THE HAWAI‘I CLIMATE CHANGE MITIGATION & ADAPTATION INITIATIVE

Pili Na Mea A Pau

“All Things Are Related”

Sea Level Rise Vulnerability & Adaptation Report

April 7, 2018

State of Hawaii,
Office of Planning

TETRA TECH

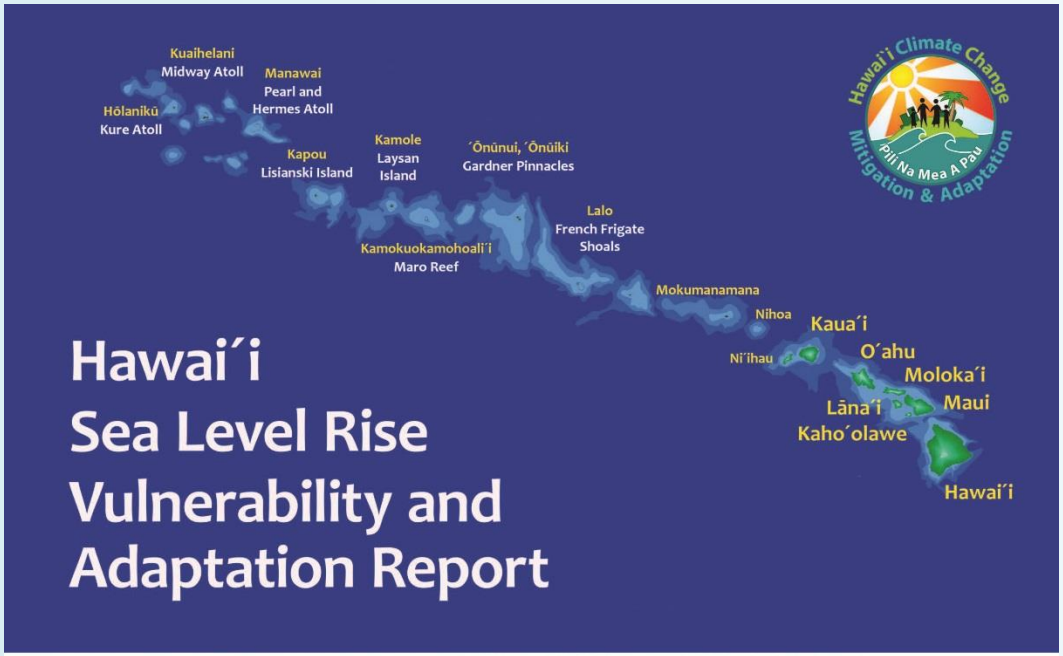
SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY

Sea Grant University of Hawai‘i

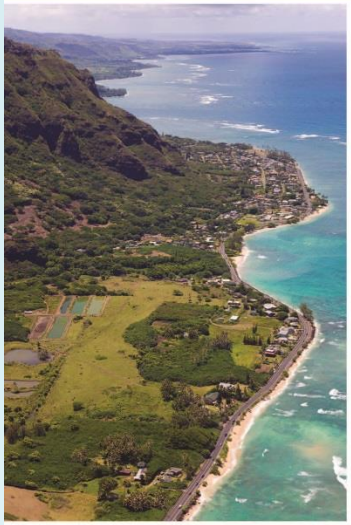
PACIFIC ISLANDS CLIMATE SCIENCE CENTER PI-CSC

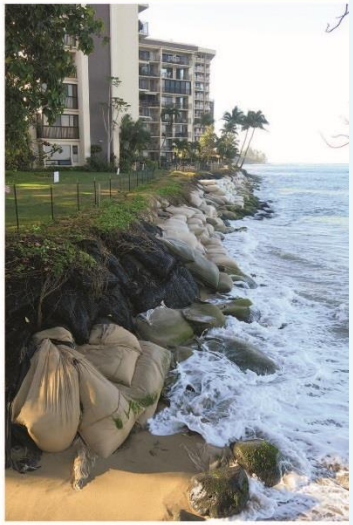
THE HAWAI`I SEA LEVEL RISE VULNERABILITY & ADAPTATION REPORT

- Available to the public December 2017.
- A technical report not an adaptation plan.
- Assesses vulnerabilities to coastal hazards with sea level rise.
- Provides recommendations for improving resilience to coastal hazards.
- Provides a framework for assessing other climate change impacts.



Hawai´i Sea Level Rise Vulnerability and Adaptation Report





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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

Sea Level Rise Outlook: Global and Local Observations and Projections

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

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, O'ahu January 2016

Located at the center of the North Pacific basin, Hawai'i 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 Hawai'i 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 Hawai'i 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.

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.

MODELING

Passive Flooding →

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).

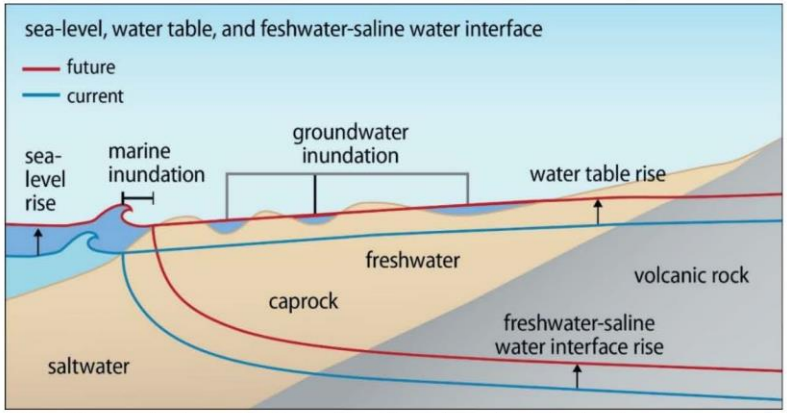


Figure 19. Schematic diagram showing passive marine and groundwater flooding from current sea level (blue) to future sea level (red) (Rotzoll and Fletcher 2013)

Annual High Wave Flooding →

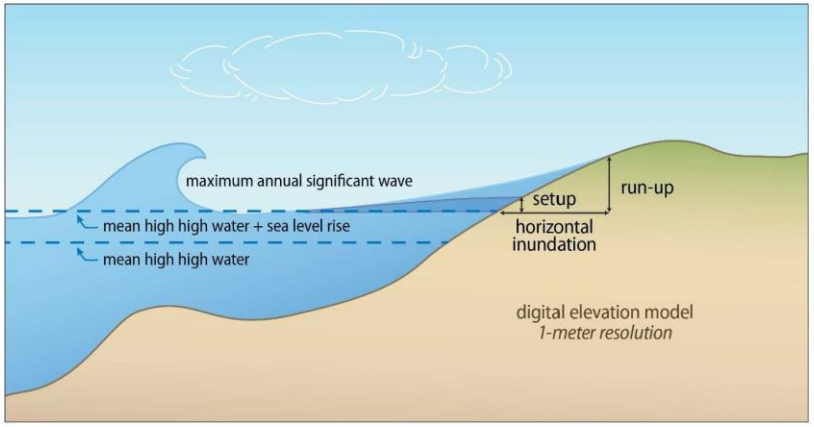


Figure 23. Schematic diagram of showing key inputs and outputs of modeling annual high wave flooding

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 O'ahu, Kaua'i, 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).

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.

