Technical Memorandum
Hoaloha Park Adaptation Plan

Coastal Hazard Exposure, Park Vulnerabilities, and Adaptation Pathways and Opportunities

Prepared for

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

FEMA	Federal Emergency Management Agency
DEM	digital elevation model
DLNR	State of Hawaii Department of Land and Natural Resources
DPR	Maui County Department of Parks and Recreation
DOT	State of Hawaii Department of Transportation
Integral	Integral Consulting Inc.
NDBC	National Data Buoy Center
NOAA	National Oceanic and Atmospheric Administration
RSM	Regional Sediment Management
SLR-XA	Sea Level Rise Exposure Area (Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report)
TWL	total water level
USACE	U.S. Army Corps of Engineers

1 EXECUTIVE SUMMARY

This technical memorandum presents a coastal hazards analysis and adaptation pathway for Hoaloha Park, a 5-acre urban shoreline park located in Kahului Harbor, Maui, Hawaii. Two erosion models, XBeach and FEMA/Bruun, were employed to analyze expected erosion impacts and prevalence of coastal flooding for 1.1, 2.0, and 3.2 foot Sea Level Rise scenarios. The results were then used to evaluate the park's vulnerabilities to sea level rise and associated coastal hazards, and to help identify viable adaptation strategies to enhance resilience to these hazards.

The key findings of the analysis included:

- Existing park facilities and infrastructure face minimal risk at current sea level, but significant vulnerabilities emerge with sea level rise.
- At 1.1 ft of Sea Level Rise, moderate shoreline erosion and potential encroachment of coastal hazards on existing structures may occur.
- At 2.0 ft of Sea Level Rise, severe erosion, loss of canoe storage areas, and potential structural damage to existing facilities may occur.
- At 3.2 ft of Sea Level Rise, catastrophic erosion, loss of structures, and widespread coastal flooding may occur.

Several Adaptation Strategies were identified that, if implemented, could serve to help mitigate these hazards. Such strategies include:

- Preserving and expanding existing vegetation. Vegetated dunes showed significantly higher resilience to erosion and flooding compared to non-vegetated areas.
- Raising and widening the foredune. Taller and wider dunes are more resistant to erosion and wave overtopping.
- Reducing and reorienting shoreline access pathways to minimize the impacts of foot traffic/trampling on the foredune.
- Adding barrier berms and flood walls to mitigate the potential extent of coastal flooding across the park.
- Pursuing beneficial reuse of dredged material for beach nourishment and other proposed strategies requiring fill material.
- Long-term managed retreat of park facilities

This memorandum emphasizes that holistic, collaborative approaches to coastal adaptation is essential, involving adjacent property owners and wider community, county, and state initiatives. This memorandum is meant to provide a science-based foundation and justification for phased implementation of adaptation strategies, guided by specific triggers, timelines, and community input, to enhance Hoaloha Park's long-term resilience to sea level rise and coastal hazards.

2 INTRODUCTION

The Maui County Department of Parks and Recreation (DPR) has solicited the development of an Adaptation Plan for Hoaloha Park, a 5-acre urban shoreline park located in Kahului Harbor, Maui, Hawaii, southwest of Pier 2. A recent study[1] by DPR identified Hoaloha Park as having a medium potential to withstand the impacts of sea level rise. In addition, further development and a growing population in the surrounding community threaten to contribute additional anthropogenic impacts to the park and its shoreline. Considering these factors, an adaptation plan that identifies existing cultural and community uses of the park, its vulnerabilities to climate change related hazards, and pathways to adapt to these hazards while protecting and enhancing its existing uses, is being prepared. This report provides a summary of previous research characterizing the physical processes in and around the park, and results of new coastal hazard and sea level rise modeling of the park's shoreline to identify storm wave flooding and coastal erosion exposure over time. The mapping of these hazards as shown in this report have also been shared for use in other technical reports related to this project. The hazard modeling was conducted on select cross shore transects to provide insight into existing and future risk, identify key elevations and thresholds of sea level rise where coastal hazard impacts become significant, and illustrate different approaches to nature-based adaptation options on reducing the exposure and coastal hazard risk in the future.

2.1 PURPOSE OF THIS REPORT

This report summarizes results of technical and scientific analyses of sea level rise on the existing park, presents the results of site-specific hazard modeling, identifies possible vulnerabilities, and identifies potential adaptation strategies that could be integrated into the adaptation plan to avoid, mitigate, or delay hazard exposure.

The overall approach documented in this report was to conduct site-specific coastal hazard modeling influenced by sea level rise, including modeling of coastal erosion, storm wave flooding, and tidal inundation extents over various sea level rise elevations. Integral Consulting Inc. (Integral) modeled these hazards under different storm and sea level rise elevations at a relevant spatial scale to provide insight into the timescale and severity of impacts resulting from sea level rise. The results of this modeling task mapped the extent of erosion distances and wave flooding along with wave flooding depths along five separate transects across the park, and compared the site-specific analyses with other publicly available regional coastal hazard (Federal Emergency Management Agency [FEMA]) and sea level rise mapping results (State of Hawaii Sea Level Rise Exposure Area [SLR-XA]).

[1] Tetra Tech, "Beach Parks Vulnerability and Adaptation Study", County of Maui Department of Parks and Recreation 2022.

Mapped results of the hazard analyses were then utilized in subsequent reports completed by other team members on hazards exposure, park vulnerabilities, and possible adaptation measures to avoid or mitigate hazards. The report identifies thresholds of flood elevation exposure with sea level rise, and identifies ways to plan for hazard avoidance and nature-based adaptation strategies as an alternative to hardened shoreline structures to preserve community use of the park. The approaches described can be integrated into the adaptation plan as a phased approach over time, based on active monitoring of erosion rates, escalating impacts from storm events, and other triggers that can be used to justify the implementation of individual strategies or projects.

2.2 STUDY AREA

Kahului Harbor is located on the north shore of Maui in Kahului, which is the island's most populous region. Hoaloha Park is located within the harbor, southwest of Pier 2. The park is predominantly used by Hawaiian canoe paddlers and other ocean sport participants. The shoreline along the park consists of a white carbonate sand beach with a partially vegetated foredune and is bordered by a rock groin at its southwest end (referred to by the USACE as "East Groin"[2]). The beach continues roughly 220 yards to the northeast, fronting private and Hawaii State Department of Transportation property, terminating at the concrete face of Pier 2. Three "hale" structures exist near the shoreline on the site, two with modern construction originally built in the 1990s and used primarily as clubhouses and for the storage of outrigger canoes, and one with traditional construction used primarily as a community education and gathering space. Continuing mauka from the hale structures, the site is generally flat with paved and unpaved parking areas.

[2] USACE, "O&M REPORT FOR Kahului Bay Prevention & Mitigation of Shore Damages". October 14, 2010.

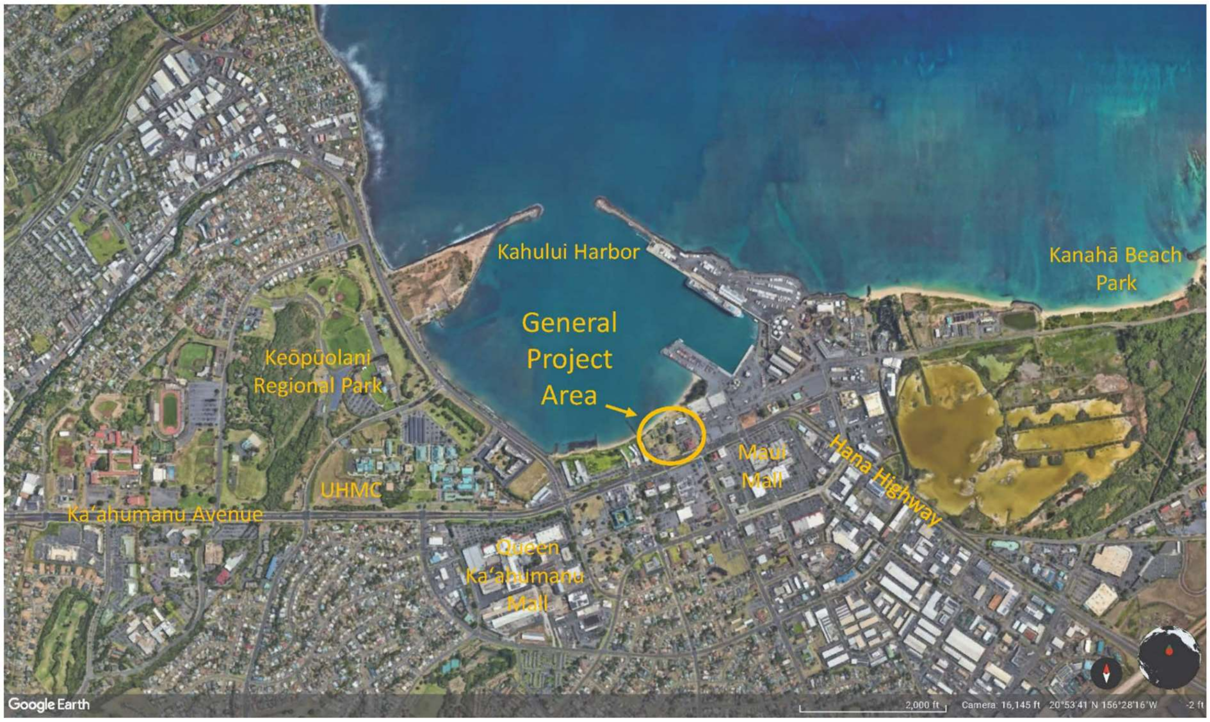

Figure 1. General site location map (SSFM[3])

2.3 SITE HISTORY AND GEOMORPHOLOGY

Kahului Harbor and its surrounding areas have a long and noteworthy history. The Kahului area historically existed as mostly dry and sandy hinterlands that hosted a Hawaiian settlement, probably of primarily fishermen, who would have used the shore of the bay to launch their fishing canoes and collect shellfish from the coastal flats. An extraordinarily fertile area existed to the northwest, which was traditionally called Na Wai ʻEha or "the four waters," after the four nearby streams.[4] Several battles between Hawaiian chiefs took place in the area, including between chief Kahekili of Maui, and chief Kalaniopuʻu of the Big Island around 1781, and between Kahekili and Kamehameha the Great around 1790. A significant feature of these battles was the landing of war canoes on the shores of the now Kahului Harbor. There is also documentation of surfing taking place on the reefs offshore of Kahului as early as the 1600s.[5]

In the late 1800s, Kahului Railroad built its first line from a starting point on the beach at Kahului, where the company's headquarters were also located, to Wailuku. In 1905, this same company began to build the original eastern breakwater on top of the eastern reef to protect

[3] SSFM International, Inc., "Hoaloha Park Adaptation Plan Work Plan", December 2023.
[4] David J. Welch at al., "Archaeological and Cultural Impact Assessment of Cultural Resources in Kahului Harbor", International Archaeological Research Institute, 2004.
[5] Tomonari-Tuggle and Welch, 1995.

the natural harbor from trade wind swell and storm swell from the north. By 1910, the original extents of the eastern breakwater were complete, the harbor had been dredged, and a wharf had been constructed near present-day Pier 2. By 1918, the east breakwater had been lengthened, a western breakwater had been constructed to impede wave energy and sediment transport into the harbor from the northwest, and the harbor had been further dredged. In 1926, the original wharf was demolished, and Pier 2 was constructed. The length of Pier 2 has remained unchanged since then but was widened by 42 ft to the southwest in 1963 and has received periodic structural maintenance.

