of sea level rise than the other islands in the State. However, over time, as the sea level continues to rise, low-lying, economically important areas, such as Hulopoʻe Bay and Mānele Bay (Figure 86), would experience increased frequency and extent of flooding. Decisions about where to use coastal armoring and when to retreat will need to be made carefully. It should be noted that seawalls may not be effective at preventing flooding with sea level rise in some low-lying areas as rising groundwater can infiltrate through porous geology in low-lying areas. While specific responses to sea level rise would need to be place-based, larger regional issues should also be considered, such as whether to armor in place or whether to relocate vulnerable development inland.

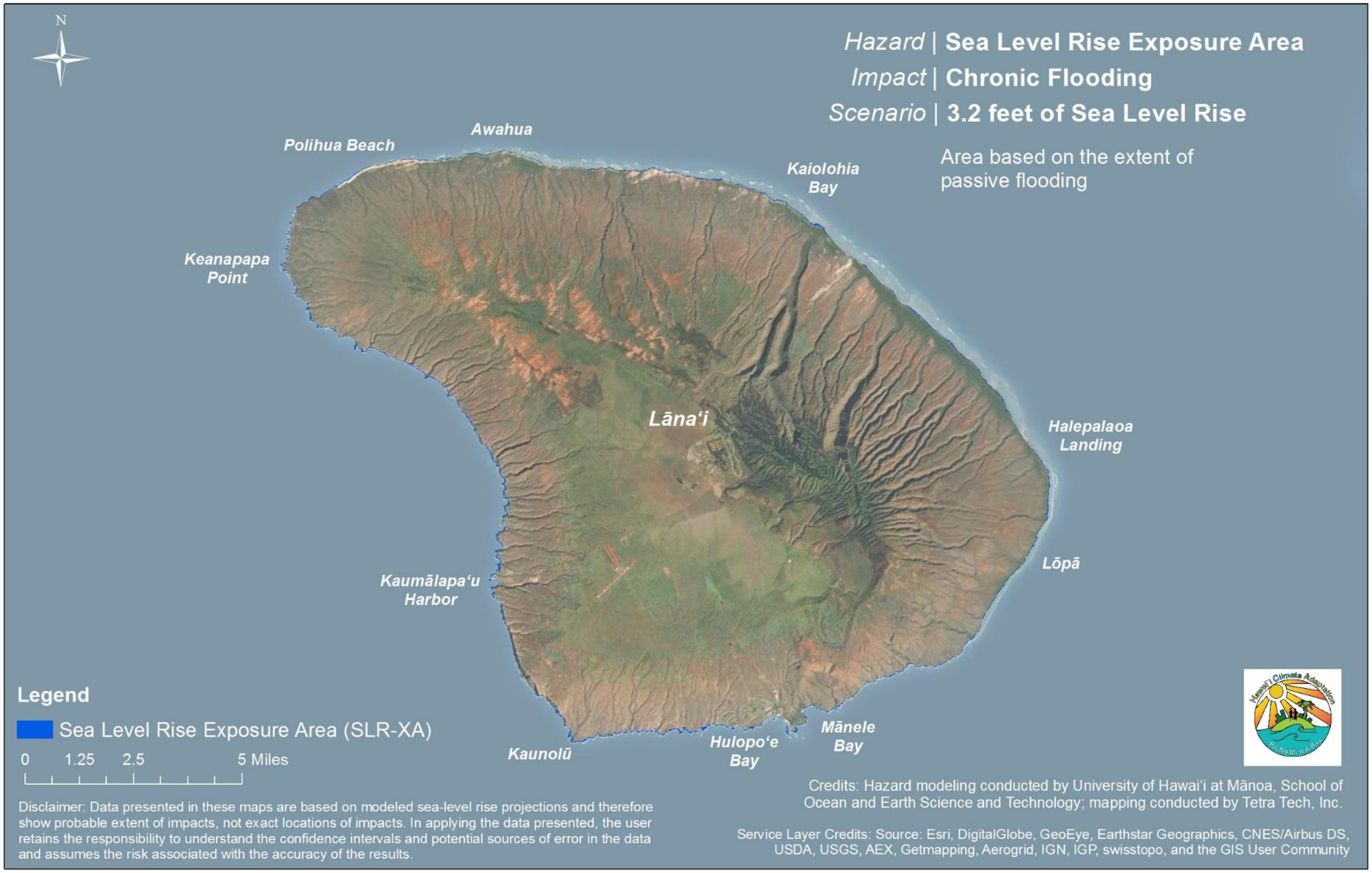


Figure 85. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise (a thin barely visible blue line) for Lānaʻi

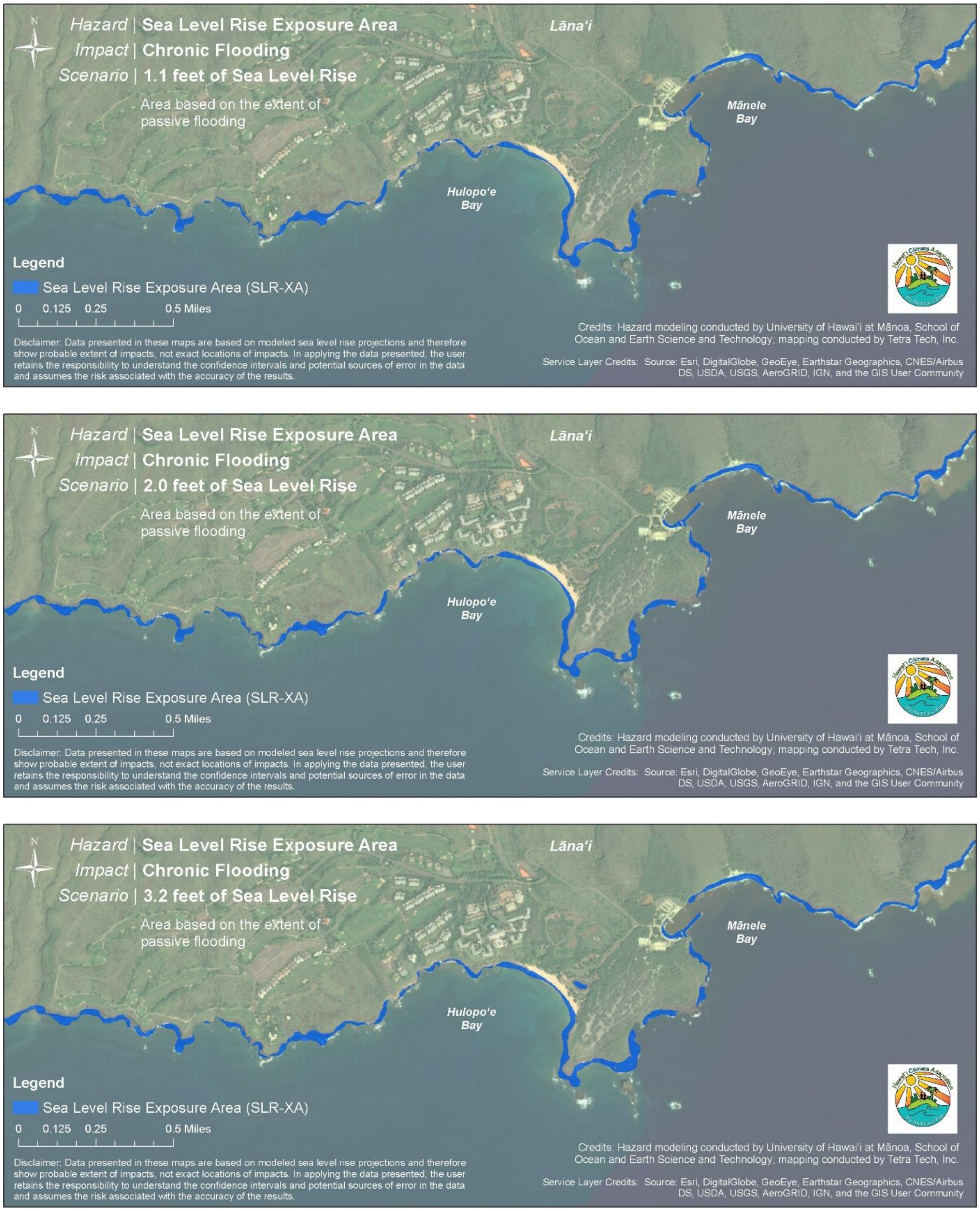


Figure 86. Potential chronic flooding in the SLR-XA with 1.1, 2.0, and 3.2 feet of sea level rise in Hulopo'e Bay and Mānele Bay, Lāna'i

POTENTIAL IMPACTS TO LAND USE

Sea level rise would result in impacts within the State Urban, Rural, Agricultural, and Conservation Land Use Districts around the island, however, Conservation District lands would experience the greatest extent of chronic flooding (Figure 87). More than half of the 380 acres of land located within the SLR-XA are designated as Conservation lands while only approximately 16% of the 380 acres of land located within the SLR-XA are within the Urban District. However, it should be noted that only approximately 2% of Lanai's 89,920 acres are located in either the Urban or Rural District which coincides with the rural nature of the island and the fact that the majority of the population and businesses are concentrated in Lānaʻi City, on the central plateau. Therefore, impacts from sea level rise on areas with concentrated development would be less significant on Lānaʻi than on other islands in the State. There are, however, a number of Urban designated lands along the coast, especially along the western and southern shore of the island around Kaumalapau Harbor and Mānele, that are within the SLR-XA with 3.2 feet of sea level rise. In instances such as these, there may be some pressure to convert existing Conservation District or Rural lands to Urban designated lands to accommodate redevelopment away from the shoreline.

RECOMMENDATION HIGHLIGHTS

- Recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone in the County General Plan and Community Plan updates.
- Strive to balance managed retreat strategies from vulnerable urban areas with preservation of agriculture and conservation lands.
- Seek opportunities to plan new development well landward of the SLR-XA with 3.2 feet of sea level rise under a long-term, comprehensive adaptation strategy.

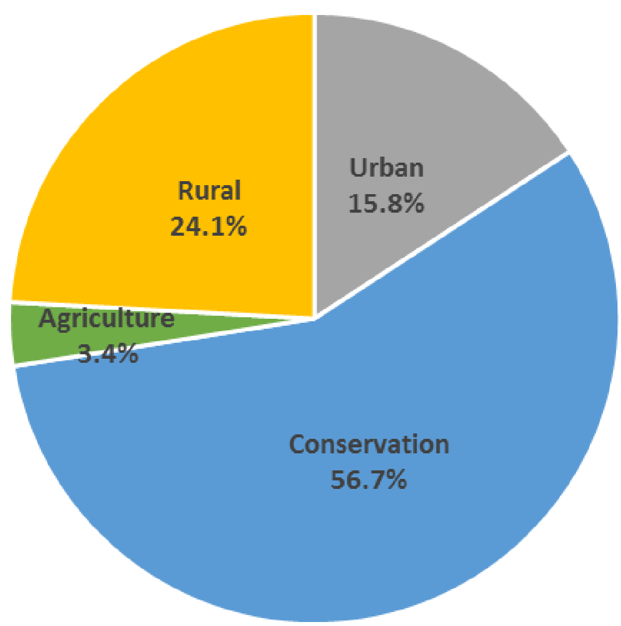


Figure 87. Estimated percentages of Land Use Districts impacted in the SLR-XA with 3.2 feet of sea level rise on Lānaʻi

POTENTIAL IMPACTS TO PEOPLE AND PROPERTY

Across the State, people living and working within the SLR-XA would be displaced when homes, condominiums, and business become flooded due to sea level rise. The potential number of people displaced is estimated by assigning an estimated occupancy for each type of structure in the SLR-XA. Potential economic loss in the SLR-XA is estimated based on the value of land and structures flooded. Loss estimates are assessed at the parcel level and aggregated into 1-hectare grids. The potential economic loss associated with flooded roads, water/wastewater facilities, and other critical infrastructure is not accounted for in the assessment of economic impacts, and would add significant increases in losses.

No residents island-wide are expected to be directly displaced by 3.2 feet of sea level rise; however, residents could be displaced due to economic impacts on major employers, such as the Four Seasons Resort, or from the loss of lands associated with their homes. Potential economic losses (all structures and land) island-wide would increase from an estimated $9 million with 1.1 feet of sea level rise to $10 million with 3.2 feet of sea level rise (Figure 88). Approximately 11% of the potential economic loss with 3.2 feet of sea level rise is attributed to the loss of residential land. This potential economic loss is associated with approximately 13 structures in the SLR-XA with 3.2 feet of sea level rise and approximately 380 acres of land.

With 3.2 feet of sea level rise, potential economic loss would occur in low-lying coastal areas, with the greatest loss along the southern shore, around Mānele and Hulopoʻe Bays, due to the commercial land and harbor facilities (Figure 89 and Figure 90).

RECOMMENDATION HIGHLIGHTS

- Require mandatory disclosure for vulnerable properties and consider acquisition to protect valuable coastal resources.
- Develop design standards to increase flood resiliency for existing and new development within the SLR-XA that cannot be relocated.
- Seek opportunities to plan new development well landward of the SLR-XA with 3.2 feet of sea level rise under a long-term, comprehensive adaptation strategy.
- Develop a multi-pronged financing strategy at federal, state, county, private sector, and philanthropic levels to address costs of adaptation to sea level rise.

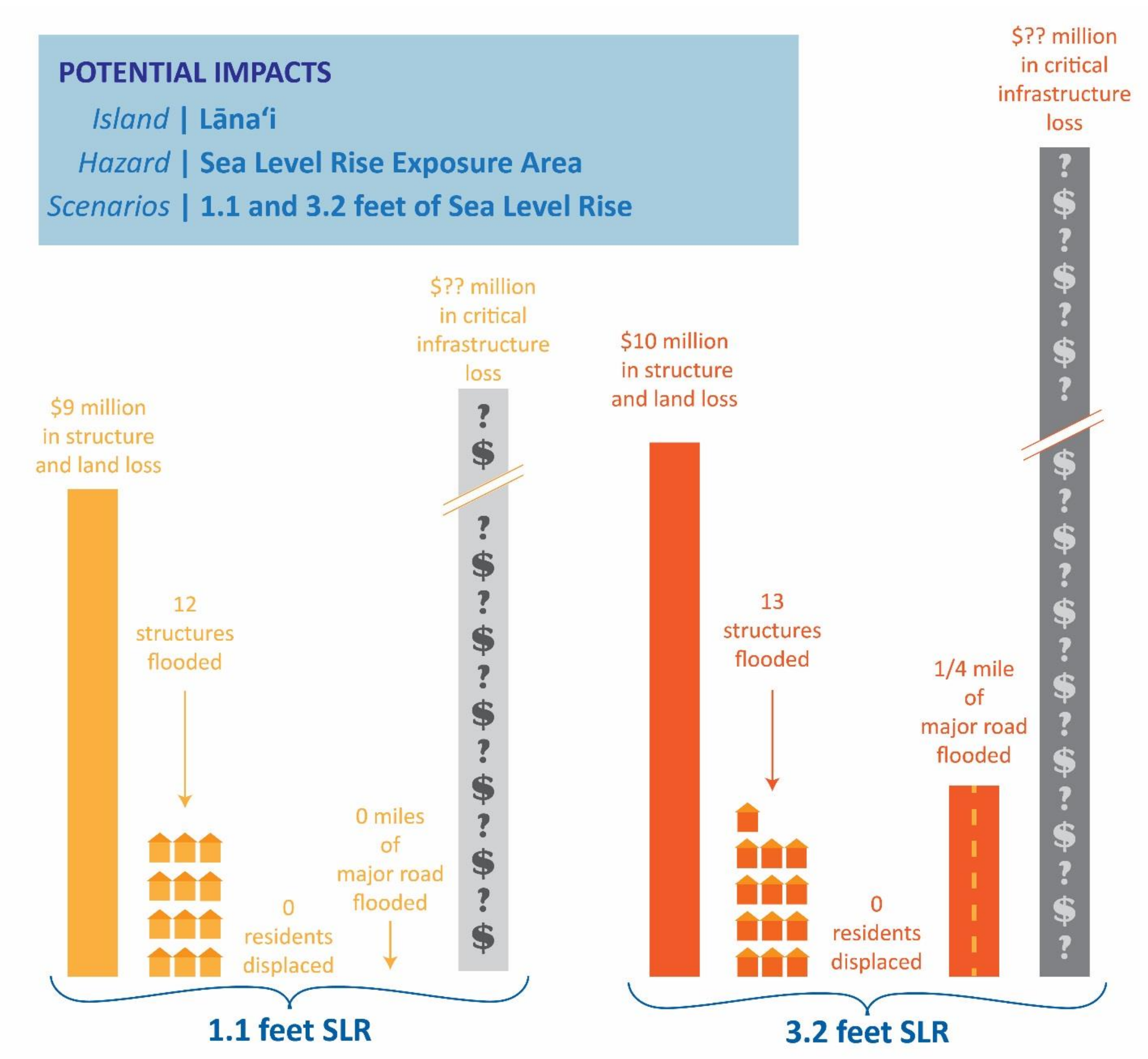


Figure 88. Summary of potential impacts in the SLR-XA with 1.1 feet and 3.2 feet of sea level rise on Lānaʻi

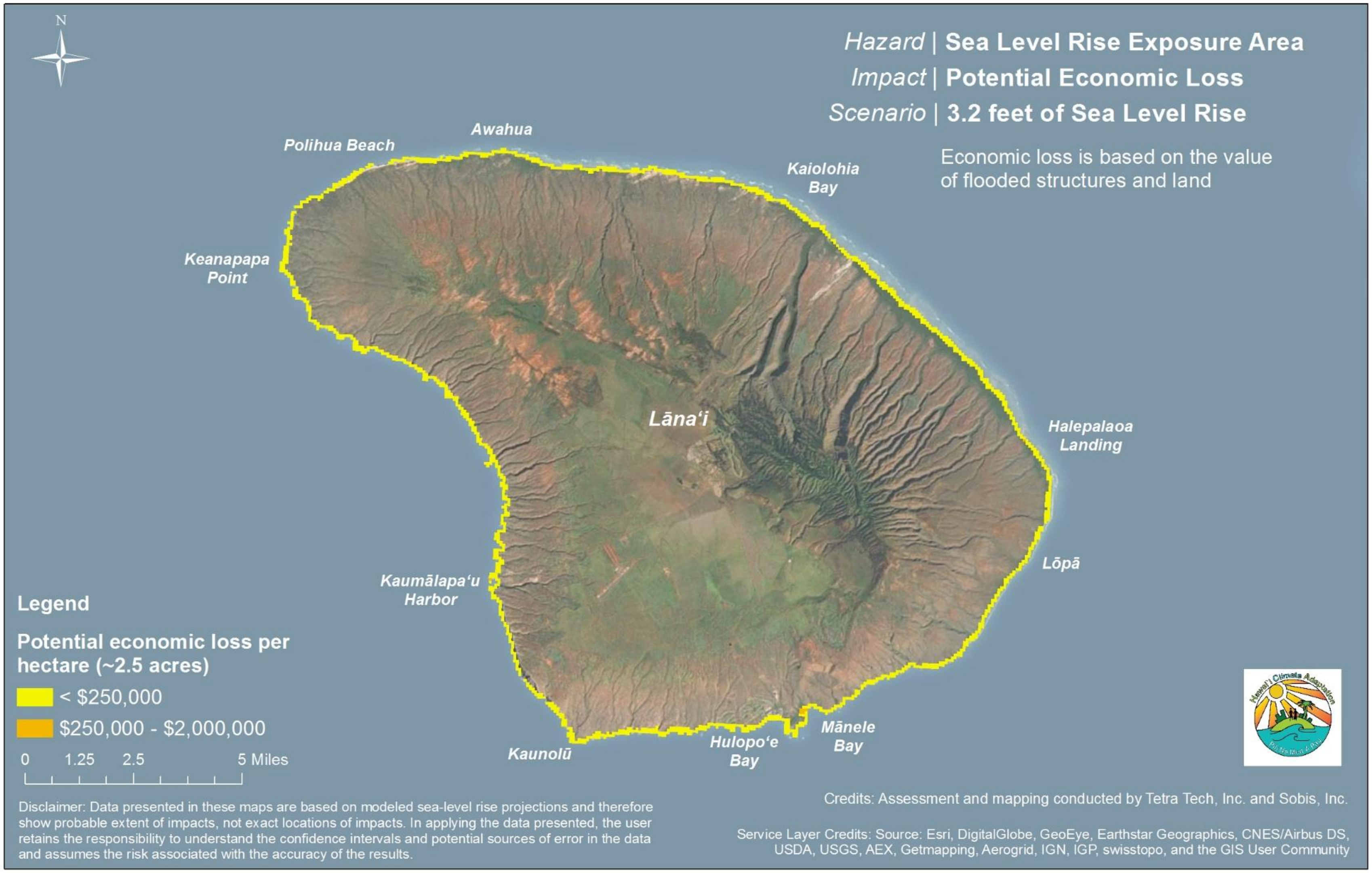
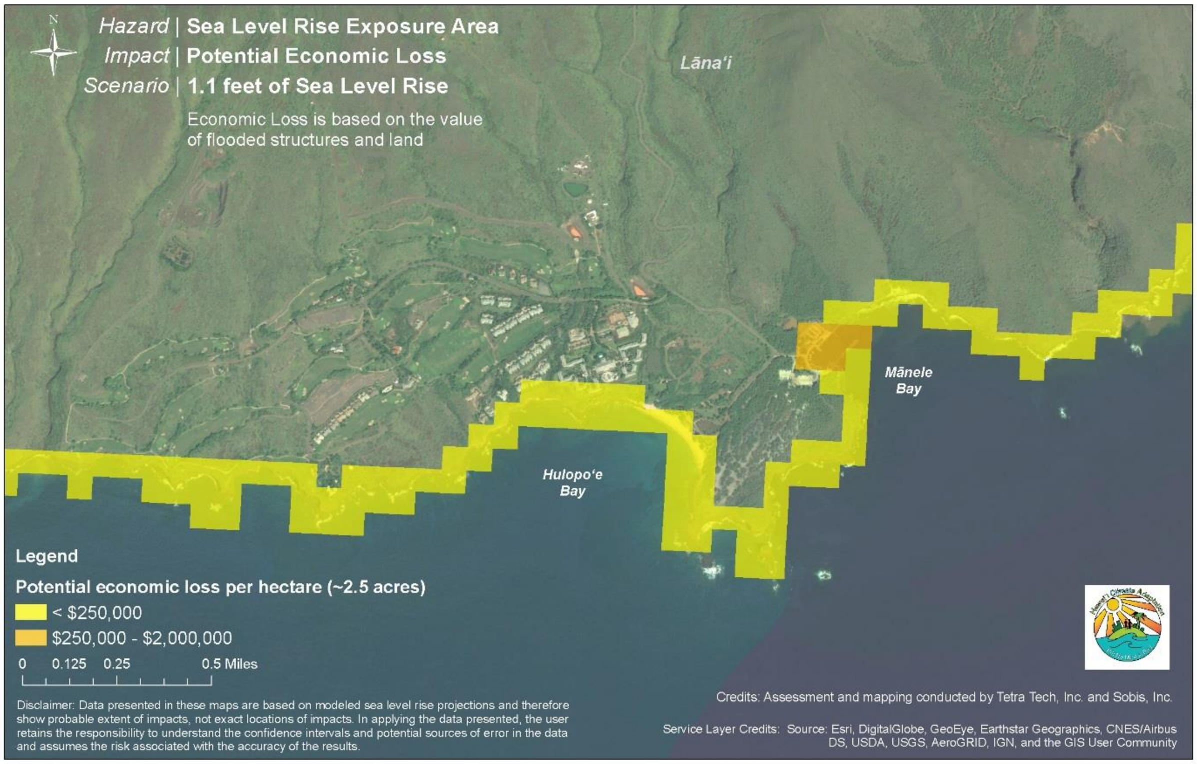


Figure 89. Potential economic loss in the SLR-XA with 3.2 feet of sea level rise on Lānaʻi



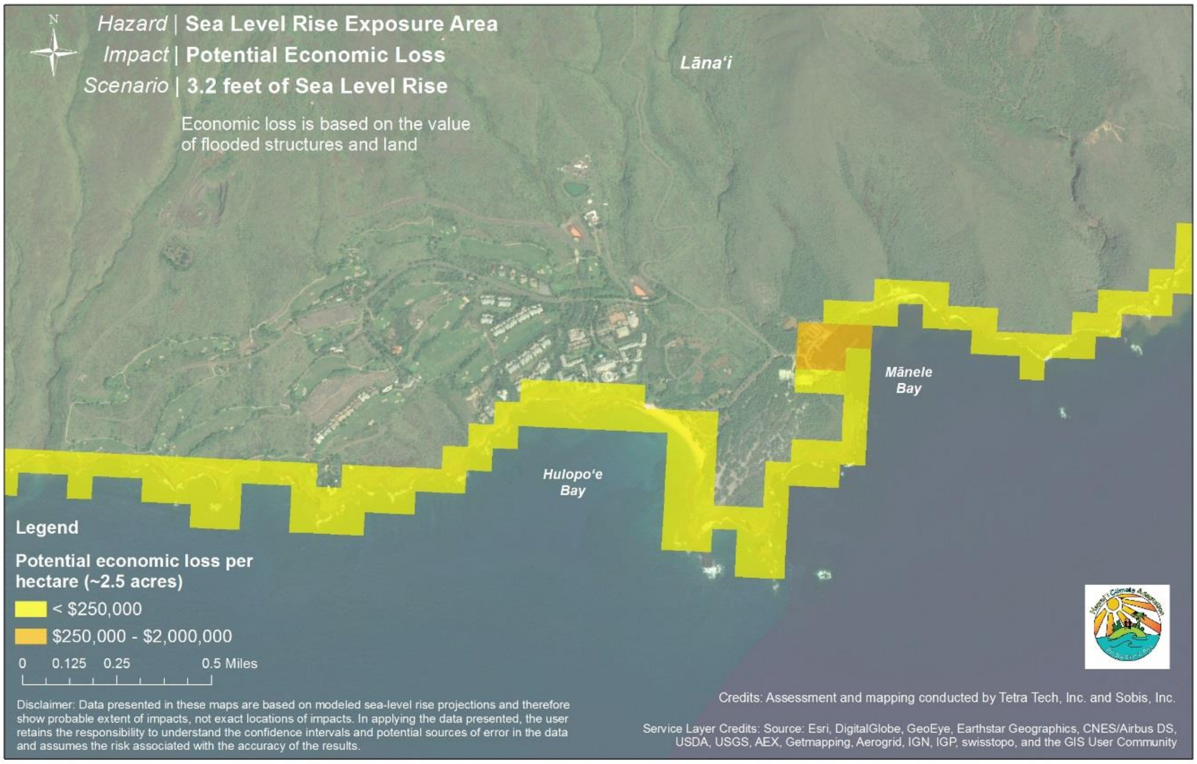


Figure 90. Potential economic loss in the SLR-XA with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise in Mānele Bay, Lānaʻi

POTENTIAL IMPACTS TO CRITICAL INFRASTRUCTURE

As with most development on the island, most of Lānai's critical infrastructure is located outside of the projected flooding area in the SLR-XA. While sea level rise would result in a few notable impacts to coastal roads, no major roads would be flooded in the SLR-XA with 3.2 feet of sea level rise.

Lānaʻi has one airport and two harbors. The Lānaʻi Airport is located at higher elevations and outside of areas likely to be flooded with 3.2 feet of sea level rise. However, the principal commercial harbor, Kaumālapaʻu Harbor (Figure 91), and Mānele Small Boat Harbor would become increasingly exposed to chronic flooding from sea level rise. Interruption to interisland shipping and travel would impact residents, visitors, and all forms of economic activity. No schools, fire stations, police stations, hospitals, or wastewater treatment plants are located in the SLR-XA with 3.2 feet of sea level rise. A more detailed analyses of vulnerability and adaptation options for critical infrastructure, particularly the harbor facilities, is needed to evaluate adaptation options such as retrofitting or relocation.

Please keep in mind that the economic loss resulting from critical infrastructure was not estimated due to the complexity and uncertainty involved in design, siting, and construction (Figure 88). However, it should be noted that these costs could be an order of magnitude greater than the potential economic losses estimated from land and structures.

RECOMMENDATION HIGHLIGHTS

- State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., flood proofing and relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.
- Require the design and siting of new development and capital improvement projects to include an in-depth analysis of sea level rise impacts based on elevation, tolerance for risk, and lifetime of the structure.

Figure 91. Harbor facilities in the SLR-XA with 3.2 feet of sea level rise on Lāna'i

POTENTIAL IMPACTS TO NATIVE HAWAIIAN COMMUNITIES AND CULTURAL RESOURCES

Hawaiian Home Lands are intended to provide for the economic self-sufficiency of Native Hawaiians through a homesteading program (University of Hawai'i 2015). Consistent with Native Hawaiian culture, Hawaiian Home Lands include areas from mauka to makai *(*from the mountain to the sea). While there is a section of Hawaiian Home Lands located in Lāna'i City, there are no coastal Hawaiian Home Lands (Figure 92) that could be flooded due to sea level rise. However, fishing and cultural practices taking place along the shore may be impacted as beaches erode.

Just as important as the Native Hawaiian communities themselves, many Native Hawaiian cultural resources are located near the shoreline and are threatened by sea level rise. Coastal erosion already threatens areas that have served as burial grounds, home sites, fishponds, and other places of cultural significance (Kane et al. 2012). The number of cultural sites on Lāna'i in the SLR-XA is projected to increase from 33 sites with 1.1 feet of sea level rise, to 34 with 3.2 feet of sea level rise. For example, the Kalamanui Complex, a small historic settlement area (County of Maui 2015a) north of Kaumālapa'u, may be flooded as a result of sea level rise (Figure 93).

RECOMMENDATION HIGHLIGHTS

- Develop an inventory of Native Hawaiian cultural resources and practices impacted by sea level rise.
- Work with Native Hawaiian communities to determine steps they want to take regarding climate impacts.
- Develop adaption plans to preserve access to coastal land and water within Native Hawaiian communities.

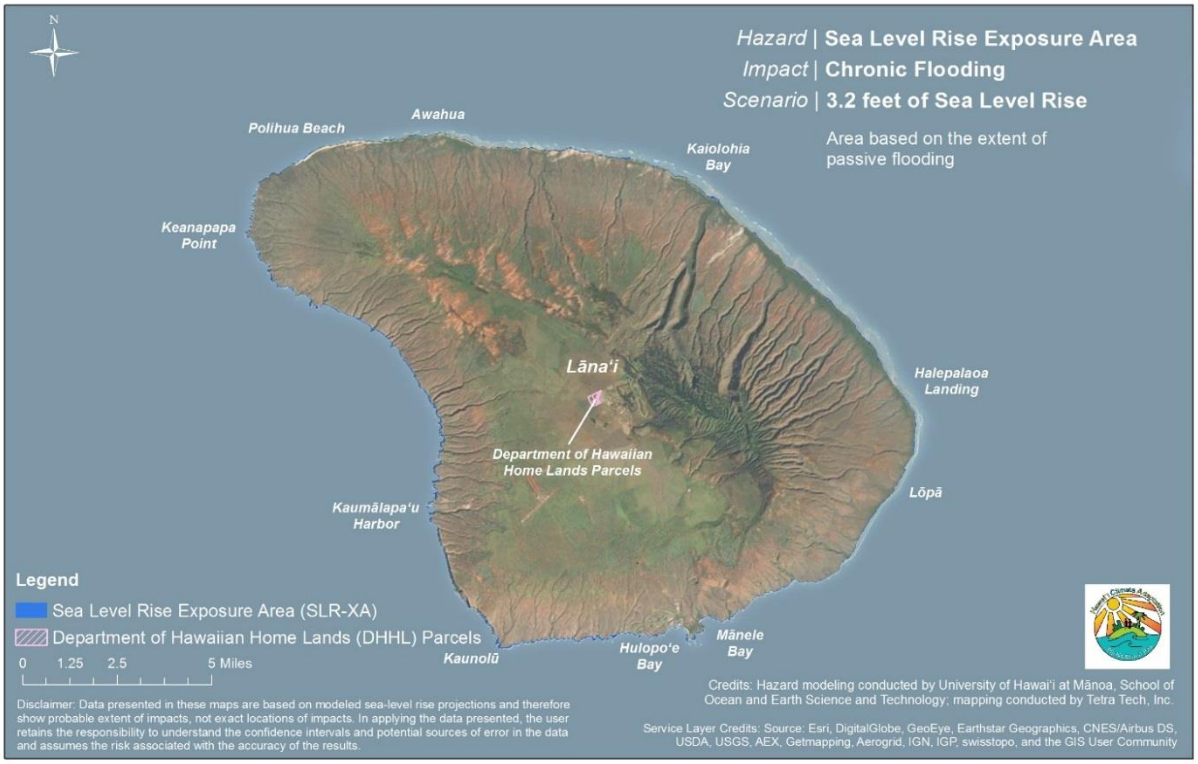


Figure 92. Hawaiian Home Lands on Lānaʻi located outside of SLR-XA with 3.2 feet of sea level rise

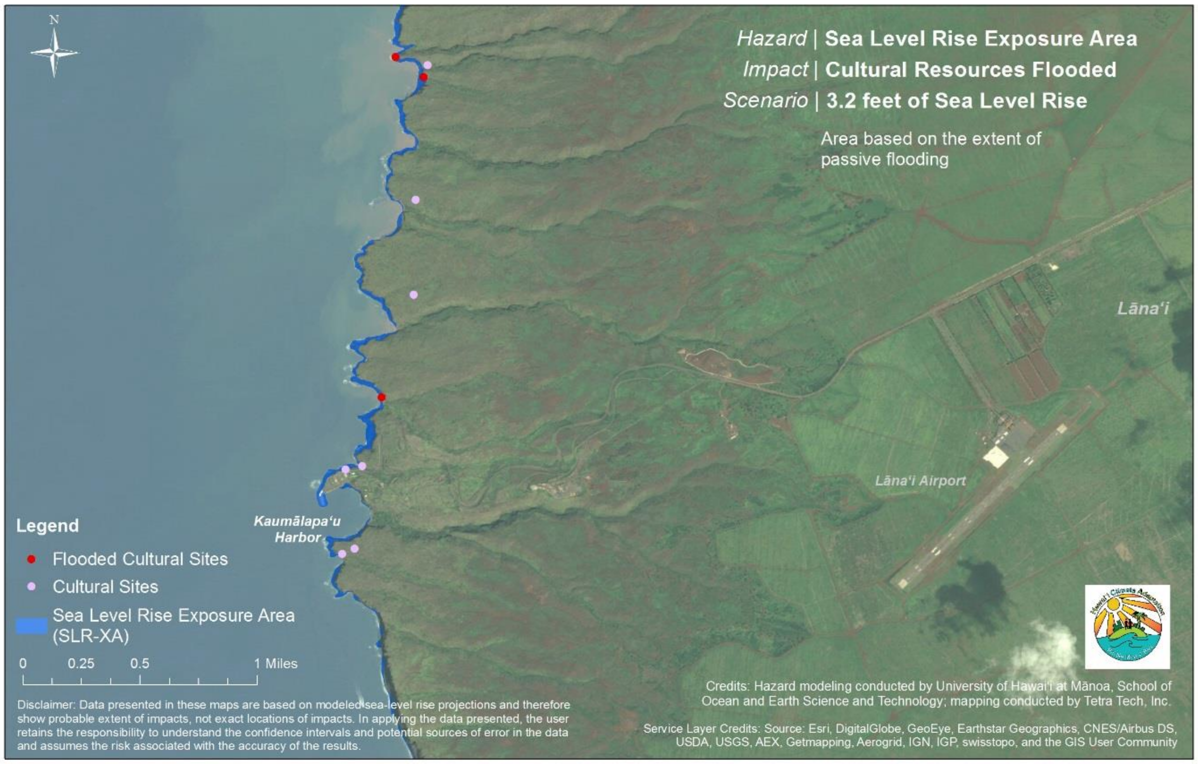


Figure 93. Cultural resource sites (light and dark pink) located in the SLR-XA (blue) with 3.2 feet of sea level rise along the western shoreline of Lāna‘i

POTENTIAL IMPACTS TO COASTAL RESOURCES AND PUBLIC ACCESS

While beaches play a critical role in recreation for residents and Hawaii’s overall economy (Cristini et al. 2013), no public beach parks (inclusive of city, state, and federal parks) on Lāna‘i are located in the SLR-XA with 3.2 feet of sea level rise. However, public beaches, such as at Hulopo‘e Bay (Figure 86), could be lost if structures or terrain stop beaches from migrating landward as the sea level rises.

Besides recreational areas, a variety of coastal habitats, vital to aquatic organisms and wildlife would become flooded with sea level rise, changing the nature of such habitats and the organisms that rely on them. Due to the island’s lack of perennial streams, Lāna‘i does not have many estuarine habitats or coastal wetland areas that could be flooded by the SLR-XA. However, future flooding may create new coastal wetlands in low-lying areas and impact existing fishponds on the island, including the Ka‘a Fishpond on the northeastern shoreline of the island (Figure 94).

Sea level rise also has the potential to impact facilities that release wastewater or hazardous materials to nearshore waters and coastal habitats. Septic tanks, cesspools and other OSDS, as well as hazardous materials storage and disposal sites could become flooded and release wastewater or contaminants to nearshore waters. While OSDS are commonly located along more rural areas of shoreline, data to assess the number of OSDS that would be flooded on Lāna‘i was not available.

RECOMMENDATION HIGHLIGHTS

- Amend the State Legacy Lands Act to set aside funding for preserving priority coastal lands and use of a variety of practices and tools to enable legacy beaches to persist.
- Develop shoreline conservation and restoration priorities and guidelines to support adaptation to sea level rise.
- Expand the area of national, state, and county parks and wildlife refuges on the main Hawaiian Islands to preserve wetlands and wildlife.
- Protect nearshore water quality by identifying hazard mitigation measures to address coastal flooding of hazardous material/waste storage facilities and OSDSs vulnerable to sea level rise.

Figure 94. Ka'a Fishpond, located on the northeastern shoreline of Lāna'i, located in the SLR-XA with 3.2 feet of sea level rise

Challenges and Opportunities

The impacts of sea level rise on the island of Lānaʻi are less severe than the impacts projected for the other islands given the island's development patterns and terrain. Even so, several structures and properties along the coast would be vulnerable to chronic and event-based flooding due to sea level rise, which could have significant impacts ranging from loss of beach access for recreational and cultural use, to interruption of interisland shipping through Lānai's two harbors.

Over the next 30 to 70 years, properties located on or near Lānai's shorelines will increasingly be flooded, eroded, or completely lost to the sea. Beaches, like Hulopoʻe, will increasingly be eroded and may be permanently lost if structures or terrain impede their landward migration. Impacts to harbors and coastal resort facilities, including potential loss of beaches, would impact the tourism economy and thus impact the people whose livelihoods depend on it.

This Results section highlights just a few of the challenges on Lānaʻi with a scenario of 3.2 feet of sea level rise by the mid- to latter-part of the century. However, sea level rise will not stop at the middle or end of the century. As highlighted throughout this Report, higher sea level rise projections are considered "physically plausible" by the end of the century based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). While this Report models sea level rise up to 3.2 feet, it should be noted that NOAA has modeled passive flooding scenarios with up to 6 feet of sea level rise in their Sea Level Rise Viewer (NOAA 2017b). To illustrate potential impacts from higher sea level scenarios, the 5-foot passive flood layer from NOAA was incorporated into the vulnerability assessment which increases the area of the SLR-XA on Lāna'i by 29%. While there is uncertainty over when the islands might experience such extreme sea level rise, the information provided illustrates the likely scenario of continued sea level rise over the next century.

With abundant land outside of the SLR-XA, Lānaʻi has opportunities to plan for sea level rise now by considering the recommendations for adaptation presented in Chapter 5 of this Report. Another threat that we will have to face in a world with climate change is increased coastal flooding from tropical storms, hurricanes, and tsunamis. The added risk from event-based coastal flooding exacerbated by sea level rise is not included in this Report. However, these events pose a potential for loss of human life and property and for severe and long-term economic disruption. Communities should consider planning new development to reduce exposure from severe events by recognizing that the coastal floodplain will migrate landward with increased sea level rise. Hazard mitigation and disaster recovery projects should be reviewed and revised to address chronic and event-based flooding and consider the additive effects of accelerating sea level rise.

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Mapunapuna, Honolulu, Oahu
Source: Dolan Eversole

Oʻahu

The Island of Oʻahu has appropriately been nicknamed the "Gathering Place" within the Hawaiian Island archipelago. It is home to the city of Honolulu, which is the State's most populous city and serves as the State's Capitol. With 998,714 residents (State of Hawai'i 2015), Oʻahu accounts for 70% of the State's population. A doubling of Oahu's population over the last 50 years coupled with a growing tourism industry—over 5.4 million visitors came to Oʻahu in 2016 (State of Hawai'i 2016)—has placed ever increasing demands on Oahu's housing market, natural resources, critical infrastructure, and basic services. Many of these resources and services are at significant risk from flooding and erosion damage from sea level rise. Thus, a major impact from sea level rise on Oʻahu can easily reverberate and translate into major economic and social impacts for the neighbor islands.

Key Take Aways

- Over the next 30 to 70 years, homes and businesses on Oahu's shorelines will be severely impacted by sea level rise. Nearly 4,000 structures would be chronically flooded with 3.2 feet of sea level rise.
- Of the 9,400 acres of land located within the SLR-XA, over half is designated for Urban land uses, making Oʻahu the most vulnerable of all the islands.

- With 3.2 feet of sea level rise, almost 18 miles of Oahu's coastal roads would become impassible, jeopardizing access to and from many communities.
- O'ahu has lost more than 5 miles of beaches to coastal erosion fronting seawalls and other shoreline armoring. Many more miles of beach could be lost with sea level rise, if widespread armoring is allowed. Chapter 5 (Recommendations) explores opportunities to reduce beach loss by improving beach protection policies.
- A more detailed economic loss analysis is needed of Oahu's critical infrastructure, including harbor facilities, airport facilities, sewage treatment plants, and roads. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.

This section provides a picture of the future of the Island of O'ahu with sea level rise and the potential impacts from chronic flooding. The results are based on modeling coastal flooding with sea level rise due to passive flooding, annual high wave flooding, and coastal erosion in the SLR-XA with up to 3.2 feet of sea level rise, and depicts flood hazards that may occur in the mid- to latter-half of this century. This timeframe is within the expected lifespan of most new construction and much of our existing development. It should be noted that sea level rise projections greater than 3.2 feet are "physically plausible" by the end of the century, based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). Vulnerability to 1.1 feet of sea level rise in the SLR-XA is used to approximate current or near-term exposure to coastal hazards and sea level rise. Vulnerability is assessed in terms of potential impacts to land use, people, property, cultural and natural resources, and critical infrastructure (only land and structures are monetized, not infrastructure).

The reader is urged to exercise caution in interpreting the results, which could be to a greater or lesser extent depending on actual observed future sea level rise, technological innovations in climate change mitigation and adaptation, unknown economic variables, as well as future societal choices which cannot be known today. Further, the reader should visit the Hawai'i Sea Level Rise Viewer to explore the full extent of the vulnerability maps for each island.