Coastal Erosion →

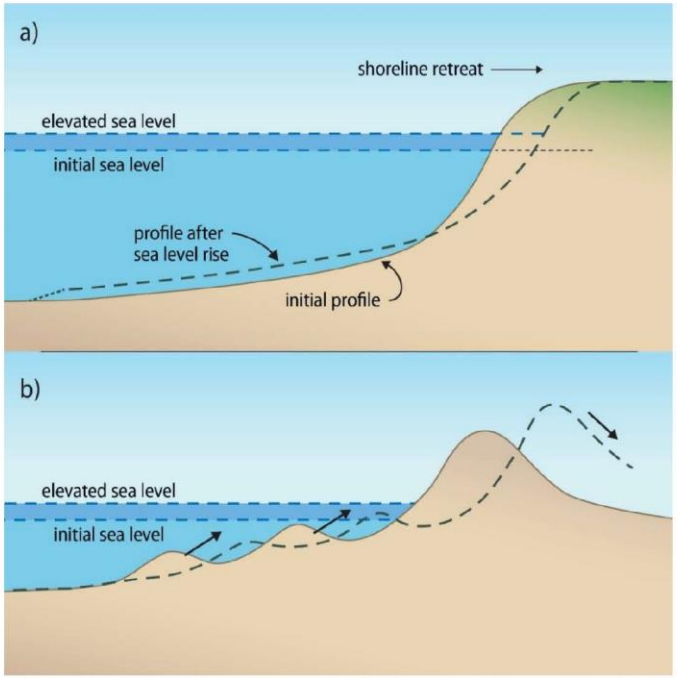
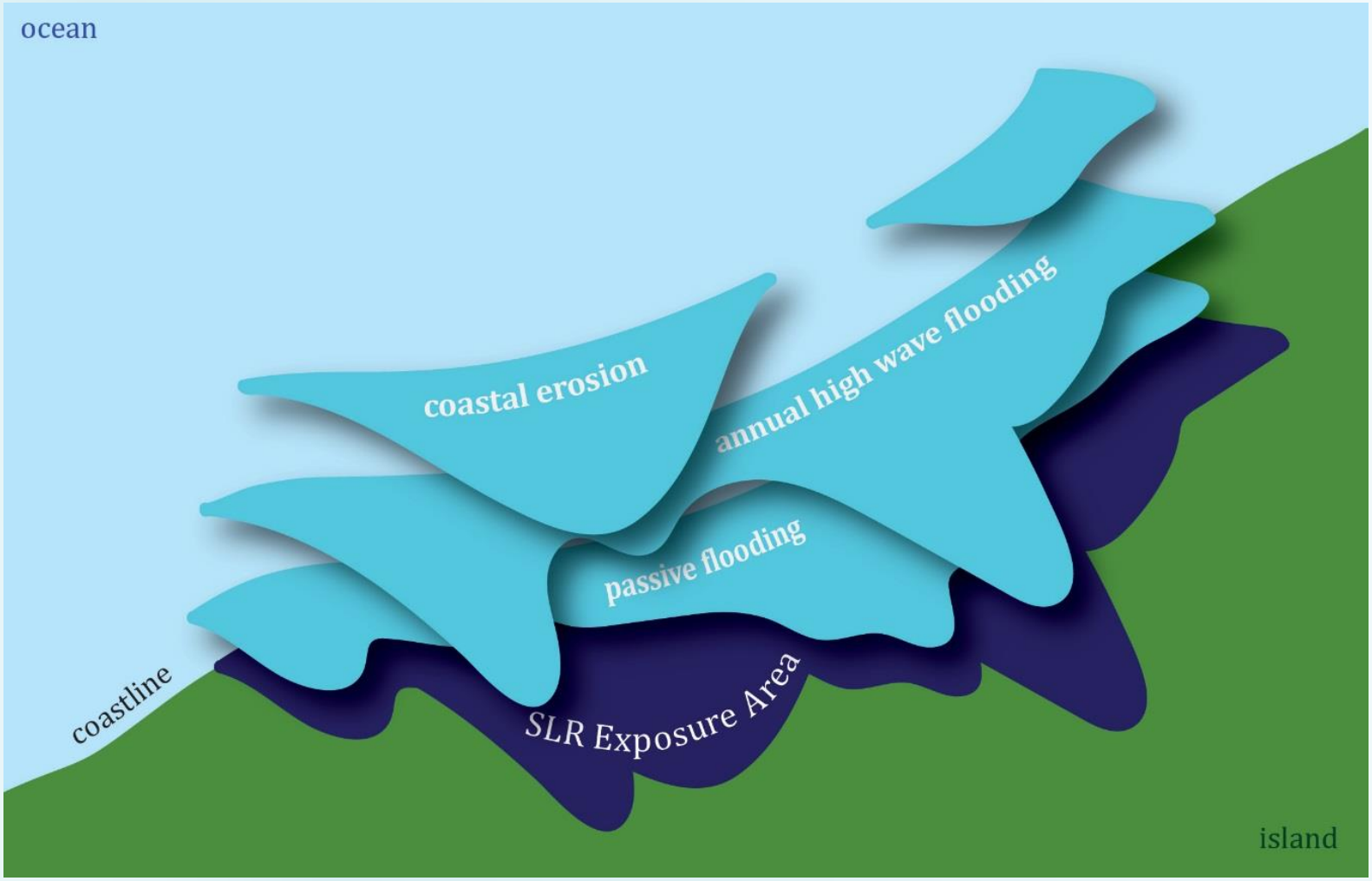


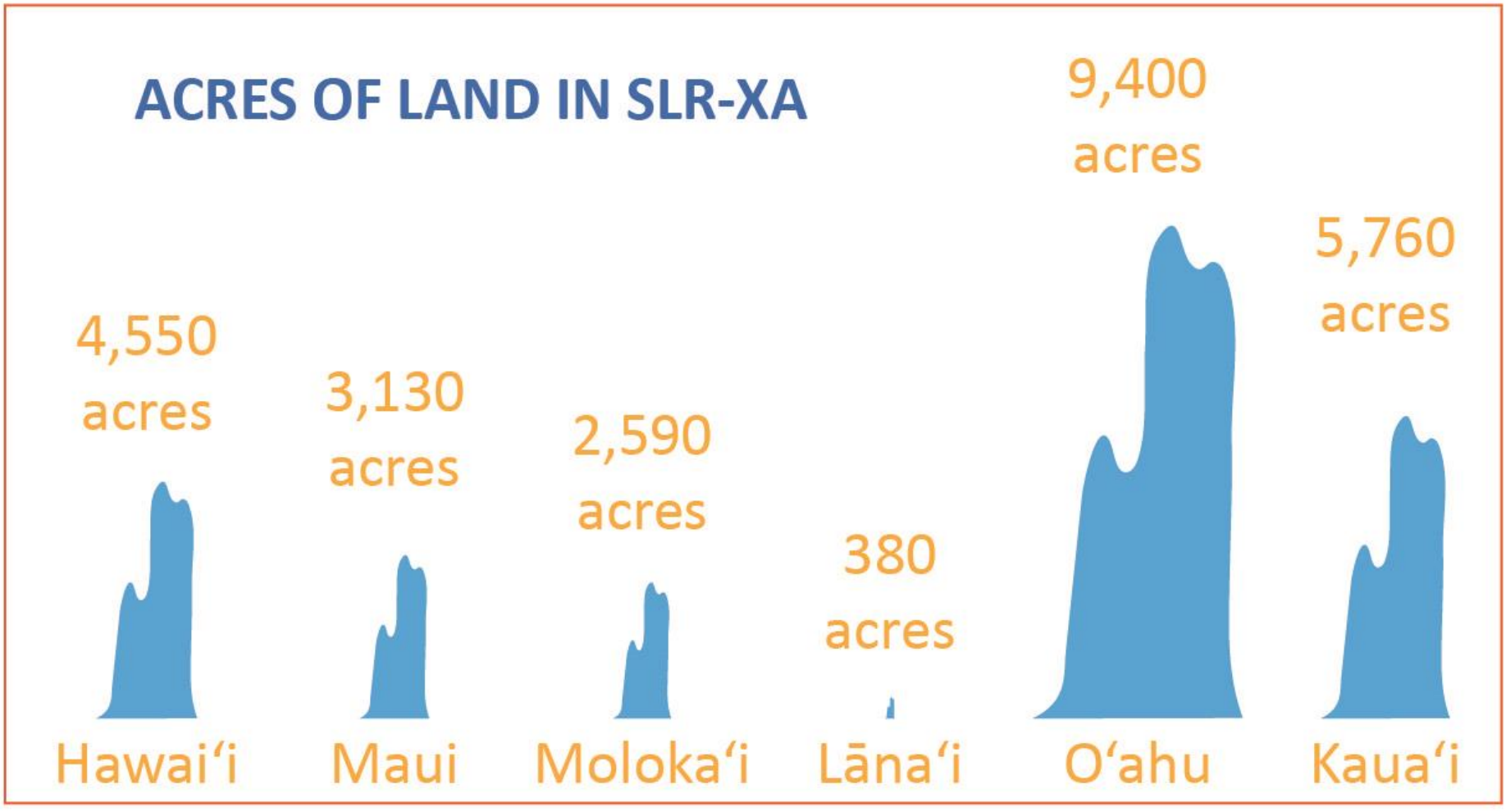
Figure 26. Schematic diagram of showing key inputs and outputs of modeling coastal erosion (a) and the change in shoreline profiles with sea level rise (b)

