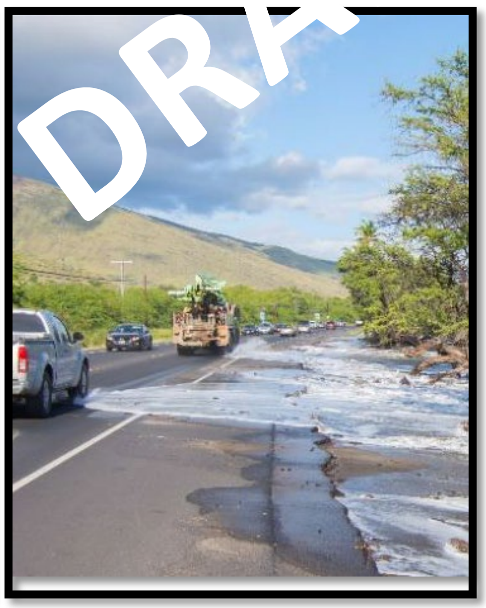
Guidance for Using the Sea Level Rise Exposure Area in Local Planning and Permitting Decisions



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A supplement to the Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report

Pre-Final Draft 10/14/2020

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Contents

I. Introduction

This document is a supplement to the Hawai‘i Sea Level Rise Vulnerability and Adaptation Report (“Report”; Hawai‘i Climate Change Mitigation and Adaptation Commission, 2017) and the Hawai‘i Sea Level Rise Viewer (“Viewer”) (both available at climate.hawaii.gov). The primary purpose of this document is to assist planners, natural resource and infrastructure managers, and others with understanding and using the Sea Level Rise Exposure Area (SLR-XA) from the Report and Viewer in day to day planning and permitting decisions, particularly at the project or property-level scale (Figure 1). This guidance was developed in response to requests from county planning departments and other stakeholders to provide information on appropriately interpreting and applying the SLR-XA map data in land use planning and permitting decisions while understanding the methods, assumptions, and limitations of the data.

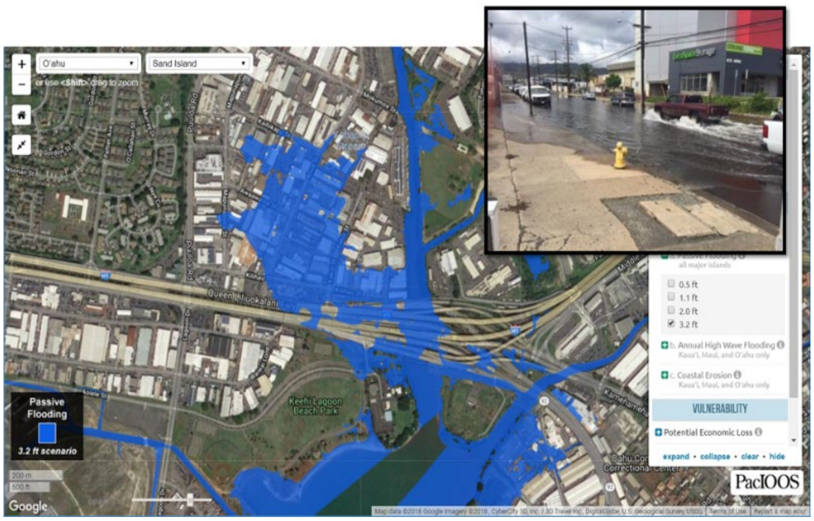

Figure 1. *Example of the SLR-XA with 3.2 feet of sea level rise and impacts at the property-scale at Māpunapuna in Honolulu with present day extreme high tide (“King Tide”) flooding in the area (inset photo: Hawaii Sea Grant King Tides Project).*

The SLR-XA is the combined projected footprint of three chronic flooding hazards with sea level rise: passive flooding, annual high-wave flooding, and coastal erosion (Figure 1). Following initial inquiries from county agencies, a working group of county and state agency representatives and subject matter experts was convened in 2019 to discuss challenges with and opportunities for applying the SLR-XA map data and its three constituent hazard models at the property scale. This guidance is intended to address the following needs and challenges posed by the working group and others:

- Incorporating the SLR-XA in land use plans and policies;
- Interpreting and applying the spatially-variable SLR-XA data;
- Applying the SLR-XA in permit review at the property scale; and
  Relating the SLR-XA model projections to existing shoreline hardening and backshore geology.

As expected, the science of sea level rise observations and projections has continued to advance since completion of the 2017 Report. The latest science further supports using the 3.2ft SLR-XA as the primary benchmark for land use planning and also supports considering higher scenarios, like six feet of sea level rise, for critical infrastructure and other projects with long expected lifespans and low tolerance for risk. While SLR-XA map data has not yet been produced to represent higher scenarios beyond 3.2 ft, passive flooding hazards have been modeled by NOAA and are available on their sea level rise viewer (NOAA, 2020). An update on the most recent sea level rise science from peer-reviewed publications and government reports since the 2017 Report is provided in Appendix 1. Descriptions and links to additional resources for sea level rise planning in support of this document are provided in Appendix 2.

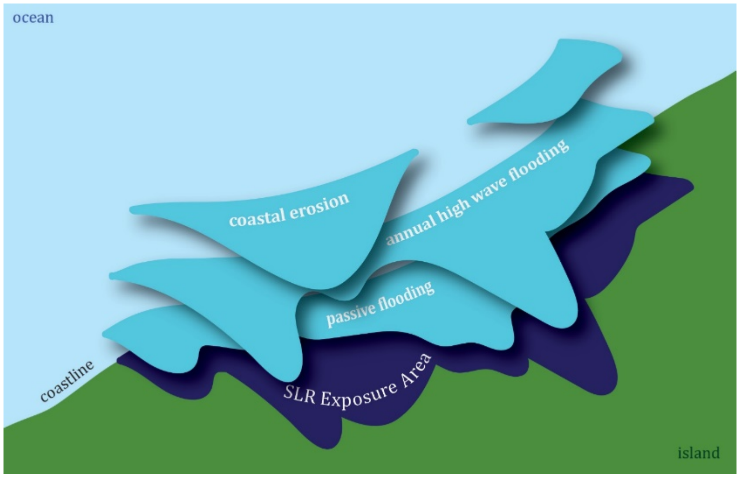

Figure 2. *The SLR-XA is the combined exposure to sea level rise from passive flooding, annual high wave flooding, and coastal erosion (Hawai'i Climate Change Mitigation and Adaptation Commission, 2017)*

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This document is for guidance purposes only and is not meant to be prescriptive. A range of approaches for the interpretation and application of the Report and Viewer map data are offered with discussion of benefits and drawbacks. Planning and policy approaches will continue to vary somewhat among jurisdictions to suit local needs, however interagency coordination and collaboration is strongly encouraged when attending to issues overlapping multiple jurisdictions.

II. Background

The Report was initially mandated by Act 83 in 2014, (Session Laws Hawai'i (SLH) 2014, Hawai'i Climate Change Adaptation Initiative) and expanded by Act 32 in 2017 (SLH 2017, Hawai'i Climate Change Mitigation and Adaptation Initiative), and provides the first state-wide assessment of vulnerability to sea level rise, as well as recommendations to reduce exposure and increase adaptative capacity. The Report and Viewer were completed and accepted by the State Climate Change Mitigation and Adaptation Commission at their December 2017 meeting. The 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, 2013), more recent scientific reports from the National Oceanic and Atmospheric Administration (NOAA) (Sweet W. , et al., 2017), the National Aeronautics and Space Administration (NASA, 2017a; 2020a; 2020b), and the best-available peer-reviewed scientific research articles. The Report also provides recommendations based on emerging good practices, framed through extensive agency and stakeholder consultations.

The Viewer is intended to serve as an online interactive atlas for the Report map data. The Viewer includes summary descriptions of the SLR-XA and other map layers as well as access to download the map layers in various formats. The SLR-XA map layers are also available for download at the [Hawaii Statewide GIS Program website](#).

The SLR-XA detailed in the Report and Viewer is a scientifically-rigorous product of model projections of future hazard exposure with rising sea level. In their November 27, 2018 meeting the State Climate Commission determined that:

> *Based on the methodology of sea level rise modeling used in the Hawai'i Sea Level Rise Vulnerability and Adaptation Report (Report) and the Hawai'i Sea Level Rise Viewer (Viewer), having gone through peer review and publication in the Nature Journal Scientific Reports* (Anderson et al., 2018)*, the results of this study are sufficiently validated to be appropriately used in land management decisions as the best available information as of the date of publication of the Report, December 2017, consistent with the intent of Act 83 SLH 2014 as amended. This Report is intended to provide a state-wide assessment of Hawaii's vulnerability to sea level rise. The location of projected impacts and economic costs from damages are estimates based on a particular sea level rise scenario. The hazard and vulnerability data and maps provided herein are based on observational data and computer-based models as described in the Report and in published research (Anderson et al., 2018). As with all models, it is important to understand the methods, assumptions, limitations, and uncertainties of the methods used.*

In addition, at their September 2018 meeting, the State Climate Commission agreed to a statement that included support for the establishment of a State initiative, now called Climate Ready Hawai'i, to provide resources to assist in planning for sea level rise. This guidance document is one of the initial resources under this initiative.

The SLR-XA data has enabled a paradigm shift in planning for the impacts of sea level rise in Hawai'i. In 2018, the Mayors of Maui and Honolulu issued proclamations recognizing the growing hazard risks from climate change and sea level rise, acknowledging the Report, Viewer, and SLR-XA data, and directing county departments and offices to employ the data in their plans and programs. As a result, counties are endeavoring to integrate the SLR-XA in planning at the community to island scale in updates of community plans, including for West Kaua'i, urban Honolulu, West Maui, and Hawai'i Island.

The 2018 State Hazard Mitigation Plan, which directs the prioritization and funding of hazard mitigation projects statewide, included expanded consideration of future climate change and sea level rise hazards to life and property based in large part on the Report and SLR-XA data. The Hazard Mitigation Plan also included mapping of a 1% annual chance flood using FEMA methods plus sea level rise, resulting in the 1% Annual Chance Coastal Flood Zone (1%CFZ-3.2). This provides another layer for consideration in vulnerability assessments and adaptation planning.

The counties are also considering updates to shoreline setback and special management area policies based on the improved understanding of sea level rise hazards. As one example, Maui County is presently proposing to use the SLR-XA erosion hazard line as the basis of their setback policy.

State and county planning and permitting departments are now beginning to consider sea level rise hazards at the project/property-level scale out of precaution and following recent directives and policies. The SLR-XA is beginning to be employed in the review of permit applications following county policies and through environmental assessments following State Act 17, SLH 2018, which directed the State Environmental

Council to adopt rules requiring all environmental assessments and environmental impact statements to include consideration of climate change and sea level rise.

State and county resource and infrastructure agencies are utilizing the SLR-XA data in planning and policy. The Department of Land and Natural Resources is considering rule updates for conservation lands including expanded consideration of future conditions with sea level rise. The State Department of Transportation used SLR-XA erosion projections and other data in their 2019 Statewide Coastal Highway Program Report. The Honolulu Board of Water Supply is utilizing the SLR-XA and other hazard data in their update of their watershed management plans.

Recent updates to the State Coastal Zone Management Act (CZMA, Hawaiʻi Revised Statutes (HRS) 205A, through Act 16, SLH 2020) and Administrative Rules for environmental assessment (HRS 343, Hawaiʻi Administrative Rules (HAR) 11-200.1) provide increased statutory support for integrating sea level rise considerations in planning and permit review. The updates to the CZMA include recognition that coastal hazards are increasing with sea level rise, strengthens prohibitions against coastal armoring, increases scrutiny for shorefront development, and strengthens protections for beaches and other coastal environments.

In summary, state and county agencies, with support from elected officials, are taking critical first steps in utilizing the SLR-XA data, although additional guidance has been requested. This addendum to the 2017 Report is intended to provide meaningful guidance towards application of SLR-XA hazard maps for planning and permitting decisions.

III. Understanding and Interpreting the SLR-XA Models

The SLR-XA map data in the Report and Viewer depicts escalating hazard exposure with expected sea level rise. The map data includes the output of three sea level rise hazard models that can be used to identify vulnerabilities to specific hazards (Figure 2):

- Passive flooding: “still water” high tide flooding without consideration of influence from waves or other ocean/atmospheric phenomena;
- Annual high wave flooding: wave overwash landward of the present beach area during the largest wave events of the year; and,
- Coastal erosion: exposure to future land loss from coastal erosion.