Potential Impacts in the Sea Level Rise Exposure Area

The SLR-XA depicts the area of potential chronic flooding from exposure to passive flooding with sea level rise. For the purposes of exposure and planning, we focus mainly on a scenario with 3.2 feet of sea level rise.

With 3.2 feet of sea level rise, low-lying coastal areas around the island within the SLR-XA may become chronically flooded within the mid- to latter-half of this century (Figure 95). This land will become submerged as a result of coastal erosion, coastal flooding from tides and waves, or become new wetlands behind the shoreline from rising water tables and reduced drainage. More than half of Oahu's 9,400 acres in the SLR-XA with 3.2 feet of sea level rise are Urban designated lands. Some examples of areas that will be exposed to chronic flooding include Campbell Industrial Park, Pearl Harbor, Kahuku, and Waimānalo, as shown in Figure 96. Portions of Campbell Industrial Park and Pearl Harbor, two of the largest job centers in Hawaiʻi, would be permanently flooded with 3.2 feet of sea level rise. New and expanded wetland areas would form around Kahuku potentially improving wildlife habitat. As Waimānalo Beach erodes and retreats with rising seas, properties along the shoreline would become increasingly vulnerable to flooding and erosion. If we continue to follow past practices of allowing shoreline armoring, portions of Waimānalo Beach will erode away. In the Māpunapuna area, existing communities and businesses are already experiencing recurring flooding during the highest tides because of rising seas. Difficult decisions will have to be made to either abandon such areas or invest in expensive multi-decadal mitigation projects to dewater or raise the ground above the rising water.

Over time, as sea level continues to rise, low-lying, populated coastal communities such as Waialua would experience increased frequency and severity of flooding ultimately leading to permanent inundation and making some areas of the coast impassable or uninhabitable (Figure 97). Decisions about where to use coastal armoring and when to retreat will need to be made carefully. It should be noted that seawalls may not be effective at preventing flooding with sea level rise in many low-lying areas as rising groundwater can infiltrate through porous geology. While specific responses to sea level rise would need to be place-based, larger regional issues should also be considered, such as whether to armor in place or whether to relocate roads and other critical infrastructure inland. A good example of this is where Kamehameha Highway passes through an area known as Laniākea on the North Shore. The road is overtopped by waves in the winter months and the beach in front of the highway has nearly vanished. The Department of Transportation (DOT) Highways Division is considering options including armoring and raising the road or relocating the road inland.

In the case of Waialua, opportunities for managed retreat inland exist, as there are ample vacant lands immediately mauka (landward) and outside of the SLR-XA. However, as discussed in the Recommendations chapter of this Report, and as with other populated coastal areas with adjacent vacant lands, large-scale boundary amendments should be predicated on appropriate state policies and guidelines (e.g., within Chapter 205, State Land Use Act) to provide the supportive legal basis for major land use changes.

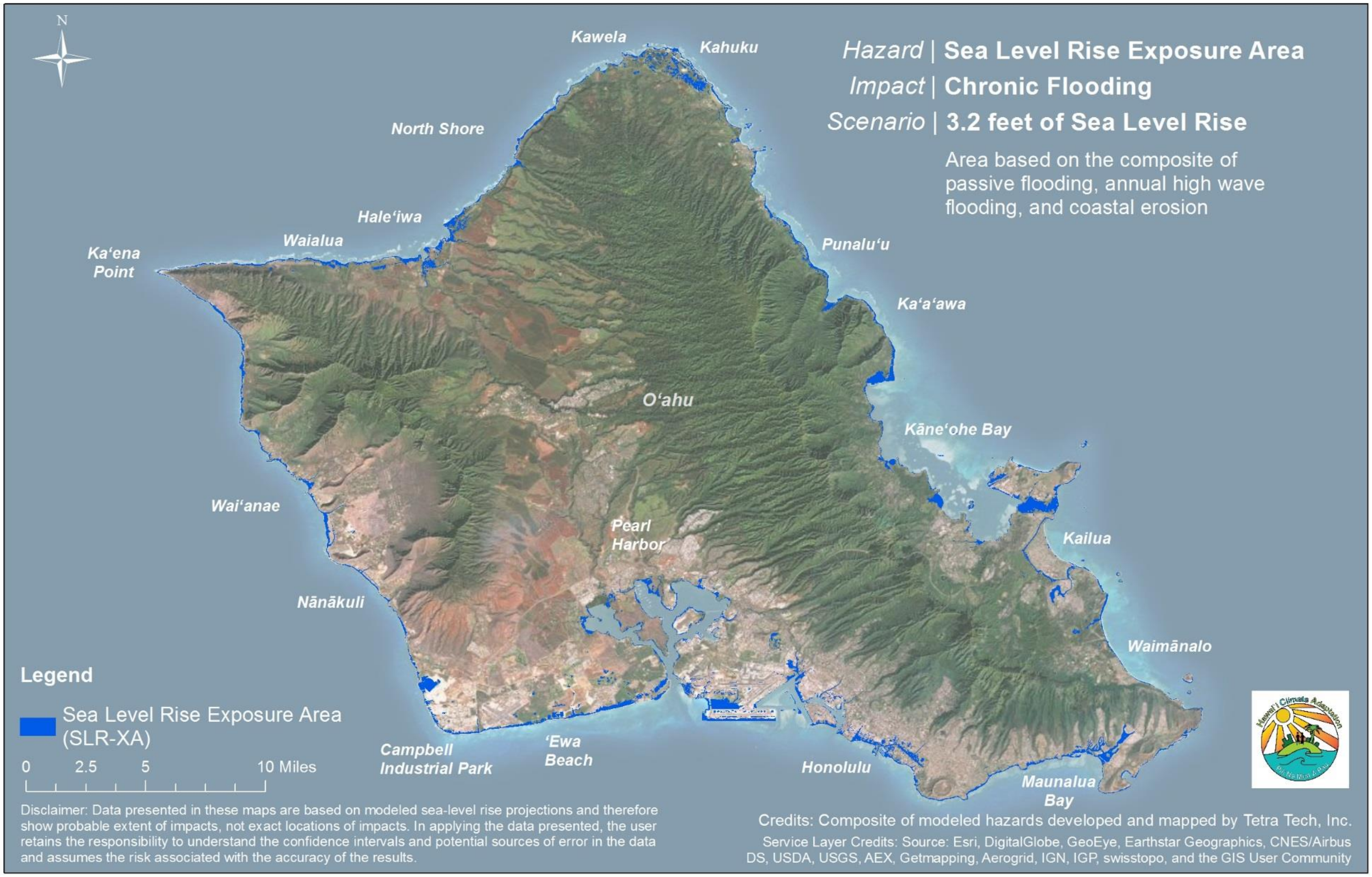


Figure 95. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise for O'ahu

Figure 96. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise in four areas on O'ahu

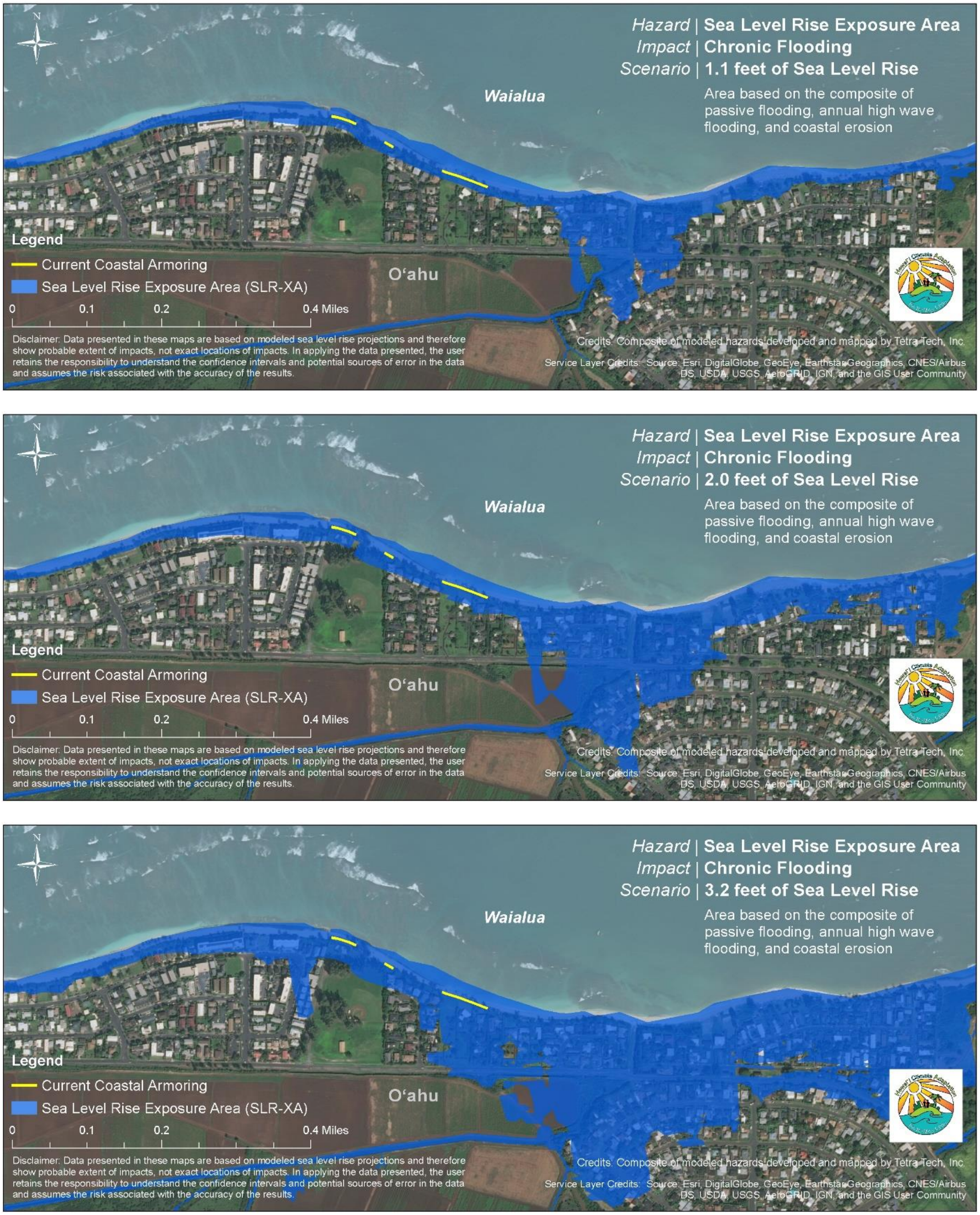


Figure 97. Potential chronic flooding in the SLR-XA with 1.1, 2.0, and 3.2 feet of sea level rise in Waialua, O'ahu

POTENTIAL IMPACTS TO LAND USE

Oahu's total land area, 386,188 acres, is 85% smaller than the land area of the Island of Hawai'i, the biggest island in the archipelago. Currently, almost one third of Oahu's land area is located in the State Land Use Urban District (State of Hawai'i 2015). Over the last 50 years, an estimated 26,000 acres of agricultural land, almost 7% of the total land area, has been converted to urban land to address the growing demand for housing. As sea level rises, and more land area becomes chronically flooded, there will be increasing pressure to convert Agricultural and Conservation District lands to Urban District land.

Sea level rise would result in impacts within the State Urban, Agricultural, and Conservation Land Use Districts around the island. However, Urban District lands would experience the greatest extent of chronic flooding (Figure 98) as almost 60% of the 9,400 acres located within the SLR-XA are designated for Urban use. Due to the density and extent of vulnerable lands within the SLR-XA, leaders should not rule out the potential benefits of a managed retreat approach for communities or business districts already affected by sea level rise.

While the State Land Use Law (Hawai'i Revised Statutes Chapter 205) could be used to address major land use changes as part of a managed retreat strategy, County General Plan and Community Plan updates provide important opportunities to address land use issues with rising seas at the local level. Revised and updated SMA policies, objectives, and requirements offer additional opportunities at the local level to prepare for sea level rise. Moreover, if the City & County of Honolulu chooses to recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone (one of the recommendations in Chapter 5), it might be prudent to consider adjusting SMA boundaries to coincide with the SLR-XA so that new subdivisions, commercial areas, hotels, and other development activities could undergo a higher level of review in light of sea level rise constraints. Figure 99 illustrates the partial overlap of SMA boundaries with the SLR-XA along portions of Pōka'i Bay.

Additional controls on development along the coast may be necessary to protect Native Hawaiian traditional and customary practices; iwi kūpuna (ancestral bones); archaeological, heritage, and cultural resources; to ensure public access; and to mitigate the impacts of coastal hazards.

RECOMMENDATION HIGHLIGHTS

- Recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone in the County General Plan and Community Plan updates.
- Strive to balance managed retreat strategies from vulnerable urban areas with preservation of agriculture and conservation lands.
- Seek opportunities to plan new development outside of the SLR-XA, wherever possible, under a long-term comprehensive adaptation strategy.

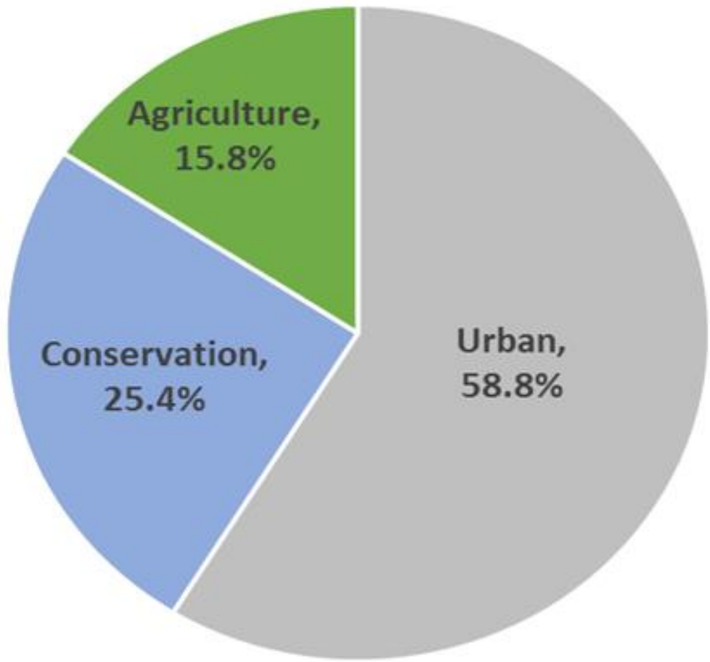


Figure 98. Estimated percentage of Land Use Districts impacted in the 3.2 feet sea level rise exposure area on O‘ahu

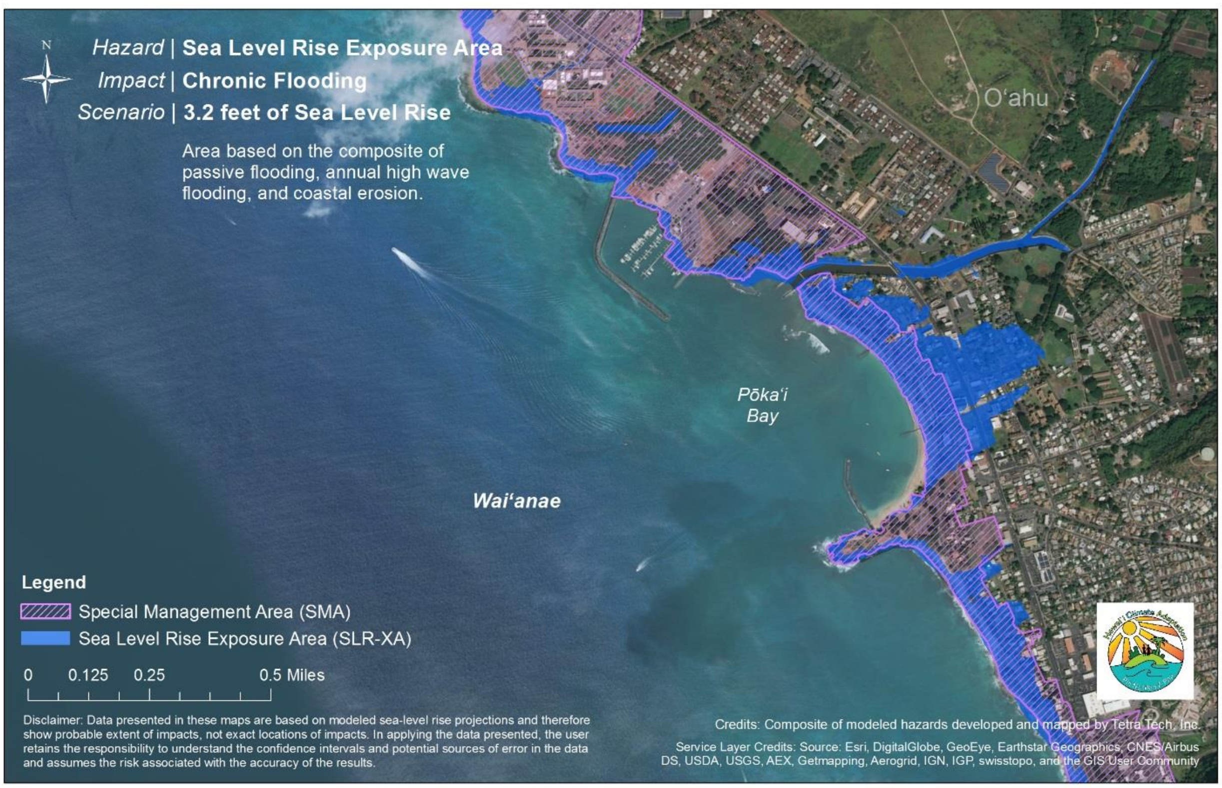


Figure 99. Portions of the SLR-XA (blue) around Pōka‘i Bay extending beyond the Special Management Area (SMA) boundary (pink hatched area) that would not be subject to SMA permitting requirements

POTENTIAL IMPACTS TO PEOPLE AND PROPERTY

People living and working within the SLR-XA would be displaced when homes, condominiums, and businesses become flooded due to sea level rise. The potential number of people displaced is calculated by assigning an estimated occupancy for each type of structure in the SLR-XA. Potential economic loss in the SLR-XA is estimated based on the value of land and structures flooded. Loss estimates are assessed at the parcel level and aggregated into 1-hectare grids. The potential economic loss associated with flooded roads, water/wastewater facilities, and other critical infrastructure is not accounted for in the assessment of economic impacts and would add significant increases in losses.

The potential number of displaced people island-wide could rise from 2,000 residents with 1.1 feet of sea level rise, to over 13,000 residents with 3.2 feet of sea level rise (Figure 100). The people displaced would include a range of income levels and living arrangements. In addition, approximately 46% of the occupied housing units on O‘ahu are occupied by renters (U.S. Census Bureau 2015b), so both homeowners and renters would be affected.

Potential economic losses (all structures and land) island-wide would increase from an estimated $4.1 billion with 1.1 feet of sea level rise, to $12.9 billion with 3.2 feet of sea level rise (Figure 100). Approximately 72% of the potential economic loss with 3.2 feet of sea level rise is attributed to the loss of residential structures and land. The potential economic loss across all sectors is associated with approximately 3,800 structures and approximately 9,400 acres of land in the SLR-XA with 3.2 feet of sea level rise. A number of the potentially flooded structures are hotels located in in Waikīkī, which is considered an important visitor destination area on the south shore of O‘ahu (Figure 101). Private and public entities in Waikīkī and parts of Honolulu should begin to factor in long-term preparedness for sea level rise adaptation including dealing with basement flooding, beach restoration at Waikīkī Beach, and even consideration of how best to prepare for higher sea levels in the future.

With 3.2 feet of sea level rise, potential economic loss would occur in low-lying coastal areas island-wide, with the greatest loss along the south shore due to the concentration of high-value residential and commercial land and structures (Figure 102). Over time, as the sea level continues to rise, communities on the west side of the island, such as ‘Ewa Beach (Figure 103), would also experience increasing potential economic loss.

RECOMMENDATION HIGHLIGHTS

- Require mandatory disclosure for vulnerable properties and consider acquisition to protect valuable coastal resources.
- Seek opportunities to plan new development well landward of the SLR-XA with 3.2 feet of sea level rise under a long-term, comprehensive strategy.
- Develop design standards to increase flood resiliency for existing and new development within the SLR-XA that cannot be relocated.
- Develop a multi-pronged financing strategy at federal, state, county, private sector, and philanthropic levels to address costs of adaptation to sea level rise.

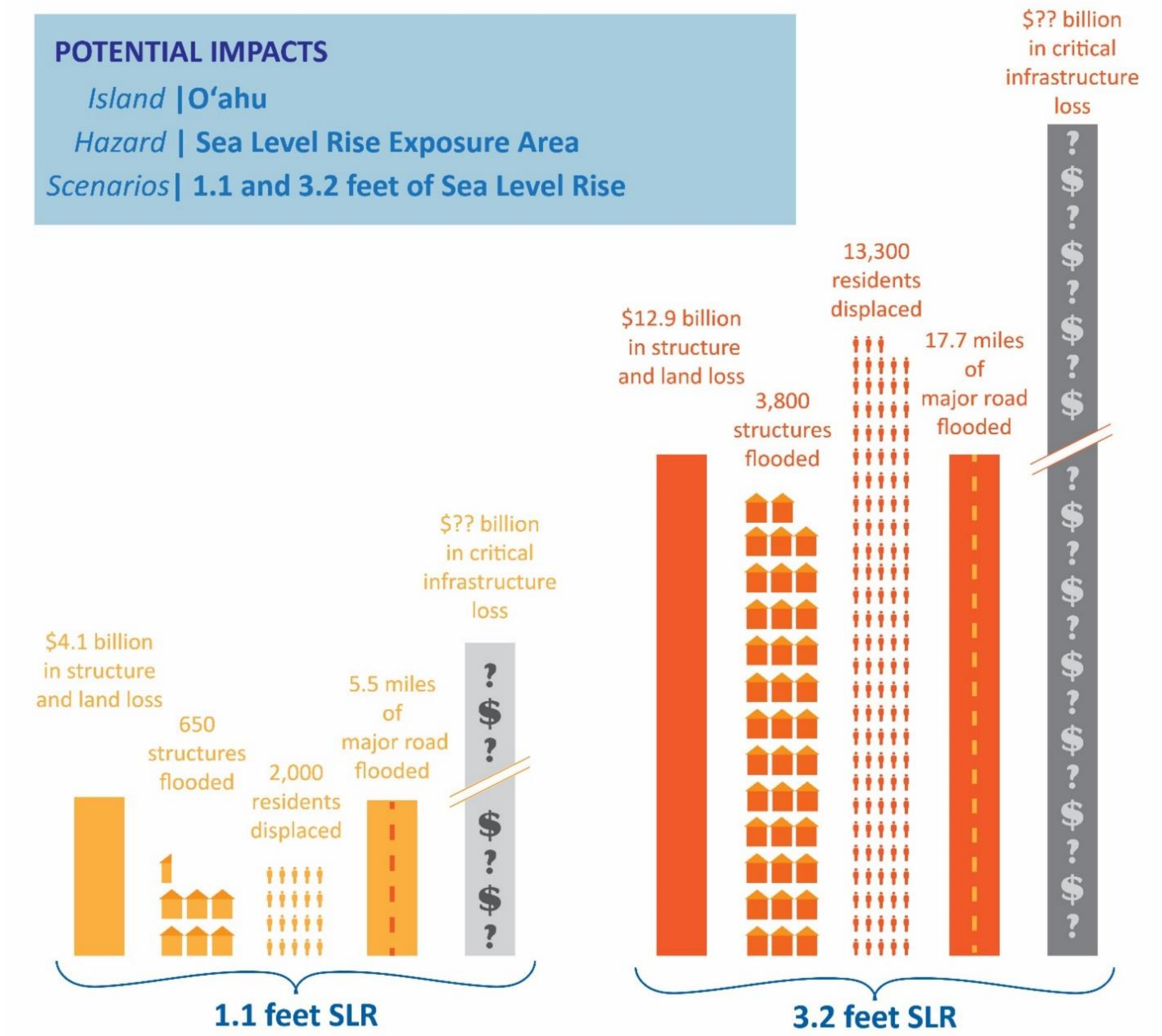
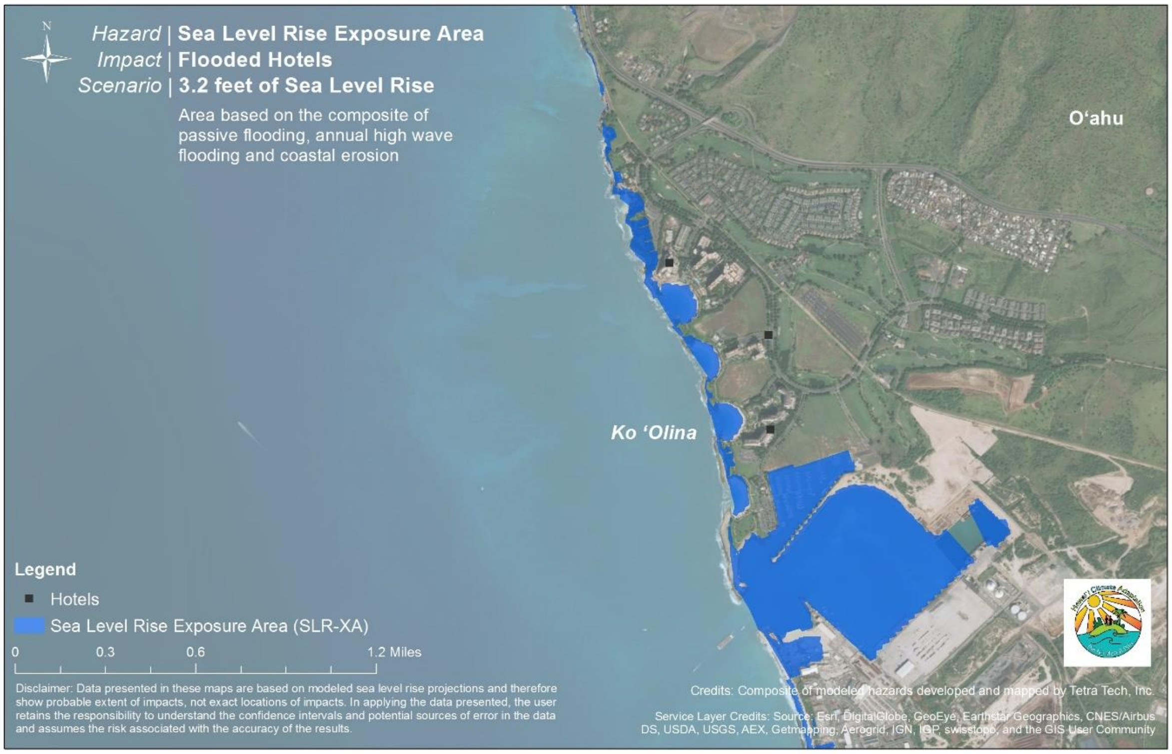


Figure 100. Summary of potential impacts in the SLR-XA with 1.1 feet and 3.2 feet of sea level rise on Oʻahu



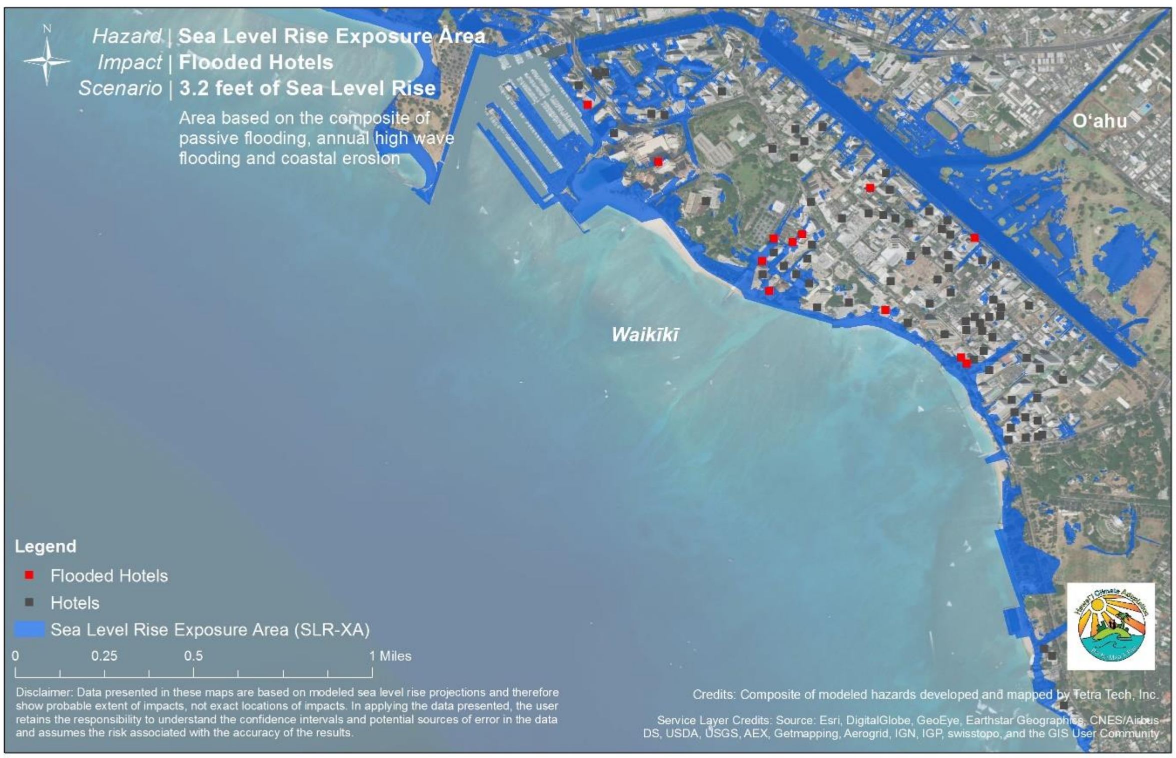


Figure 101. Hotels that may experience chronic flooding or are located outside of the SLR-XA with 3.2 feet of sea level rise in Ko 'Olina (top) and Waikīkī (bottom) on O'ahu

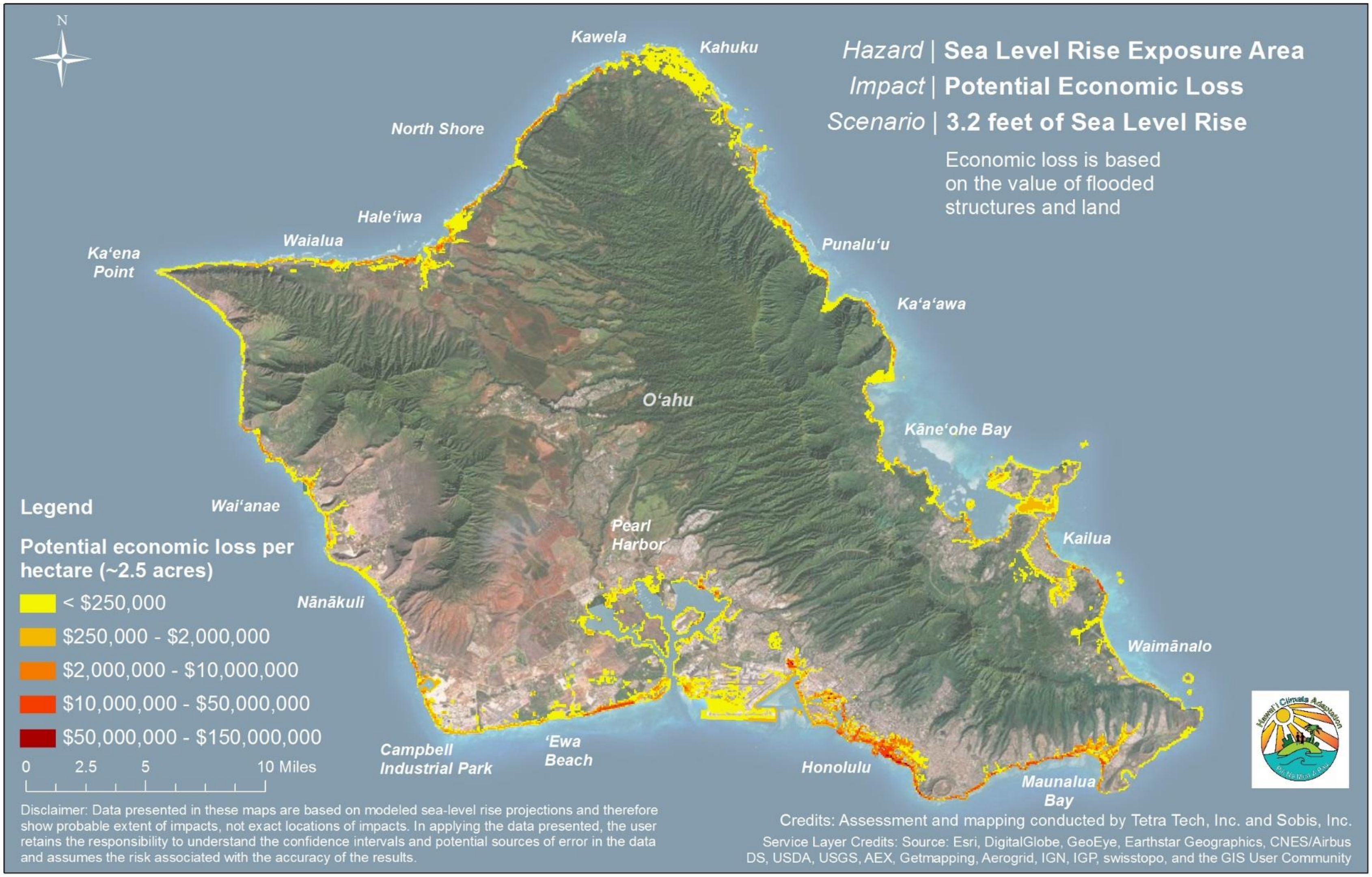
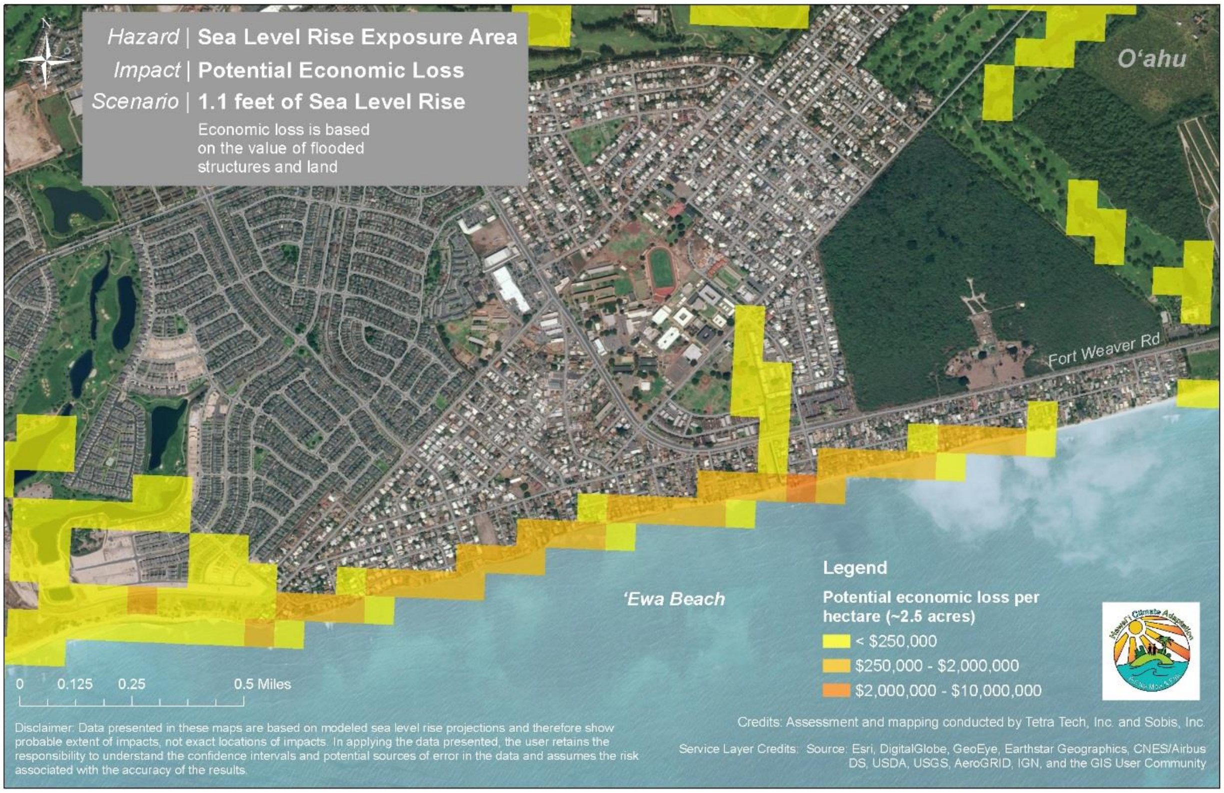


Figure 102. Potential economic loss in the SLR-XA with 3.2 feet of sea level rise on O'ahu



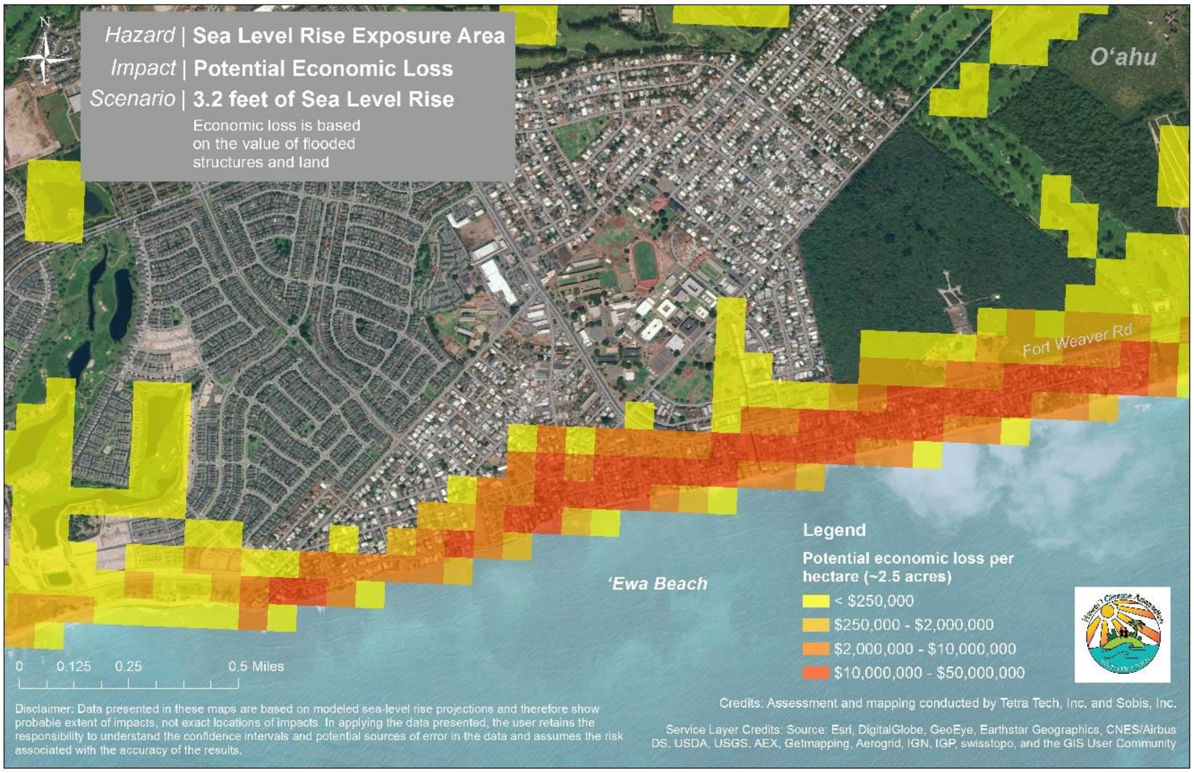


Figure 103. Potential economic loss in the SLR-XA with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise in 'Ewa Beach, O'ahu

POTENTIAL IMPACTS TO CRITICAL INFRASTRUCTURE

Sea level rise would result in significant impacts to roads, airports, harbors, electrical and telecommunications infrastructure, water/wastewater facilities and conveyance systems, and other public service facilities (i.e. schools, fire stations, police stations, medical facilities) on Oʻahu. Following the trends of private development, Oahu's critical public infrastructure is concentrated along low-lying shores and is highly vulnerable to flooding and erosion in the SLR-XA. An estimated 5.5 miles of major roads would be flooded in the SLR-XA with 1.1 feet of sea level rise, increasing to over 17 miles with 3.2 feet of sea level rise (Figure 100). Portions of many coastal roads, such as Kamehameha Highway in the vicinity of the community of Kaʻaʻawa, would become chronically flooded and eroded away (Figure 104). Kamehameha Highway, in the vicinity of Kaʻaʻawa, is already one of the most vulnerable coastal highways in Hawaiʻi. It is ironic that Hawaiians referred to this area as He kai ʻaʻai ko Kaʻaʻawa, a sea that wears away the land. Wide-spread damage of coastal highways would result in the loss of commerce, loss of access to emergency services, and increased traffic on other roads and highways, some of which serve as the only access in and out of many communities. Electric and telecommunication transmission lines commonly follow roads and those located underground in the SLR-XA may be impacted by sea level rise resulting in service disruptions.

The primary transportation arteries for the entry of people and goods to the State, the Daniel K. Inouye International Airport and Honolulu Harbor, would become increasingly exposed to chronic flooding from sea level rise (Figure 105). The Honolulu International Airport, the busiest airport in the state, serves more than 19 million passengers a year and receives more than 228,000 tons of cargo (based on the amount of incoming cargo in 2014) (State of Hawai'i 2015). More than 14.6 million tons of commodities pass through Honolulu Harbor annually (based on cargo that passed through the harbor in 2014) and more than 400,000 cruise ship passengers sailed into or out of the harbor in 2015 (State of Hawai'i 2015). Interruption of interisland and transoceanic shipping and travel would impact residents, visitors, and all forms of economic activity.

