

Memorandum – Coastal Engineering Review

KAHO Kaloko Fishpond

TAR 31946

8 August 2023

INTRODUCTION AND TAR REQUEST

Loko iʻa, Hawaiian fishponds, were a significant technological, social, economic, and cultural development of ancient Hawaiians. These ponds were developed to provide a reliable source of fresh seafood for the chief and royal court, and they helped to stabilize the community, manage natural resources, and enrich relationships (Keala 2007).

The Kaloko Fishpond located in Kaloko Honokohau National Park is an example of a *loko kuapā* type (seawall type) fishpond made of water worn lava stone and coral. At 30-40 feet wide, 6.5 feet high, and 250 yards long, it is the largest retaining fishpond wall in the state (NPS 2021). The first documented reference of Kaloko was approximately 300-years ago, and it is thought that the wall is about 600 years old (NPS 2023, 2019). Many of the original Hawaiian fishponds disappeared during the twentieth century due to westernization, development, changes in land use, spread of invasive species, and sediment accumulation due to lack of management (McDaniel 2018). Storms in the 1950s destroyed the Kaloko wall, and the National Park Service (NPS) has worked to restore it, relying on archeological evidence, oral histories, a *kupuna* or elder, and the guidance of a master mason skilled in traditional stonewall construction to maintain traditional Hawaiian culture (NPS 2019). Rising sea levels and increasing storm frequencies and intensities have led to increased wave forces that cause more frequent damage to the Kaloko Fishpond wall, making it difficult to maintain. The NPS is spending approximately \$190,000 per year to maintain the wall and would like to investigate alternatives to reduce the damage to the wall while maintaining its cultural integrity.

This memo provides an overview of how climate change is impacting fishpond restoration, restoration techniques used by others, alternatives for increasing the strength of the wall, alternatives for decreasing wave loads, and a discussion on how numerical modeling can be used to help support management decisions for the site.

Climate Change and Impacts to Fishponds

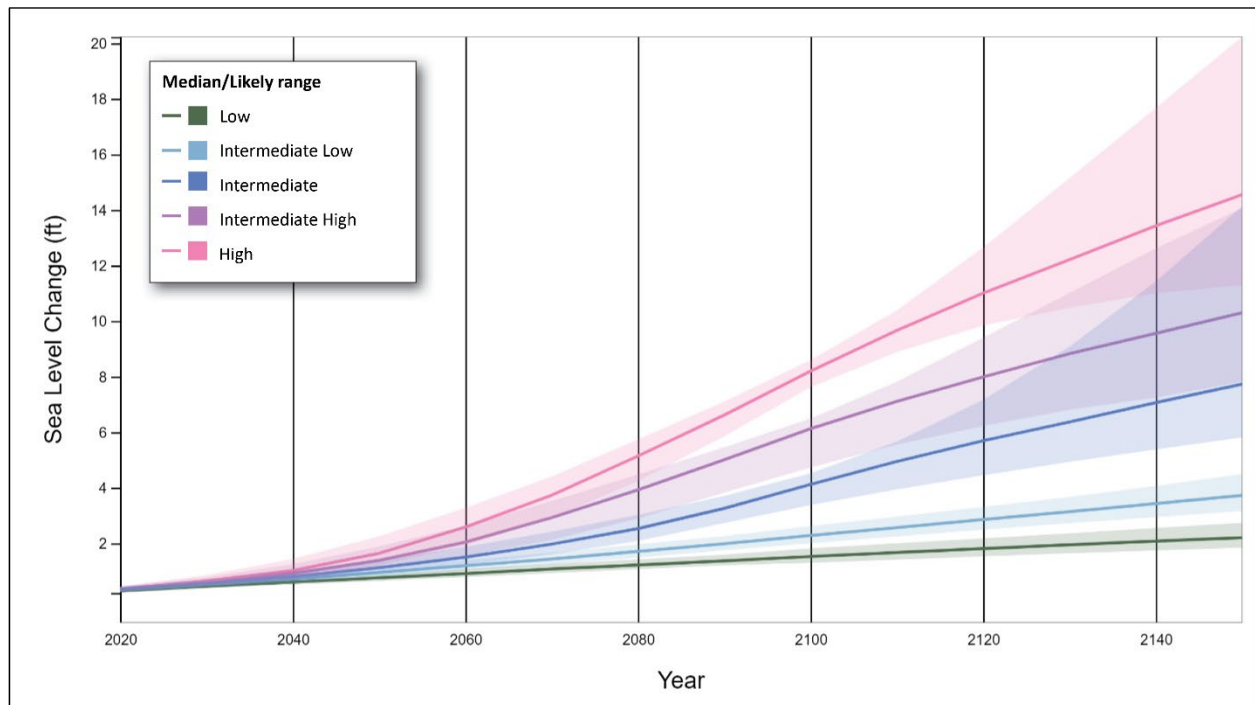
Climate change in Hawaii is having an impact on rainfall, extreme events, intensity of tropical storms, carbon dioxide concentrations increasing, air and ocean temperatures rising, changing wind and wave patterns, ocean chemistry, baseflow in streams decreasing, changes in habitats and species distribution and increases in sea levels (USGCRP 2018). Increases in sea level have impacted coastal erosion, episodic flooding, permanent inundation, heightened exposure to marine hazards, saltwater intrusion to surface water and groundwater, and increased wave loads (USGCRP 2018).

