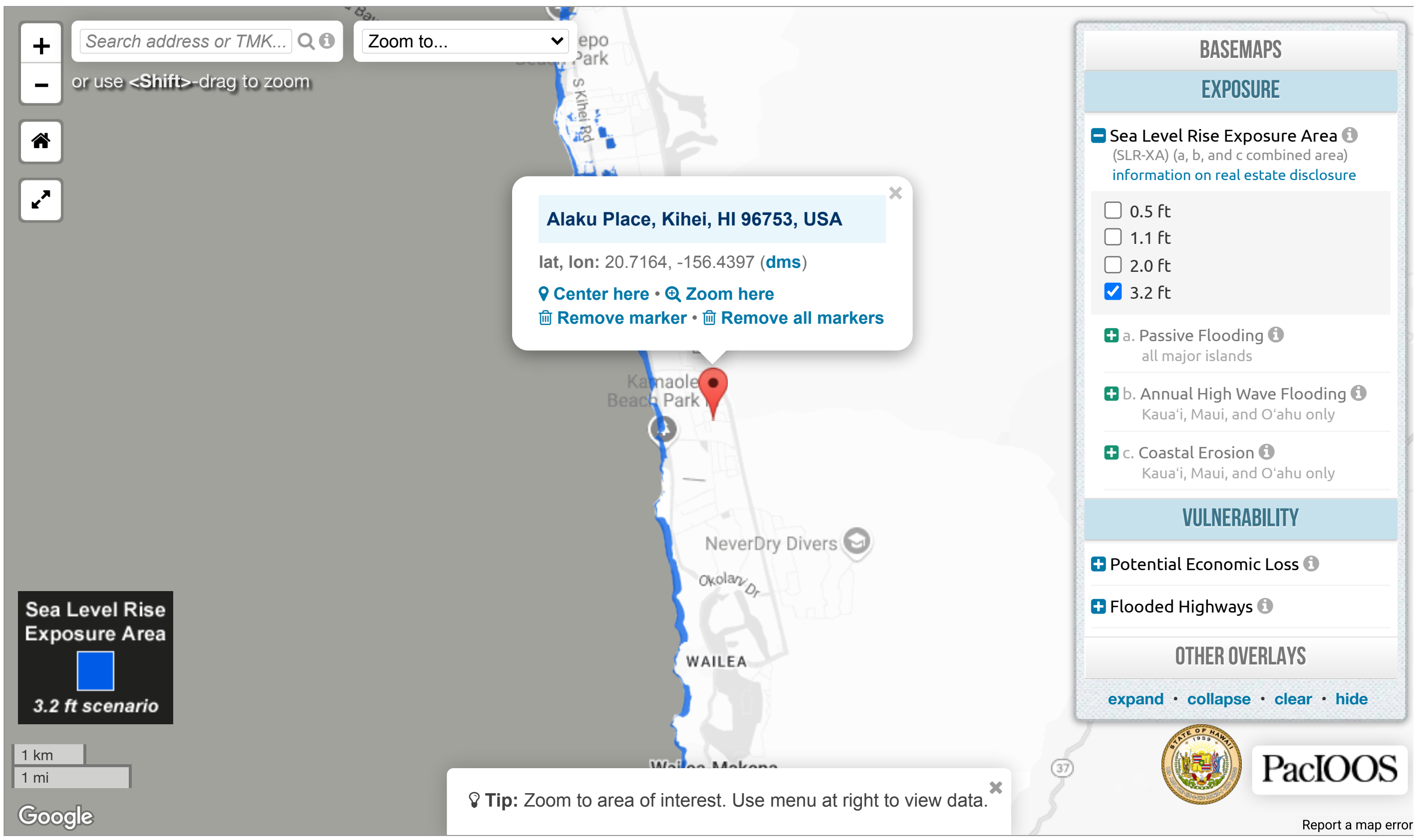
Sea Level Rise : State of Hawai'i Sea Level Rise Viewer

An Interactive Mapping Tool in Support of the State of Hawai'i Sea Level Rise Vulnerability and Adaptation Report



opacity: 75% cursor: 20.7432°, -156.3687°

Funding provided by the National Oceanic and Atmospheric Administration (NOAA) through their 2016 Regional Coastal Resilience Grants Program.

DISCLAIMER (updated November 27, 2018): Based on the methodology of sea level rise modeling used in the Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report (Report) and the Hawaiʻi Sea Level Rise Viewer (Viewer), having gone through peer review and publication in the *Nature* journal *Scientific Reports*, 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 Hawaiʻi'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. The risks associated with use or non-use of the results are assumed by the user. At its November 27th, 2018 public meeting, the Hawaiʻi Climate Change Mitigation and Adaptation Commission agreed to replace the original Report Disclaimer with an updated Disclaimer, adapted here for the Viewer. The Commission's decision on this matter is detailed in meeting minutes from November 27, 2018.

SUGGESTED CITATION: Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2021. *State of Hawaiʻi Sea Level Rise Viewer*. Version 1.15. Prepared by the Pacific Islands Ocean Observing System (PacIOOS) for the University of Hawaiʻi Sea Grant College Program and the State of Hawaiʻi Department of Land and Natural Resources, Office of Conservation and Coastal Lands, with funding from National Oceanic and Atmospheric Administration Office for Coastal Management Award No. NA16NOS4730016 and under the State of Hawaiʻi Department of Land and Natural Resources Contract No. 64064. http://hawaiisealevelriseviewer.org. Accessed [date].

NOTE: Additionally, please cite any data sources used and related publications as suggested in the dataset descriptions further below.

DISCLOSURE REQUIREMENT for residential real estate in the Sea Level Rise Exposure Area: The State of Hawaiʻi enacted an update to the Mandatory Seller Disclosures in Real Estate Transactions Law in 2021, codified within Hawaiʻi Revised Statutes §508D-15, requiring that real estate transactions within the State of Hawaiʻi must disclose any risk of sea level rise to that property based on the 3.2-feet Sea Level Rise Exposure Area (SLR-XA). More information is available in the following resources:

- Sea Level Rise Viewer Disclosure Requirements FAQs and Tutorial Video for Realtors (Hawaiʻi Realtors Association)
- Disclosure Requirement for Residential Real Estate in the Sea Level Rise Exposure Area flyer (State of Hawaiʻi)

If you have questions or comments about the resources and information contained on these pages, please contact slviewer@hawaii.edu.

Overview

The Hawaiʻi Sea Level Rise Viewer (Viewer) is an online, interactive atlas to support the Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report (Report) that was mandated by Act 83, Session Laws of Hawaiʻi (SLH) 2014 and Act 32, SLH 2017. A five-year update to the Report was completed in 2022 that provides an overview of the latest sea level rise science, an assessment of the accomplishments related to the 2017 Report recommendations, and updated recommendations. Please visit the Hawaiʻi Climate Change Portal website to view the full report and for more information on climate mitigation and adaptation.

The Viewer is intended to provide map data depicting projections for future hazard exposure and assessing economic and other vulnerabilities due to rising sea levels. Users may view and download map data for:

- Coastal hazard exposure areas with sea level rise including passive flooding (still water high tide flooding), annual high wave flooding (over wash during the largest wave events of the year), and coastal erosion.
- An aggregate of the above hazard layers into a combined Sea Level Rise Exposure Area (SLR-XA). It should be noted that for the islands of Lānaʻi, Molokaʻi, and Hawaiʻi, the SLR-XA represents only the passive flooding hazard due to the lack of historical data needed to model the other two hazards.
- Vulnerability assessment layers, including potential economic impacts to land and structures and threats to coastal highways from sea level rise and coastal hazards.
- Other base maps and overlays to support vulnerability assessment and adaptation planning include passive flooding with 6 feet of sea level rise from NOAA, a 1%-Annual-Chance Coastal Flood Zone with 3.2 feet of Sea Level Rise (1%CFZ-3.2) from the 2018 Hawaiʻi Hazard Mitigation Plan, present day flood hazard zones, coastal geology, and TMK parcel boundaries.

