Assessing the Impact of Tidal Flooding on Cultural & Recreational Assets on Oahu Using Crowdsourcing and Survey Data

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I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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I would like to dedicate this thesis to the communities on Oahu, Hawaii.

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ABSTRACT

It has been noted in literature that coastal regions will be negatively impacted by flooding as sea-level rise (SLR) increases. The impacts of coastal flooding will change the way residents interact with the land. Many of the locations that have been impacted by tidal flooding are highly used for recreational and cultural activities. Infrastructure vulnerability resulting from tidal flooding has been well studied and documented in literature (Habel, Fletcher 2020). However, there is a lack of research and understanding of how tidal flooding will impact cultural and recreational assets. This study highlights the impacts that projected SLR would have on Hawaiian cultural activities along the coast as well as general outdoor and water-related recreational activities. Using data from the 2015-2019 Hawaiian King Tides Photo Project and community surveys, cultural and recreational assets affected by tidal flooding on the island of Oahu were mapped and overlaid with the projected SLR flooding maps. By considering how the current tidal flooding affects the various kinds of cultural and recreational activities, community concerns, and risk perceptions this study can help develop potential adaptation strategies that accommodate community needs.

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1.0 INTRODUCTION

1.1 BACKGROUND

The rise in sea level is not slowing down. Currently, the sea level is rising at 3-4 mm/yr globally, and due to ocean warming and land ice melt global sea level will continue to grow, ranging anywhere from .3 m to 2.0 m by the year 2100 (Figure 1.1) (Vitousek, Barnard, et al., 2017). The rise in sea level will not be uniform around the world. Tropical regions further away from ice sheets, such as Hawaii, will experience a higher rate of local sea level rise (SLR) than land outside the tropics due to a lower elevation of land (Vitousek, Barnard, et al., 2017). Globally sea level is projected to rise 5-10 cm between 2030-2050; this amount of SLR will double the coastal flooding frequency within tropical regions (Vitousek, Barnard, et al., 2017). When it comes to SLR, Hawaii will need to adapt faster than other regions of the world.

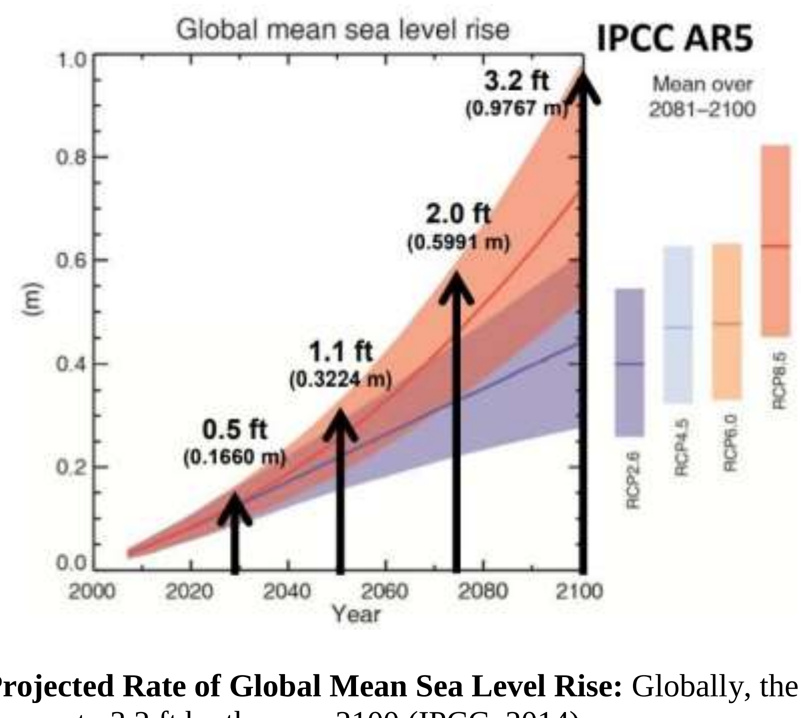


Figure 1.1 Projected Rate of Global Mean Sea Level Rise: Globally, the projected sea level will increase to 3.2 ft by the year 2100 (IPCC, 2014).

High tides affect each side of Hawaii differently. Understanding the height and direction of swells in the Hawaiian Islands can give an insight into how rapidly the coast will erode on certain sides of the island and how heavily infrastructure would be affected (Vitousek, Fletcher, 2008). Within the north, to the north-west region of the Hawaiian Islands, winter swells can reach over 5m in height multiple times a year, and summer swells around 2m at the south of the islands (Figure 1.2) (Vitousek, Fletcher, 2008). Extreme weather changes are a result of El Nino Southern Oscillation (ENSO) which causes increased ocean temperatures in the equatorial region, and Pacific Decadal Oscillation (PDO), known as a long-lived ENSO (NOAA,2021). These events are known to influence seasonal swell patterns in Hawaii (Vitousek, Fletcher, 2008).

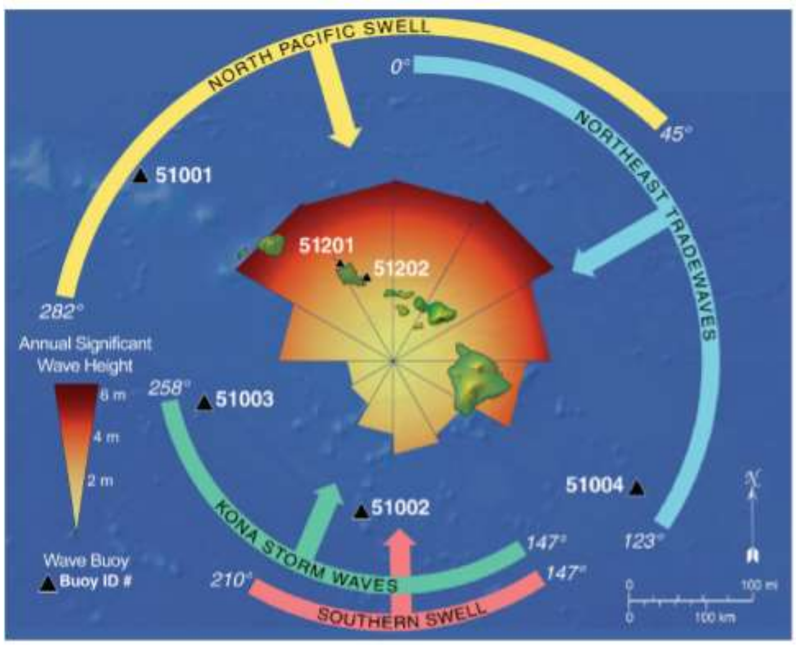


Figure 1.2: Annual Significant Wave Height In Hawai'i (Vitousek, Fletcher, 2008, pp.542).

On Oahu, the coastlines are heavily urbanized and populated, leaving them highly vulnerable to coastal flooding and sea level rise. SLR can lead to various adverse impacts along the coast, specifically passive high-tide inundation of low-lying coastal areas, increased frequency, severity, and duration of coastal flooding, increased beach erosion, groundwater inundation, changes to wave dynamics, and displacement of communities (Vitousek, Barnard, et al., 2017). Passive flooding on Oahu has become increasingly more evident in low-lying areas. According to Habel and Fletcher et al. (2020), direct marine flooding, drainage backflow, and groundwater inundation are three common types of passive flooding in coastal regions (Figure 1.3). Direct marine flooding results from elevated sea levels during high tides or extreme weather events, causing floodwater to surpass the low-lying land surface (Figure 1.4) (Habel, Fletcher, et al., 2020). Sidewalks and streets within low-lying coastal areas often experience storm drain backflow (Habel, Fletcher, et al., 2020). Storm drain backflow occurs during a high tide or heavy rainfall event that often slows or reverses drainage rate resulting in urban flooding within coastal communities. In terms of groundwater inundation, aquifers along the coast are directly connected to the ocean (Hoover, Odigie, et al.,2017). During high tide events, saltwater intrudes the fresh groundwater leading to an elevation of the groundwater table (Hoover, Odigie, et al.,2017). In low-lying areas such as Honolulu, the groundwater has already risen above the ground surface at extreme tides and has begun to flood existing infrastructure (Habel, Fletcher, et al., 2020).

Underground infrastructure such as sewer mains and storm drains are the first to be affected by SLR, which can negatively impact urban cities' public health, contaminate coastal waters, and threaten economic revenue (Habel, Fletcher, et al., 2017). In particular, 23% of Waikiki on Oahu will be affected by groundwater inundation, causing 86% out of 259 active cesspool sites to overflow and threatening 5 billion dollars of taxable real estate (Habel, Fletcher, et al., 2017). Due to structural and land loss, at 3.2 ft of projected SLR, Oahu will lose 12.29 billion dollars, which is the greatest economic loss than any other Hawaiian island (Hawaii Climate Change Mitigation, 2017). Along with the financial loss, 3.2 ft of flooding will cause 9,400 acres of land and 17.7 miles of road to be lost to flooding and 13,300 of Oahu's residents to relocate (Hawaii Climate Change Mitigation, 2017). With the significant losses expected to come, understanding and preparing for the impacts of future SLR will be crucial to the survival of communities on Oahu.

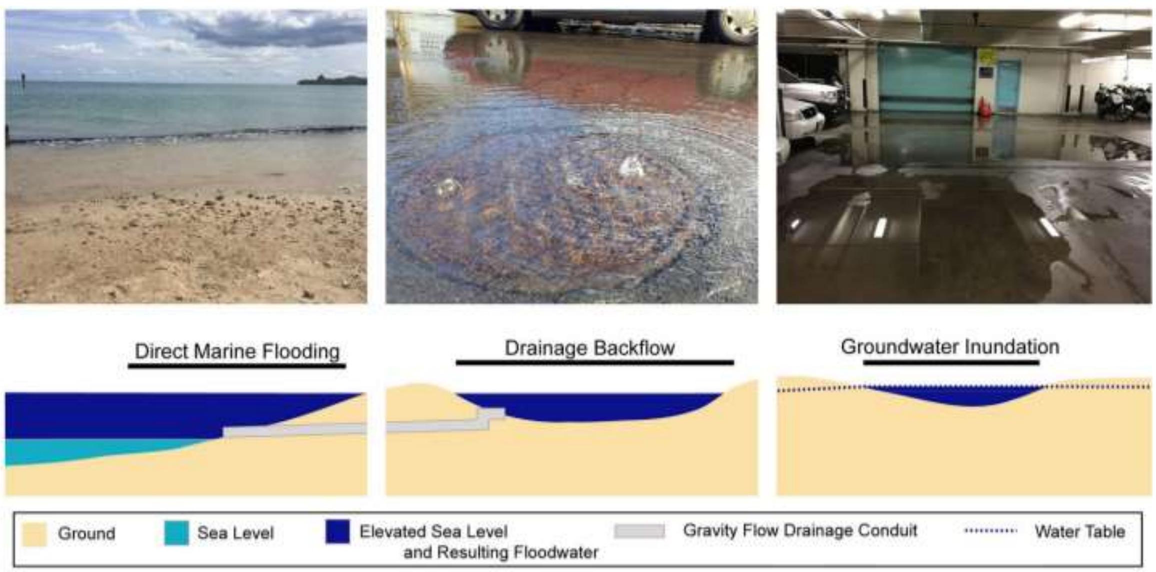


Figure 1.3 Three Main Types Of Flooding: Direct marine flooding, storm drainage backflow, and groundwater inundation (Habel, Fletcher 2020, pp. 2).