Wave loads, which can be generated by wind driven waves or tsunamis, are increased with rising sea levels because water depth limits how large a wave can become before it breaks. As sea levels increase, larger waves can develop and penetrate the site, which then break on the walls of the fishpond causing increased damage. Median projections for regional sea level rise (SLR) for five different scenarios from

2020 to 2150 relative to a 2000 baseline were calculated (figure 1). The projection is for the station located at latitude 20, longitude -156 (the closest station to the site, approximately 20 miles from the Kaloko Fishpond). The scenarios shown include median projection and 90% confidence range for the low, intermediate-low, intermediate, intermediate-high, and high Shared Socioeconomic Pathway scenarios relative to a 2000 baseline year (Sweet et al. 2022). For the purposes of this analysis, the intermediate SLR value was used.

Figure 1. SLR projections for latitude 20, longitude -156.

(Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force 2022)



The intermediate projection is about 2 feet of water elevation increase over the next 50 years. At the project site, an increase of this magnitude would result in wave loads similar to those associated with the existing 10-year return period event (10% annual chance of occurring) being experienced on at least an annual basis based on a preliminary analysis described in the following section.

Alternatives for KAHO Site

A preliminary/conservative analysis was performed using empirical equations and estimates of water depth assumed based on site photographs and water levels listed in Federal Emergency Management Agency's (FEMA) Flood Insurance Study No. 155166V001B (FEMA 2017) and offshore wave conditions from the US Army Corps of Engineers (USACE) Wave Information Study Pacific Station No. ST83462 (USACE 2022), which were transformed to depth-limited waves based on figure 8-5 in FEMA's Coastal Construction Manual (FEMA 2011). These parameters were input into the Hudson Formula to approximate the stable weight of rock required to withstand forces associated with the hydrodynamic loads caused by storms at the site (USACE 1984). The results of this analysis are listed in table 1.

Table 1. Minimum stone size to resist various return period storm events:

Storm Event Return Period (Yr)	Transformed Wave Height - No SLR (ft)	Transformed Wave Height – SLR (ft)	Min Stone Size (ft) (No SLR - assumed approx. sphere)	Min Stone Size (ft) (SLR - assumed approx. sphere)
1	5.1	6.7	2.4	3.2
10	6.9	8.4	3.3	4.0
50	7.9	9.5	3.8	4.5
100	8.6	10.2	4.1	4.9

This analysis could be further refined with better bathymetric data or more complex modeling, however this preliminary analysis showed that even during the 1-yr return period event, which can be expected annually, stones that are not secured and smaller than 2.4 feet in diameter (lighter than ~2500 pounds) will not be stable and will be subject to damage. Based on site photographs, it appears that many of the stones used to construct the Kaloko Fishpond wall are smaller than this threshold and the wall is subject to damage during even minor storms and possibly even typical (monthly) events. To decrease the frequency in which the wall needs to be repaired, at least one of two things must be accomplished:

1. The strength of the wall needs to be increased (table 2) or
2. The wave loads need to be decreased (table 3).

There are several methods that could be used to accomplish either or both goals. These methods include:

Alternatives to increase the strength of the structure

1. Increase stone size.
2. Reinforce the wall with concrete, mortar, and/or epoxy.
3. Dowel the stones together.
4. Use gabion baskets to hold the stones together.