The three exposure areas can be viewed individually or combined as the multi-hazard SLR-XA. Each exposure area was modeled considering 0.5, 1.1, 2.0 and 3.2 foot increases in sea level. The 3.2-foot projection of sea level rise was originally based on the sea level rise model for 2100 under the high emissions scenario (RCP 8.5) published in the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2014). This scenario is consistent with more recent reports on sea level rise including a NOAA 2017 report, which compiled the latest and best available projections of SLR and finds that 3 feet or more of SLR could occur in an “intermediate” scenario by 2100 and as soon as 2060 in an “extreme” scenario (Sweet, et al., 2017).

These scientific sea level rise projections will continue to evolve as understanding regarding the contribution from ice melt continues to advance, particularly regarding contributions from the Greenland

and Antarctica ice sheets. Recent observations of ice sheet losses show that melt is tracking near the upper range of IPCC AR5 projections, suggesting that higher-end sea level rise scenarios are becoming increasingly likely in this century (Slater et al., 2020). Some of the latest science related to observations and projections of sea level rise is provided in Appendix 1. While fixed increments of global mean sea level rise are considered here, it is important to keep in mind that sea level will continue to be variable at the regional to local scale due to tides and other ocean and atmospheric phenomena. This sea surface variability occurs in conjunction with or on top of an overall trend of global mean sea level rise. Thus, the SLR-XA map data can be interpreted as flooding likely to occur as ocean levels reach specified elevations. These elevations will be reached and surpassed with progressively increasing regularity (e.g., nuisance flooding/King Tides) first at the highest tides and ultimately as permanent inundation in many areas.

The following sections describe methods used to produce each type of model, and how each can be used to interpret a location's vulnerability to specific sea level rise induced hazards.

A. Passive Flooding

The Hawaiian Islands feature extensive low-lying coastal plains, which are vulnerable to multiple passive flood sources including rising groundwater tables, backflow through gravity-flow stormwater drainage infrastructure, and direct over-land marine flooding. Passive flood mapping is one of the simplest and most commonly used methods of identifying sea level rise flood exposure. It is the primary tool used by communities around the world to develop sea level rise adaptation plans, and Hawaiʻi has had passive flood maps available for coastal communities on Oʻahu, Maui, and Kauaʻi since at least 2010 (Cooper, et al., 2013).

Passive flood mapping is accomplished by using high-accuracy elevation data to identify areas with elevation lower than projected sea level at the average daily highest tide (known as mean higher high water or MHHW)[1]. It is important to keep in mind that ocean levels regularly reach elevations above MHHW because of the combined effect of tides, mesoscale eddies[2], wave setup, onshore winds, low atmospheric pressure, and other dynamic meteorological and oceanographic phenomena

Passive flood maps produced here identify exposure to flooding that originates both above and below the ground surface. Low-lying surface areas connected to the ocean are exposed to direct marine flooding, groundwater inundation and drainage backflow, while areas that are isolated from the ocean may be exposed to flooding from water moving below the ground surface (e.g., groundwater inundation and/or drainage backflow), as well as precipitation runoff especially at high tide.

Groundwater inundation is often overlooked as a source of sea level rise -induced flooding; however, it is a particularly difficult flood type to manage as it represents complete saturation of the ground (e.g., a wetland) and can evade coastal barriers designed to manage direct marine sources of flooding such as

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[1] *Mean Higher High Water (MHHW) is the average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. See: https://tidesandcurrents.noaa.gov/datum_options.html#MHHW*

[2] *Mesoscale eddies are large vortices that raise sea level 10-20 cm (4-8 in) and are typically <100 km (62 mi) in diameter. They migrate through Pacific waters regularly and contribute to extreme tides. See: https://www.gfdl.noaa.gov/ocean-mesoscale-eddies/*

seawalls or bulkheads. Groundwater in the lower caprock aquifer of Hawaii's coastal plains is influenced in part by changes in sea level, moving up and down with the level of the tide. As sea level rises, so too does the level of groundwater. Because groundwater inundation represents full saturation of the ground, it can damage buried and low-lying infrastructure as groundwater is lifted above critical elevations. A recent study showed that passive flood mapping can be used as a first-cut approach to identify vulnerabilities to groundwater inundation, although passive flood maps cannot be used to thoroughly identify vulnerabilities for underground assets/infrastructure (i.e., cesspools, septic tanks, buried electrical infrastructure, basements, etc.) (Habel et al., 2019).

Passive Flood Mapping: Assumptions and Limitations

In passive flood modeling (Figure 3), mapping uncertainties (horizontal and vertical positional accuracy) is determined from digital elevation model error statistics as it is assumed that the height of sea level is known (i.e.., a static MHHW level). The passive flood mapping product provides a highly conservative visualization of anticipated flooding for some areas, particularly along wave-exposed shorelines, as it does not consider dynamic processes such as seasonal swell, storm surge, and coastal erosion. For this reason, the coastal erosion and annual high wave flooding models were produced for the 2017 Report, which provide a more comprehensive picture of sea level rise -related hazard exposure.

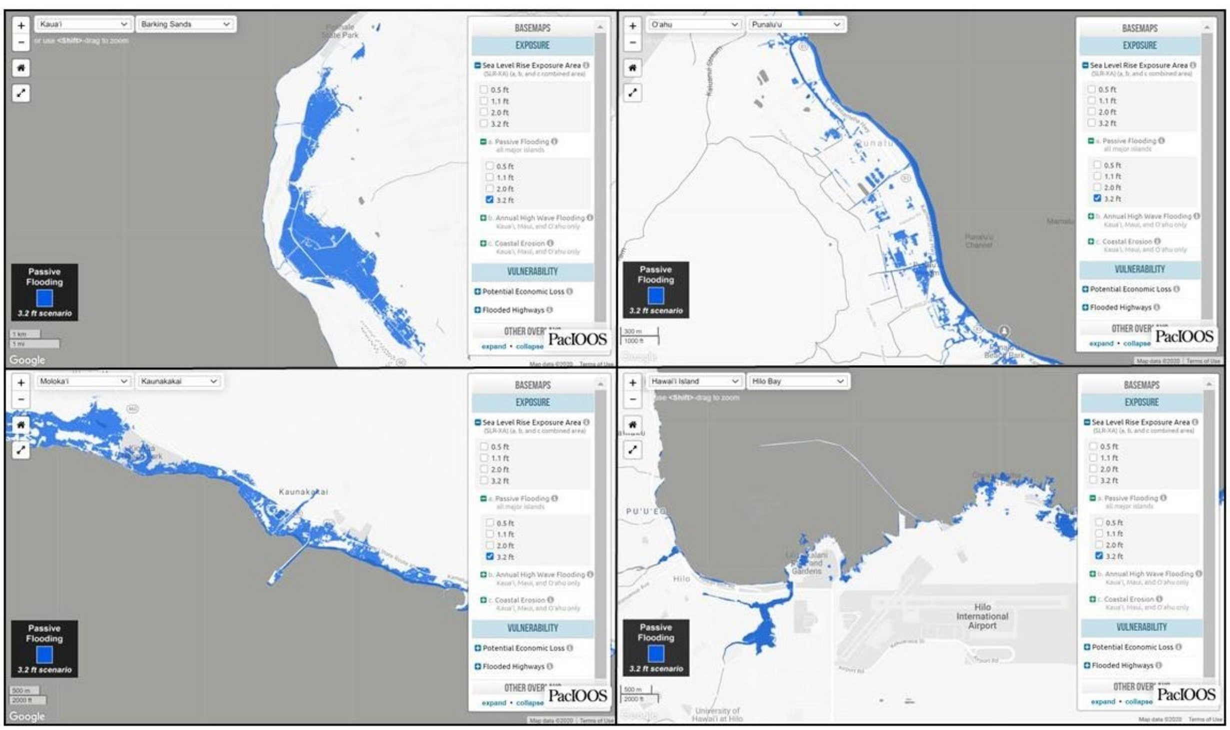

Figure 3. *Passive flooding with 3.2 feet of sea level rise from the Hawai'i Sea Level Rise Viewer. Shown, clockwise from upper left are Barking Sands, Kaua'i; Punalu'u, O'ahu; Hilo Bay, Hawai'i Island; Kaunakakai, Moloka'i. Because high accuracy elevation data were used in the making of the passive flood layer, areas located below given flood thresholds are identified with accuracy. However, flood maps produced using the passive flood layer should be considered a highly conservative characterization of sea level rise related flooding because modeling does not consider effects of waves and coastal erosion.*

The passive flood maps do not account for flooding generated by rainfall and resulting runoff. Sea level rise will increase flooding rate and depth with rainfall in low-lying coastal areas due to reduced unsaturated space for infiltration and reduced pathways for drainage from storm-drain backflow. The passive flood exposure maps provide an initial look at low-lying areas that will be exposed increased stormwater flooding with impaired drainage from sea level rise. More research is needed to improve understanding and map combined projected impacts of sea level rise and rainfall flooding.

B. Annual High Wave Flooding

All sides of the Hawaiian Islands are exposed to open-ocean swell (large, deep water waves) that are generated by seasonal storms in distant locations in the North and South Pacific, tradewind waves, and more localized storm waves. Annual high wave flooding results from wave set-up (temporary increases in water elevation at the shoreline) and waves running up over the shoreline. The distance over which waves run up and wash across the shoreline grows with increased wave size and elevated sea level. Damage from high wave flooding can be compounded by velocity of the wave overwash.

The annual high wave flooding maps identify areas exposed to sea level rise induced increases in wave run-up, and flooded area. The flooded areas specifically represent projected exposure to seasonal high wave events occurring with annual frequency. Modeling was completed for most wave-exposed coasts of Maui, O‘ahu, and Kaua‘i.

Annual High Wave Flooding: Assumptions and Limitations

The annual high wave flooding exposure maps are produced considering average annual highest wave events calculated from historical records of wave heights recorded at offshore data buoys around the islands. Therefore, the model recognizes differences in wave exposure for coasts around the islands, such as north shores versus south shores and windward versus leeward. The mapping does not consider potential changes in future wave conditions with changing storm patterns, effects of storm surge, more extreme yet less-frequent wave events, or tsunamis. Smaller wave events occurring with higher frequency are not modelled but can be expected to cause impacts nearer to the shoreline. The modeling also does not consider changes in shoreline location due to coastal erosion, which will compound the effects of wave run-up, allowing waves to reach farther inland along chronically eroding or seasonally sand-depleted shorelines. High wave flooding modeled using a highly accurate digital elevation dataset assuming an impermeable surface that does not include the presence of buildings, vegetation, etc.

Modeled flood depths of less than 10 cm (4 in) are not included in the final exposure maps. These areas are removed from the final output to account for model uncertainty, the assumption of an impervious surface, and to account for limited impact of these shallow flood levels when only occurring on average once per year. Low-lying, flood-prone areas in the backshore are identified in the passive flooding model.

The one-dimensional model is run on transects oriented perpendicular to the shoreline with spacing of 20 meters (66 feet) alongshore. At a limited number of shoreline locations fronted by natural or artificial channels in the nearshore reef this one-dimensional model method can result in over-prediction of wave run-up. The over-prediction generally occurs in places where, in reality, the presence of shallow reef on either side of a channel causes refraction and dissipation of wave energy, which is not picked up by the model due to the reef being located outside of the model transect. Examples of such artifacts are visible in the high wave flooding model at Kaka'ako in Honolulu due to the presence of the Kewalo Basin entrance channel (Figure 4).

Figure 4. *Modeling errors in the annual high wave flooding model (and combined SLR-XA) are found at a limited number of shoreline areas landward of natural and artificial channels in the nearshore reef (example from Ala Moana and Kaka'ako, O'ahu). Also shown in this figure are clipping errors, which are mapping artifacts that identify offshore submerged areas as being flooded by sea level rise. These artifacts result from clipping of the SLR-XA map data using a shoreline boundary (Special Management Area), which in some areas differs from the natural shoreline.*

On the other hand, because the modelling is done along one-dimensional shore-perpendicular transects, it can under-predict flooding that would occur as water moves not only inland but sideways, spilling into adjacent lower-lying areas. To account for this under-prediction, low lying areas shown as flooded by passive flood modeling and surficially connected to the ocean were added into the final wave runup model results (Figure 5).