SEA LEVEL RISE EXPOSURE AREA (SLR-XA)

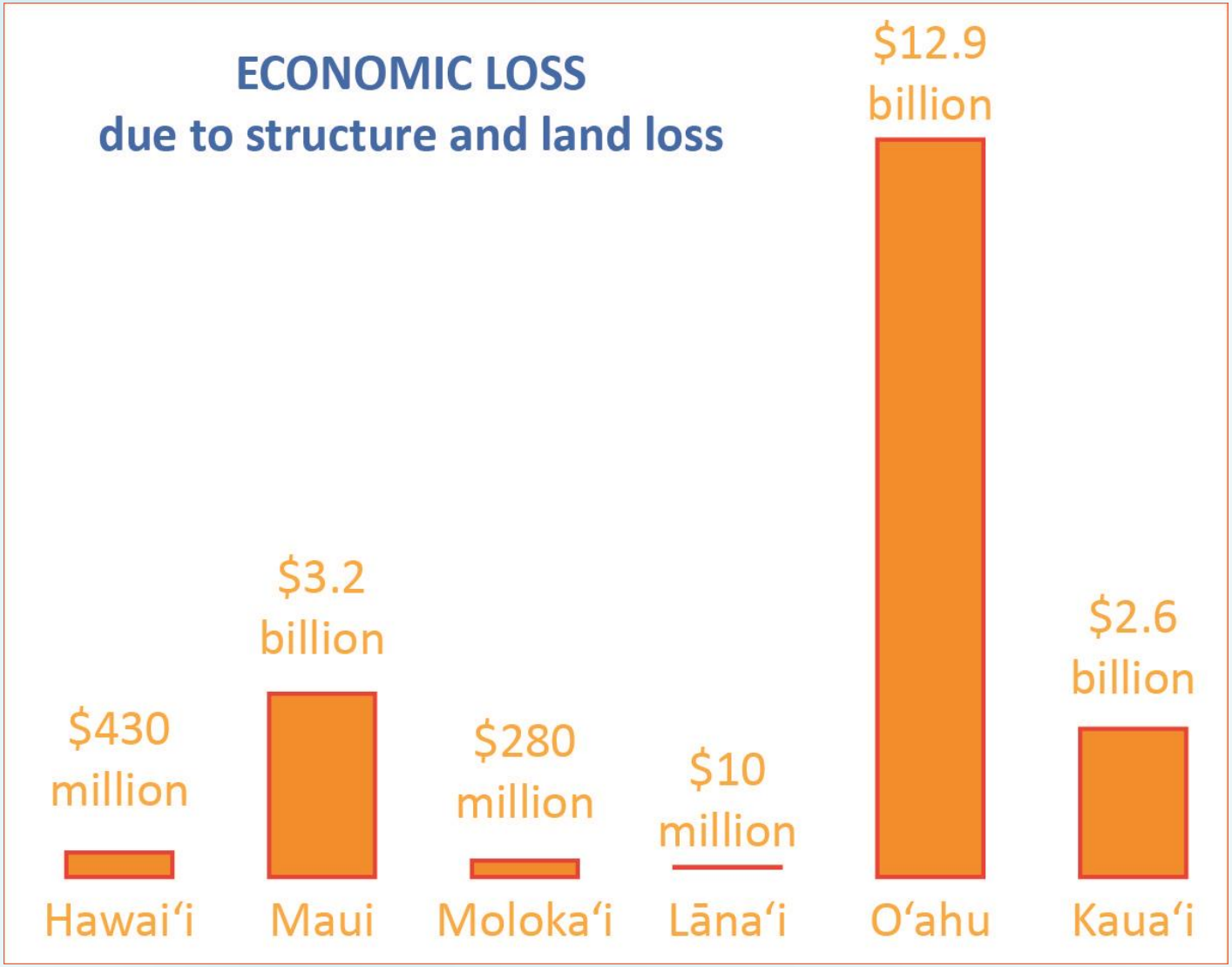


STATE-WIDE SUMMARY

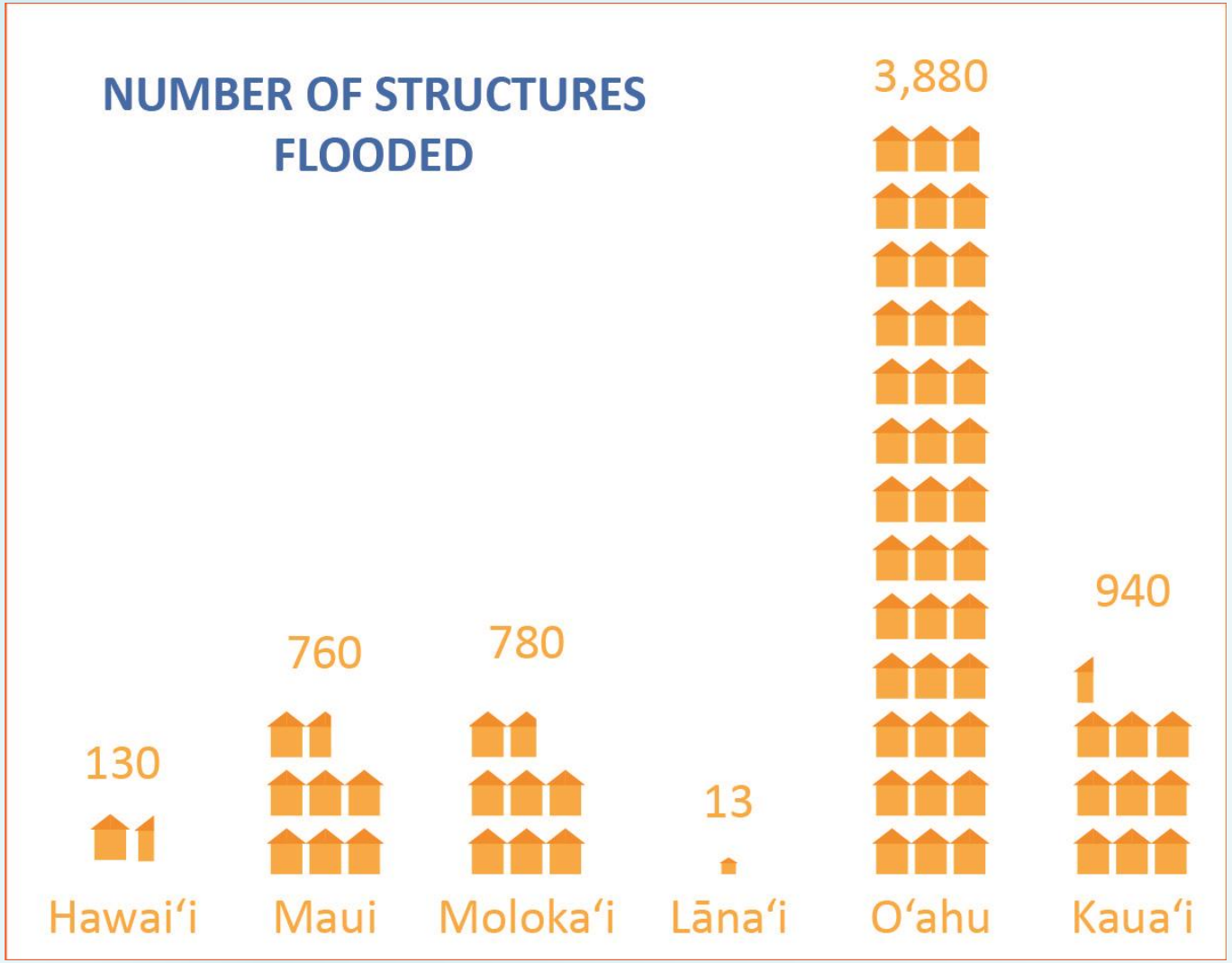
SLR-XA WITH **3.2** FEET OF SEA LEVEL RISE

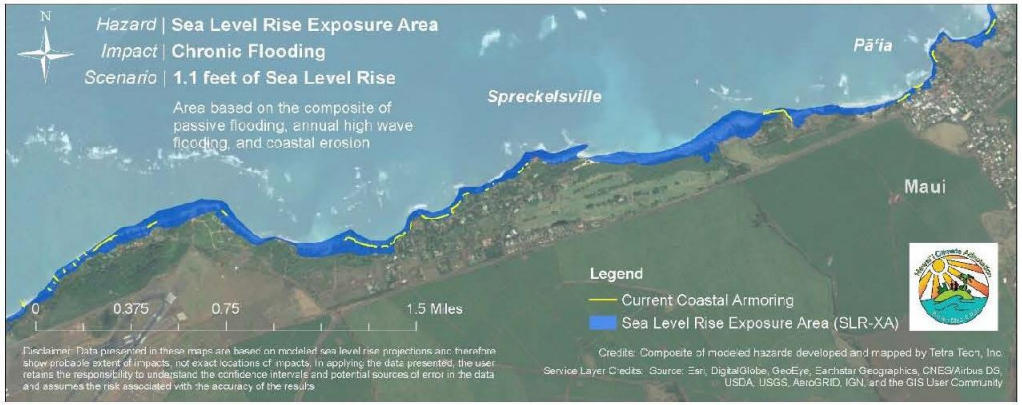


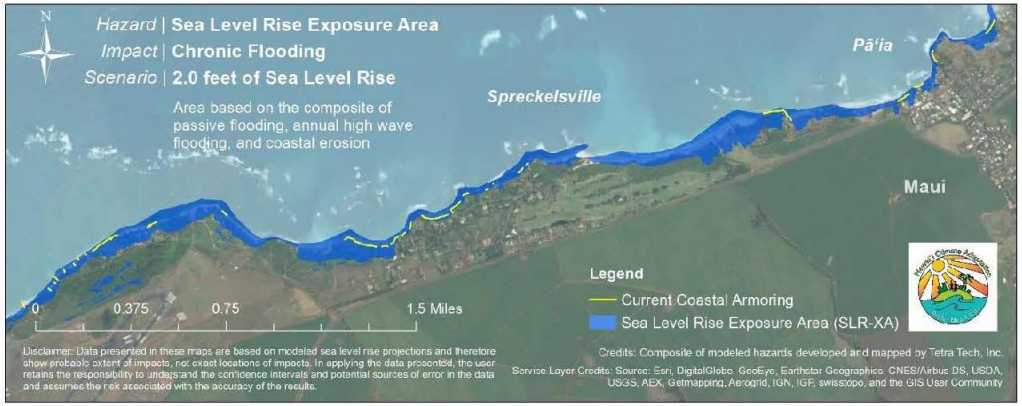
STATE-WIDE SUMMARY