Alternatives to reduce the wave loads

1. Revise the structure geometry.
2. Offshore wave dissipation with a structure.
3. Offshore wave dissipation with a Nature-based Solution (NbS).

The advantages and disadvantages of each method are described in tables 2 and 3. It is noted that due to the site's exposure and size of the fishpond wall, many of these alternatives listed will impact the cultural and historical integrity of the wall. Working with the Native Hawaiian communities to restore fishponds and maintain cultural integrity is of particular importance, but to combat the increased loads due to climate change not previously encountered, some fishpond practitioners in Hawaii are also combining contemporary science with these traditional practices to adapt to today's sustainability challenges to restore and improve fishponds (NOAA 2021). As such, these alternatives are included for completeness.

The alternatives provided in tables 2 and 3 may be used independently or in conjunction with one another. Some of these alternatives would impact the cultural and historical integrity of the wall, though they were included to provide a wide array of potential solutions. Given that climate change is resulting in more frequent events that cause damage.

Table 2. Alternatives to Increase the Strength of the Wall

Alternative	Advantages	Disadvantages
Increase Stone Size – Larger stones will be more able to resist the wave loads. To effectively resist wave loads, a double layer of large stones should surround smaller stones to keep them in place. The gradation of the larger stone should be determined using a full engineering evaluation (site investigation and analysis using numerical models or empirical equations). A preliminary analysis of the Kaloko Fishpond site shows that even during minor events, stones larger than 2500 pounds (2.5 feet in diameter) are recommended. If this alternative is pursued, it is likely that stones greater than 3 feet in diameter will be required to stabilize the wall.	- Decrease the frequency of repairs. - Wall will remain permeable allowing seawater to circulate in the pond. - Does not require use of materials such as concrete, rebar, etc. so it will be more resistant to corrosion.	- Would require the use of heavy machinery and a specialized construction crew. - Stones that are a suitable size will likely need to be sourced from other areas. - Alters the cultural and historical integrity of the wall
Reinforce the wall with concrete, mortar and/or epoxy – The strength of the wall could be increased by using mortar or epoxy to hold the stone together or by using reinforced concrete to anchor stones.	- Decrease the frequency in which the wall requires repair. - Allows for smaller stones to be used in wall construction.	- Would require the use of heavy machinery and a specialized construction crew. - Joining the stone together will decrease the permeability of the wall. - This method was tried unsuccessfully in the 1950's (NPS 2023). The material will be subject to the corrosive marine environment, so care should be taken to ensure that the repair is properly specified. - Alters the cultural and historical integrity of the wall

Alternative	Advantages	Disadvantages
Dowel stones together – Doweling smaller stones together involves attaching them together with rebar or something similar. This will allow them to be better anchored to resist wave loads. It is also possible to anchor stones to the ground depending on the substrate.	- Decrease the frequency in which the wall requires repair. - Allows for smaller stones to be used in wall construction. - Wall will remain permeable allowing seawater to circulate in the pond.	- Would require the use of heavy machinery and a specialized construction crew. - Care should be taken when choosing stones to be doweled together to avoid splitting or damaging the stones. - Care should be taken when specifying doweling material as it will be subject to the corrosive marine environment. - Alters the cultural and historical integrity of the wall
Gabion basket to hold stone together – Gabion baskets are typically woven wire mesh-filled baskets that can be used to hold groups of stones together. At the site, gabion baskets would allow the existing stones to be fixed to one another.	- Decrease the frequency in which the wall requires repair. - Allows for smaller stones to be used in wall construction. - Wall will remain permeable allowing seawater to circulate in the pond.	- Will require the use of heavy machinery and a specialized construction crew. - Not visually appealing - Baskets will deteriorate if not properly maintained, potentially leaving debris and adverse impacts. - Care should be taken when specifying basket material as it will be subject to the corrosive marine environment. - Alters the cultural and historical integrity of the wall