More details on these map layers are provided below. Guidance for integrating the sea level rise map data in planning and permitting is available at the Hawaiʻi Climate Change Portal.

The Viewer was developed by the Pacific Islands Ocean Observing System (PacIOOS) at the University of Hawaiʻi School of Ocean and Earth Science and Technology (UH SOEST) through a collaborative project led by the University of Hawaiʻi Sea Grant College Program (Hawaiʻi Sea Grant) in partnership with

DLNR and the State of Hawai‘i Office of Planning. The Report was developed by Tetra Tech, Inc. and the State of Hawai‘i Department of Land and Natural Resources (DLNR), Office of Conservation and Coastal Lands (OCCL). Coastal hazard exposure map data (passive flooding, annual high wave flooding, and coastal erosion) were developed by the Coastal Geology Group at UH SOEST. The combined SLR-XA and vulnerability assessment layers were developed for the Report and Viewer by Tetra Tech, Inc. The 1%-Annual-Chance Coastal Flood Zone with 3.2 feet of Sea Level Rise (1%CFZ-3.2) was developed by Sobis, Inc. and Tetra Tech, Inc. for the 2018 State of Hawai‘i Hazard Mitigation Plan. The passive flooding area with 6 feet of sea level rise comes from the NOAA Sea Level Viewer. Funding for the Viewer development was provided by NOAA through their 2016 Regional Coastal Resilience Grants Program and the DLNR through Act 83, SLH (2014).

Sea Level Rise Projections For Modeling

Sea level rise exposure mapping in the 2017 Hawai‘i Sea Level Rise Report and Hawai‘i Sea Level Rise Viewer is based on an upper-end projection in the 2013 Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report of 3.2 feet of global mean 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, peer-reviewed scientific literature as well as government and multinational reports increasingly point to 3 to 4 feet of sea level rise by 2100 as a mid-range, rather than high-end, scenario for Hawai‘i. 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 is committed to rise for centuries to millennia according to the 2021 IPCC Sixth Assessment Report (IPCC 2021).

Since 1993, 27 years of continuous satellite altimeter measurements tied to tide gauges and averaged across the planet (Figure 1) show that global mean sea level is rising at a rate of 3.56 mm/yr (1.40 inches per decade) and has accelerated to 4.42 mm/yr (1.74 inches per decade) averaged over the past decade (February 2013 – February 2023, AVISO+ Satellite Altimetry Data). Global mean sea level rise is accelerating at a rate that will lead to 23 cm (9 inches) by 2050 (relative to the year 2000; Nerem et al., 2022). Continued global warming is expected to increase this rate of acceleration, and therefore 9 inches of sea level rise by 2050 is likely a conservative (low-end) sea level rise scenario for that timeframe.

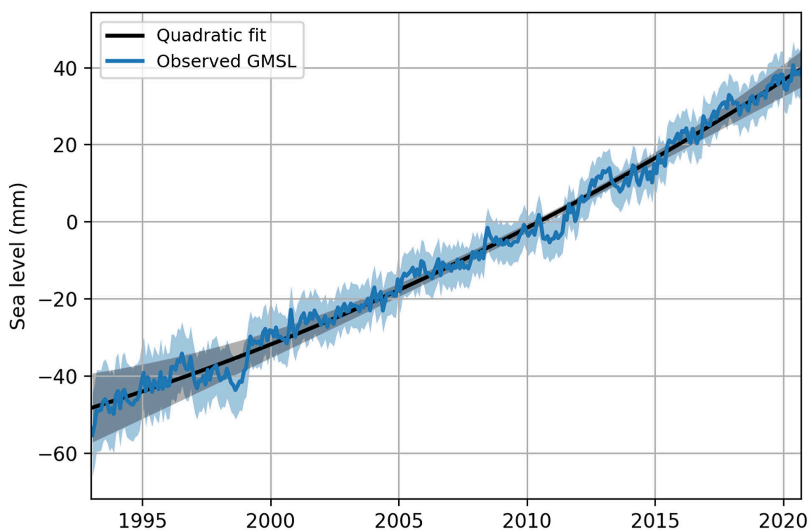


Figure 1. Global mean sea level is rising at a rate of 3.56 mm/yr (1.4 inches per decade, AVISO+ Satellite Altimetry Data) and this rate is accelerating (Figure: Nerem et al., 2022).

The most recent projections of global and regional sea level rise are published in a 2022 interagency report led by NOAA (Sweet et al., 2022). The 2022 report builds on a 2017 NOAA report (Sweet et al., 2017) and global mean sea level rise scenarios from the IPCC Sixth Assessment Report (IPCC 2021). Key findings of the 2022 interagency sea level rise report include:

- Increased confidence, regardless of greenhouse gas (GHG) emissions scenario, in sea level rise projections at 2050 with sea level expected to rise as much over the next 30 years as it has over the last 100 years.
- An increase in magnitude and frequency of coastal flooding by 2050 from high tide and storm surge flood events with significant consequences to coastal infrastructure, communities, and ecosystems.
- A 50% probability of exceeding 0.5 m (1.6 ft) of sea level rise globally by 2100 with an increase in average global temperature of 2°C above preindustrial levels (global temperature has already risen 1.1°C since 1880 (https://climate.nasa.gov). The probability of exceeding 0.5 m (1.6 ft) of global sea level rise increases to 80% to 99% under higher GHG emissions scenarios with 3°-5°C of warming, respectively. These probabilities do not consider the potential for faster-than-projected ice sheet losses in Antarctica and Greenland within this century, which is a focus of ongoing research.
- There is a 50% probability of exceeding 1.0 m (3.3 ft) and 10% probability of exceeding 2.0 m (6.6 ft) of global sea level rise by 2100 when considering a high GHG emissions scenario that leads to an average global temperature increase of 5°C plus the impact of earlier and faster ice sheet losses

from Antarctica and Greenland. While physically plausible, the likelihood of widespread ice sheet collapse to that extent within this century is currently unknown and is an active area of ongoing observation and research.

Long-term observational data from local tide gauge stations show that sea level is rising around Hawaiʻi. Models indicate that Hawaiʻi and other tropical Pacific sites will experience sea level rise that is 16% to 20% higher than the global average (Sweet et al., 2022). The 2022 interagency report provides a range of regionalized sea level rise scenarios based on differing GHG emissions pathways and associated global warming and ice sheet melt (all projections relative to sea level in the year 2000):

- Sea level will rise around Hawaiʻi between 0.7 and 1.5 feet by 2050.
- The Intermediate (mid-range) estimate is for a rise of 1.0 feet by 2050.
- Sea level will rise between 1.3 and 8.0 feet by 2100.
- The Intermediate (mid-range) estimate is for a rise of 3.9 feet by 2100.