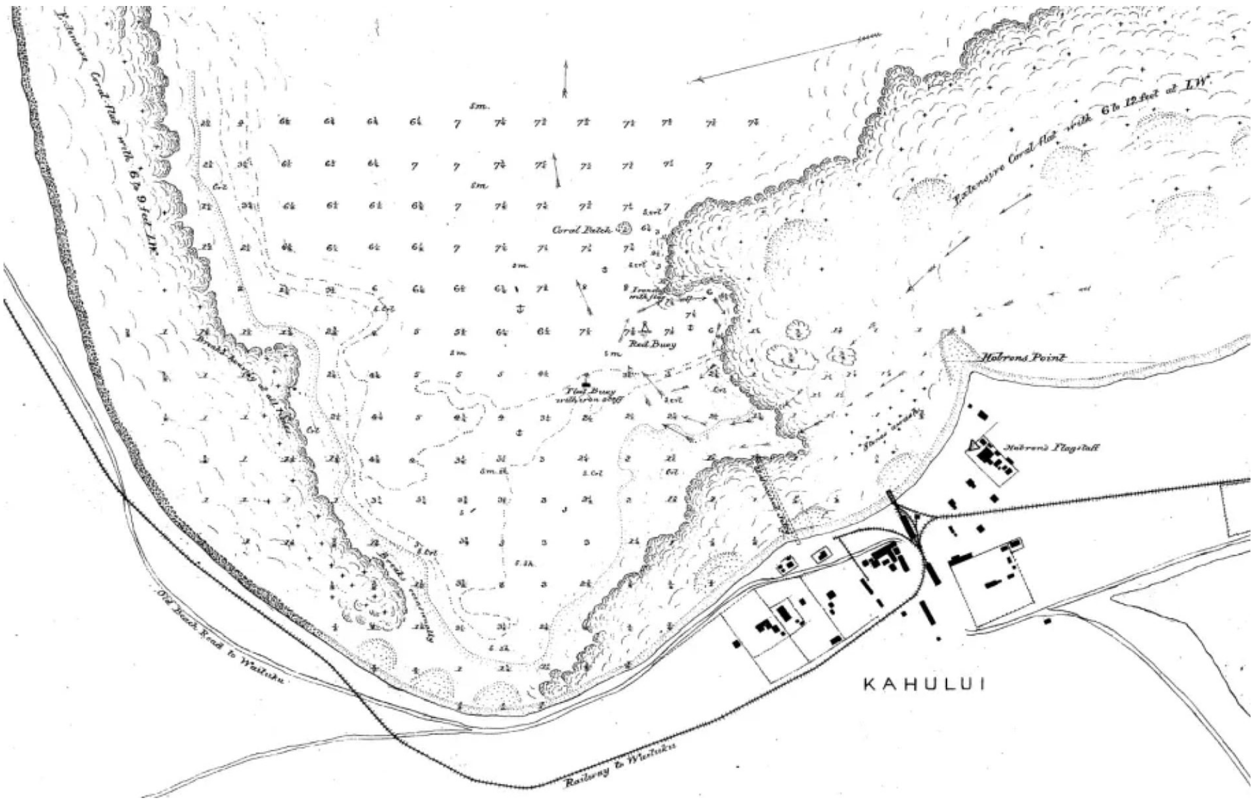

Figure 2. Hawaiian Government Survey of Kahului Harbor, September 1881.

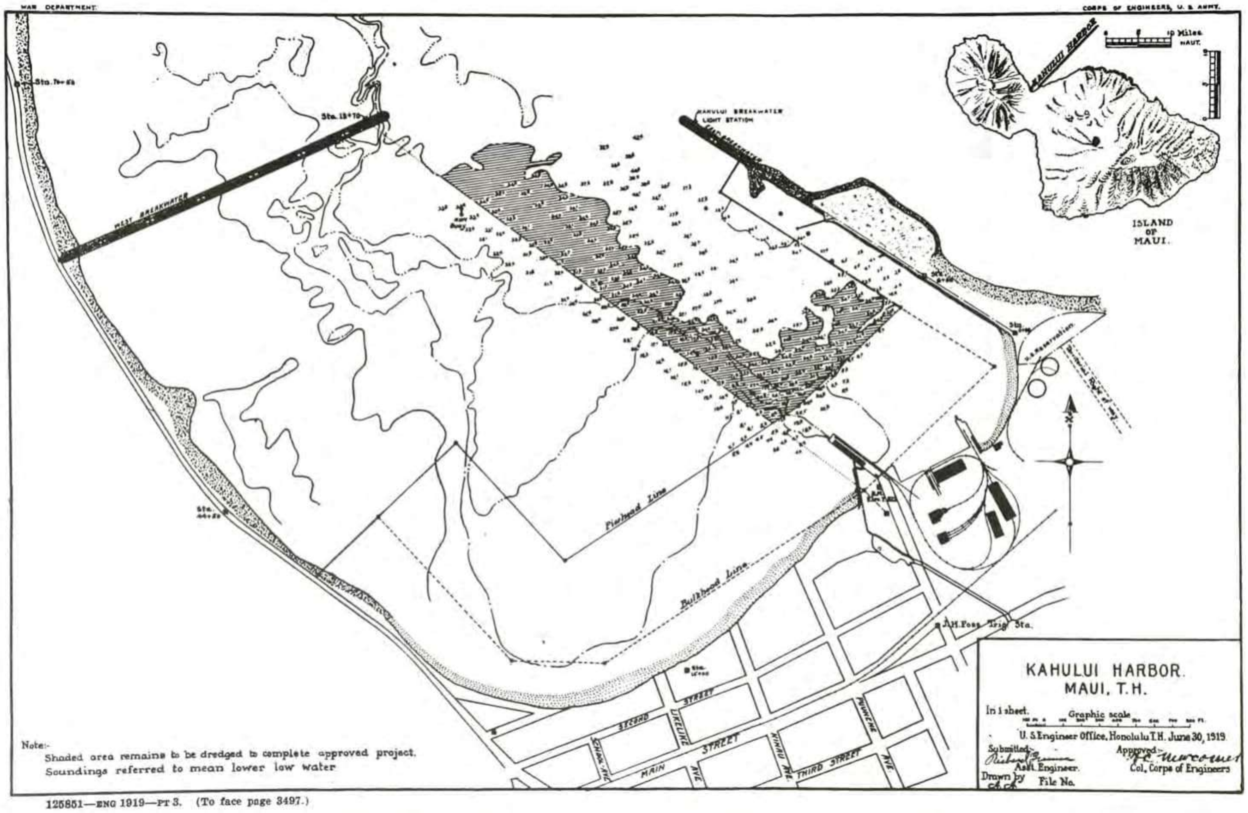

Figure 3. Kahului Harbor, 1918. The shaded area delineates the extents of dredging performed at that time. Courtesy USACE.

Figure 4. Aerial photograph of Kahului Harbor in 1925, looking east. The location of the Hoaloha Park site is in the lower right corner of the image.

In 1962, a year prior to the widening of the pier, the harbor basin was dredged to its current extents, with the dredged material placed in the west corner of the harbor adjacent to the west breakwater. The history of harbor dredging is further discussed below in section 2.9. Throughout this history of harbor construction and improvements, there have also been reports of dredged material[6] being deposited near the shoreline in the same vicinity as the current park.

Just offshore of the park is a shallow nearshore reef where board and canoe surfing sometimes occur when conditions are conducive. Additional surf spots exist within the harbor to the northwest.

[6] David J. Welch at al., "Archaeological and Cultural Impact Assessment of Cultural Resources in Kahului Harbor", International Archaeological Research Institute, 2004.

2.4 TIDES AND WATER LEVELS

The great diurnal tide range for National Oceanic and Atmospheric Administration (NOAA) tide gauge (#1615680) in Kahului Harbor, located at the end of Pier 2, is 2.25 ft, with the highest astronomical tide 2 ft above mean sea level. Currents within the harbor are influenced by tides but also by wind and waves. Observations made by "Marine Advisors for the state of Hawaii" in 1964 indicate currents primarily flow west to east along the shoreline fronting Hoaloha Park.[7] Currents observed during a rising tide along with moderate swell entering the harbor are illustrated in Figure 5.

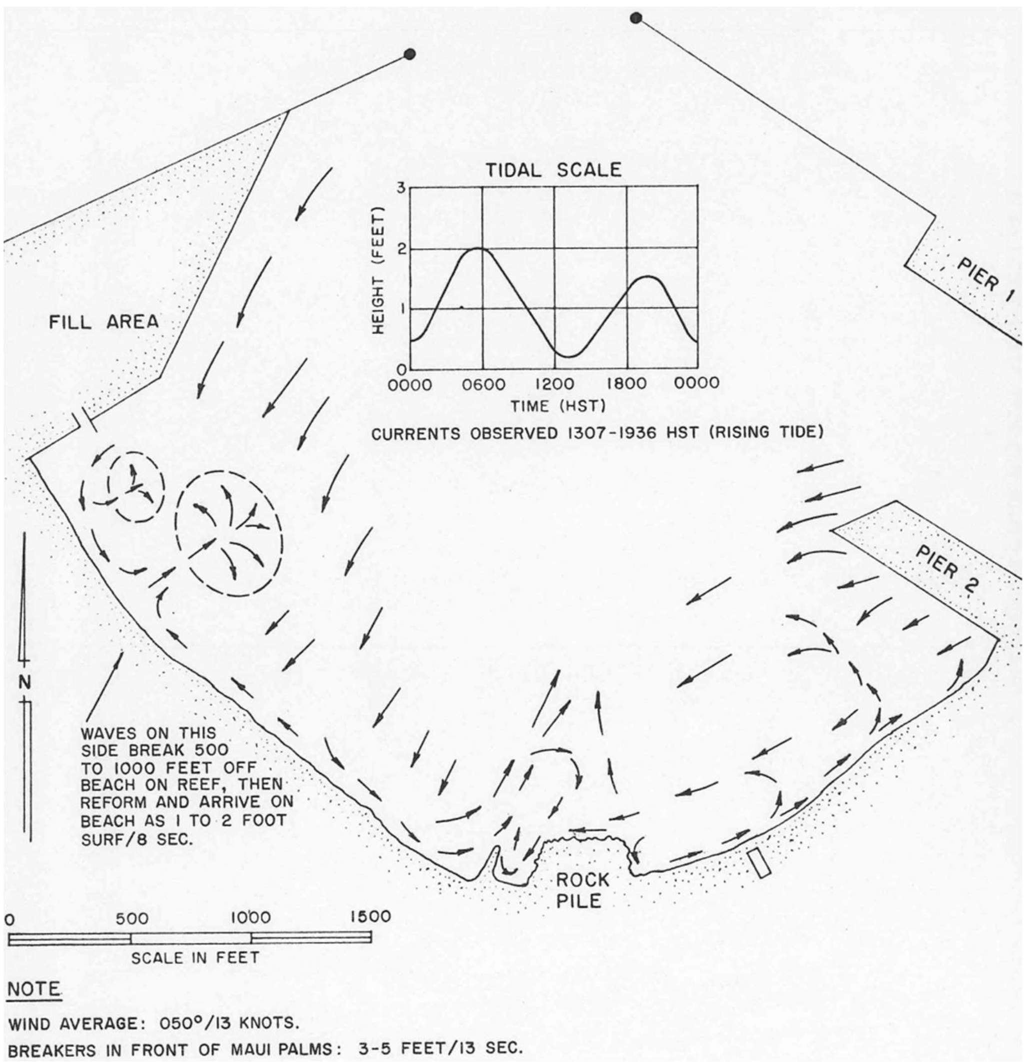

Figure 5. Observed littoral currents in Kahului Harbor on December 31, 1964, on a rising tide. Courtesy Marine Advisors for the State of Hawaii[6].

[7] U.S. Army Engineer Division, "Detailed Project Report for Prevention and Mitigation of Shore Damages, Kahului Harbor, Maui, Hawaii", 1973.

2.5 SEA LEVEL RISE, COASTAL EROSION

The NOAA tide station located in Kahului Harbor indicates that the sea level has been rising at an average rate of 2.21 mm/year since the 1940s, consistent with rising sea levels observed around the planet. Furthermore, guidance produced by the State of Hawaii Department of Land and Natural Resources (DLNR) in 2017 recommended 3.2 feet of sea level rise as a reasonable planning benchmark for the end of the century[8].

Computer model simulations of future annual high wave flooding were conducted by the Coastal Geology Group at the University of Hawaii School of Ocean and Earth Science and Technology using methods described in Anderson et al. (2018). These methods included using the non-hydrostatic XBeach model with data from offshore wave buoys, as well as a 1m bare-earth digital elevation model (DEM). To estimate future erosion hazards, a probabilistic method presented by Anderson et al. (2018), which combines the long-term historical shoreline change rates with a geometric Bruun-type model to adjust for future sea level rise (in excess of historical sea level rise trends) was used. The model results are available to the public through an online interface titled "State of Hawaii Sea Level Rise Viewer."[9] The areas that the models identified as vulnerable to flooding or erosion are considered to be within the "Sea Level Rise Exposure Area" (SLR-XA). This modeling effort suggested that consistent shoreline erosion, ultimately encroaching beyond the current position of the existing hale structures is forecasted to occur in a 2–3.2 ft sea level rise scenario. The output of the SLR-XA viewer for the 3.2 ft scenario at Hoaloha Park is presented in Figure 6.