SLR-XA WITH **3.2** FEET OF SEA LEVEL RISE



STATE-WIDE SUMMARY
SLR-XA WITH **3.2** FEET OF SEA LEVEL RISE







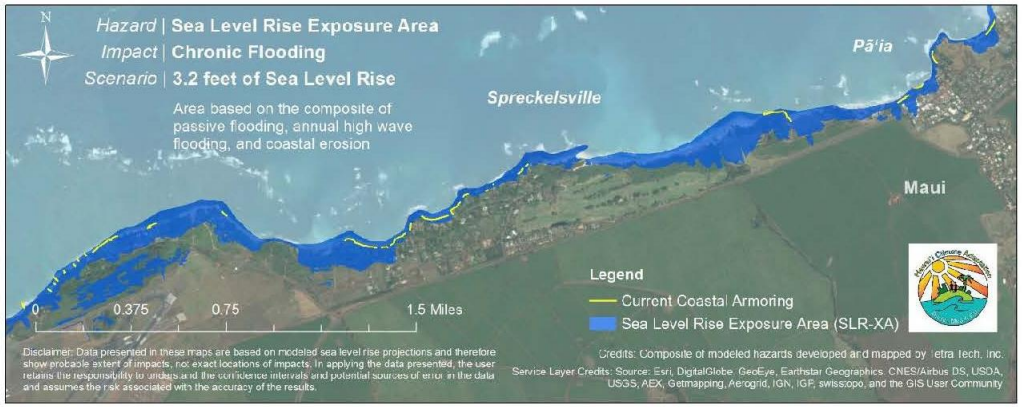


Figure 55. Potential chronic flooding in the sea level rise exposure area with 1.1, 2.0, and 3.2 feet of sea level rise in Spreckelsville, Maui

Economic Loss:

- Parcel based
- Property/structures
- Aggregated into one hectare grids

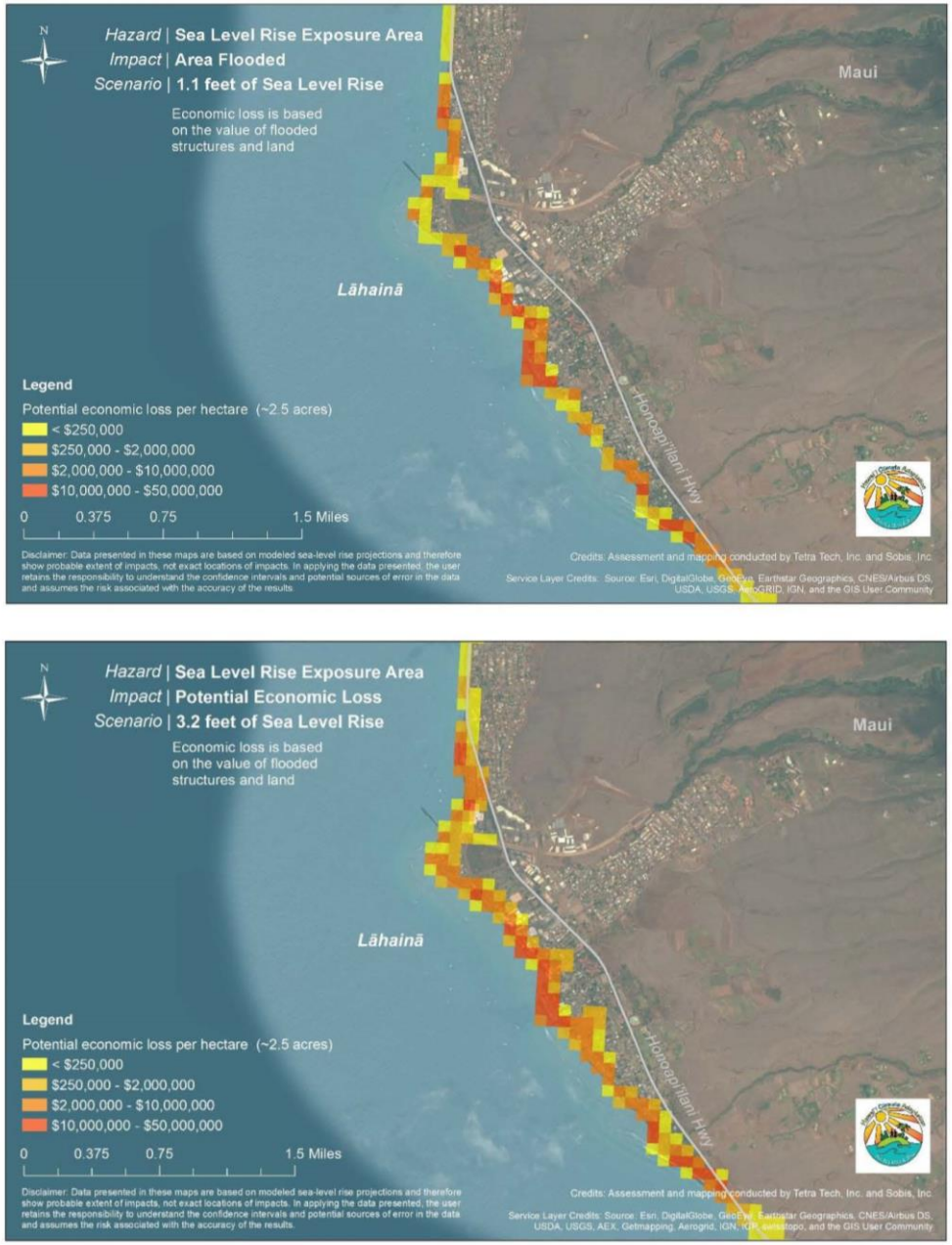


Figure 61. Potential economic loss in the SLR-XA with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise in Lāhainā, Maui

Roads

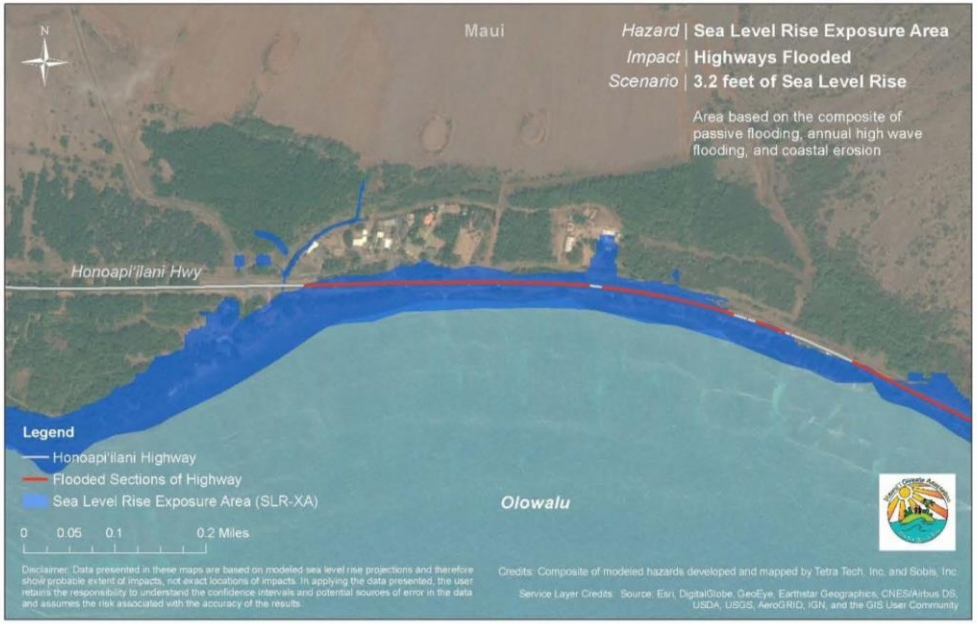


Figure 62. Projected chronic flooding of Honoapi'ilani Highway in the SLR-XA (red) with 1.1 feet (top) and 3.2 feet (bottom) of sea level rise road flood in Olowalu, Maui