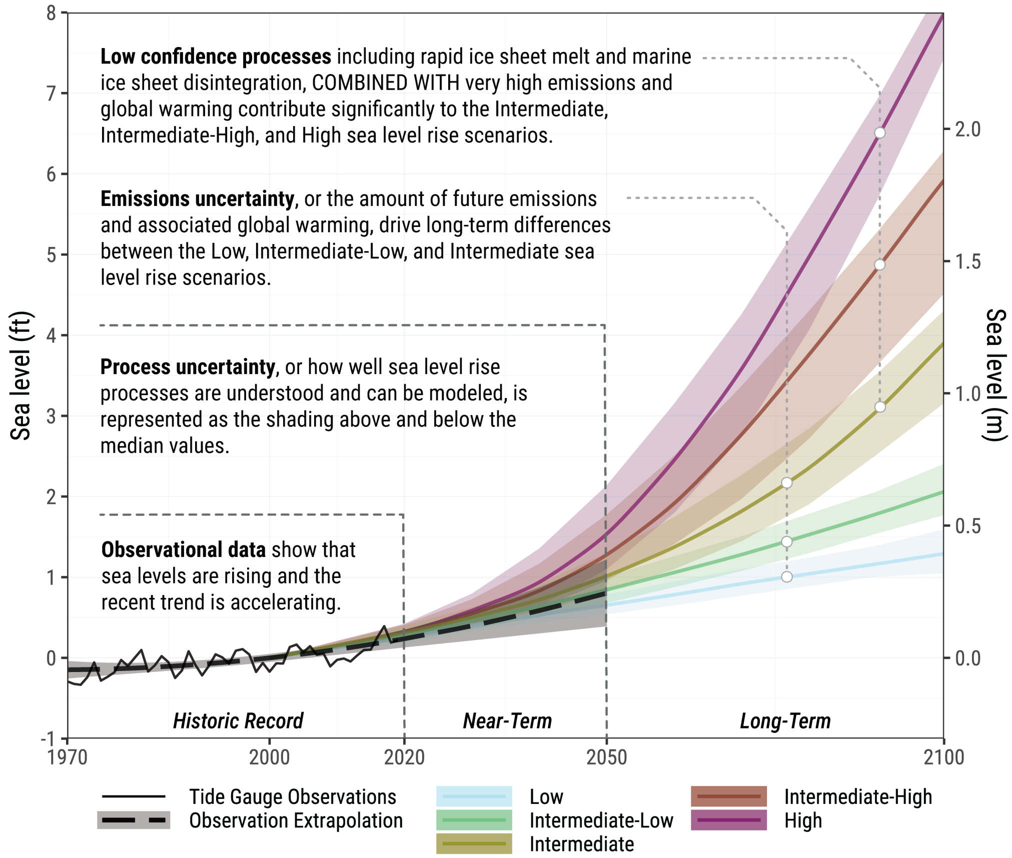


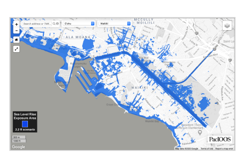
Figure 2. Sea level rise observations (solid black line), extrapolated observed trend (dashed black line), and sea level rise scenarios for Hawaiʻi from the NOAA-led interagency sea level rise report (Sweet et al., 2022). The text in the figure describes the various processes and uncertainties that contribute to the various sea level rise scenarios (Figure by Jamie Carter, NOAA).

A NASA Interagency Sea Level Rise Scenario Tool provides up-to-date sea level rise scenarios for tide gauge locations in all U.S. States, including Hawaiʻi, out to the year 2050 based on data from the NOAA-led interagency sea level rise report (Sweet et al., 2022).

Exposure

Sea Level Rise Exposure Area (SLR-XA)



Data source: Tetra Tech, Inc. combining hazard exposure data layers from the University of Hawaiʻi Coastal Geology Group

Modeling, using the best available data and methods, was conducted to determine the potential future exposure of each island to multiple coastal hazards as a result of sea level rise. Three chronic flooding hazards were modeled: a. passive flooding, b. annual high wave flooding, and c. coastal erosion (see descriptions of individual hazard layers, below). The footprint of these three hazards were combined to define the projected extent of chronic flooding due to sea level rise, called the sea level rise exposure area (SLR-XA, Figure 3). Flooding in the SLR-XA is associated with long-term, chronic hazards punctuated by annual or more frequent flooding events. Each of these hazards were modeled for four future sea level rise scenarios: 0.5 foot, 1.1 foot, 2.0 feet and 3.2 feet based on the upper end of the IPCC AR5 RCP8.5 GMSL rise scenario.

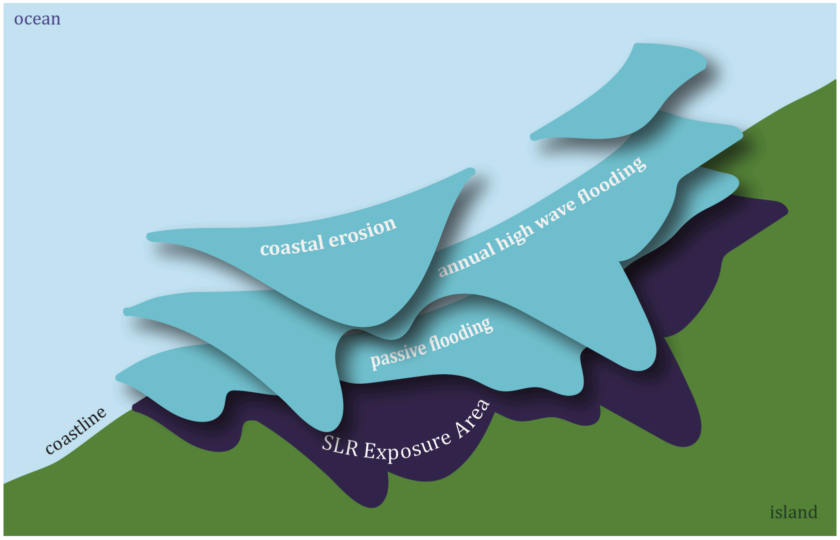


Figure 3. Schematic diagram of the SLR-XA as the combined exposure to sea level rise from passive flooding, annual high wave flooding, and coastal erosion.

Assumptions and Limitations: The assumptions and limitations described below for the three chronic flooding hazards apply to the SLR-XA. Not all hazards were modeled for each island due to limited historical information and geospatial data. The SLR-XA for the islands of Hawaiʻi, Molokaʻi, and Lānaʻi is based on modeling passive flooding only. Additional studies would be needed to add the annual high wave flooding and coastal erosion to the SLR-XA for those islands.

The SLR-XA is an overlay of three hazards and does not account for interactive nature of these hazards as would be expected by natural processes. As with the individual exposure models, the SLR-XA maps hazard exposure on the present landscape. The modeling does not account for future (unknown) land use changes, including any adaptation measures. The SLR-XA also does not include impacts from less frequent high wave events (e.g., a 1-in-10 year event), storm surge, or tsunami. In addition, mapping errors may be found in some areas due to clipping (subsetting) of the original map layers using a shoreline (Special Management Area) boundary and possible modeling errors in the Annual High Wave Flooding model at reef and harbor channels (Figure 4). See descriptions of the individual Sea Level Rise Exposure models below for more information.

Figure 4. Mapping errors may exist in some areas due to clipping (subsetting) at the shoreline and errors from the Annual High Wave Flooding model at reef and harbor channels (example from Kaka'ako, O'ahu).

Data access: Shapefile, ArcGIS REST (layer: "SLR Exposure Area – 3.2 Ft. Scenario"), WMS (layer: "26"), WFS, metadata

Sea level rise: 3.2 ft

SUGGESTED DATA CITATION: Tetra Tech, Inc. and University of Hawai'i Coastal Geology Group. 2017. *Sea Level Rise – Exposure Area*. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

RELATED PUBLICATIONS: Hawai'i Sea Level Rise Vulnerability and Adaptation Report; Anderson et al. 2018.