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

[9] https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

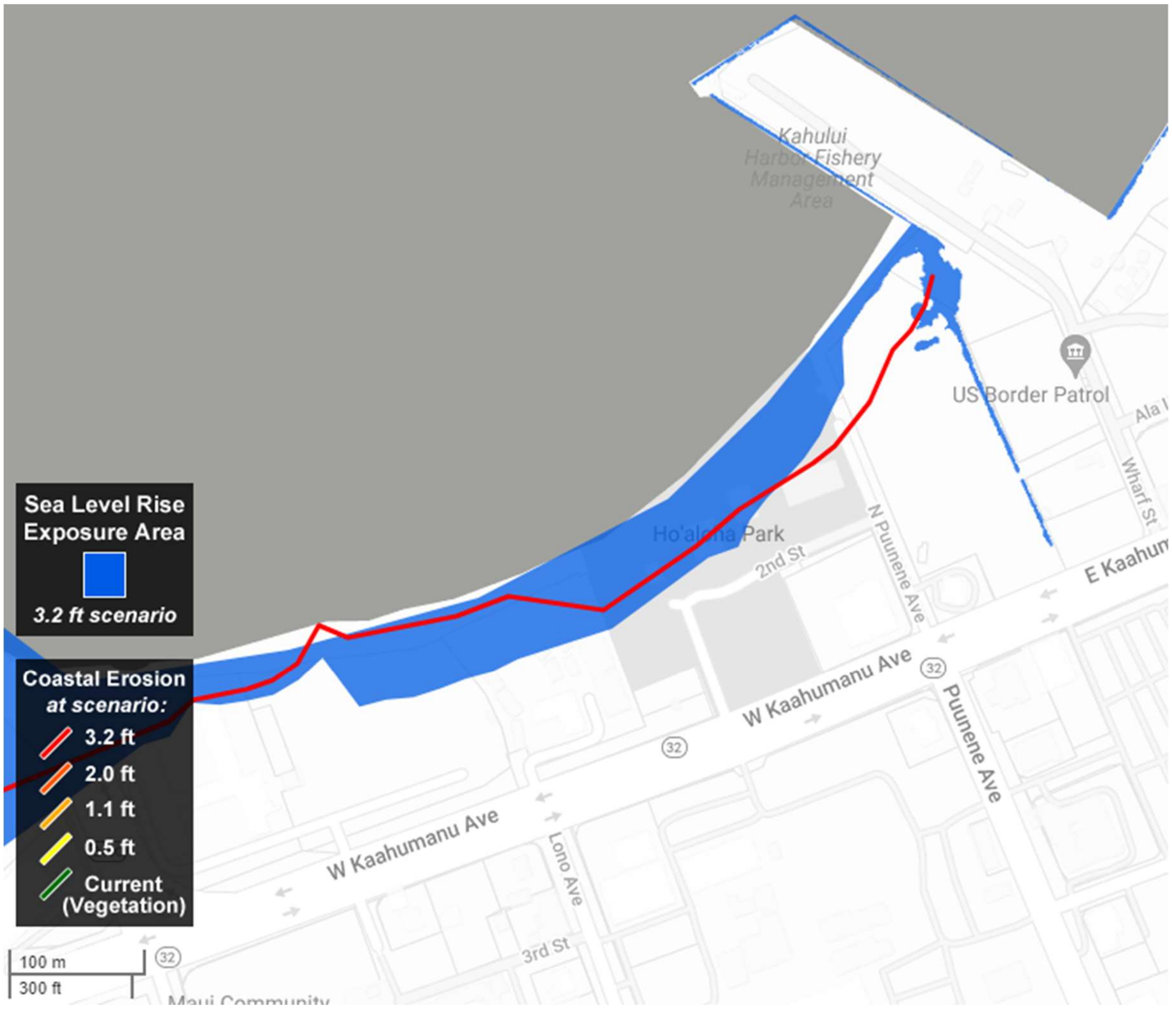

Figure 6. SLR-XA viewer output for a 3.2-ft sea level rise scenario at Hoaloha Park.

While this is a valuable tool for future planning at the state level, more accurate models tailored specifically to Hoaloha Park were utilized for the purpose of this adaptation plan. In order to more accurately estimate the expected impacts of future sea level rise and storm events, the models presented here took into account the specific extents of existing shoreline vegetation and varying beach/dune cross-sections along the shoreline of the park. The models also incorporated locally observed wave heights and used transect locations that were strategically located along the shoreline to capture the varying profile and presence of vegetation. Ultimately, the results of the modeling provided insight into what existing features are most resilient to expected sea level rise scenarios, as well as quantitative data such as expected wave run-up elevations and expected shoreline transgression distances. These specific, site-level insights provide a more robust foundation upon which to base an adaptation plan than the state-level SLR-XA model can provide.

2.6 WAVES

Wave conditions at the site are taken from National Data Buoy Center (NDBC) buoy 51205, located approximately 9 miles offshore of Kahului Harbor and presented below in Figure 7. Swell conditions at the site are based on data provided in the "2002 USACE Wave Climate and Wave Response, 2025 Plan, Kahului Harbor, Maui, Hawaii," also presented below in Figure 8 and Figure 9. The largest waves at the site are typically experienced during the winter months, when long period swells from the north are able to enter the harbor. Wave heights of roughly 2 ft were calculated to be exceeded 1 percent of the time at the site.

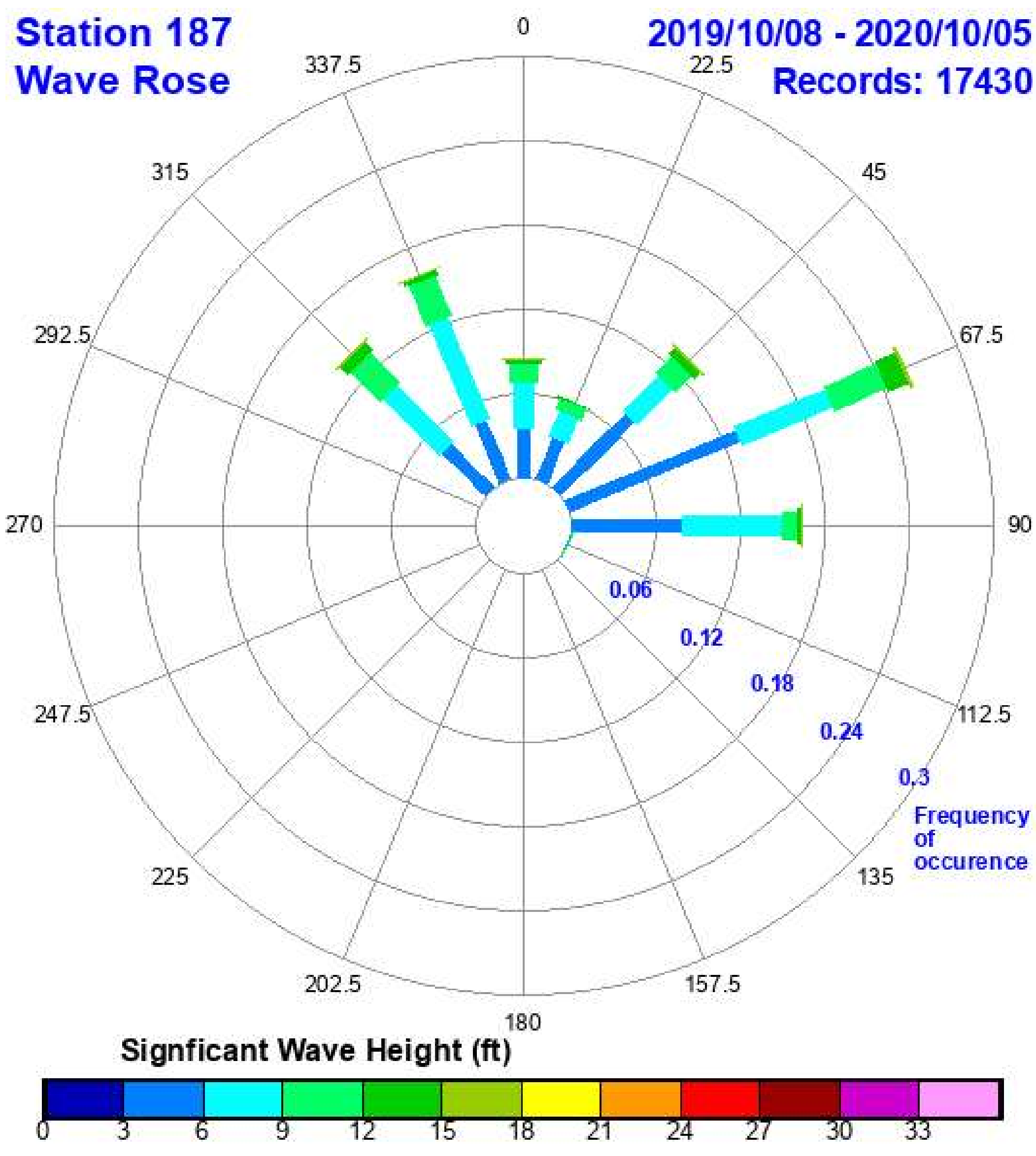

Figure 7. Wave rose for NDBC buoy #51205 (CDIP #187) over an approximately a 1-year period between October 2019 and October 2020.

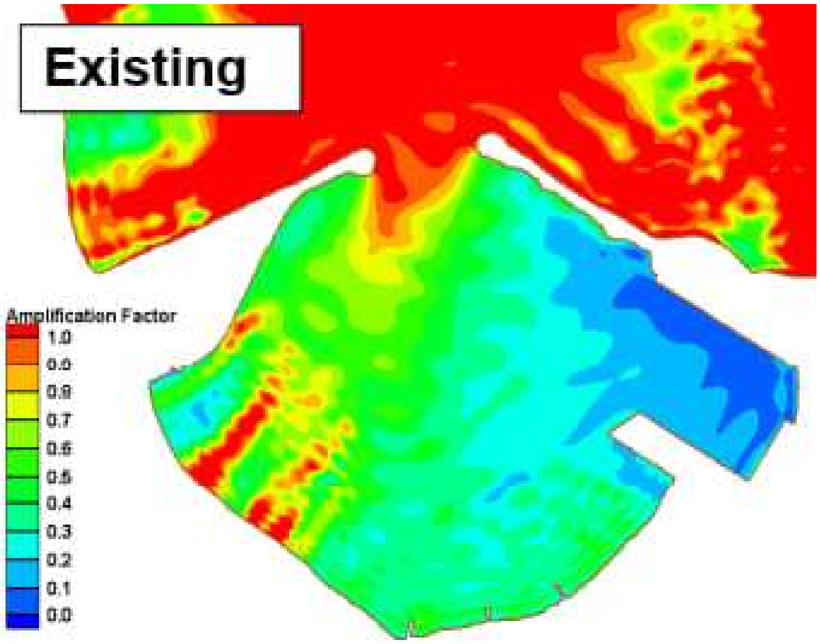

Figure 8. Modeled "Wave amplification factor" during an impactful swell event in 1994. Courtesy USACE, 2002.

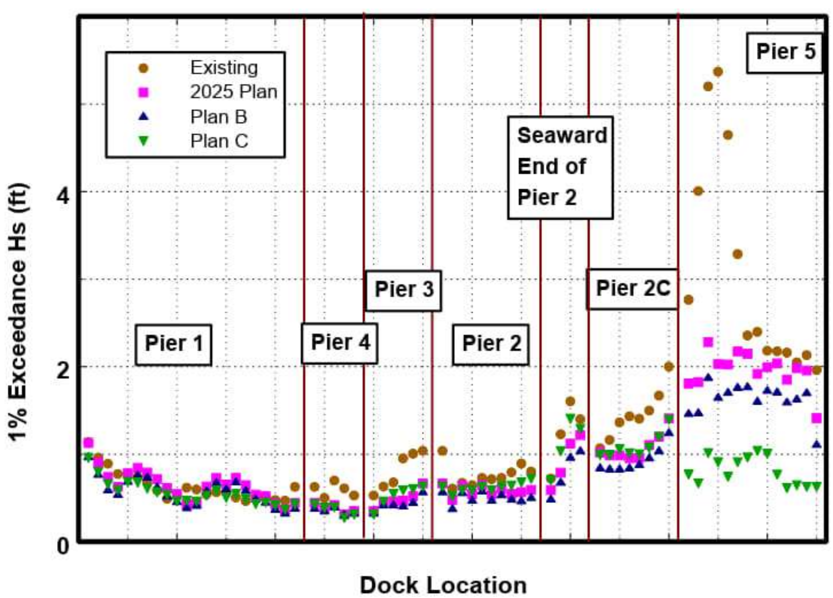

Figure 9. One percent exceedance significant wave height values within Kahului Harbor (Pier 2C is most representative of the site). Courtesy USACE, 2002.

2.7 WINDS

Winds at Kahului Harbor are quite consistent, blowing primarily out of the northeast. A wind rose for station KLIH1, located at the end of Pier 2, is provided in Figure 10 below. Due to the location of the park in the more fetch-limited area of the East harbor, the potential for wind-generated waves to impact the site is relatively low for most of the year.