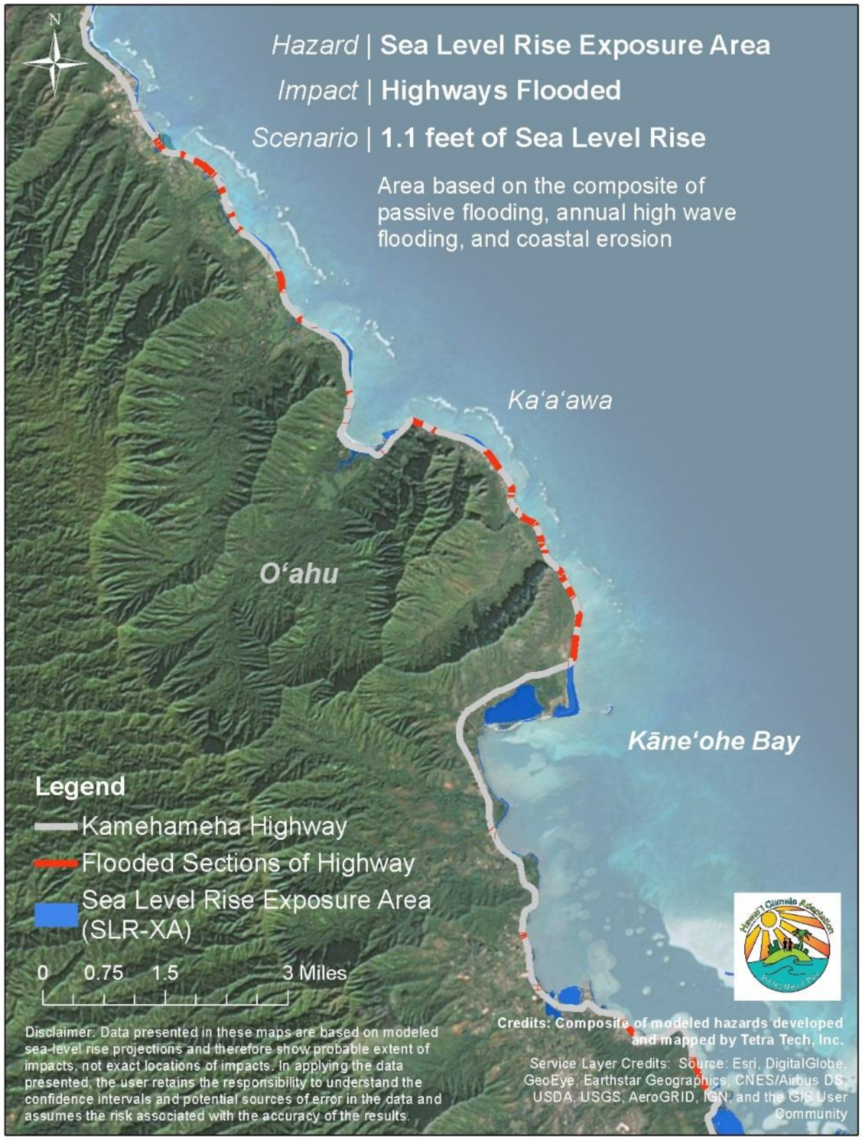
While no wastewater treatment facilities on Oʻahu are located within the SLR-XA with 3.2 feet of sea level rise, sea level rise may impact wastewater stabilization ponds immediately surrounding the Sand Island and Kahuku Wastewater Treatment Plants. Flooding of these ponds would have the potential of releasing wastewater into nearshore waters. There are also no hospitals located with the SLR-XA. However, the Hauʻula fire station, the Waikīkī Police Substation, and the Straub Hawaiʻi Kai Family Health Center, along with nine schools, are located in the SLR-XA with 3.2 feet of sea level rise.

More detailed analyses of vulnerability and adaptation options for critical infrastructure are needed to evaluate adaptation options such as retrofitting or relocation. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., flood proofing and relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years. Please keep in mind that infrastructure losses have not been monetized. However, it should be noted that these costs could be an order of magnitude greater than the potential economic losses estimated from land and structures.

RECOMMENDATION HIGHLIGHTS

- Conduct in-depth vulnerability assessments and evaluation of adaptation strategies for existing critical infrastructure throughout the County.
- Consider long-term cost savings from implementing sea level rise adaption measures now (e.g., major flood proofing or relocation) compared to the cost of maintaining and repairing chronically threatened public infrastructure over the next 30 to 70 years.
- Require that the design and siting of new development and capital improvement projects include an in-depth analysis of sea level rise impacts based on elevation, tolerance for risk, and lifetime of the structure.

Kamehameha Highway, Ka'a'awa, O'ahu
Source: DLNR



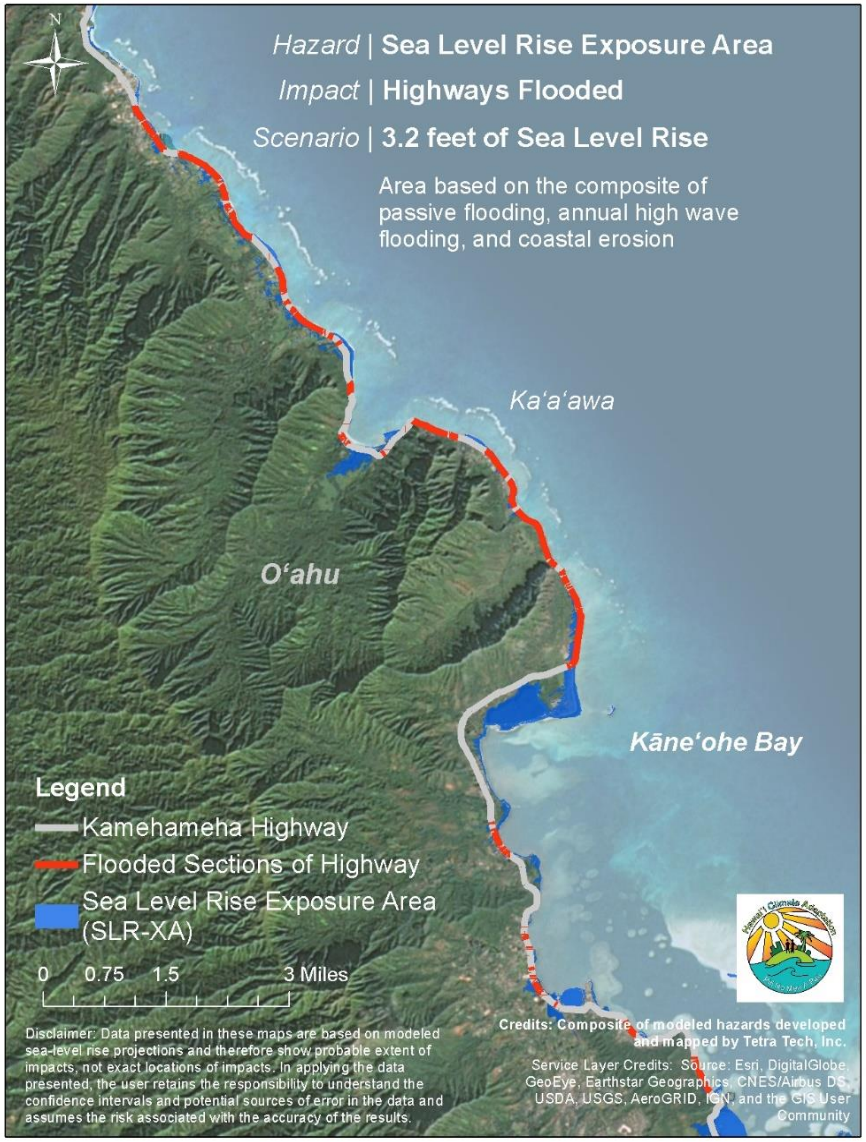


Figure 104. Sections of Kamehameha Highway in the SLR-XA (red) with 1.1 feet (left) and 3.2 feet (right) of sea level rise in Ka'a'awa, O'ahu

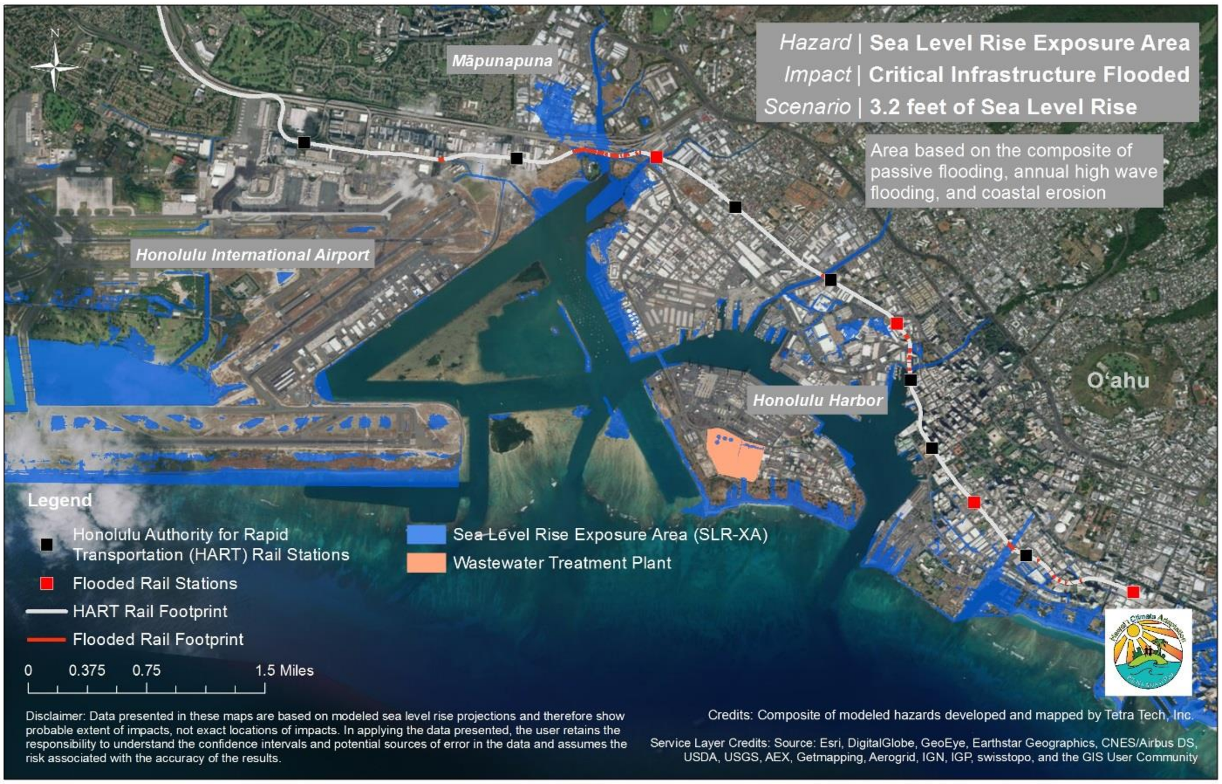


Figure 105. Key transportation facilities and routes in the SLR-XA with 3.2 feet of sea level rise on O‘ahu

POTENTIAL IMPACTS TO NATIVE HAWAIIAN COMMUNITIES AND CULTURAL RESOURCES

Hawaiian Home Lands are intended to provide for the economic self-sufficiency of Native Hawaiians through a homesteading program (University of Hawai‘i 2015). Consistent with Native Hawaiian culture, Hawaiian Home Lands include areas from mauka to makai (from the mountain to the sea). Coastal portions of Hawaiian Home Lands, such as in Nānākuli (Figure 106), would be flooded with sea level rise displacing Native Hawaiian families that live in this area. In addition, fishing and cultural practices taking place along the shore would be impacted as beaches erode. In a recent study of multiple coastal hazards, three of the six Hawaiian Home Lands on O‘ahu—Nānākuli, Princess Kahanu Estates, and Waimānalo—are estimated to have the greatest potential for people to be displaced by tsunamis, waves, and sea level rise (University of Hawai‘i 2015).

In addition to Native Hawaiian communities, many Native Hawaiian cultural and historical resources are located near the shoreline and are threatened by sea level rise. Coastal erosion already threatens areas that have served as burial grounds, home sites, fishponds, and other places of cultural significance (Kane et al. 2012). The number of cultural sites on O‘ahu in the SLR-XA is projected to increase from 105 sites with 1.1 feet of sea level rise, to 189 with 3.2 feet of sea level rise. This includes the Pahipahi‘ālua burial and a portion of the Kawela Bay Subsurface Cultural Deposit, which may be flooded as a result of sea level rise (Figure 107). Flooding caused by rising seas would also impact loko i‘a (ancient Hawaiian fishponds) such as the He‘eia Fishpond.

RECOMMENDATION HIGHLIGHTS

- Develop an inventory of Native Hawaiian cultural resources and practices and their locations that may be impacted by sea level rise.
- Work with Native Hawaiian communities to determine steps they want to take regarding climate impacts.
- Develop adaption plans to preserve access to coastal land and water within Native Hawaiian communities.

Figure 106. Potential chronic flooding of the Nānākuli Hawaiian Home Lands on O'ahu (pink) in the SLR-XA (blue) with 3.2 feet of sea level rise

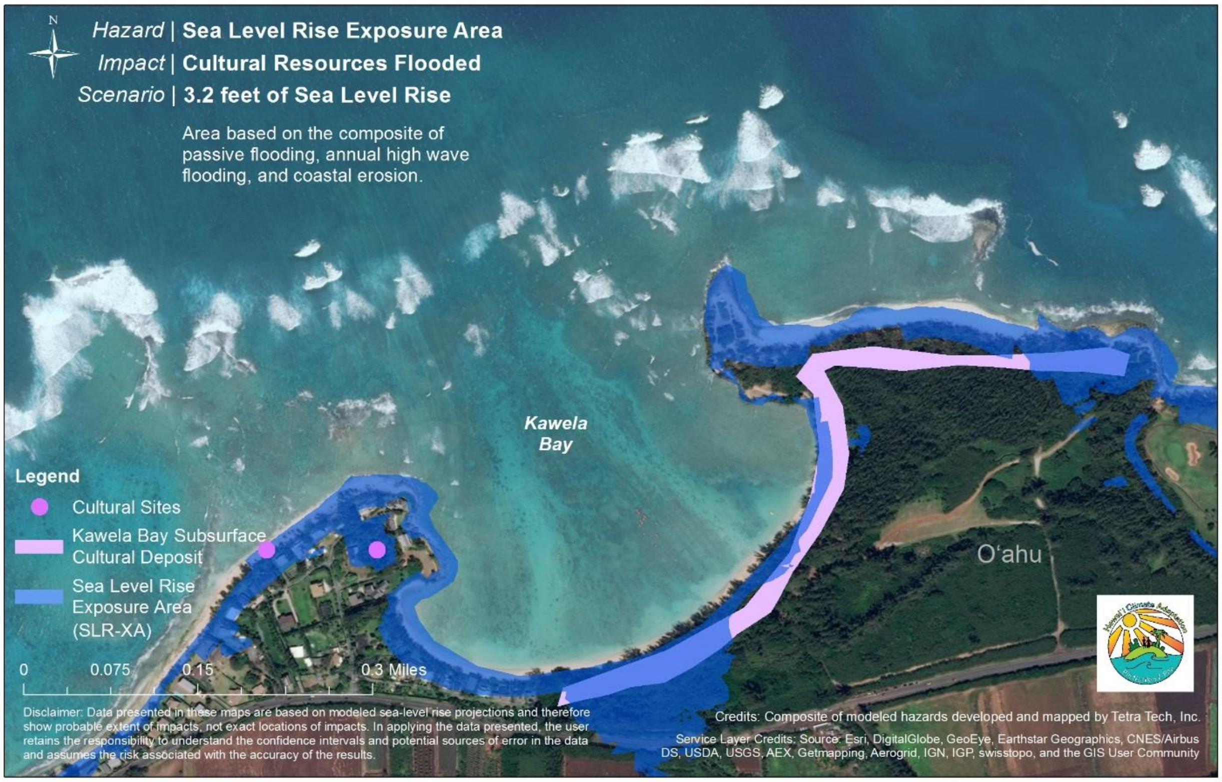


Figure 107. Cultural resource sites (light and dark pink) located in the SLR-XA (blue) with 3.2 feet of sea level rise along the shoreline of Kawela Bay, O‘ahu

POTENTIAL IMPACTS TO COASTAL RESOURCES AND PUBLIC ACCESS

Oahu’s beaches play a critical role in recreation for our residents and Hawaii’s overall economy (Cristini et al. 2013). Oahu’s beaches are estimated to provide recreational services valued at roughly $700 million per year, of which $32 million comes from Hanauma Bay (Penn et al. 2016). Waikīkī Beach is estimated to be worth over $2 billion in annual visitor expenditures (Hospitality Advisors LLC 2008).

Approximately 1,200 acres of public beaches and parks (inclusive of city, state and federal parks) on O‘ahu are located within the SLR-XA with 3.2 feet of sea level rise. Many of these parks, such as Mā‘ili Beach Park in Wai‘anae (Figure 108) are located on the seaward side of major roads, and demonstrate how lightly-developed parkland can provide a buffer between eroding shorelines and development for many decades. However, sea level rise will lead to extensive beach loss if widespread shoreline hardening is permitted and beach systems are not allowed to migrate landward. Most beaches on O‘ahu are backed by deposits of older beach and dune sand (Sherrod et al. 2007) which are crucial sources of sediment along eroding coasts. In a natural state, a beach can be maintained as it migrates landward if there is sufficient sand available in the backshore to nourish the beach as it erodes. Shoreline hardening locks up this backshore sediment source leading to beach narrowing and loss on chronically eroding beaches.

A study of historical shoreline changes in Hawaiʻi by the U.S. Geological Survey and the University of Hawaiʻi (Fletcher et al. 2012) found that 60% of Oʻahu beaches are chronically eroding. Over the past century, shoreline hardening was the typical response when beachfront property was threatened by erosion or flooding. As a result, approximately 20 miles of Oʻahu beaches are backed by seawalls and other shoreline hardening structures. Over 5 miles of beach fronting those structures has already been completely eroded away with waves now breaking directly against the structures.

Looking at the future, sea level rise presents a serious threat to Oʻahu beach environments and public shoreline access. At present, 15 miles of beach remains with shoreline hardening on the backshore (20 miles minus the 5 miles of beach already lost). These 15 miles of beaches have a very high risk of being eroded away in coming decades under increasing rates of chronic erosion with sea level rise. With 1.1 feet of sea level rise, an additional 7 miles of unprotected beachfront development will be exposed to erosion and flooding (i.e., within the SLR-XA). These 7 miles include 5 miles of homes and buildings and 2 miles of coastal highway. With 3.2 feet of sea level rise, 20 miles of unprotected beachfront development will be exposed to erosion and flooding. These 20 miles include 13 miles of homes and buildings and 7 miles of coastal highway. Beaches fronting these areas of exposed development face a high risk of loss if widespread shoreline hardening is allowed rather than allowing beaches to migrate landward with sea level rise.

As described in the Methods section, this analysis considers a scenario where widespread armoring is permitted and does not consider other adaptation scenarios such as managed retreat from impacted areas or beach nourishment, which would help to extend the life of beaches. This analysis also does not account for effects of accelerated erosion that typically occurs fronting and adjacent to coastal armoring, leading to more widespread impacts. More research is needed to improve the understanding and projections of localized vulnerability of beach and environments to the combined impacts of encroaching beachfront development and erosion and flooding with sea level rise.

Besides recreational areas, a variety of coastal habitats vital to aquatic organisms and wildlife would become flooded with sea level rise, changing the nature of such habitats and the organisms that rely on them. Estuarine habitats, where freshwater from rivers and streams and saltwater from the sea meet and mix, would become increasingly marine with rising seas. This dynamic would impact areas such as Nuʻupia Ponds, an estuarine wetland between Kāneʻohe and Kailua Bays (Figure 109). Hawaiian anchialine pools, land-locked bodies of water of varying salinity that are adjacent to the ocean (The Nature Conservancy 2012), are occupied by small endemic red shrimp (*Halocaridina* and others) called ʻōpaeʻula and the endangered shrimp, *Procaris hawaiana* (Fish and Wildlife Service 2016). These pools have indirect, underground connections to the sea, and show tidal fluctuations in water level. Other species, restricted to the surface waters of the pools, include a few fish species, crustaceans and other invertebrates. Two endangered waterbirds (Hawaiian Stilt and Hawaiian Coot), and several species of migratory waterfowl also use these pools (The Nature Conservancy 2012).

Sea level rise also has the potential to impact facilities that release wastewater or hazardous materials to nearshore waters and coastal habitats. Septic tanks, cesspools and other OSDS, hazardous materials storage and disposal sites, and Superfund sites (sites deemed by the EPA [U.S. Environmental Protection Agency] to be contaminated with hazardous waste) could become flooded and release wastewater or contaminants to nearshore waters.

OSDS are located along many shoreline areas around O'ahu, in both urban and rural areas such as along the North Shore's iconic Sunset Beach (Figure 110). There are approximately 1,330 OSDS within the SLR-XA with 3.2 feet of sea level rise island-wide. A recent study of OSDSs in Honolulu revealed the potential for direct and widespread seepage of untreated sewage directly into coastal groundwater from the inundation of OSDSs by groundwater with sea level rise (Habel et al. 2017). Further, this study indicated that 86% of the OSDSs in the study area were non-compliant with construction standards.

On O'ahu, there are three Superfund sites. Only one of the Superfund sites, the Pearl Harbor Naval Complex, is within the SLR-XA with 3.2 feet of sea level rise. The site's listing indicates it is in an active military facility whose associated activities have contaminated soil, sediment, and groundwater with metals, organic compounds, and petroleum hydrocarbons. The reader should visit the online Hawai'i Sea Level Rise Viewer to determine if any infrastructure of interest is located in the SLR-XA.

RECOMMENDATION HIGHLIGHTS

- Amend the State Legacy Lands Act to set aside funding for preserving priority coastal lands and use of a variety of practices and tools to enable legacy beaches to persist.
- Develop shoreline conservation and restoration priorities and guidelines to support adaptation to sea level rise.
- Expand the area of national, state, and county parks and wildlife refuges on the main Hawaiian Islands to preserve wetlands and wildlife.
- Protect nearshore water quality by identifying hazard mitigation measures to address coastal flooding of hazardous material/waste storage facilities and OSDSs vulnerable to sea level rise.

Figure 108. Potential chronic flooding of Mā'ili Beach Park in the SLR-XA with 3.2 feet of sea level rise along the Wai'anae Coast, O'ahu

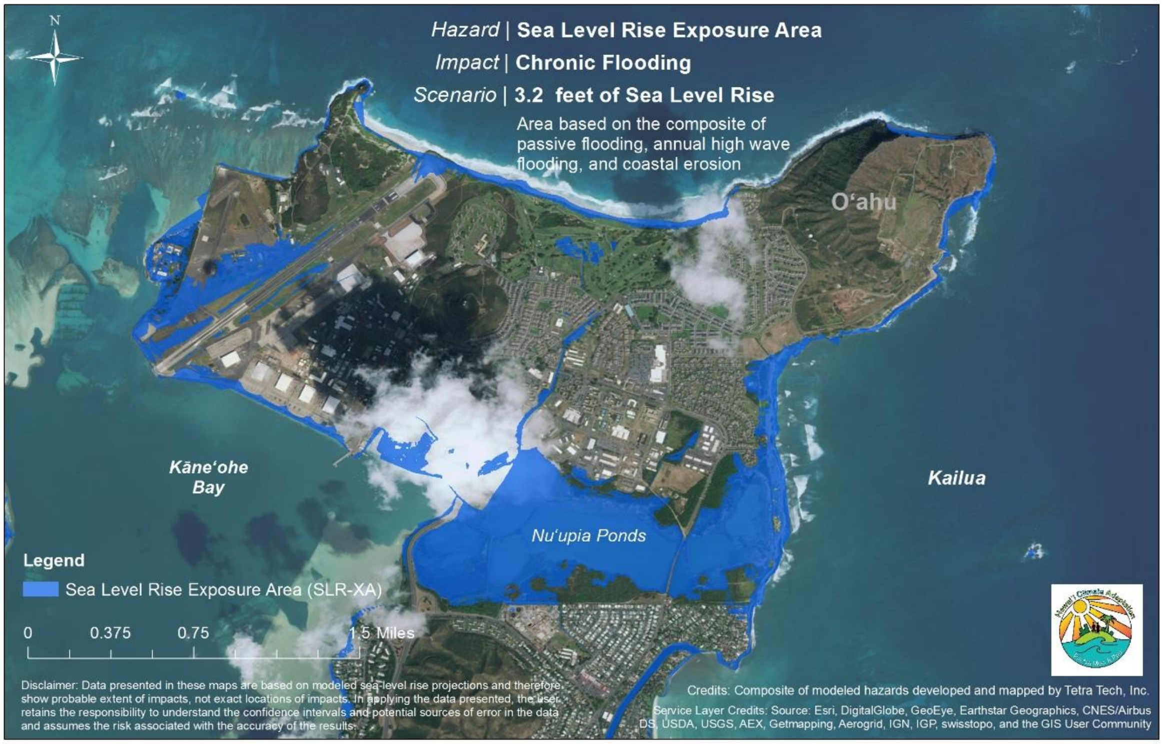


Figure 109. Nu'upia Ponds Wildlife Management Area in the SLR-XA with 3.2 feet of sea level rise on Kaneohe Marine Corps Airbase, O'ahu

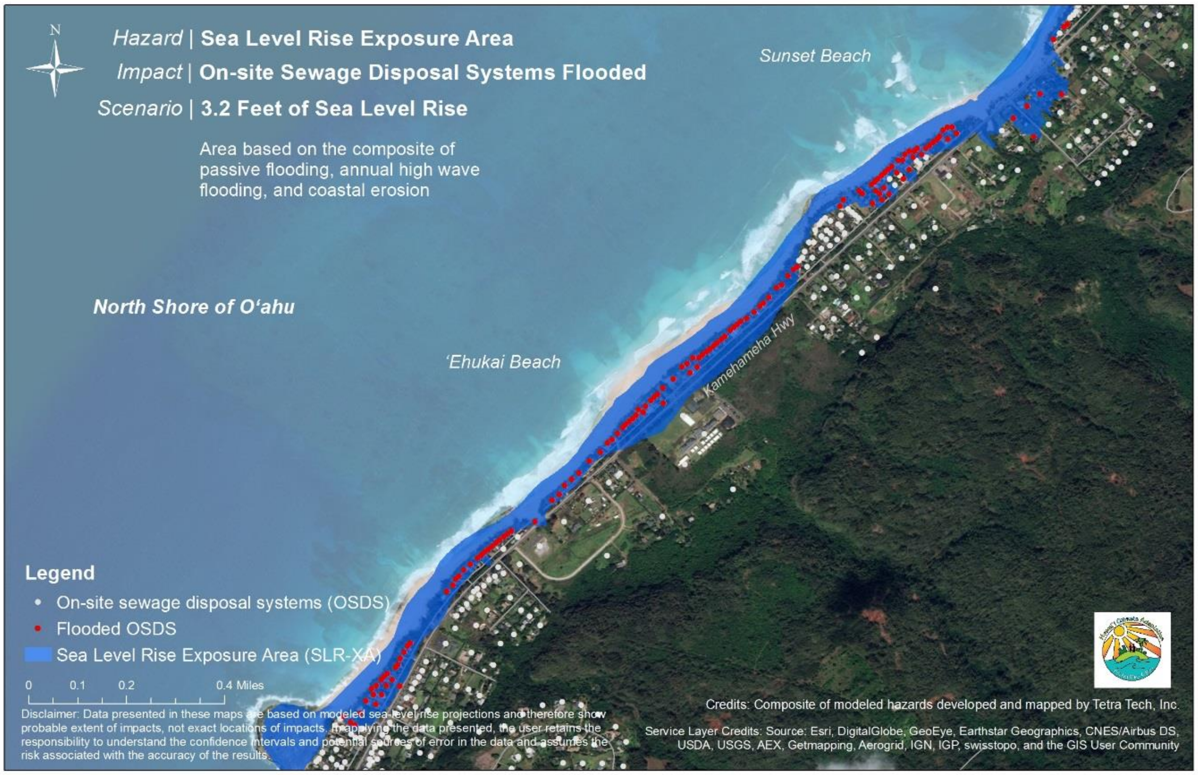


Figure 110. On-site sewage disposal systems flooded in the SLR-XA with 3.2 feet of sea level rise along the North Shore of O‘ahu

Challenges and Opportunities

The impact of sea level rise on O‘ahu alone is greater than all of the other islands combined due to the size of the population, and the extensive urbanization of vulnerable coastal areas. Even more troubling is the fact that impacts from chronic flooding with sea level rise on O‘ahu can easily reverberate and translate into major economic and social impacts for the other islands.

Over the next 30 to 70 years, properties located on or near Oahu’s shorelines will increasingly be flooded, eroded, or completely lost to the sea. Portions of coastal roads will also become flooded, eroded, and even impassible or irreparable jeopardizing access to and from many communities. Beaches, like the Seven Mile Miracle on the North Shore will increasingly be eroded and permanently lost if hard structures such as roads and seawalls impede their landward migration. The flooding impacts to hotels and transportation systems, along with the loss of beaches, would impact the tourism economy and thus impact not only the people whose livelihoods depend on it, but the State’s economy which relies heavily on revenues from the tourism industry.

This Results section highlights just a few of the very real challenges on O‘ahu with a scenario of 3.2 feet of sea level rise by the mid- to latter-part of the century. However, remember that sea level rise will not stop at the middle or end of the century. As highlighted throughout this Report, higher sea level rise projections are considered “physically plausible” by the end of the century based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). While this Report models sea level rise up to 3.2 feet, it should be noted that NOAA has modeled passive flooding scenarios with up to 6 feet of sea level rise in their Sea Level Rise Viewer (NOAA 2017b). To illustrate potential impacts from higher sea level scenarios, the 5-foot passive flood layer from NOAA was incorporated into vulnerability assessment which increases the area of the SLR-XA on O‘ahu by 36%. Figure 111 shows how 5 feet of passive flooding with sea level rise would impact communities along Maunalua Bay. While there is uncertainty over when the islands might experience such extreme sea level rise, the information is provided merely to remind readers that sea level rise is going to continue for the remainder of the century and beyond.

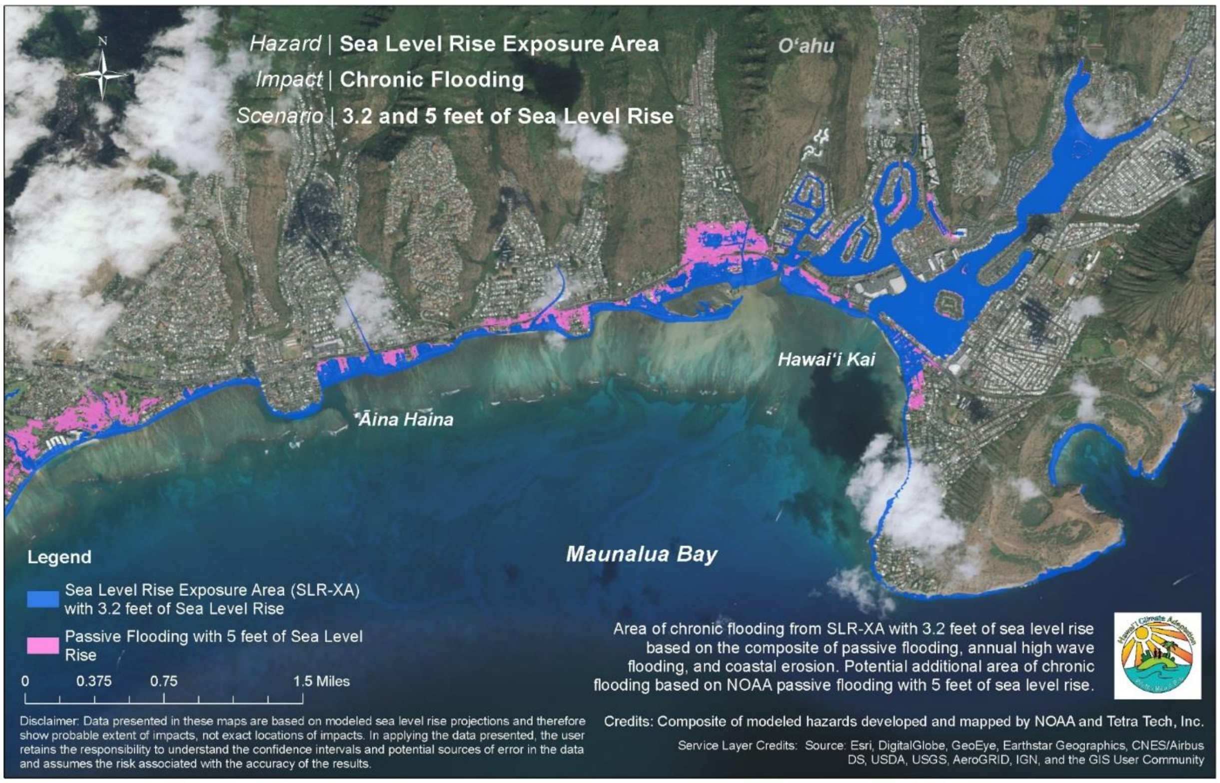


Figure 111. Potential additional area of chronic flooding with 5 feet of sea level rise along Maunalua Bay, O‘ahu

O‘ahu has opportunities to plan for sea level rise now by considering the recommendations for adaptation presented in Chapter 5 of this Report. Another threat that we will have to face with climate change is increased coastal flooding from tropical storms, hurricanes, and tsunamis. The added risk from event-based coastal flooding exacerbated by sea level rise is not included in this Report. However, these events pose a potential for loss of human life and property, and for severe and long-term economic disruption. Communities should consider planning new development to reduce exposure from severe events by recognizing that the coastal floodplain will migrate landward with increased sea levels. Hazard mitigation and disaster recovery projects should be reviewed and revised to address chronic and event-based flooding and consider the additive effects of accelerating sea level rise.

SEA LEVEL RISE STORIES

City & County of Honolulu

CONSIDERING SEA LEVEL RISE IN SUSTAINABLE COMMUNITIES AND DEVELOPMENT PLANS

"As a community, Honolulu has prepared for the risk of coastal flooding in a number of ways, but there is always room for improvement, especially with the changes likely due to climate change," said Mayor Kirk Caldwell. The City & County of Honolulu Administration believes that climate change is real and must be reflected in its plans, regulations, rules and standards. What is needed now, explained Art Challacombe, former Deputy Director of the City & County Honolulu Department of Planning and Permitting (DPP), is translating those priorities into regulatory action to ensure that Oahu's coastal environments, development and communities are protected from sea level rise.

To reflect these adaptation priorities, the DPP began incorporating "no regrets" climate change adaptation policies and guidelines in its development plans and sustainable community's plans. These are the long-range regional land use and infrastructure plans guiding public and private development for Oʻahu, including those for North Shore, Waiʻanae and ʻEwa.

To implement the sea level rise policies and guidelines in these plans, which call for analysis of the possible impact of sea level rise on all new public and private shoreline area projects, DPP began asking in 2015 that environmental assessments and other applications for shoreline projects submitted to the Department for review and comment include such an analysis.

You can read more of this story at
climateadaptation.hawaii.gov/climate stories

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Kapa'a , Kaua'i
Source: Ruby Pap

Kauaʻi

The Island of Kauaʻi, the oldest and northernmost of the main Hawaiian islands, earns its reputation as the "Garden Isle" as 55% of the island's land area is designated as being within the State Land Use Conservation District and includes 24 state-managed reserves, preserves, and park areas (County of Kaua'i Planning Department 2017). Kauaʻi is the State's fourth largest island with 353,504 acres, but only accounts for 5% of the State's population with 71,735 residents (State of Hawai'i 2015). Although the population is relatively small, it has more than doubled over the last 50 years. This growth coupled with a growing tourism industry—over 1.18 million visitors came to Kauaʻi in 2016 (State of Hawai'i 2016)—has placed ever increasing demands on natural resources and basic services. Kauaʻi currently faces many challenges including ageing infrastructure, planning for future growth, and lack of affordable housing. The impacts of sea level rise on the communities of Kauaʻi have the potential to exacerbate these existing challenges.

Key Take Aways

- Over the next 30 to 70 years, homes and businesses located near the shoreline will be impacted by sea level rise. Over 900 structures would be chronically flooded by 3.2 feet of sea level rise.

- Of the 5,760 acres of land located within the SLR-XA, approximately 17% is designated for urban land uses.
- With 3.2 feet of sea level rise, approximately 6.5 miles of Kauai's coastal roads would become impassible jeopardizing access to and from many communities.
- Kaua'i has lost almost 4 miles of beaches to erosion fronting seawalls and other shoreline armoring. Many more miles of beach could be lost with sea level rise, if widespread armoring is allowed. Chapter 5 (Recommendations) explores opportunities to reduce beach loss by improving beach protection policies.
- A more detailed economic loss analysis is needed of Kauai's critical infrastructure, including harbor facilities, airport facilities, sewage treatment plants, and roads. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.

This section provides a picture of the future of the Island of Kaua'i with sea level rise and the potential impacts if no action is taken. The results are based on modeling coastal flooding with sea level rise due to passive flooding, annual high wave flooding, and coastal erosion in the SLR-XA with up to 3.2 feet of sea level rise, and depicts flood hazards that may occur in the mid- to latter-half of this century. This timeframe is within the expected lifespan of most new construction and much of our existing development. It should be noted that sea level rise projections greater than 3.2 feet are "physically plausible" by the end of the century, based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). Vulnerability to 1.1 feet of sea level rise in the SLR-XA is used to approximate current or near-term exposure to coastal hazards and sea level rise. Vulnerability is assessed in terms of potential impacts to land use, people, property, cultural and natural resources, and critical infrastructure (only land and structures are monetized, not infrastructure).

The reader is urged to exercise caution in interpreting the results, which could be to a greater or lesser extent depending on actual observed future sea level rise, technological innovations in climate change mitigation and adaptation, unknown economic variables, as well as future societal choices which cannot be known today. Further, as not all parts of the island can be shown in detail, the reader should also visit the Hawai'i Sea Level Rise Viewer to explore the full extent of the vulnerability maps for each island.

Potential Impacts in the Sea Level Rise Exposure Area

The SLR-XA depicts the area of potential chronic flooding from exposure to passive flooding with sea level rise. For the purposes of exposure and planning, we focus mainly on a scenario with 3.2 feet of sea level rise.

With 3.2 feet of sea level rise, low-lying coastal areas around the island within the SLR-XA may become chronically flooded within the mid- to latter-half of this century (Figure 112). This land will become submerged by coastal erosion, direct marine flooding from tides and waves, or become new wetlands behind the shoreline from rising water tables and reduced drainage. Approximately 5,760 acres of land on Kaua‘i is estimated to be located in the SLR-XA with 3.2 feet of sea level rise. Some examples of areas that would be exposed to chronic flooding include Kē‘ē Beach, Kīlauea, Polihale Beach, and Nāwiliwili Harbor as illustrated on Figure 113. The Town of Kīlauea is one of the areas identified in the Kaua‘i County General Plan that may be able to accommodate future growth. However, chronic flooding associated with 3.2 feet of sea level rise in Kīlauea’s low-lying beach areas would impact how and where this growth could occur. Many communities and businesses are already experiencing tidal flooding. Locations like Kē‘ē and Polihale provide the best opportunity for conserving natural beach environments if backshore lands remain undeveloped and the beach is allowed to migrate landward with sea level rise. Portions of Nāwiliwili Harbor, the primary commercial harbor for Kaua‘i, would be flooded with 3.2 feet of sea level rise. This may significantly impact residents and visitors to the island as essential commodities are dependent on ocean transport (County of Kaua'i Planning Department 2017).

Over time, as sea level continues to rise, low-lying, populated coastal communities, such as Kekaha, would experience increased frequency and extent of flooding potentially making some sections of the coastal highway impassible and some beachfront lots uninhabitable (Figure 114). Decisions about where to use coastal armoring and when to retreat will need to be made carefully. It should be noted that seawalls may not be effective at preventing flooding with sea level rise in many low-lying areas as rising groundwater can infiltrate through porous geology.

While specific responses to sea level rise would need to be place-based, larger regional issues should also be considered, such as whether to armor in place or whether to relocate roads and other critical infrastructure inland. In the case of Kekaha, where there may be opportunities to consider a managed retreat strategy as there are ample vacant lands immediately mauka (landward) and outside of the SLR-XA with 3.2 feet of sea level rise. However, as discussed in Chapter 5 (Recommendations), large-scale boundary amendments should be predicated on appropriate state policies and guidelines (e.g., within Chapter 205, State Land Use Act) to provide the supportive legal basis for major land use changes.