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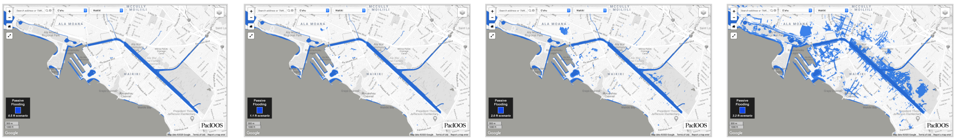
a. Passive Flooding



Data source: University of Hawai'i Coastal Geology Group. Adapted for display and vulnerability assessment by Tetra Tech, Inc.

Passive flooding was modeled by the Coastal Geology Group at UH SOEST using a modified "bathtub" approach following methods described in Anderson et al. 2018. The passive flooding model 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). Data used in modeling passive flooding include the GMSL rise projections discussed above in Sea Level Rise Projections for Modeling, digital elevation models (DEM), and the mean higher high water (MHHW) datum from local tide gauges. DEMs used in this study are freely available from NOAA and the U.S. Army Corps of Engineers (USACE). DEMs are derived from aerial light detection and ranging (LiDAR) data. The horizontal and vertical positional accuracies of the DEMs conform to flood hazard mapping standards of the Federal Emergency Management Agency (FEMA 2012). The IPCC AR5 RCP8.5 sea level rise scenario was used in modeling exposure to passive flooding from sea level rise at 0.5, 1.1, 2.0, and 3.2 feet.

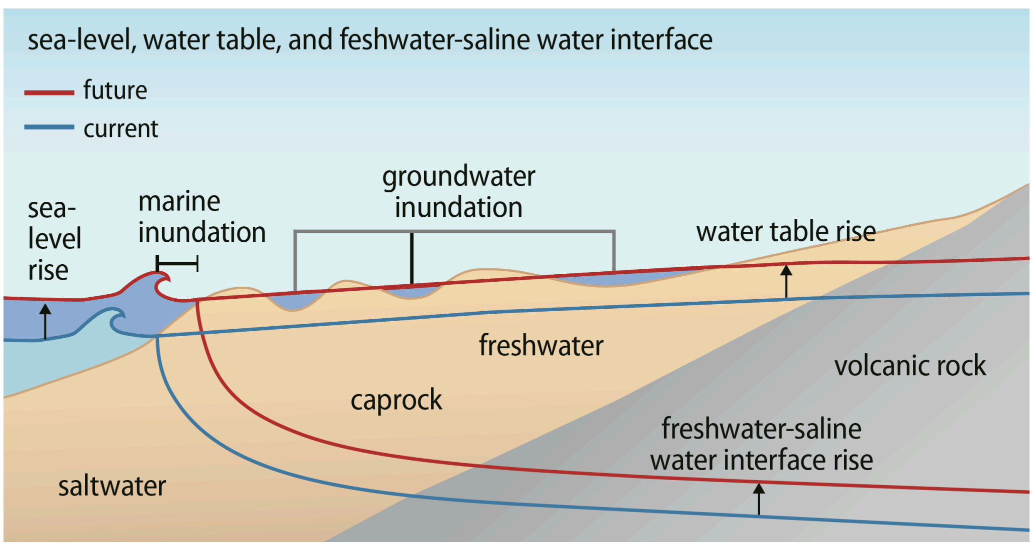


Figure 5. Schematic diagram showing passive marine and groundwater flooding from current sea level (blue) to future sea level (red) (adapted from Rotzoll and Fletcher 2012).

Passive flooding was modeled using the DEMs in geographic information systems software to identify areas below a certain sea level height (flooded by sea level rise) when raising water levels above current Mean Higher High Water (MHHW) tidal datum. In other words, water levels are shown as they would appear during MHHW, or the average higher high water height of each tidal day. The area flooded was derived by subtracting a tidal surface model from the DEM.

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

The passive flooding model does not explicitly include flooding through storm drain systems and other underground infrastructure, which would contribute to flooding in many low-lying areas identified in the model. The DEMs used in the modeling depict a smoothed topographic surface and do not identify basements, parking garages, and other development below ground that would be affected by marine and groundwater flooding with sea level rise. More detailed hydrologic and engineering modeling may be necessary to fully assess passive marine flooding hazards at the scale of individual properties. Mapping errors may be found in some areas due to clipping (subsetting) of the original map layers using a shoreline (Special Management Area) boundary (see Figure 4, above).

Data access: Shapefile, ArcGIS REST (layer: "SLR Passive Flooding – 3.2 Ft. Scenario"), WMS (layer: "22"), WFS, metadata

Sea level rise: 3.2 ft

SUGGESTED DATA CITATION: University of Hawai'i Coastal Geology Group and Tetra Tech, Inc. 2017. *Sea Level Rise – Passive Flooding*. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

RELATED PUBLICATIONS: Hawai'i Sea Level Rise Vulnerability and Adaptation Report; Anderson et al. 2018.

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b. Annual High Wave Flooding




Data source: University of Hawaiʻi Coastal Geology Group. Adapted for display and vulnerability assessment by Tetra Tech, Inc.

Hawai'i is exposed to large waves annually on all open coasts due to our location in the Central North Pacific Ocean. The distance over which waves run-up and wash across the shoreline will increase with sea level rise. As water levels increase, less wave energy will be dissipated through breaking on nearshore reefs and waves will arrive at a higher elevation at the shoreline.

Computer model simulations of future annual high wave flooding were conducted by the Coastal Geology Group at UH SOEST using methods described in Anderson et al. 2018. The model propagates the maximum annually recurring wave, calculated from offshore wave buoy data, over the reef and to the shore along one-dimensional (1D) cross-shore profiles extracted from a 1-meter DEM. Profiles are spaced 20 meters apart along the coast. This approach was used to model the transformation of the wave as it breaks across the reef and includes shallow water wave processes such as wave set-up and overtopping. The RCP8.5 scenario was used to model exposure to sea level rise of 0.5, 1.1, 2.0, and 3.2 feet.

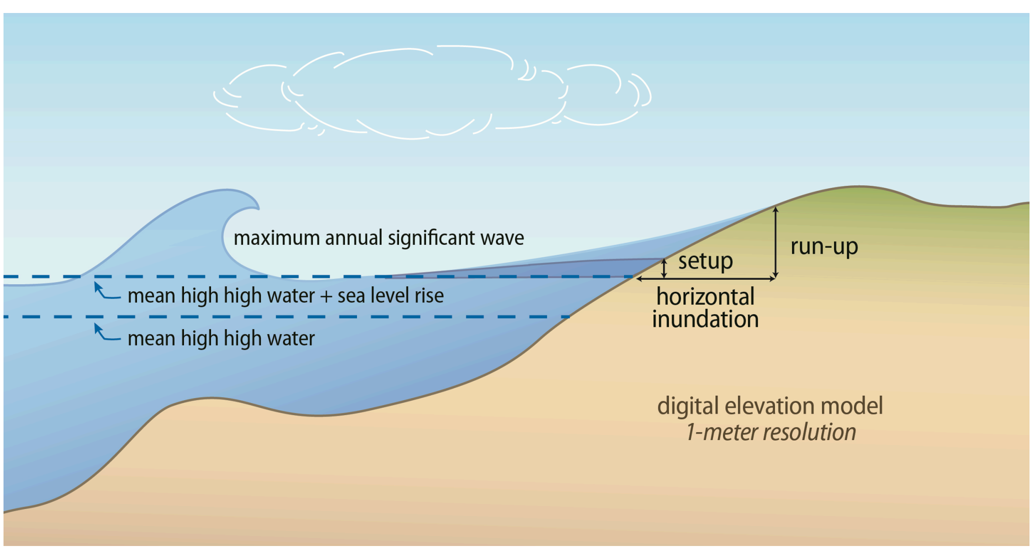

Figure 6. Schematic diagram showing key inputs and outputs of modeling annual high wave flooding.