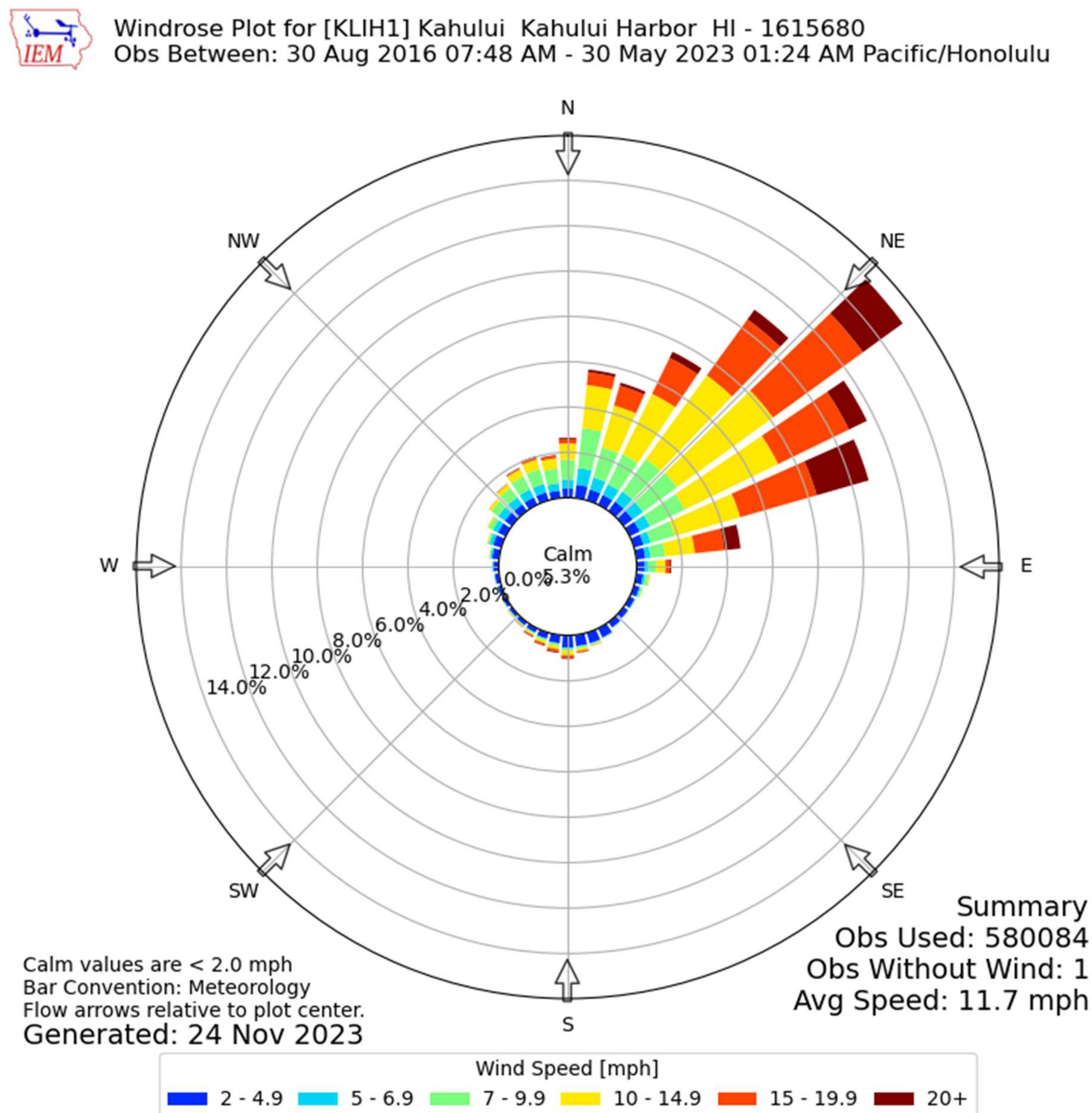

Figure 10. Wind rose for Kahului harbor for the period August 30, 2016 to May 30, 2023. Courtesy Iowa Environmental Mesonet.

2.8 HISTORICAL DUNE EROSION AND SEDIMENT TRANSPORT

Verbal feedback from stakeholders suggests that erosion of the shoreline has been occurring in recent years. Observations on site suggest that erosion is occurring along some portions of the shoreline, especially in areas where existing dunes are void of vegetation. It is unclear whether this dune erosion has been caused primarily by episodic storm wave events or trampling of the dunes associated with park users. Review of historical accounts and historical aerial photographs of the shoreline position since the original construction of Pier 2 in 1926 indicate that the rate of shoreline erosion fronting the beach park is very low, and that portions of the shoreline northeast of the project site have either been filled or experienced accretion. This pattern is generally supported by littoral currents as described in “Littoral Processes and Shore Protection at Kahului Harbor” by Marine Advisors for the state of Hawaii, 1965. Figures from this report are reproduced as Figure 11 and Figure 12 below.

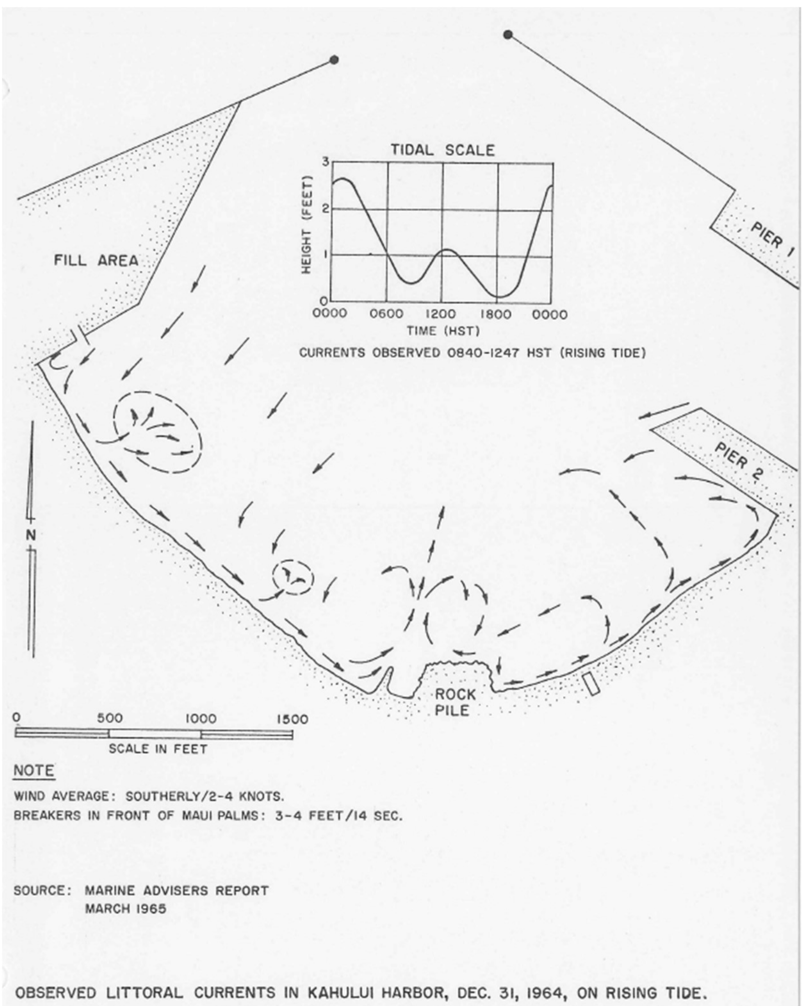

Figure11. Observed littoral currents in Kahului Harbor on December 31, 1964, on a rising tide. Courtesy Marine Advisors for the state of Hawaii.

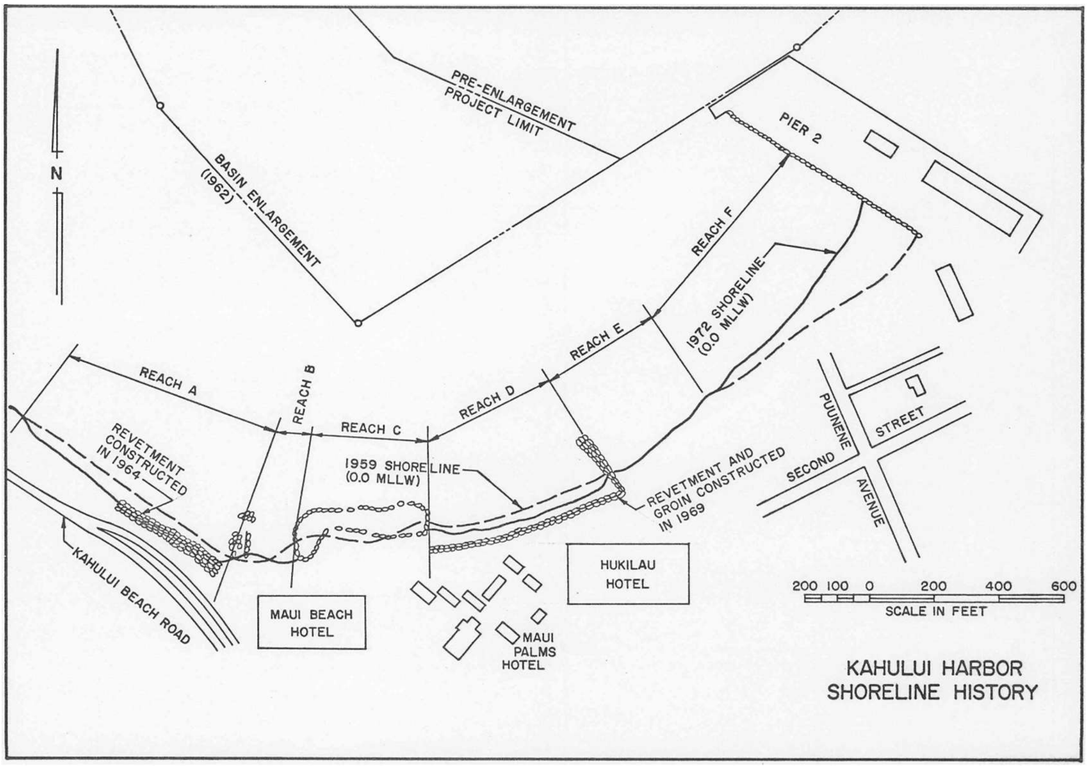

Figure 12. Figure from USACE report "1973 Prevention and Mitigation of Shore Damages: Kahului Harbor" indicating accretion or fill has occurred along the shoreline Northeast of the park between 1959 and 1972.

Figure13. A trace of the shoreline position in 1950 (yellow line) overlaid on an aerial photo from 2015, indicating accretion or fill has occurred along the northeast portion of the shoreline, while the southwest portion has been stable or eroded slightly.

2.9 HARBOR DREDGING

The dredged basin within the harbor has been expanded multiple times since development began in the early 1900s. It was expanded to its current extent in 1962, when 860,000 cubic yards of material was dredged and used as fill along the west breakwater. A plan sheet from the project depicting the dredging and fill areas is provided in Figure 14, below. Since that time, maintenance dredging has occurred roughly once every 10 years, most recently in March 2024 when an estimated 130,000 cubic yards was dredged.[10]

As part of the Hawaii Regional Sediment Management (RSM) Program, in 2011, USACE produced a report for the Kahului and Kihei regions, which included a discussion of several conceptual RSM projects. One project discussed was the “Kahului Harbor Dredge Material Beneficial Reuse” project. The report cites sediment sample testing performed during maintenance dredging in 1999, which offered promising results for the beneficial reuse of dredged material as beach fill.[11] The report further states that samples collected along the western edge of the entrance channel contained 73 percent sand.