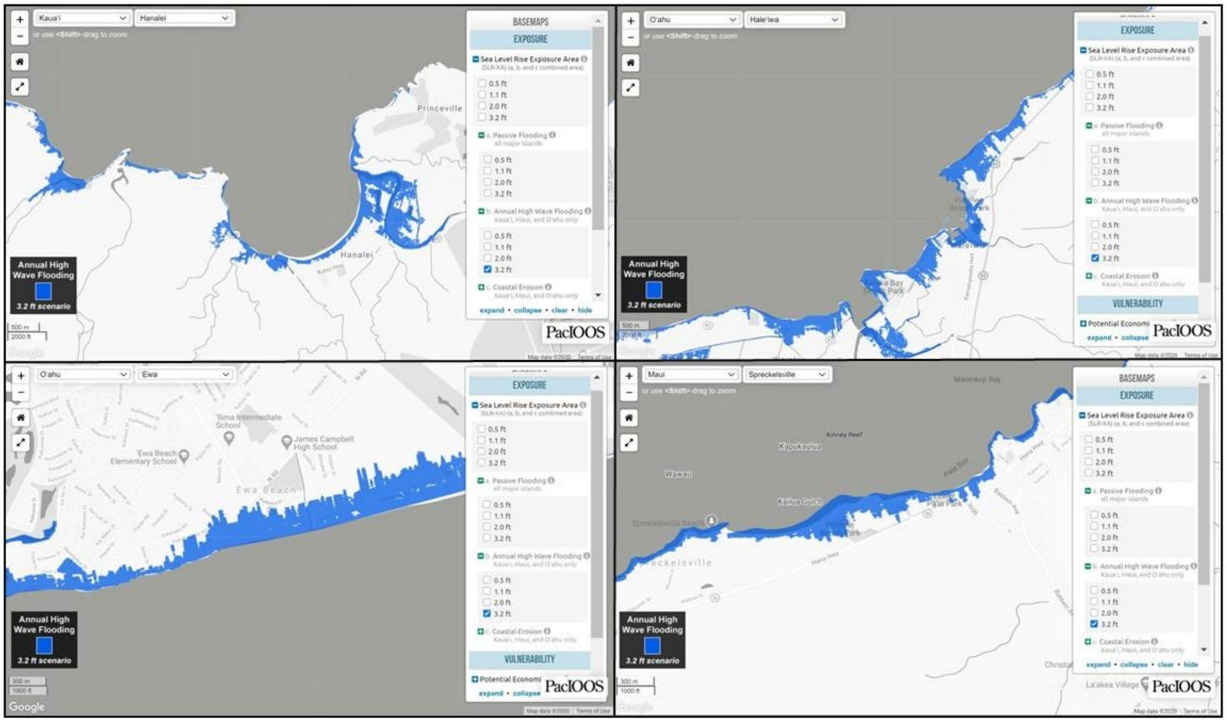

Figure 5. *Annual high wave flooding with 3.2 feet of sea level rise from the Hawaiʻi Sea Level Rise Viewer. Shown, clockwise from upper left, are Hanalei, Kauaʻi; Haleʻiwa, Oʻahu; Spreckelsville, Maui; and ʻEwa, Oʻahu. Note the alongshore variability of the annual high wave flooding model resulting from the one-dimensional modeling approach at regularly-spaced transects. Also, note that portions of streams, canals, other inland water features, and other low-lying backshore areas are identified in the annual high wave flooding model in all but the Spreckelsville map above. This results from the mapping method, in which passive and wave runup model results are combined to identify low-lying backshore areas with surficial connections to the ocean.*

C. Coastal Erosion

Chronic coastal erosion is a widespread problem in the Hawaiian Islands. Research indicates that 70% of beaches on Kauaʻi, Oʻahu, and Maui are chronically eroding such that shorelines are progressively receding landward (Fletcher et al., 2012). More than 11% of beaches studied have been completely lost to erosion at hardened shorelines (e.g., seawalls, revetments, sandbags, etc.). Chronic long-term erosion generally represents permanent shoreline recession and land loss and is often manifested in the form of seasonally or episodically recurring erosion events from which the shoreline never fully recovers (Summers et al., 2018).

The erosion hazard projections consider both historic shoreline change data and modeled responses of the beach profile to increased sea level (Anderson et al., 2018). The erosion model is available for most sandy shorelines on wave-exposed coasts of Maui, Oʻahu, and Kauaʻi.

Historical erosion rates (Fletcher et al., 2012) are calculated by measuring changes in the location of a low-water mark feature (or "beach toe") at the seaward edge of the beach, a feature that is readily identified in aerial photographs. Within the coastal erosion model, the historical erosion data account for alongshore variability in shoreline change from both natural processes and shoreline engineering.

Model calculations of the future erosion exposure area are projected from the vegetation line under incrementally rising sea level (0.5, 1.1, 2.0, and 3.2 feet). The vegetation line is a noteworthy feature as it is a fairly good approximation of the administrative shoreline, which is a legal designation that is central to many aspects of coastal zone management, planning, and regulatory decision making in Hawai‘i. It functions as a jurisdictional and land ownership boundary and baseline for shoreline construction setbacks.

Coastal Erosion: Assumptions and Limitations

The erosion projections (Figure 6) are calculated at an 80% subceedance probability level. Meaning that, based on the model, there is 80% certainty that areas landward of the projected line (outside of the erosion hazard area) will be safe from erosion at that sea level rise scenario (e.g., 3.2 feet).

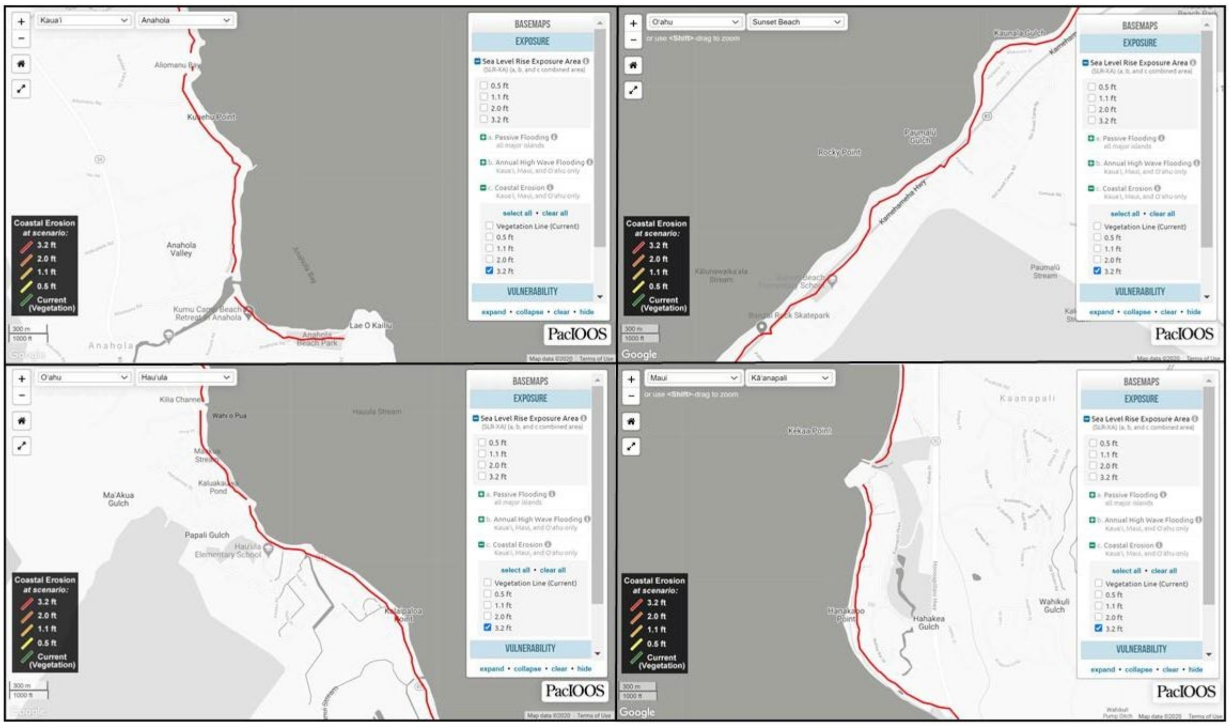

Figure 6. *Coastal erosion with 3.2 feet of sea level rise from the Hawai‘i Sea Level Rise Viewer. Shown clockwise from upper left are Anahola, Kaua‘i; Rocky Point, O‘ahu; Ka‘anapali, Maui; and Hau‘ula, O‘ahu. Note that locations featuring less-erodible material (i.e., rocky and mixed rocky/soil bluffs) were not included in the erosion modelling, which focused on beaches.*

Areas that feature less-erodible material such as rocky coastlines and mixed rocky/soil bluffs were not considered in the erosion model; however, such coastlines can be at risk of undercutting and slope-failure. The model does not consider changes in erosional behavior due to the presence of existing seawalls or other coastal armoring in the backshore. Where the beach was lost to erosion fronting coastal armoring, the historical erosion rate is calculated up to and including the last low-water mark shoreline before the beach disappeared. Therefore, the erosion projections consider the rate at which the preexisting beach was lost and, as a result, the erosion projection often extends well landward of the armoring structures. Guidance for interpreting the erosion projections behind coastal armoring is provided in Part IV.

The model does not consider likely increases in wave energy propagating across the fringing reef as sea levels rise, potential changes in reef accretion, possible changes in nearshore sediment processes as sea levels rise, or potential changes in sediment supply from future shoreline development and engineering, such as construction or removal of coastal armoring or other coastal engineering. The model also does not include potential changes in movement of sand or other sediment along the shoreline beyond what is captured in historical erosion trends. This means that, in some areas, erosion may be more severe than depicted in the model due to increases in wave energy at the shoreline and/or changes in sediment transport.

Locations with relatively sparse or highly variable historical shoreline position data may feature erosion hazard areas that extend farther inland than other areas. Because erosion projections are based in part on long-term historical shoreline change data, large seasonal or episodic erosion/accretion events captured in the historical data set can translate into a large spread in possible future shoreline positions, and thus a more landward extent of the coastal erosion exposure area. Examples of this may be found on sections of the North Shore of Oʻahu and West Shore of Kauaʻi, where seasonal changes in wave conditions cause dramatic variations in shoreline location. In such cases, the erosion hazard area extends farther inland compared to a shoreline with a similar long-term trend and less pronounced seasonal swings in shoreline location. This does not necessarily mean that the erosion hazard is "over-predicted" or erroneous at these highly variable beaches. Rather, the model is accounting for the potential for compounding impacts of a long-term erosion trend with shorter term (e.g., seasonal) episodes of shoreline erosion.

SLR-XA: Assumptions and Limitations of the Combined Exposure Area

The SLR-XA includes the assumptions and limitations of each of the three individual models described above. Each model type was produced using a "bare earth" digital elevation model, which is used to represent the ground surface in the absence of buildings, trees, and other structures. The digital elevation model was constructed using light detection and ranging (LiDAR) data, which does not capture base elevations of underground assets such as basements or drainage. In short, areas located outside of the SLR-XA boundary may still be exposed to flooding of underground assets. Mapping artifacts produced by clipping of the map data using a shoreline boundary that can differ from the natural shoreline are visible in limited areas and appear as offshore areas identified as being flooded or areas of beach or shoreline directly adjacent to the water that do not appear as flooded.

The SLR-XA does not consider less frequent and more severe flood events such as those illustrated by the 1%CFZ-3.2 described below. For the islands of Lānaʻi, Molokaʻi, and Hawaiʻi, the SLR-XA only includes the passive flooding exposure area. Future updates to the modeling in the Viewer could include annual high wave flooding and coastal erosion projections for those islands. Further, the modeling does not account for the interactive and compounding nature of the three SLR-XA hazards (Habel et al., 2020), as would be expected by natural processes. The modeling does not consider future land use changes including adaptation measures, which are largely unknown.

D. 1% Annual-Chance Coastal Flood Zone with Sea Level Rise

In addition to the SLR-XA, which models chronic (i.e., annual to daily) flooding hazards with sea level rise, a 1% Annual-Chance Coastal Flood Zone augmented with 3.2 feet of sea level rise (1%CFZ-3.2) is available to provide supplementary data for considering less frequent but more severe coastal flood events with sea level rise[3]. The 1%CFZ-3.2 is a coastal flood zone modeled for future flood hazard assessment in the 2018 Hawaiʻi State Hazard Mitigation Plan (HMP). The 1%CFZ-3.2 was modeled with the HAZUS program, used for mapping Special Flood Hazard Areas in FEMA Flood Insurance Studies (FIS), with the addition of sea level rise. It calculates a 1%-annual-chance stillwater elevation, wave setup, and wave run-up (called maximum wave crest) at regularly-spaced transects around the islands based on historical data, plus additional water level from sea level rise (Figure 7). The 1%CFZ-3.2 is effectively the FEMA Flood Zone V or VE, an area with coastal flood and velocity hazard, with the addition of sea level rise. A full description of the 1%CFZ-3.2 is available in Appendix F of the HMP.