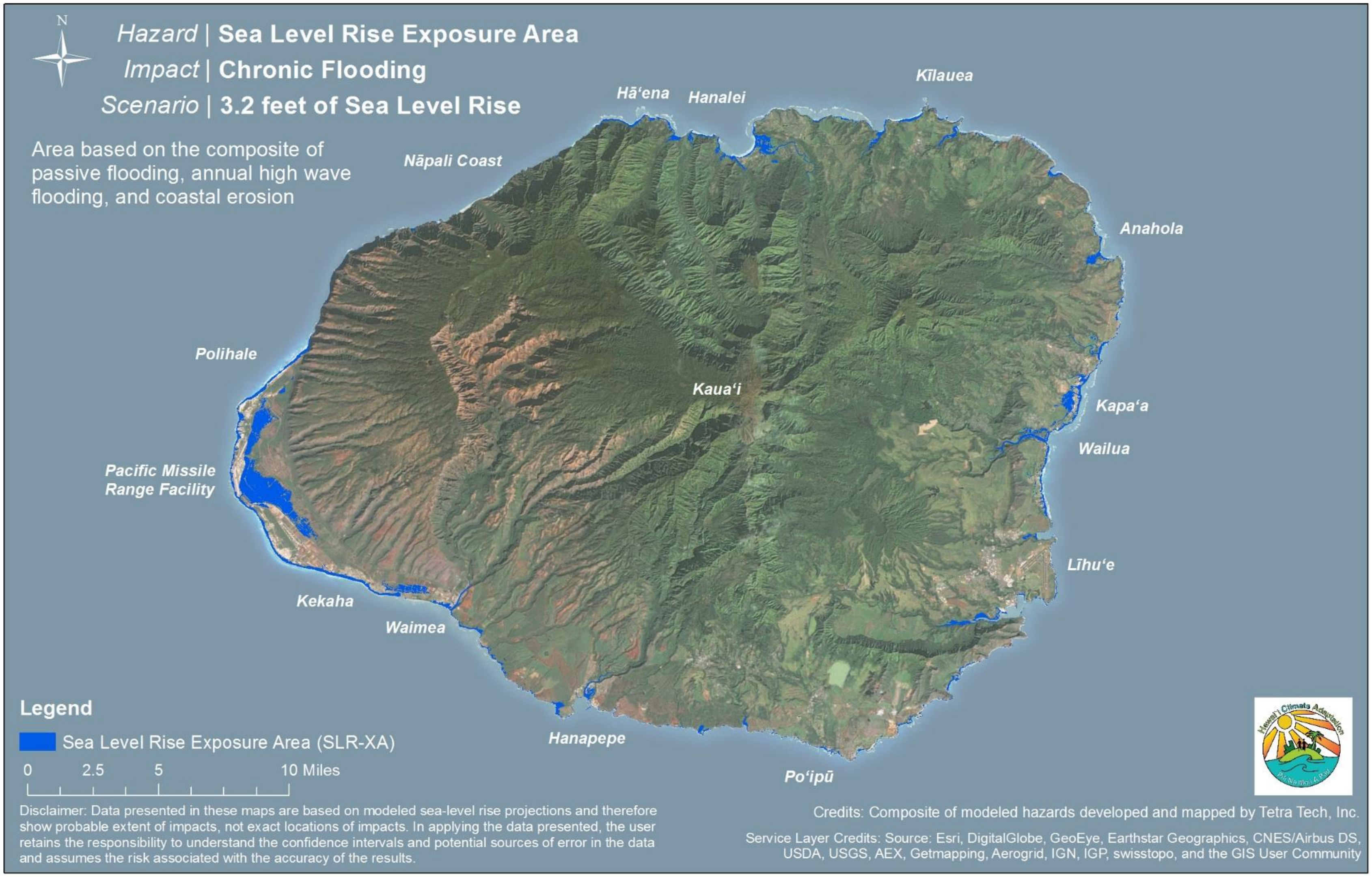


Figure 112. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise on Kauaʻi

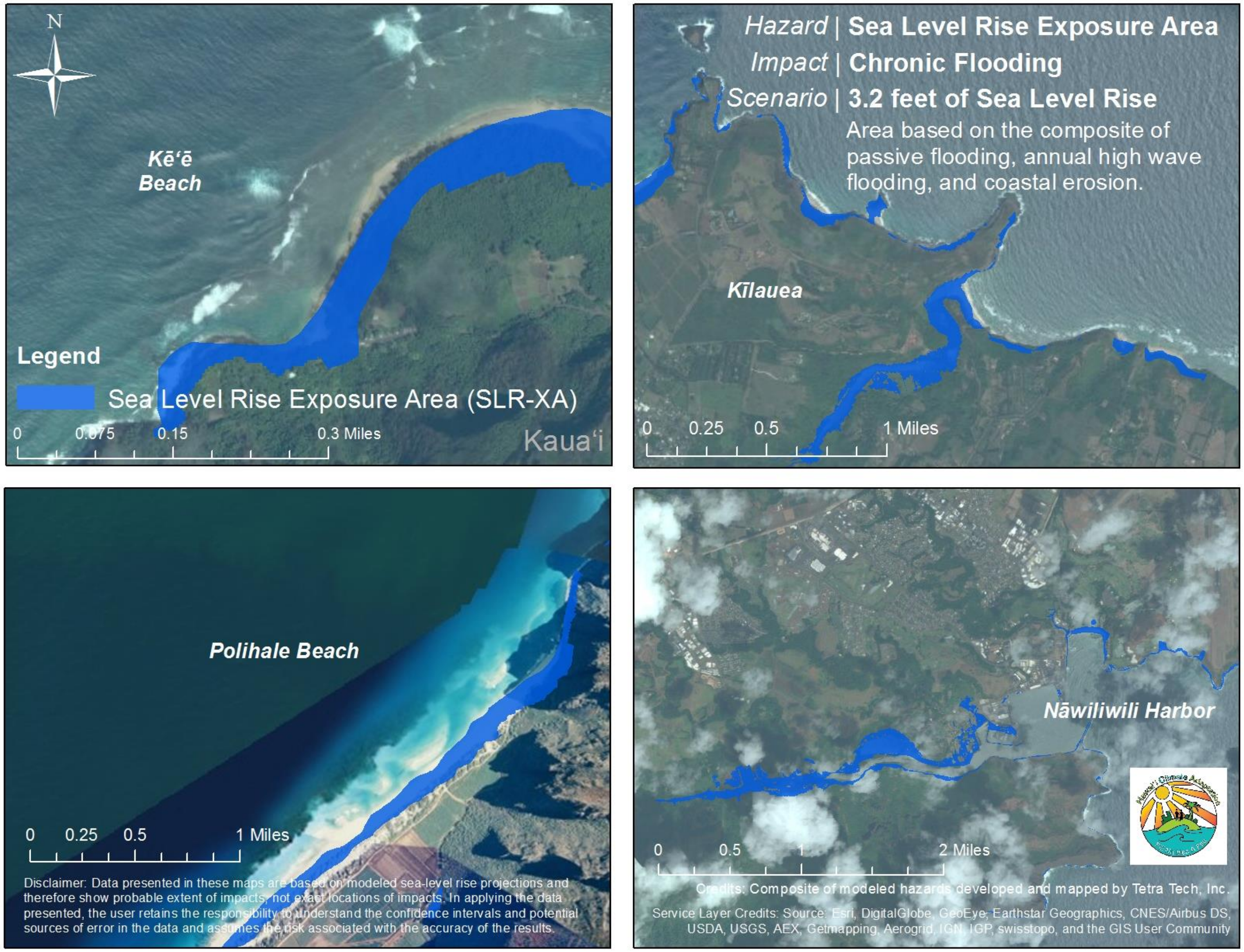


Figure 113. Potential chronic flooding in the SLR-XA with 3.2 feet of sea level rise in four areas on Kaua'i

Figure 114. Potential chronic flooding in the SLR-XA with 1.1, 2.0, and 3.2 feet of sea level rise in Kekaha, Kaua'i

POTENTIAL IMPACTS TO LAND USE

While sea level rise would result in impacts within the State Agricultural, Urban, Rural, and Conservation Land Use Districts around the island, Agricultural lands would experience the greatest extent of chronic flooding with over half of the 5,760 acres of land located within the SLR-XA designated for agricultural use (Figure 115). This is in stark contrast to that of Oʻahu which has over 50% of lands within the SLR-XA designated for urban use. Only 17% of the lands on Kauaʻi within the SLR-XA with 3.2 feet of sea level rise are located in the urban district. However, considering that currently only 4% of island's total land area of 353,900 acres is within the Urban Land Use District (State of Hawai'i 2015), sea level rise would likely increase demands to convert existing agriculture and conservation lands to urban areas to respond to the likely shift in coastal infrastructure and population away from the shoreline.

While the State Land Use Law (Hawaiʻi Revised Statutes Chapter 205) could be used to sort out major land changes as part of a managed retreat strategy, County General Plan and Community Plan updates provide important opportunities to address land use issues with rising seas at the local level. Revised and updated SMA policies, objectives, and requirements offer additional opportunities at the local level to prepare for sea level rise. Moreover, if the County of Kauaʻi chooses to recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone (one of the recommendations in Chapter 5), it might be prudent to consider adjusting SMA boundaries to coincide with the SLR-XA so that new subdivisions, commercial areas, hotels, and other development activities could undergo a higher level of review in light of sea level rise constraints. Figure 116 illustrates the partial overlap of SMA boundaries with the SLR-XA along portions of Hanamaulu Bay. Additional controls on development along the coast may be necessary to protect Native Hawaiian traditional and customary practices, iwi kūpuna (ancestral bones) and other archaeological, historical, and cultural resources, and to ensure public access and mitigate the impacts of coastal hazards.

RECOMMENDATION HIGHLIGHTS

- Recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone in the County General Plan and Community Plan updates.
- Strive to balance managed retreat strategies from vulnerable urban areas with preservation of agriculture and conservation lands.
- Seek opportunities to plan new development outside of the SLR-XA, wherever possible, under a long-term comprehensive adaptation strategy.
- Develop design standards to increase flood resiliency within the SLR-XA.

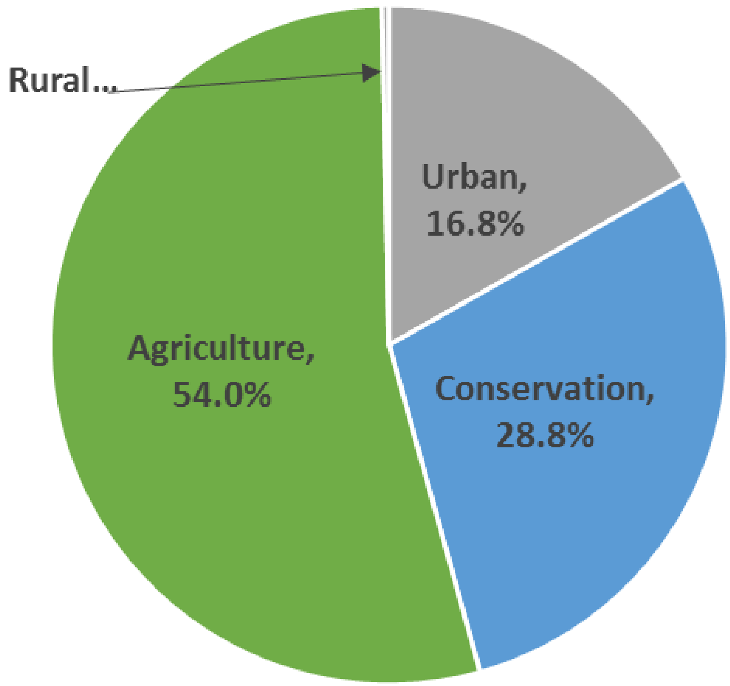


Figure 115. Estimated percentage of Land Use Districts impacted in the 3.2 feet sea level rise exposure area on Kaua‘i

Figure 116. Portions of the SLR-XA (blue) around Hanamaulu Bay, Kaua‘i extending beyond the Special Management Area (SMA) boundary (pink hatched area) that would not be subject to SMA permitting requirements

POTENTIAL IMPACTS TO PEOPLE AND PROPERTY

People living and working within the SLR-XA would be displaced when homes, condominiums, and business become flooded due to sea level rise. The potential number of people displaced is calculated by assigning an estimated occupancy for each type of structure in the SLR-XA. Potential economic loss in the SLR-XA is estimated based on the value of land and structures flooded. Loss estimates are assessed at the parcel level and aggregated into 1-hectare grids. The potential economic loss associated with flooded roads, water/wastewater facilities, and other critical infrastructure is not accounted for in the assessment and would add significant increases in losses.

The potential number of displaced people island-wide could rise from 990 residents with 1.1 feet of sea level rise, to over 3,370 residents with 3.2 feet of sea level rise (Figure 117). The people displaced would include a range of income levels and living arrangements. In addition, approximately 38% of the occupied housing units on Kaua‘i are occupied by renters (U.S. Census Bureau 2015c), so both homeowners and renters would be affected island-wide.

Potential economic losses (all structures and land) island-wide would increase from an estimated $763 million with 1.1 feet of sea level rise, to more than $2.59 billion with 3.2 feet of sea level rise (Figure 117). Approximately 84% of the potential economic loss with 3.2 feet of sea level rise is attributed to the loss of residential structures and land. This potential economic loss is associated with approximately 930 structures and approximately 5,760 acres of land in the SLR-XA with 3.2 feet of sea level rise.

With 3.2 feet of sea level rise, potential economic loss would occur in low-lying coastal areas island-wide, with the greatest loss in urban areas along the coastline including Kapa‘a, Waimea, Hā‘ena, and Hanalei (Figure 118). Over time, as the sea level continues to rise, communities such as Waimea (Figure 119), would experience increasing potential economic loss.

RECOMMENDATION HIGHLIGHTS

- Require mandatory disclosure for vulnerable properties and consider acquisition to protect valuable coastal resources.
- Develop design standards to increase flood resiliency for existing and new development within the SLR-XA that cannot be relocated.
- Seek opportunities to plan new development well landward of the SLR-XA with 3.2 feet of sea level rise under a long-term, comprehensive strategy.
- Develop a multi-pronged financing strategy at federal, state, county, private sector, and philanthropic levels to address costs of adaptation to sea level rise.

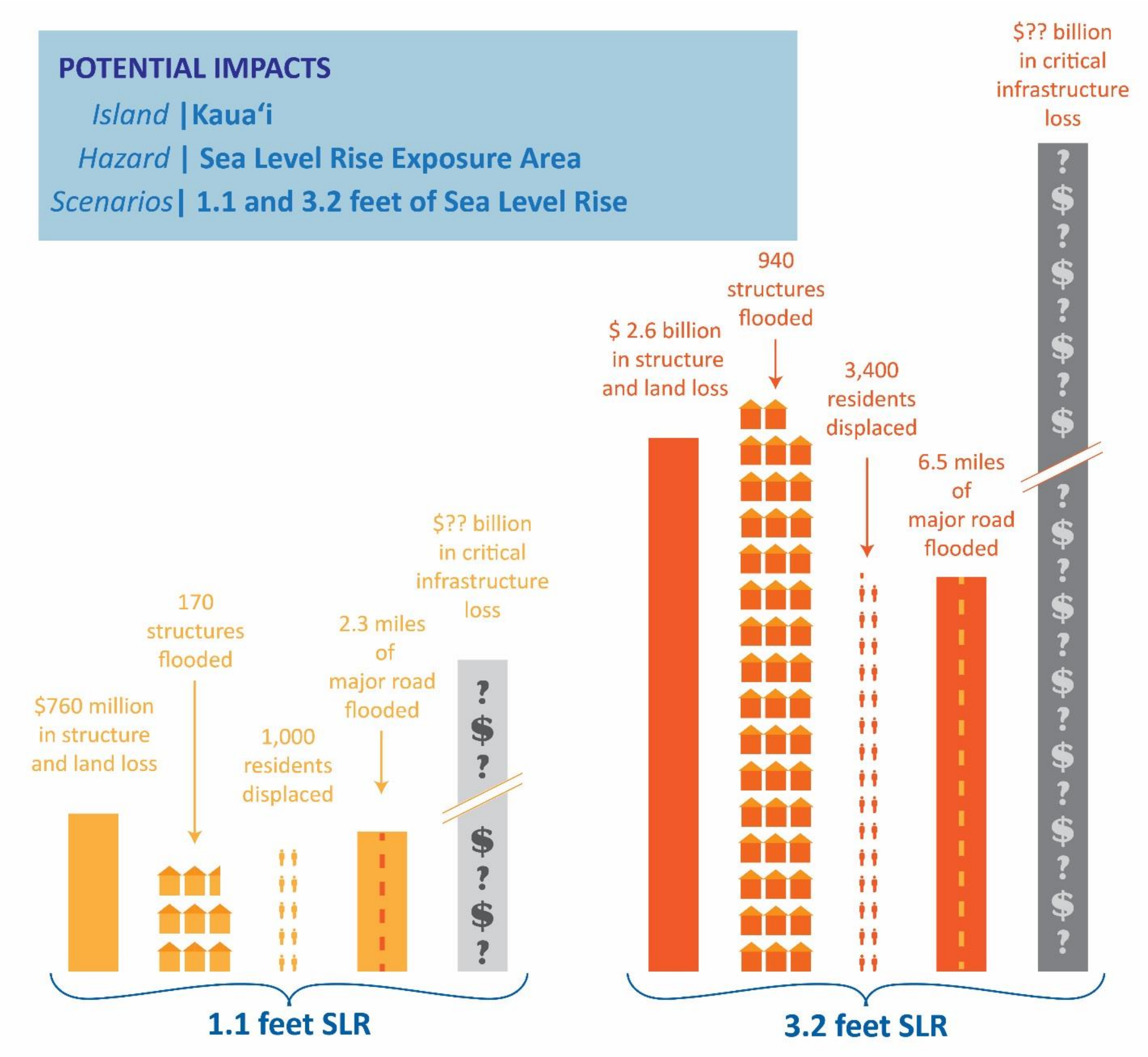


Figure 117. Summary of potential impacts in the SLR-XA with 1.1 feet and 3.2 feet of sea level rise on Kauaʻi

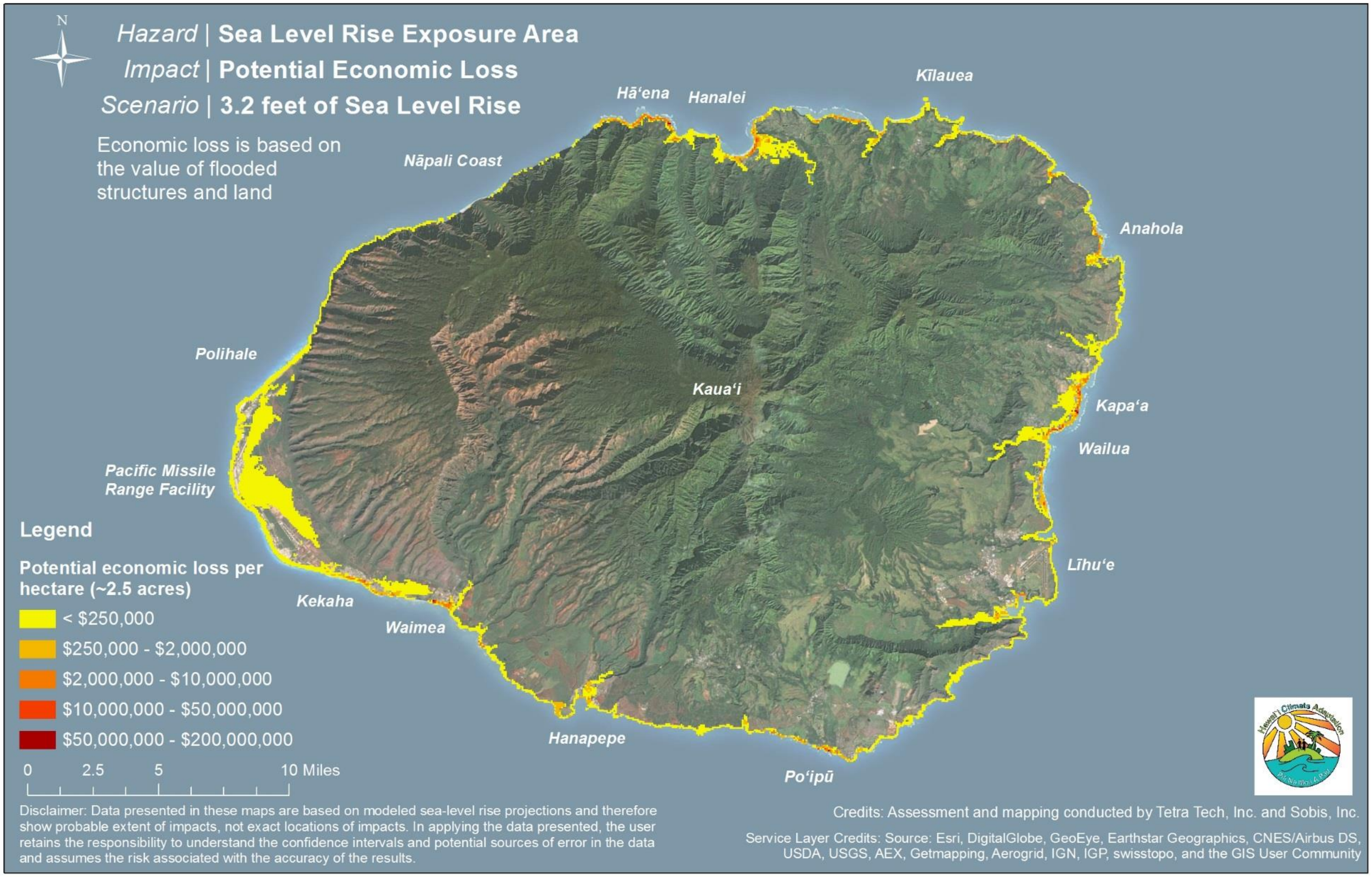
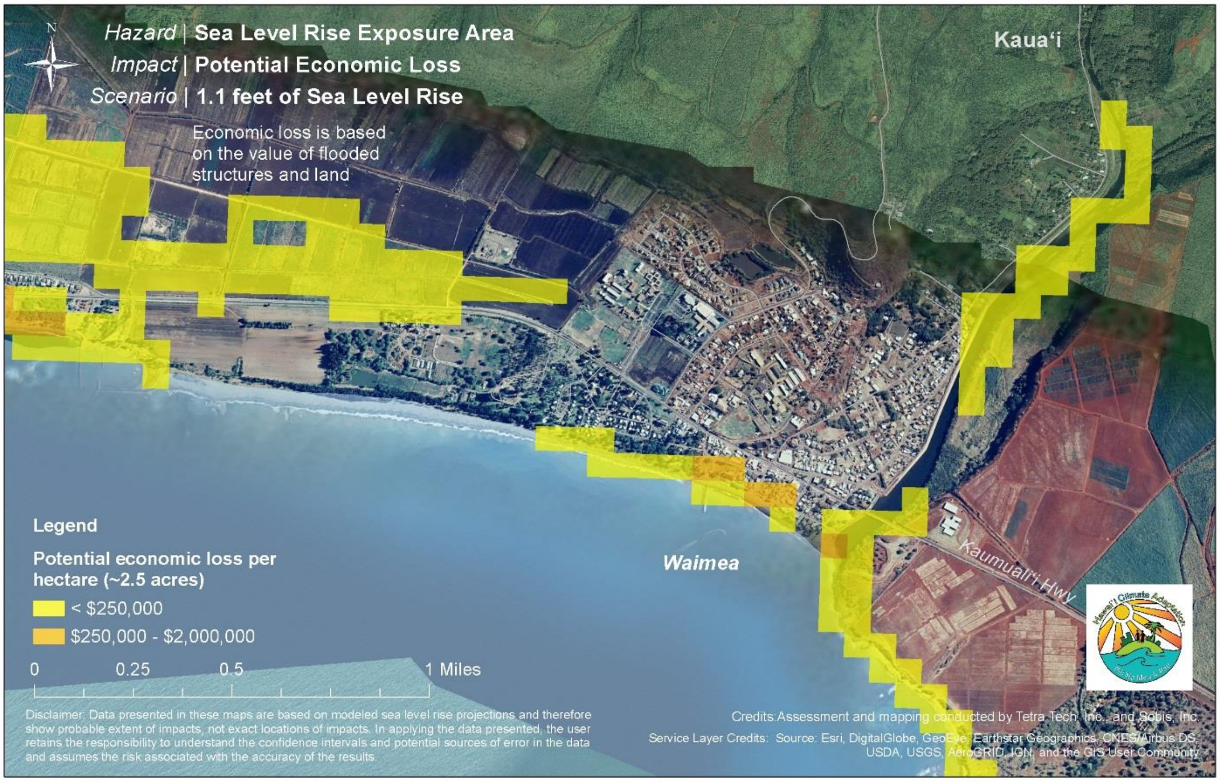


Figure 118. Potential economic loss in the SLR-XA with 3.2 feet of sea level rise on Kaua'i



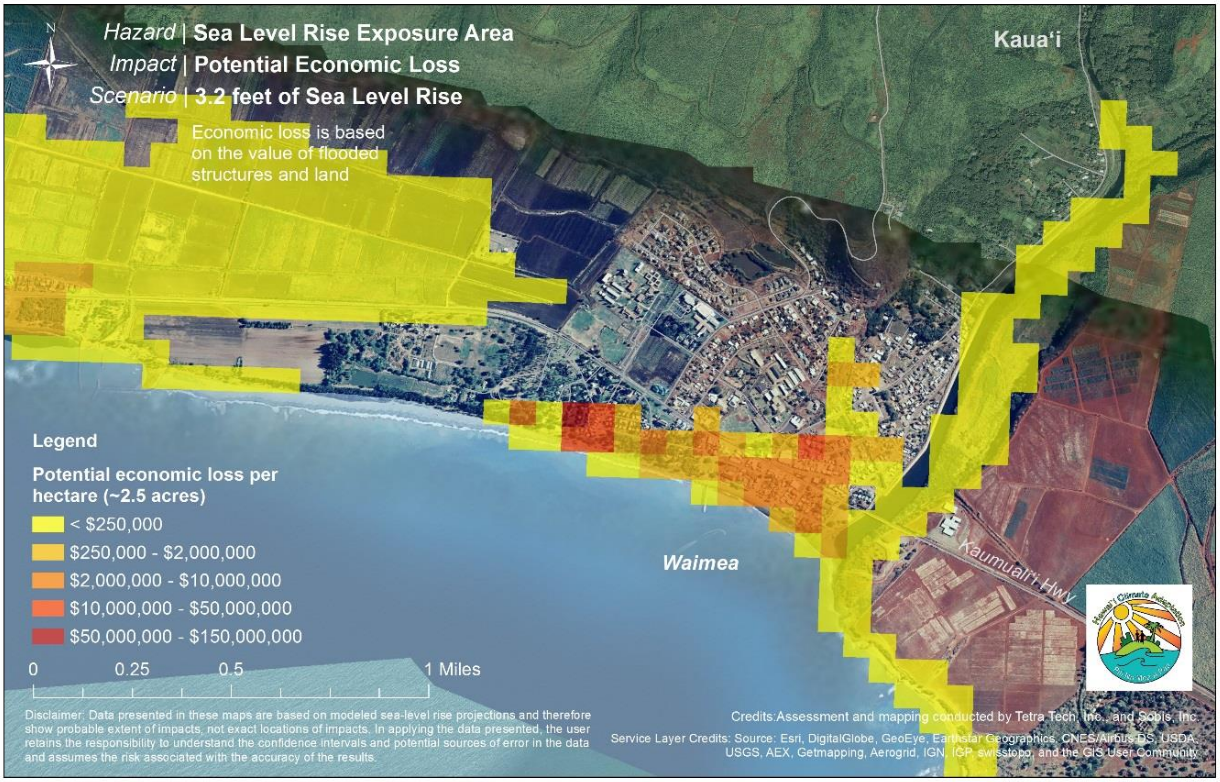


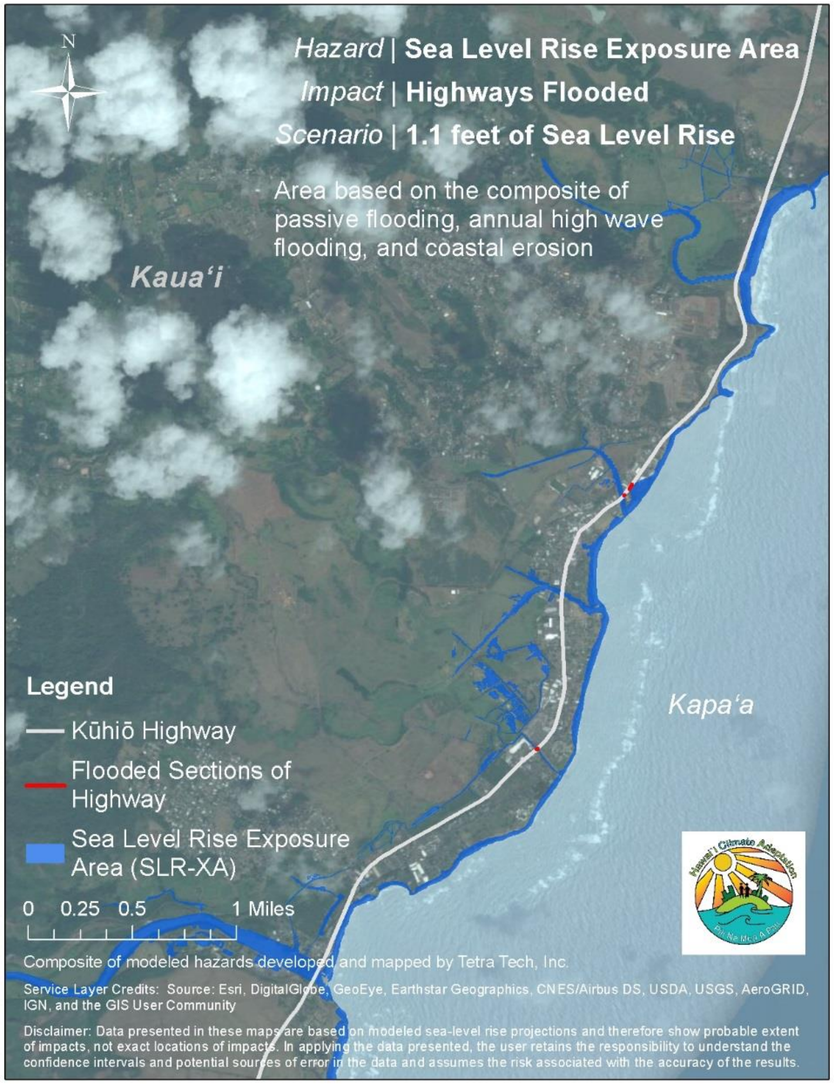
Figure 119. Potential economic loss in the SLR-XA with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise in Waimea, Kaua'i

POTENTIAL IMPACTS TO CRITICAL INFRASTRUCTURE

Sea level rise would result in significant impacts to roads, airports, harbors, electrical and telecommunication infrastructure, water/wastewater facilities and conveyance systems, and other public service facilities (i.e. schools, fire stations, police stations, medical facilities) on Kauaʻi. Following the trends of private development, portions of Kauaʻi's critical public infrastructure is concentrated along low-lying shores and is vulnerable to flooding and erosion in the SLR-XA. An estimated 2.3 miles of major roads island-wide would be flooded in the SLR-XA with 1.1 feet of sea level rise, increasing to 6.5 miles with 3.2 feet of sea level rise (Figure 117). Portions of many coastal roads, such as Kūhīo Highway, would become chronically flooded and eroded away (Figure 120). This could result in wide-spread regional issues such as loss of commerce and increased traffic on other roads and highways, some of which serve as the only access in and out of many communities. Electric and telecommunication transmission lines commonly follow roads and those located underground in the SLR-XA may be impacted by sea level rise resulting in service disruptions.

One of the primary transportation arteries for the entry of people and goods to the island is Līhuʻe Airport. However, due to the rocky coastline around the airport, minimal chronic flooding with 3.2 feet of sea level rise is projected. In contrast, Port Allen Airport, a smaller airport servicing the Hanapepe area, would have a greater exposure as over 60 acres of its runway and facilities would be exposed to chronic flooding in the SLR-XA. Further, Nāwiliwili Harbor, another primary transportation artery, would also become increasingly exposed to chronic flooding from sea level rise (Figure 121). This could result in interruption to interisland and transoceanic shipping and travel, impacting residents, visitors, and overall economic activity. In addition, two schools are expected to be flooded with 3.2 feet of sea level rise. No fire stations, police stations, hospitals or wastewater treatment plants are located within the SLR-XA with 3.2 feet of sea level rise.

More detailed analyses of vulnerability and adaptation options for critical infrastructure would be needed to evaluate adaptation options such as retrofitting or relocation. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., flood proofing and relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years. Please keep in mind that infrastructure losses have not been monetized. However, it should be noted that these costs could be an order of magnitude greater than the potential economic losses estimated from land and structures.



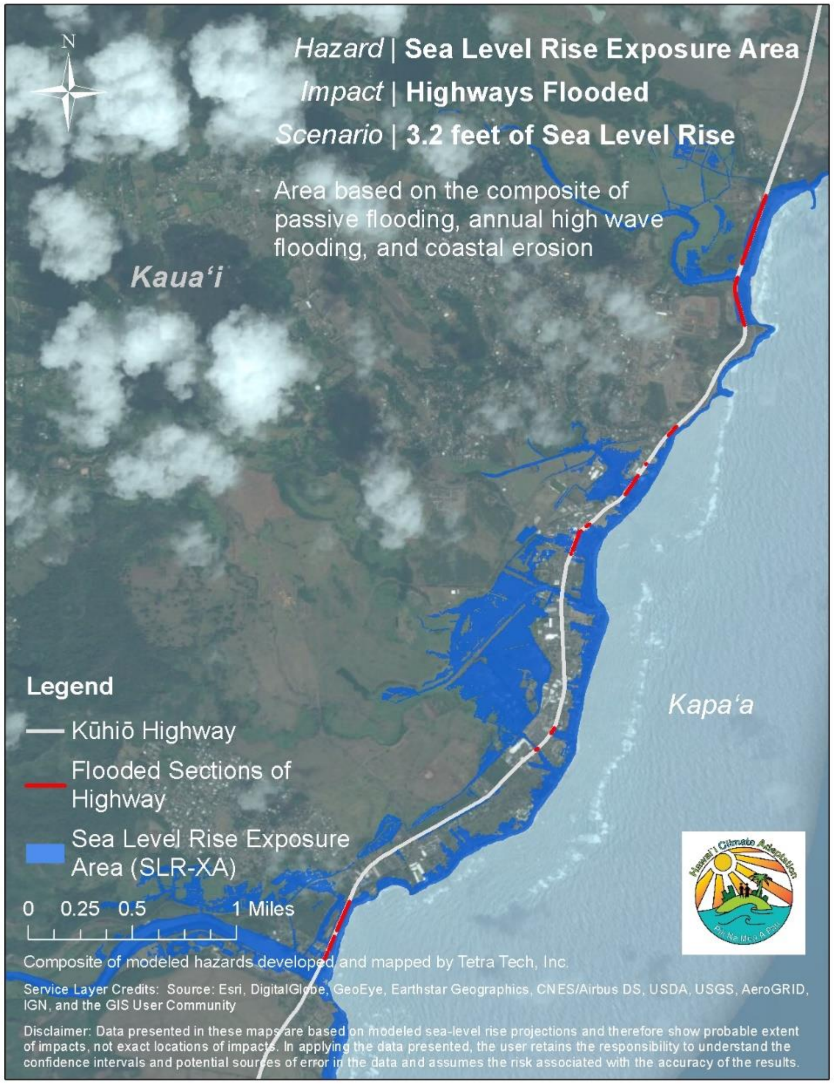


Figure 120. Projected chronic flooding along the Kūhiō Highway in the SLR-XA with 1.1 feet (left) and 3.2 feet (right) of sea level rise in Kapa'a, Kaua'i

Figure 121. Līhuʻe Airport and Nāwiliwili Harbor, Kauaʻi and the SLR-XA with 3.2 feet of sea level rise

RECOMMENDATION HIGHLIGHTS

- Conduct in-depth vulnerability assessments and evaluation of adaptation strategies for existing critical infrastructure throughout the County.
- Consider long-term cost savings from implementing sea level rise adaption measures now (e.g., major flood proofing or relocation) compared to the cost of maintaining and repairing chronically threatened public infrastructure over the next 30 to 70 years.
- Require the design and siting of new development and capital improvement projects to include an in-depth analysis of sea level rise impacts based on elevation, tolerance for risk, and lifetime of the structure.

POTENTIAL IMPACTS TO NATIVE HAWAIIAN COMMUNITIES AND CULTURAL RESOURCES

Hawaiian Home Lands are intended to provide for the economic self-sufficiency of Native Hawaiians through a homesteading program (University of Hawaiʻi 2015). Consistent with Native Hawaiian culture, Hawaiian Home Lands include areas from mauka to makai (from the mountain to the sea). Coastal portions of Hawaiian Home Lands, such as in Anahola (Figure 122), would be flooded with sea level rise displacing Native Hawaiian families that live in this area. In addition, fishing and cultural practices taking place along the shore would be impacted as beaches erode. In a recent study of multiple coastal hazards, three of the eight Hawaiian Home Lands homesteads on Kauaʻi—Anahola, Kekaha, and Kapaʻa—are estimated to have the greatest potential for people to be displaced by tsunamis, waves, and sea level rise (University of Hawaiʻi 2015).

In addition to Native Hawaiian communities, many Native Hawaiian cultural and historical resources are located near the shoreline and are threatened by sea level rise. Coastal erosion already threatens areas that have served as burial grounds, home sites, fish ponds, and other places of cultural significance (Kane et al. 2012). The number of cultural sites in the SLR-XA on Kauaʻi is projected to increase from 55 sites with 1.1 feet of sea level rise, to 80 with 3.2 feet of sea level rise. This includes the Palikū Beach burial which may be flooded as a result of sea level rise (Figure 123). Additionally, the traditional practice of hana paʻakai (salt making) is at risk due to sea level rise. The salt ponds in Hanapēpē (Figure 124), which have been maintained and harvested for many generations, have experienced impacts from increasing flooding in recent years due to the higher high tides and changes in weather. Normally, underground sea water seeps up through the bottom of a main well known as the puna and that water is then transferred to a secondary well called a wai ku. Once salt crystals begin to form, the brine is transferred to a clay drying bed or loʻi where the salt crystals will start appearing. The recent flooding has interrupted the drying of the salt so farmers have implemented adaptation strategies such as raising the level of the loi's and fortifying the walls of the wai ku (Hiraishi 2017).

RECOMMENDATION HIGHLIGHTS

- Develop an inventory of Native Hawaiian cultural resources and practices impacted by sea level rise.
- Work with Native Hawaiian communities to determine steps they want to take regarding climate impacts.
- Develop adaption plans to preserve access to coastal land and water within Native Hawaiian communities.

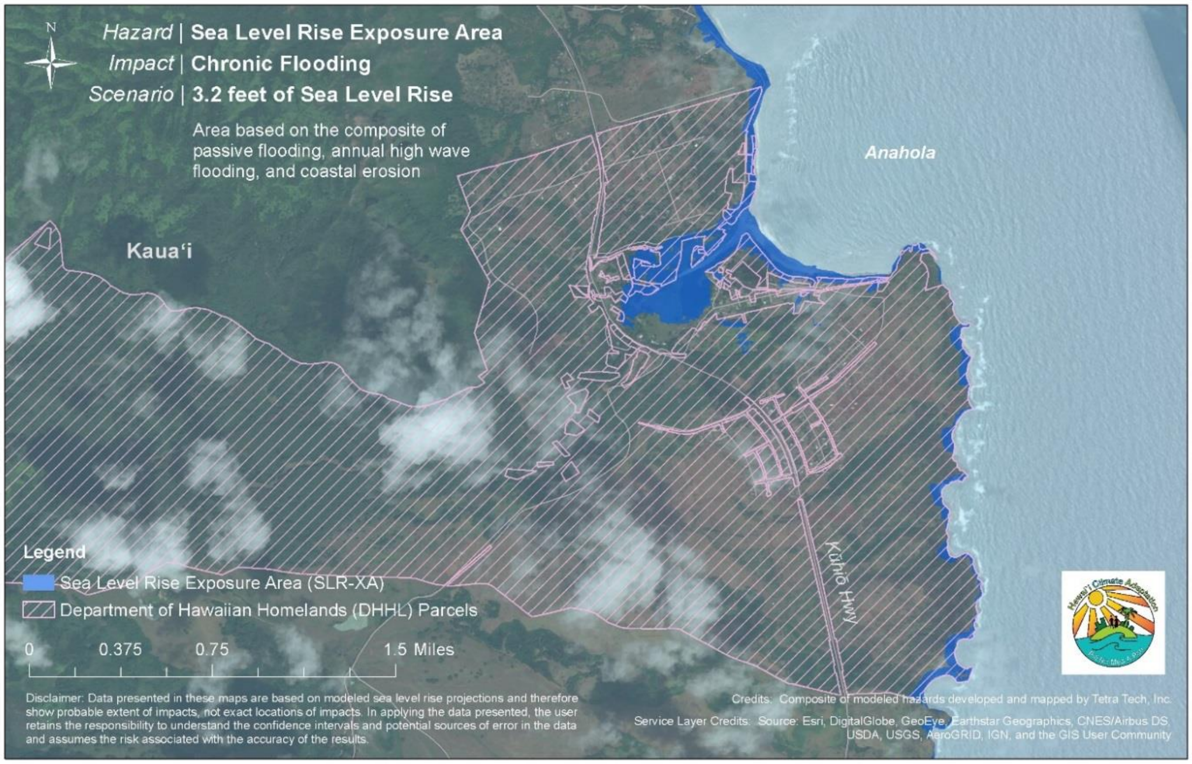


Figure 122. Potential chronic flooding of Anahola Hawaiian Home Lands, Kaua'i (hatched pink) in the SLR-XA (blue) with 3.2 feet of sea level rise

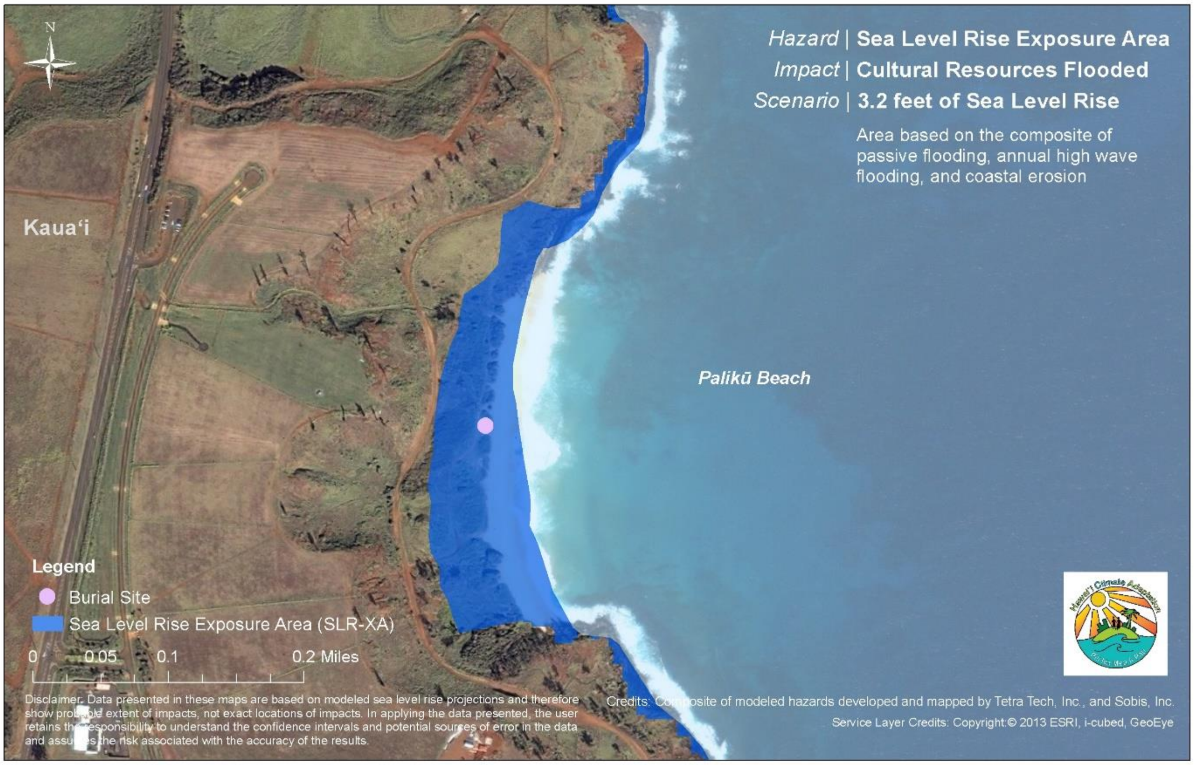


Figure 123. Cultural resource site (light pink) located in the SLR-XA (blue) with 3.2 feet of sea level rise along the shoreline of Palikū Beach, Kaua'i

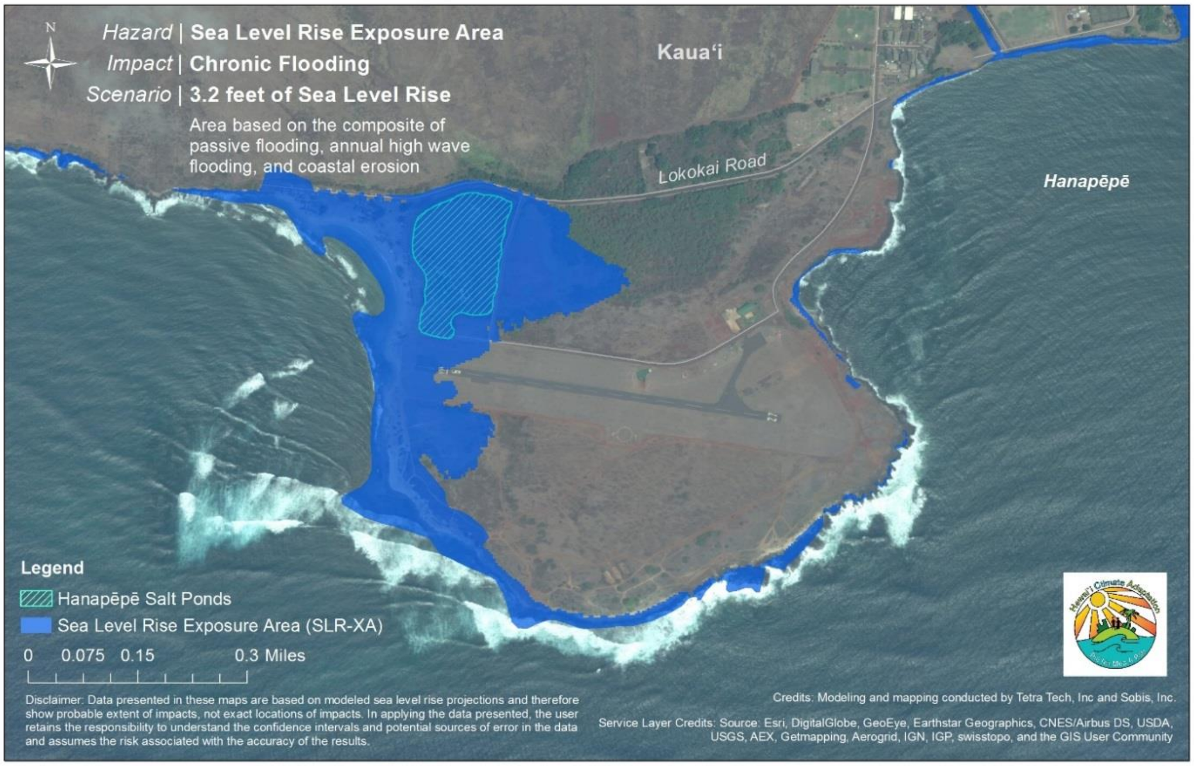


Figure 124. Potential chronic flooding of Hanapēpē Salt Ponds, Kaua‘i in the SLR-XA with 3.2 feet of sea level rise

POTENTIAL IMPACTS TO COASTAL RESOURCES AND PUBLIC ACCESS

Kaua‘i has approximately 55 miles of sandy beaches, including the longest stretch of beach in the State, Polihale Beach, located on the west side of the island (O'Connell 2010). These beaches play a critical role in recreation for Kauai’s residents and economy. According to the County of Kauai’s General Plan (County of Kaua'i Planning Department 2017) employment in tourism-related industries accounts for 30% of all employment on the island.