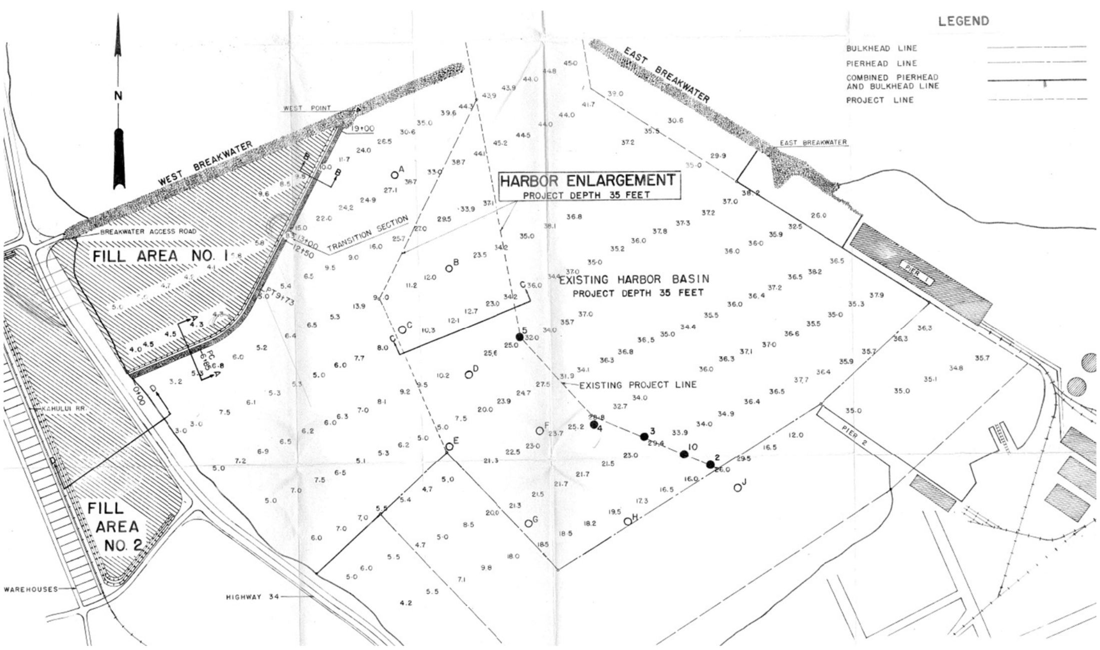

Figure 14. USACE dredge plans to expand the harbor basin to its current extents, 1961.

[10] USACE, “INFORMATION PAPER, Kahului Deep Draft Harbor, Maui, Hawaii”, 9 February 2024.
[11] USACE, “HAWAII REGIONAL SEDIMENT MANAGEMENT KAHULUI AND KIHEI REGIONS FINAL REPORT”, 16 February, 2011.

2.10 HISTORICAL COASTAL FLOODING

To date, no coastal flooding of the project site due to storm/wave action has been reported or found in the historical record. However, coastal flooding of Kahului Beach Road to the west of the project site has been reported during times of corresponding high tides and high surf, pushing debris onto and threatening to undermine the roadway.

In addition, coastal flooding of the park and the surrounding area has occurred multiple times due to tsunamis, most recently on March 11, 2011. In that event, tsunami flood waters traveled over a quarter mile inland up Puunene Ave just east of Hoaloha Park, reaching Wakea Ave.[12] Canoe club members reported that flooding in the park was caused by receding waters, and that water flowed through the canoe hales. Standing water remained in the low-lying areas of the park after the Tsunami, as shown in Figure 15.

Figure 15. Aerial photograph of Hoaloha Park, captured the morning after the March 2011 tsunami, showing standing water in the low-lying portions of the grass parking area.

[12] Christie Wilson, Honolulu Star-Advertiser, "Maui sees boat damage and flooding but little else", 12 March, 2011.

FEMA flood maps of the project area indicate a "VE" flood zone, with flood elevations of 17 ft above mean sea level at Hoaloha Park, which could occur in the case of a severe tsunami. The FEMA flood map is shown in Figure 16.

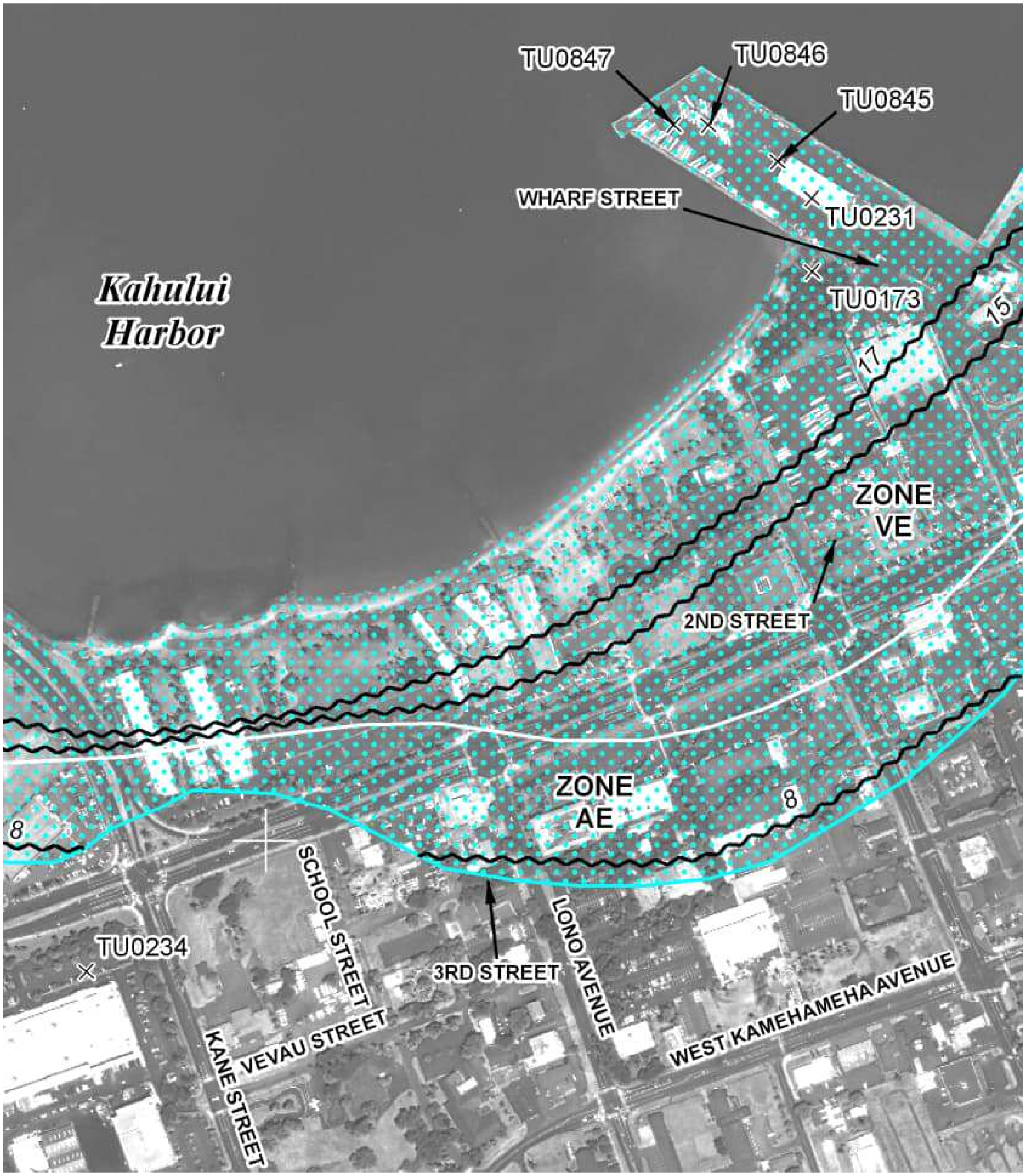

Figure 16. FEMA FIRM map of the project area, as shown on Panel 392 of 825, Map Number 1500030392E, effective June 1, 1981, and last revised September 25, 2009.

3 COASTAL HAZARDS ANALYSIS METHODS AND RESULTS

The coastal hazard analysis consisted of two steps:

1. Modeling and mapping of coastal hazard extents (shoreline retreat, storm induced dune erosion, and storm wave flood extents and depths)
2. Analysis of which park infrastructure and features would be most exposed to coastal hazards.

The coastal hazards consisted of dune erosion distances and flooding depths that were modeled with two separate methods: XBeach (same model used in the HI SLR-XA efforts) and FEMA storm erosion for dunes with sea level rise. Integral determined vulnerable assets over the time span of the modeled scenarios by overlaying the coastal hazards (erosion distances and coastal flooding depths) with park infrastructure for each sea level rise horizon, and determined which park features and infrastructure would be impacted for each sea level rise horizon.

3.1 ELEVATION DATA SETS

DEMs were used as an input to model coastal hazards. Specifically, the models require DEM topographic and bathymetric data as an input to determine the extent of inland flooding and erosion with sea level rise. Model accuracy depends on the accuracy of input data; therefore, the highest-quality publicly available data sets were utilized for the modeling effort. The primary data set utilized was a bare-earth topobathy data set collected as part of the USACE Coastal Mapping Program between September and December 2013, with 1 m horizontal resolution. The data targets a swath 300 m inland and offshore to the 50 m depth contour. Estimated topographic vertical accuracy is ± 0.15 m, and estimated bathymetric vertical accuracy is ± 0.3 m. Integral also evaluated the following data sets for feature delineation and understanding of existing site conditions:

- County of Maui 2019 DTM and hillshade (1 m resolution)
- Aerial image from EagleView, 2023
- Private aerial photos.

All elevations used in this analysis are in feet above mean sea level. The shoreline dune crest varies in elevation between roughly 8 and 13 ft, and the rest of the park slopes generally downward toward Ka'ahumanu Ave, with a particularly low area around 6 ft elevation located near the east side of the grass parking area. The finished floor elevation of both modern hales is 9.5 ft.

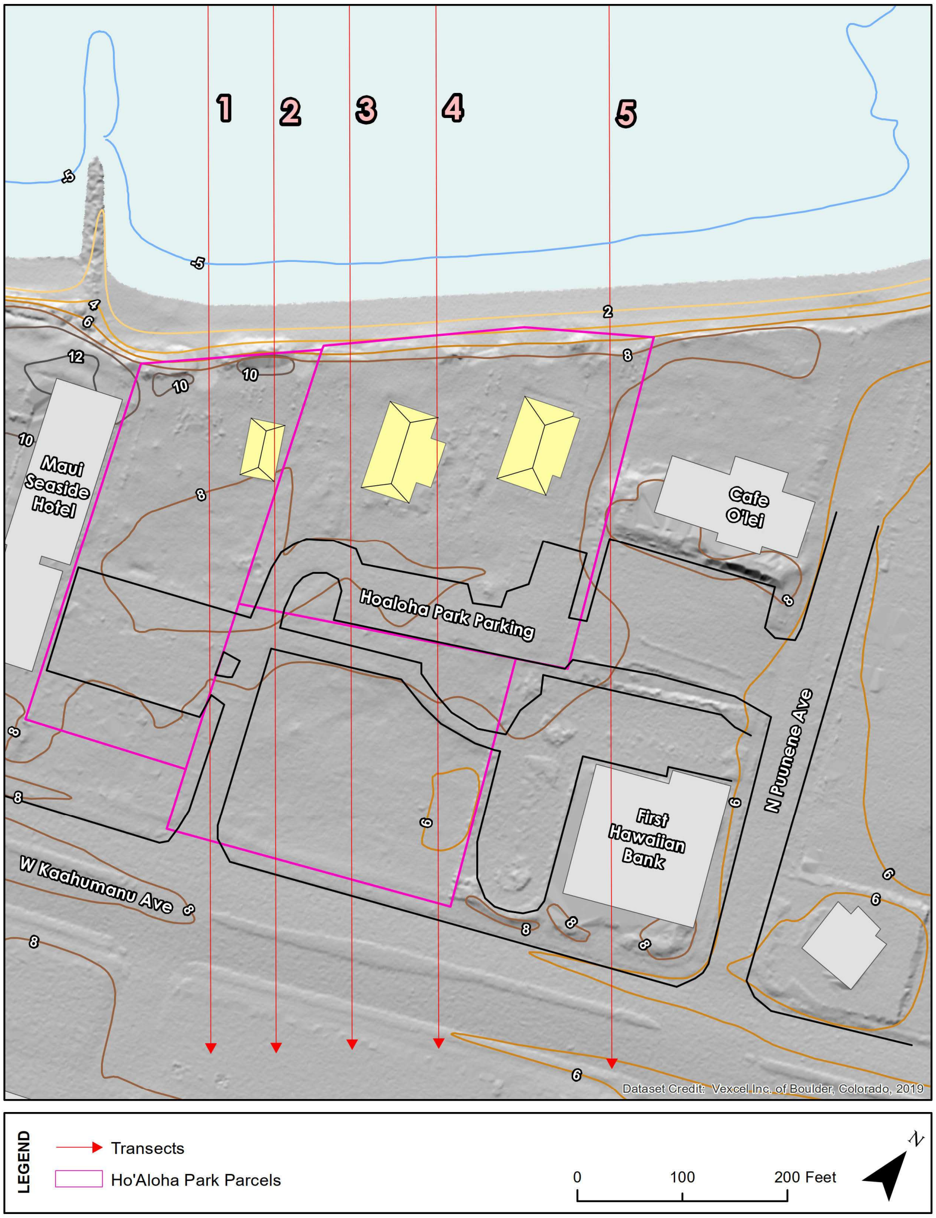

Figure 17. "Hillshade" figure showing park elevations, including 2-ft elevation contours referenced to mean sea level.