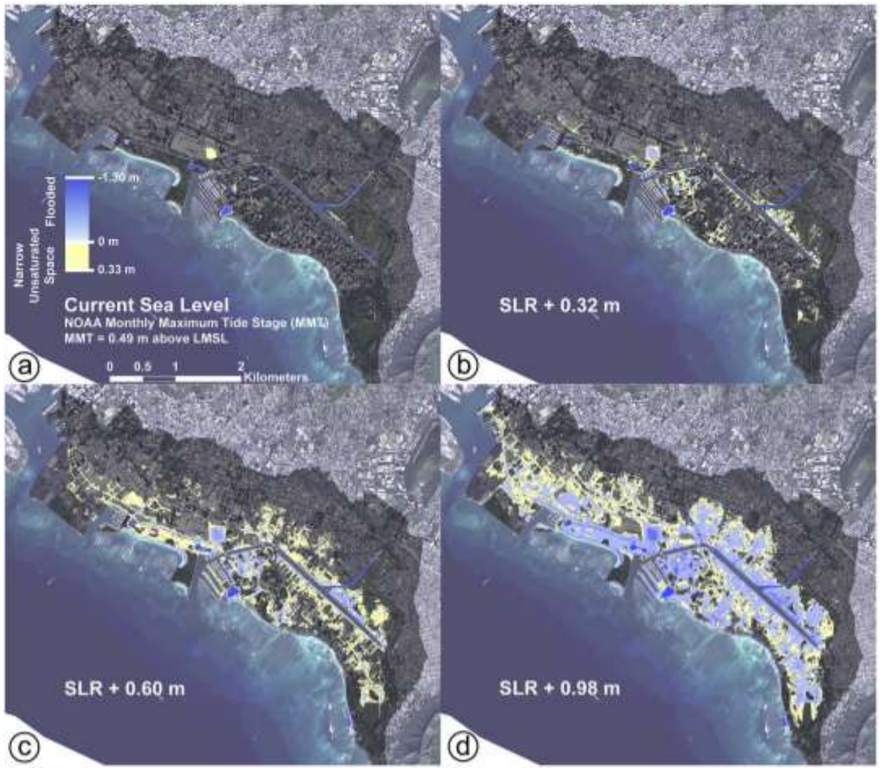


Figure 1.4 Stimulated Image Of Sea-level Rise & Groundwater Inundation In Waikiki, Oahu: a) Current sea level b) Sea level at .32 m= 1 ft c) Sea Level at .60 m= 2ft d) Sea level at .98m= 3.2 ft. (Habel, Fletcher, et.al, 2017, pp. 132).

While infrastructure vulnerability resulting from tidal flooding has been well studied and documented on Oahu (Habel, Fletcher 2020), there is a lack of research and understanding as to how tidal flooding will impact Oahu's cultural and recreational assets. With Oahu being home to many cultural and recreational activities that involve the natural environment, many of these activities will be affected by beach erosion and flooding. Nearly 550 cultural sites in the state of Hawaii are projected to be flooded by 3.2 ft of SLR, and many Hawaiian Homelands will be impacted by flooding (Hawaii Climate Change Mitigation, 2017). Due to the threat that cultural and recreational locations face, the scope of this study focuses on the impacts SLR will have on community's access to cultural and recreational assets in particular. This study highlights how the projected sea level rise and coastal flooding will impact the community's cultural and recreational activities and relevant infrastructure assets using crowdsourcing data collected by the Hawaii King tide project and community survey. The results provide community members, scientists, and decision-makers a starting point to develop adaptation strategies that help preserve the coastal areas' cultural and recreational functions.

1.2 CULTURAL AND RECREATIONAL ACTIVITIES

Hawaiian sanctuaries and places of refuge are essential to the survival of Hawaiian culture. Although native Hawaiians have faced many hardships over the years, many cultural practices have been maintained, for instance, taro cultivation, farming, fishing, and the preservation of the Hawaiian language (Minerbi, Luciano, 1992). The increase in urban development and the negative impacts of climate change are now threatening Hawaiian culture and historical traditions. As many cultural activities are along the coast, understanding how SLR will impact Hawaiian cultural activities will play an essential role in preserving Hawaiian culture and identity.

An ecological model of Native Hawaiian well-being created by Pomaika'i (2003) helped land-use planners understand how to support Native Hawaiians in land use planning. Within the community segment of the model, Pomaika'i (2003) mentioned that the majority of Hawaiian youth are taught about many traditional cultural activities that occur in natural environments such as restoring taro patches and fishponds, learning about the medicinal uses of plants, fishing methods, and canoe paddling. The land utilized for these activities provides a place of community gathering and is critical to the preservation of Hawaiian culture and identity. When considering SLR adaptation strategies and areas that need immediate attention, residents' voices need to be considered by land-use planners to effectively preserve community gathering space while also reducing the impacts of SLR.

Through crowdsourcing data, community surveying, and passive flooding projections, various recreational and cultural activities within Oahu were mapped using the geographic information system (GIS). Based on the SLR projections, the resulting maps displayed the vulnerability of locations that provided recreational and cultural services. The cultural activities observed within this study are practiced explicitly along the coast, such as canoeing and fishpond locations. These cultural activities are likely to be more vulnerable to SLR than activities practiced more inland. Along with focusing on how Hawaiian cultural activities along the coast are affected by tidal flooding, this study also focuses on how general outdoor and water-related recreational activities practiced along the coast are affected. These included boating, swimming, surfing, picnics, bicycling, fishing, and scenic locations.

1.3 HAWAII KING TIDE PROJECT

To better understand how tidal flooding impacts Hawaii, The University of Hawai'i Sea Grant launched a program titled the "King Tides Project." The King Tides Projects encouraged residents of Hawaii and the Pacific islands to photo document instances of coastal flooding within their community. This data collection method is known as crowdsourcing, which allows for a larger pool of data collection over a more extended period of time through the participation of community members (Molina, Joglekar, et al., 2016). As a result, a total of 3,305 photos within 2015-2019 were taken in Hawaii and 1,980 on Oahu (Figure 1.5). Many of these photos document coastal erosion, direct marine flooding, street and infrastructure flooding, and many more. These photo documentations are publicly accessible and have provided policymakers, scientists, and community members insight into how SLR has impacted Hawaii.

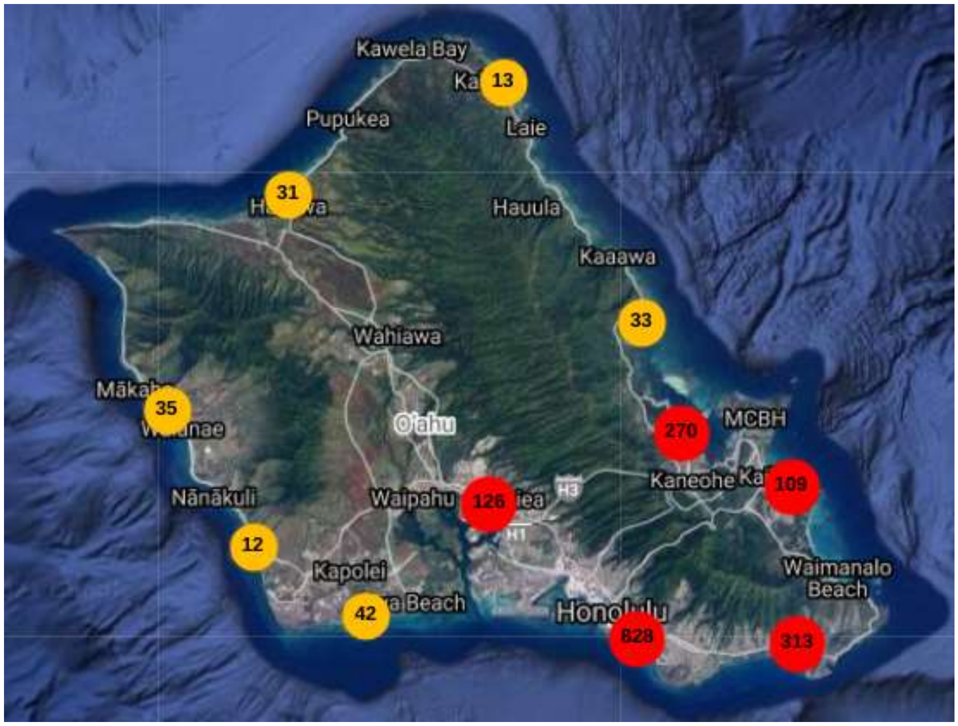


Figure 1.5 Photo Density Map Of Oahu Within The Hawaii King Tide Project: The southeast side of the island, particularly Honolulu (828) and Maunalua Bay (313) have the highest number of photo submissions. © Hawaii Sea Grant King Tides Project, <*2015-2019*>. Some rights reserved. Licensed under the Creative Commons Attribution 4.0 International License (**CC BY 4.0**).

Although crowdsourcing data allows for a larger pool of data to be collected, there are some limitations. Crowdsourcing data within this project has caused some regions of Oahu to be more represented than others. The southeast side of Oahu, particularly Honolulu and Maunalua Bay, has the highest photo documentation within the project due to the higher population density in these regions than low-density regions such as the north and west side of Oahu (Figure 1.5). There is a possibility that other areas of Oahu either have not experienced much impact or have not been reported equally despite impacts. This study tries to reduce such potential under-representation within the King Tides data by additional community survey to gain insight into other areas where SLR may impact Oahu. The survey also collects community members' inputs about their preference of SLR adaptations measures.

1.4 SEA LEVEL RISE ADAPTATIONS

Assessing the vulnerability of each recreational and cultural location is crucial for adaptation and decision-making. Various SLR adaptation techniques such as seawalls can negatively impact cultural and recreational access, coastal erosion, and coastal marine ecosystems. One adaptation will not be suitable for all of Oahu, as the impacts of SLR vary from each region. By considering how SLR affects each region and the types of flooding that have occurred, this study can help identify potential adaptation strategies that accommodate community needs.

Selecting effective adaptations to SLR has been an essential debate for coastal planning. There are many different approaches to adaptation, such as retreat, accommodation, and protection (Figure 1.6) (IPCC, 1990). Economically, retreat would negatively impact coastal landowners due to the loss of property and the cost of rebuilding infrastructure (IPCC, 1990). Environmentally, retreat would expand the original beach area to combat soil erosion and would not have a negative impact on marine ecosystems (IPCC, 1990). Due to high urbanization along the coast, the cost of retreating at-risk coastal areas and rebuilding infrastructure and homes at a higher ground will be costly (Gibbs, 2016). There are three approaches to retreating high flood risk areas: pre-emptive, just-in-time, and reactionary (Gibbs, 2016). A pre-emptive retreat can include relocating existing structures before impact or preventing new structures from being built along the coast (Gibbs, 2016). The just-in-time approach includes retreating before SLR significantly affects existing structures (Gibbs, 2016). Following a natural disaster or a flooding event, the reactive retreat is usually implemented to relocate communities within high-risk areas (Gibbs, 2016).

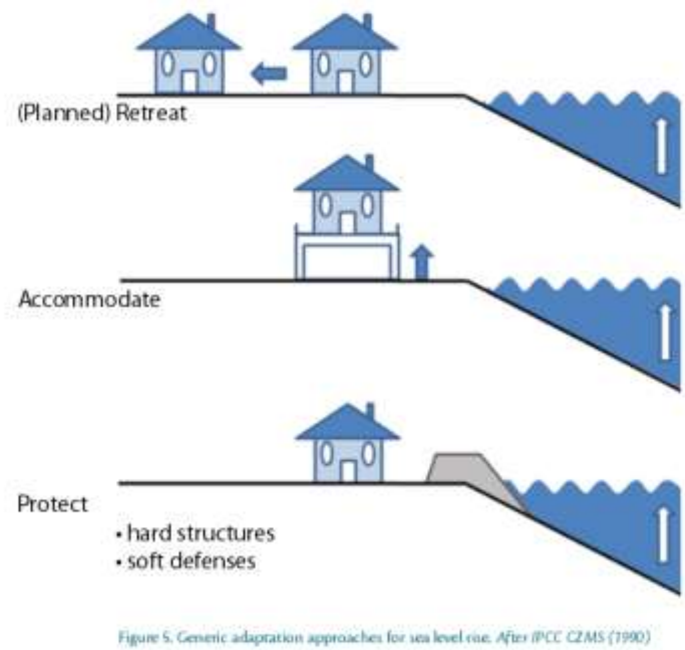


Figure 1.6 Visualization Of Retreat, Accommodation, & Protection (IPCC,1990, pp. 2).

Similar to retreating, accommodation does not focus on preventing the land from becoming flooded but finding ways for people to utilize the area at risk (IPCC, 1990). Common accommodation methods can include updating infrastructure to allow water to drain out of the structure with minimal damage, known as wet proofing (British Columbia Ministry of Environment, 2013). This method also includes dry-proofing infrastructure, such as elevating or creating a non-habitable space on the lower level of homes or buildings (British Columbia Ministry of Environment, 2013). Accommodation does not significantly impact marine ecosystems, but economically, there would be a change in property values and costs for adapting infrastructure along the coast (IPCC, 1990).