Harbors & Airports

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

Hawaiian Home Lands & Cultural Sites

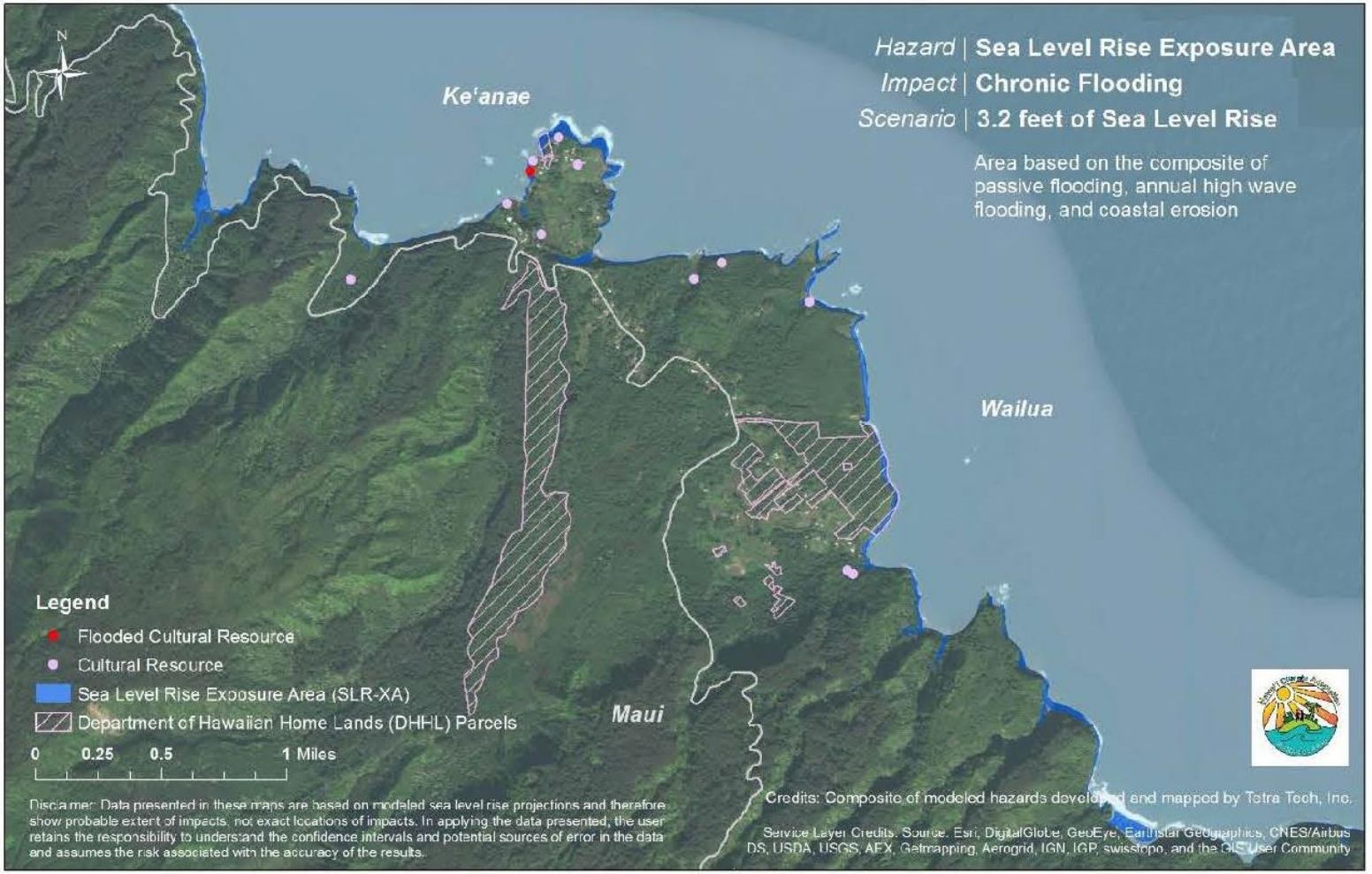


Figure 64. Potential chronic flooding of Ke'anae and Wailua Hawaiian Home Lands on Maui (pink) and cultural resources (red) in the SLR-XA (blue) with 3.2 feet of sea level rise

Parks

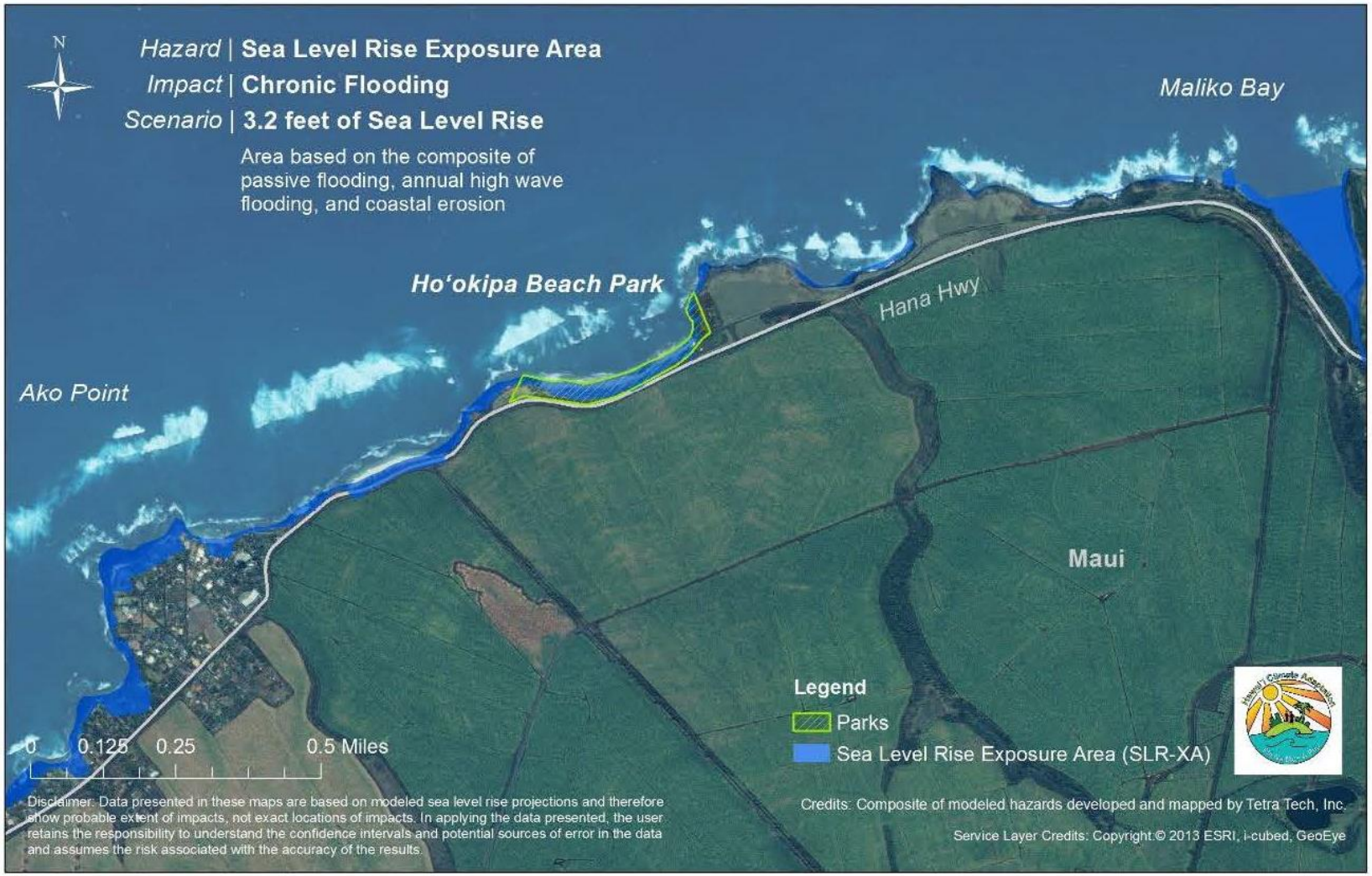


Figure 65. Potential chronic flooding of Ho'okipa Beach Park in the SLR-XA with 3.2 feet of sea level rise along Maliko Bay, Maui