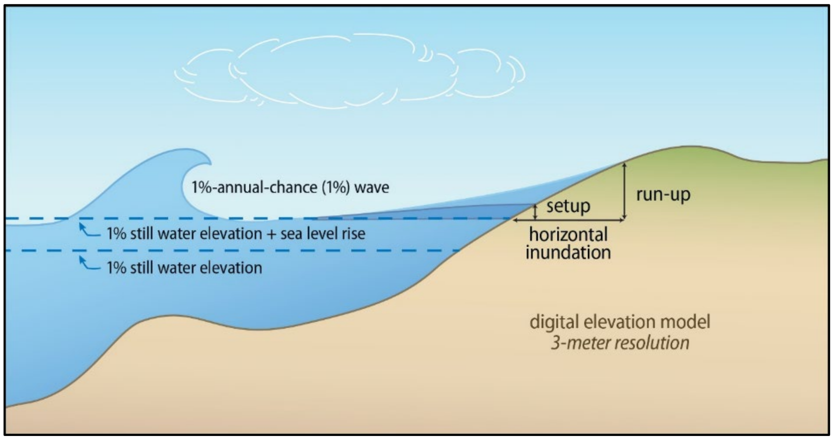

Figure 7. *Key inputs and outputs of modelling the 1%-annual-chance coastal flood zone with 3.2 feet of sea level rise (1%CFZ-3.2; credit: 2018 State of Hawaiʻi Hazard Mitigation Plan).*

1%CFZ-3.2 Assumptions and Limitations

The wave and storm conditions in the 1%CFZ-3.2 come from a historical database in the FEMA FIS that does not consider potential changes in storm or wave conditions in the future with climate change. Like the SLR-XA passive and wave run-up models, the 1%CFZ-3.2 is based on present day shoreline conditions and does not consider the compounding effects of coastal erosion (shoreline recession), which would lead to more landward and severe flooding in many areas. In addition, rainfall or stream flooding is not included in the modelling. Further guidance on how this data may be interpreted and utilized is provided in Part IV.

IV. Guidance for Using the SLR-XA in Planning and Permitting Decisions

The SLR-XA data allows for proactive coastal hazards and sea level rise planning. Guidance has been requested by county planners related to interpreting and applying the high spatial resolution (i.e., granularity) of the data sets. Guidance is also provided on the closely related topics of incorporating the SLR-XA in land use and zoning maps, permit reviews at the property scale, and interpreting existing shoreline hardening and backshore geology. The intent of this guidance is to provide a range of approaches, with discussion of benefits and drawbacks, to be combined with place-based knowledge and localized adaptation priorities.

A. Incorporating the SLR-XA in Land Use Plans and Zoning

[3] *Currently available from the Hawaii Emergency Management Agency. At the time of writing, the authors are working to have this layer added to the Viewer.*

The counties are making important progress in updating land use plans (i.e., general and community plans) that refer to the SLR-XA maps while communicating sea level risks and adaptation considerations that were articulated in the Report. The process of updating plans and subsequent policies along with vetting by the public and approval by various boards and councils will take time.

Guidance, recommended practices, and initial efforts to incorporate SLR-XA data into the community planning process are captured in Hawaii Sea Grant's *Guidance for Addressing Sea Level Rise in Community Planning in Hawaiʻi* (Courtney, et al., 2020; see Appendix 2 for more information and link to the document). The Guidance was developed through extensive input from planners in each of the counties and captures many examples of hazard mitigation practices that can be incorporated into local plans and policies.

Planners have always turned to the best available data to make permit and other development-related decisions, and they should continue to do that now. Legislative authority for acting on sea level rise risks was recently strengthened through updates to the Hawaiʻi Environmental Protection Act (HRS 343, through HAR 11-200.1) and Coastal Zone Management Act (HRS 205A; through Act 16, Session Laws Hawaiʻi, 2020), which recognize sea level rise and other coastal hazards in their respective policies and provisions. The data and methodology presented herein and within the other documents and tools referenced reflect a growing continuum of understanding of and statutory support for addressing growing risks from coastal hazards to people and the built and natural environment.

At the most basic level we recommend utilizing the combined SLR-XA (and/or a multi-hazard map including the SLR-XA) as a screening tool to identify vulnerable coastal properties when creating a new plan and consideration should be given to whether additional development, i.e., increased density, is appropriate.

Use of the SLR-XA as a regulatory tool in zoning or otherwise is also possible. The SLR-XA represents the minimum exposure to sea level rise related impacts at a given height of sea level rise. A logical step would be for agencies to adopt the SLR-XA for planning and regulatory purposes. Section B, below goes into more detail on how to address the spatial variability in the data to help achieve this.

B. Interpreting and Applying the Spatially-Variable SLR-XA Data

The location of the landward edge of the SLR-XA data can vary considerably along the coast, from one property to the next, particularly where the passive flooding or annual high wave flooding determine the landward extent of the SLR-XA[4] (Figure 8). Similarly, there may be gaps or "holes" within the SLR-XA area. This variability arises from the high-resolution digital elevation models and cutting-edge modeling methods described above. The SLR-XA data and its three component models are provided at or near their original resolution. One part of a property or structure's footprint may lie within the SLR-XA while another portion of that property or structure, at slightly higher elevation or further landward, may lie outside of the SLR-XA. Similarly, neighboring properties or buildings with slightly different elevations or shoreline conditions may be within or out of the SLR-XA.

[4]*The erosion hazard line in the SLR-XA tends to be relatively smooth compared to the passive flooding and annual high wave flooding models because the erosion model incorporates historical erosion rates that are mathematically smoothed using a weighted moving averaging function by the Hawaiʻi Coastal Geology Group.*

Utilizing the SLR-XA in planning and permitting may require adjusting boundaries to allow for seamless implementation of sea level rise adaptation standards and guidelines. Local planning agencies may adjust the boundaries to coincide with property boundaries, roads, neighborhood extent, and/or topographic features in proximity to a SLR-XA boundary; understanding that there will likely be exposure to some type of sea level rise in these areas of similar elevation and shoreline conditions whether its passive flooding, wave inundation, or erosion, or all coincidentally. There are a number of approaches that county and state agencies may adopt to address the "granularity" of the SLR-XA data, each with particular benefits and drawbacks.

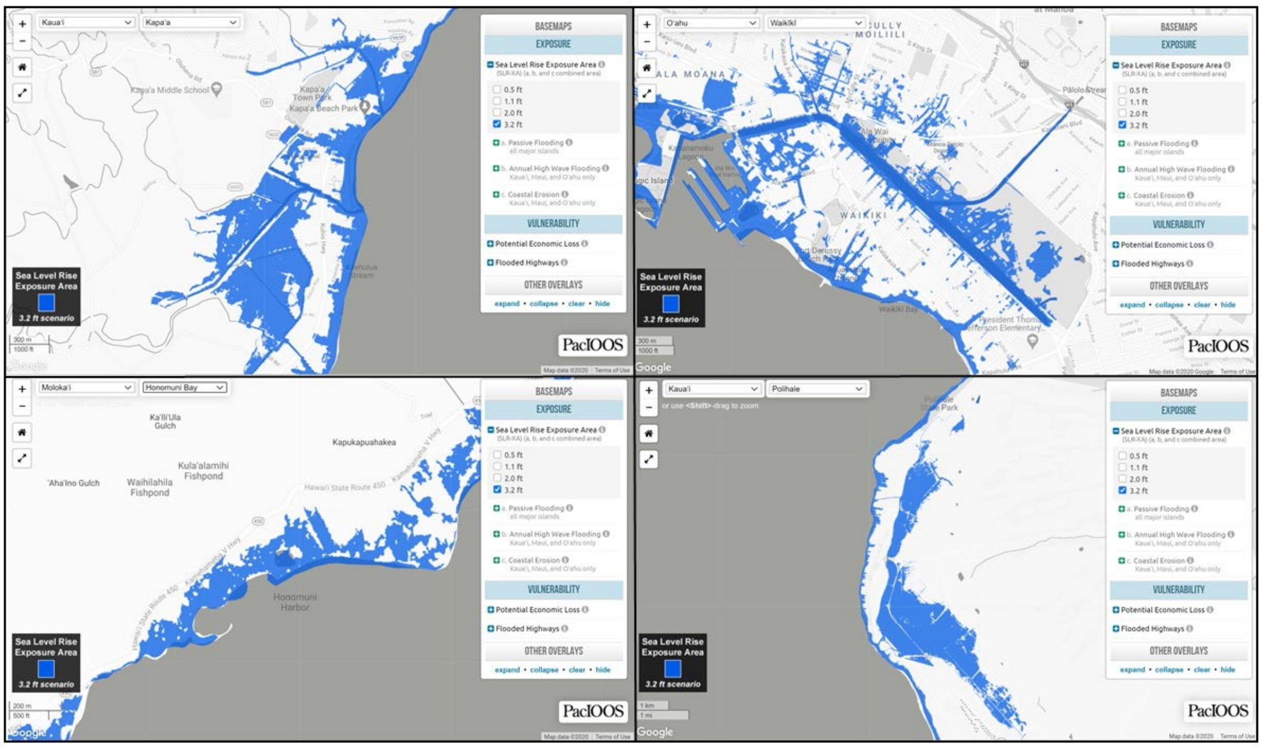

__Figure 8.__ Examples of spatial (alongshore and cross-shore) variability of the SLR-XA. Shown clockwise from upper left are Kapa'a, Kaua'i; Waikīkī, O'ahu; Polihale, Kaua'i and Honomuni Bay, Moloka'i.

Potential Approaches (Options):

- *Option 1: Utilize the SLR-XA as-is and require adaptation measures only within the portion(s) of the property in the SLR-XA.*

Benefits: Using the SLR-XA modelling at its original resolution, does not require additional decisions about how to adjust (smooth) the hazard zone boundary. This is the simplest approach as it does not require changes to the hazard zone boundary and policies apply only to development in the SLR-XA. Similar to requirements for flood hazard mitigation in FEMA Special Flood Hazard Areas, counties may choose to require adaptation measures for an entire building if any portion of the structure's footprint lies within the SLR-XA. This may have the added benefit of incentivizing building outside of (landward of) the SLR-XA, if there is room on the property, rather than attempting to adapt in place. Option 1 may be implemented quicker than some of the following options because it does not require further analysis or developing criteria and adopting policies for adjusting the exposure area.

Drawbacks: This approach may underestimate and not fully mitigate long-term coastal hazard risk on the property and in surrounding areas. The SLR-XA is a conservative estimate of SLR exposure in many areas as described in Section III. Portions of a property and neighboring properties may be in/out of the SLR-XA due to small differences in topography or shoreline conditions with the high-resolution modeling process (Figure 8). This will result in a "patchwork" approach to adaptation following the spatial variability of the SLR-XA data and may not support holistic, neighborhood-scale adaptation approaches needed for infrastructure networks such as stormwater and wastewater systems. As another example, differing elevations in a beachfront dune between two neighboring properties (i.e., on two different model transects) may result in differences in the landward extent of the annual high wave flooding model between the two properties. However, this does not account for the effects depicted by the erosion model, which may indicate that the dune would be eroded away at that particular sea level height.

- *Option 2: Utilize the SLR-XA as-is and consider an entire property to be exposed to sea level rise if any portion of that property is in the SLR-XA (Figure 9).*

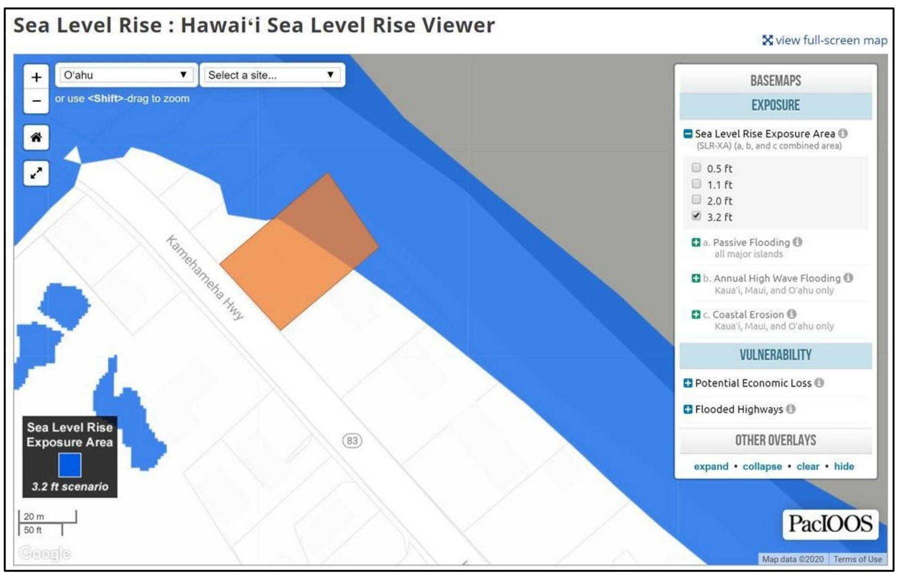

Figure 9. *Considering a whole property to be exposed to sea level rise if partially within the SLR-XA (Example location: La'ie, O'ahu, Hawai'i)*

Benefits: This approach allows for use of the SLR-XA data at its original resolution but would require sea level rise adaptation measures for any development on a property if the property (rather than just the building footprint) is partially or wholly in the SLR-XA. This provides a more precautionary approach to long-term hazard risk than the first option, as the SLR-XA can be a conservative estimate of coastal hazards exposure with sea level rise for some properties as described in Section III. This approach may be adopted relatively quickly as it doesn't require developing criteria for adjusting the exposure area, though special criteria may need to be developed for lots with substantial differences in elevation across the property, i.e., properties with substantial landward topographic slope.