Depending on the priorities of stakeholders and values of residential communities, particular protective adaptations measures to SLR are not as accepted as others. Unlike accommodation and retreat, protection focuses on preventing the land from being flooded by implementing hard and soft structures such as sea walls, dikes, beach nourishment, and vegetation (IPCC, 1990). In Hawaii, protection measures such as beach nourishment and shoreline hardening have been the most common adaptation method (Onat, Yaprak, et al., 2018). For example, soft structures such as maintaining and restoring wetlands prioritize water quality and preserving habitats for vulnerable species could slow down erosion by acting as a buffer to storms themselves (U.S. EPA, 2009). Many protective adaptation options that prioritize specific goals that have their tradeoffs. Beach nourishment is another soft adaptation that involves adding sand to eroded beaches extending the shoreline but will need periodic maintenance that can become costly (U.S. EPA, 2009). Hard structure adaptations such as hardening shorelines with a sea wall are a quick fix to flooding issues but can induce further erosion along adjacent beaches and affect intertidal habitats (U.S. EPA, 2009).

This study will consider multiple factors, such as the frequency of tidal flooding, projected SLR, community preference, recreational and cultural usage, and infrastructure vulnerability, to propose adaptation strategies that preserve cultural and recreational functions. By analyzing the unique factors of different regions in the case study area, this study intends to propose the most suitable types of adaptation for each region on Oahu.

1.5 RESEARCH OBJECTIVES

Using crowdsourcing data, geographical information system data, and information collected from community surveys, this study aims to understand how communities' use of cultural and recreational assets is being affected by tidal flooding and what their concerns are with future sea level rise. The specific objectives of this project are to:

1. Analyzing the crowdsourcing data collected through Hawaii King Tide Project to understand the local concerns and priorities related to the impacts of tidal flooding on cultural and recreational activities
2. Validate and complement the findings from crowdsourcing data with community insight on cultural and recreational values and their adaptation preference through surveys.

The findings could help to strengthen residents' understanding of how SLR will affect the community's use of coastal cultural and recreational assets, with the hope to trigger the inner dialogue between local community members and decision makers as to how best to preserve or adapt crucial cultural and recreational assets to the impacts of SLR.

2.0 METHODS

2.1 STUDY DESIGN

Crowdsourcing geospatial photo data for the study area, the island of Oahu, was obtained from the Hawaii King Tides Project. The geocoded photos are processed based on thematic coding to create thematic maps to display the experienced impacts. “Authoritative” projected flooding maps will then be used to identify and validate sites that are experiencing tidal flooding within Oahu. Questionnaires will be distributed through an online survey to collect data from concerned environmental groups and neighborhood boards to gather community inputs on their value perception and adaptation priorities to complement the Hawaii King Tides Project. Questionnaires will also be utilized to assess the cultural and recreational significance of planning regions to support adaptation decision-making.

2.2 DATA COLLECTION

Participants within the Hawaiian King Tide Project were asked to document areas within Hawaii where tidal flooding has occurred and the impacts it has had on their community. Within the state of Hawaii, there are 3,305 photos from 2015-2019; for this project, only pictures of Oahu will be analyzed, which makes up 1,980 of the 3,305. Similar to auto-photography, crowdsourcing allows the participants to take and choose photos that represent their own perspective, which offers a way to look at the participants’ world through their eyes (Glaw, Inder, 2017). Within this study, the images taken by residents of Oahu will provide insight and highlight the various ways tidal flooding has impacted their everyday lives. However, this data collection method also leaves room for error and gaps. It potentially causes some locations to be more underreported than others, which prevents understanding the full impacts of tidal flooding in each region of Oahu.

2.3 IMAGE THEMATIC CODING ANALYSIS

Thematic analysis is an analytical technique for analyzing photos and reporting patterns within the data collected (Glaw, Inder, et.al, 2017). One researcher categorized each photo based on a coding scheme (Table 2.1). To test the coding scheme, two researchers then utilized the coding scheme to individually analyze the photos and then compare the consistency of their results. During this process, the research team has discussed and resolved the definitions of categories and coding rules. The process for coding photos from the Hawaiian King Tide data was based on the steps mentioned in Glaw, Inder, et.al, (2017) and was modified to fit this project.

Step 1: Collect Oahu photo data from the Hawaiian King Project.

Step 2: Code data based on common themes within the photos and research question.

- Photos were coded based on cultural and recreational activities being practiced and infrastructure being affected by flooding. Categories for cultural and recreational activities include bicycling, fish ponds, running, surfing, picnic, fishing, canoeing, boat harbor, and swimming. Categories for infrastructure include canals, roads, parking, homes, and storm drain.
- Coding scheme table:

Theme	Codes
Cultural	Fishponds
	Canoe Paddling
Recreational	Boat harbors

	Beach Parks
	Surfing
Other Infrastructure	Storm drain
	Roads
	Parking
	Homes

Table 2.1 Coding Scheme Table

Step 3: Data is then finalized as attributes to the georeferenced locations and geocoded to create the thematic map. Table 2.2 shows an example to process one of the images showing road infrastructure at risk.

Step 1:	
Step 2:	**Theme:** Infrastructure **Code:** Road

Step 3:	

Table 2.2 Image Thematic Coding Example

2.4 ONLINE SURVEY

An online survey was conducted and sent to concerned expert groups such as neighborhood boards, planning agencies, and community organizations to complement the data crowdsourced from the general public within the King Tides Project.

The rate of reporting in the King Tides Project was relatively proportional to the number of population for each region of Oahu, making areas such as Honolulu to be more reported than others. Through the survey, additional information was retrieved regarding the frequency of flooding and what activities are practiced in other underrepresented areas. The online survey was held on google forms and sent to University of Hawaii at Mānoa students, 10 coastal neighborhood boards on Oahu, 14 planners and scientists, and 16 environmental nonprofits groups, all of which are actively involved or concerned about sea level rise and climate adaptation. In total, 37 respondents fully completed the survey, which provided more insight into the community preferred SLR adaptations and cultural and recreational practices. 11 respondents were urban planners and scientists, 15 were University of Hawaii at Mānoa students, one neighborhood board member, and 10 environmental nonprofits. The survey has also been approved by the Office Of Research Compliance Human Studies Program. The data collected was analyzed and presented in Chapter 4. (See Appendix Table 6.9 for survey questions).

2.5 PASSIVE FLOODING MAPS

The passive flooding map created by scientists within the University of Hawaiʻi Sea Grant College Program flooding layer uses a "bathtub" approach to analyze SLR and only compares water level to land elevation (Figure 2.1) (Gallien, Sanders, et al., 2014). The passive flooding map considers marine/overland flooding and groundwater/storm drain flooding (Anderson, Fletcher, et al., 2018). The passive flooding map does not include seasonal waves, storm surges, or coastal erosion, which can be detrimental to coastal communities (Anderson, Fletcher, et al., 2018). Using data from Hawaii tide gauges that measure changes in sea level height, Anderson et al. (2018) created four SLR scenarios based on present conditions in 2015. The resulting maps display the projected sea levels for the year 2030 at .5 ft, 2050 at 1.1 ft, 2075 at 2 ft, and the year 2100 at 3.2 ft of SLR (Anderson, Fletcher, et al., 2018). Due to the passive flooding layer relying on a "bathtub" approach, the layer is a conservative projection of how SLR will impact Hawaii as there has been a significant land cover of Hawaii that has been ignored in this scenario (Anderson, Fletcher, et al., 2018).

Figure 2.1 Passive Flooding Projection of 3.2 ft For Waikiki PacIOOS (2017)

The 3.2 ft passive flooding layer projection will be utilized within this study to explore what cultural and recreational locations are vulnerable to SLR. A 3.2 ft passive flooding map will be created to display the inundation of cultural and recreational locations identified with the King Tides data. Another flooding map, created using data obtained from the Hawaii Statewide GIS Program developed by the Hawaii Office Of Planning and 3.2 ft passive flooding layer, will be utilized as an authoritative map to display specific locations of the vulnerable cultural and recreational assets. I will compare these two maps to identify what cultural and recreational locations may be underrepresented within the King Tides data.

3.0 RESULTS

This section presents the findings of the king tide data analysis and image thematic coding analysis. Figure 3.1 displays which categories have the highest photo documentation overall for Oahu in the King Tides Project. Cultural locations utilized for picnicking (32%) and surfing (26%) had the highest reporting frequency within the King Tides data (Figure 9). Infrastructure for roads (17%) and homes (15%) was the second-highest reporting category, while recreational locations such as canoe paddling (8%) and fishponds (8%) had the lowest documentation (Figure 3.1). The fluctuation in the documentation within Oahu could result from the difference in the population density of each region. Documentation rates could also result from categories such as infrastructure, culture, and recreation being more affected by SLR in some areas than others. This will be further assessed in the upcoming sections.

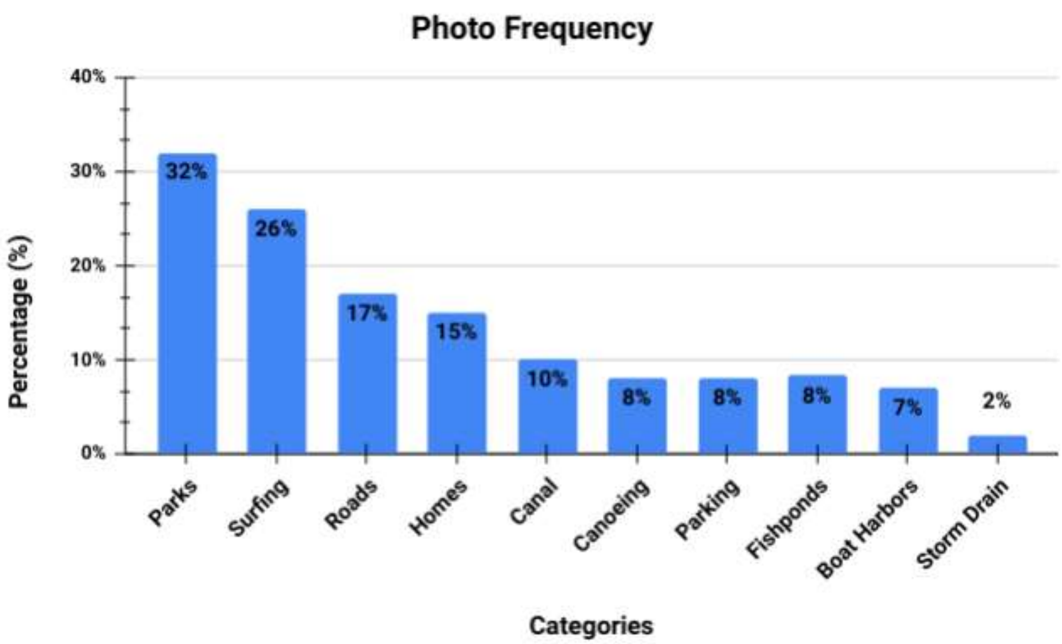


Figure 3.1 Photo Frequency Of King Tides Project: Within the King Tides Project, 1,980 photos documentations are of Oahu. The percentage of photo documentation within each created category displays which categories are of the highest risk to tidal flooding. Recreational locations and infrastructure have the highest rate of documentation within the King Tides Project. (Refer to Table 6.1).

3.1 FLOODING IMPACTS ON CULTURAL ACTIVITIES

Fishponds and canoeing locations within the cultural category seem to be heavily affected by flooding under all SLR projection scenarios (Figure 3.2). Out of the 165 photo documentations of fishponds impacted by tidal flooding, the He'eia fishpond location had the highest documentation within the King Tides project (Figure 3.3 & Table 6.2). At 3.2 ft, 50% of the documented fishpond locations will be affected by flooding; in particular, the He'eia fishpond will be completely submerged (Figure 3.2 & Figure 3.4). The photo documentation within the King Tide data of fishpond locations may have been underreported as there seem to be various other locations such as Kaewai and Loko Ea that would also be affected (Figure 3.3). Out of the 150 photo documentations of canoeing, 61% of those locations will be affected by 3.2ft of SLR (Figure 3.2 & Table 6.2). Honolulu and Maunalua Bay are the highest documented locations where canoeing locations are being affected by SLR (Figure 3.5). There was no additional data to complete a further analysis to determine if canoeing locations have been under-represented within the data. These results imply that current canoeing and fishpond locations documented between 2015-2019 are expected to be significantly impacted by SLR in the near future.