Wildlife Sanctuary

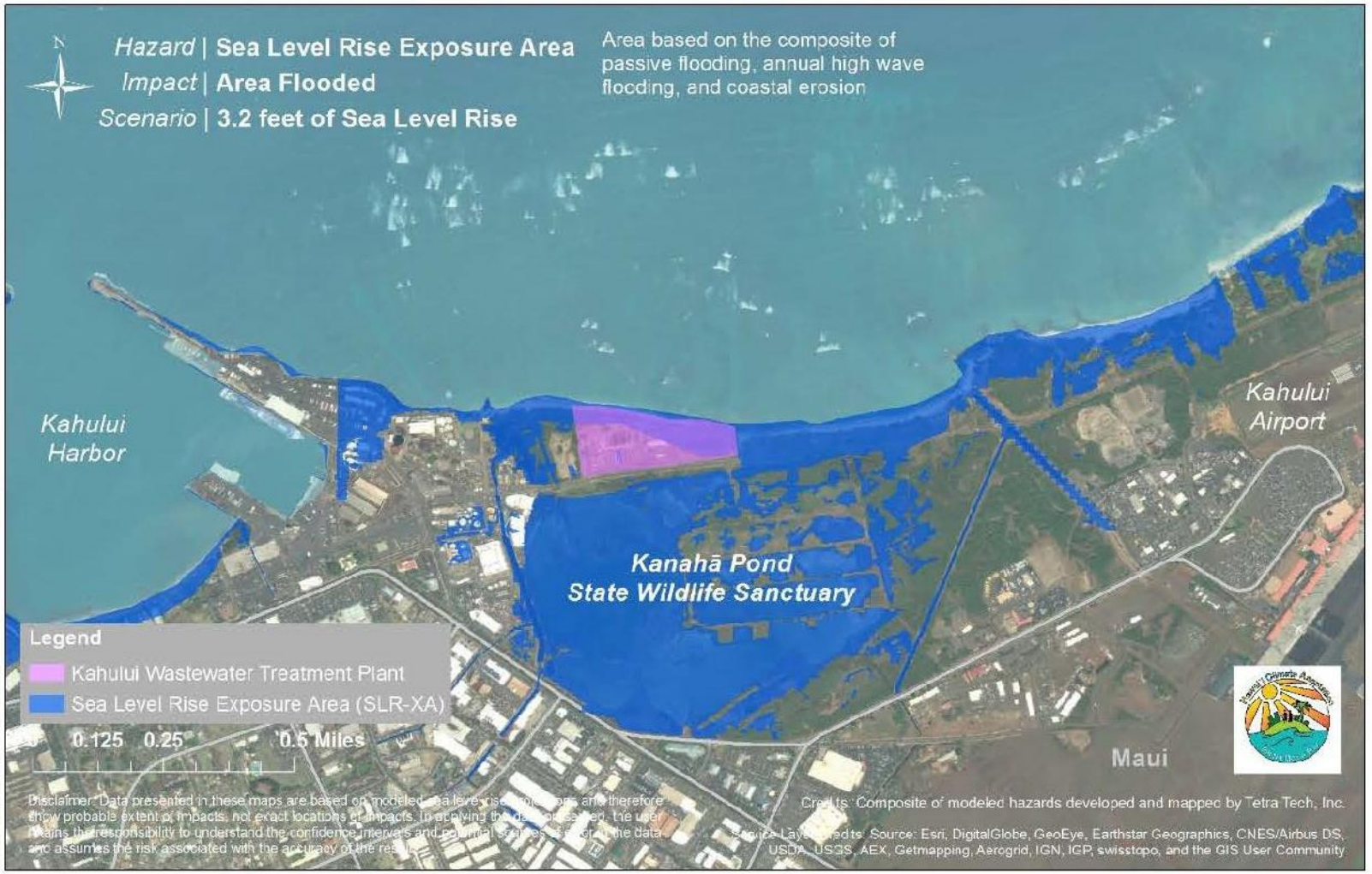


Figure 66. Kanahā Pond State Wildlife Sanctuary in the SLR-XA with 3.2 feet of sea level rise in Kahului, Maui

On-site Sewage Disposal Systems

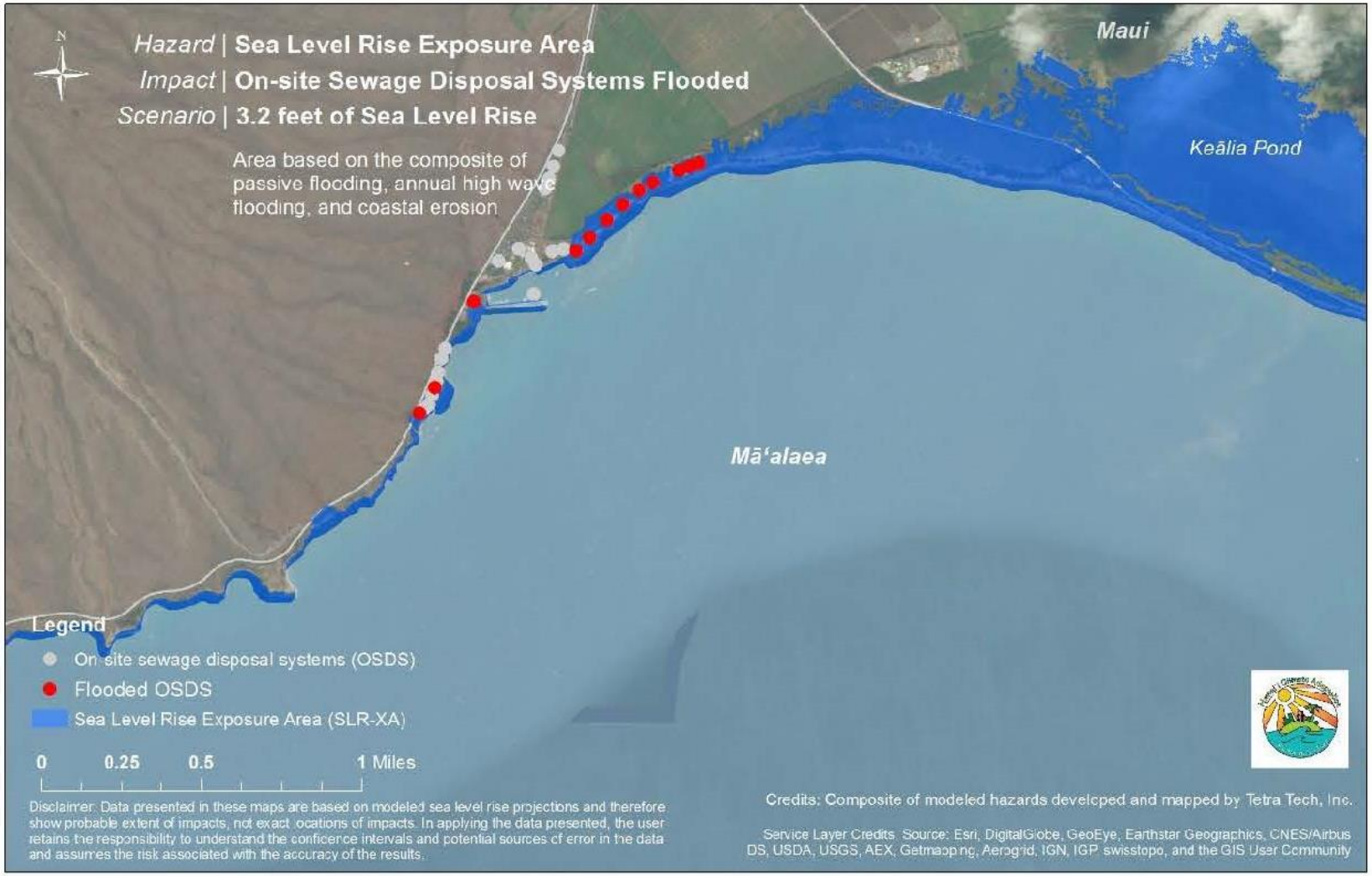
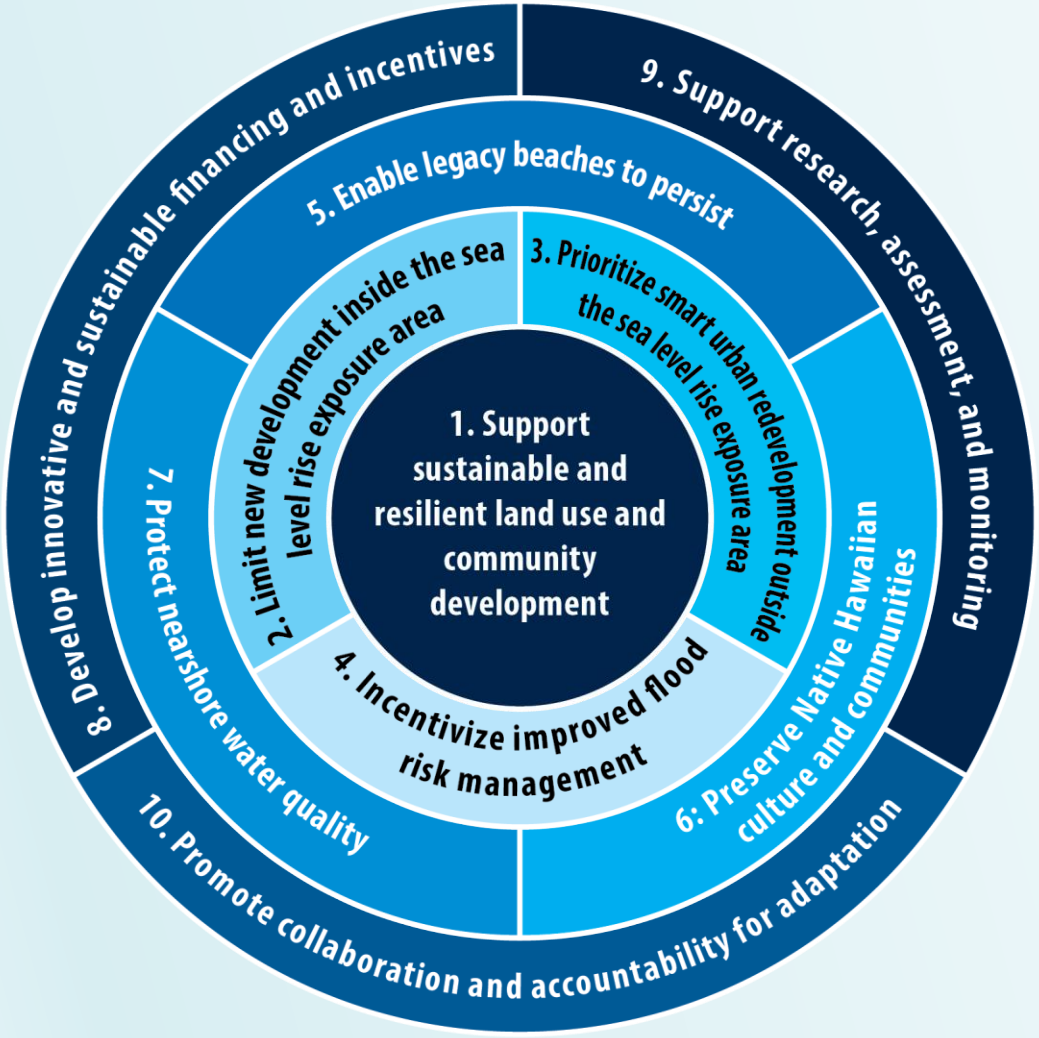