Approximately 372 acres of public beaches and parks (inclusive of county, state and federal parks) on Kaua‘i are located within the SLR-XA with 3.2 feet of sea level rise. Many of these parks, such as Kekaha Beach Park (Figure 125), are located on the seaward side of major roads, and demonstrate how lightly-developed parkland can provide a buffer between eroding shorelines and development for many decades. Sea level rise will lead to extensive beach loss if widespread shoreline hardening is permitted and beach systems are not allowed to migrate landward. Most beaches on Kaua‘i are backed by deposits of older beach and dune sand (Sherrod et al. 2007) which are crucial sources of sediment along eroding coasts. In a natural state, a beach can be maintained as it migrates landward if there is sufficient sand available in the backshore to nourish the beach as it erodes. Shoreline hardening locks up this backshore sediment source leading to narrowing and loss of chronically eroding beaches.

Figure 125. Potential chronic flooding of Kekaha Beach Park in the SLR-XA with 3.2 feet of sea level rise in the Waimea-Kekaha District, Kaua‘i

A study of historical shoreline changes in Hawai‘i by the U.S. Geological Survey and the University of Hawai‘i (Fletcher et al. 2012) found that 70% of Kaua‘i beaches are chronically eroding. Over the past century, shoreline hardening was the typical response throughout Hawai‘i when beachfront property was threatened by erosion or flooding. As a result, approximately 5 miles of Kauai’s beaches are backed by seawalls and other shoreline hardening structures. Nearly 4 miles of beaches fronting those structures has already been completely eroded away.

Looking at the future, sea level rise presents a serious threat to Kaua‘i beach environments and public shoreline access. At present, 1 mile of beach remains with shoreline hardening on the backshore (5 miles minus the 4 already lost). This 1 mile of beach has a very high risk of being eroded away in coming decades under increasing rates of chronic erosion with sea level rise. With 1.1 feet of sea level rise, an additional 5 miles of unprotected beachfront development will be exposed to erosion and flooding (i.e. within the SLR-XA). These 5 miles include 3 miles of homes and buildings and 2 miles of coastal highways. With 3.2 feet of sea level rise, 12 miles of unprotected beachfront development will be exposed to erosion and flooding. The 12 miles include 8 miles of homes and buildings and 4 miles of coastal highways. Beaches fronting these areas of exposed development face a high risk of loss if widespread shoreline hardening is allowed rather than allowing beaches to migrate landward with sea level rise.

As described in the Methods section, this analysis considers a scenario where widespread armoring is permitted and does not consider other adaptation scenarios such as managed retreat from impacted areas or beach nourishment, which would help extend the life of beaches such as Poʻipū and Kapaʻa. This analysis also does not account for effects of accelerated erosion that typically occurs fronting and adjacent to coastal armoring, leading to more widespread impacts. More research is needed to improve the understanding and projections of localized vulnerability of beach and environments to the combined impacts of encroaching beachfront development and erosion and flooding with sea level rise.

Kauai's Erosion-based Shoreline Building Setbacks with Rising Seas

In 2014, Kauaʻi adopted an updated erosion-rate-based shoreline building setback ordinance (State of Hawai'i Council of the County of Kaua'i 2014) based on study of historical coastal erosion rates conducted for the County by the University of Hawaiʻi Coastal Geology Group. The ordinance categorizes two different lot/property types for shoreline setbacks; (1) lots that were included in the erosion study (generally, lots fronting beaches) and (2) lots not included in the erosion study. For lots included in the erosion study, the distance of the shoreline setback line is measured from the certified shoreline as shown in the table below.

Average Lot Depth	Setback Line
Less than 140 feet	40 feet plus (70 X annual coastal erosion rate) plus 20 feet
140 feet to 220 feet	Greater of: 40 feet plus (70 X annual coastal erosion rate) plus 20 feet -or- (Average Lot Depth minus 100 feet) ÷ by 2 plus 40 feet
Greater than 220 feet	Greater of: 40 feet plus (70 X annual coastal erosion rate) plus 20 feet -or- 100 feet from the certified shoreline

For lots not included in the erosion study (e.g., rocky coasts), the setback is calculated by the following formula, (Average Lot Depth-100)/2+40), subject to the following:

- For lots with natural occurring rocky shorelines, the shoreline setback line shall be no less than 40 feet.
- For all other lots, the shoreline setback line shall be no less than 60 feet.
- For all lots, the maximum setback that can be required shall be 100 feet.

This ordinance is one of the most aggressive of its kind in the State and one of the most progressive in the nation. While this ordinance will go a long way in the short-term to protect beaches and new development threatened by sea level rise, like the other islands, Kauaʻi faces the challenge of addressing potential erosion and flooding impacts to older, existing beachfront development sited without sufficient setbacks. In addition, erosion rates will accelerate with sea level rise. As depicted in this Report as the SLR-XA, chronic flooding due to sea level rise is a composite of passive flooding, annual high wave flooding, and coastal erosion.

Besides recreational areas, a variety of coastal habitats, vital to aquatic organisms and wildlife would become flooded with sea level rise changing the nature of such habitats and the organisms that rely on them. Estuarine habitat, where freshwater from rivers and streams and saltwater from the sea meet and mix, such as those feeding into Hanalei Bay, would become increasing marine with rising seas. Existing wetlands, such as those located near the Pacific Missile Range Facility, could be altered through chronic flood conditions from marine inundation and changes in groundwater tables (Figure 126). In addition, new wetlands could be created.

Sea level rise also has the potential to impact facilities that release wastewater or hazardous materials to nearshore waters and coastal habitats. Septic tanks, cesspools and other OSDSs, as well as hazardous materials storage and disposal sites, could become flooded and release wastewater or contaminants to nearshore waters. OSDS are located along populated areas of Kauai's shoreline, such as along Hāʻena on the North Shore (Figure 127). Island-wide there are approximately 456 OSDS within the SLR-XA with 3.2 feet of sea level rise. The reader should visit the online [Hawaiʻi Sea Level Rise Viewer] to determine if infrastructure of interest is located in the SLR-XA.

RECOMMENDATION HIGHLIGHTS

- Amend the State Legacy Lands Act to set aside funding for preserving priority coastal lands and use of a variety of practices and tools to enable legacy beaches to persist.
- Develop shoreline conservation and restoration priorities and guidelines to support adaptation to sea level rise.
- Expand the area of national, state, and county parks and wildlife refuges on the main Hawaiian Islands to preserve wetlands and wildlife.
- Protect nearshore water quality by identifying hazard mitigation measures to address coastal flooding of hazardous material/waste storage facilities and OSDSs vulnerable to sea level rise.

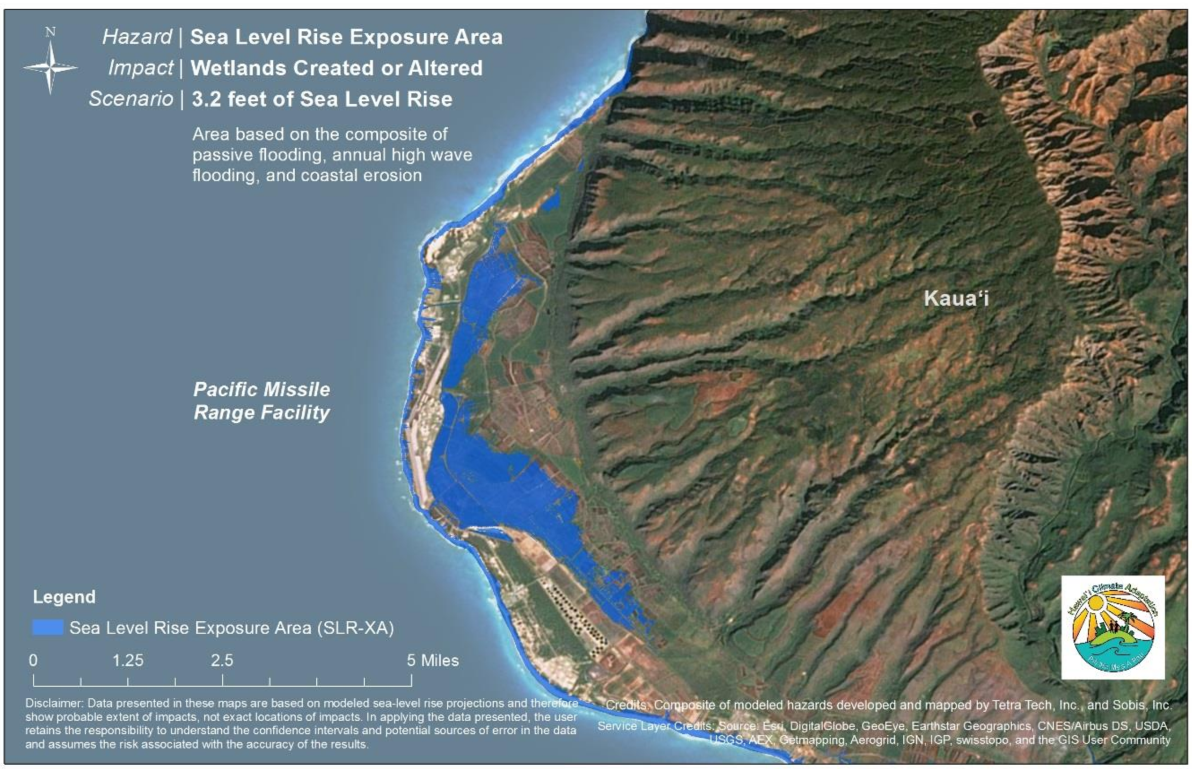


Figure 126. Potential wetland creation areas in the SLR-XA with 3.2 feet of sea level rise near the Pacific Missile Range Facility on Kauaʻi

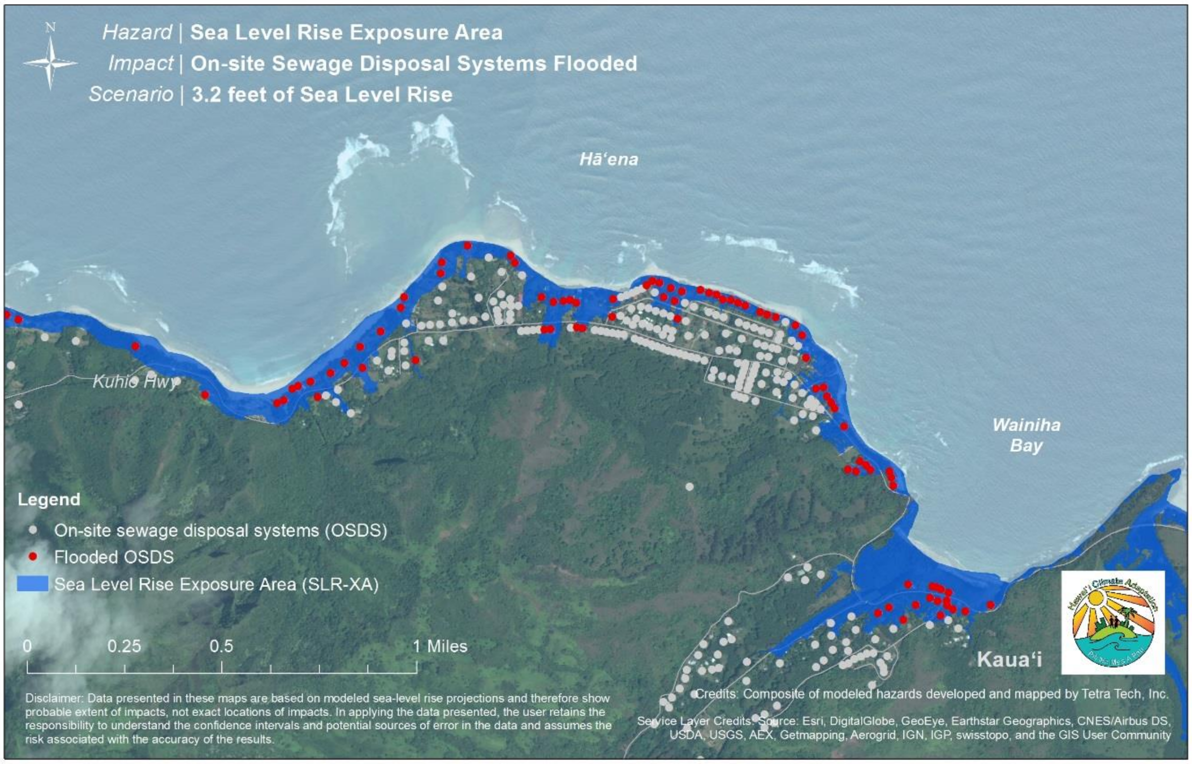


Figure 127. On-site sewage disposal systems flooded in the SLR-XA with 3.2 feet of sea level rise in Hā'ena, Kaua'i

Challenges and Opportunities

Over the next 30 to 70 years, properties located on or near Kauai's shorelines will increasingly be flooded, eroded or completely lost to the sea. Portions of coastal roads will also become flooded, eroded, impassible, and irreparable jeopardizing access to and from many communities. Beaches will increasingly be eroded and permanently lost if hard structures such as roads and seawalls impede their landward migration. The flooding of hotels and transportation systems, along with the loss of beaches, would impact not only the people whose livelihoods depend on it, but the State's economy which relies heavily on revenues from the tourism industry. This Results section highlights just a few of the very real challenges on Kaua'i with a scenario of 3.2 feet of sea level rise by the mid- to the latter-part of the century.

Sea level rise will not stop at the middle or end of the century. As highlighted throughout this Report, higher sea level rise projections are considered "physically plausible" by the end of the century based on the latest climate science (Sweet et al. 2017, Le Bars, Drijfhout, and de Vries 2017). While this Report models sea level rise up to 3.2 feet, it should be noted that NOAA has modeled passive flooding scenarios with up to 6 feet of sea level rise in their Sea Level Rise Viewer (NOAA 2017b). To illustrate potential impacts from higher sea level scenarios, the 5-foot passive flood layer from NOAA was incorporated into our vulnerability assessment which increases the area of the SLR-XA on Kaua'i by 29%. Figure 128 shows the potential extent of 5 feet of passive flooding with sea level rise in the community of Wailua. While there is uncertainty over when the islands might experience such extreme sea level rise, the information is provided merely to remind readers that sea level rise is going to continue for the remainder of the century and beyond.

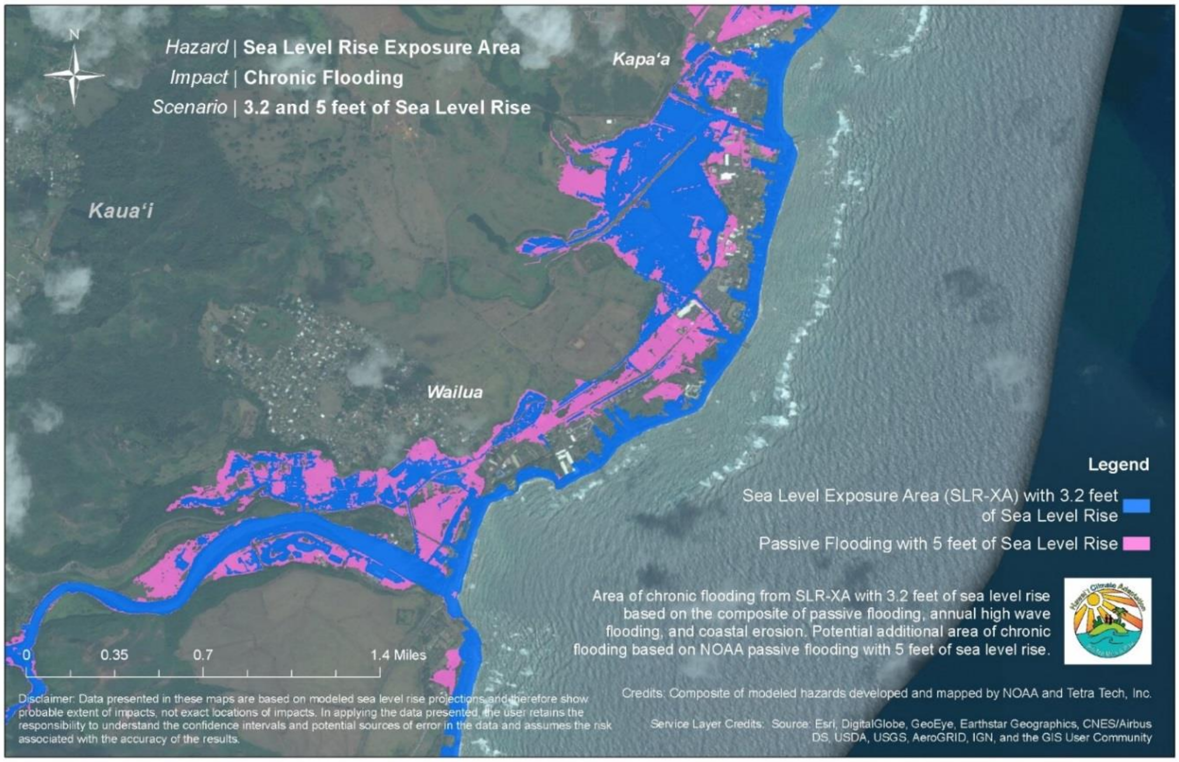


Figure 128. Potential additional area of chronic flooding with 5 feet of sea level rise in Wailua, Kaua'i

Kaua'i has opportunities to plan for sea level rise now by considering County General Plan and Community Plan updates that recognize the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone and to plan for future land use now. In addition to chronic coastal flooding from sea level rise, tropical storms, hurricanes, and tsunamis create waves that flood low-lying coastal areas. The added risk from event-based coastal flooding exacerbated by sea level rise is not included in this Report. However, these events pose a potential for loss of human life and property, and for severe and long-term economic disruption. Communities should consider planning new development to reduce exposure from severe events by recognizing that the coastal floodplain will migrate landward with increased sea level. Hazard mitigation and disaster recovery projects should be reviewed and revised to address chronic and event-based flooding and consider the additive effects of accelerating sea level rise.

SEA LEVEL RISE STORIES

Kauaʻi County

CONSIDERING SEA LEVEL RISE IN THE COUNTY'S GENERAL PLAN

As Kaua'i County works to update their general plan, sea level rise impacts and adaptation strategies are being considered for the first time in the county's long-range planning. To do this, the County approached the University of Hawai'i Sea Grant College Program to prepare a technical study on climate change and coastal hazard impacts to inform the General Plan which hadn't been updated since 2000.

The study, the Kaua'i Climate Change and Coastal Hazards Assessment, is groundbreaking in that it marks the first time that climate change impacts will be considered in the long-range planning of the Kaua'i General Plan. Kaua'i County has been active in some sea level rise adaptation measures to date, but this effort will be the first time that language is included in the General Plan, informing actions across county departments for the next 30 years.

The incorporation of climate change adaptation into long-range planning such as the Kaua'i County General Plan is critical for cohesive and sustained response to sea level rise. Kaua'i Planning Director Michael Dahilig expressed the need to act to address sea level rise, "We're trying to get ahead of the curve in anticipating that yes, given all the science, given everything that is pointing in this direction, we may not see it immediately now but we anticipate it and that's just good planning in general."

You can read more of this story at
climateadaptation.hawaii.gov/climate stories

Northwestern Hawaiian Islands

The Northwestern Hawaiian Islands (NWHI) are comprised of small islands, atolls, and shoals located to the northwest of the islands of Kaua'i and Ni'ihau (Figure 129). These islands are part of the State of Hawai'i, with the exception of Midway Atoll which is an unincorporated territory of the United States. Spanning more than 1,200 nautical miles, all of the islands are uninhabited, little known, and rarely visited. Only a few wildlife managers, researchers, and cultural practitioners are allowed to visit on a temporary basis. While the total land area of the NWHI is only 3.1 square miles (the main Hawaiian Islands has a total land area of 5,362 square miles) the islands, atolls, shoals and waters of the NWHI are highly protected because of the area's biological, cultural, and historical resources and significance. Because of this, the Northwestern Hawaiian Islands Marine National Monument was established by Presidential Proclamation on June 15, 2016, and a year later it was given its Hawaiian name, Papahānumokuākea. The name Papahānumokuākea commemorates the union of two Hawaiian ancestors—Papahānumoku and Wākea—who gave rise to the Hawaiian archipelago, the taro plant, and the Hawaiian people. The Papahānaumokuākea Marine National Monument (PMNM) encompasses all the NWHI (Figure 129) and includes the Midway Atoll National Wildlife Refuge and the NWHI National Wildlife Refuge. The PMNM is globally recognized as a United Nations Educational, Scientific, and Cultural Organizations (UNESCO) site.

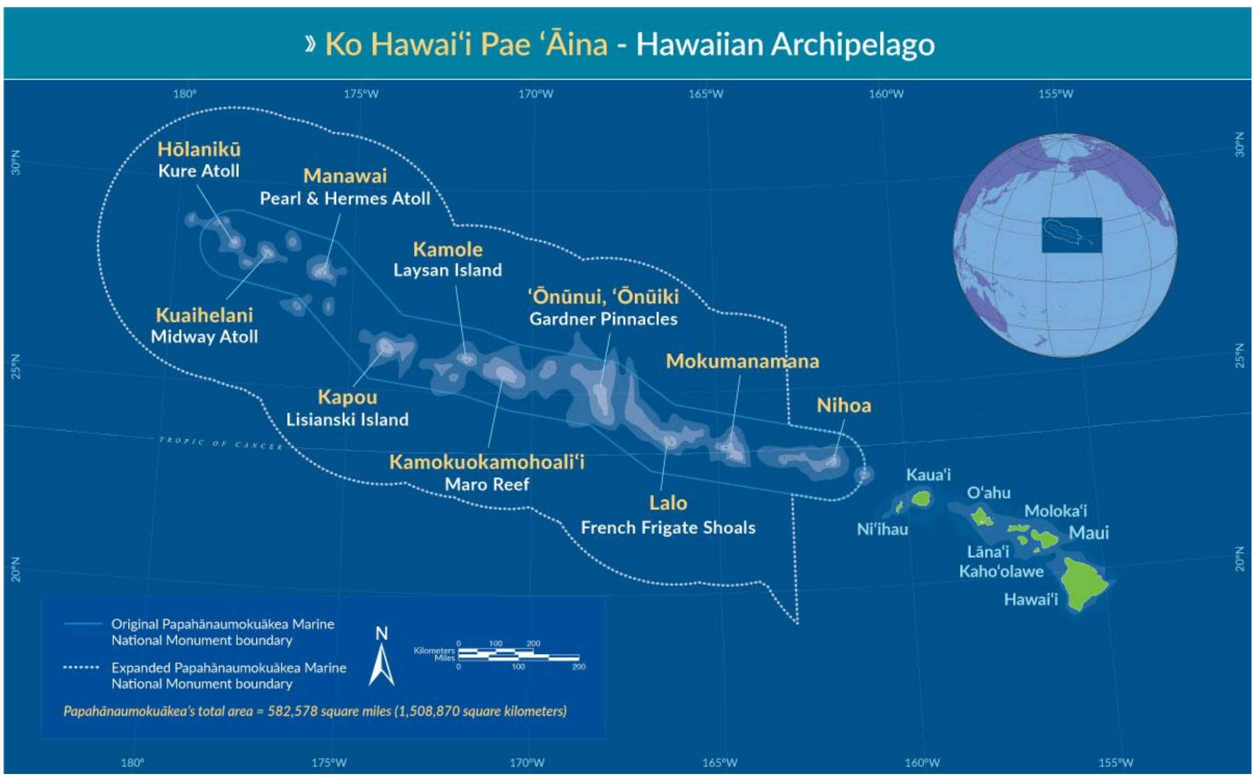


Figure 129. Northwestern Hawaiian Islands and the Papahānaumokuākea Marine National Monument (NOAA Office of Marine National Sanctuaries 2017)

Key Take Aways

- Flooding and loss of beaches utilized as hauling-out sites for resting and pupping, could threaten the endangered Hawaiian monk seal population.
- Flooding and loss of Hawaiian green turtle nesting areas, especially the area of French Frigate Shoals where 90% of the species' population nests, could cause dramatic migration or decline in population.
- Flooding and loss of low-lying coastal lands, which serves as seabird nesting habitat for 25 protected migratory birds, could cause migration or decline in populations.
- Flooding due to sea level rise could cause significant land loss to the already small land area of the NWHI. With 6.6 feet of sea level rise, some atolls could be submerged completely.

The coral reef and low island ecosystems of the NWHI are among the places most vulnerable to climate change (Wagner and Polhemus 2016). Changes in ocean circulation, chemistry, and productivity may result in impacts to wildlife that inhabit both land and sea. In the context of sea level rise, it is very likely that within the next 50 to 100 years, NWHI's low-lying atolls will be submerged with some atolls being affected sooner and more extensively (Wagner and Polhemus 2016). Beach and coastal strand habitats are very likely to be lost as a result of sea level rise, storm inundation, and erosion with significant implications for endangered species that rely on these habitats for nesting and breeding, including monk seals, sea turtles, and seabirds. Inland waters, both freshwater habitats and the hypersaline lake on Laysan, are likely to be degraded by passive flooding, storm overwash, and changes in precipitation, compromising critical habitats for a range of endemic and protected species.

Potential Impacts of Sea Level Rise

HAWAIIAN MONK SEALS

Protected under the Endangered Species Act (ESA), Marine Mammal Protection Act (MMPA), and Hawai‘i state law, ‘Ilio-holo-i-ka-uaua or Hawaiian monk seal (*Neomonachus schauinslandi*) is one of the most endangered marine mammals in the world (NOAA Fisheries 2017c). Endemic to Hawai‘i, the main population of Hawaiian monk seals reside in the NWHI. The best estimate of the current total Hawaiian monk seal population is 1,400 seals; about 1,100 in the NWHI and about 300 in the main Hawaiian Islands (from Ni‘ihau to Hawai‘i). The overall population decline in the NWHI has been moderated by the increasing population of seals in the main Hawaiian Islands. The most recent annual population assessment shows that the Hawaiian monk seal, bucking past trends, has increased in numbers by 3% annually for the past three years. While numbers have increased since 2013 across the archipelago, the long-term decline in abundance at the six main NWHI sites (French Frigate Shoals, Laysan, Lisianski, Pearl and Hermes, Midway, and Kure) remains concerning.

Endangered Hawaiian monk seal with pup on French Frigate Shoals
(Source: U.S. Fish and Wildlife Service [USFWS])

In the NWHI, the monk seals area already dealing with the loss of terrestrial habitat, especially at French Frigate Shoals, where pupping and resting islets have shrunk or disappeared (Reynolds et al. 2012, Antonelis et al. 2006). The French Frigate Shoals (Figure 130), located in the center of the NWHI (Figure 129), is the primary pupping and resting site for Hawaiian monk seals throughout the Hawaiian archipelago. The loss of atoll islets, such as French Frigate Shoals will increase with sea level rise. However, efforts to mitigate this ongoing loss of habitat are already being taken. Specifically, the rules under the ESA regarding Hawaiian monk seal critical habitat have been revised to expand the critical habitat designation to the NWHI and include new areas in the main Hawaiian Islands to reflect new information about Hawaiian monk seal habitat use (NOAA Fisheries (2017a). Critical habitats are geographic areas that contain features that are essential to the conservation of a threatened or endangered species and that may require special management considerations or protections. The critical habitat areas contain one or a combination of the features essential to Hawaiian monk seal conservation including preferred pupping and nursing areas, significant haul-out areas, and marine foraging areas out to 200 meters in depth (Figure 131).

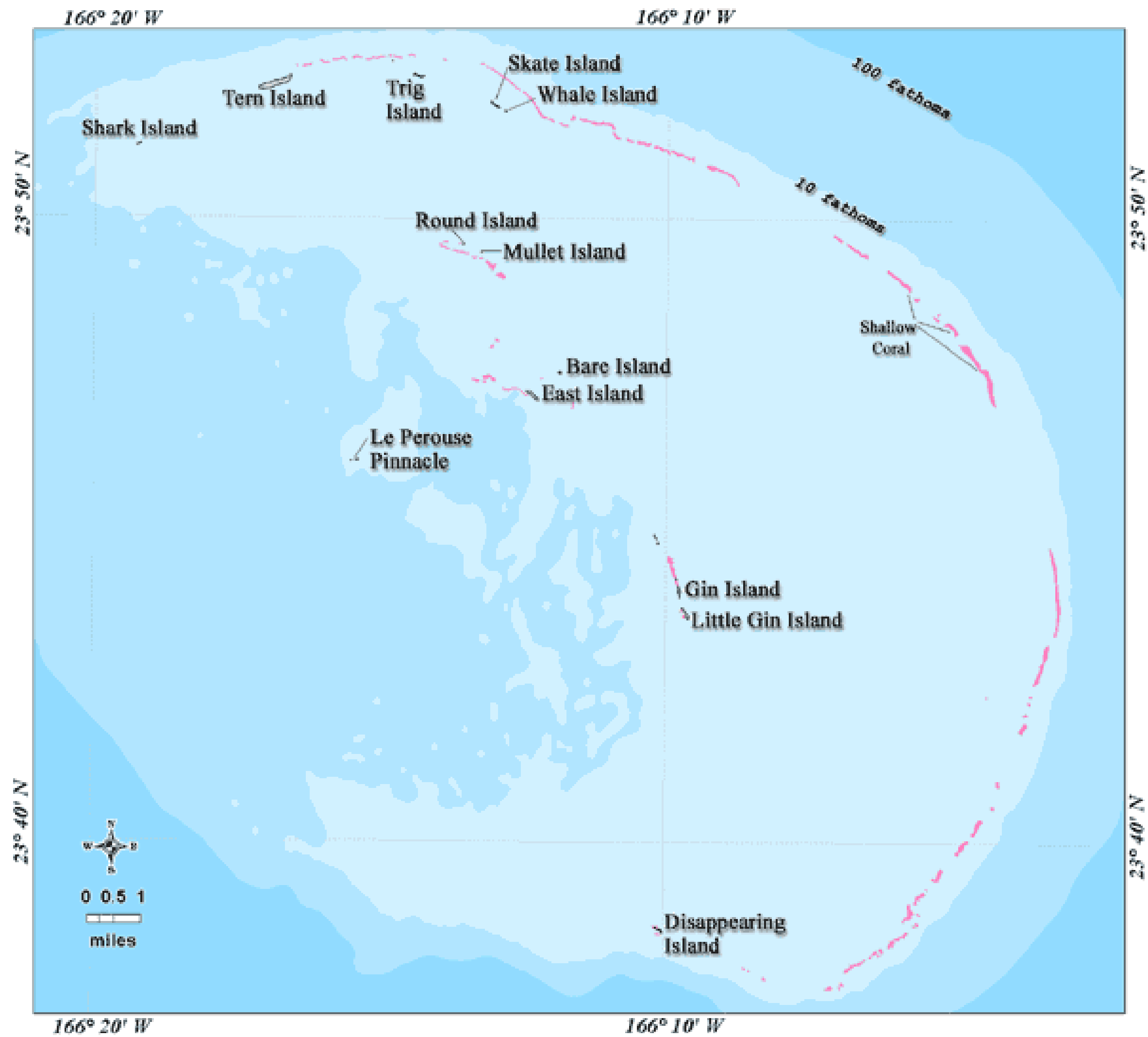


Figure 130. Islands and reef areas of French Frigate Shoals in the Northwestern Hawaiian Islands

Endangered Hawaiian monk seals are likely to be adversely affected by sea level rise as their breeding sites and haul-out sites are inundated and eroded and the abundance of their prey is reduced (Wagner and Polhemus 2016). In order to mitigate the effects of sea level rise, we should being planning for the landward migration of the terrestrial portion of the monk seal critical habitat in the main Hawaiian Islands so that we can ensure the survival of the species with rising seas.

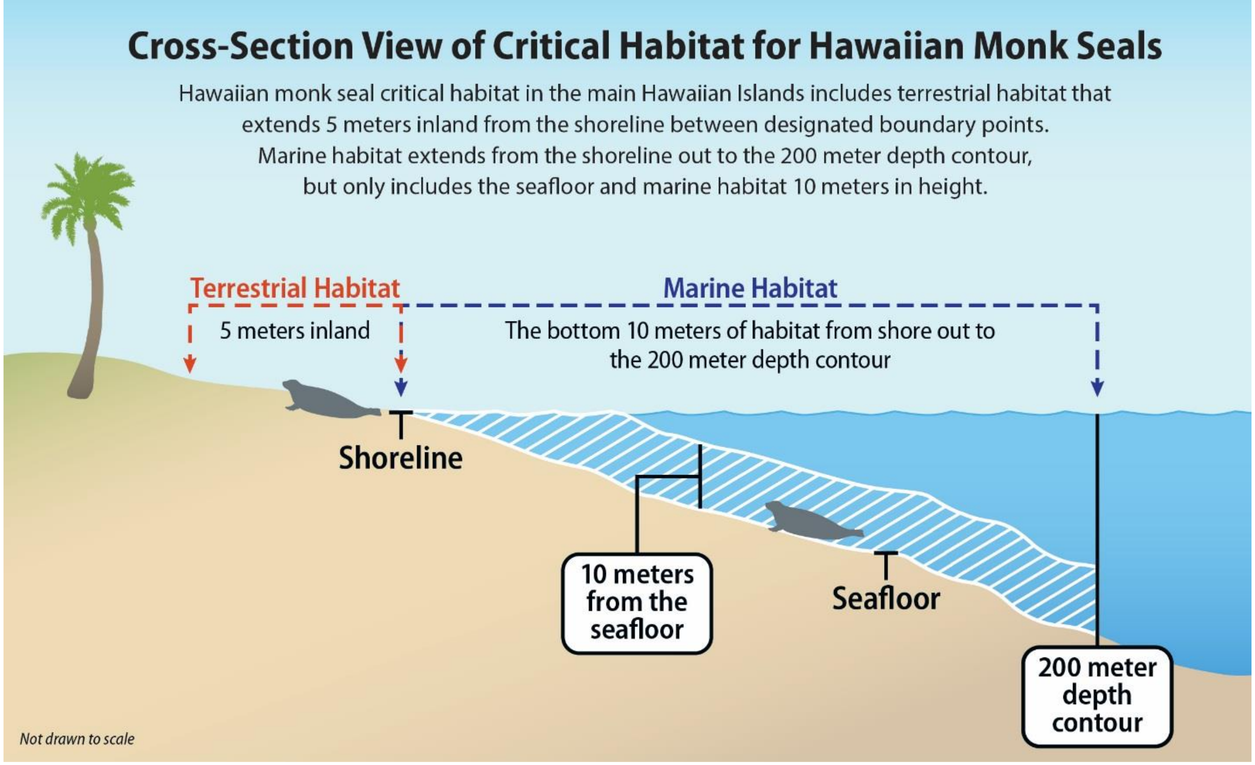


Figure 131. Cross-section view of critical habitat for Hawaiian monk seals designated under the Endangered Species Act adapted from NOAA Fisheries (2017a)

Hawaiian monk seal resting on higher ground in West Maui during tidal flooding in 2017 illustrating the landward migration of critical habitat (Source: Asa Ellison)

HAWAIIAN GREEN TURTLE

The threatened honu or Hawaiian green turtle (*Chelonia mydas*) is also protected under the ESA and Hawai‘i State Law. While green turtles are found throughout tropical and subtropical areas of the world, the threatened Hawaiian green turtle is genetically distinct from the other green sea turtle populations (NOAA Fisheries (2017b). While this species was in a steep decline due to the direct harvesting of both the turtles themselves and their eggs by humans in the NWHI and main Hawaiian Islands (Van Houtan et al. 2012, Kittinger et al. 2013, Van Houtan and Kittinger 2014), the population has grown steadily over the last thirty years following ESA protection in 1978.

Hawaiian green turtles nest throughout the archipelago in at least five major nesting sites; four of which are in the NWHI (Kittinger et al. 2013) and they migrate to feed mainly in the coastal areas of the main Hawaiian Islands. Today, more than 90% of the population of the Hawaiian green turtles nests solely on East Island at French Frigate Shoals (Figure 130) (Pilcher, Chaloupka, and Woods 2012). This location is particularly vulnerable to sea level rise due to low elevation of nesting sites. (Baker, Littnan, and Johnston 2006). Sea level rise will flood and erode existing and potential new nesting beaches for Hawaiian green turtles. Therefore, it would be prudent that we begin planning for the migration of this species to beaches suitable for nesting on the main Hawaiian Islands.

Threatened Hawaiian green turtle at French Frigate Shoals (Source: NOAA)

SEABIRDS

The NWHI is the largest tropical seabird rookery in the world, hosting over 5.5 million breeding adult seabirds (Keller et al. 2009). It provides nesting habitat for 25 species that are protected under the Migratory Bird Treaty Act, including the short-tailed albatross, which is also listed under the ESA (Wagner and Polhemus 2016). In addition, 95% of the world’s Laysan and black-footed albatrosses nest in the NWHI, as do globally significant colonies of Bonin petrels and Tristam’s storm petrels. Some of the largest colonies of white terns and red-tailed tropicbirds in the Central Pacific are found in the NWHI, and numerous shorebird species overwinter or transit through NWHI during their migrations to the north and south. Endemic birds found in the NWHI's include remarkably isolated species such as the Nihoa finch, Nihoa millerbird, Laysan finch, and Laysan duck, one of the world's rarest ducks. Of these four species, the Laysan finch is listed as vulnerable by International Union for Conservation of Nature (IUCN) and the other three are listed as critically endangered.

The majority (72%) of the world's nesting population of mōlī or Laysan albaltross (*Phoebastria immutabilis*), resides on Midway Atoll (Figure 132). Wisdom, the oldest known banded bird in the wild, is a female Laysan albatross that nests within the world's largest albatross colony on Midway Atoll National Wildlife Refuge. She is at least 65-years old and is a world renowned symbol of hope for all species that depend upon the health of the ocean to survive. As with Hawaiian monk seals and green turtles, sea birds and other wildlife that depend on low-lying coastal areas throughout the Hawaiian archipelago are expected to become sea level rise refugees seeking new safe areas to reproduce, feed, and take care of their young. Land use decisions and sea level rise adaptation planning in the main Hawaiian Islands should consider and accommodate the needs of protected species.

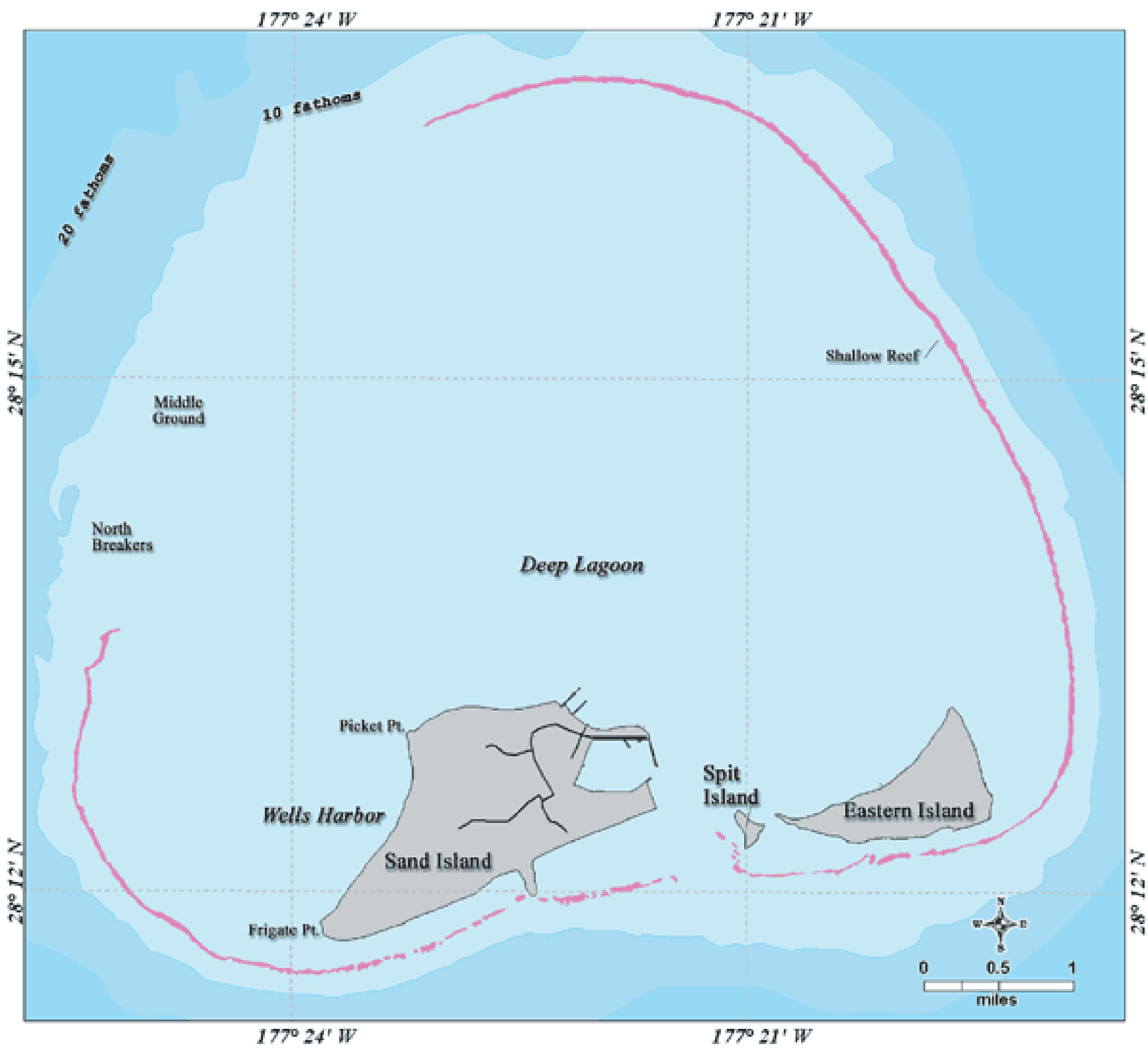


Figure 132. Islands and reef areas of Midway Atoll in the Northwestern Hawaiian Islands

Nesting grounds of Laysan albatross and black-footed albatross at Midway Atoll (Source: USFWS)

Wisdom and her mate, the oldest known tagged Laysan albatross in the world at Midway Atoll (Source: USFWS)

Overwash from tsunamis and storms at Midway and other Northwestern Hawaiian Islands will become more severe with sea level rise (Source: USFWS)

The NWHIs tangible cultural and heritage resources, which include historical and archeological sites and artifacts, will be negatively affected by climate change and sea level rise. More frequent or intense flooding and erosion from storms and high waves could damage archeological and sacred sites on Nihoa and Mokumanamana, potentially uncovering or submerging iwi kūpuna or ancestral bones. In addition to the vulnerability of tangible cultural and heritage resources, there are intangible values associated with the NWHI; universal values, Native Hawaiian values, heritage values, and values derived from PMNM's opportunity to serve as an exemplar site for science and management. As in the past, Hawaiian traditional ecological knowledge could persist through engaging with changing conditions.