3.2 INFRASTRUCTURE DATASETS

Infrastructure data was sourced from the County of Maui and is discussed in further detail in the technical memorandum by Brown and Caldwell.[13]

3.3 REPRESENTATIVE TRANSECTS

Five representative transect locations were selected along the shoreline of the park based on unique site features, in order to gain additional insight into the potential impacts to these features from coastal hazards under various sea level rise scenarios. The transect locations are described and depicted in Figure 18 and Figure 19 below:

- Transect 1: located where pedestrians and canoe paddlers traverse between the park facility and the shoreline.
- Transect 2: located where the highest vegetated dune exists with a crest elevation of ~13 ft.
- Transect 3: located where canoe paddlers access the beach between the park facility and the shoreline.
- Transect 4: located where existing dunes are generally lowest, and intersecting the second (middle) of the three existing hale structures.
- Transect 5: located where the lowest beach and back berm exists along the facility shoreline. This is the most heavily used access and the primary location of user conflicts in the park (cross reference with park user profile).

[13] Brown and Calwell, "DRAFT Technical Memorandum No. 2, Existing Infrastructure", 7 May, 2024.

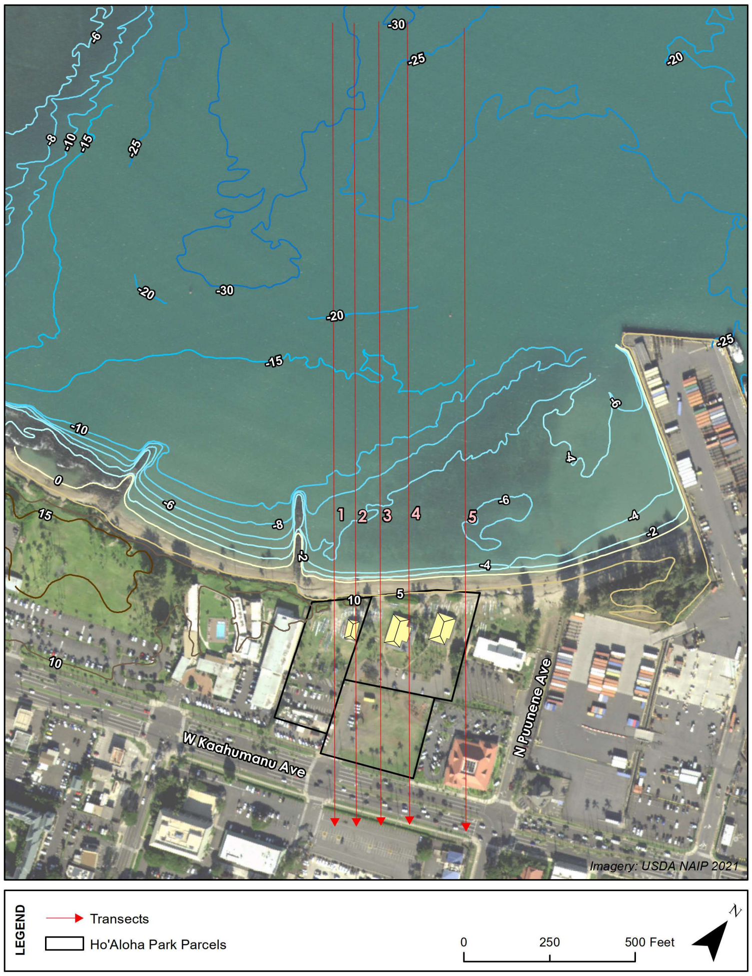

Figure 18. The five transect locations selected for coastal hazard modeling. Depth contours are referenced to mean sea level.

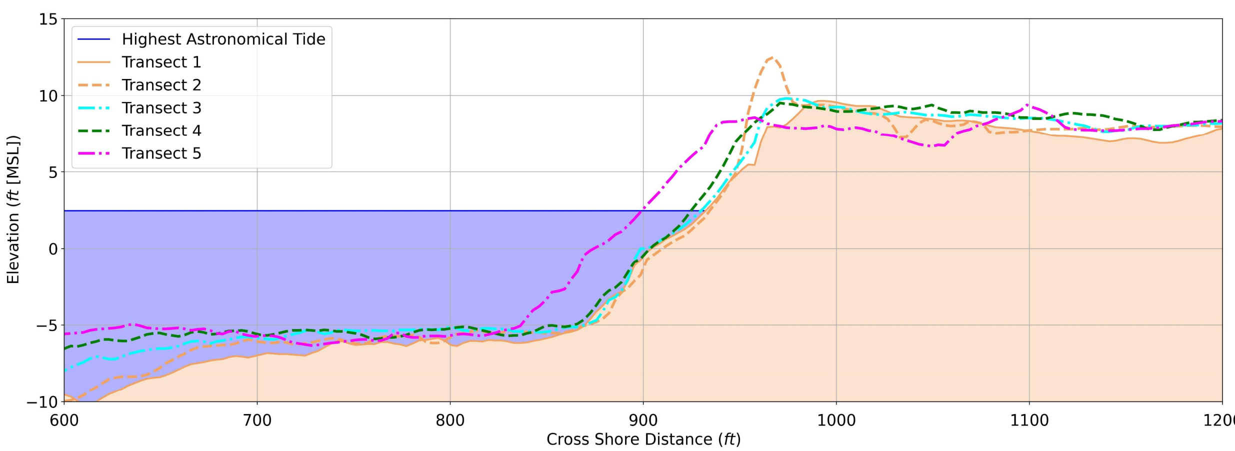

Figure 19. Cross section of the five transects, showing existing topography.

3.4 MODELING METHODS AND RESULTS

Two models were used to evaluate coastal hazard exposure over time:

FEMA/Bruun: Examines shoreline transgression or retreat from sea level rise and included estimate of dune erosion associated with a 1 percent annual chance storm (100-year) according to FEMA guidance.

XBeach: Dune erosion and coastal wave flooding extents (similar to model used for SLR-XA).

3.4.1 Model Assumptions

Table 1. Coastal hazard assessment methods and input values.

Hazard	Model	Wave Characteristics	Tides	Sea Level Rise (ft)	Sediment	Bathymetry
Coastal Flooding / Dune Erosion	XBeach	2,4,6,12-hour Hs = 3.0 Tp = 16s	Changing tide levels hourly, reaching 2.0 ft highest from -0.79 ft lowest	0, 1.1, 2, 3.2	Variable in the cross-shore, 0.275-0.622 mm	Minimum for each of the three transects
Coastal Flooding/ Shoreline Transgression	Bruun + FEMA	3 hour Hs = 3.0 ft Tp = 16s	2.0 ft	0, 1.1, 2, 3.2	Average 0.320 mm	Minimum for each of the three transects

3.4.2 FEMA Storm Erosion for Dunes with Sea Level Rise Methods

The extent of dune erosion was assessed for the same sea level rise elevations as were modeled in XBeach: 1.1, 2, and 3.2 ft. A dune is characterized by a toe elevation (bottom of the dune that is the more seaward), crest elevation (top of the dune that is more inland), and crest locations. For each sea level rise scenario, a new equilibrated dune toe and crest location was predicted. The predictions were made using the Bruun rule (Bruun 1954) with FEMA guidance on storm waves erosion including storm duration adjustments. The Bruun rule and FEMA guidance determine how much erosion would occur due to sea level rise and a large storm, respectively. Both models are built on the principle that the beach will maintain equilibrium with the hydrodynamic forces of the ocean; as water levels increase, the beach will respond by shifting landward and, if possible, upward to maintain its geometry. Total water levels (TWLs) were calculated as the sum of several hydrodynamic forces: tides, storm wave runup, and sea level rise. The parameters for the model are summarized in Table 1.

The "wave" term in the TWL equation is composed of wave run-up. Wave run-up is the uprush of water above the still water line, due to waves. Wave characteristics, such as wave height, period, and direction, and shore characteristics, such as beach slope and sediment grain size, affect the wave run-up elevation. The run-up elevation was calculated using the method of Stockdon (2006).

It takes time for a dune to respond and reach an equilibrium with rising sea levels, but the process is accelerated during storm wave events. FEMA guidance determines how much erosion would occur due to storm waves by using storm characteristics, sediment grain size, and dune geometry. The Bruun rule, however, is more straightforward and only uses the topography characteristics (specifically, offshore beach slope) to determine recession distances due to sea level rise.

The assumptions of FEMA + Bruun rule are valid so long as there are no projected major losses of sediment from the system. Such sediment losses are not expected to occur at the park's shoreline. Also, the Bruun rule assumes that the alongshore wave conditions are similar and does not consider any wave focusing or diffraction.

3.4.3 FEMA + Bruun Results

The FEMA + Bruun modeling results provided two outputs: future shoreline position and flooding extents during storm events. Notably, with 1 ft of sea level rise, the equilibrated dune crest location is expected to shift landward, driving erosion and transgression of the dune and eventually encroaching upon the canoe hale structures. At 3.2 ft of sea level rise, the equilibrated dune crest location has retreated roughly 130 ft landward of its original position, which would drive erosion that will eventually permanently damage or destroy the canoe hales. However, the model does not take into account the potentially protective effects of existing vegetation, which would serve to slow the rate of erosion, or the implementation of a shoreline adaptation plan.

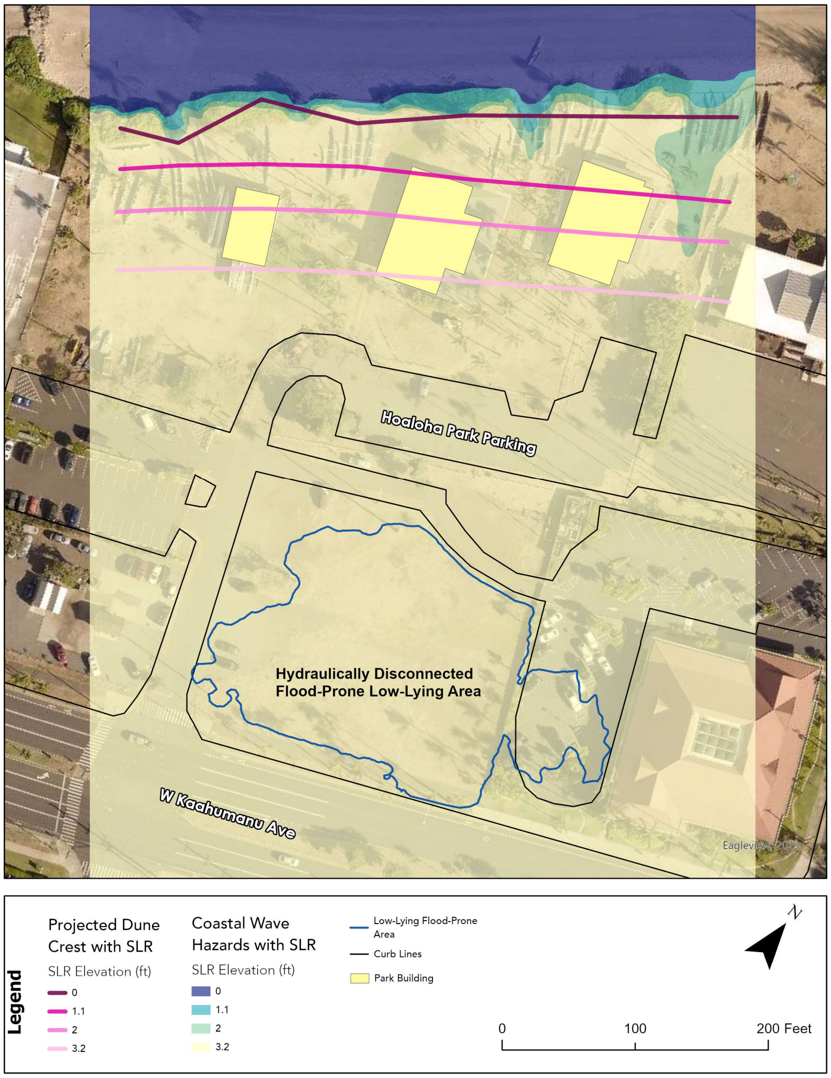

Figure 20. FEMA + Bruun model results, indicated equilibrated shoreline position and flood depths due to storm wave overtopping.

3.4.4 XBeach Methods

Coastal flooding was simulated by predicting the water surface elevation at the facility due to a combination of oceanic factors. Site-specific estimations of water surface elevation can be obtained using a process-based numerical model such as XBeach (Roelvink et al. 2010). XBeach is a morphological numerical model that couples sediment transport and hydrodynamic equations. It was developed to simulate the effect of storms on beaches for kilometer-long stretches of coastline. It can simulate hydrodynamic processes, such as wave shoaling, wave-generated currents, overwash and inundation, and geomorphic/sediment transport processes, such as suspended and bed-load sediment transport and dune face scarping. The model was run in “hydrostatic” mode, meaning that infragravity wave processes were resolved without the consideration of short waves, which greatly reduces computational time. Because infragravity waves are assumed to be the major contributor to wave run-up, hydrostatic mode was assumed to be sufficient.