Historical data used to model annual high wave flooding include hourly measurements of significant wave height, peak wave period, and peak wave direction, and was acquired from offshore wave buoy data from PacIOOS. Maximum surface elevation and depth of the annual high wave flooding is calculated from the mean of the five highest modeled water elevations at each model location along each profile. Output from the simulations is interpolated between transects and compiled in a 5-meter map grid. Depth grid cells with values less than 10 centimeters are not included in the impact assessment. This was done to remove very thin layers of water excursions that (1) are beyond the accuracy of the model and (2) might not constitute a significant impact to land and resources when only occurring once annually. Any low-lying flooded areas that are not connected to the ocean are also removed.

Assumptions and Limitations: Annual high wave flood modeling covered wave-exposed coasts with low-lying development on Maui, Oʻahu, and Kauaʻi. Annual high wave flooding was not available for the islands of Hawaiʻi, Molokaʻi, and Lānaʻi, nor for some harbors or other back-bay areas throughout all the islands. Additional studies would be needed to add the annual high wave flooding for those areas. The maximum annually recurring wave parameters (significant wave height, period, direction) were statistically determined using historical wave climate records and do not include potential changes in future wave climate, the effects of storm surge, or less-frequent high wave events (e.g., a 1-in-10 year wave event). In some locations, the extent of flooding modeled was limited by the extent of the 1-meter DEM.

Changes in shoreline location due to coastal erosion are not included in this modeling. As shorelines retreat, annual high wave flooding will reach farther inland along retreating shorelines. Waves are propagated along a "bare earth" DEM which is void of shoreline structures, buildings, and vegetation, and waves are assumed to flow over an impermeable surface. The DEM represents a land surface at one particular time, and may not be representative of the beach shape during the season of most severe wave impact, particularly for highly variable north and west-exposed beaches.

Undesirable artifacts of 1D modeling include over-predicted flooding along some transects with deep, shore-perpendicular indentations in the sea bottom such as nearshore reef channels (see Figure 4, above). The 1D modeling does not account for the presence of nearby shallow reef which refracts and dissipates some of the wave energy traveling through the channel toward the shore. Wave flooding modeling may be improved in future efforts by employing more complex and data-intensive 2D modeling and through local field experiments. In addition, mapping errors may be found in some areas due to clipping (subsetting) of the original map layers using a shoreline (Special Management Area) boundary (see Figure 4, above).

Data access: Shapefile, ArcGIS REST (layer: "SLR Annual High Wave Flooding – 3.2 Ft. Scenario"), WMS (layer: "18"), WFS, metadata

Sea level rise: 3.2 ft

SUGGESTED DATA CITATION: University of Hawai'i Coastal Geology Group and Tetra Tech, Inc. 2017. *Sea Level Rise – Annual High Wave Flooding*. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

RELATED PUBLICATIONS: Hawai'i Sea Level Rise Vulnerability and Adaptation Report; Anderson et al. 2018.

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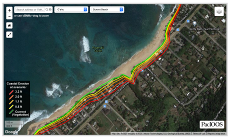
c. Coastal Erosion



Data source: University of Hawaiʻi Coastal Geology Group

2020 Data Update: The coastal exposure map data in the Viewer were updated in 2020 by the University of Hawaiʻi Coastal Geology Group. Details on that update are provided below, following *Assumptions and Limitations*.

Studies of historical shoreline change using aerial photographs and survey maps show that 70% of beaches on Kauaʻi, Oʻahu, and Maui are eroding (receding landward) (Fletcher et al. 2012). Beaches exist in a delicate balance between existing water levels, wave energy, and sand supply.

Coastal erosion modeling was conducted for sandy shorelines of Kauaʻi, Oʻahu, and Maui by the Coastal Geology Group at UH SOEST. The methods are described in Anderson et al. 2018 and combine historical shoreline change data with a model of beach profile response to sea level rise in order to estimate probabilities of future exposure to erosion at transects (shore-perpendicular measurement locations) spaced approximately 20 meters apart along the shoreline. The model accounts for localized alongshore variability in shoreline change by incorporating trends from the historical erosion mapping studies. The modeling is shown schematically in the following figure.

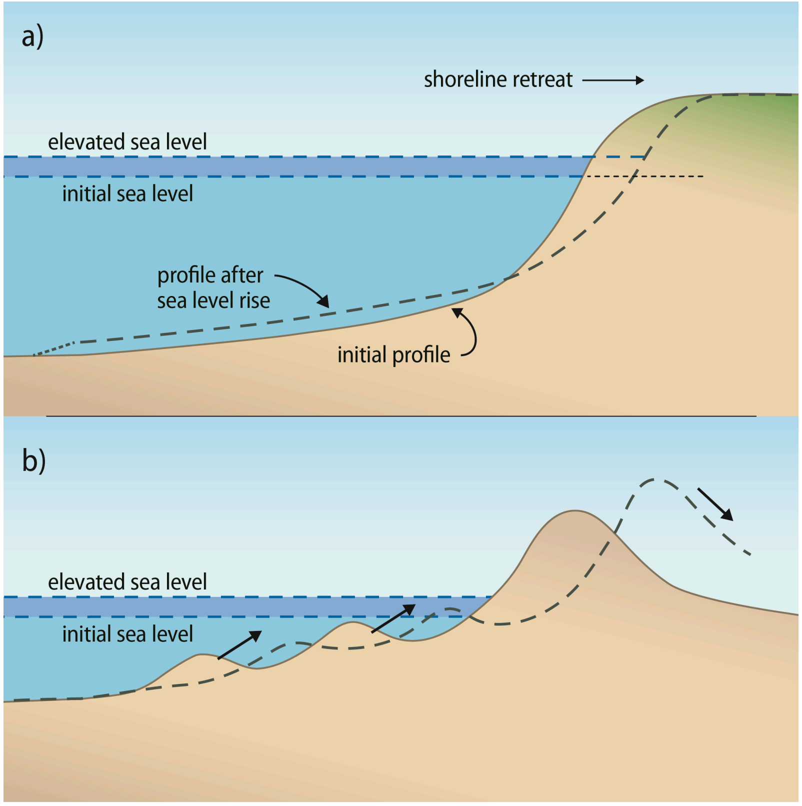


Figure 7. Schematic diagram showing key inputs and outputs of modeling coastal erosion (top) and the change in shoreline profiles with sea level rise (bottom).

Historical data used to model coastal erosion consisted of: (1) historical shoreline positions and erosion rates measured from high-resolution (0.5 meters) ortho-rectified aerial photographs and NOAA topographic charts dating back to the early 1900s (Fletcher et al. 2012, Romine et al. 2013), and (2) beach profile field survey data (Gibbs et al. 2001, Fletcher et al. 2012). The vegetation line was identified in the most recent aerial photography dating from 2006 to 2008.

The output of the modeling is the estimated exposure zone to future erosion hazards. Based on the model and IPCC RCP8.5 sea level rise scenario, there is an 80% probability that land impacted by erosion would be confined within the exposure zone at that particular time. The exposure zones extend landward from the current-day shoreline (vegetation line) up to the 80% cumulative probability contour for each of the four sea level rise scenarios, which incorporates the uncertainty (upper and lower bounds) of the IPCC RCP8.5 sea level rise projection.