RECOMMENDATION HIGHLIGHTS

- Develop an archipelagic-wide inventory of Native Hawaiian cultural resources and practices impacted by sea level rise.
- Develop a culturally-based adaptation process and protocols to preserve Native Hawaiian cultural resources and practices with sea level rise.

POTENIAL LAND LOSS

Some modeling efforts, independent of this Report, have attempted to quantify the potential loss of land in NWHI due to flooding with sea level rise (Berkowitz et al. 2012, Krause et al. 2012). These models considered either passive flooding, wave-driven flooding, or a combination of both, to estimate the area flooded under scenarios of 3.3 feet or 6.6 feet of sea level rise. On Laysan Island, where the mean elevation is 14 feet, land loss was estimated between 1.6% (passive flooding only) to 12.0% (wave flooding with passive flooding) with 3.3 feet of sea level rise (Berkowitz et al. 2012). With 6.6 feet of sea level rise, those land loss percentages increase to 3.8% and 29.6% respectively (Berkowitz et al. 2012). On Spit Island, which is a part of Midway Atoll and whose mean elevation is 2.6 feet, passive flooding with 3.3 feet of sea level rise could cause over 73% land loss and the atoll could be completely submerged with 6.6 feet of sea level rise (Krause et al. 2012). Land loss of this magnitude could force animals who use the island, such as seals, turtles, and seabirds, to seek refuge on higher islands such as in the main Hawaiian Islands.

RECOMMENDATION HIGHLIGHTS

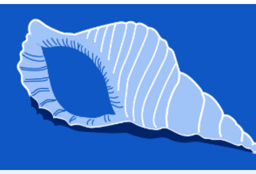
- Expand the area of national, state, and county parks and wildlife refuges on the main Hawaiian Islands to preserve wetlands and wildlife.

Challenges and Opportunities

Sea level rise, together with potential increased severe storm activity will render the low-lying atolls, islands, and islets extremely vulnerable to passive flooding, high-wave overwash, and coastal erosion. The loss of beaches, coastal vegetation, and other habitats, and ultimately complete islands could make the area uninhabitable for many of the unique, threatened, and highly endangered species. While strategies to protect some islands through engineering solutions may provide relief for some species, there is a need to plan for the migration and accommodation of many wildlife species on the main Hawaiian Islands. This migration could add to existing conflicts between humans and wildlife on the main Hawaiian Islands. Extensive education and outreach, coupled with increased surveillance and enforcement in the main Hawaiian Islands will be needed to ensure that wildlife is able to persist with humans in the face of the challenges posed by sea level rise. More detailed modeling and improved monitoring of impacts from passive flooding, wave overwash, and coastal erosion should be an integral part of observing and forecasting the sustainability of NWHI terrestrial habitats over the coming decades with climate change and sea level rise.

SEA LEVEL RISE STORIES

Kaʻena Point, Oʻahu as a Refuge



EXPANDING PROTECTED HABITAT FOR THREATENED AND ENDANGERED MARINE SPECIES WITH SEA LEVEL RISE

Oahu's western most extent, Kaʻena Point Natural Area Reserve has a dream-like quality about it—sapphire blue waves wash the rocky shores, native plants cover the white coralline beaches, and the calls of seabirds float over the air. The seabirds, such as Laysan albatross and wedge-tailed shearwater, nest in the vegetation while not foraging at sea.

Fortunately, sea level rise is not projected to impact Kaʻena Point severely, making it an important refuge for future climate change adaptation as many refugia on low-lying atoll islands in the NWHI will see the effects of sea level rise. According to Beth Flint, U.S. Fish and Wildlife Service National Wildlife Refuge Manager, millions of seabirds are at risk from climate change and sea level rise. Rising seas will directly impact their ability to nest and raise young in coastal habitats, and the warming of the seas will affect their ability to find food. It is imperative to find solutions to such problems now, rather than wait for these events to reach a tipping point. Once a population declines severely, it takes several years to establish new colonies.

Habitats like Kaʻena Point provide excellent research venues for wildlife biologists to understand colony dynamics, and seek answers to climate change impacts on seabirds. Such refugia also serve as excellent education tools. Most people will never get to see the NWHI due to restricted access. But because Kaʻena Point hosts similar ecosystems to those of the NWHI, it can serve as a window into the biological and cultural importance of the NWHI and inspire more protection of both locations.

The Kaʻena Point Natural Area Reserve should continue to be maintained and protected as marine mammals and seabirds from the NWHI are forced to seek refugia in the main Hawaiian Islands. In addition, other coastal sites that could serve as potential refugia should be identified and protected—which will become increasingly difficult as sea level rise puts pressure on coastal development across the State.

You can read more of this story at
climateadaptation.hawaii.gov/climate stories

Learning Questions for the 5-Year Report Update

Learning questions for the Results chapter of this Report highlight the need to monitor vulnerability assessment results with observations over time. As the results of the vulnerability assessment are based on global projections of sea level rise, there is a need to monitor conditions on the ground over time. As such, learning questions for the 5-year Report update include:

1. To what extent is potential chronic flooding in the SLR-XA with 1.1 foot of sea level rise aligned with areas currently exposed to chronic flooding?
2. Are there any new developments or critical infrastructure in the SLR-XA with 3.2 feet of sea level rise not accounted for in the vulnerability assessment?
3. To what extent have land and structure values for parcels in areas potentially impacted by sea level rise changed as a basis for estimating potential economic loss?
4. To what extent has human migration from other Pacific Islands and wildlife migration from the NWHI to the main Hawaiian Islands changed?
5. What adaptation measures have been taken to reduce vulnerability to sea level rise?

Recommendations

ʻAʻohe hana nui ke alu ʻia. No task is too big when done together by all.

There is an ʻōlelo noʻeau, a Hawaiian proverb, that gives insight into a clever method that the ancient Hawaiians once used in response to flooding—Mānā, i ka puʻe kalo hoʻoneʻeneʻe a ka wai. Translated, it means "Mānā, where the mounded taro moves in the water." The story behind the proverb takes place in Mānā, Kauaʻi, which was once home to deep water kalo (taro) patches that flooded for several weeks during the rainy season. To save their crops, the mahiʻai kalo, (taro farmers) would construct rafts and paddle out to the kalo patches where they would dive down and carefully wiggle the roots of the kalo free from the soil, bringing the kalo to the surface one by one. Once the plants were at the surface, they would secure the stalks to the rafts so that their leaves could continue to grow above water. Eventually, the entire patch became a floating network of rafts and kalo plants, thus saving the crops. We must endeavor to be as cleaver and resilient as the mahiʻai kalo.

Call to Action

"We need to teach/educate everyone on sea level rise risks and what each individual can do to help reduce risks. State and county governments should incorporate sea level rise risk into all infrastructure plans, support smart growth, and provide space place for wildlife to migrate. The results of these activities will help make sure people are aware of and establish policies and programs that help to reduce sea level rise risks."

Group message developed during the 1st Sea Level Rise Vulnerability and Adaptation Workshop
Oʻahu, January 2016

This chapter introduces various recommendations and recommended actions to improve our capacity to ameliorate the social, economic, and environmental impacts of sea level rise (Figure 133). The adaptation strategies are by no means all-encompassing, and to some extent, fall short of offering complete solutions to the problem of a rising sea, for complete solutions go beyond governance and policy actions. Natural, economic, political, and social systems all have a great deal of intrinsic momentum that will challenge our ability to adjust and adapt to this unfolding crisis. At best, we hope that the recommendations and recommended actions discussed herein provide a strong basis for the people of Hawaiʻi to continue, in earnest, the climate adaption discourse despite its daunting specter.

At the onset of the Report, we explained that there is uncertainty in the scientific community on the exact timing and rates of sea level rise. The former ICAC initially agreed to accept the upper-end IPCC projection of 1.1 feet of sea level rise by mid-century and 3.2 feet of sea level rise by the end of this century as planning benchmarks out of precaution and to examine what is potentially vulnerable.

Science and forecasts of sea level rise have evolved rapidly since the 2014 IPCC AR5 and over the three years that this Report was developed, with the evolution primarily in the direction of higher sea level scenarios. As described in the Sea Level Rise Outlook Chapter, NASA has reported that at least 3 feet of sea level rise is inevitable given the GHG emissions and warming we have already added to the climate system, though questions remain around the exact timing of that rise due largely to uncertainties around future behavior of Earth's cryosphere and global GHG emission trajectories. NOAA's 2017 report (Sweet et al. 2017), which reviewed the most up-to-date scientific literature on sea level rise, describes 3 feet of sea level rise in this century as an intermediate scenario and includes a "physically plausible" upper end scenario of over 6 feet of sea level rise by the end of this century. Tidal flooding in 2017 showed us that 1 foot of sea level rise is a present to near-term scenario that will be experienced with increasing frequency and severity over the next few decades. Thus, as you examine the recommendations, strategies, and actions that follow, please read them with a sense of urgency. Think about the things we can start today to lay groundwork for a smoother transition to accommodate changing shorelines. Do not let the uncertainty of "when and how much" sea level rise is going to happen dissuade you from acting now.

At the core of an adaption strategy for Hawaiʻi is a commitment to support sustainable and resilient land use and community development (Recommendation 1). Community resiliency should be thought of as a core societal value that can serve as the anchor or center of our State's comprehensive adaption strategy. As seen in Figure 133, each recommendation nestles around the anchor, both supporting it and working outward from its core. Recommendation 9, "Promote collaboration and accountability for adapting to sea level rise," provides guidelines to help us collaborate within and between all levels of government and walks of life. Such togetherness, or "ʻAʻohe hana nui ke alu ʻia", might be realized and perpetuated in such things as the Hawaiʻi Climate Commission, the City & County of Honolulu Office of Climate Change, Sustainability and Resiliency, Hawaiʻi Green Growth, and other sustainability and resiliency efforts being undertaken throughout the State.

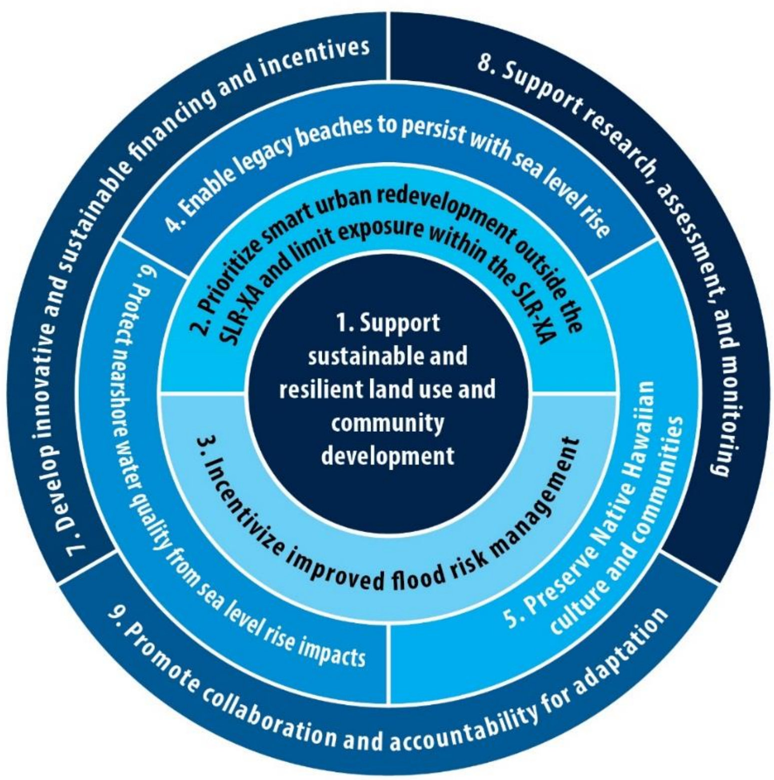


Figure 133. Recommendations to increase Hawaii's capacity to adapt to sea level rise

Throughout this Chapter, we refer to a "Comprehensive Adaptation Strategy" which may multiple strategies such as managed retreat, avoidance, and protection. We want to be clear to readers that this is a technical report. ***It is not a comprehensive adaptation strategy***. Recommendations are provided only to highlight potential actions and consequences which could be components of a comprehensive adaptation strategy. This strategy should be part of our long-range state-wide planning framework.

Recommendation 1: Support sustainable and resilient land use and community development

Overview

Shorefront communities have valued assets, such as homes, shopping centers, roads, schools, critical infrastructure, and beaches, at risk to chronic flooding. Protection of these built and natural assets from the effects of sea level rise is critical to sustaining our State's long-term health and well-being. However, the loss of land designated for urban use due to sea level rise will increase pressure to convert agricultural and conservation lands for urban expansion, and encroaching seas may lead to an increase in the number of seawalls and other shoreline protection structures which damage our beaches and intertidal environments. It is therefore paramount that government and private sector entities be given appropriate guidance to accommodate sea level rise threats to improve sustainability and resilience at community, island, and state levels.

The following Recommended Actions are designed to lay the groundwork for identifying more specific sea level rise adaptation strategies that support resilient and sustainable land use and community development and to form the basis for improved flood zone management as well as managed retreat strategies. No doubt, hard decisions at all levels of government will need to be made, such as, when to flood proof structures in place, versus when to demolish and move structures and facilities inland and upward; whether or not to protect development with shoreline hardening, or when to let the sea reclaim the land; and when, where, and how to rezone lands to accommodate managed retreat. Figure 134 provides an example of some considerations that could be a part of a comprehensive adaptation strategy utilizing sustainable and resilient land use practices while recognizing the SLR-XA with 3.2 feet of sea level rise[3] as a state-wide vulnerability zone.

[3] For the purposes of this section, all further mentions of the SLR-XA refer to the SLR-XA with 3.2 feet of sea level rise. As mentioned throughout this Report, the science of sea level rise is dynamic and impacts appear to be coming sooner than later. For instance, although past predictions indicate at least 1 foot of sea level rise by 2050, we note in the Sea Level Rise Outlook Chapter that Hawai'i experienced sea level heights close to 1 foot above predicted astronomical tides with the tidal flooding of 2017. These elevated water levels were due to long-term sea level rise and shorter-term Pacific-wide climatic and oceanic variability. We can expect extreme water levels like this to occur with increasing frequency and severity in the next couple decades with increasing sea level rise. Thus, accommodations for sea level rise must be considered today as new development and much of our existing development have expected lifespans well into the latter half of this century.

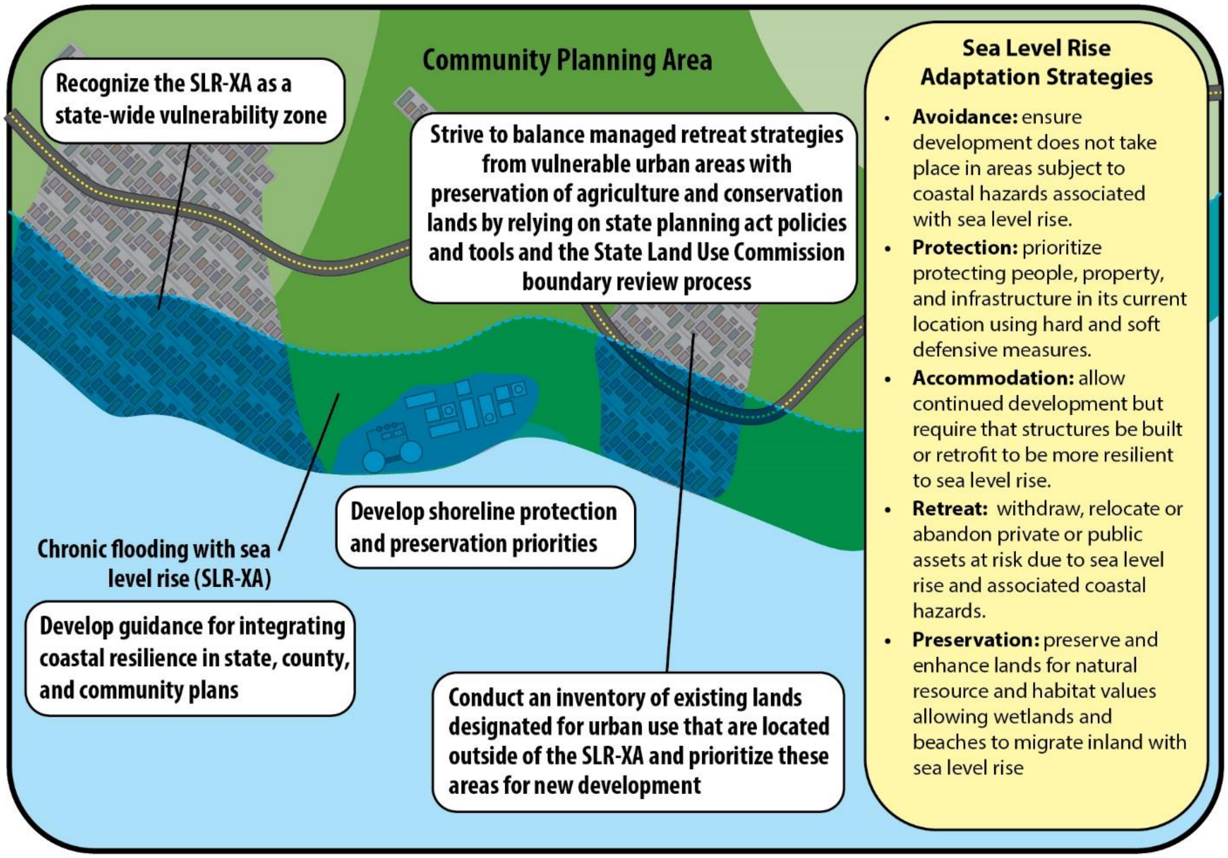


Figure 134. Support sustainable and resilient land use and community development

This Report recommends that the State and Counties recognize the SLR-XA as a state-wide vulnerability zone for strategic planning purposes. In planning, recognition and acceptance of vulnerable areas would enable policy-makers at all levels of government to take stock of conservation, agriculture, urban, and rural land uses at risk from chronic flooding with sea level rise, and to strive to locate new development outside these areas.

State, county, and community plans would need to determine whether to avoid risks by siting development outside areas with chronic flooding, to protect existing development through shoreline hardening, to accommodate new development through floodable design, to retreat from the shoreline by developing outside areas of chronic flooding, or to preserve the shoreline allowing landward migration of beaches, wetlands, and other natural features. Guidance is needed to help state, counties, and communities integrate sustainable and resilient land use and community development into plans and programs. Community plans should serve as a critical entry point for collaborative governance needed to adapt to sea level rise. Community planning can facilitate collaboration among federal, state, and county governments and communities to plan land use, delivery of government services, and any other matters relating to the planning area. Localized vulnerability assessments, including data from this Report, and a community visioning process, are needed as part of this guidance to identify adaptation strategies within and outside areas exposed to sea level rise.

Recommended Actions

1.1 Recognize the SLR-XA as a state-wide vulnerability zone

State and County agencies may consider officially recognizing the SLR-XA as a state-wide vulnerability zone through legislative or executive action. This state-wide vulnerability zone could be employed by agencies to formulate comprehensive adaptation strategies incorporating many of the tools and concepts discussed in this chapter.

As with the Recommendations within this Report, there are priorities, sequencing, and synergies among the Recommend Actions. Recommended Action 1.1 is considered a priority that forms a cornerstone for the following recommended actions in this Report. The recognition of the SLR-XA as an actualized vulnerability zone is mission critical to the State's preparedness for and response to sea level rise, and should be used as "advisory" until comprehensive adaptation plans and strategies can be developed and adopted at state and county levels.

In the meantime, the State and Counties should seek immediate opportunities (low hanging fruit) to implement sea level rise adaptation actions, such as, planning new infrastructure outside of the SLR-XA; strengthening flood design standards for re-development within the SLR-XA and other flood hazard areas where large-scale managed retreat is infeasible at this time; considering amendments to state and local land use policies to promote managed retreat from the shoreline where feasible; taking stock of lands suitable for future development beyond the SLR-XA; protecting "legacy" coastal areas and beaches from inappropriate development; and working with non-governmental sectors to incentivize flood risk avoidance and proper real estate disclosure. Finally, as new climate science and methods emerge, the SLR-XA may need to be revisited and revised, necessitating a "phased" approach to long-term sea level rise adaptation. However, this adaptive management process should not be used as an excuse to delay action. It is highly recommended that, in recognizing a state-wide vulnerability zone, readers remember that sea level rise does not stop at 3.2 feet or at the end of this century. Communities and policy-makers are encouraged to consider long-range planning for anticipated future sea level rise beyond 3.2 feet, particularly for the most critical infrastructure and resources.

1.2 Seek opportunities to plan new development outside of the SLR-XA under long-term, comprehensive managed retreat strategy

It is paramount that we recognize the inherent threat of sea level rise to our coastal communities. Continued investment in new housing development, commercial areas, and critical infrastructure that are located in the SLR-XA must be weighed against the timing and extent of flooding from sea level rise. Efforts must be made to locate new development landward of this vulnerability zone wherever possible. The Results Chapter of this Report (Chapter 4) estimates economic losses from 1.1 foot and 3.2 feet of sea level rise if no adaption measures are taken. For instance, the Island of O'ahu could experience losses (property and structures) of $13 billion with 3.2 feet of sea level rise, but this number does not include losses from infrastructure damage and maintenance, loss of business opportunities, and loss of our (in)valuable beaches and other natural resources. Without a comprehensive adaptation strategy that includes preplanning, incentives, and financing for managed retreat from the shoreline, chronic flooding of structures, land, and businesses would result in unsustainable economic losses in coastal real estate and increasing maintenance costs for infrastructure sited along our coasts (i.e. airports, wastewater treatment facilities, roads, etc.). These and other factors should be considered when we weigh the benefits and costs of permitting development in areas potentially exposed to chronic flooding against the significant up-front costs required to move development landward of the areas vulnerable to sea level rise.

1.3 Conduct an inventory of existing lands designated for urban use that are located outside of the SLR-XA and prioritize these areas for new development

The Office of Planning, together with the Counties, should conduct a lands inventory to identify lands that are available for development or redevelopment within an urban growth boundary, but outside of the SLR-XA. The goal of this process is to identify, assess, and prioritize underutilized land within urban zoned areas that could represent opportunities for redevelopment that would be resilient to sea level rise. Once the inventory is completed and development capacities are estimated utilizing sustainable and resilient land use practices, there should be an assessment of potential developable lands outside of urban growth boundaries suitable for future development (e.g., managed retreat). The inventory should also include a review of any existing redevelopment plans and other related plans and studies to assess consistency with goals related to sea level rise and managed retreat.

For each existing urban zoned area, a variety of factors and existing conditions should be evaluated to determine suitability for development or redevelopment including: total land area, current buildout, vacant/underutilized parcels, flood and other hazard areas, infrastructure capacity and condition, current zoning, and compatibility with existing uses and community plans. Maps, data and qualitative information should be used to aid in the process of inventorying underutilized parcels that could become a key component of a long-term redevelopment and managed retreat strategy. Stakeholder engagement should also be used to provide necessary insight to further refine an understanding of the priority sites on which to focus future development efforts.

The inventory should include, but not be limited to the following factors:

- Existing land use classification and ownership;
- Historic land use patterns;
- Critical land uses such as agriculture and conservation for water resources;
- Areas that are currently eroding;
- Areas where shoreline armoring is already in place;
- Areas that have a high potential for landward migration;
- Areas of particular social, cultural, economic, and environmental value;
- Areas currently supporting critical infrastructure; and
- Anticipated vulnerability and timing of the area to sea level rise impacts;

This process should include the identification of existing assets in urban areas that could be leveraged to support smart redevelopment in areas not vulnerable to sea level rise. This should include the identification of key local and regional assets that could be capitalized on to catalyze redevelopment and private investment in desirable areas. These assets could include the unique characteristics and amenities of the area, anchor institutions, large-scale public infrastructure, terrain and physical conditions, tourist attractions, and recent and planned real estate development among others.

Constraints to potential redevelopment in each area should also be evaluated, including flood hazard areas, sensitive environmental resources such as beaches and wetlands, conservation areas, agricultural lands of importance, and existing infrastructure capacity and condition. This inventory would help identify areas which are most suitable for re-development and could then be evaluated and prioritized as part of an overall smart urban redevelopment managed retreat strategy (see Recommendation 3).

1.4 Strive to balance managed retreat strategies from vulnerable urban areas with preservation of agriculture and conservation lands by relying on state planning act policies and tools and the State Land Use Commission boundary review process.

The Hawai‘i State Land Use Law classifies all lands in the State as urban, rural, agricultural, or conservation, specifying uses and activities within district boundaries. Since the law was enacted, changes in land use districts have been approved as a result of individual reclassification petitions and three 5-year boundary review amendments (State of Hawai‘i Office of Planning 2006).

The Hawai‘i State Land Use Commission (LUC) is responsible for implementing the Hawai‘i State Land Use Law and is responsible for establishing and amending the land use district boundaries for the entire State. This makes them vital to a smart, managed retreat strategy. As it is the LUC’s job to act on petitions for land use boundary changes submitted by private landowners, developers, and state and county agencies, they should be given specific legislative authority to develop an explicit policy to address managed retreat onto agriculture and conservation lands that supports the State’s sustainability goals and protects these lands to the greatest extent possible. Actions that seek to redesignate agriculture and conservations lands should include strict performance guidelines that minimize urban sprawl, promote energy and transportation efficiencies, avoid hazards, and protect important agricultural lands and natural resources.

Further, the LUC should be granted specific legislative authority through HRS Chapters 205 to amend the State Land Use District classifications to not only accommodate urban expansion into areas outside of the SLR-XA, but to also direct growth to appropriate areas in ways that reduce sprawl, reduce hazard exposure, and preserve environmentally sensitive, culturally significant, and agriculturally important areas. The information presented in this Report provides data, assessments, and recommendations that form a practical and factual basis from which the LUC could support and act upon a managed retreat strategy as part of a subsequent boundary review. Special attention should be given in this review to identify and strengthen protections for agricultural and conservation lands needed to support sustainable and resilient communities.

1.5 Integrate sea level rise adaptation plans and policies into state, county and community plans

The Hawai‘i State Planning Act (HRS Chapter 226) was amended in 2012 with the addition of the Climate Change Adaptation Priority Guidelines (Act 286). These guidelines were created to encourage the collaboration needed to address climate change, recognizing that impacts will occur to multiple sectors including agriculture, conservation lands, coastal and nearshore marine areas, natural and cultural resources, education, higher education, energy, health, historic preservation, water resources, the built environment, and the economy (State of Hawai'i Senate 2012).

As the Hawai‘i State Planning Act identifies the Office of Planning as the agency that shall provide technical assistance in administering this law, the Office of Planning, together with its partners, should develop specific guidance for applying the Climate Adaptation Priority Guidelines of the State Planning Act (HRS §226-109) and the recommendations/recommended actions from this Report to address sea level rise impacts in plans and programs within the state planning system. The guidance should help planners, together with communities, integrate the best available science and methodologies for assessing our State’s vulnerability to coastal hazards with sea level rise and identify and evaluate adaptation options including managed retreat. A community visioning process is needed as part of this guidance that would help planners and communities envision an aspirational future including sea level rise adaption to generate social awareness, ownership, and acceptance of the needs and opportunities of achieving that vision. A phased and incremental planning process may be necessary with triggers for implementing specific strategies such as those adopted by the California Coastal Commission (ESA 2016, California Coastal Commission 2015). Updated plans should support the overall goal of sustainable and resilient community development. This guidance should also be reviewed and adopted by the Hawai‘i Climate Commission. Further, the Office of Planning should periodically review selected State and County plans and programs for consistency with the Climate Adaptation Priority Guidelines as well as future policies that may be developed, and report the status of its implementation to the Hawai‘i Climate Commission.

Federal, state, and counties around the United States are developing similar guidance and tools to support sustainable and resilient land use and community development. For example, FEMA has developed guidance for integrating risk into general, comprehensive, and land use plans (FEMA 2015). FEMA’s guidance encourages integration or the two-way exchange of information and incorporation of ideas and concepts between hazard mitigation plans (state and local) and other community plans. California’s General Plan guidelines require that sea level rise exposure be considered as a factor in developing an inventory of land suitable for development (State of California 2017). In addition, the California Coastal Commission has developed guidelines for addressing sea level rise in local coastal programs and coastal development permits (California Coastal Commission 2015, 2017).

1.6 Develop shoreline protection, conservation, and restoration priorities and guidelines

Shoreline armoring is either prohibited or heavily discouraged under the Hawai‘i CZM Act unless a statutory exemption is in place or a waiver has been obtained. The DLNR and Office of Planning, along with the

Counties, should identify near-term and long-term shoreline conservation and restoration priorities to support adaptation to sea level rise. Each island has existing shoreline armoring that includes seawalls, floodwalls, bulkheads, revetments, and other similar structures that are used to protect infrastructure and property. These structures have had an overall negative impact on beach resources and public shoreline access. While Hawai‘i state law currently prohibits or discourages hard armoring, it is likely that pressure for such variances would increase as the effects of sea level rise become more pronounced. Proactive policies and guidelines are needed to combat reactive or emergency variances that are implemented in a piecemeal fashion and that may not be in the public interest, cost-effective, or successful.

A systematic assessment and decision-making framework is needed to identify shoreline conservation and restoration priorities that is holistic, transparent, and incorporates stakeholder feedback. This decision-making framework would need to be reconciled with natural and cultural resources conservation priorities and recommendations (see Recommendations 5 and 6). County regulations and guidelines should be reviewed and revised in the context of these priorities. Shoreline armoring variances should be an option of last resort and conditioned to minimize risk of adverse impacts on beach processes. Variances could similarly be conditioned to prohibit future repairs and to not allow property owners to seek variances or permits to expand or strengthen such structures in the future. County ordinances could also require property owners to consider relocation of residences and non-structural or soft-armoring protection methods before hard armoring structures are even considered. In addition, significant fees and lease payments for shoreline armoring structures could be put in place to discourage hard armoring, and also serve as revenues to agencies to help underwrite the cost of adaptation planning. Further, state and local governments could adopt policies generally favoring non-structural armoring, such as beach nourishment, over hard armoring as a shoreline protection measure. Finally, the real estate industry should consider new disclosure guidelines for properties located in vulnerable areas.

Recommendation 2: Prioritize smart urban redevelopment outside the SLR-XA and limit exposure within the SLR-XA

Overview

Highly urbanized areas along the coast will be severely impacted by chronic flooding with sea level rise. In a recent study, experts and residents of flooded communities in the United States defined the threshold of chronic flooding that would disrupt people’s daily lives and routines to be when 10% of a town or city's useable land experiences flooding 26 or more times each year (Spanger-Siegfried et al. 2017). The potential for fragmented and unsustainable development would be expected over time as more urban areas become chronically flooded. In island environments where land is highly limited, a proactive and smart urban redevelopment strategy is needed to adapt to changing conditions, protect lives and property, offer a good quality of life, and promote a thriving economy now and in the future (EPA 2017).

Smart urban redevelopment is a core element of a sea level rise adaptation. A first step would be to evaluate existing policies and institutional capacity for implementing smart redevelopment state-wide. This would also include identifying any regulatory and policy barriers as well as any fiscal challenges that may hinder smart redevelopment. Further, consideration of societal disparities such as ensuring affordable housing, as well as timing uncertainty of sea level rise projections would present challenges. Using the results of a land inventory (see Recommended Action 1.3), target areas for smart redevelopment should be located outside of the SLR-XA. Market studies and detailed redevelopment strategies are also needed to enable capital improvement planning for infrastructure. Examples of recommended actions to support smart urban redevelopment outside the SLR-XA and limit exposure inside the SLR-XA are provided in Figure 135 and Figure 136, respectively.

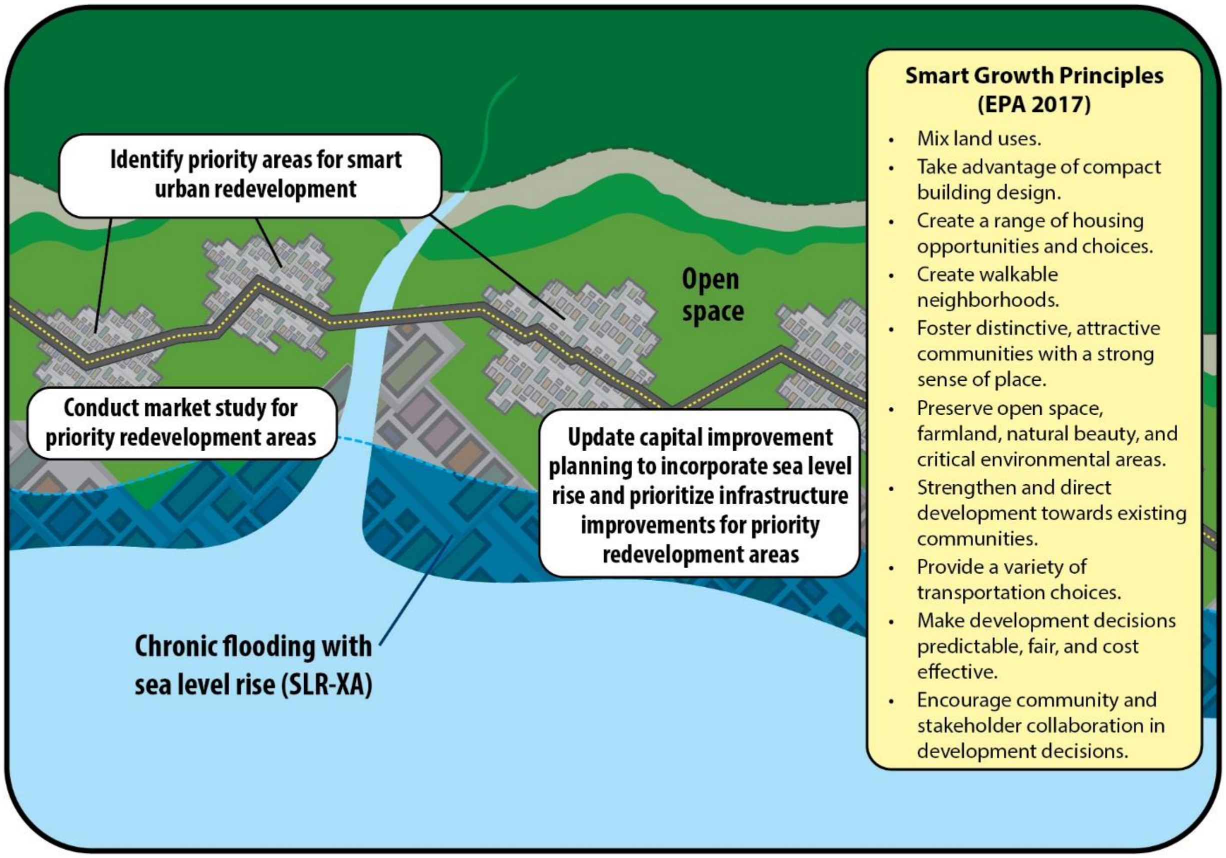


Figure 135. Prioritize smart urban redevelopment outside the SLR-XA

Recommended Actions

2.1 Evaluate existing policies and institutional capacity of implementing smart redevelopment

Smart redevelopment strategies help communities grow in ways that expand economic opportunity while protecting human health and the environment. Smart growth promotes efficient and sustainable land development, incorporates redevelopment patterns that optimize prior infrastructure investments, and consumes less land that is otherwise available for agriculture, open space, natural systems, and rural lifestyles. The State, through Act 130, Session Laws of Hawaiʻi 2016 (Senate Bill 3077) designates the Office of Planning as the lead state agency to coordinate and advance smart growth and transit-oriented development (TOD) planning in the State. TOD is a great example of smart growth as it is a type of community development that includes mixed-uses (housing, office, retail, etc.) in a walkable neighborhood that is located near quality public transportation. It may also involve redevelopment of existing facilities or may involve new development. An example of this is the City & County of Honolulu's TOD program. The establishment of the Honolulu rail transit system under Ordinance 07-01, paved the way for Ordinance 09-04 which established the City's TOD program and enabled the creation of special districts around each rail transit station (within 2,000 feet from the station). Each station will have its own unique identity as each TOD development is intended to fit the surrounding community's context. To ensure this, each station area will involve the preparation of a neighborhood TOD plan that includes implementing regulations along with extensive community participation.

Similar to how the State and City & County of Honolulu have passed laws to facilitate, coordinate, and advance smart growth and TOD planning, the state and counties should continue to review existing policies and regulatory processes to assess whether the current framework supports smart redevelopment of urban areas as part of sea level rise adaptation planning. Where appropriate, opportunities should be identified for amendments that would encourage and incentivize private investment, redevelopment of priority areas outside of the SLR-XA, a healthy mix of uses, and appropriate economic growth and development. Potential updates may include revisions that promote diverse housing stock, allow for increased density in appropriate areas, require consideration for future conditions, support TOD, and improve the efficiency of development approval processes, among others.

The New York City (NYC) Office of Environmental Remediation provides a good example of efforts to review redevelopment planning to increase resilience. The NYC Office of Environmental Remediation conducted climate resiliency and green remediation and development audits of cleanup and redevelopment plans for projects in the NYC Voluntary Cleanup Program (formerly known as the NYC Brownfields Program) (NYC Office of Environmental Remediation 2017). The audits focused on reviewing plans for remediation and redevelopment submitted by development teams and identified best management practices (BMPs) and other items with potential to improve those plans with respect to "green and sustainable" considerations. Subjects of the audits included: encouraged attention to climate resilience, improved energy efficiency and reduced emissions, improved water use efficiency and reduced runoff, optimized material use with utilizing green materials, minimized waste (including recycling and reuse), encouraged green design and improved quality of environment, optimized remediation, and development of a culture of sustainability. One of the primary goals of the audits was to increase resiliency by informing the development teams of other programs that could provide information and benefits regarding green and sustainable approaches.

2.2 Identify priority areas for smart redevelopment as part of a managed retreat strategy

An unbiased evaluation of urban areas vulnerable to sea level rise should be conducted to establish priority redevelopment areas for managed retreat. A committee should be established to conduct a detailed risk analysis using the vulnerability assessment results of this Report, the lands inventory as suggested in Recommended Action 1.2, and the shoreline conservation priorities as described in Recommended Action 1.6 that could then be used to develop prioritization criteria. The detailed risk analysis should also consider other factors such as quantifying potential loss (i.e., structural loss, economic loss such as income level and social justice, loss jobs/wages, loss tax, etc.) which could be one component of the prioritization methodology. Areas would be ranked using the committee-identified criteria and spatial analyses (clusters, hot-spot, etc.) to help determine the order of investment to retreat or adapt. A prioritized action plan should also be developed to identify the most at-risk infrastructure and include corresponding adaptation options as well as funding sources for implementation. During this evaluation, outreach should be conducted with property owners to discuss potential incentives that would encourage retreat from areas vulnerable to future sea level rise, particularly for shoreline areas that have been identified as priority shoreline conservation areas (Recommended Action 1.6).

2.3 Conduct a market study for priority redevelopment areas

The State and Counties should develop a comprehensive regional market assessment that provides defensible estimates of current market conditions and opportunities for supportable future growth across various economic sectors. The market assessment would help signify opportunities for appropriate new growth and development and should include analyses to validate and consider the depth of the market for a diversity of potential uses by analyzing workforce, demographic, and economic data sets, and identify current and emerging local economic base industries. The assessment should include quantitative and qualitative information that would collectively present a comprehensive assessment of the market and define supportable residential, commercial, and industrial development potential.

2.4 Develop detailed redevelopment strategies for priority areas and incentivize development

The State and Counties should create redevelopment strategies for priority urban areas that reflect the findings from the redevelopment and market assessments conducted in Recommended Actions 2.2 and 2.3. The primary result of these efforts should be detailed strategies for each priority area that illustrate feasible approaches to potential redevelopment. The State and Counties should use cumulative information gathered for each priority area and identified reuse sites to recommend the most effective redevelopment strategies based on a variety of criteria, including physical conditions, hazard areas, desired scale and density, and the ability to achieve established goals and objectives.

Within each priority redevelopment area, a more detailed, site-level assessment should be conducted to recommend the highest and best use for priority redevelopment sites. To the extent that it is readily available, basic information about each site should be collected including, but not limited to, parcel number, current or former use, estimated size, basic description of the location, current ownership, current zoning, and existing infrastructure servicing the property.

Detailed redevelopment strategies should then be developed for each area which include specific recommendations that are tailored to unique local conditions and designed to support the realization of the vision and goals outlined during this process. Potential actions that may support successful redevelopment of priority areas may include but are not limited to:

- Providing incentives for infill development that make private investment more efficient and desirable in existing urban areas not exposed to sea level rise. Examples of potential incentives include, but are not limited to: (a) expediting permitting/approvals, (b) fee waivers, (c) flexible zoning incentives, (d) parking initiatives (shared parking, payment in lieu of parking, etc.), (e) tax relief/abatements, (f) public funding assistance;
- Amending zoning ordinances and specific property classifications as necessary to support redevelopment and private investment, and to ensure a healthy mix of uses. This may include updating existing ordinances to adjust allowable uses, densities, scale of development, floor area ratios, setbacks, and conservation requirements, among other provisions;
- Identifying and prioritizing opportunities to focus redevelopment around existing infrastructure;
- Identifying and planning for necessary infrastructure expansions or upgrades to support new development;
- Implementing public realm improvements to support walkability and desirability of development areas;
- Preserving historic assets and encouraging adaptive reuse to retain local character, create a sense of place, and encourage development in desirable areas;
- Implementing a transfer of development rights (TDR) program that designates formal “receiving” areas within priority growth areas not exposed to sea level rise; and
- Coordinating land swaps to relocate development from hazard areas to safer areas. Land swaps are an exchange of municipally owned land for privately owned land, used to strategically assemble and re-purpose large areas to increase resilience through conservation, open space, green infrastructure, and more.