Inputs to XBeach included a model grid (topography of bathymetry and dune face), tides, and waves (both long and short period). The model grid was developed using the minimum topography elevation, as described in the previous section. A time series of tides was fed into the model, where the peak tide level reached the current highest astronomical tide (2 ft), as well as sea level rise scenarios of an additional 1.1, 2, and 3.2 ft on top of the current highest astronomical tide. A 6-hour storm was simulated, where the storm characteristics (offshore wave height and wave period) were held constant throughout the storm. The parameters for the model are summarized in Table 1.

These coastal hazards represent a potential worst-case future scenario of an extreme storm condition impacting existing site topography. This model does not incorporate any theoretical future shoreline conditions, like a shift of the dune complex landward in response to sea level rise, additional sediment being added to the site (from dredged material or otherwise), or adaptation strategies applied to the shoreline such as raising the dune profile or adding vegetation. However, by studying how existing dune profiles respond to a future worst-case scenario, we can identify which profiles are naturally resilient and why, and apply these insights to a nature-based adaptation strategy.

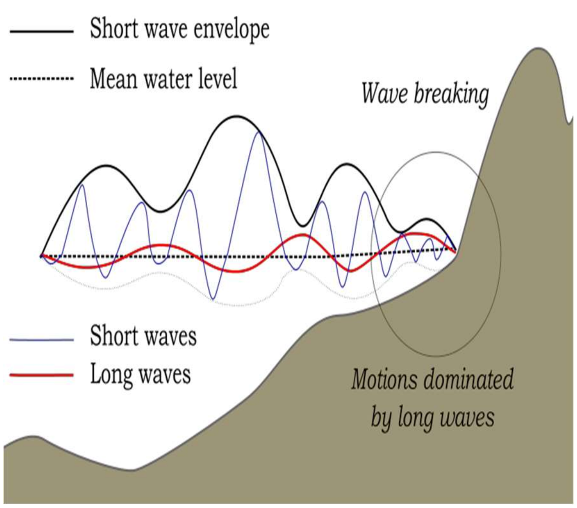

Figure 21. Wave types that impact the shoreline.

3.4.5 XBeach Results

3.4.5.1 Transects 1, 3, and 4: Access Pathways

The results for coastal storm wave flooding depth, inland extents, and dune erosion distances are provided in the figure below for Transect 1. The results for Transects 3 and 4 are nearly identical and are thus included in the discussion here.

Under the modeled storm conditions, the existing dune remains generally protective of the facility up through 2 ft of sea level rise. The dune at Transect 1, with an existing crest elevation of roughly 10 ft, was sufficient to protect against the modeled maximum wave runup elevation of 9.7 ft under a 2 ft sea level rise scenario. At 3.2 ft of sea level rise, erosion of the dune resulted in wave overtopping and flooding of the park.

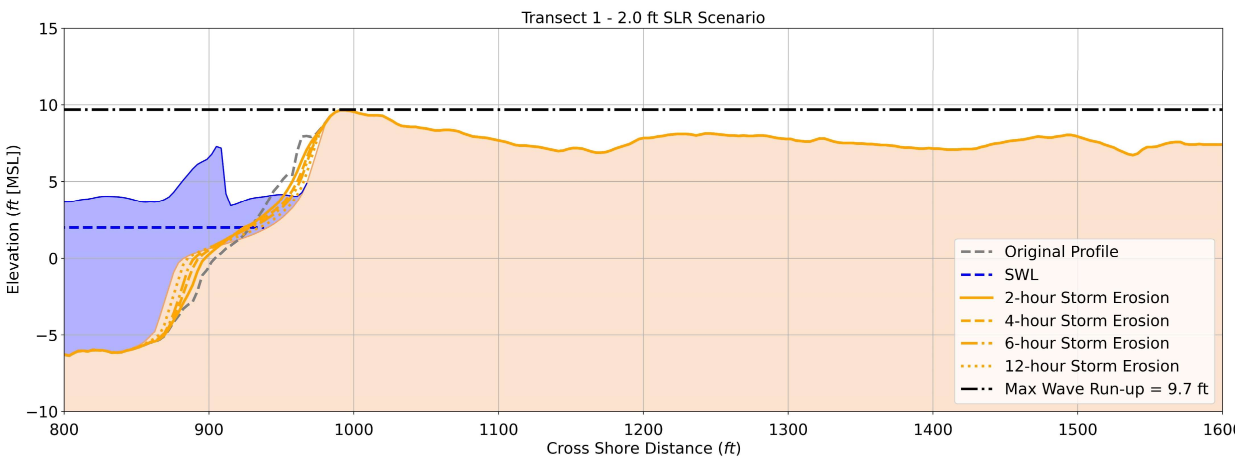

Figure 22. XBeach model results for the 2.0 ft sea level rise scenario at Transect 1.

3.4.5.2 Transect 2: Tall Vegetated Dune

In a 3.2 ft sea level rise scenario, several factors in addition to dune height contribute to the effectiveness or ineffectiveness of the dune system at preventing wave overtopping and flooding of the facility. Notably, vegetation present at Transect 2 provided protection from wave overtopping even in the maximum 3.2 ft sea level rise scenario with a maximum wave runup of 11.6 ft. Maximum erosion extents at this transect were modeled to be less than 5 ft. A model run of the same transect, but without vegetation, resulted in erosion of the dune and wave overtopping and flooding of the facility.

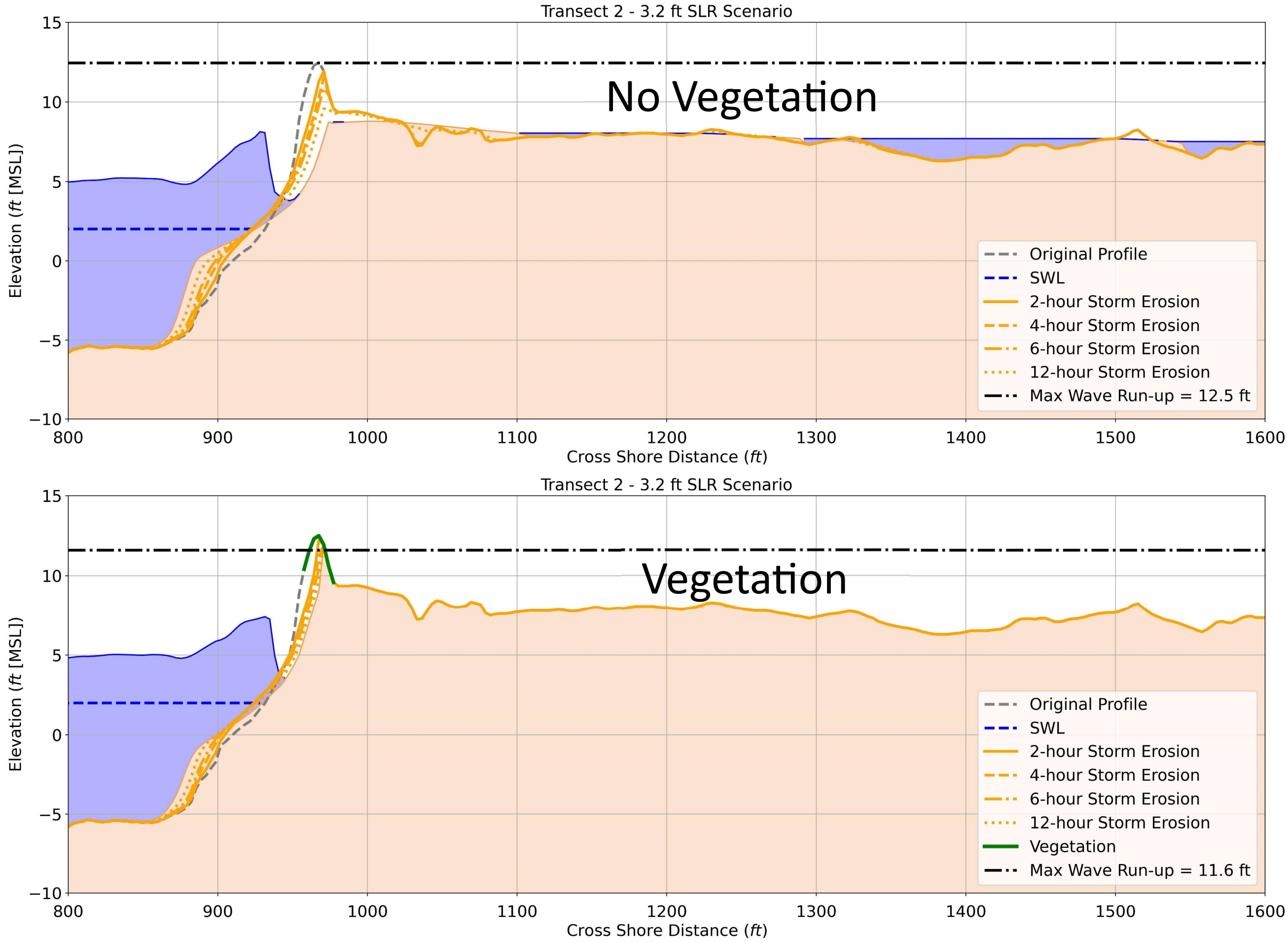

Figure 23. XBeach model results for the 3.2 ft sea level rise scenario at Transect 2, with and without vegetation.

3.4.5.3 Transect 5: Low Dune with Back Berm

Another notable result was found with Transect 5, which despite having a lower beach profile and foredune elevation, also resisted wave overtopping in the worst-case 3.2 ft sea level rise scenario. This appears to be due to a "back berm" located at this transect, which provided the additional protection needed to prevent extensive flooding of the park even as the foredune eroded and was pushed landward. In general, a dune or berm feature further inland from the shoreline, even at a relatively lower elevation, can be more effective at preventing wave overtopping and flooding by allowing wave energy to be dissipated at the foredune.

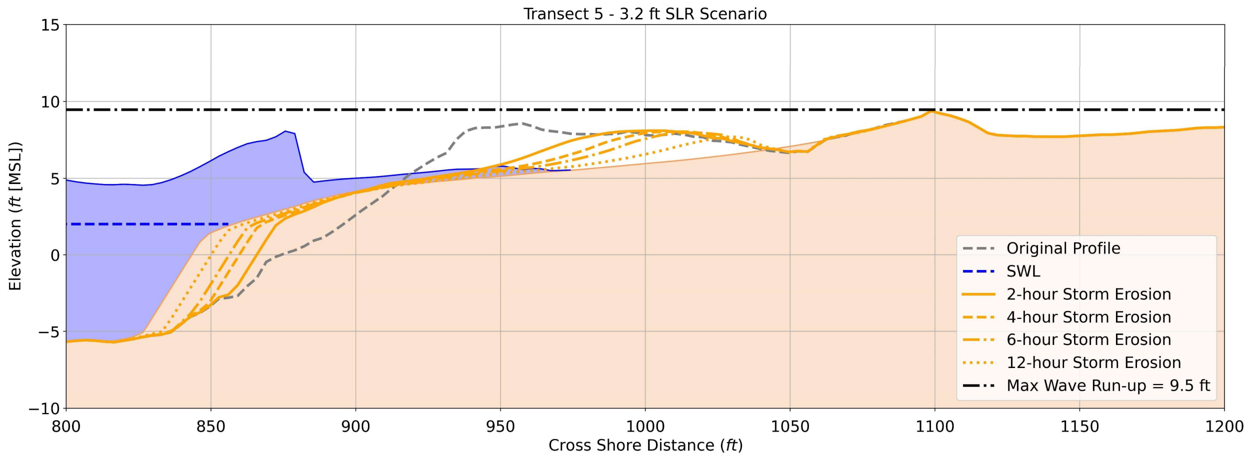

Figure 24. XBeach model results for the 3.2 ft sea level rise scenario at Transect 5

In all scenarios in which waves overtopped the foredune (apart from Transect 5), flooding extended beyond the landward limits of the facility, encroaching into and beyond Kaahumanu Ave. This is due to the topography of the facility landward of the shoreline dune, which is generally flat and/or sloping down away from the shoreline.

3.4.6 Comparison With the Hawaii SLR-XA Modelling Effort

Quantifiable differences between the XBeach model results and the SLR-XA map are presented below (Table 2). Differences in the variables each model considered are discussed in Section 3.4 above. Our modeling estimated erosion distances consistently further inland than the SLR-XA modeling.