Table 3. Alternatives to Decrease Wave Loads

Alternative	Advantages	Disadvantages
Revise structure geometry – Revising the geometry of the fishpond wall could help to reduce wave loads. This may include adding a slope to the seaward face of the wall to dissipate wave energies or a rock shelf in front of the wall to break waves. It is recommended that the gradation of the stone required be determined using an engineering evaluation which consists of a site investigation and analysis using numerical models or empirical equations.	- Reduced wave loads. - Decrease the frequency in which the wall requires repair. - Allows for smaller stones to be used in wall construction. - Wall will remain permeable allowing seawater to circulate in the pond.	- Will likely require the footprint of the structure to increase. - May adversely impact coastal resources, especially benthic habitat. - May not reduce loads enough to prevent the need for additional mitigation. - May alter the cultural and historical integrity of the wall
Offshore wave dissipation with structure – An offshore structure such as a rubble mound, concrete or floating breakwater could be used to break waves offshore. This would reduce the wave heights and loads on the fishpond wall. An engineering analysis with site investigation, robust data collection, site monitoring, and numerical modeling should be conducted to properly design the offshore structure.	- Reduced wave loads. - Decrease the frequency in which the wall requires repair. - If properly designed, will allow existing stones to be used in the fishpond wall construction. - Wall will remain permeable allowing seawater to circulate in the pond. - Can be designed to positively impact circulation and sediment transport patterns or have positive ecological benefits such as habitat creation.	- Costly to construct. - Will likely require use of heavy machinery and a specialized construction crew to construct. - May adversely change circulation and sediment transport patterns if not properly designed. - May adversely impact coastal resources. - Typically, has impacts to navigation. - An engineering analysis with site investigation, robust data collection, site monitoring, and numerical wave modeling is recommended for design, which is a costly and time-consuming process.

Alternative	Advantages	Disadvantages
Offshore wave dissipation with NbS – NbS could dissipate wave energy. Options include stimulating reef or vegetation growth immediately offshore of the site. An engineering analysis with site investigation, robust data collection, site monitoring, and numerical modeling should be conducted to properly design the offshore structure.	- Reduced wave loads. - Decrease the frequency in which the wall requires repair. - If properly designed, will allow existing stones to be used in the fishpond wall. - Wall will remain permeable allowing seawater to circulate in the pond. - NbS can be designed to enhance habitat and coastal resources. - Can be designed to positively impact circulation and sediment transport patterns at the site.	- Will take time to establish and not immediately reduce wave loads. - May adversely change circulation and sediment transport patterns if not properly designed. - Typically, has impacts to navigation. - An engineering analysis with site investigation, robust data collection, site monitoring, and numerical wave modeling is recommended for design, which is a costly and time-consuming process.

The park may wish to consider options that offer a balance between keeping the cultural and historical integrity of the wall and increasing the structural integrity and reducing maintenance needs of the wall.

Modeling

Forecasting the long-term changes to the nearshore coastal and sediment dynamics is increasingly important for managers to protect cultural and natural resources as climate change continues to cause more frequent and intense storms and SLR, creating conditions not previously encountered. In the past, these changes were difficult to predict, but with computing capacity increasing exponentially (i.e. progression is not linear and modeling capabilities are far ahead of where they were even 5-years ago) and improvements in accuracy, the use of and access to state-of-the-art numerical models has increased. Additionally, models can be better validated and calibrated due to advancements in data gathering technology.

Numerical models can help inform managers about the best use of specific management strategies (tables 2 and 3). The combination of data gathering, monitoring and modeling is essential for understanding existing systems and predicting future coastal processes (Vimala et al. 2012). Models can be used to help determine a variety of items such as optimum elevation and geometry for the fishpond wall, placement of a nearshore structure or NbS to reduce wave heights without adversely impacting circulation, predicting future functionality of the site, sea level rise projections, and changes in weather patterns.

The first step in modeling is to perform a numerical modeling assessment of the existing conditions and calibrate/validate it with site data. The existing conditions model can then be compared to a future condition, which would include the proposed improvement strategy as well as anticipated effects of climate change (e.g., sea level rise, storm intensity).

State-of-the-art models and improved design tools linked with climate projections can provide answers about how to best protect the Kaloko Fishpond. Examples of how research, models and design tools are currently being used to are given below:

University of Hawaii State-wide Climate Resilience Through Data Science

The University of Hawaii's Established Program to stimulate Competitive Research (Hawaii EPSCoR) received a \$20-million grant through the National Science Foundation to fund research related to climate science through a collaboration with multiple partners inside and outside of the University's system. The collaboration, called Change HI will use advanced data science techniques including computational simulations, data visualization, natural language processing, machine learning, artificial intelligence, and statistical modeling to aid in decision making related to the climate and environment (University of Hawaii 2022).