2.5 Update capital improvement planning to incorporate sea level rise and prioritize infrastructure improvements for priority redevelopment areas

Identify and plan for public infrastructure improvements necessary to support growth/redevelopment of priority areas. Improvement projects should be outlined in a capital improvement plan and should include the full range of infrastructure necessary to support redevelopment including transportation assets, storm water facilities, sewer and potable water, utilities, telecommunications, as well as pedestrian and public realm improvements/amenities.

2.6 Develop design standards for existing and proposed land uses that limits urban growth and increases flood resiliency within the SLR-XA

The State and Counties should develop design standards applicable for managing flood risk within the SLR-XA (Figure 136). These design standards would be developed and applied as BMPs and may or may not be regulatory in nature.

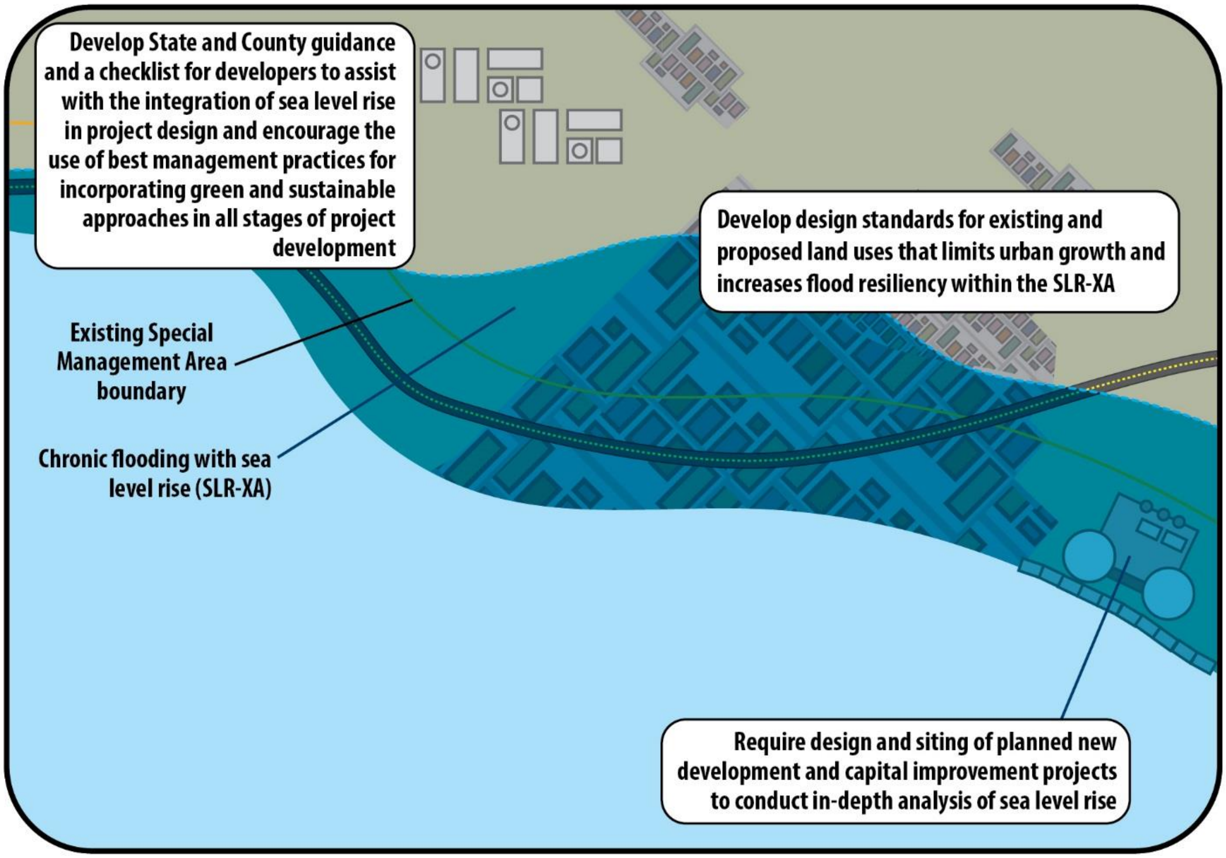


Figure 136. Limit exposure inside the SLR-XA

2.7 Require the design and siting of planned new development and capital improvement projects to include an in-depth analysis of sea level rise impacts based on elevation, tolerance for risk, and lifetime of the structure

State and Counties should adopt a review and approval process to ensure that new development and capital improvement projects with an expected life span of 30 years or more are designed and sited to address the impacts of sea level rise utilizing the SLR-XA as a vulnerability zone (see Recommended Action 1.1). All planned new development and critical infrastructure located within areas potentially exposed to chronic flooding with sea level rise should be subject to an in-depth analysis of the potential impacts of sea level rise on elevation, risk tolerance, and lifetime of the structure. Any redevelopment within existing footprints should be dependent on established, resilient building design guidelines, or otherwise be subject to relocation to a more suitable area.

2.8 Develop State and County guidance and a checklist for developers to assist with the integration of sea level rise in project design and encourage the use of best management practices for incorporating green and sustainable approaches in all stages of project development

As a part of a sea level rise adaptation strategy, the State and Counties should provide guidance and a checklist that would help developers integrate sea level rise in their project designs, permits and planning applications. In addition, the guidance document(s) and/or checklist should identify BMPs, offer design considerations and protection measures/techniques, provide tools/resources available to improve development plans, and reference GIS resources (e.g., sea level rise overlays). It should also encourage the incorporation of green and sustainable approaches such as: improved energy efficiency and reduced emissions; improved water use efficiency and reduced runoff; optimized material use with utilizing green materials; minimized waste (including recycling and reuse), and encouraged green design and improved quality of environment.

2.9 Develop guidance on integrating sea level rise and climate change in the environmental review process and incorporating environmental justice considerations

The Hawai‘i Environmental Impact Statement Law (HRS Chapter 343) and the Hawai‘i Environmental Impact Statement Rules (Hawai‘i Administrative Rules §11-200) requires any agency (for government actions) or person (for individual/private actions), that needs to obtain agency approval prior to proceeding with implementing actions located in certain specified areas or actions that require certain types of amendments to existing county general plans, to undergo an environmental review process. The environmental review process is triggered should a proposed project fall within one of the nine established categories of action pursuant to HRS §343-5 and HAR §11-200-6. The purpose of an environmental assessment is to disclose potential environmental, social, and economic impacts of a proposed project based on an analysis of the current environment with or without the project.

The State of Hawai‘i, Office of Environmental Quality Control (OEQC) should issue specific guidance on integrating sea level rise and climate change in the environmental review process. Guidance on sea level rise should highlight the need for analysis of the proposed action in terms of design and siting to address the impacts of sea level rise utilizing the SLR-XA as a vulnerability zone. Guidance on integrating climate change should highlight the need for analysis of the proposed action in the context of the future state of the environment. This guidance should be modeled after new federal guidance issued by the U.S. Council on Environmental Quality for federal departments and agencies on consideration of GHG emissions and the effects of climate change (State of Hawai‘i OEQC 2016). Further, there is a need to address the disproportionate environmental burdens borne by marginalized, underrepresented, or otherwise vulnerable communities from projects as environmental justice concerns are likely to be exacerbated as sea level rise results in changes in land use and development.

2.10 Integrate sea level rise vulnerability considerations into the Hawai'i Coastal Zone Management (CZM) Act

The Hawai'i CZM Act (HRS Chapter 205A) is an important planning tool for guiding land use development within the coastal zone. It should be noted that for Hawai'i, the CZM area encompasses the entire State as there is no point of land more than 30 miles from the ocean. The Office of Planning is the State's designated lead agency tasked with coordinating activities within the CZM areas state-wide. In addition, under the CZM Act, counties are tasked with establishing SMA boundaries and exercise authority over permits and variances within the SMA.

The Hawai'i CZM Act and the SMAs are existing tools that can be used to encourage appropriate development in areas exposed to coastal hazards with sea level rise. This could be achieved by amending the Hawai'i CZM law related to SMA guidelines to consider sea level rise vulnerability and to support the development of managed retreat strategies. Currently, there are ten objectives: (1) recreational resources; (2) historic resources; (3) scenic and open space resources; (4) coastal ecosystems; (5) economic uses; (6) coastal hazards; (7) managing development; (8) public participation; (9) beach protection; and (10) marine resources.

Specifically, the CZM Act could be amended to these and other provisions:

- Include sea level rise and specify adaptation strategies for accommodation, protection, and/or retreat in response to sea level rise within the Act's objectives and policies;
- Integrate environmental justice considerations;
- Consider language that results in more restrictive conditions on variances and SMA permits or modifying laws and rules to make variances and permits more difficult to obtain within the SLR-XA as a vulnerability zone (see Recommended Action 1.1); and
- Adopt rolling easement policies that facilitate managed retreat from the shoreline.

In addition, State and County agencies may choose to adopt and enforce rules that comply with the Act's objectives and policies.

Recommendation 3: Incentivize improved flood risk management

Overview

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

Administration and the Mitigation Directorate, components of the FEMA. The DLNR has been designated as the State Coordinating Agency responsible for assisting the coordination of the program between the federal and county agencies in Hawaiʻi. All four of our Counties are participating communities in the NFIP and each community has a representative County Floodplain Manager that should be consulted for building permit-related questions.

Financial exposure to coastal flooding could be further reduced by increasing participation in the NFIP Community Rating System (CRS) program and encouraging at-risk property owners to purchase flood insurance. The CRS program is voluntary and recognizes and encourages community floodplain management activities that exceed the minimum NFIP standards. Depending upon the level of participation, flood insurance premium rates for policyholders can be reduced up to 45%. Besides the benefit of reduced insurance rates, CRS floodplain management activities enhance public safety, reduce damages to property and public infrastructure, avoid economic disruption and losses, reduce human suffering, and protect the environment. Participating in the CRS also provides an incentive to maintaining and improving a community's floodplain management program over the years. Further, implementing some CRS activities can help projects qualify for other Federal assistance programs.

An immediate measure to reduce disaster spending would be to encourage property owners, outside historically based flood hazard zones, to purchase flood insurance as it has been proven that hazard mitigation is critical to reducing disaster risks and spending. FEMA reports that for every $1 spent on mitigation, it saves society an average of $4. In addition, the federal government has recognized the importance of hazard mitigation through the passing of the Disaster Mitigation Act of 2000 (Public Law 106-390) which provides the legal basis for FEMA mitigation planning requirements for state and local governments as a condition of mitigation grant assistance. The Disaster Mitigation Act of 2000 also amended the Robert T. Stafford Disaster Relief and Emergency Assistance Act by repealing the previous mitigation planning provisions and replacing them with a new set of requirements that emphasize the need for state and local entities to closely coordinate mitigation planning and implementation efforts. The Act further established a new requirement for local mitigation plans and authorized up to 7% of Hazard Mitigation Grant Program (HMGP) funds to be available to a State for development of State and local mitigation plans.

The purpose of the HMGP is to help communities implement hazard mitigation measures following a Presidential Major Disaster Declaration in the areas of the state requested by the Governor. The key purpose of this grant program is to enact mitigation measures that reduce the risk of loss of life and property from future disasters. Mitigation includes long-term efforts to reduce the impact of future events. HMGP recipients have the primary responsibility for prioritizing, selecting, and administering state and local hazard mitigation projects. Although individuals may not apply directly to the state for assistance, local governments may sponsor an application on their behalf.

Pre-disaster recovery planning can also provide opportunities for communities to build back better when difficult decisions about rebuilding are made before a disaster even strikes. The fundamental key to this approach is answering the question, "Do we want to build it back?" Pre-disaster recovery planning helps to identify these opportunities before a disaster takes place. Disaster scenarios based on potential impacts from hurricanes and tsunamis, and even sea level rise, provide opportunities to consider enhanced resilience and adaptation. It is important to note that every disaster creates an opportunity to correct prior land use decisions based on new information on risk. However, to leverage those opportunities, there must be an incentive at the state and local level as the notion of an action being the "right thing to do" is not enough. Strengthening rebuilding restrictions could foster safer redevelopment of disaster-stricken shoreline areas consistent with sea level rise adaptation objectives. Examples of recommended actions to incentivize improved flood risk management are shown in Figure 137.

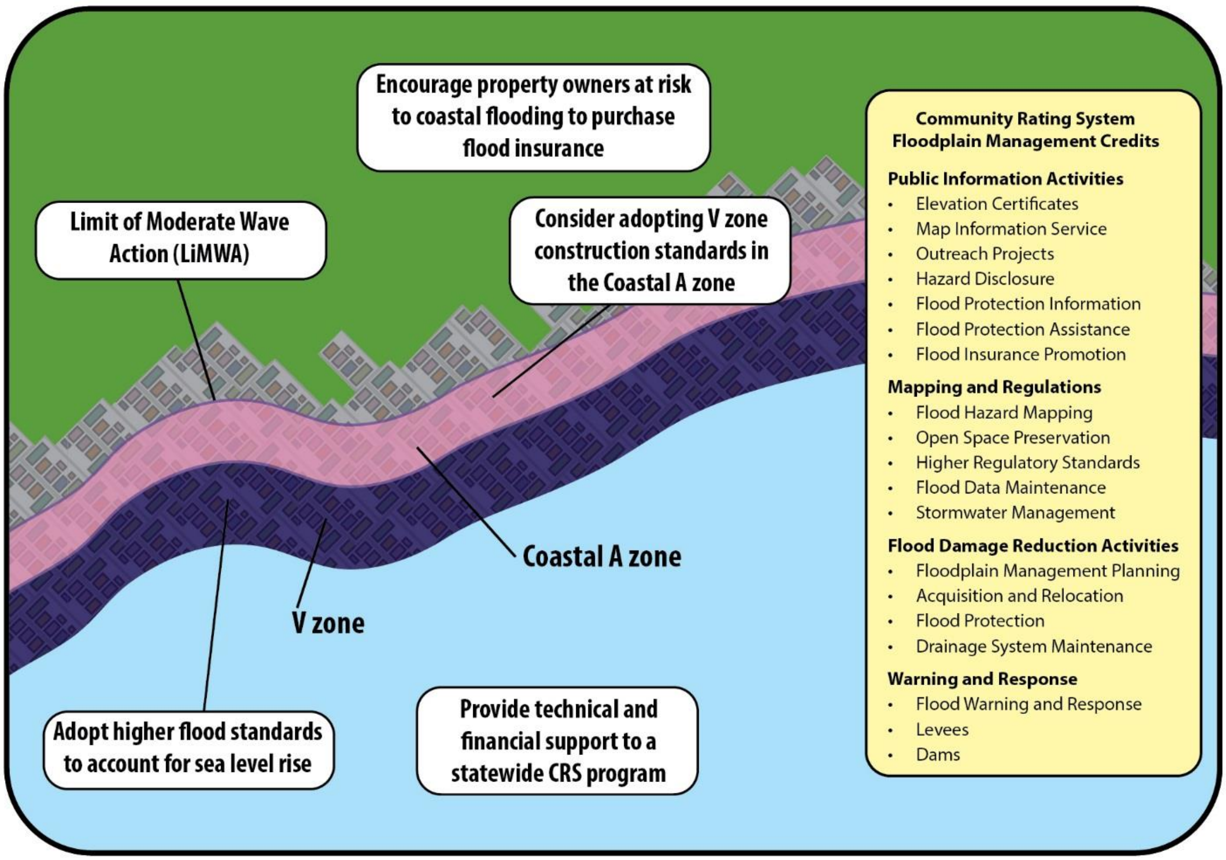


Figure 137. Incentivize improved flood risk management

Recommended Actions

3.1 Adopt higher flood standards to account for sea level rise

The State should adopt higher flood standards to account for sea level rise and potential future redevelopment. Other states in the nation have adopted higher standards to account for potential future development, such as the State of New Jersey. New Jersey has decided to delineate a "flood hazard area design flood" (State of New Jersey 2017a) which is defined as *a flood equal to the 100-year flood plus an additional amount of water in fluvial areas to account for possible future increases in flow due to* *development or other factors.* This additional amount of water also provides a factor of safety in cases when the 100-year flood is exceeded. The New Jersey Flood Hazard Design Flood is depicted on FIRMs and is used to regulate the permitting process and address design and construction standards for activities in and near surface waters. Other states have adopted sea level rise projections to guide future planning efforts and to be considered for certain permit and funding programs. For example, the New York State, Department of Environmental Conservation introduced the Community Risk and Resiliency Act (New York State Department of Environmental Conservation 2017) which requires permit and certain funding applicants demonstrate that future physical climate risk due to sea level rise, storm surge and flooding have been considered. Further, the New York State Department of Environmental Conservation adopted sea level rise projections on a regional basis (6 NYCRR Part 490, Projected Sea-level Rise).

3.2 Consider adopting V zone construction standards in the Coastal A Zone

Flood risk zones subject to inundation from the 1%-annual chance flood are designated as SFHAs on the FIRMs produced by FEMA. SFHAs along coasts subject to inundation by the 1% annual chance flood event with additional hazards associated with storm-induced waves subject to coastal inundation are designated as V zones. Coastal A zones are areas landward of a V zone or landward of an open coast without mapped V zones. In a Coastal A zone, the principal source of flooding is from astronomical tides, storm surges, seiches, or tsunamis. Currently, the minimum NFIP standards do not require that structures located in Coastal A zones be constructed to withstand coastal flood hazards such as high velocity flows, wave action, erosion and scour; however, individual communities may adopt higher regulatory standards that require such considerations in building design. At the time of next update, FEMA will determine the limit of moderate wave action (LiMWA). The LiMWA is the landward extent of the Coastal A zone for each county's FIRM. Delineating the Coastal A zone and LiMWA on the effective FIRM is voluntary; however, it should be noted that displaying the LiMWA on FIRMs is a pre-requisite for participation in the CRS.

3.3 Provide technical and financial support to a state-wide Community Rating System program

FEMA identifies flood hazards and assesses flood risks and partners with states and communities to develop FIRMs as part of the NFIP for developing regulations and flood insurance requirements. As FEMA updates Flood Insurance Study and updates hazard zones, many landowners would be required to purchase flood insurance and meet more costly construction standards. As stated earlier, the CRS is a voluntary program that provides flood insurance premium discounts in recognition of flood risk management program elements that exceed the minimum requirements of the NFIP. Creditable activities include: land acquisitions and restoration to open space uses, relocation, flood-proofing, open space preservation, and other measures that reduce flood damages. If a county participates in the CRS, residents may qualify for discounted flood insurance.

It is recommended that the State Legislature consider requiring all counties to participate in the CRS and provide annual funding to support CRS participation. This in turn would encourage the Counties to strive to advance their CRS rating to reduce impacts and repetitive loss from flooding and enable homeowners to obtain discounted flood insurance. It should be noted that while all four counties currently participate in the NFIP, only the County of Maui and the County of Hawaii are active CRS communities. Participation in a state-wide CRS program could also be tied to the Community Assistance Program administered by the DLNR under the NFIP as the State of Hawaii's Floodplain Coordinating Agency. The Community Assistance Program provides funding to states to provide technical assistance to communities participating in the NFIP and to evaluate community performance in implementing NFIP floodplain management activities. The Community Assistance Program helps to ensure that the flood loss reduction goals of the NFIP are met, build state and community floodplain management expertise and capability, and leverage state knowledge and expertise in working with their communities. This recommendation is based on the understanding that the full responsibility for the commitment to participate and maintain status in the CRS program lies with the individual county and that the State's role would be to support those efforts defined above. It should be noted that many recommendations in this Report could potentially provide CRS credits.

Support from the State could include the following:

- Address community compliance issues.
- CRS application and annual recertification support.
- Facilitate the identification and crediting of state-wide uniform minimum credits under CRS.
- Facilitate the formation and implementation of a CRS Users Group.
- Develop a state-wide model flood damage prevention ordinance that includes CRS creditable elements for sea level rise provisions.
- Support the development and maintenance of all local and state hazard mitigation plans and assure that they are developed such that they are creditable under the CRS program.
- Support the development of a state-wide program for public involvement that is creditable under the CRS Activity 330.
- Continue to mine the best available data and science on all flood risk within the State.
- Support the Counties in the capture of perishable data that memorializes flood risk following flood events.

It is understood under this recommendation that the full responsibility for the commitment to participate and maintain status in the CRS program lies with each individual county and that the State's role under this recommendation would be to support those efforts as defined above. It should be noted that many recommendations in this Report could potentially provide CRS credits.

3.4 Encourage property owners at risk to coastal flooding to purchase flood insurance

Coastal flooding from high tides and annual high waves results in damage to structures and their contents. With sea level rise, many new properties located outside of FEMA-established coastal flood zones, where flood insurance is required to obtain a mortgage, could become exposed to coastal flooding from high tides, annual high waves, hurricanes and tropical cyclones. The success of this recommendation would be tied to Recommended Action 3.3 as the cost of flood insurance in these zones would be more affordable based on the positive impacts on flood insurance premiums from participation in the CRS program.

3.5 Incorporate sea level rise into state and county hazard mitigation plans

Hazard mitigation is the use of long-term and short-term policies, programs, projects, and other activities to reduce death, injury, and property damage that can result from a disaster. State and county hazard mitigation plans should incorporate the findings of this Report, where appropriate.

In additional, local hazard mitigations plans could be assembled such that components of the plans could qualify as Community Development Block Grant Disaster Recovery (CDBG-DR) Program Action Plans following a declared disaster where CDBG-DR funding has been made available. The CDBG-DR program provides flexible grants to help cities, counties, and states recover from presidentially declared disasters, especially in low-income areas. Grantees may use CDBG-DR funds for recovery efforts involving housing, economic development, infrastructure and prevention of further damage to affected areas for low-income residents in and around communities that have experienced a natural disaster. Eligible governments must develop and submit a Disaster Recovery Action Plan before receiving CDBG-DR grants. The action plan must include a needs assessment, strategies, and projected uses of the disaster recovery funds.

3.6 Adopt a state-wide program that supports the BCEGS program for insurance rating

Administered by the International Organization for Standardization (ISO), the Building Code Effectiveness Grading Schedule (BCEGS) assesses the building codes in effect in a particular community and how the community enforces its building codes, with special emphasis on mitigation of losses from natural hazards. BCEGS develops a relative Building Code Effectiveness Classification for each community for insurance rating and underwriting purposes. The concept is simple: municipalities with effective, well-enforced codes should demonstrate better loss experience, and insurance rates can reflect that. The prospect of lessening catastrophe-related damage and ultimately lowering insurance costs provides an incentive for communities to enforce their building codes rigorously—especially as they relate to windstorms and seismic damage. BCEGS encourages the implementation and enforcement of effective building codes, resulting in safer buildings, less damage, and communities that suffer less damage when natural disasters occur. It should be noted that the BCEGS is similar in concept to ISO’s Public Protection Classification evaluations of municipal fire suppression capabilities used by insurers for decades. Currently, none of the four counties in Hawai‘i have a BCEGS rating.

The State should first assess why the BCEGS program is not being utilized within Hawai‘i. Once the issues for lack of participation have been identified and addressed, the State should consider formally adopting the BCEGS program as part of its insurance rating program. Additionally, the State should provide technical resources to the Counties to support the establishment of a BCEGS classification for each county, and commit to providing technical resources to support the maintenance of that classification. Similar to Recommended Action 3.3, this recommendation is based on the understanding that the full responsibility for the commitment to participate and maintain status in the BCEGS program lies with each individual county and that the State's role under this recommendation would be to support those efforts within the resources and capabilities of the State.

3.7 Develop pre-disaster recovery frameworks at state and county levels that incorporate opportunities to adapt to sea level rise through disaster recovery

Disasters can provide opportunities to adapt to sea level rise. Pre-disaster recovery strategies can support managed retreat and other adaptation strategies by engaging community stakeholders in making decisions about land use in the event that a major hazard event, such as a hurricane or tsunami, occurs. Using pre-disaster planning and post-disaster recovery as opportunities for implementation of sea level rise adaptation is as advantageous as it is cost effective and reduces repetitive losses. Within these efforts, disaster recovery frameworks should be made for adaptation strategies than can be individually and voluntarily adopted before formal regulations can be put in place.

3.8 Perform a study to identify what other incentives could be utilized to promote improved flood risk management.

While Recommended Actions 3.3 and 3.6 have identified incentive-based programs such as the CRS and BCEGS that support enhanced flood risk management, these are not the only options available. A study should be commissioned by the State, based on proactive public engagement, that seeks to identify other incentives that would drive the private sector to action. The results of this study could inform strategic plans that evolve from this Report and set the course for implementation actions.

Recommendation 4: Enable legacy beaches to persist with sea level rise

Overview

The loss of beaches throughout the Hawaiian archipelago with sea level rise endangers recreational uses, cultural practices, critical habitat for wildlife, the economy, and the natural buffering capacity of the shoreline from waves. As beaches erode, properties along the shoreline will become increasing vulnerable to coastal hazards prompting owners to request emergency waivers for temporary protection which can exacerbate erosion along adjacent shorelines. The loss of beaches also means the loss of wildlife habitat across the archipelago, most notably for the endangered Hawaiian monk seal, Hawksbill and green sea turtles, and many of our seabirds such as the Laysan albatross and the Newell's shearwater. Increasing beach loss coupled with the continued degradation of coral reef ecosystems from land-based pollution, overfishing, and climate change means that coastal environments are in great jeopardy.

Recommended actions in this section focus on the need to enable beaches in Hawaiʻi to persist with sea level rise and are based around the need for a state-wide assessment of vulnerable beaches to identify legacy beach conservation priorities (Figure 138). These priorities should be identified based on a number of social, cultural, economic, and environmental factors, aligned with shoreline protection and preservation priorities and in consultation with communities as part of the community development planning process (see Recommendation 1). Recommended actions also consider funding for land acquisition and beach restoration activities through public-private sector partnerships as well as explore other alternative actions to help protect beaches. This may include the realigning of roads and other structures to eliminate barriers that would normally disrupt the natural process of erosion and landward migration of beaches into sand-rich coastal plains. In other locations, groins or other beach stabilization structures and sand nourishment may be needed to maintain beaches in front of development. Sand nourishment may also be needed for areas that lack natural sand deposits in the backshore.

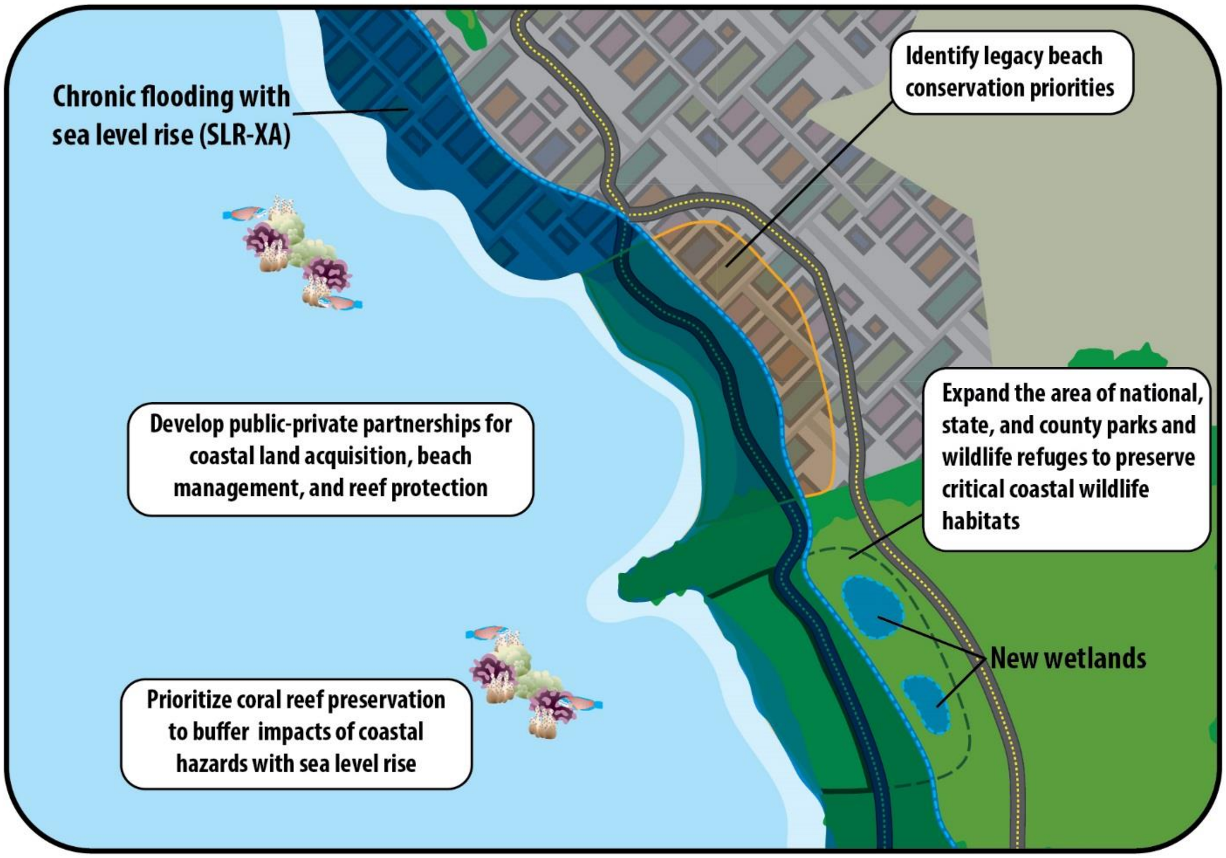


Figure 138. Enable legacy beaches to persist with sea level rise

Recommended Actions

4.1 Conduct a state-wide assessment to identify legacy beach conservation priorities

The DLNR, Office of Conservation and Coastal Lands (OCCL), together with federal, state, and county governments, nongovernmental organizations, and local stakeholders, should undertake a state-wide assessment to prioritize beaches that are important for recreational uses, cultural practices, and wildlife habitat. As indicated in the results section in Chapter 4, many beaches in the Hawaiian archipelago will become very narrow or completely lost by mid to late century from 3.2 feet of sea level rise. However, beaches may be able to thrive, even as sea level rises, if their landward migration into upland sand deposits is not impeded by coastal structures. We may need to identify "rolling beach easements" and prohibit development in such areas, and even consider removing development from areas with upland sand deposits if we hope to retain this vital natural and cultural resource for future generations.

The State and Counties should also work hand in hand to identify “Legacy Beaches” where special adaptation measures, such as preservation of undeveloped lands, managed retreat, and prohibition of coastal armoring, should be implemented in earnest. The tools identified in this Report are integrated with an overall vision of community sustainability, so that the beaches that are vital to our island culture and vital to protected wildlife species, are protected along with our coastal communities and vital infrastructure.

4.2 Establish a “willing seller” program to move development away from legacy beaches

The State should establish a “willing seller” program that pre-identifies property owners that would be willing to sell or relocate their property outside of the state-wide vulnerability zone. As such, lands acquired through the program could be used to establish legacy beaches. There are many successful examples of “willing seller” programs, the most notable of which is the City of Portland, Oregon’s “Johnson Creek Willing Seller Program” which helps move people and property out of areas that frequently flood. Restoration projects on land acquired through the program increase flood storage, improve fish and wildlife habitat, restore wetlands, and create passive recreational activities for city residents. For more information regarding this program, please visit https://www.portlandoregon.gov/bes/article/106234.

4.3 Amend the State Legacy Lands Act to set aside funding for priority coastal lands and enable the use of a variety of practices and tools

The State Legacy Lands Act, passed in 2005, established a permanent fund for land conservation and the preservation of open space and scenic resources in Hawai‘i. Specific projects eligible for funding include conservation of watersheds, coastal areas, beaches, ocean access, habitat protection, cultural and historic sites, natural areas, and open spaces and scenic resources among others. Funding is provided through a conveyance tax and 10% of the program’s annual budget is directed into the State’s Land Conservation Fund. Monies from the Land Conservation Fund must be used to acquire lands for public purposes, which the law defines as preservation of any of the following: watershed protection; coastal areas, beaches, and ocean access; habitat protection; cultural and historical sites; recreational and public hunting areas; parks; natural areas; agricultural production; and open spaces and scenic resources. The Federal Coastal and Estuarine Land Conservation Program can also provide matching funds to acquire property from willing sellers either through fee simple purchase or through conservation easements.

In addition to land acquisition for legacy beaches, a variety of tools, including buffer zones and conservation easements, are needed to support conservation of coastal lands through incremental changes in the shoreline. Buffer zones could be used to restrict development within specified distances of natural and cultural resources. For example, Hawai‘i law requires buffer zones to protect artesian water aquifers and archaeological sites. As another example, Kaua‘i and Maui Counties utilize shoreline construction setbacks that are based on historical erosion rates to provide a buffer between chronically retreating shorelines and development. Expanding buffer zones around beaches, sand dunes, and coastal wetlands would provide space for these environments to migrate landward with rising sea levels.

Conservation easements seek to “[p]reserve and protect land predominantly in its natural, scenic, forested, or open-space condition” (Codiga and Wager 2011). Conservation easements are legal agreements between landowners and land trusts or government agencies that restrict development or uses while allowing property to remain in private ownership (Codiga and Wager 2011). In Hawai‘i, conservation easements could be created by deed restrictions, covenants, or conditions. They are freely transferrable, perpetual, not personal, may restrict certain types of activity, and are obtainable by purchase, agreement, donation, devise, or bequest, but not by eminent domain. State law authorizes public bodies and nonprofit organizations to hold conservation easements for the purposes of preserving and protecting open space, natural landscapes, cultural and historical sites and resources, and agricultural lands. Traditional conservation easements prohibit all development on burdened parcels but some modern conservation easements do not necessarily prohibit but rather limit development to appropriate and desired development.

4.4 Expand the area of national, state, and county parks and wildlife refuges to preserve critical coastal wildlife habitats

The DLNR, working together with federal and county agencies and nongovernmental organizations, should identify existing and potential new areas for coastal wildlife refuges throughout the State to support both new wetlands that may form and wildlife migration from the NWHIs. Hawaii’s endangered wildlife including the Hawaiian monk seals, Hawksbill and green sea turtles, and seabirds such as the Laysan albatross and Newell’s shearwater, depend on a range of low-lying habitats that would be lost as a result of sea level rise in the main Hawaiian Islands and the NWHIs. These habitats include beaches and coastal strands, mudflats and wetlands, coastal shrub lands and woodlands, and freshwater habitats. In anticipation of wildlife climate refugees from the NWHIs, we should consider expanding wildlife refuges on the main Hawaiian Islands in areas that would provide suitable habitat. The expansion of parks and wildlife refuges and the identification of legacy beaches (Recommended Action 4.1) should especially factor in the preservation of critical habitat for the highly endangered Hawaiian monk seal (NOAA Fisheries 2017a) which includes a landward portion that extends 15 feet on land from the shoreline.

4.5 Prioritize coral reef preservation to buffer the impacts of coastal hazards with sea level rise

Healthy coral reefs and reef flats provide many ecosystem services including sand for beaches and protection from wave energy. In addition to local threats to Hawaii’s coral reefs, increasing sea surface temperatures that cause coral bleaching and ocean acidification that weakens coral skeletal structures and calcification, pose new and significant stresses to these vital ecosystems. More than ever, Hawaii’s coral reefs need to be protected and restored to support multiple ecosystems services. In September 2016, Governor Ige made a World Conservation Congress Legacy Commitment to have 30% of Hawaii’s nearshore waters effectively managed by 2030. This commitment needs to be backed with greater human and financial resources.

4.6 Develop public-private partnerships for coastal land acquisition, beach management, and reef protection

Public-private partnerships can be an effective conservation tool. State and counties, together with private land owners, should explore opportunities to preserve coastal resources along the shoreline. The State’s Natural Area Reserve System is a model for public-private partnerships for natural resource conservation that could be expanded to cover more shoreline areas. In addition, a number of private and nongovernmental organizations in Hawai‘i are dedicated to preserving and acquiring land to be held for public access and coastal resource conservation. Organizations such as, The Nature Conservancy, The Hawai‘i Trust for Public Land, and the Hawaiian Islands Land Trust, use a variety of tools to acquire and protect valued lands.

Recommendation 5: Preserve Native Hawaiian culture and communities with sea level rise

Overview

Many Native Hawaiian cultural resources, practices, and communities that are located along and depend on access to the coast would be impacted by chronic flooding with sea level rise. Native Hawaiian cultural heritage is central to identifying a sense of place as the capacity of cultural resources to move or change is limited due to their strong ties to place.

Recommended actions in this section are proposed to help preserve Native Hawaiian culture and communities with sea level rise (Figure 139). First, an archipelagic inventory of Native Hawaiian cultural resources and practices potentially impacted by sea level rise is needed to understand the full extent of the impacts. A culturally informed process and protocols are needed to make decisions about cultural resources threatened by rising seas. An adaptation planning process is also needed to ensure that coastal land and access to the sea is preserved for Native Hawaiian communities as the sea level rises.

It is important to note that unlike historic sites which have identifiable boundaries, locations where Hawaiian customs and practices have traditionally occurred are much harder to document because many of these heritage resources are intangible. Yet, this indigenous and local knowledge is an invaluable asset, and in many ways, the most vulnerable. Some of this information may be available through existing resources, yet there is unlikely to be a single aggregated database. In many cases, kua‘āina (people of the land), particularly practitioners such as fishermen, are resistant to identify locations where resources are still abundant. With careful consideration of sensitive data that should not be made public, an inventory of locations where traditional and customary practices occur should be developed.

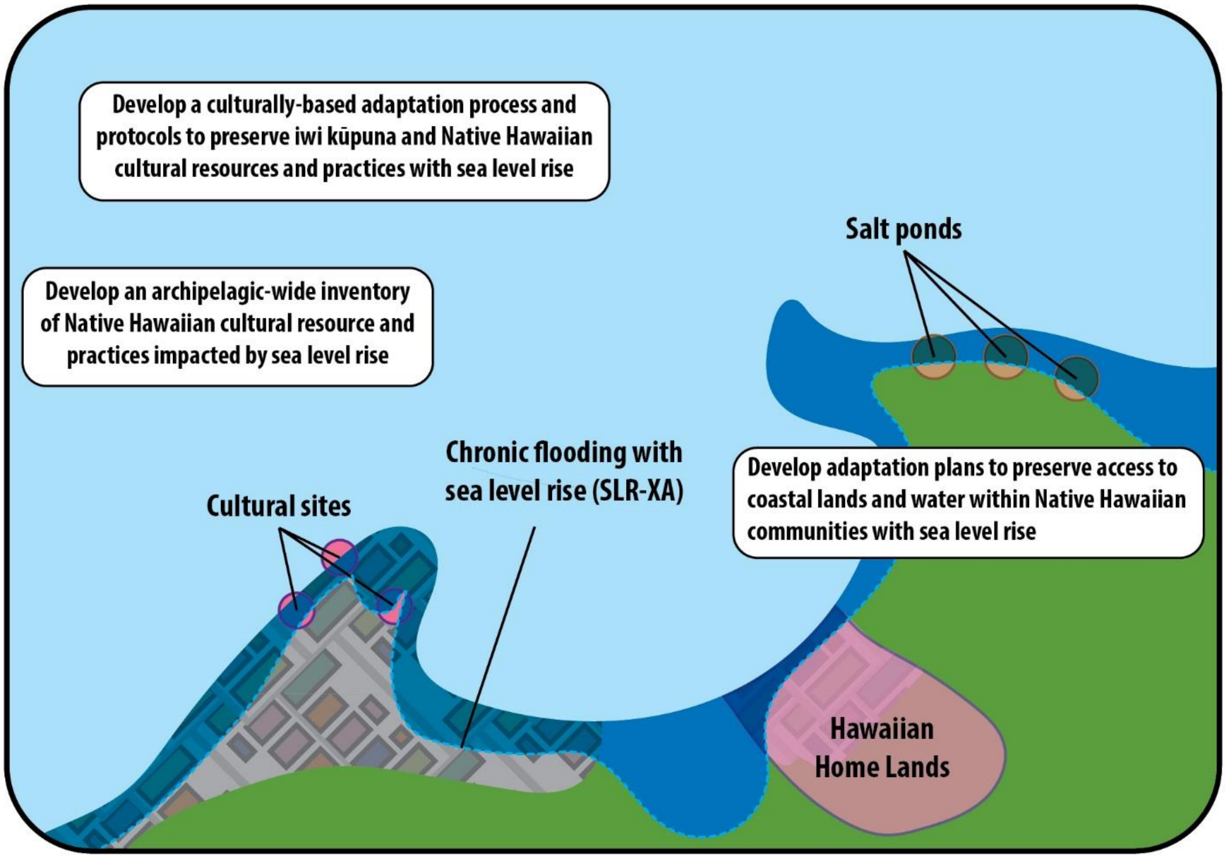


Figure 139. Preserve Native Hawaiian culture and communities with sea level rise

Recommended Actions

5.1 Develop an archipelagic-wide inventory of Native Hawaiian cultural resources and practices impacted by sea level rise

In addition to updating the state-wide survey and inventory developed by the State of Hawai'i Historic Preservation Division (SHPD) (prepared pursuant to HRS §6E-3), which identifies and documents historic properties, aviation artifacts, and burial sites, an inventory of traditional and customary Native Hawaiian cultural resources and practices impacted by sea level rise should also be developed building on the results of this Report and other studies (Marrack and O'Grady 2014, Wagner and Polhemus 2016, Kane et al. 2012, University of Hawai'i 2015). Working together with SHPD, the State of Hawai'i Office of Hawaiian Affairs (OHA), the Burial Councils, and the 'Aha Moku Councils, the use of the two inventories should identify priorities to relocate or reinforce Native Hawaiian cultural resources.

5.2 Work with Native Hawaiian Communities to develop a culturally-based adaptation process and protocols to preserve iwi kūpuna and Native Hawaiian cultural resources and practices with sea level rise

A culturally based adaptation process, as well as protocols, should be developed to address impacts of sea level rise on Native Hawaiian cultural resources and practices (University of Hawaiʻi 2015). Integral to this strategy would be: (1) ranking the vulnerability of threatened cultural features based upon significance and the timing of sea level rise impacts, (2) developing protocols to appropriately manage the assets, such as possible relocation and preservation of cultural features, and (3) developing a mitigation strategy with lineal and/or cultural descendants of the iwi kūpuna (Kane et al. 2012). This effort would likely require a concert of agencies including SHPD, OHA, the Burial Councils, the ʻAha Moku Councils, the NWHIs Native Hawaiian Cultural Working Group, and other Native Hawaiian organizations across the State. It would require a state-wide framework that would need to be tailored to each island that would start with conversations with families and groups on each moku to ask how they would like to plan for their resources (e.g., relocation or reinforcement). This conversation would be different for each community and each resource, for example, a loko iʻa might have a different overseeing group than a heiau.