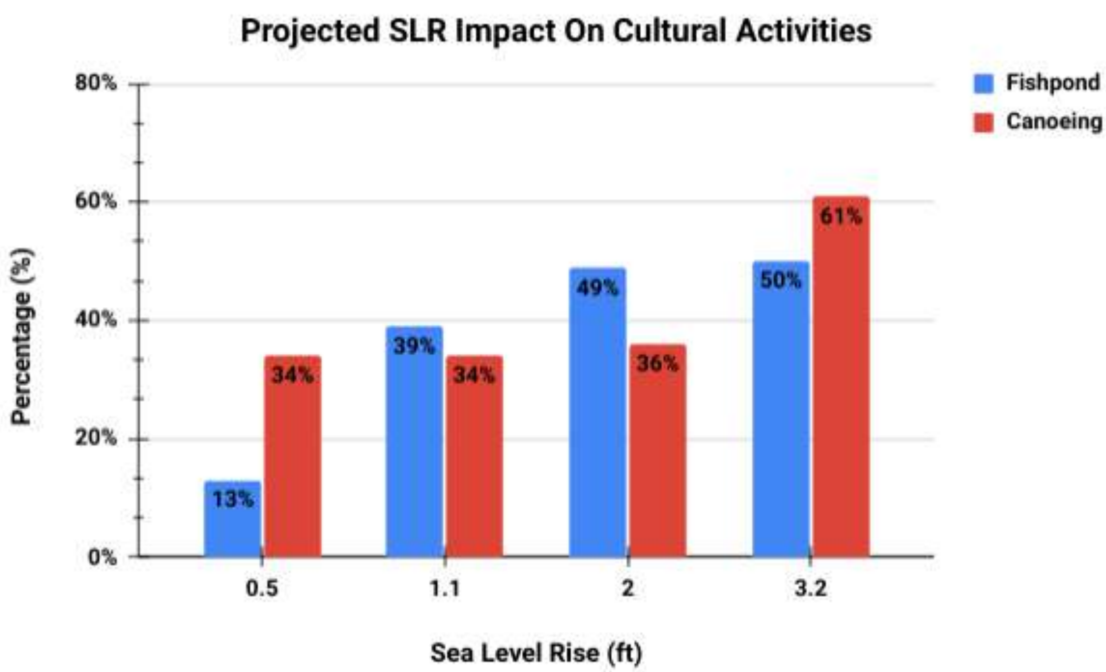


Figure 3.2 Projected Sea-Level Rise Impact On Cultural Activities The specific location of each photo documentation within the King Tides data was overlaid with projected SLR layers that displayed Oahu at .5 ft, 1.1ft, 2ft, and 3.2 ft. As a result, the percentage of photos within the cultural category that overlapped with SLR projection layers displayed how SLR would impact fishpond and canoeing locations. Overall within the King Tides, data of fishpond and canoeing locations have a high vulnerability to SLR within each SLR projection. (Refer to Table 6.2).

3.1.1 FLOODING IMPACTS ON FISHPONDS

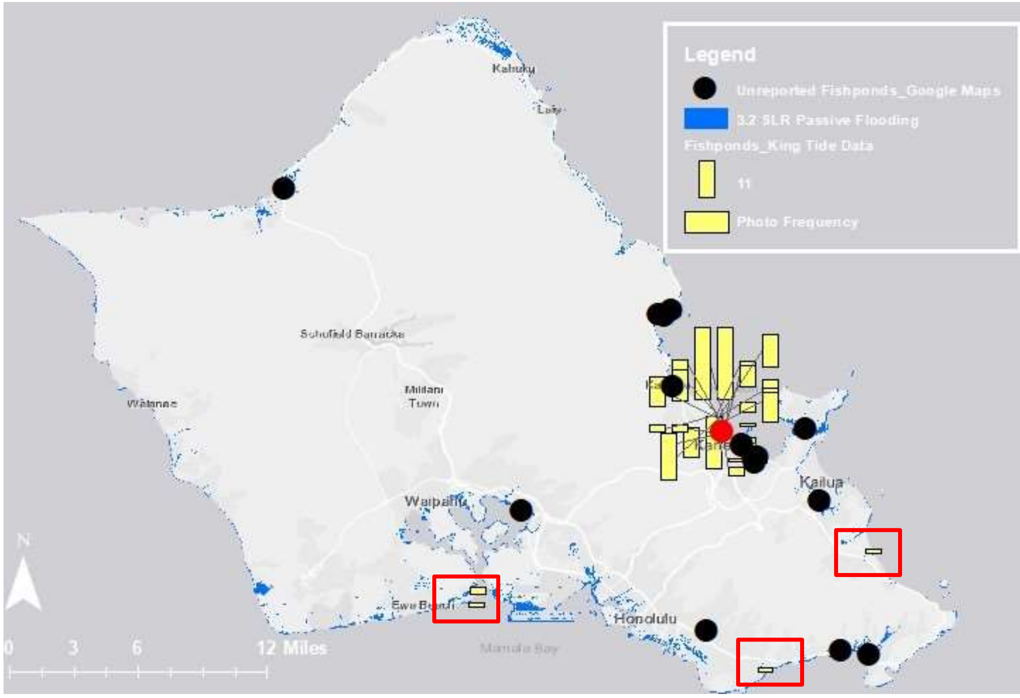


Figure 3.3 Oahu Fishpond Locations Affected By 3.2 ft Of Passive Flooding: Fishpond locations reported within the King Tides project are identified by yellow bars to represent the rate of photo frequency. An additional layer of fishpond locations, according to google maps, were overlaid to determine which sites were underrepresented within the King Tides Project. The black points represented unreported fishpond locations, while the red point confirms that the fishpond location has been documented within the King Tides Project. The red rectangles are used to highlight the small photo frequency locations. There seems to be heavy underrepresentation of fishpond locations within the east and southeast region of Oahu. Fishpond data collected from Hawaii King Tide Project. Passive flooding layer composed from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.4 He’eia Fishpond, Oahu Affected By 3.2 ft Of Passive Flooding: The He’eia fishpond is the most documented fishpond location within the King Tides Project (Figure 3.3). This map displays the effect of 3.2 ft of passive would have on this location. When the layers are overlaid the He’eia fishpond seems to be completely submerged. Fishpond data collected from Hawaii King Tide Project. Passive flooding layer collected from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.5 Current Flooding Conditions Of He’eia Fishpond, Oahu: Water is overflowing the fishpond barrier wall (left) and walkway (right). Images taken by Rebeca Zamora, Hawaii King Tides Project, 2017.

Fishponds are significantly critical aquaculture systems that displayed ancient Hawaiian engineering and agricultural skills (Kikuchi, 1976). Not only were fishponds used for aquaculture, but they had tremendous cultural significance as well. Fishponds were symbols of a chief's political power and were also sacred places because of their spiritual power and presence of Akua (gods) and Aumakua (ancestral gods) (Hlawati, 2002). Before contact with westerners, there were nearly 488 fishponds estimated to be located in Hawaii (Kikuchi, 1976). There are not as many fishponds today as there were in the 20th century due to urban development, floods, and tsunamis (Kikuchi, 1976). In 1901, only 99 out of the 360 fishponds identified were active in Hawaii (McDaniel, n.d.). The restoration and preservation of fishponds are essential in protecting Hawaiian history and culture and focus on many nonprofit groups in Hawaii today.

In the King Tides Project, there were a total of 165 photos from 2015-2019 documenting instances when fishponds were impacted by tidal flooding (Table 6.2). In particular, the King Tides photos display that direct marine flooding was the cause of the documentation (Figure 1.2). Out of the 165 photos, 13% of the photo-documented locations will be impacted further by .5 ft of SLR, 39 % at 1.1ft, 49% at 2ft, and 50% at 3.2 ft of SLR (Figure 3.2). The most reported location within the King Tides data is the He'eia fishpond (Figure 3.3). The He'eia fishpond was constructed 800 years ago and is now managed by a nonprofit organization named Paepae O He'eia that focuses on preserving the fishpond and keeping it active. When the He'eia fishpond is overlaid with the 3.2 ft passive flooding layer, the entirety of the fishpond is projected to be affected by SLR (Figure 3.4). A map layer of fishponds locations based on google maps was overlaid with the 3.2 ft projection layer to confirm the King Tides project findings and determine if there was an underrepresentation of photos within the database. When the 3.2 SLR layer and a google map of fishpond locations are overlaid, it shows that even more fishponds, specifically the Kanewai fishpond in Maunalua Bay, Loko Ea fish pond in Aiea, Loko in Ea Haleiwa, along with other fishponds within Kaneohe, may be impacted by SLR (Figure 3.3).

The He'eia fishpond receives freshwater input from nearby streams and saltwater through the fishpond wall barrier (Young & Williams, 2011). The fishpond gates allow for the fishpond overseers to manage a healthy balance of fresh and saltwater sources for the fish living within the pond (Young & Williams, 2011). The increase in water pressure resulting from heavy rainfall and flooding events often causes the walls to burst and change the nutrient composition of the fishpond (Young & Williams, 2011). An example of this event occurred in 1927 and 1965, where the He'eia fishpond wall burst due to extreme flooding and was not fully repaired until 2015 (Young & Williams, 2011). Current flooding conditions display that the He'eia fishpond is already at risk of damage to the fishpond barriers in the event of a heavy flood (Figure 3.5).

As climate change is expected to impact the amplitude, frequency, and seasonal timing of weather events such as El Nino, the He'eia fishpond will likely see an increase in structural damage and fish deaths (McCoy, Daniel, et al., 2017). In particular, the 2009-2010 El Nino created hypoxic conditions within the He’eia fishpond due to the abrupt increase in sea surface temperature and weakened trade winds (McCoy, Daniel, et al., 2017). As a result, 3,000 *(Pacific threadfin (Polydactylus sexfilis, Moi*) fish died within a short time frame of May 24-29, 2009, along with 10,000 Moi fish on October 10, 2009 (McCoy, Daniel, et al., 2017). As climate change is projected to increase the severity of weather events, certain efforts implemented by fishpond overseers will play a critical role in the survival of the He'eia fishpond (McCoy, Daniel, et al., 2017). Such as installing artificial aeration systems to reduce fish hypoxia or relocating fishpond gates closer to sites with the highest water flow rate to reduce hypoxia and decrease water temperature (McCoy, Daniel, et al., 2017).

3.1.2 FLOODING IMPACTS ON CANOE PADDLING

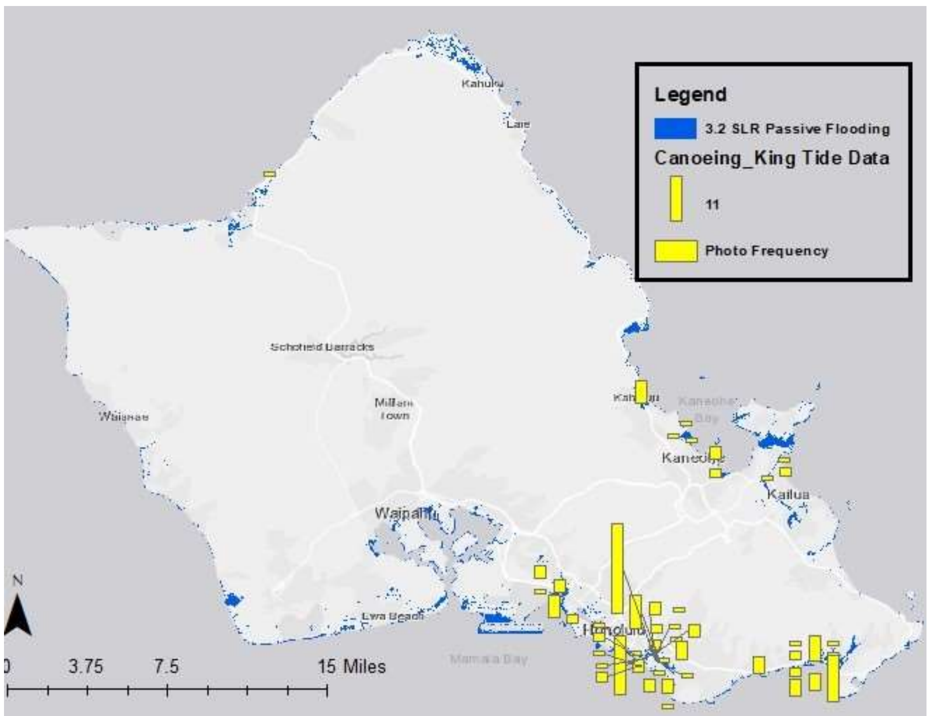


Figure 3.6 Oahu Canoe Paddling Locations Affected By 3.2 ft Of Passive Flooding: Canoe paddling locations documented within the King Tides data were overlaid with the 3.2 ft passive flooding projection layer. The canoe paddling locations within the southeast of Oahu seem to be the most documented and heavily impacted by 3.2 ft of SLR. Canoeing data collected from Hawaii King Tide Project. Passive flooding layer composed from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.7 Honolulu & Maunalua Bay, Oahu Canoe Paddling Locations Affected By 3.2 ft Of Passive Flooding: Canoeing locations within Honolulu (left) and Maunalua Bay (right), had the highest documentation within the King Tides data (Figure 3.6). This map displays that canoeing may be completely or partially submerged by 3.6 ft of SLR. Canoeing data collected from Hawaii King Tide Project. Passive flooding layer collected from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.8 Current Flooding Conditions Of Honolulu & Maunalua Bay, Oahu Canoe Paddling Locations: Water is overflowing within the Ala Wai Canal canoe paddling location (left). The Maunalua Bay canoe paddling location is experiencing an

overflow of water and erosion of the beach (right). Left image taken by Antoinette Freitas, Hawaii King Tides Project, 2017, and right image by Peggy Foreman Hawaii King Tides Project, 2017.