Figure 67. On-site sewage disposal systems flooded in the SLR-XA with 3.2 feet of sea level rise along Mā'alaea, Maui

RECOMMENDATIONS



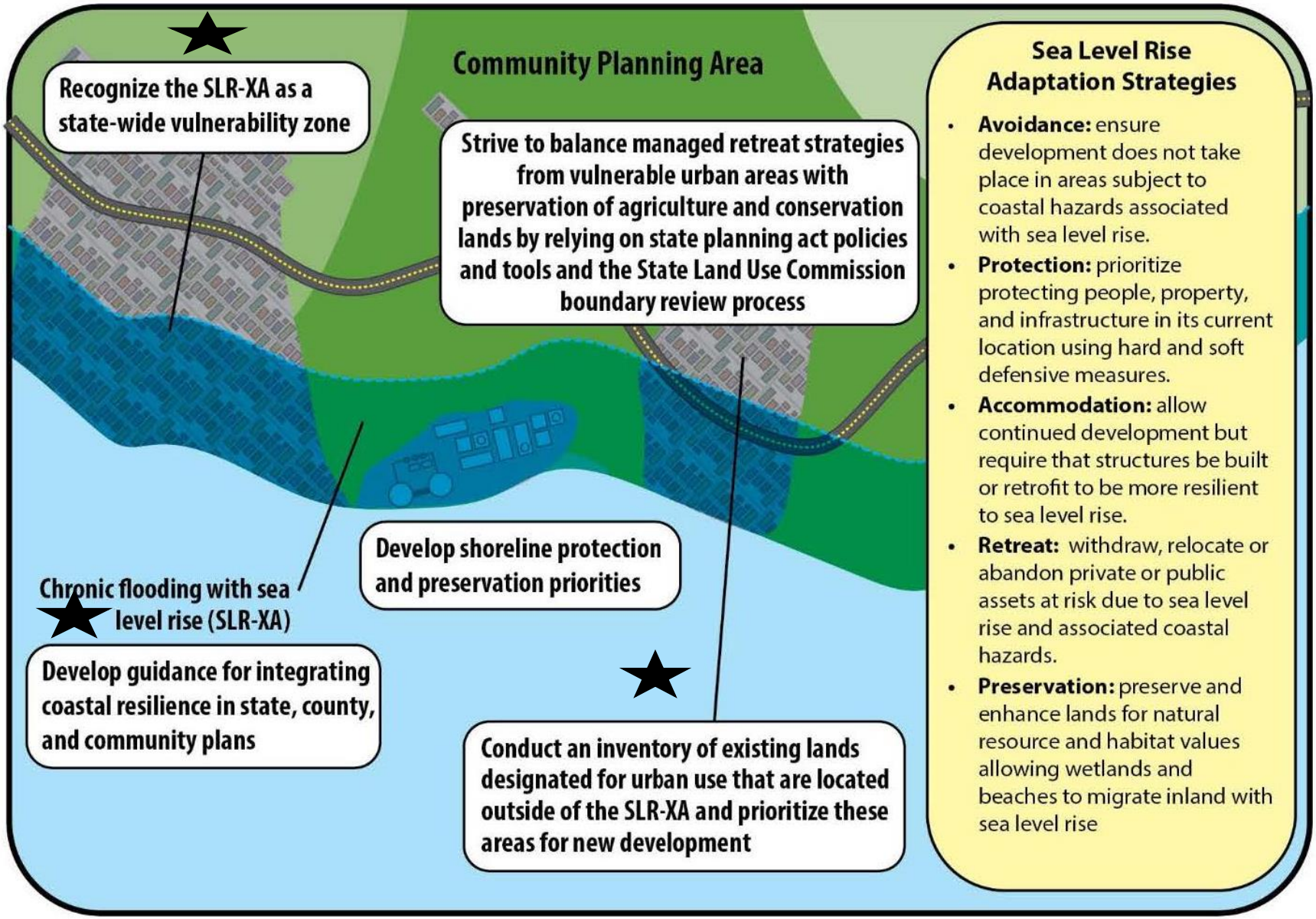


Figure 134. Support sustainable and resilient land use and community development

FROM RECOMMENDATIONS TO IMPLEMENTATION

Hawai‘i Coastal Resilience Guidance Series:

1. Planning for Coastal Hazards with Sea Level Rise.
2. Pre-disaster Reconstruction.
3. Hawai‘i Sea Level Rise Viewer.

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TETRA TECH

PacIOOS PACIFIC ISLANDS OCEAN OBSERVING SYSTEM

NOAA

Funding from: NOAA NOS Regional Coastal Resilience Grants Program

Mahalo

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