Assumptions and Limitations: Historical shoreline change data and beach profiles needed to model coastal erosion are available only for sandy shores of Kauaʻi, Oʻahu, and Maui. Exposure was not modeled for less-erodible rocky coasts and bluffs, though the latter can be prone to sudden failure in some areas. In addition, modeling did not account for:

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

*Where a beach was lost to erosion fronting coastal armoring, historical shoreline change rates used in the coastal erosion model were calculated using historical shoreline positions up to and including the first shoreline indicating no beach.

2023 Data Update: Prior versions of the erosion hazard polylines were transformed (reprojected) incorrectly into the NAD83 (HARN) datum. This represents a minor, sub-version release: no modeling was performed to provide or change future hazard zone or line positions or extents. Please see the layer metadata for more information.

2020 Data Update: The coastal erosion exposure map data in the Viewer were updated in 2020 by the University of Hawaiʻi Coastal Geology Group following the methods described above for the 2017 Report and in Anderson et al. 2018. For the update, historical shoreline change rates were recalculated for Kauaʻi, Oʻahu, and Maui with the addition of a new historical shoreline position (ca. 2014-2018, depending on location) to the database of previously existing historical shoreline positions. The erosion models were then recalculated using the updated historical change rates following the methods described above.

The combined SLR-XA from the 2017 Report was not updated with the updated 2020 erosion models. As a result, users may notice some mismatch between the coastal erosion projections and the SLR-XA in areas where the landward extent of the SLR-XA is defined by the coastal erosion hazard line. The addition of the new shoreline generally has a more pronounced influence on study areas with high seasonal or inter-annual variability in shoreline position. The coastal erosion exposure model is depicted as lines in the Viewer. The data are also available for download as polygons (exposure areas) below. In addition to changes in the landward extent of the erosion exposure areas, the seaward edge of updated erosion exposure polygons does not match up with the SLR-XA or the previous (2017) erosion exposure polygons. This is because the seaward edge of the 2017 data is defined by a Special Management Area shoreline boundary, whereas the seaward edge of the updated 2020 data is defined by the location of a vegetation line.

Data access: polylines: Shapefile, ArcGIS REST (layer: "SLR Coastal Erosion (Line) – 3.2 Ft. Scenario"), WMS (layer: "14"), WFS, metadata

Data access: polygons: Shapefile, ArcGIS REST (layer: "SLR Coastal Erosion – 3.2 Ft. Scenario"), WMS (layer: "10"), WFS, metadata

Sea level rise: 3.2 ft

Vegetation line: Shapefile, ArcGIS REST (layer: "SLR – Vegetation Line (2005-2008)"), WMS (layer: "30"), WFS, metadata

SUGGESTED DATA CITATIONS: University of Hawaiʻi Coastal Geology Group. 2020, updated 2023. *Sea Level Rise – Coastal Erosion*. Version 2.1. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date]; University of Hawaiʻi Coastal Geology Group. 2017. Sea Level Rise – Vegetation Line. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

RELATED PUBLICATIONS: Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report; Anderson et al. 2018.

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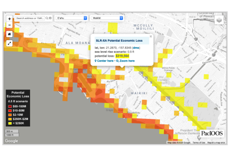
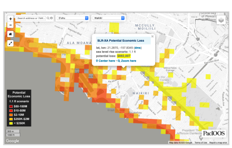
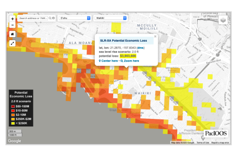
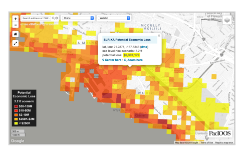
Vulnerability

Potential Economic Loss

Data source: Tetra Tech, Inc.

Vulnerability was assessed for the main Hawaiian Islands using the outputs of the coastal hazard exposure modeling. Potential economic loss was based on the value of the land and structures from the county tax parcel database permanently lost in the SLR-XA for each projected sea level rise height.

Potential economic loss was analyzed individually for each hazard (passive flooding, annual high wave flooding, or coastal erosion) at the parcel level and subsequently aggregated in 1-hectare (100 square meter or 1,076 square foot) grids. For the islands of Hawaiʻi, Lānaʻi, and Molokaʻi, the potential economic loss was based solely on passive flooding. Potential economic loss in the SLR-XA area was determined from the highest loss value of any one hazard within the 1-hectare grid, thus avoiding double counting a loss of a particular asset from multiple hazards. Those maximum values for each sector are then summed to determine the total economic loss to property in each grid.

Assumptions and Limitations: The vulnerability assessment addressed exposure to chronic flooding with sea level rise. Key assumptions of the economic analysis for the SLR-XA included: (a) loss is permanent; (b) economic loss is based on the value in U.S. dollars in 2016 as property values in the future are unknown; (c) economic loss is based on the value of the land and structures exposed to flooding in the SLR-XA excluding the contents of the property and does not include the economic loss or cost to replace roads, water conveyance systems and other critical infrastructure; and (d) no adaptation measures are put in place that could reduce impacts in the SLR-XA.

Economic value data were not available for length of roads, water and wastewater lines, and other public infrastructure due to the variable cost of such infrastructure depending on location, and the complexity and uncertainty involved in design, siting, and construction. Additionally, environmental assets such as beaches and wetlands were not assessed economically due to the complexity in valuing ecosystem services. The loss of both public infrastructure and environmental assets from flooding would result in significant economic loss. Therefore, the total potential economic loss figures estimated in the Report and Viewer are likely an underestimate.

Data access: Shapefile, ArcGIS REST (layer: "SLR Potential Economic Loss – 3.2 Ft. Scenario"), WMS (layer: "6"), WFS, metadata

Sea level rise: 3.2 ft

SUGGESTED DATA CITATION: Tetra Tech, Inc. 2017. *Sea Level Rise – Potential Economic Loss*. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

RELATED PUBLICATION: Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report.

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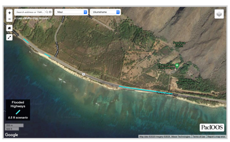
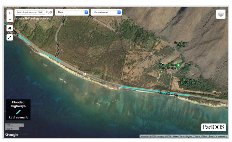
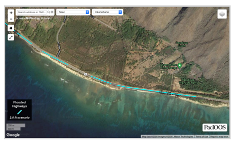
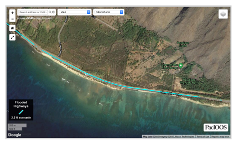
Flooded Highways

Data source: Tetra Tech, Inc.

Potential impacts to roads were assessed in terms of exposure to chronic flooding in the SLR-XA, but were not monetized. The SLR-XA is overlaid with these assets to determine locations impacted by chronic flooding with sea level rise.

Data access: Shapefile, ArcGIS REST (layer: "SLR Potential Flooded Highways – 3.2 Ft. Scenario"), WMS (layer: "2"), WFS, metadata

Sea level rise: 3.2 ft

SUGGESTED DATA CITATION: Tetra Tech, Inc. 2017. *Sea Level Rise – Flooded Highways*. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

RELATED PUBLICATION: Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report.

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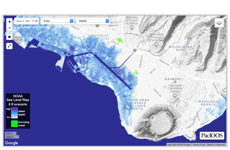
Other Overlays

Passive Flooding 6 ft (NOAA)



Data source: National Oceanic and Atmospheric Administration (NOAA)

Passive flooding with 6 feet of sea level rise from the NOAA Sea Level Rise Viewer is provided to support assessment of sea level rise hazards, particularly for critical infrastructure and for other development with low tolerance for risk.