Canoe paddling is an essential cultural practice used for voyaging and navigation between islands (Ho-Latismosa, Hwang, 2014). Many nonprofit organizations use canoeing practices to pass down cultural knowledge through hands-on experiences. A nonprofit organization named God's Country Waimanalo utilizes the activity of canoe paddling to reteach pre-colonial Hawaiian voyaging and navigation practices to help develop cultural identity and a sense of community with Native Hawaiians (Ho-Latismosa, Hwang, 2014). A similar organization named the Polynesian Voyaging Society, founded in 1973, utilizes traditional canoe and sailing techniques to travel worldwide. The Polynesian Voyaging Society is widely known for its successful trip in 1999 taken by the Hōkūleʻa canoe across the three outer corners of the Polynesian Triangle (Polynesian Voyaging Society, n.d.). Preserving locations utilized for canoe paddling are essential to the restoration and preservation of Hawaiian culture and identity.

There were 150 photos from the King Tide Project that pictured canoe paddling being practiced within locations that have been impacted by tidal flooding (Table 6.2). Like the fishpond locations, direct marine flooding seems to be the type of flooding affecting canoe paddling locations (Figure 1.2). Out of the 150 photo documentations, 34 % of the sites documented will experience the impacts of SLR at .5 & 1.1 ft, and 36% at 2 ft (Figure 3.2). At 3.2 ft of SLR, 61% of the locations documented will be further affected by flooding (Figure 3.2). Canoe paddling locations within the southeast of Oahu, such as the Ala Wai Canal in Honolulu and along the beach coast of Maunalua bay, seem to be the most impacted by SLR (Figure 3.7). There were no other GIS map layers to do further analysis with the King Tide data to determine if other canoe paddling locations within Oahu were affected by SLR but were not reported.

In the event of heavy rainfall or flooding, canoe locations can become hazardous for canoe paddlers. The Ala Wai Canal is a popular canoe paddling location in Honolulu that often experiences flooding that often overflows within the canal (Figure 3.8). During heavy weather events, the channel becomes polluted due to sediment buildup and surface runoff that causes pesticides, trash, and fertilizer to enter the canal, resulting in health concerns or even illnesses for paddlers (Quach, Nguyen, et al., 2018). During extreme weather events, there is also an increased risk for paddlers to experience injury or drowning (Yonge, 2021). This is caused by the canoe becoming increasingly difficult to maneuver due to high tides and a higher chance of the canoe capsizing (Yonge, 2021).

3.2 FLOODING IMPACTS ON RECREATIONAL ACTIVITIES

Recreational activities within the Honolulu, Kaneohe, and Maunalua Bay region seemed to be the most affected by tidal flooding within the King Tides Project. More specifically, boat harbor locations in all three areas had the highest photo frequency within the King Tide Project (Figure 3.10). In contrast, only Honolulu and Maunalua Bay were the most impacted regions for picnicking on the beach and Honolulu for surfing activities (Figure 3.14 & Figure 3.18). Within the King Tide data, each recreational category seemed to be equally affected by 3.2 ft of SLR. 26 % of boat harbor locations were impacted by 3.2 ft, 24% beach park locations, and 17% for surfing (Figure 3.9). Within the photo database, recreational sites seem to be underrepresented, and there may be more recreational locations affected by SLR that have not been documented.

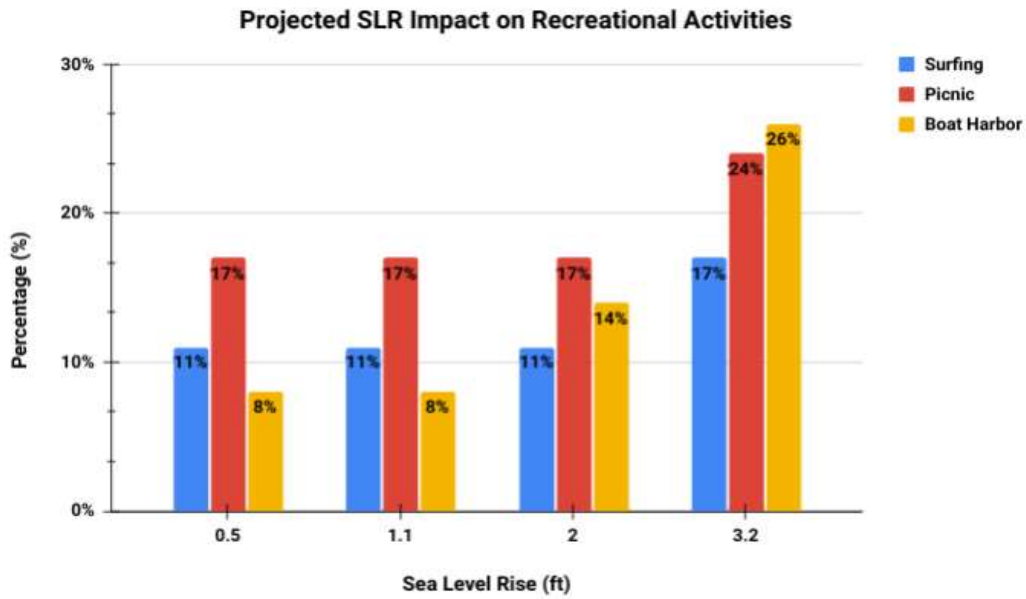


Figure 3.9 Projected Sea Level Rise Impact On Recreational Activities: The specific location of each photo documentation within the King Tides data was overlaid with projected SLR layers that displayed Oahu at .5 ft, 1.1ft, 2ft, and 3.2 ft. As a result, this graph shows the percentage of photos within each recreational category that overlapped with SLR projection layers, revealing how SLR would impact boat harbors, picnic, and surfing locations. Although the recreational data within the King Tides data may be underrepresented, each category has a relatively high vulnerability to SLR within each SLR projection. (Refer to Table 6.3).

3.2.1 FLOODING IMPACTS ON BOAT HARBORS

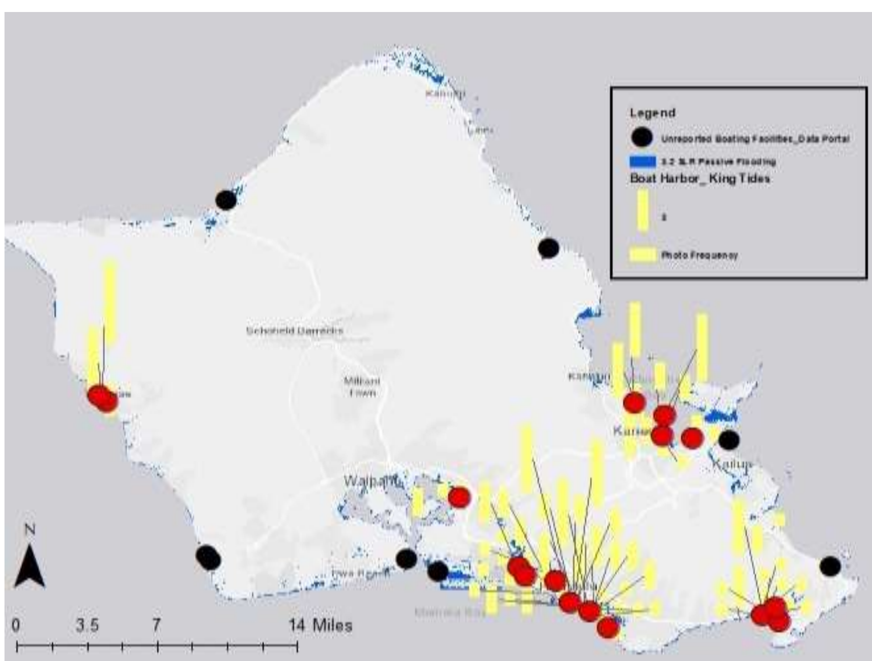


Figure 3.10 Oahu Boating Locations Affected By 3.2 ft Of Passive Flooding: Boat harbor locations reported within the King Tides project are identified by yellow bars to represent the rate of photo frequency. An additional layer of boat harbor locations from the Hawaii Statewide GIS Program was overlaid to determine which sites were underrepresented within the King Tides Project. The black points represent unreported boat harbor locations, while the red point confirms that the boat harbor location has been documented within the King Tides Project. Overall the resulting map confirms that boat harbor locations do not seem to be heavily underrepresented within the King Tides data. Passive flooding layer collected from (https://www.pacioos.haw aii.edu/shoreline/slr-hawaii/). Boat harbor layer collected from Hawaii Statewide GIS Program (https://geoportal.hawaii.gov/).