Projects like Loli Aniau, Makaʻala Aniau, (Climate Change, Climate Alert) or “LAMA” have long been sounding the alarm on climate impacts in Hawaiʻi and across the Pacific. As such, Hawaiian communities have already begun building their capacity to address and respond to climate threats. In some cases, protocols already exist, like in the case of iwi kūpuna, well-established protocols under HRS Chapter 6E and the applicable administrative rules specify the process. To some degree, there are numerous state and federal laws that provide helpful guidance on how to address sea level rise impacts on historic properties, however, the guidance was not intended for sea level rise (see https://www.nps.gov/tPS/how-topreserve/preservedocs/Moving-Historic-Buildings.pdf). Nonetheless, historic preservation guidance does exist on the relocation of historic properties that could be repurposed for addressing sea level rise. In other cases, thorough documentation of sites may be the only solution, which could be accomplished through Recommended Action 5.1.

The reality is that like many other resources, and due to the uncertainty of the timing and extent of sea level rise, the cultural response to sea level rise is going to be largely case-by-case, or at best, at a community level. As with all other resources and assets at risk, responses to sea level rise are largely dependent on the financial resources available, therefore it would be essential to manage the expectations of communities as to what can realistically be saved. This is why it is important to recognize the validity of the SLR-XA as a vulnerability zone so that communities can appropriately document cultural resources that could be lost in the future.

5.3 Develop adaptation plans to preserve access to coastal lands and water within Native Hawaiian communities with sea level rise

Agencies such as the Department of Hawaiian Homelands (DHHL), OHA, and the ʻAha Moku Councils should work with Native Hawaiian communities to develop adaptation plans to preserve access to coastal lands and water impacted by sea level rise. A combination of adaptation strategies may be required to preserve access. These adaptation plans should build on the vulnerability assessment results of this Report.

Recommendation 6: Protect nearshore water quality from sea level rise impacts

Overview

Underground storage tanks (USTs), OSDS, including septic systems, cesspools, and wastewater treatment plants, and hazardous materials/waste storage facilities currently pose risks to aquifers, nearshore water quality, and coral reef ecosystems. These risks would increase with sea level rise. USTs not designed to withstand corrosive seawater may have increased failures. OSDS in coastal areas would also be vulnerable to flooding from the ocean as well as from rising groundwater tables. Increased flooding and coastal erosion with sea level rise would increase pollutant runoff, and could provide new sources of contaminant pathways from existing wastewater facilities and hazardous waste sites or storage facilities not designed to withstand constant flood conditions.

The Recommended Actions proposed in this section could be taken over the short-term as well as changes in laws and regulations over the long-term to protect nearshore water quality with sea level rise. Strategies and recommendations for adapting to sea level rise would include a mixture of: (1) reviewing existing laws, regulations, and best management practices (BMPs), (2) crafting and implementing new laws, regulations, and BMPs, and (3) evaluating current conditions to prioritize near-term actions (Figure 140).

The State of Hawai'i, Department of Health maintains policies, guidelines, and procedures for the construction, maintenance, and mitigation of USTs, OSDS or wastewater treatment, and hazardous materials/waste storage facilities. Inherently, each of these systems pose current and future risks to our aquifers, nearshore water quality, and marine ecosystems. Maintaining oversight of these systems is already a very challenging task for the implementing agencies—and the multiple effects of sea level rise would greatly increase the complexity of planning, permitting, and mitigating possible breaches or leaks to these systems. The possible effects of sea level rise include:

- The boundary of salt water intrusion moving more landward (where fresh groundwater flows from inland areas meets with the saline groundwater from the ocean), resulting in new saline, corrosive conditions;
- The boundary of salt water intrusion found at higher elevations, resulting in subsurface soil inundation that did not exist previously;
- The higher elevation of salt water intrusion causing groundwater to elevate higher than previously, also resulting in subsurface soil inundation that did not exist previously;
- Increased rainfall associated with climate change could also contribute to increased upland groundwater recharge, and therefore also increase groundwater levels beyond those associated with sea level rise; and

- In fairly low coastal areas where saline water or fresh groundwater levels rise above current land elevations, these areas would become flooded, introducing a new threat to water quality through interaction with surface soil hazards or contamination.

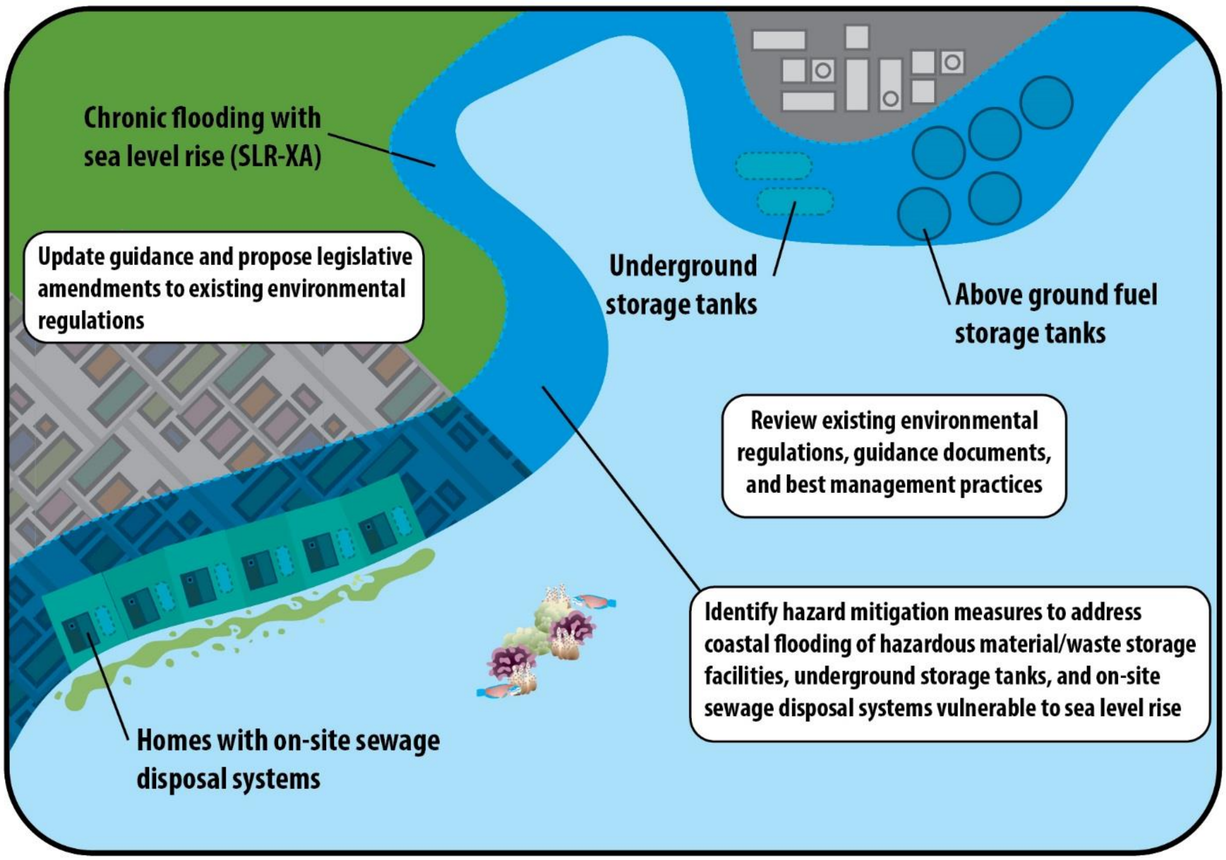


Figure 140. Protect nearshore water quality from sea level rise impacts

USTs may not be designed to withstand elevated water levels and therefore would be compromised. For OSDS/wastewater systems, the higher water table reduces the distance from the ground surface to the leach field, compromising their effectiveness to treat bacteria and pathogens. In addition, the ripple effect of the failure of one system would exacerbate possible weaknesses of other systems, causing additional concerns and challenges for the implementing agencies. Risks of failures to all of these systems would increase with sea level rise. Because sea level rise would only compound these issues in the future, agencies could address these gaps in the management structure sooner than later.

Recommended Actions

6.1 Identify hazard mitigation measures to address coastal flooding of hazardous material/waste storage facilities, underground storage tanks, and on-site sewage disposal systems vulnerable to sea level rise

Based on existing permits, site records, and agency files, conduct a thorough review of UST, OSDS, and hazardous material/waste storage facilities within the SLR-XA as a vulnerability zone (see Recommended

Action 1.1). The objective of the review would be to identify sites or geographic areas with the highest probability of large or catastrophic failures or releases associated with increased coastal flooding with sea level rise. Once a priority list has been prepared, develop hazard mitigation measures that landowners, permittees, and operators of these facilities can implement to address these threats. Technical support is needed to provide standards and BMPs for water proofing, improved flood control, and possibly re-siting options. Educational and outreach efforts should strive to increase awareness of potential impacts from increased flooding and/or sea water intrusion and provide public forums to discuss near-term actions and long-term mitigation measures.

Examples of actions similar to the one proposed can be found in California, where San Mateo County inventoried hazardous waste sites that may be affected by sea level rise within their vulnerability assessment with emphasis on those near beneficial groundwater uses. In Delaware, a vulnerability study assessed hazardous waste storage facilities within the path of rising sea levels and identified those which should initiate plans to prevent releases. Further abroad, the Commonwealth of the Northern Mariana Islands' Bureau of Environmental and Coastal Quality has updated their above ground storage tank website to direct permit holders to review the "Saipan Climate Change Vulnerability Assessment: Saipan Sea Level Rise Inundation" as a guide when siting new above ground storage tanks.

6.2 Review existing environmental regulations, guidance documents, and best management practices

The State of Hawaiʻi Department of Health maintains policies, guidelines, and procedures for the construction, maintenance, and mitigation of USTs, OSDS or wastewater treatment, and hazardous materials/waste storage facilities. Recognizing that sea level rise would result in inundation of USTs, Act 179 was passed in 2016, prohibiting the issues of permits for new USTs within 100 yards of the shoreline and other provisions. A comprehensive review and gap analysis of current Hawaiʻi laws and guidance pertaining to USTs, OSDS, and hazardous waste sites and facilities is needed to identify potential areas for revision. This review should focus on existing regulations that allow for siting new facilities in flood hazard prone areas as well as monitoring or enforcement of existing vulnerable systems and facilities. This review should highlight priority actions, which could be implemented immediately by each agency to protect against failures of vulnerable systems. The gap analysis would identify recommendations for changes and improvements to current regulations and guidance for future updates. A successful example of this is the State of New Jersey's Climate Adaptation Alliance, which conducted a gap analysis in 2013 to summarize opportunities for improvement in order to inform climate change policy recommendations (New Jersey Climate Adaptation Alliance (NJCAA) 2013).

6.3 Update guidance and propose legislative amendments to existing environmental regulations

Based on the gap analysis conducted under Recommend Action 6.2, updates to existing guidance could be made and legislative changes proposed that could require additional measures to protect against vulnerable wastewater and hazardous waste systems and increased failures. For example, the siting and design or reengineering of these facilities should take into account the potential impacts of sea level rise, or permits for new USTs or OSDS should be prohibited in the state-wide vulnerability zone (see Recommended Action 1.1). New guidance could include the preparation of hazard mitigation plans to prevent leaks from existing facilities or increased performance standards to protect against new threats associated with increased and constant flood conditions. Recommended changes could include increased monitoring and enforcement of land-based pollutant runoff from shorelines exposed to sea level rise. Specifically, HRS §340D-50.5 (Act 248, 2016), which prohibits the discharge of treated or raw sewage into state waters after December 31, 2026, could be amended to take into account impacts from sea level rise and be used as a measure to assist in the "enforcement of land-based pollutant runoff."

Recommendation 7: Develop innovative and sustainable financing and incentives to support adaptation to sea level rise

Overview

One of the many challenges of adapting to sea level rise is determining how to pay for adaptation initiatives such as retrofitting or relocating critical infrastructure, buy-out programs for highly vulnerable communities, and land acquisitions to enable Hawaii's beaches to persist. A combination of financing and incentive programs are needed to support the planning and implementation of long-term adaptation strategies.

Recommended actions in this section are proposed to support innovative and sustainable financing and incentives needed to address the complexities of adapting to sea level rise. More comprehensive financial and economic analyses of the impacts of sea level rise are needed to quantify the loss to tax revenues and the economy from sea level rise. The potential economic impacts assessed in this Report are limited to primarily the loss of structures and land. Additional analyses would provide a greater understanding of what would be lost as well as the cost of adaptation. A multi-pronged financing strategy drawn through partnerships with public, private, and philanthropic entities needs to be developed building on lessons from the latest innovations and identified best practices. Economic incentives to avoid risks from sea level rise such as through TDRs, purchase of development rights (PDR), and buy-out programs, combined with mandatory real estate disclosures of sea level rise risks, are needed to support a comprehensive approach to addressing the cost of adaptation.

Recommended Actions

7.1 Conduct more detailed financial and economic analysis of sea level rise impacts in the SLR-XA

The estimated economic impacts to the State assessed in this Report are limited to the loss of structures and land. Based on the modeling in the results chapter, the State should conduct a more detailed impact analysis to understand the full economic impact to the State and Counties of both reducing or mitigating the impacts of sea level rise compared to not doing anything (i.e. benefit-cost analysis). This information would inform State and County officials and citizens of the full economic impact of sea level rise as it specifically relates to each County. Based on higher resolution economic impact assessments, agencies could then have a more realistic or purposeful discussion regarding financial burdens, liabilities, and future opportunities presented as a result of sea level rise. For commercial and industrial uses, impacts that would need to be considered include job loss, secondary and tertiary business impacts, and impacts to the tourism industry state-wide. For private properties impacted by sea level rise, the impact would be tremendous for families and well as county tax coffers.

7.2 Develop a multi-pronged financing strategy at federal, state, county, private sector, and philanthropic levels to address costs of adaptation to sea level rise

A multi-pronged funding strategy should be developed at federal, state, county, private sector and philanthropic levels to secure significant and sustainable funding for investments that reduce risks, harm to people, and disaster spending from coastal hazards with sea level rise. Based on prioritized projects, the funding strategy would identify applicable sources, eligibility criteria, application processes, outreach strategies, and detailed implementation steps to achieve a defined set of funding goals.

Some of the costs anticipated as a result of sea level rise include: (1) land acquisition, (2) relocation or retrofitting of critical infrastructure (such as roads, airports, harbors, and power, water, and wastewater facilities and distribution lines), (3) relocation of residential areas and retrofitting to increase flood resiliency, and (4) land acquisition for wetland and beach migration and public access.

As part of this strategy, the Hawaiʻi Legislature could adopt laws enabling state and local governments to develop tax incentive programs and special tax districts. Incentives could be used to encourage landward relocation, retrofitting to increase flood resiliency, siting of new development in upland areas, conservation of open space along the shoreline, and preservation or restoration of natural flood buffers. Although tax incentives may lack support in times of budget shortfalls, they are a proven policy tool to achieve key social, economic, and environmental objectives. Creating financial incentive programs for sea level rise and other climate change impacts, however, would require decision-makers to establish clear priorities regarding the type of development (e.g., new or existing, critical infrastructure, and residential development) to be encouraged or discouraged in particular areas.

The private sector also could be employed through either voluntary contribution of funding, or compensatory payment of assessments such as impact fees, sustainability fees on permit applications for new development, or other assessments on real property. These mechanisms could be enacted locally, or authorized at the State level and adopted at local discretion.

Finally, philanthropic interests such as the Rockefeller and MacArthur Foundations could be approached to gain their support address Hawaiʻi's acute and imminent challenge of sea level rise, an idea likely to be of great interest to these foundations given their significant financial contributions to resilience. The City and County of Honolulu has already taken advantage of this support by being chosen to participate as one of the Rockefeller Foundation's 100 Resilient Cities (100RC). 100RC supports the adoption and incorporation of a view of resilience that includes not just "shocks" (i.e. earthquakes, fires, floods, etc.), but also the stresses that weaken the fabric of a city on a day to day or cyclical basis. Cities in the 100RC network are provided with resources necessary to develop a "roadmap" to resilience along four main pathways:

1. Financial and logistical guidance for establishing an innovative new position in city government, a Chief Resilience Officer, who will lead the city's resilience efforts;
2. Expert support for development of a robust Resilience Strategy;
3. Access to solutions, service providers, and partners from the private, public and non-governmental organization sectors who can help them develop and implement their Resilience Strategies; and
4. Membership of a global network of member cities who can learn from and help each other.

In addition, Hawai‘i may wish to form its own nonprofit foundation to raise funds for project that protect vulnerable populations such as those who are economically disadvantaged, seniors, disabled persons, and veterans.

A growing number of different financing and incentive strategies are beginning to emerge to support adaptation to sea level rise. A number of best practices for financing adaptation to sea level rise were identified for the San Francisco Bay Area such as enterprise revenue bonds, sales tax, and general obligation funding (Urban Land Institute 2015). In New Jersey, a state-wide buy-out program for Blue Acres was created after Hurricane Sandy (State of New Jersey 2017b). The Blue Acres program was funded with a combination of federal, state and local grants and established a protocol for purchasing homes from willing sellers in communities subject to repeated flooding. Once the property was purchased, the structures were demolished and the property was designated as open space. The main focus of this program were properties (including structures) that have been damaged by, or may be prone to incurring damage caused by storms or storm-related flooding, or that may buffer or protect other lands from such damage. Cost-benefit analyses of strategy combinations would be essential to support community-level adaptation planning. As such, a multi-pronged, multi-stakeholder, and phased funding strategy would be required that takes into account the complexity of issues surrounding adaptation to sea level rise.

7.3 Require mandatory disclosure for private properties and public offerings located in areas with potential exposure to sea level rise

The State should work with the real estate and insurance industries to require mandatory disclosures of risks for all properties located within the SLR-XA. The list of disclosable hazards should be expanded for public offerings to include future risks of sea level rise, including erosion and flooding, and other risks from climate change.

7.4 Explore the use of transfer of development rights and purchase of development rights programs that facilitate managed retreat and legacy beach preservation

All counties should consider adopting ordinances for TDR/PDR programs that facilitate sea level rise adaptation. Implementation would require counties to:

- Designate sending areas (e.g., areas vulnerable to sea level rise and coastal hazards, areas serving as natural flood buffers, or areas that have experienced repeated or heavy storm damage);
- Designate receiving areas (e.g., areas located upland or inland that are less vulnerable for development);
- Calibrate credit values by balancing the market value of lots in receiving areas with the market value of lots in sending areas;
- Develop a pool of development rights that are legally severable from the land; and
- Establish a procedure for transferring rights from one party to another (either through private transactions or a publicly owned and operated TDR bank) (Codiga and Wager 2011, Christ Hart & Partners 2007).

Legacy beach conservation program funding (Recommended Action 4.3) could be used to cover the cost of these TDRs and PDRs and related coastal land acquisition programs for legacy beach priority areas. Other potential sources of revenue for this fund might include a portion of the Transient Accommodations Tax), green bonds, gasoline tax, property tax, tax credits, short-term vacation rental tax, or penalties for unauthorized or unpermitted land uses. The Waikīkī Beach Special Improvement District Fund is one example where all commercial properties in Waikīkī pay into a special beach fund for Waikīkī, which is based on the assessed value for property taxes.

The State should also develop and offer a grant program to the Counties for the development of ordinances creating TDR and PDR programs related to sea level rise. This would allow the Counties to access experts in the field of municipal law and TDRs and PDRs to develop these ordinances.

7.5 Consider the feasibility of a buy-out program for residential property owners vulnerable to sea level rise

Managed retreat has long been avoided in public dialogue as an adaptation strategy. Yet when weighed against the magnitude of risk faced by coastal and riverine communities, retreat should be included in the toolbox of strategies for climate adaptation. While there do not appear to be any existing residential land acquisition programs for sea level rise vulnerability, there are corollary programs at the federal level that could provide us with lessons and tools.

The Flood Mitigation Assistance Grant Program (FMA) provides funding to States and local communities for projects and planning that reduces or eliminates long-term risk of flood damage to structures insured under the NFIP. FMA funding is also available for managing costs. Under the FMA, FEMA allows for up to 100% of the costs to be covered for Severe Repetitive Loss properties unlike for Repetitive Loss properties in which FEMA usually only covers 90% of the cost. Severe Repetitive Loss properties consists of any NFIP-insured residential property that has met as least one of the following paid flood loss criteria since 1978, regardless of ownership:

- 4 or more separate claim payments of more than $5,000 each (including building and contents payments); or
- 2 or more separate claim payments (building payments only) where the total of the payment exceeds the current value of the property.

Repetitive Loss properties consist of NFIP-insured residential properties that have had one or more claim payment(s) for flood damages.

The State could develop a policy for prioritizing areas for acquisition within the State-wide vulnerability zone and model it after the FMA program. However, timing of such a program presents new challenges since a goal would be to preemptively move development from areas of increasing flooding and erosion risk before catastrophic losses occur, rather than compensating people after a disaster event. Nevertheless, a buy-out program for at-risk coastal properties needs serious discussion, given our expanded understanding of present and future risks of erosion and flooding risks through this Report and other data tools referenced herein.

As a normal course of action each year, the State should also focus its efforts on developing applications to both of FEMA's Pre-Disaster Mitigation Grant Program (PDM) and the FMA Grant Program. PDM provides funds for hazard mitigation planning and projects. This funding is available on an annual basis and is awarded on a competitive basis. The goal of this program is to reduce overall risk to the residents, structures and facilities from future hazard events, which includes flooding before a flooding disaster.

Post-Flooding Disaster Policy. After a flooding disaster, a state may be provided funding opportunities from several sources that could also support buy-outs of impacted residential properties that are located in the SLR-XA. The State, Counties, and local communities should prioritize investments in qualified properties and facilities as a way to remove them from the areas of inundation and return the existing land to its pre-development condition and prevent future development. Where possible, government and communities should also focus post-disaster recovery funds on rebuilding infrastructure in areas that are out of the areas of present day flood zones and the SLR-XA. If the infrastructure cannot be removed, then efforts should be focused on making them more resilient to sea level rise and flooding through the recovery process.

One example of potential funding would be through the HMGP that is provided after a presidentially declared disaster. According to FEMA: "the purpose of the HMGP is to help communities implement hazard mitigation measures following a Presidential Major Disaster Declaration in the areas of the state, tribe, or territory requested by the Governor or Tribal Executive. The key purpose of this grant program is to enact mitigation measures that reduce the risk of loss of life and property from future disasters." A second potential funding source would be the CDBG-DR program. When appropriated by the U.S. Congress, these funds may be used in eligible areas of the community for un-met needs focused on residential housing buy-outs, elevations and rehabilitation projects/programs. The funds may also be used for infrastructure and economic development. All three major uses of these funds can focus not only on recovery from a disaster, including flooding, but also resilience. Making the community more resilient through eligible projects/programs is one of the targets of this funding.

State-wide Buy-out Program. Buy-out programs could be designed and implemented to yield successful outcomes for residents and government entities alike (Freudenberg et al. 2016). Although buy-out programs have not been established for sea level rise vulnerability, buy-out programs have been employed in New York, New Jersey, and Connecticut following Hurricanes Irene and Sandy. Of the billions of federal aid spent on resilience and recovery in the New York metropolitan region, at least $750 million was spent on buy-outs, which alleviated the flood risk for more than 1,500 homes. Lessons learned based on case studies conducted within the New York metropolitan region detail key areas for improvement which include:

- Rethinking the purpose and timeline of buy-out programs;
- Improving the administration of funding for buy-out programs;
- Considering alternative funding models for buy-out programs;
- Improving planning processes to anticipate and integrate buy-out programs;
- Making participation in buy-outs easier and more attractive for municipalities; and
- Streamlining buy-outs to facilitate participation (Freudenberg et al. 2016).

Recommendation 8: Support research, assessment, and monitoring to support adaptation to sea level rise

Overview

As science continues to advance, new projections and modeling will be available to update the vulnerability assessment. Scientific and community-based monitoring would be needed to validate changing conditions over time. Other types of research and assessment, including cost-benefit analyses and more detailed economic studies are needed to support the evaluation of adaptation strategies at community, county, and state levels. Research, assessment and monitoring are essential in supporting flexible, anticipatory, and phased, approaches to sea level rise adaptation based on the latest and best science. The State has premier research institutions to develop and implement a robust and relevant science agenda to support understanding of and adaption to climate change and sea level rise.

Recommended Actions in this section highlight the vital role that supporting ongoing research, assessment, and monitoring plays as part of an overall adaptation strategy. At the heart of the 5-year update of this Report, as mandated by Act 32, is determining the need to update the coastal hazards modeling and vulnerability assessment based on new global projections of sea level rise and new methods. There is also an important role of citizen science in monitoring the impacts of sea level rise.

Recommended Actions

8.1 Update coastal hazards modeling and vulnerability assessment as needed based on new climate science, sea level rise projections, and methods

The Hawaiʻi Climate Commission should establish a maintenance schedule to review the SLR-XA as a state-wide vulnerability zone for planning, policies, and regulations and to determine if updates are warranted. The need for updating coastal hazards modeling should be determined based on the extent to which new modeling would substantially change exposure and vulnerability in the SLR-XA. Small, pilot modeling efforts should be conducted in selected areas with high vulnerability to sea level rise to evaluate the degree to which any new modeling would substantially change the hazard overlays or contributes to more robust design standards based on SLR-XA (see Recommended Actions 1.1, 2.6, 3.1, and 3.2). As a priority, additional data collection and modeling should include coastal erosion and annual high wave flooding for the islands of Molokaʻi, Lānaʻi and Hawaiʻi. Further, a comprehensive review of models should be conducted to determine if a new approach is needed to model coastal hazards with sea level rise. If new modeling is warranted, the updated results should be integrated in state, county, and community plans and which could serve as a basis for floodplain regulations.

8.2 Engage communities in monitoring the impacts of sea level rise

Community engagement would become increasingly important to validate changing conditions over time. The following offers ideas for community engagement strategies to keep residents informed, educated and involved in monitoring the impacts of sea level rise.

- Update the Hawaiʻi SLR Viewer with new sea level rise modeling results.
- Use community-based planning to educate communities on their risk to sea level rise.
- Develop a phone application to visualize sea level rise based on geolocation and projections.
- Collect historic photographs or photographs of landmarks and utilize the Hawaiʻi Sea Level Rise Viewer to develop photo simulations on how future flooding might look.
- Work with science centers to educate communities about sea level rise and its impacts.
- Leverage the State and County hazard mitigation plan stakeholder and outreach strategies to include sea level rise.
- Develop an online web map to allow residents to capture changes over time (e.g., photographs, spatial extent, and textual observations).

The University of Hawaiʻi Sea Grant Center for Coastal and Climate Science and Resilience has already initiated a successful citizen science program for documenting tidal flooding (see description in Sea Level Rise Outlook chapter of this Report). The King Tide Project engaged citizen scientists in documenting tidal flooding in May, June, and July 2017, contributing more than 2,400 photo records (University of Hawaiʻi Sea Grant College Program 2016).

8.3 Conduct in-depth assessment of vulnerability and evaluation of adaptation strategies for critical infrastructure throughout the State

The State and Counties should conduct an in-depth risk and vulnerability assessment to determine critical infrastructure at risk to sea level rise throughout the State as part of the hazard mitigation planning and risk assessment process. The vulnerability assessment results in this Report could be used as one component of a prioritization methodology to rank the infrastructure to help determine the order of investment to protect, retrofit, or relocate. This effort should be coordinated with efforts to prioritize shoreline protection and preservation (see Recommended Action 1.6). Additional elements to include in the ranking would include current condition, years of useful life left, and other cost-benefit components. A prioritized action plan should be developed to identify the most at-risk infrastructure and then associated adaptation options and funding sources for implementation. The analysis and future updates could be conducted concurrently with the State and County hazard mitigation plan updates to ensure results are linked to the updated mitigation strategies and associated prioritization.

8.4 Develop a sea level rise research, assessment, and monitoring agenda to support the 5-year update process

The Hawaiʻi Climate Commission should convene a multisectoral experts group to identify research, assessment, and monitoring priorities to support the 5-year update process. These priorities should be informed by the learning questions presented in this Report and reviewed and refined over time. This agenda of research, assessment, and monitoring priorities should endeavor to use scientific findings as well as traditional and local knowledge. The development of this agenda should be integrated with the monitoring and evaluation plan developed for the 5-year update (see Recommended Action 9.5).

Recommendation 9: Promote collaboration and accountability for adapting to sea level rise

Overview

Adapting to sea level rise will require difficult decisions on when, how, and where to adapt. These decisions would need to be coordinated among different agencies and sectors, and reviewed and updated as conditions change. Collaboration among federal, state, and county agencies is essential to ensure that plans and programs are regularly reviewed and aligned to support effective and efficient adaptation as well as avoid maladaptation. Adaptation efforts would need to cross-jurisdictional boundaries, consider the natural boundaries, and address multiple scales of planning (Urban Land Institute 2015). Establishing collaborative processes through which public and private stakeholders can work together would be critical to Hawaii's efforts to address the impacts of sea level rise, while meeting other state goals and objectives.

Recommended actions in this section emphasize the need to promote collaboration and accountability for sea level rise adaptation. The Hawaiʻi Climate Commission should serve as a forum for interagency collaboration and accountability for sea level rise adaptation. The Commission should consider new actions to take such as prioritizing areas for managed retreat, developing a science agenda, and promoting the recommendations put forward in this Report. Further, the continued support to agencies such as the OCCL, Office of Planning/CZM and the Counties is essential in providing coordination and technical support to the Commission and strategic partnerships among government, nongovernment, and private stakeholders and the public. In addition, strategic partnerships with a range of stakeholder groups should be formed to guide and support the work of the Commission. A comprehensive education and outreach program would build an informed constituency encompassing all sectors and all ages. Monitoring and evaluation is essential for accounting for progress or making course corrections to address Hawaii's vulnerability to sea level rise.

Recommended Actions

9.1 Develop sea level rise adaption priorities for the Hawaiʻi Climate Commission

The Hawaiʻi Climate Commission should develop priorities that move the ideas and recommendations within this Report to actions. Should the Hawaiʻi Climate Commission decides to embark on a comprehensive strategic plan for climate change mitigation and adaptation, sea level rise should be a major component of that effort. Once developed, the sea level rise adaption priorities could be presented to the Governor, the County mayors, and the public. In addition, the Hawaiʻi Climate Commission could also oversee how the priorities are being implemented through annual reports or updates from the Commission staff.

The recommendations of this Report could be further developed and incorporated as initiatives into adaptation plans, working hand and hand with all stakeholders. Lead agencies, timelines, funding sources, and performance metrics could be developed for such plans. In addition, the Commission should identify and secure funding sources for initiatives; assess current legislation that may promote maladaptation or hinder proactive adaptation efforts; develop a system by which to review newly proposed legislation for such concerns; and develop a public engagement strategy to provide coordinated, clear and concise messaging on climate change impacts. To support the multiple work streams of the Hawaiʻi Climate Commission, working groups could be formed to provide technical input and feedback. As an example, initial work groups for the Commission could include the following:

- Education and Outreach Working Group
- Adaptation and Response Working Group
- Climate Mitigation Working Group
- Scientific and Technical Working Group
- Legislative Review Working Group

There are several examples of proactive planning and collaboration to support the development of an approach to mitigate the impacts of sea level rise. The California Coastal Commission has a regularly updated strategic plan that includes a goal to address climate change through local coastal program planning, coastal permitting, interagency collaboration and public education. The California Coastal Commission has also developed guidance on sea level rise adaptation for local government and residents (California Coastal Commission 2013, 2017, 2015). The Washington DC Silver Jackets team formalized in

2014 (Washington 2017), is an interagency working group composed of more than 25 federal, district, regional, and academic partners working to collaboratively address flood risk in the area. The team has established five task groups: Development of Flood Inundation Mapping/Stream Gauges; Flood Emergency Planning; Interior Drainage Flooding; Levee Certification and Accreditation; and Flood Risk Communication. Each task group has responsibilities that aid in fulfilling the team's overall mission and goals. The risk communication group has developed an internal and external communication guide to ensure consistent and clear messaging to the public, as well as standards for communicating between agencies that are a part of the team.

9.2 Continue to support the Office of Planning and DLNR, OCCL to provide leadership, technical support, education and outreach, and interagency coordination to the Hawaiʻi Climate Commission and other stakeholders for sea level rise

Together, the OCCL, CZM, and the county planning departments, are responsible for regulating development and managing resources along a changing shoreline. These offices already face substantial challenges in their permitting and planning processes due to the predominant trend of coastal erosion and ever-growing pressure to develop and protect private shorefront lands and infrastructure. The burden on these offices will continue to grow in coming years as flooding and erosion impacts become more severe and frequent with increasing sea level rise. Once the Report is released, the OCCL, CZM, and the county planning departments should continue to provide leadership and coordination among government agencies, nongovernment organizations, private sector stakeholders, and communities in understanding the consequences of sea level rise and applying this knowledge to their decision-making. Partnerships with the University of Hawaiʻi Sea Grant College Program and others should be leveraged to provide support. At the direction of the Hawaiʻi Climate Commission, the OCCL, CZM, and the county planning departments should be responsible for implementing many of actions based on the Report's Recommendations.

9.3 Develop a multi-agency, multi-media, and multi-stakeholder education and outreach program as part of a long-term commitment to building an informed and active constituency on climate change mitigation and adaptation

A comprehensive education and outreach program should be developed and maintained informed by the latest research in social science and guidance on climate change communication (FEMA 2013, Center for Research on Environmental Decisions and ecoAmerica 2014, Center for Research on Environmental Decisions 2009). Consistency in messaging is critical. A program for public information built off the best practices established by the NFIP CRS should be developed. This program should identify appropriate messages for various target audiences; projects, programs, and other community efforts that should convey these messages; materials to be used to support the identified messages; and ways to determine the success of identified outreach.

Outreach materials and messages would require an adaptive approach as sea level rise science changes and lessons are learned about effective outreach. Communication channels should be two-way, providing multiple opportunities for stakeholders to share information, good practices, and lessons in adapting to sea level rise. A sea level rise conference could be organized every two years to facilitate the process of sharing lessons learned and good practices. Further, the Climate Adaptation Portal could be expanded to provide communities opportunities to share the sea level rise adaptation stories, good practices and a venue to ask questions. Partnerships with the University of Hawai'i Sea Grant College Program and others should be leveraged to provide support for education and outreach.

9.4 Develop a monitoring and evaluation plan with benchmarks and indicators to support the 5-year update process

The Hawai'i Climate Commission should develop a monitoring and evaluation plan that would provide the data and information needed for anticipatory and adaptive management as part of the 5-year update process. The process of adapting to sea level rise would be implemented over time. As adaptation strategies and practices are proposed and implemented, there is a need to monitor, evaluate, and document the effectiveness of these efforts in reducing risk and supporting sustainable and resilient communities in the face of sea level rise. The learning questions provided in each chapter of this Report can serve as a framework for developing a monitoring and evaluation plan with measurable indicators and targets to track progress and document successes and lessons learned. Benchmarks and indicators adopted by City & County of Honolulu's participation in the 100 Resilient Cities Initiative may be relevant to monitoring progress toward increasing Hawaii's capacity to adapt to sea level rise.

Documentation of successful approaches and lessons learned would support continuous and shared learning for effective and efficient adaptation. The goal of increasing Hawaii's capacity to adapt to sea level rise along with selected indicators and targets should be included as part of the Aloha+ Challenge Dashboard. The Dashboard is an online open data platform to track progress, provide accountability, and ensure transparency of the Aloha+ Challenge, which is a state-wide commitment to sustainability. The online dashboard is designed for decision makers, practitioners, and the public to inform policy, data driven decision making, and inspire action on Hawaii's state-wide sustainability goals.

Another example of a successful monitoring and evaluation tool is the Los Angeles Mayor's Dashboard (City of Los Angeles 2017), which provides information on the provision of various city services and planning efforts. The tool represents an innovative, data-based approach to public transparency and governmental accountability, while providing a mechanism through which residents can learn more about their city and efforts that are underway to work toward a prosperous, livable, safe, and well-run city.

Priorities, Sequencing, and Synergies

As defined in the Introduction, this Report is first and foremost a technical report not a plan. The recommendations highlight actions to increase our capacity to adapt to sea level rise but do not lay out a plan for implementation. The Hawai'i Climate Commission provides a collaborative multisectoral forum for furthering discussions on how, when, and where to implement many of these recommendations. During the *2nd Sea Level Rise Vulnerability and Adaptation Workshop* held in February 2017, a number of recommendations were identified as priorities to be fast-tracked for implementation through discussions with the Hawai'i Climate Commission and other stakeholders. In addition, sequencing considerations and synergies among the recommendations need to be recognized and planned for. These priorities, sequencing, and synergies are described below to begin the discussion for transforming from "business as usual" to concrete, implementable actions.

Education and outreach at all levels was identified as a priority. This includes state and county government, the private sector, and the public including children. A comprehensive education and outreach program on sea level rise vulnerability and adaptation (Recommended Action 9.3) is needed to communicate the results of this Report and engage stakeholders over the long-term. A communication and outreach strategy and clear and consistent messaging and materials, such as factsheets, presentations, and other materials, are needed to support questions from the public as well as from state and county agencies and other stakeholders. Engaging communities in monitoring the impacts of sea level rise (Recommended Action 8.2) should form one component of this education and outreach program that would not only raise public awareness of the impacts of sea level rise but also generate ideas and lessons on how to adapt. Continued support of DLNR, OCCL and other entities, such as the Office of Planning, CZM, and county partners (Recommended Action 9.2) is needed to support a state-wide response to sea level rise. Staff and funding for OCCL would not only support the education and outreach program, but provide technical and administrative support to the Hawai'i Climate Commission (Recommended Action 9.3) on all matters related to sea level rise.

State and county agencies have been asking for guidance on planning for sea level rise. The use of the SLR-XA with 3.2 feet of sea level rise as a vulnerability zone (Recommended Action 1.1), identified as a priority by state and county agencies, would serve as an important benchmark for planning. While sea level rise projections used to develop the vulnerability zones may need to be updated as new science and modeling become available (Recommended Action 8.1), this eventuality should not paralyze (i.e., "paralysis by analysis") the use of this vulnerability zone for strategic planning now. Complementary Recommended Actions 2.1 and 3.1, and 3.3 should be considered to provide state vulnerability zone design standards and regulatory flood controls for new development and critical infrastructure in areas subjected to chronic and event-based flooding. Guidance on integrating community resilience to coastal hazard and sea level rise (Recommended Actions 1.5) would also help the State, Counties, and communities use the results of this Report and other data and information for planning.

A lands inventory (Recommended Action 1.3) should be conducted to identify opportunities and constraints for redevelopment within urban land use zones of each county. These opportunities and constraints would help to identify critical infrastructure that needs to be protected or relocated, potential areas for redevelopment as part of a managed retreat strategy, and areas that need to be preserved for ecological, cultural, recreation, and economic values. In addition to the lands inventory, the identification of shoreline protection and preservation priorities (Recommended Action 1.6) and legacy beach conservation priorities (Recommended Action 4.1) should be fast-tracked to help place boundary conditions on shoreline armoring needed to support planning and enable legacy beaches to persist. Together, these recommendations should provide the basis for identifying priority target areas for redevelopment (Recommended Action 3.2).

Finally, guidance is needed on integrating adaptation to sea level rise into state, county and community plans (Recommended Action 1.5) as part of comprehensive managed retreat strategies. As part of this guidance, the development of a community visioning process was identified during stakeholder consultations and workshops as a priority to help communities plan for sea level rise. This guidance can be developed now and updated over time as new requirements and priorities are established.

The Hawai‘i Climate Commission should support the establishment of a committee to develop prioritization criteria for identifying priority target areas for smart redevelopment as a part of a managed retreat strategy (Recommended Action 2.2). An early action could be to integrate sea level rise in the environmental review process and the Hawai‘i CZM Act (Recommended Actions 2.9 and 2.10). All major new development and capital improvement projects should be subjected to an in-depth analysis of sea level rise impacts based on elevation, tolerance for risk, and lifetime of the structure (Recommended Action 2.7). Overall, there is a need for in-depth assessment of vulnerability and evaluation of adaptation strategies for all critical infrastructure through the State (Recommended Action 8.3).

Technical and financial support is needed to initiate a state-wide CRS program (Recommended Action 3.3). Participation in the CRS improves flood risk management for both riverine and coastal flooding and provides incentivizes in terms of lower flood insurance rate premiums. The State and Counties should work together to identify actions that can be taken to obtain credits to enable CRS participation by Kaua‘i and O‘ahu and to increase the CRS rating of Maui and Hawai‘i. The following recommendations may contribute to credits under the CRS: (a) developing education and outreach on improving flood risk management (as part of Recommended Action 10.1), (b) integrating coastal hazards with sea level rise in hazard mitigation plans (Recommended Action 4.5, identified priority), (c) encouraging property owners located outside FEMA-designated flood zones to purchase flood insurance (Recommended Action 4.4), and (d) requiring the mandatory disclosure for private properties and public offerings located in areas with potential exposure to sea level rise (Recommended Actions 8.3 and 10.1).

The coastal modeling and vulnerability assessment presented in this Report would need to be reviewed as part of the 5-year update process (Recommended Action 8.1) as mandated under Act 32. The Hawai‘i Climate Commission should set priorities for (Recommended Action 9.2) the 5-year update of this Report and develop a monitoring and evaluation plan to track progress (Recommended Action 9.5) and support a learning and adaptive management approach. Research, assessment and monitoring priorities should be identified to support the 5-year update (Recommended Action 8.4). These priorities should be funded now.

Finally, financing and incentives for sea level rise adaptation (Recommendation 7) are needed to support many of these recommendations. As part of a multi-pronged financing strategy (Recommended Action 7.2), the establishment of a sea level rise adaptation trust fund, if established now with a core amount and regular and modest inputs over time, could accrue to a substantial and sustainable financing means to help highly vulnerable and low-income residents with buy-out programs (Recommended Action 7.5) or other adaptation measures. The exploration of TDRs and PDRs (Recommended Action 7.4) to facilitate managed retreat from the shoreline was identified as a priority. Further, TDRs and PDRs should be prioritized to support legacy beach conservation priorities (Recommended Action 4.1). The mandatory disclosure of sea level rise risks of real estate listings of private property and public offerings (Recommended Action 7.3) was identified as a priority action to raise awareness of the risks of sea level rise. A range of incentives need to be identified (Recommended Action 3.9) to promote improved flood risk management and reduce the costs of adaptation and disaster recovery.

Learning Questions for the 5-Year Report Update

Learning questions for this recommendation chapter highlight the need to monitor the status of implementation of the recommendations as well as lessons learned and successes achieved along the way. As such, learning questions for the 5-year Report update include:

1. What recommendations have been implemented and why?
2. What recommendations have not been implemented and why?
3. What have been barriers to implementation and measures taken to overcome these barriers?
4. To what extent has Hawaii's capacity to adapt to sea level rise increased based on benchmarks and measurable indicators?

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