Areas that are hydrologically connected to the ocean are shown in shades of blue (darker blue = greater depth). Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may also flood.

The methods, assumptions, and limitations are essentially the same as those described above in Passive Flooding. A sea level rise projection of 6 feet above a local mean higher high water (MHHW) datum is used in modeling. In many areas around the State, representing sea level rise from passive marine flooding will likely produce an underestimate of the area inundated or permanently submerged because the model does not account for waves and coastal erosion, important processes along Hawaiʻi's highly dynamic coasts. Please see the NOAA Sea Level Rise Viewer for more detailed information.

Data access: File Geodatabases, ArcGIS REST, WMTS

SUGGESTED DATA CITATION: NOAA Office for Coastal Management. *Sea Level Rise Viewer*. https://coast.noaa.gov/slr/. Accessed [date].

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Community Plan Areas

Data source: Hawaiʻi Office of Planning Statewide GIS Data Program

Community planning district boundaries for the islands of Kauaʻi, Oʻahu, Maui, Molokaʻi, Lānaʻi, Kahoʻolawe, and Hawaiʻi Island are provided by the State of Hawaiʻi Office of Planning. Community plans are required by the county charters and adopted by ordinance through the county councils and must be updated at regular intervals. The plans, developed through the planning departments of each county, are intended to provide vision, guidelines, and implementing policies for each area. Community plans can provide an important existing framework for addressing sea level rise vulnerability because the plans provide recommendations concerning land use, density and design, transportation, community facilities, infrastructure, visitor accommodations, commercial and residential areas and other matters related to development that are specific to the region of the plan.

Data access: Shapefile, ArcGIS REST (layer: "Development Plan Areas"), WMS (layer: "15"), WFS, metadata

SUGGESTED DATA CITATION: Hawaiʻi Statewide GIS Program. *Development Plans*. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

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Moku Boundaries

Data source: Office of Hawaiian Affairs and Hawaiʻi Office of Planning Statewide GIS Data Program

Historic land divisions. Each island, or mokupuni, is divided into large districts, or moku. These are then further divided into ahupuaʻa (see below). Created by the Office of Hawaiian Affairs. Although not survey grade, and not checked for legal validity, the boundaries correspond to 19th-century survey maps. The orthography of each name was researched, including spelling and diacritical marks. Traditional moku boundaries extended into the ocean. However, this seaward extension is not depicted by this layer.

Data access: Shapefile, ArcGIS REST (layer: “Moku”), WMS (layer: “2”), WFS, metadata

SUGGESTED DATA CITATION: Office of Hawaiian Affairs and Hawai‘i Statewide GIS Program. *Moku Boundaries (Historic Land Divisions).* https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

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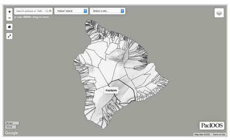
Ahupua‘a Boundaries



Data source: Office of Hawaiian Affairs and Hawai‘i Office of Planning Statewide GIS Data Program

Historic land divisions. Each island, or mokupuni, is divided into large districts, or moku (see above). These are then further divided into ahupua‘a, usually extending from the uplands to the sea. Created by the Office of Hawaiian Affairs. Although not survey grade, and not checked for legal validity, the boundaries correspond to 19th-century survey maps. The orthography of each name was researched, including spelling and diacritical marks. Traditional ahupua‘a boundaries extended into the ocean. However, this seaward extension is not depicted by this layer.

Data access: Shapefile, ArcGIS REST (layer: “Ahupuaa”), WMS (layer: “1”), WFS, metadata

SUGGESTED DATA CITATION: Office of Hawaiian Affairs and Hawai‘i Statewide GIS Program. *Ahupua‘a Boundaries (Historic Land Divisions).* https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

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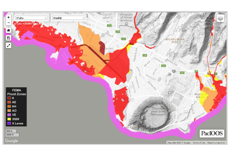
Flood Hazard Zones



Data source: Federal Emergency Management Agency (FEMA) and Hawai‘i Office of Planning Statewide GIS Data Program

Flood hazard zones for the State of Hawai‘i are established by the U.S. Federal Emergency Management Agency (FEMA) through the Flood Insurance Rate Maps (DFIRM). Areas that fall within the 100-year flood boundary (a.k.a. base flood or floodplain) are called Special Flood Hazard Areas (SFHA) and are divided into insurance risk zones A, AE, AH, AO, or VE. The term 100-year flood indicates that the area has a 1% chance of flooding in any given year. Zones X500 and X Levee are Non-Special Flood Hazard Areas (NSFHA) and have moderate-to-low flood risk. The FIRMS are used by the National Flood Insurance Program (NFIP) for floodplain management, mitigation, and insurance purposes. The FIRMs are based on hydraulic modeling of present day flood risk and do not include future increases in flood hazards with sea level rise. See also: State of Hawai‘i, Department of Land and Natural Resources (DLNR), Flood Hazard Assessment Tool (FHAT).

Data access: Shapefile, ArcGIS REST (layer: “State DFIRM”), WMS (layer: “2”), WFS, metadata

SUGGESTED DATA CITATION: Federal Emergency Management Agency and Hawai‘i Statewide GIS Program. *Flood Hazard Zones.* https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

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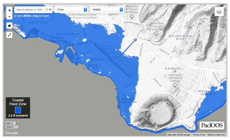
Coastal Flood Hazard Zone with Sea Level Rise



Data source: Tetra Tech, Inc. and Sobis, Inc.

The State of Hawaiʻi 2018 Hazard Mitigation Plan (HMP) incorporated the results of modeling and an assessment of vulnerability to coastal flooding from storm-induced wave events with sea level rise (Tetra Tech Inc., 2018). The 1%-annual-chance coastal flood zone with 3.2 feet of sea level rise (1%CFZ-3.2) was modeled to estimate coastal flood extents for wave-generating events including tropical storms, hurricanes, tsunamis, and other severe wave events with sea level rise.

Modeling was conducted by Sobis, Inc. under State of Hawaiʻi Department of Land and Natural Resources (DLNR) Contract No. 64064. The 1%CFZ-3.2 was utilized in the HMP to assess vulnerability to coastal event-based flooding in mid-to-late century.

The 1%CFZ-3.2 depicts estimates of future coastal flood zones for comparison to present-day National Flood Insurance Program (NFIP) flood insurance rate maps (FIRMs) Special Flood Hazard Areas (SFHA) coastal "V" and "A" Flood Zones, which do not include sea level rise. This modeling can highlight areas of greater risk of being damaged by storm surge and inform land use planning and the development of hazard mitigation projects to address event-based coastal flooding that would have less frequent but more extensive flooding impacts than depicted by the SLR-XA.

A simplified version of the Wave Height Analysis for Flood Insurance Studies (WHAFIS) extension included in FEMA Hazus-MH system software, was used to create the 1%-annual-chance coastal floodplain. Hazus is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, tsunamis, and hurricanes. A schematic of key inputs and outputs of modeling the 1%CFZ-3.2 is shown in Figure 8.