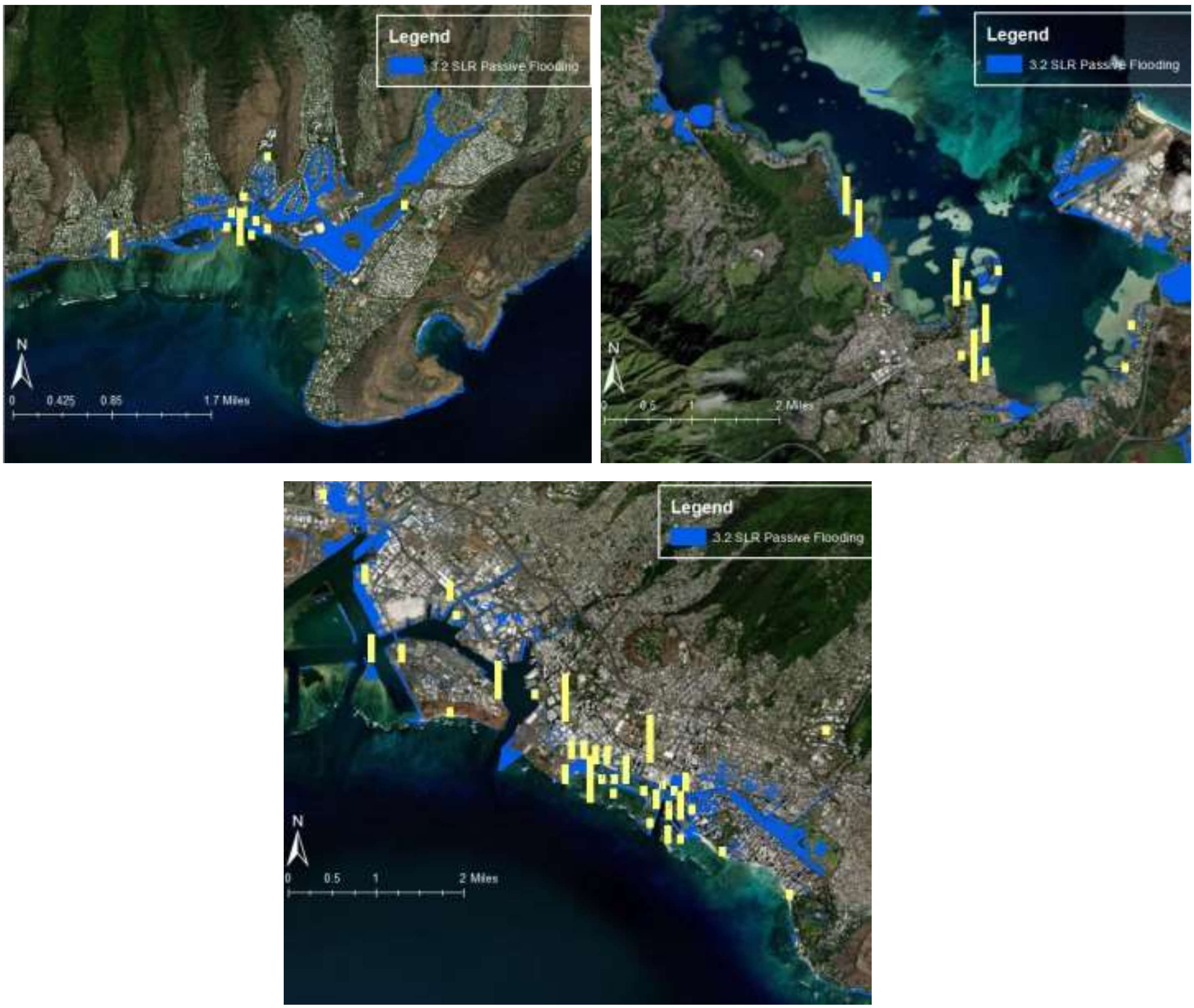


Figure 3.11 Maunalua Bay, Kaneohe, & Honolulu, Oahu Boating Locations Affected By 3.2 ft Of Passive Flooding: Boat harbors locations within Maunalua Bay (Left) & Kaneohe (Right) & Honolulu (Bottom) have the highest photo documentation within the King Tides Project (Figure 3.10). These maps display that boat harbor locations are most likely to be partially or completely submerged by 3.2 ft of SLR. Boat harbor data collected from Hawaii King Tide Project. Passive flooding layer collected from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.12 Current Flooding Conditions of Honolulu, Oahu Boat Harbor Locations: Water level has almost risen as high as the boating dock in both images. Left image n.d., Hawaii King Tides Project, 2017 and right image taken by Matthew Gonser, Hawaii King Tides Project, 2017**.**

From the 140 photos that documented tidal flooding impacting boat harbors in Oahu, there is a high number of photo documentations located in Honolulu, Kaneohe, Waimanalo, and Maunalua Bay (Figure 3.10). The photos within the dataset confirm that the rise in water level is a result of direct marine flooding (Figure 1.2). Based on the data collected 8% of the locations documented within the photos will be affected by .5 and 1.1 ft of SLR, 14% at 2ft SLR, and 26% at 3.2 ft (Figure 3.9). This implies that as time goes on boat harbors will continue to increase in vulnerability to SLR. To determine if there is underrepresentation within the data the 3.2 ft SLR layer is overlaid with a map layer from the Hawaii Statewide GIS Program displaying the exact locations of boat harbors in Oahu. The resulting map displays that boat harbor locations are not heavily underrepresented within the King Tides data except within the north region of Oahu (Figure 3.10). Although each site has been documented, there may have been under-representation in reporting the frequency of flooding. Current water levels display that boating docks are at risk of becoming partially or even fully submerged by water (Figure 3.12). As the water level is expected to increase, boating docks will need to be raised to higher elevations to avoid becoming unusable due to water overflow.

3.2.2 FLOODING IMPACTS ON BEACH PARKS

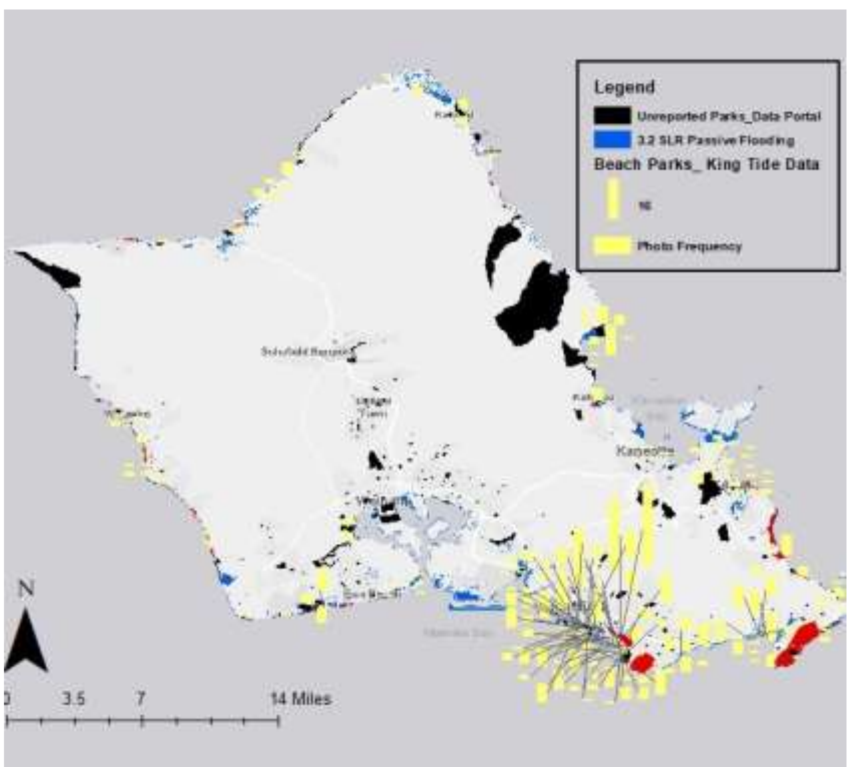


Figure 3.13 Oahu Beach Park Locations Affected By 3.2 ft Of Passive Flooding: Boat park locations reported within the King Tides project are identified by yellow bars to represent the rate of photo frequency. An additional layer of beach park locations from the Hawaii Statewide GIS Program was overlaid to determine which sites were underrepresented within the King Tides Project. The black areas represent unreported beach park locations, while the red regions confirm that the beach park location has been documented within the King Tides Project. The south region of Oahu had the highest documentation than the north, east, and west regions. Passive flooding layer collected from (https://www.pacioos.haw aii.edu/shoreline/slr-hawaii/). Beach park layer composed from Hawaii Statewide GIS Program (https://geoportal.hawaii.gov/).

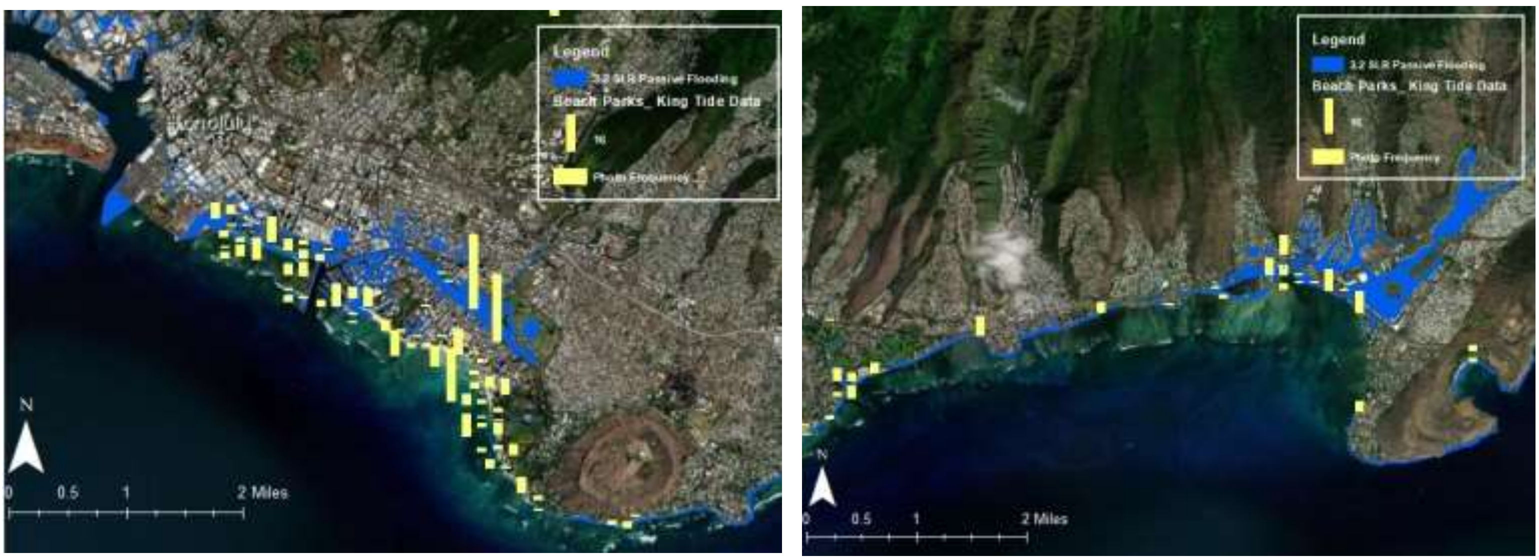


Figure 3.14 Honolulu & Maunalua Bay, Oahu Beach Park Locations Affected By 3.2 ft Of Passive Flooding: Picnic activities in Honolulu (left) and Maunalua Bay (right) have the highest photo documentation of beach parks within the King Tides Project (Figure 3.13). These maps confirm that beach park locations within Honolulu and Maunalua Bay are significantly vulnerable to SLR. Beach park data was collected from Hawaii King Tide Project. Passive flooding layer composed from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.15 Current Flooding Conditions of Waikiki and Kuhio Beach Parks: The water level has risen above the beach shoreline of both Waikiki (left) and Kuhio beach park (right), leaving no place for picking activities. Left image taken by Darren Okimoto, Hawaii King Tides Project, 2019, and right image taken by Matthew Gonser, Hawaii King Tides Project, 2016.

Beach parks are the center of community building and are home to many recreational activities. Many of the beach parks in Oahu were negatively impacted by direct marine flooding (Figure 1.2). Current flooding conditions lead many beach parks to suffer from coastal erosion and less shoreline for beachgoers to practice recreational activities such as picnicking (Figure 3.15). The photos within the King Tides data were coded according to beach picnic activities displayed within the image. Out of the 629 pictures of picnic locations impacted by tidal flooding, 17 % of those photos will be affected by SLR at .5 & 1.1 ft, 2 ft, and 24 % at 3.2 ft (Figure 3.13). Honolulu and

Maunalua had the highest image documentation within the King Tides data displaying how tidal flooding has impacted the beach picking experience (Figure 3.14). When the 3.2 ft passive flooding layer and beach park locations from the Hawaii Statewide GIS Program were overlaid, the resulting map confirms that picnic locations along the Honolulu and Maunalua Bay coast are significantly vulnerable to SLR (Figure 3.13). The Hawaii Statewide GIS Program layer also implies that there are other beach park locations within the north, east, and west side of Oahu that will be impacted by 3.2 ft and is under-documented within the King Tides data (Figure 3.13). The under documentation of the beach park locations is likely due to a higher population within the Honolulu and Maunalua Bay regions.

3.2.3 FLOODING IMPACTS ON SURFING

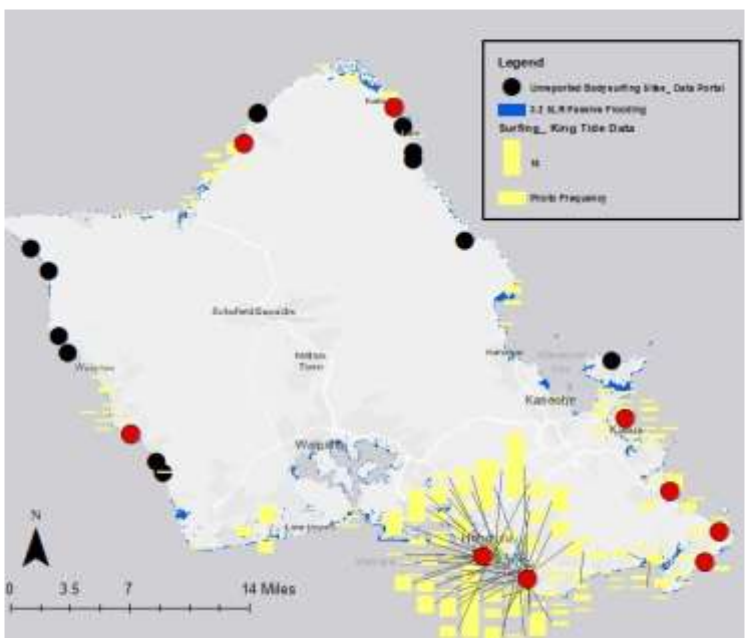


Figure 3.16 Oahu Surfing Locations Affected By 3.2 ft Of Passive Flooding: Surfing locations reported within the King Tides project are identified by yellow bars to represent the rate of photo frequency. An additional layer of body surfing locations from the Hawaii Statewide GIS Program was overlaid to determine which sites were underrepresented within the King Tides Project. The black points represent unreported

surfing locations, while the redpoint confirm that the surfing location has been documented within the King Tides Project. The map demonstrates that surfing locations were underrepresented within the north and west regions of Oahu. Passive flooding layer collected from (https://www.pacioos.haw aii.edu/shoreline/slr-hawaii/). Surf layer is collected from the Hawaii Statewide GIS Program (https://geoportal.hawaii.gov/).