Drawbacks: This approach may result in a somewhat smoother application of the SLR-XA in some areas where the SLR-XA is already relatively smooth. However, in other areas where the SLR-XA is particularly variable it may still result in a "patchwork" application of the SLR-XA - just scaled up to the size of individual properties - where one property is partially in the SLR-XA and a neighboring property is out, though the properties may be at only slightly different elevations. Therefore, this approach could raise questions about fairness between similar neighboring properties facing different adaptation requirements but with similar shoreline conditions and elevations. This approach also may not may not support holistic, neighborhood-scale adaptation approaches needed for infrastructure and utility networks. If a decision is made to implement adaptation "in place," (e.g., raising ground elevations, drainage improvements) on one property but not another in close proximity, such actions could increase flooding on the neighboring property(s). This type of approach would also require developing criteria or policies for addressing properties with substantial variations in elevation, i.e., properties with substantial landward increasing elevation (slope).

- *Option 3: Adopt an adjusted sea level rise hazard area based on the SLR-XA and specific criteria (Figure 10)*

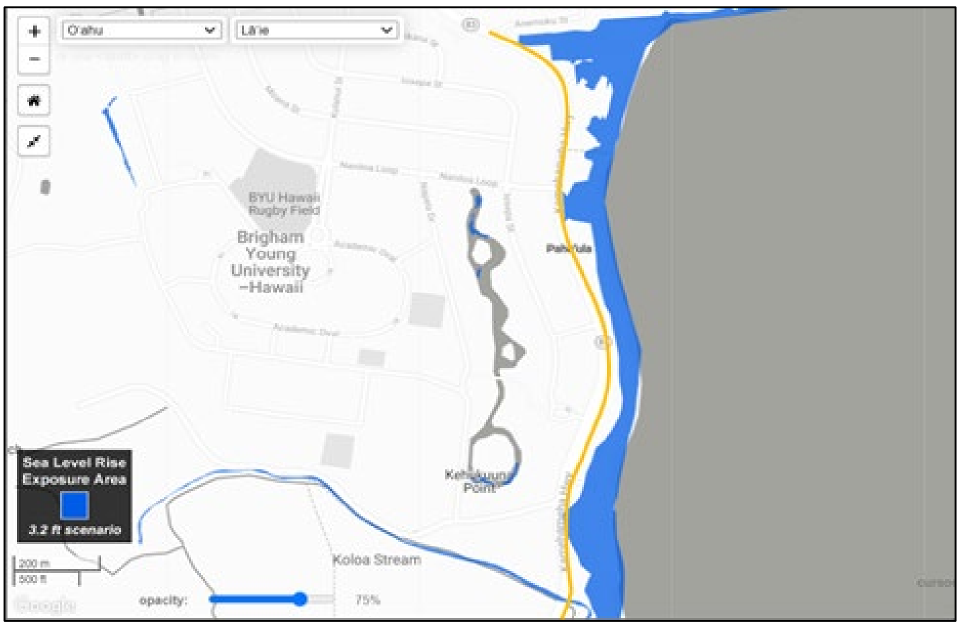

Figure 10. *SLR-XA boundary adjusted to nearest major road. The orange line represents the landward extent of the adjusted sea level rise hazard area.*

Benefits: This approach would attempt to "smooth-over" alongshore variability in the original SLR-XA model to allow for easier interpretation of the sea level rise hazard area (or hazard overlay zone) and a more spatially-consistent approach to adaptation that supports holistic neighborhood-scale adaptation. Assuming the hazard area is adjusted in a landward direction throughout, this approach would provide a more precautionary approach to sea level rise adaptation.

Drawbacks: This approach will take longer to implement than using the raw SLR-XA data since it will require further analysis to develop criteria for adjusting the hazard overlay and will likely require amending administrative rules and/or ordinances to adopt the sea level rise hazard area. Developing criteria for adjusting the SLR-XA will require analysis by GIS specialists and other technical experts. Specific criteria may be difficult to develop and apply consistently county/island-wide, given varying geographies and development patterns. Some areas of the SLR-XA will be adjusted more than others depending on the alongshore variability of the SLR-XA and criteria chosen for adjusting the line.

Should a county choose to adjust the landward boundary of the SLR-XA to create a sea level rise hazard area, further analysis and criteria for adjusting the landward boundary could include the following:

- The sea level rise hazard area may be extended from the SLR-XA boundary to the nearest landward shore-parallel road to support neighborhood-scale adaptation. Further analysis would be needed to develop criteria for this process, such as which type(s) of road to smooth the line to (e.g., the nearest shore-parallel road of any type or to a major county or state road) and determining whether criteria can be applied consistently county-wide. Criteria would also need to be developed for backshore areas prone to passive flooding, which are isolated from the shoreline erosion and annual high wave flooding areas (e.g., the isolated SLR-XA areas landward of the coastal highway in Figure 8). One approach in that situation may be to adjust or expand these isolated areas to the scale of one or more neighborhood blocks (i.e., to the nearest surrounding roads). In both situations, it will be important to include the roads as well because they are typically lower elevation than adjoining lands and contain drainages and right-of-ways for other critical infrastructure and utilities.

- An adjusted sea level rise hazard area could also be derived from the SLR-XA by manually "smoothing" or "connecting the dots" between the landward-most extents of the SLR-XA (Figure 11). This would require developing criteria for this process including determining the frequency at which to place vertices along the landward extent of the SLR-XA. Similar to the previous option, criteria would also need to be developed to address areas of inland passive flooding that are isolated from the erosion and high wave flooding hazard areas. There may be locations where backshore areas of passive flooding are sufficiently distinct from the shoreline flood hazards that they may be justified as isolated areas in the overlay, such as around a backshore marsh. For those cases, criteria may include utilizing elevation contours (e.g., 4, 5, or 6 feet elevation) to further verify if there are substantial differences in elevation between the areas to support leaving a gap between a shoreline and a backshore portion of the hazard overlay.

- If creating a sea level rise hazards area with either of the two methods above, criteria or policies will also need to be developed for how to consider or utilize the individual passive flooding, annual high-wave flooding, and coastal erosion models as these will no longer match-up with the landward extent of the adjusted hazard area. One approach is to consider the sea level rise hazard area as a combined chronic flood hazard zone (like the SLR-XA) and additionally consider the erosion hazard line, which is already relatively smooth along the shore, as an area of higher risk (e.g., a setback area). More discussion on how to consider the individual passive flooding, annual high wave flooding, and coastal erosion models is provided in Part C.

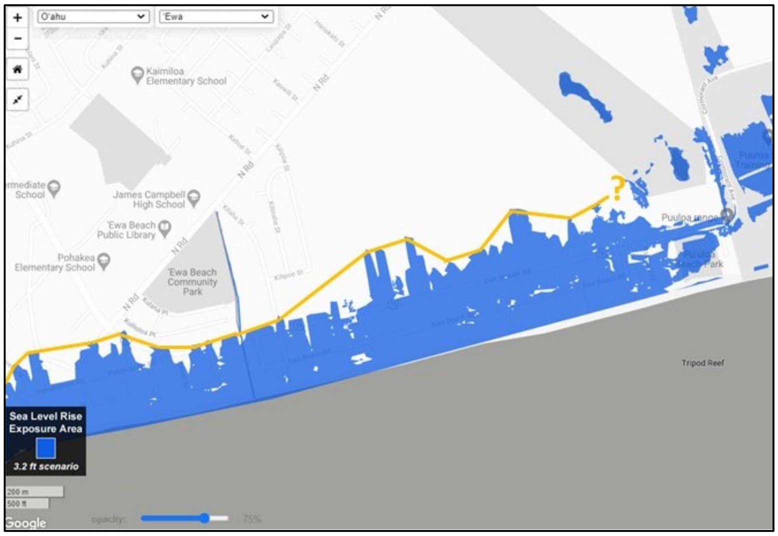

Figure 11. *Example of an adjusted sea level rise hazard area (yellow line) derived from the SLR-XA by manually "smoothing" or "connecting the dots" between the landward-most extents of the SLR-XA. Criteria would need to be developed for the process of placing vertices (e.g., spacing) and addressing areas of backshore passive flooding that are not attached to the shoreline flood hazards.*

- *Option 4: Adopt a coastal multi-hazard area combining the SLR-XA and other hazard zones such as FEMA Special Flood Hazard Areas and/or the 1%CFZ-3.2 (Figure 12)*

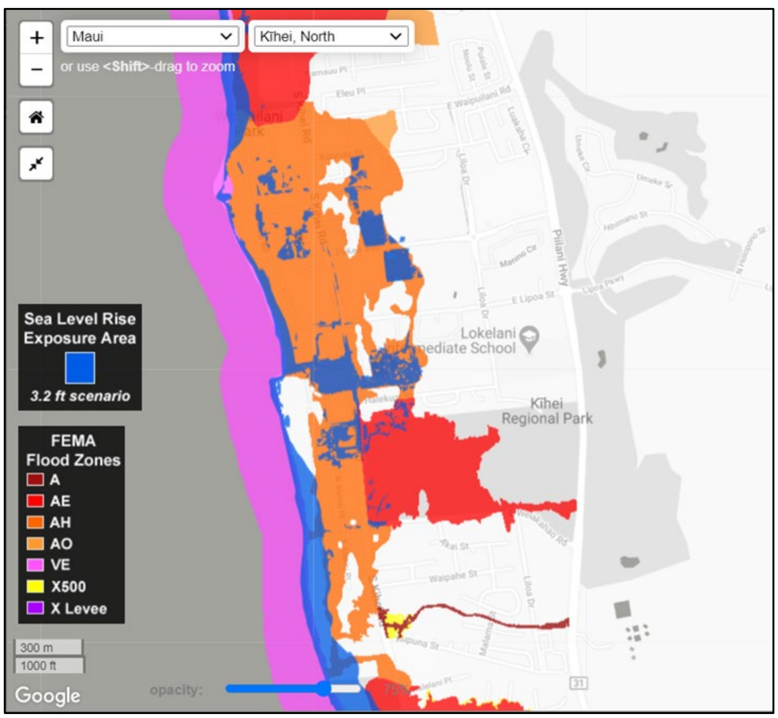

Figure 12. *Example of a coastal multi-hazard area based on SLR-XA and 1% annual chance flood zone.*

Benefits: This is a precautionary approach to hazard assessment and adaptation as it can also account for less frequent but more severe coastal hazards such as a 1% annual chance ("100-year") coastal flood event. This approach may also allow for a more spatially-consistent (e.g., "smoother") approach to hazard assessment and adaptation, depending on the boundaries of the map layers used. Though, the FEMA flood zones, for example, can also be somewhat irregular and variable along the shore as shown in Figure 11.

Drawbacks: Using a coastal multi-hazard area will still require understanding and addressing the varying details and limitations of each model within the overlay and in making decisions about where and what type(s) of adaptation measures to require. The key limitation of the existing FEMA Special Flood Hazard Areas is that they do not account for the effects of climate change and sea level rise, including rising coastal groundwater and resulting increasing rainfall flooding. The 1%CFZ-3.2 accounts for sea level rise effects on coastal flooding with extreme high waves but does not account for changes in land-based rainfall flooding. Variable policies and construction standards and codes may need to be applied differently within the coastal multi-hazards area depending on the type of hazard. For example, development/improvements within the erosion hazard area may be unsustainable versus development/improvements within the 1%CFZ-3.2, but outside of the SLR-XA, may be sustainable when adapted in-place.

A note about the Special Management Area boundaries and regulations:

In addition to utilizing the SLR-XA or a derivative sea level rise hazard area, counties should ensure that the Special Management Area (SMA) extends at least as far landward as the SLR-XA or coastal multi-hazard area. Counties may also update their SMA ordinance with measures to improve sea level rise resilience and strengthen protections for beaches, dunes, and coastal wetlands as nature-based infrastructure and critical ecosystems.

C. Applying the SLR-XA in Permit Review at the Property-Scale

Whether counties elect to adjust the (combined) SLR-XA boundary landward or not, the erosion, annual high wave flooding, and passive flooding models should be considered individually when reviewing a permit application for proposed development (or redevelopment beyond some threshold) that is exposed to sea level rise hazards (Figure 13). The SLR-XA depicts areas that will be chronically flooded at a particular height of sea level rise, that is, flooded on an annual to daily basis.