The project looks to address Hawaii's unique challenges as climate change impacts natural resources, ecological sustainability, economic vitality, and human health. Numerical modeling will be used to provide an understanding for how variations in the atmospheric and land surface conditions influence weather processes. This can be used to predict shifts in rainfall patterns over various climate projections (University of Hawaii 2022).

The information gathered through the collaboration will provide stakeholders in the State of Hawaii with access to climate data that can be used for decision-making. These data can be beneficial to the Kaloko Fishpond site to predict future environmental conditions at the site given anticipated effects of climate change.

Hydrodynamic and Sediment Transport Modeling

At Aberdeen Proving Ground (APG) in Harford County, Maryland, EA and the USACE Coastal and Hydraulic Laboratory (CHL) are modeling several recommended NbS to understand the impacts on the hydrodynamics and morphology during normal conditions and storm events. The ADvanced CIRCulation modeling (ADCIRC) along with the Coastal Storm Modeling System (CSTORM-MS) will be used to evaluate storm surge and wave impacts to select recommended NbS for APG. Storm events to be modeled include historical storm events and high-frequency synthetic storms.

An Adaptive Hydraulics (AdH) model will then be developed to determine the impacts of these NbS on hydrodynamics and sediment transport in the region around APG on a finer scale than feasible in the ADCIRC model. The storm scenarios, along with a year-long timeframe scenario, will be simulated using CSTORM-MS results as boundary conditions and both the CSTORM-MS and AdH models will be used to simulate with and without project conditions for present-day sea levels along with four additional projected future SLR scenarios.

A similar model could be used at Kaloko Fishpond site to review how a proposed offshore breakwater or NbS would function at the site. It could also be used to optimize the proposed structure or NbS layout.

Living Breakwaters

After Hurricane Sandy's impact to the Tottenville community located on the south shore of Staten Island in New York City in 2012, resulted in an unprecedented loss of property and life, U.S. Department of

Housing and Urban Development (HUD) launched Rebuild by Design (RBD), a competition to develop a way to protect the community. Historically the community had been protected by a wide shelf and series of oyster reefs, but due to siltation, overharvesting, channel dredging, changes in water level, and human pathogens in the water, the once abundant oyster reef no longer protected the community from incoming waves. To mitigate risk from both event-based and long-term shoreline erosion, preserve beach width, and reduce wave heights along the shoreline, the living breakwaters project was developed (New York State Governor's Office of Storm Recovery 2019). The project also sought to increase the ecology in Raritan Bay and foster social resiliency by providing community programming, education, research, stewardship activities (New York State Governor's Office of Storm Recovery 2019). The project resulted in the design of approximately 2,400 linear feet of near-shore breakwaters made from partially submerged rip-rap stone located between 790 and 1,800 feet from shore.

For the project, numerical modeling was used in conjunction with physical modeling to understand impacts to shoreline change, reduction in wave heights, and to optimize the layout and geometry of the structures to provide the most benefit to the community. Sea level rise scenarios were also modeled to show that the proposed breakwater will continue to reduce the risk from waves as the seas continue to rise. The models also allowed the breakwater to be designed such that they would help sediment accrete on the beaches (New York State Governor's Office of Storm Recovery 2019). A similar modeling effort could be done at the Kaloko Fishpond if offshore structures or NbS are proposed to reduce wave energy.

Specific modeling needs of a site should be assessed during the data gathering stage. No matter what the objective of the modeling exercise is, each model must be validated and calibrated before the information is used for decision-making. Validating and calibrating a model involves comparing model results to observed data. Sufficient data must first be collected, then the model must be run until the results are representative of the data collected. If sufficient data are not available, they must be collected prior to modeling. The data collection process alone may take months or even years.

CONCLUSIONS

The National Park Service is spending approximately \$190,000 a year to maintain the walls of the Kaloko Fishpond located in Kaloko-Honokohau National Park. A preliminary analysis showed that the existing stones are too small to resist the wave loads regularly experienced onsite, and without increasing the strength of the wall or decreasing the wave loads on the site, ongoing maintenance will be required. Rising sea levels and increasing storm frequencies and intensities due to climate change will only increase the frequency of the ongoing maintenance to the wall in years to come.

Several alternatives to either increase the strength of the wall or decrease the wave loads on site were considered. These alternatives should be reviewed alongside the goals and objectives of the park to determine which alternative would provide the best opportunity going forward when considering the current and projected environmental conditions at the site.

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