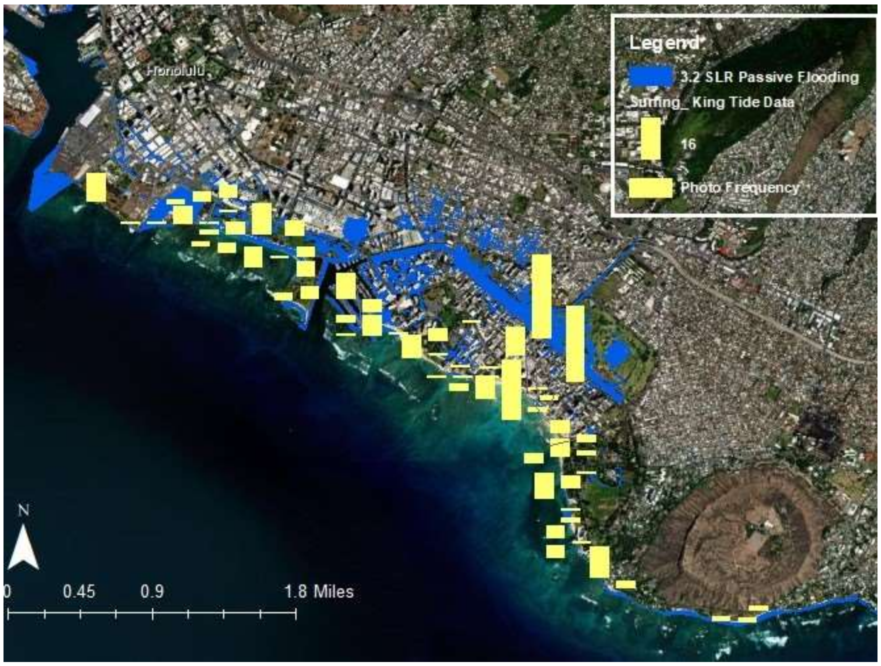


Figure 3.17 Honolulu, Oahu Surfing Locations Affected By 3.2 ft Of Passive Flooding: Honolulu had the highest photo documentation of surfing locations impacted by tidal flooding within the King Tides data (Figure 3.16). This map displays the vulnerability of the Honolulu region overlaid with 3.2 ft of passive flooding. Surfing data collected from Hawaii King Tide Project. Passive flooding layer collected from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.18 Current Flooding Conditions of Honolulu Surfing Locations: Water levels have risen to surfboard shacks along the shore in both images. Left image taken by Doug Miller, Hawaii King Tides Project, 2019, and right image taken by Darren Okimoto, Hawaii King Ties Project, 2017.

From the 514 surfing locations documented, 11% of these locations will be impacted by .5, 1.1, and 2ft of SLR, and 17% at 3.2 ft (Figure 3.9). As a result of direct marine flooding and a projected increase in sea level, the entry pathway into the beach for surfers is likely to be reduced to erosion and flooding (Figure 1.2 & 3.18). The Honolulu region has the highest photo documentation within the King Tides data due to a higher population within this region (Figure 3.16). To discover what areas of Oahu were under-reported, body surfing locations, according to the Hawaii Statewide GIS Portal, were overlaid with 3.2 ft of SLR (Figure 3.16). The resulting map displayed that Oahu's north and west regions were under-reported within the dataset (Figure 3.16).

3.3 FLOODING IMPACTS ON INFRASTRUCTURES

All infrastructure categories seem to be heavily impacted by 3.2 ft of SLR (Figure 3.19). 48% of roads, 47% canals, 45% storm drains, 39% of parking and 31% of homes, photo-documented within the King Tides project are infrastructures that are projected to be impacted by 3.2 ft (Figure 3.19). The Honolulu region was the highest reported location within infrastructure categories such as canals, roads, storm drains, and parking. Regions within Kaneohe and Maunalua were the most documented for homes affected by tidal flooding (Figure 3.23). With most infrastructure documentation occurring in Honolulu, there are potentially more locations that have been explicitly underrepresented in categories such as storm drains, parking, roads, and homes.

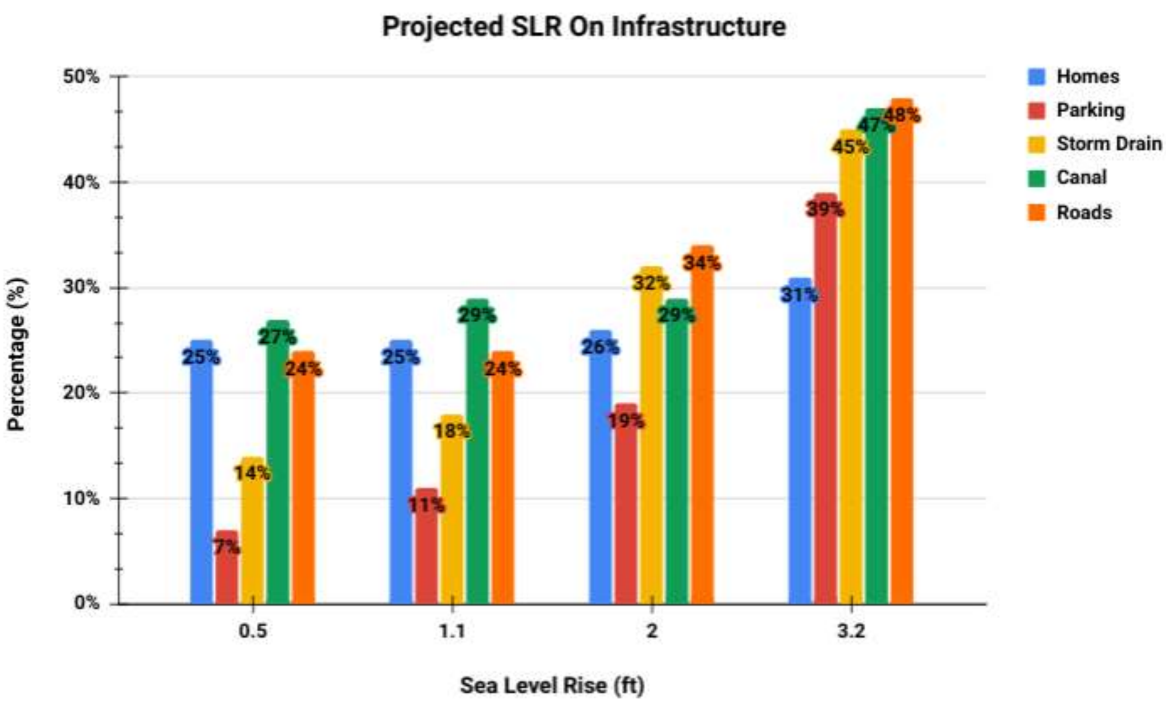


Figure 3.19 Projected Sea-Level Rise On Infrastructure: The specific location of each photo documentation within the King Tides data was overlaid with projected SLR layers that displayed Oahu at.5 ft, 1.1ft, 2ft, and 3.2 ft. As a result, the percentage of photos within the infrastructure category that overlapped with SLR projection layers

showed how SLR would impact homes, parking, storm drains, canals, and roads. Honolulu has the highest rate of photo documentation within each infrastructure category, and there are many regions within Oahu that have been underrepresented within the dataset. Even though infrastructure documentation within the King Tides data is low, each category is highly vulnerable to impacts of SLR within each projection layer (Table 6.1)

3.3.1 FLOODING IMPACTS ON CANAL

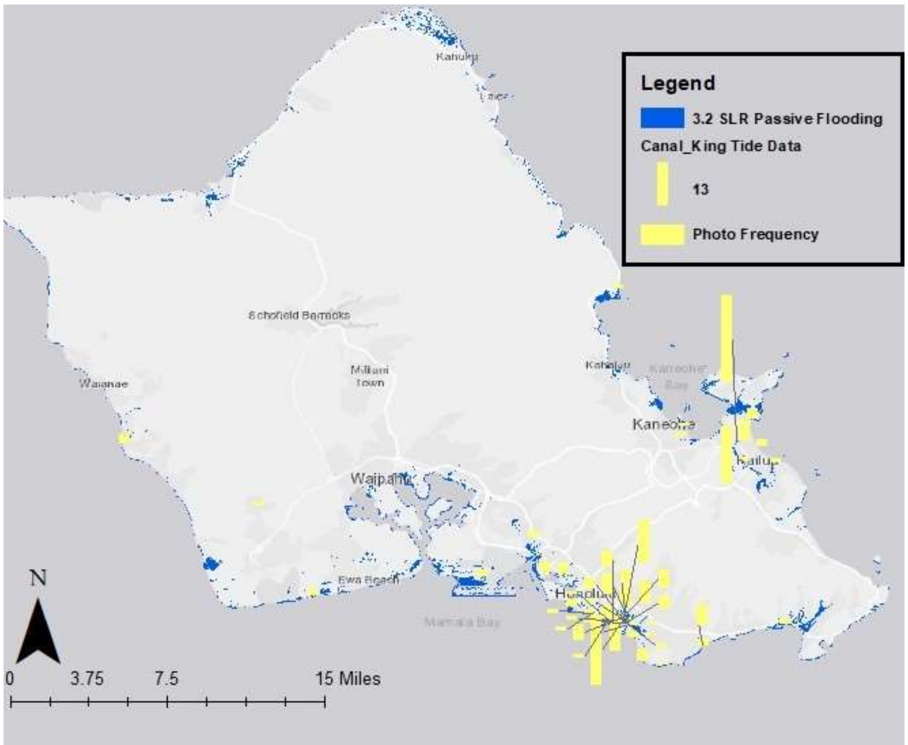


Figure 3.20 Oahu Canal Locations Affected By 3.2 ft Of Passive Flooding: Canal locations documented within the King Tides data were overlaid with the 3.2 ft passive flooding projection layer. Canal locations within Honolulu and Kailua were heavily recorded within the King Tide Project. Canal data was collected from the Hawaii King Tide Project. Passive flooding layer composed from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.21 Kailua & Honolulu, Oahu Canal Locations Affected By 3.2 ft Of Passive Flooding: Canal's in Kailua (Left) & Honolulu (Right), had the highest documentation within the King Tides Project (Figure 3.20). This map displays that the Kailua and Honolulu canal will be fully submerged at 3.2 ft of passive flooding.
Canal data collected from Hawaii King Tide Project. Passive flooding layer collected from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.22 Current Flooding Conditions of Ala Wai and Kailua Canal: The water level within the Ala Wai Canal has almost risen above the steps and onto the sidewalk (left). The water level within the Kailua canal seems to have risen onto the grass (right). Left image taken by Alex Roy, Hawaii King Tides Project, 2017 and right image taken by n.d., Hawaii King Tides Project, 2017.

Based on the photo data from the King Tide's Project, the canals in Kailua and Honolulu have the highest photo documentation of being impacted by direct marine flooding (Figure 3.21 & 3.22). From the 207 photos of tidal flooding impacting canals, 27 % of the photo locations will be affected at .5 ft of SLR, 29% at 1.1 & 2 ft, and 47% at 3.2 ft of SLR (Figure 3.19). Built in the 1920s, the Ala Wai Canal extends from the Ko`olau Mountains to Waikiki to drain coastal wetlands (USAE, 2020). As seen in (Figure 3.8), the Ala Wai Canal is also heavily used by the community for cultural uses such as canoeing. During a major flooding event, it is estimated that the Ala Wai Canal could damage nearly 3,000 structures and cost more than 1.14 billion to repair (USAE, 2020). When the Ala Wai Canal is then mapped with the 3.2 ft passive flooding layer, the resulting layer shows that the canal will be severely affected further by SLR (Figure 3.21). Similar to the Ala Wai Canal, the waterways in Kailua will also be severely affected by 3.2 ft of passive flooding (Figure 3.21).