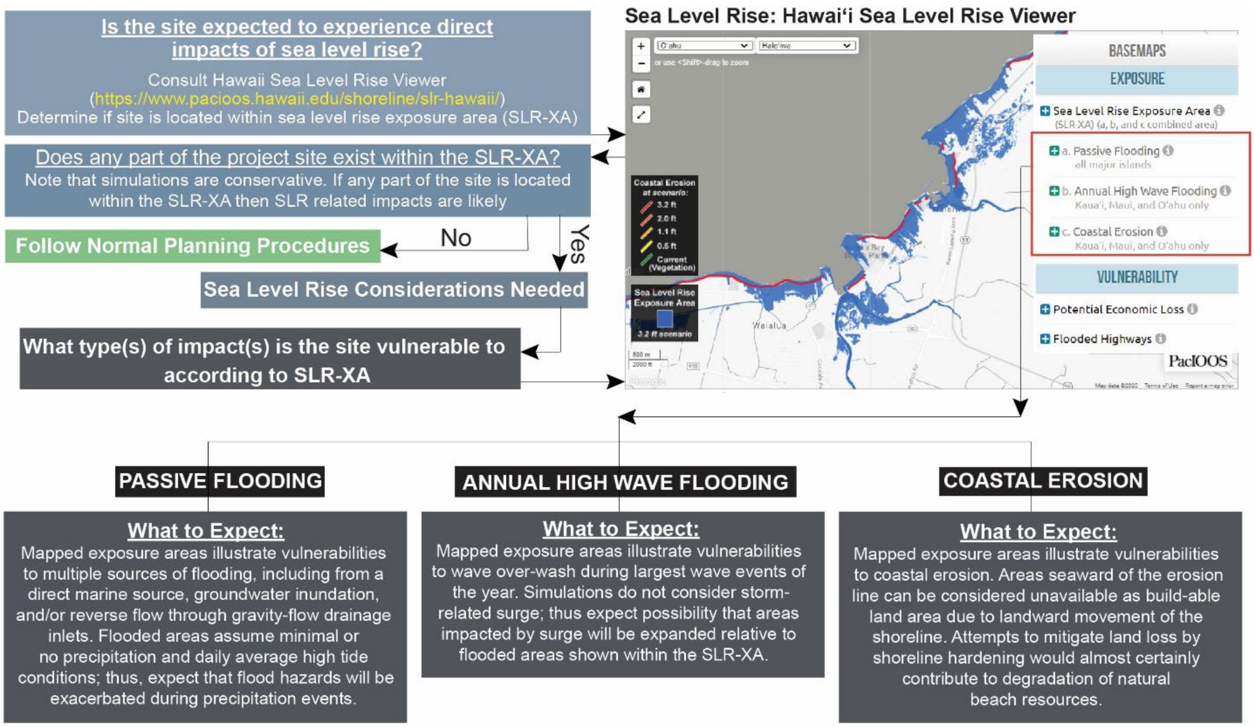

Figure 13. *Example workflow for planners to consider the individual SLR-XA model layers in planning/permitting decisions.*

However, it is important to understand the implications of the three models in the SLR-XA individually when considering increasing frequency and severity of flooding impacts. This may require different adaptation approaches depending on the relative impact of each of the hazards at the property/project-scale. Adaptation in-place may be possible in some backshore areas that are projected to be impacted only by passive flooding, whereas land lost to erosion will no longer be buildable. Planners should consider expected lifespan of existing or new development, tolerance for risk, and compounding impacts of multiple flood hazards (e.g., SLR-XA plus FEMA Special Flood Hazard Areas). Moreover, in areas with beaches, engineering in place (e.g., seawalls and other shoreline hardening and fortification of building foundations) may not be an option due to impacts on beach ecosystems and prohibitions against shoreline armoring in these areas.

Analyzing permit applications in this manner will require a discretionary process that may be beyond what regulatory planners are accustomed to. Due to unique qualities at each site and the compounding nature of the hazards, it may be challenging to develop a checklist-like approach to permit review. County and state planners have increased statutory support for a discretionary review process based on recent updates to the State CZMA (HRS 205A). For instance, new provision in the CZMA appear to require a major Special Management Area Use Permit for new residential development exposed to coastal hazards and prohibit shoreline armoring in areas with sand beaches. In addition, recent updates to state administrative rules for environmental assessment require consideration of climate change and sea level rise hazards in the development process (HAR 11-200.1 under HRS 343). Planning departments have access to coastal hazards and community resilience specialists at the University of Hawaiʻi, including Hawai'i Sea Grant, to help in understanding and interpreting sea level rise hazards for permit applications.

Coastal Erosion

The landward boundary of the coastal erosion hazard area is relatively smooth because historical erosion rates incorporated in the model are smoothed alongshore using a moving averaging function by the University of Hawai‘i Coastal Geology Group. However, the coastal erosion hazard area has prompted some questions related to applying it for zoning and regulation at the property-scale. As previously discussed, the coastal erosion model depicts areas that are prone to future land loss and would become unbuildable, assuming the shoreline is allowed to retreat naturally. In many cases the shoreline may not be allowed to migrate naturally (to the detriment of the beach environment), which is why we incorporate a discussion of existing shoreline armoring and backshore geology that should be considered carefully in the coastal erosion area (see Part D). The coastal erosion model depicts an 80% probability that lands landward of the boundary are safe from erosion at that particular height of sea level rise (e.g., 3.2 feet).

<u>Recommendations:</u>

Because of the risk of catastrophic land loss, the state and counties have stricter development restrictions for lands within the erosion hazard areas including but not limited to shoreline setback regulations. Kaua‘i County’s existing setback policy includes an additional setback buffer of 20 feet to account for intermittent coastal hazards and sea level rise in addition to a historical erosion rate-based setback formula. Maui County is assessing and discussing adopting the 3.2-foot SLR-XA erosion area in updates to their setback rules. Honolulu and Hawai‘i Counties and State OCCL are also considering updates to their setback policies recognizing increasing erosion threats to shoreline properties.

One particular challenge with shoreline setbacks is that they apply only to new or complete redevelopment of shoreline lots. Shorefront property owners are likely to do all that they can to maintain non-conformity for existing structures within the setback area. To increase awareness about sea level rise risks to coastal properties, several bills have been introduced at the State Legislature that would require disclosure of sea level rise hazards with real estate transactions based on the SLR-XA and latest science. The County of Kaua‘i has gone a step further with updates to their shoreline setback ordinance by including a provision for unilateral agreements with applicants prohibiting future armoring, among other limitations, if new structures are permitted in the setback area (County of Kaua‘i Ordinance 979 Shoreline Setbacks).

Building standards and codes may be of limited help in areas where the land is projected to eventually be lost to erosion. Prohibiting slab-on-grade foundations and masonry or concrete building construction in the setback may facilitate elevating or moving a building landward in the future, if there is room to relocate. Elevating homes or other buildings on deep pilings may protect from intermittent flooding but, if allowed in the erosion hazard zone, will ultimately lead to the building encroaching into public coastal lands as the shoreline retreats under the structure, to the detriment of the coastal environment and public access. Continuous exposure to the elements with increased sea level rise, velocity impacts and scouring from waves, increased storminess, and land loss may eventually result in total failure of many improvements on the shoreline.

Managed Retreat, which is the planned relocation of buildings and infrastructure away from coastal hazards, will be a necessary component of long-term climate adaptation in Hawai‘i, particularly for the most vulnerable areas that are prone to repeat loses and where priority coastal environments including beaches are at risk. More discussion and analysis of managed retreat strategies is needed following the State Office of Planning - Coastal Zone Management Program's report (2019), *Assessing the Feasibility and Implications of Managed Retreat Strategies for Vulnerable Coastal Areas in Hawai'i*. The need to develop policies and programs supporting proactive retreat has become increasingly urgent with recent updates to the State Coastal Zone Management Act that prohibit shoreline hardening on beaches, particularly on private lands. The state and counties can begin by implementing adaptation pilot projects, including managed retreat where appropriate, in priority vulnerable areas to demonstrate pathways for multi-jurisdictional and public-private collaboration, planning, design, and funding.

Annual High Wave Flooding

Lands in the annual high wave flooding area of the SLR-XA are projected to be flooded annually or more frequently due to high waves overwashing the shoreline. Lands at the seaward end of this hazard zone will be flooded more frequently (i.e., multiple times per year) and with greater depth and velocity than lands at the back of the zone. Unlike passive flooding, land and structures within the annual high wave flood zone will also be exposed to velocity impacts from waves and currents causing scouring and damage.

Recommendations:

The annual high wave flooding hazard area should be considered in tandem with the erosion hazard area. Lands and structures exposed to both erosion and annual high wave flooding are facing high risk of future damage and land loss. Like erosion, the most effective way to address the annual high wave flooding hazard is through shoreline setbacks to move development back - away from the hazard. Adaptation in place may be possible for some properties in the annual high wave flooding hazard area, if not additionally exposed to erosion and passive flooding and if located toward the back of the high wave flooding hazard area. Options for adapting in-place are provided in the following sections.

Planners may want to consider a multi-hazard approach for assessing high wave flooding exposure. Lands within the 3.2 ft SLR-XA annual high wave flooding hazard area, present-day FEMA V or VE Zone, and/or 1% CFZ-3.2 will be prone to increased high wave flooding between now and the latter half of this century - within the lifespan of most existing and new development. Based on the science indicating increasing flooding hazards in these areas, counties should consider subjecting development within these areas to flood mitigation requirements beyond those currently required by FEMA and county floodplain management, such as requiring additional freeboard above base flood elevation and other building codes and standards.

Where adaptation in-place is to be allowed in the annual high wave flooding area, adaptation requirements should be similar to those described below for passive flooding. However, additional requirements should be considered for high velocity wave flooding areas, such as deeper and more robust pilings; though, deep pilings bay be counter-effective in the coastal erosion hazard area.

Passive Flooding

Lands in the passive flooding area of the SLR-XA are projected to be flooded daily at high tide or more frequently at a given sea level rise scenario (e.g., 3.2 ft). Passive flooding from sea level rise will also worsen flooding from less frequent events like the 1%-annual-chance coastal flood by increasing water levels through direct marine inundation, groundwater rise, and impaired drainage. The passive flooding model does not specifically resolve the effects of rising groundwater tables, which will add to the frequency and severity of flooding in many low-lying coastal areas. Though it does provide a good initial assessment of where groundwater flooding is likely to occur because it identifies low-lying areas (Habel et al., 2019).

Recommendations:

Adaptation in-place may be possible for properties located away from the shoreline and exposed solely to passive flooding. Some areas are already experiencing impacts from passive flooding, such as at Māpunapuna in urban Honolulu and Kaunakakai on Molokaʻi, and will require serious discussion about relocation as an alternative to adapting in place.

Following is a menu of adaptation and policy options for improving resilience to increasing coastal flooding with sea level rise. We provide some criteria of when and where each option may be most appropriate. Collaboration between county and state planners, floodplain managers, building code officials, and engineers may be needed to determine feasibility of each option and paths toward implementation.

Adopting new floodplain management and building code regulations will take time. In the meantime, counties may require adaptation measures for sea level rise through existing policies such as applying maximum allowable shoreline setbacks as well as discretionary review through Special Management Area permit applications and environmental assessment.

Options for adapting in-place to increasing coastal flooding with sea level rise:

- Nature-based solutions and Low Impact Development (LID) for flood mitigation such as creating rain gardens and other floodable areas in and around passive flooding exposure areas and FEMA Special Flood Hazard Areas, reducing impervious surfaces for infiltration in areas outside of the passive flooding exposure areas, as well as building design options such as green roofs may be the best options for reducing stormwater impacts for individual existing development or redevelopment in urban to rural settings and will reduce stormwater runoff into increasingly impaired municipal drainage systems and the marine environment. However, consideration of coastal groundwater depth should be taken into account when designing such projects, since stormwater will generally fail to infiltrate in areas where groundwater is shallow or emergent. Hawaiʻi Sea Grant has a compendium of resources related to green infrastructure for stormwater management at: https://seagrant.soest.hawaii.edu/sbcd-stormwater-links/

- Requiring additional freeboard, such as two or three feet above existing base flood elevation (or above ground elevation if not currently within a FEMA flood zone), within the SLR-XA or a flood hazard area can help mitigate for increasing flood heights with sea level rise over the lifetime of a structure. Special requirements such as strengthening or deepening pilings and other structural guidelines may be needed for properties with wave velocity exposure in the FEMA VE Zone and annual high wave flooding exposure area; though, construction on deep pilings may be conuter-effective in the erosion hazard zone as discussed above. In addition, exceptions may be added to zoning regulations to allow for additional building height for development that is incorporating additional freeboard and/or other flood mitigation measures.