Table 2. Difference between the Integral and HI SLR-XA

Sea Level Rise Horizons (ft)	1.1	2.2	3.2
Difference in the Average Dune Erosion Position (feet)	+26.3	+29.6	+38.5

Positive = Integral Position is further inland

4 VULNERABILITIES

At present sea level and coastal hazard exposures, there are no significant vulnerabilities to the facility. It is important to note that each coastal hazard poses different risks. Shoreline transgression threatens to undermine the existing hale structures, as well as reduce or eliminate park area currently used by canoe paddlers and other park users. Dune erosion threatens to increase the potential risk for wave overtopping and flooding. Such flooding has the potential to damage the hale structures and any property within the hales that is not elevated. Outside of the hales, there is little to no infrastructure within the park threatened by flooding, although flooding of the park and beyond onto Kaahumanu Avenue are associated with both access and public health concerns.

Under future sea level rise scenarios, the modeling results revealed significant erosion and flood hazards to the facility. Vulnerabilities to these hazards identified under each scenario are as follows:

1.1 ft of sea level rise

- Moderate erosion of the shoreline, roughly 25 ft landward of its current position.
- Potential encroachment of the shoreline into the footprint of the modern hale structures
- Partial loss of current canoe storage/staging area.

2 ft of sea level rise

- Severe erosion of the shoreline.
- Complete loss of current canoe storage/staging area.
- Potential undermining of the modern hale foundations, failure of the traditional hale structure
- Wave overtopping of shoreline dunes in isolated areas (Transect 5) but limited flooding.
- If the foredune were lost or degraded leading up to this condition, which is likely without intervention, overtopping and flooding would be more widespread than modeled.

3.2 ft of sea level rise

- Catastrophic erosion of the shoreline, 130 ft landward of its present position.
- Complete loss of the hale structures.
- Widespread wave overtopping of shoreline dunes during storm events, causing flooding of the entire site and beyond onto Ka’ahumanu Ave.

4.1 IMPLICATIONS OF COASTAL HAZARD ANALYSES ON ADAPTATION STRATEGIES

- Vegetation on dunes plays a significant role in preventing erosion/overtopping. “Vegetation effect”: Vegetated dunes are much more resilient to erosion and flooding.
- Raising the dune crest elevation to an elevation of 13+ ft and widening the dune in unvegetated areas may reduce flood and erosion risk.
- Water flows tend to travel along elevation contours versus perpendicular to them. Thus, wave run-up is lower across a wider dune system, as evidenced by the modeling at Transect 5. The farther back a natural dune feature is on the beach, the more protective it is at lower elevations.
- Vegetation in the park obstructing the flow path of flood waters reduces overall inland flood extents.
- Significant impacts to canoe paddling operations are likely, even in a 1 ft sea level rise scenario if dunes are not raised/additional sediment added to the shoreline.

4.2 OTHER HAZARDS NOT CONSIDERED

Other hazards not included in this analysis include flooding due to tsunami inundation or rain events. Both of these flood sources could be worsened by higher groundwater elevations, driven by sea level rise, decreasing the ability for stormwater to infiltrate into the ground. These flooding hazards are further discussed in the technical memo produced by Brown and Caldwell as a part of this project.[14]

Another factor not considered in this analysis are vulnerabilities presented by the limited geographic scope of this project. In general, sea level rise adaptation plans are more effective when they are considered and implemented holistically, as opposed to at the parcel or park scale representing only a portion of a longer shoreline. For example, Puenene Road is lower lying than the park itself and wave overtopping occurring there could flow along a lower elevation flow path through Cafe O’Lei’s parking lot into the park. This caveat is important because if adaptation strategies are implemented along only a fraction of the shoreline, erosion and flooding occurring adjacent to the area could negate or degrade the effectiveness of strategies proposed in this plan.

[14] Brown and Calwell, “DRAFT Technical Memorandum No. 1, Site Existing Conditions”, 7 May, 2024.

5 ADAPTATION STRATEGIES

As a result of insights gained from modeling results, site investigations, historical research, and community feedback, an initial list of adaptation strategies that are feasible and suitable for potential implementation at the site are discussed below. The primary adaptation strategies proposed for the park are illustrated below in the "Adaptation Pathway". The Pathway includes appropriate "triggers" that define when it may be appropriate to begin the implementation of a particular strategy, and a rough timeline for when these triggers may occur. This should be considered a "living" document, that is revisited and revised as physical site conditions and community priorities change over time.

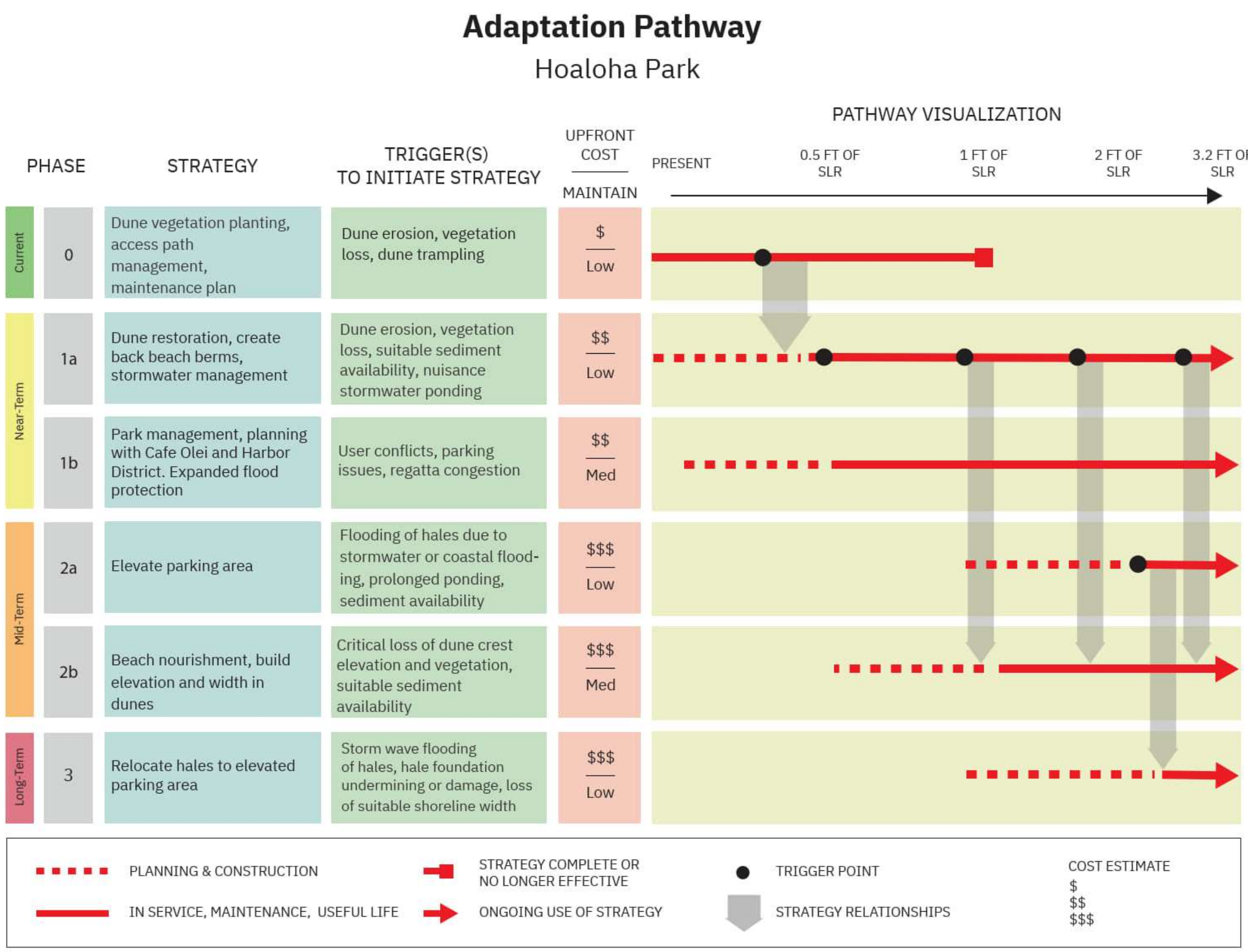

Figure 25. Hoaloha Park Adaptation Pathway

Preserve, protect, and expand existing vegetation.

All existing vegetation within the park is an asset in regard to lessening the impacts of coastal flooding. Existing vegetation should be protected and expanded to the extent feasible by implementing a maintenance plan, irrigating, and using barriers to prevent trampling. Removal of vegetation should only be considered in the context of implementing a superseding adaptation strategy.

Raise foredune crest and add vegetation.

When suitable sediment is available, expanding the existing foredune in width and height will increase the dunes resilience to erosion and overtopping. Additional vegetation should be planted on the expanded dune to further increase resilience.

Reduce number of shoreline access pathways through the dune.

Pathways through the existing foredune represent vulnerable points where storm waves can more easily cause erosion and overtop the dune. The number of these pathways should be reduced to the extent practical while maintaining suitable recreational access. Existing pathways chosen to be closed should be filled with suitable sediment to restore the dune profile, and vegetated.

Reorient access pathways to be more parallel to dominant wind direction.

Winds at the project shoreline primarily blow out of the northeast. Aligning shoreline access pathways with the dominant wind direction can help to leverage aeolian sediment transport (wind-driven sand) to build-up the dune in these locations. This can help counter increased erosion caused by foot traffic through the pathways.

Add barrier berms and flood walls.

Barrier berms and flood walls can both serve to prevent or lessen flooding in the event of storm waves overtopping the foredune. Such features can vary in size, but even small berms can be effective when strategically located. Ideally, these features should be located where they may serve to restrict or cut off coastal flood water flow paths entering the park through lower points on the dune and/or from off-site. Extending or expanding existing areas of higher elevations using berms and flood walls can also be effective.

Actively manage park uses.

Areas surrounding the modern canoe hales are currently managed by the canoe clubs unofficially. The modern hales themselves are leased by the canoe clubs but the land around them are not. Additional County management of park uses, including defining areas that may or may not be used for storing canoes, and defining corridors to the shoreline that are to be kept unobstructed, could be integrated into other adaptation strategies and serve to ease tensions between park user groups.

Elevate as much of the site as possible.

Install additional vegetation throughout as much of the site as possible.

Pursue beneficial reuse of dredged material as beach or site fill.
Collect and test sediment from Hoaloha Park and the entire shoreline between East Groin and Pier 2 to compare against potential sediment sources, such as harbor dredging or offshore sand sources. Advocate for the beneficial re-use of dredged material whenever possible, and for further study into the sediment transport patterns in and around the harbor.

Consider sand backpassing/beneficial reuse of excavated sand as beach or site fill.
Visual observations and sediment transport data suggest that sediment may be slowly drifting northeast along the shoreline and accreting along the face of Pier 2. This material may be suitable for use as beach/dune fill along the shoreline fronting the park. Excavating this material and moving it “updrift” relative to the average longshore sediment transport direction is known as sand backpassing. Excavating this material could be spurred by maintenance of the existing submerged outfall located at the shoreline along the Pier 2 wall[13].

Continue to advocate for wider-scale coastal management and adaptation planning, and collaborate with surrounding entities to address shared impacts.
Successful coastal adaptation requires a holistic approach to implementing adaptation strategies. The uneven application of adaptation strategies along a shoreline reduces their effectiveness and can in some cases be counterproductive. Sharing knowledge of expected coastal hazards, and collaborating on the implementation of adaptation strategies can be a win-win for all entities involved. Entities adjacent to Hoaloha Park that can be important partners in these efforts include the Maui Seaside/Hilton Hotel to the west, and Cafe O’Lei and DOT Harbors to the east. On a wider scale, efforts by Maui County and the state of Hawaii to incentivize coastal hazard adaptation planning and implementation of adaptation strategies are also important to support and participate in.

Managed Retreat
Over the long-term, relocation of the canoe hales and parking areas further inland may be necessary. This strategy can be implemented over time in a staged approach, for example moving the parking area first so space is available to move the hales when necessary.

Reduce wave energy reaching the shoreline: Expand and raise the nearshore reef alongshore and/or extend East Groin.

Two viable strategies to block or break-down wave energy before it has the opportunity to impact the shoreline and cause erosion are; placing material to expand and raise portions of the nearshore reef (outlined in Figure 26), and extending the East Groin structure alongshore. Both of these strategies, installed offshore in the marine environment, require careful consideration of biological resources, recreational uses of the area (like canoe regattas), and wave and sediment dynamics for successful implementation.

Figure 26. Aerial photograph of Hoaloha Park, with the nearshore reef area outlined in white, and a conceptual East Groin extension sketched in red.