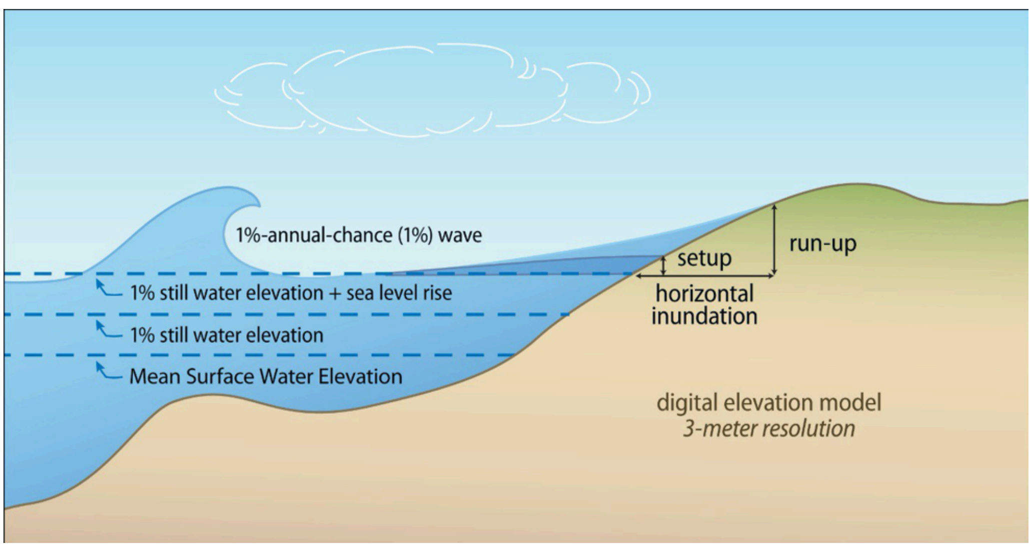


Figure 8. Schematic diagram showing key inputs and outputs of modeling the 1%-annual-chance coastal flood zone.

Assumptions and Limitations: Historical records of severe wave events used to model the 1%CFZ-3.2 do not consider potential changes in tropical cyclone or wave activity related to climate change. Also, riverine (rainfall) flooding is not included in the modeling. Historical data used to model the 1%CFZ-3.2 were based on the current Flood Insurance Study (FIS) for each island conducted by the FEMA NFIP. The FISs use historic severe wave events from hurricanes, tsunamis, and other significant events to develop the FIRMs.

The 1%CFZ-3.2 is modeled as a static rise of the base flood elevation using a fixed shoreline. As such, it does not consider potential changes in the location of the shoreline resulting from coastal erosion or chronic flooding as depicted in the SLR-XA.

Data access: Shapefile, ArcGIS REST (layer: "1% Coastal Flood Zone with 3.2 ft Sea Level Rise"), WMS (layer: "14"), WFS, metadata

SUGGESTED DATA CITATION: Tetra Tech, Inc. and Sobis, Inc. 2020. *Coastal Flood Zones with Sea Level Rise of 3.2 Feet.* https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

RELATED PUBLICATION: State of Hawaiʻi 2018 Hazard Mitigation Plan.

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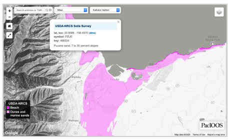
Beaches and Sand (USDA)



Data source: U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and Hawaiʻi Office of Planning Statewide GIS Data Program

The beaches and sand map layer serves as a useful guide to 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. This layer is adapted from the Gridded USDA-NRCS Soil Survey Geographic (gSSURGO) database. For the purposes of the Viewer, we have highlighted beaches and sand, including dunes and other areas with sandy substrates. These areas may be more susceptible to coastal erosion. However, it should be noted that beach environments may be sustained if they are allowed to migrate landward and erode into upland deposits of beach and dune sand, releasing this sediment into the littoral system. The Beaches and Sand layer identifies surficial deposits only. It should be used as an initial screening tool and may require verification at the site level.

Data access: Shapefile, ArcGIS REST (layer: "Soils (Areas) – NRCS"), WMS (layer: "4"), WFS, metadata

SUGGESTED DATA CITATION: U.S. Department of Agriculture, Natural Resources Conservation Service. 2016. *Gridded Soil Survey Geographic (gSSURGO) Database*. https://geoportal.hawaii.gov/datasets/soils-mu-state-of-hawaii. Accessed [date].

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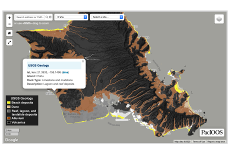
Geology (USGS)



Data source: U.S. Geological Survey Geologic Map of the State of Hawaiʻi (Sherrod, et al. 2007)

The geology map layer serves as a useful guide to 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. For the purposes of the Viewer, we have categorized the geology into beach and dune deposits, marine and lagoon deposits, alluvium deposits, and volcanic deposits. Volcanic and marine limestone deposits may be more resistant to coastal erosion. In contrast, deposits of sand and alluvium may be more susceptible to coastal erosion. However, it should be noted that beach environments may be sustained if they are allowed to migrate landward and erode into upland deposits of beach and dune sand, releasing this sediment into the littoral system. The Geology layer identifies surficial deposits only. It should be used as an initial screening tool and may require verification at the site level.

Data access: Shapefile, GeoJSON, WMS, WFS, KML, metadata

SUGGESTED CITATION: Sherrod, David R., Sinton, John M., Watkins, Sarah E., and Brunt, Kelly M. 2007. *Geologic map of the State of Hawaiʻi: U.S. Geological Survey Open-File Report 2007-1089*. http://pubs.usgs.gov/of/2007/1089/. Accessed [date].

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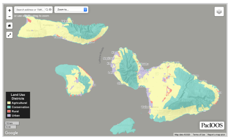
State Land Use Districts



Data source: Hawai'i Office of Planning Statewide GIS Data Program

Pursuant to Hawai'i Revised Statutes §205, all lands in the State of Hawai'i are classified and placed into four land use districts: Urban, Rural, Agricultural, and Conservation. This land use district map layer serves as a useful guide in determining potential impacts of sea level rise to the various land use classifications within a community. The boundaries depicted here are not official and for presentation purposes only. A determination of the official State Land Use District Boundaries should be obtained directly through the State Land Use Commission (LUC).

Data access: Shapefile, ArcGIS REST (layer: "State Land Use Districts"), WMS (layer: "25"), WFS, metadata

SUGGESTED DATA CITATION: State of Hawai'i Land Use Commission and Hawai'i Statewide GIS Program. *State Land Use Districts*. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

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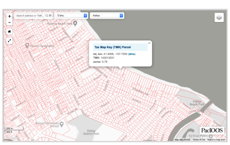
TMK Parcels



Data source: Hawai'i Office of Planning Statewide GIS Data Program

Tax Map Key (TMK) parcel boundaries for the State of Hawai'i. Misalignment between the TMK parcel boundaries and basemap layers may be visible in some areas. Parcel boundaries from the Hawai'i Office of Planning Statewide GIS Data Program were not derived from metes and bounds and are not survey grade data. Users may utilize the satellite imagery basemap along with the TMK parcels to determine if a property is exposed to sea rise hazards. All property lots in Hawai'i are defined by a 9-digit TMK number using the following format, without any special characters (e.g., 392118043):

C-Z-S-PPP-ppp

- ***C*** = county number (1 digit)
- ***Z*** = zone number (1 digit)
- ***S*** = section number (1 digit)
- ***PPP*** = plat number (3 digits)
- ***ppp*** = parcel number (3 digits)

County numbers include the following:

- 1 = City and County of Honolulu
- 2 = Maui County
- 3 = Hawai'i County
- 4 = Kaua'i County

Data access: Shapefile, ArcGIS REST (layer: "Statewide TMKs"), WMS (layer: "1"), WFS, metadata

SUGGESTED DATA CITATION: Hawaiʻi Statewide GIS Program. *TMK Parcels*. https://planning.hawaii.gov/gis/download-gis-data-expanded/. Accessed [date].

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Version: 1.15
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