- Elevating lands with fill and incorporating drainage improvements may be an option, particularly for urban areas in the passive flooding area and/or FEMA Special Flood Hazard Areas undergoing redevelopment and/or coinciding with planned infrastructure upgrades. Elevating low-lying portions of individual properties in combination with LID guidelines may be an option in both urban and rural settings. In either case, careful attention should be given not to increase flood hazards for neighboring lands. Wherever possible, agencies should integrate sea level rise adaptation into neighborhood-scale or regional flood management or adaptation plans. Elevation with fill should not be considered when it could impact an area's natural resilience and ecosystem values, or has the potential to cause contamination of nearshore areas, such as in sandy shoreline environments, low-lying wetlands, or floodplain areas.

Broader policy and program options for improving resilience to increasing coastal flooding:

- Adopt a multi-hazard coastal flood exposure area that includes the SLR-XA, FEMA Special Flood Hazard Areas, and/or 1%CFZ-3.2 can provide a basis for beginning to integrate future sea level rise considerations into floodplain management. Detailed groundwater flood modeling with sea level rise has been conducted for the Honolulu urban core and could be conducted for other areas, particularly low-lying urban centers, and integrated in a multi-hazard flood area.

- Counties may improve their Community Rating System (CRS) ranking by going above and beyond FEMA minimum requirements through some of the recommendations herein. Each CRS Class improvement has the additional benefit of providing a five percent greater discount on flood insurance premiums for properties in the Special Flood Hazard Area, though care should be taken not to use this as a means to justify or incentivize increased development in the most vulnerable areas.

- Other building codes and regulations for improved resilience can be developed for application in the passive flooding areas through collaboration between planning departments, floodplain managers, and other offices. Examples of regulations might include prohibiting slab on grade foundations in the SLR-XA, especially in beach environments, and elevating and flood-proofing utilities such as electrical meters.

D. Relating the SLR-XA Model Projections to Existing Shoreline Hardening

Many miles of Hawaiʻi coastline are hardened by vertical rock and cement walls, sloping revetments, bulkheads, and other types of structures. Shoreline hardening has had widespread negative impacts on Hawaiʻi beaches with over 13 miles of beaches completely lost to erosion in front of hardened coasts. In many locations, the SLR-XA erosion hazard lines extend inland behind existing seawalls and other shoreline hardening structures, requiring consideration of the structure's present and future impacts and what is contained behind the structure, i.e., backshore geology.

As described in Part III, the coastal erosion model in the SLR-XA is based in part on historical erosion rates tracking the landward movement of the beach toe or low water mark. The landward edge of the erosion hazard area (the "erosion hazard line") is projected from the vegetation line or landward edge of the beach, which may or may not be fixed by shoreline hardening. Thus a hardened shoreline fronted by, or formerly fronted by, sandy beach will have a SLR-XA erosion hazard area that is landward of any existing seawalls.

The area between the beach and the erosion hazard line may be thought of as the land likely to be lost by erosion should the seawall fail or be removed. In the long-term, this is not an unreasonable assumption for many coastal areas, as planning and permitting departments receive numerous requests each year to repair or rebuild failing seawalls (Figure 14). These failures will only increase with continued sea level rise.

Figure 14. *Example of a failing seawall and sinkhole caused by undermining from wave action and beach loss in West Maui (Tara Owens, Hawai'i Sea Grant).*

<u>*Recommended Approaches:*</u>

As described earlier, the erosion hazard area is based in part on historical rates of shoreline change. It should be thought of as identifying the area that is prone to erosion (land loss) at a particular future increment of sea level rise, if a seawall were to be removed (or failed) and the shoreline allowed to retreat naturally.

In reviewing permit applications for development on lands in the SLR-XA fronted by existing shoreline hardening, agencies should consider the history, legal status, and estimated remaining lifespan of the shoreline structure (Figure 15). The erosion hazard area provides an estimate of the potential for inland migration of the beach ecosystem and resulting land loss hazard in locations where a seawall may fail or be phased-out at a future time. State and county regulatory agencies should continue to enforce no-tolerance policies for unpermitted or illegal shoreline hardening structures due to the documented negative impacts of armoring on beaches.

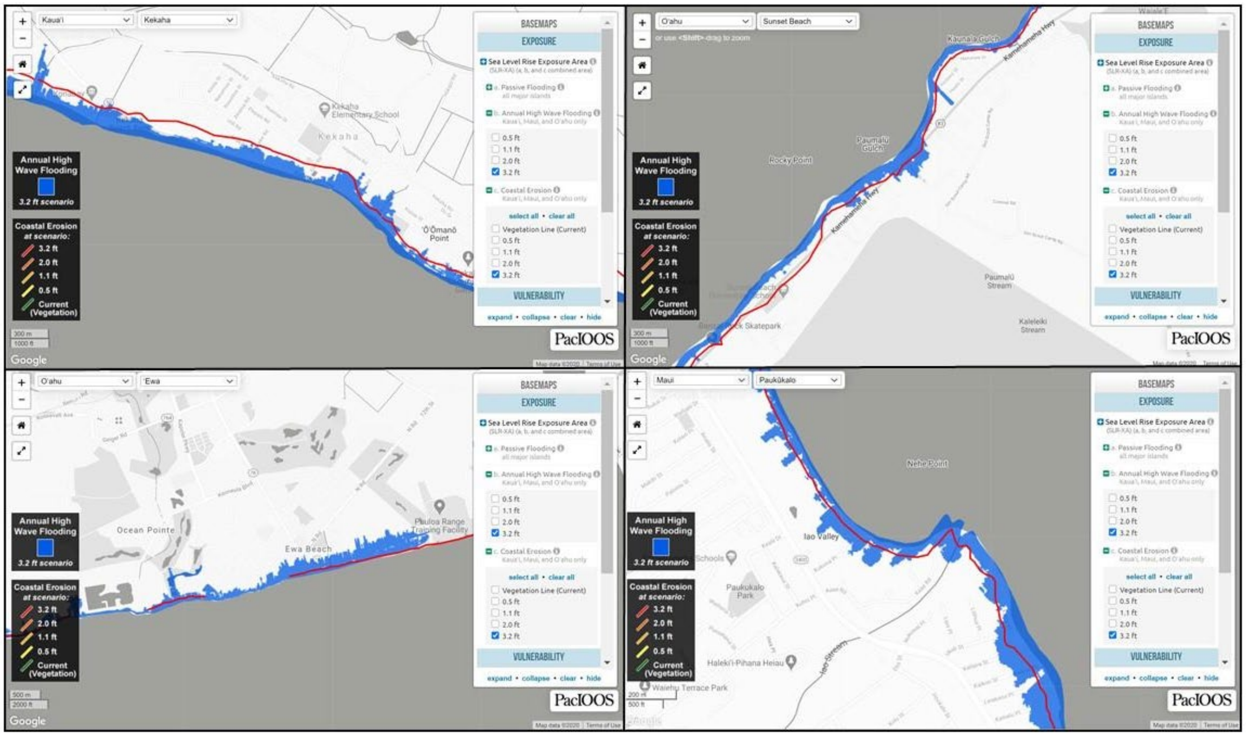

__Figure 15.__ The coastal erosion hazard area (seaward of the red line) with 3.2 feet of sea level rise in-part reflects a measured historical trend of beach changes. Careful consideration should also be given to the other coastal hazards in the SLR-XA including annual high wave flooding exposure (blue) to determine if existing armoring will be effective or sustainable in the future since wave inundation is likely to damage, overtop, and/or produce sinkholes landward of such structures.

Planners and other stakeholders should consider certain questions when interpreting the implications of erosion hazard projections on hardened shorelines when reviewing a permit application for development behind an armored shoreline.

- *What is the legal status of the shoreline hardening? Is it permitted or non-conforming? Does the county have a policy for phasing-out non-conforming structures?*
- *What are the coastal zone management goals of the county administration, the county planning department, and the State Department of Land and Natural Resources with respect to the coastal area? Are they aligned?*
- *What guidance is provided by the Community and County General Plan?*
- *Is it reasonable to assume that the existing shoreline hardening will remain intact without the need to request repair (e.g., greater than 50% repair) or expansion of the structure over the expected lifespan of the proposed backshore land use (e.g., dwelling, road)?*
- *Does SLR-XA modeling indicate that the backshore area may not be sustainable for development over the lifespan of the proposed land use due to growing exposure to groundwater flooding and/or high wave overwash?*

- *What impact has the seawall had on public access to and along the coast, the viewshed, and open space?*

- *What impact has the seawall had on beach and dune resources? Is the beach narrow or absent? Is there a healthy sand-rich dune present? What is the backshore geology? Is it sand-rich? (see the following section on Backshore Geology)*

- *What is the alongshore impact of the seawall? Is it the only structure on that particular segment of shoreline, is the majority of the shoreline already hardened, or are there a mix of hardened and unhardened segments? Is the seawall causing flanking (increased erosion impacts to neighboring, un-hardened shoreline)?*

- *What is the backshore land use? Has there been a comparative valuation of the beach and the backshore land uses? Is the potential loss of the beach an acceptable risk in the context of backshore land uses?*

- *How does the affected community feel about the potential loss of a beach in the context of sea level rise and shoreline hardening? How do adjacent homeowners and the affected immediate homeowner feel? These questions may be answered in part through public meetings, if required, and/or the Community Plan.*

- *Are there alternatives to continued shoreline hardening such as retreat, beach nourishment, or others?*

Although this list of considerations is long, it is by no means exhaustive or complete. Evaluating the implications of the SLR-XA erosion model on a hardened shoreline, especially in the context of removing negative impacts associated with the presence of one or more seawalls, is a complex process that is additionally engaged by concerned stakeholders often having opposing viewpoints. Again, coastal specialists are available at the University of Hawai‘i, including Hawai‘i Sea Grant, to help planners and communities in understanding coastal processes and impacts of shoreline hardening based on the latest and best-available science.

E. Related the SLR-XA Model Projections to Backshore Geology

The makeup of sand, soil, gravel, and/or rock behind the shoreline (i.e. “backshore geology) is also an important consideration when assessing the individual hazards in the SLR-XA at the property-scale because, even under conditions of sea level rise and increasing shoreline erosion, a beach may be sustained if allowed to erode into and release natural backshore sand deposits. The coastal erosion hazard line in the SLR-XA is based on the assumption that erodible sands extend inland beyond the vegetation line (Figure 16). This is the case at many beaches in Hawai‘i. On Kaua‘i and O‘ahu, the low-lying coastal plain is typically composed of combinations of paleo-beach and dune deposits that may be variably intermixed with alluvial (watershed) sediments. Backshore sand deposits are also prevalent in some areas of Maui and Moloka‘i. Beaches on Hawai‘i Island are typically perched on and backed by basalt rock.

The passive flooding model is based on existing topography and provides a reliable estimate of passive marine and groundwater flooding exposure with sea level rise, regardless of backshore geology. Similarly, the annual high wave flooding model is based on existing shoreline topography and provides a reliable estimate, regardless of backshore geology. However, the two models are based on the existing shoreline location and do not consider the compounding effects of coastal erosion, which would move the extent of marine flooding inland.

Figure 16. *Beachfront home constructed on beach sand and threatened by severe coastal erosion at Sunset Beach, O'ahu.*

<u>*Recommended Approaches:*</u>

Backshore geology should be considered when assessing the vulnerability of a property to sea level rise, particularly in considering the implications of projected erosion hazards. The State of Hawai'i recently strengthened prohibitions against coastal armoring, strengthened protections for beaches and dune environments, and further recognized the threat of increasing coastal hazards with sea level rise through updates to the State CZMA. Therefore, development on beaches, particularly those without existing armoring, will ultimately have to "adapt" to sea level rise by moving back, though the timing of planned retreat may vary for different coastal areas depending on the urgency of the threat, i.e., the risk depicted in the SLR-XA.

As sea level rise causes the shoreline to retreat, beach loss may be offset by two factors: 1) the absence of a hardened shoreline that would prevent natural migration, and 2) a backshore geology composed of unconsolidated sand that feeds the beach. This means that if beaches are allowed to migrate landward with sea level rise and erode into widespread backshore deposits of beach and dune sand, the released sand moves into the littoral system to maintain beaches, reeftop sand fields, and sand-floored channels in the fringing reef.

The Viewer includes *Beaches & Sand* and *Geology* digital layers adapted from U.S. Department of Agriculture and U.S. Geological Survey data (Figure 17). The *Beaches and Sand* map layers serve as screening tools for understanding the physical setting of coastal areas around the state and how these areas may be affected by increased flooding and erosion with sea level rise. The beaches and sand layers in the Viewer identify surficial deposits only and may require field verification through geologic investigations using borings or other methods. Inclusion of this information, and its interpretation, would provide critical information for a robust environmental assessment.

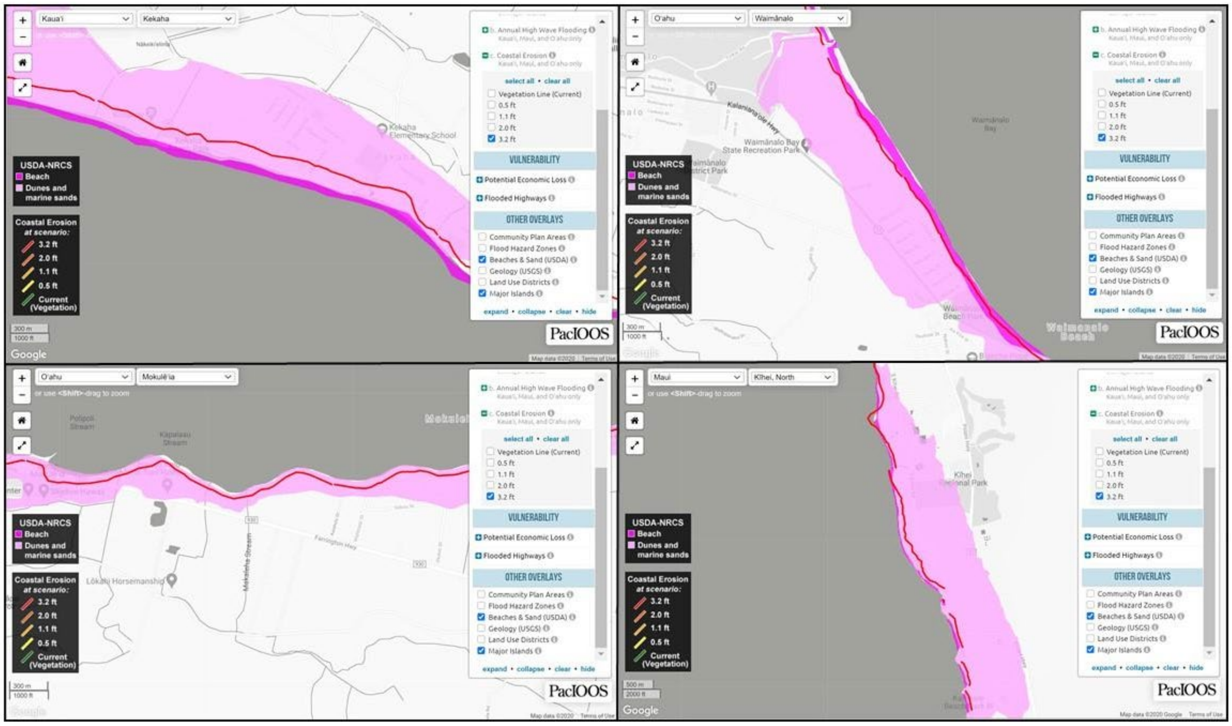

Figure 17. *Maps showing erosion hazard area (lands seaward of the red line) and backshore beach and dune deposits (pink). This information indicates that a beach likely could be sustained in this area with sea level rise if the shoreline is allowed to migrate inland. Though, this brings up other important and challenging questions about relocating shorefront development, roads, and other infrastructure.*

V. Closing Thoughts and Next Steps

In Hawai‘i, an archipelago entirely composed of mid-ocean, volcanic islands, sea level rise constitutes both a challenge and an opportunity. The challenge is embodied in growing marine floods, storm impact, coastal erosion, infrastructure failure, salt intrusion to low-lying ecosystems and land uses, groundwater inundation forming new wetlands in urban areas and elsewhere, and recognition that existing policies, practices, and even governance structures may need revision. The opportunity lies in embracing this moment of great challenge as an opportunity for transformative change in order to improve community sustainability and resilience for generations to come.

This guidance provides a range of approaches for the interpretation and application of the SLR-XA in local planning and permitting decisions with discussion of benefits and drawbacks. Planning and policy approaches will continue to vary somewhat among jurisdictions to suit local needs, though interagency coordination and collaboration is strongly encouraged when attending to complex issues overlapping multiple jurisdictions. Sharing and communicating the latest science, challenges, and successes in adapting to sea level rise across county and state agencies will continue to be vital through venues including the Hawai‘i Climate Change Mitigation and Adaptation Commission, Ocean Resources Management Plan (ORMP) Coordinated Working Group, the Hawai‘i Congress of Planning of Officials (HCPO), and Pacific Risk Management ‘Ohana (PRiMO).

Adapting to sea level rise, including implementing recommendations in this guidance may require additional funding and added human resources in government agencies. In the long run however, inaction will be the costliest and most complicated path for government and taxpayers and will result in serious risk to public safety and environmental resources. Planners may continue to reach out to organizations such as Hawai‘i Sea Grant for assistance in understanding the latest coastal, climate change, and sea level rise science and applying the information in planning and policy. The Hawai‘i Climate Change Mitigation and Adaptation Commission is working to provide additional resources to support state and county climate change and sea level rise adaptation efforts through its “Climate Ready Hawai’i” initiative. This guidance is one example of how the initiative is providing an information hub for sea level rise science and planning and supporting statewide agency and community engagement to address climate vulnerability. Please reach out to Hawai‘i Sea Grant and staff supporting the Climate Ready Hawai‘i initiative in the DLNR Office of Conservation and Coastal Lands for questions and ongoing support related to this guidance document.

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Appendix 1. An Update on Sea Level Rise Science

Sea level rise exposure mapping in the 2017 Hawaiʻi Sea Level Rise Report is based on an upper-end projection in the 2013 IPCC 5th Assessment Report of 3.2 feet of sea level rise by 2100. As expected, the science on sea level rise observations and forecasts has continued to advance. Since completion of the 2017 Report, the peer-reviewed scientific literature as well as government and multinational reports have increasingly pointed to about 3 feet of sea level rise by 2100 as a mid-range, rather than high-end, scenario and shown that sea level rise greater than 3 feet in this century is physically possible. These increasing projections of sea level rise are based on greenhouse gas emissions, which continue to increase, and observations of accelerating ice mass loss to the oceans, particularly from Greenland and West Antarctica. The projections are often provided to 2100, though sea level rise will not stop at that time but will likely continue for centuries.

Since 1993, 27 years of continuous satellite altimeter measurements[5], tied to tide gauges and averaged across the planet (Figure 16) show that global mean sea level is not only rising, it is accelerating at a rate that will lead to about 65 cm (2.13 feet) of sea level rise by the end of the century (Nerem et al., 2018). Continued global warming is expected to increase the rate of acceleration such that by the end of the century sea level will reach or exceed about 1 m (3.2 feet) above recent mean sea level.

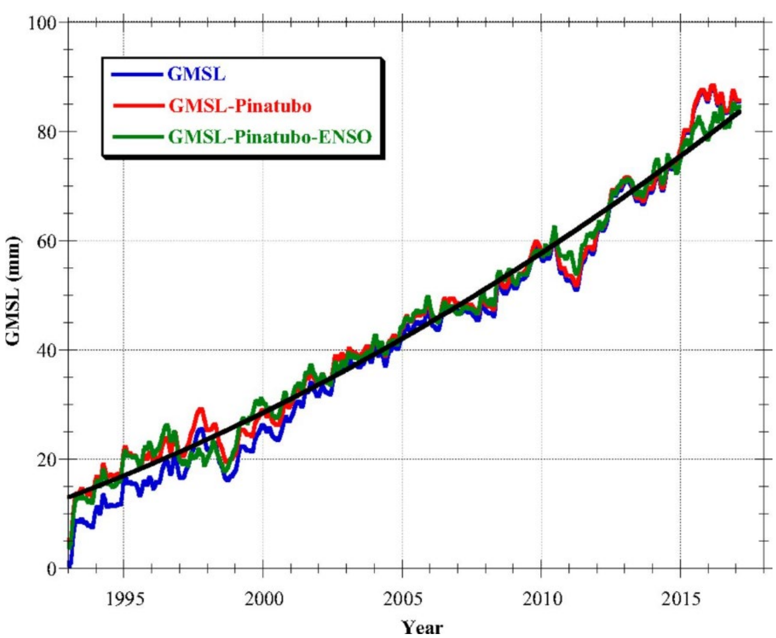

Figure 16. *Global mean sea level is rising at a rate of 3.3 mm/yr (0.13 in/yr)* (Nerem et al., 2018).

The most recent projections of global mean sea level rise are published in the 2019 Intergovernmental Panel on Climate Change (IPCC) *Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)* (Oppenheimer et al., 2019) where it was found that:

[5]*Ocean surface topography is measured using a satellite altimeter, which sends a radar pulse to the ocean surface where it reflects back to the orbiting instrument. Round-trip travel time is equivalent to the distance. Collected across the oceans and over time, altimetry data is used to monitor sea-level change.*

a. In a low greenhouse gas emissions scenario, which would require dramatic reductions in emissions over the next few decades, sea level rise relative to mean sea level 1986-2005, will reach 0.43 meters (1.41 feet) with a likely range of 0.29–0.59 meters (0.95-1.94 feet) by 2100.

b. In a high greenhouse gas emissions scenario, which we are currently tracking at or above, sea level rise relative to mean sea level 1986-2005, will reach 0.84 meters (2.76 feet) with a likely range of 0.61–1.10 meters (2.00 ft-3.61 feet) by 2100.

The SROCC also projects multi-meter sea level rise by 2300:

- 0.6–1.07 meters (1.97-3.51 feet) for low emissions
- 2.3–5.4 meters (10.5-17.72 feet) for high emissions

Importantly, the SROCC acknowledges that processes controlling the timing of future ice-shelf loss and the extent of ice sheet instabilities, could increase Antarctica's contribution to global mean sea level rise substantially higher than reported.

According to the 4th National Climate Assessment emerging science regarding Antarctic ice sheet stability indicates that under high emission scenarios, sea level rise exceeding 2.4 meters (8 feet) by 2100 is physically possible, although the probability of such an extreme outcome cannot currently be assessed (Sweet et al., 2017b). Regardless of emissions, it is extremely likely[6] that global mean sea level rise will continue beyond 2100.

[6] *The term "extremely likely" is used to denote 95-100% likelihood.*

Appendix 2. Additional Resources

In addition to the Report and Viewer, the following resources may be helpful in assessing sea level rise vulnerabilities and developing adaptation actions and policies:

- NOAA Coastal Flood Exposure Mapper: An online visualization tool that supports communities that are assessing their coastal hazard risks and vulnerabilities. The tool depicts community-level impacts from passive sea level rise flooding, up to 10 feet above average high tides. This tool is helpful for initial consideration of vulnerabilities beyond 3.2 feet of sea level rise (e.g., 6 ft for critical infrastructure), particularly for low-lying backshore areas. The sea level rise map layers in the NOAA tool depict passive flooding only and do not consider wave runup or coastal erosion as in the Hawaiʻi Sea Level Rise Viewer and, therefore, may significantly underestimate sea level rise hazards on wave-exposed shorelines. https://coast.noaa.gov/digitalcoast/tools/flood-exposure.html

- Guidance for Disaster Recovery Preparedness in Hawaiʻi: This project led by Hawaiʻi Sea Grant worked with state and county government to establish resilience-focused recovery practices before a disaster hits to enable communities to recover quickly while also adapting to sea level rise and protecting sensitive coastal environments through recommended preparedness activities and model planning and policy resources. https://seagrant.soest.hawaii.edu/resources/program-publications

- Guidance for Addressing Sea Level Rise in Community Planning: This project led by Hawaiʻi Sea Grant worked with state and county government to produce a guidance document and conduct outreach to address sea level rise and coastal hazards in the county general and community planning process. https://seagrant.soest.hawaii.edu/resources/program-publications

- State of Hawaiʻi 2018 Hazard Mitigation Plan: The 2018 update of the State's Hazard Mitigation Plan includes expanded consideration of climate change and sea level rise hazards, including hazard assessment using the SLR-XA and a 1% Annual-Chance Coastal Flood Zone with 3.2 feet of sea level rise (1%CFZ-3.2) modeled for the Plan. https://dod.hawaii.gov/hiema/sert-resources/hazard-mitigation/

- Assessing the Feasibility and Implications of Managed Retreat Strategies for Vulnerable Coastal Areas in Hawaiʻi: This report by The State Office of Planning - Coastal Zone Management Program makes findings regarding retreat programs and their relative significance to Hawaiʻi and a specific multi-prong recommendation regarding the feasibility of retreat in Hawaiʻi. https://planning.hawaii.gov/czm/ormp/ormp-action-team-project-on-the-feasibility-of-managed-retreat-for-hawaii/