3.3.2 FLOODING IMPACTS ON HOMES

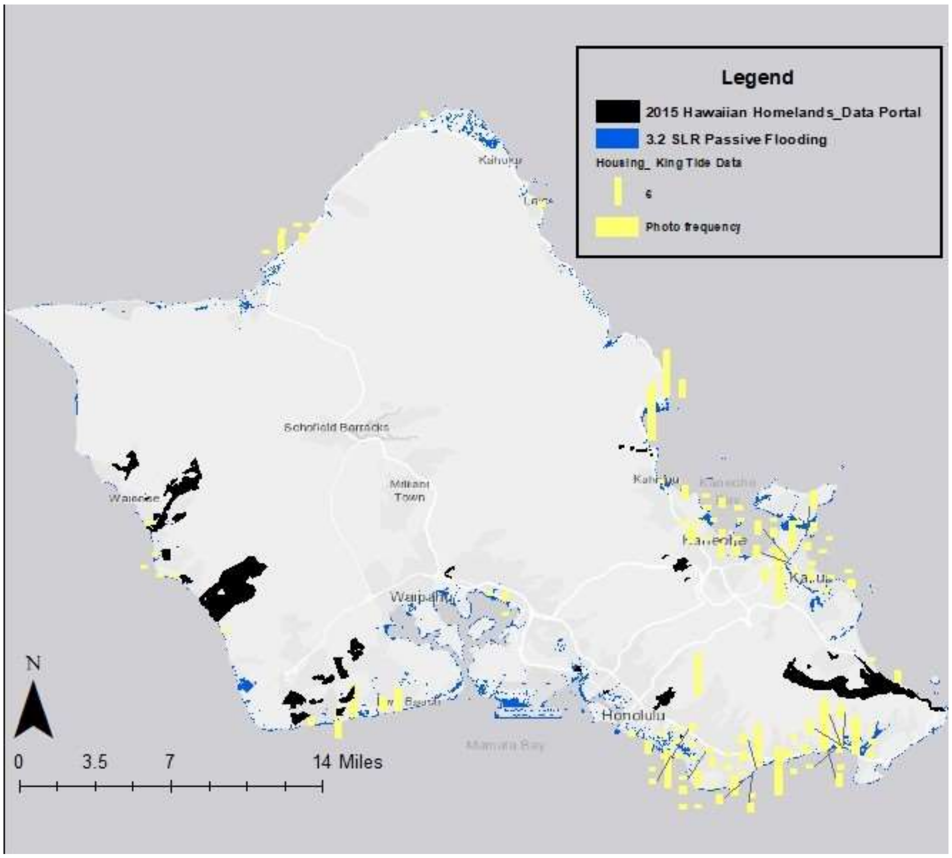


Figure 3.23 Oahu Homes Affected By 3.2 ft Of Passive Flooding: Housing locations reported within the King Tides project are identified by yellow bars to represent the rate of photo frequency. An additional layer of Hawaiian Homestead locations from the Hawaii Statewide GIS Program was overlaid to determine which sites were underrepresented within the King Tides Project. The black regions represent unreported housing locations, while the red regions confirm that the housing location has been documented within the King Tides Project. Homes collected from Hawaii King Tides Project. Hawaiian Homeland layer collected from Hawaii Statewide GIS Program (https://geop ortal.hawaii.gov/). Passive flooding layer collected from (https://www.pacioos. .edu/shoreline/slr\-hawaii/).

Figure 3.24 Kaneohe & Maunalua Bay, Oahu Homes Affected By 3.2 ft Of Passive Flooding: Homes in Kaneohe (Left) & Maunalua Bay (Right), where the most documented within the King Tides Project. Homes along the coast of these locations are likely to be partially submerged by 3.2 ft of passive flooding. Home data collected from Hawaii King Tide Project. Passive flooding layer collected from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.25 Waimanalo & Nanakuli, Oahu Hawaiian Homelands Affected By 3.2 ft Of Passive Flooding: Hawaiian Homelands along the coast of Waimanalo (Left) & Nanakuli (Right), seem to be at risk of 3.2 ft of SLR. Homeland layer collected from Hawaii Statewide GIS Program (https://geoportal.hawaii.gov/). Passive flooding layer collected from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.26 Current Flooding Condition Of Honolulu Homes: Beachfront homes in Honolulu experiencing high waves in both images. Left image taken by Karen Umemoto,

Hawaii King Tides Project, 2017 and right image taken by Kelly Ching, Hawaii King Tides Project, 2016.

Within the King Tides data, there were 289 photo documentations of homes that were being impacted by direct marine flooding, with 25% of the homes being affected by .5 & 1.1 ft of SLR, 26% at 2ft, and 31% at 3.2 ft (Figure 3.19). Maunalua Bay and Kaneohe had the highest number of photo documentation within the project and seemed to be the most at risk based on the King Tides data (Figure 3.24). Many Hawaiian Homeland locations were underrepresented within the King Tides Project. Hawaiian homelands provided permanent housing for native Hawaiians and were important to take into consideration when analyzing how SLR would affect housing. When overlaying the Hawaiian homeland map layer from the Hawaii Statewide GIS Program with the 3.2 ft of SLR, homes in Nanakuli and Waimanalo seem to be the most at risk areas to flooding (Figure 3.25). Current flooding conditions suggest that beachfront homes are severely vulnerable to flooding and were heavily under-reported within the King Tides data (Figure 3.26).

3.3.3 FLOODING IMPACTS ON ROADS

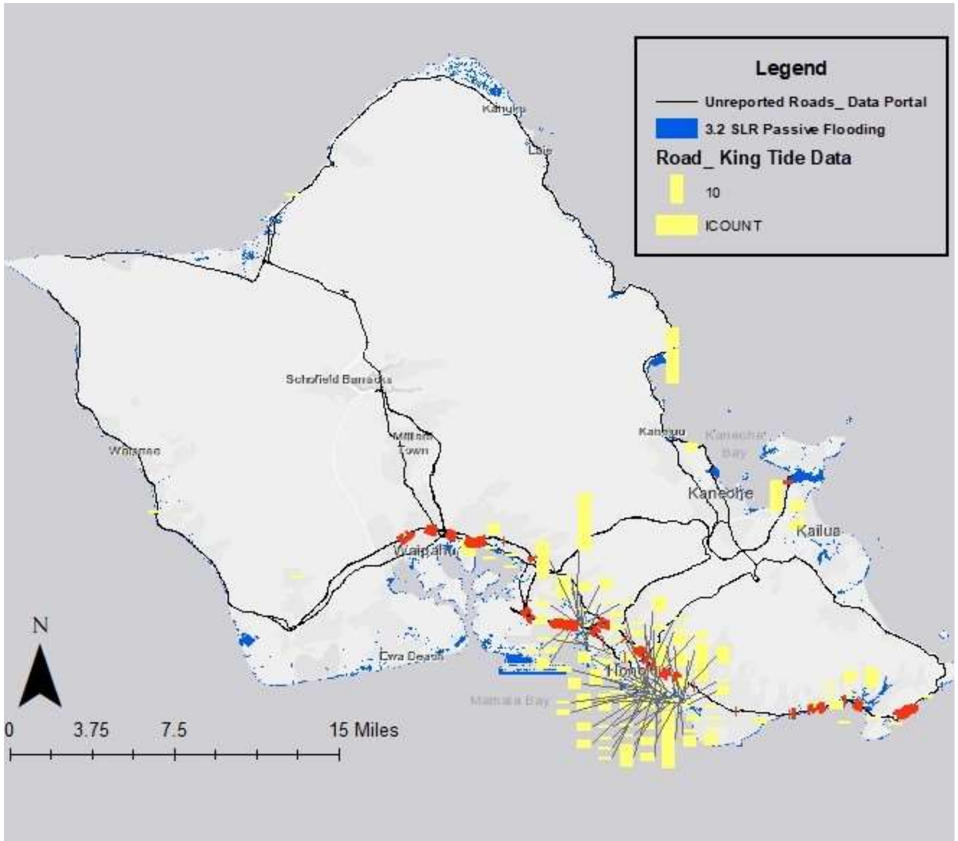


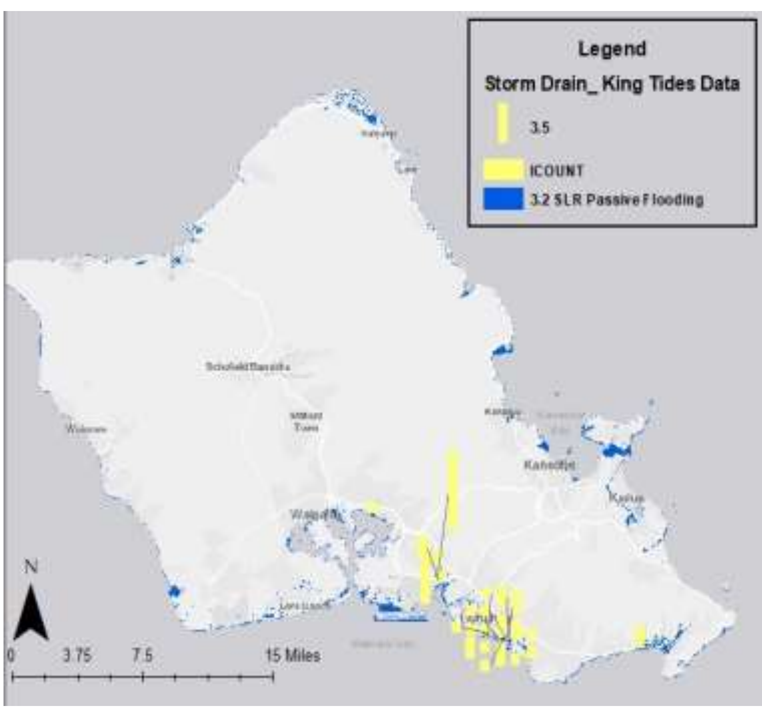
Figure 3.27 Oahu Road Locations Affected By 3.2 ft Of Passive Flooding: Roads reported within the King Tides project are identified by yellow bars to represent the rate of photo frequency. An additional layer of roads from the Hawaii Statewide GIS Program was overlaid to determine which sites were underrepresented within the King Tides Project. The black lines represent unreported roads, while the red lines confirm that the road has been documented within the King Tides Project. The map demonstrates that streets in Honolulu were heavily reported within the King Tides data. Passive flooding layer collected from (https://www.pacioos.haw aii.edu/shoreline/slr-hawaii/). Road layer is collected from the Hawaii Statewide GIS Program (https://geoportal.hawaii.gov/).

Figure 3.28 Honolulu, Oahu Road Locations Affected By 3.2 ft Of Passive Flooding: Roads in Honolulu were heavily documented within the King Tides data (Figure 3.26). The left map displays locations according to the King Tides project and the right map is according to the Hawaii Statewide GIS Program. The right map confirms that roads in Honolulu are likely to be partially flooded by 3.2 ft of passive flooding. Passive flooding layer collected from (https://www.pacioos.hawaii.e du/shoreline/slr-hawaii/). Road layer collected from Hawaii Statewide GIS Program (https://geoportal.hawaii.gov/).

Figure 3.29 Current Flooding Conditions of Honolulu Roads: Water level is tire high and above sidewalk (left). Left image taken by Mike Ching, Hawaii King Tides Project, 2017 and right image taken by Blane Heidani, Hawaii King Tides Project, 2016.

The impacts of tidal flooding on transportation were also reported within the King Tides Project. Out of the 335 photos of roads being affected by tidal flooding 24% of the photo locations will be impacted by .5 & 1.1 ft of SLR, 34 % at 2 ft, and 48% at 3.2 ft (Figure 3.19). The photos also display that roads were impacted by groundwater inundation as well as drainage backflow (Figure 2). When the King Tide photo layer and 3.2 SLR layer are overlapped, the resulting map projects Honolulu roads at a significantly high risk of flooding compared to other areas in Oahu (Figure 3.27). More specifically, roads along Waikiki and near the Alai Canal are at a higher risk and have the highest photo frequency (Figure 3.28). When the 3.2 ft SLR map layer and main road layer from the Hawaii Statewide GIS Program are overlapped, the resulting map confirms the findings from the King Tide data that roads in Honolulu are significantly at risk to SLR (Figure 3.28).

3.3.4 FLOODING IMPACTS ON STORM DRAINS



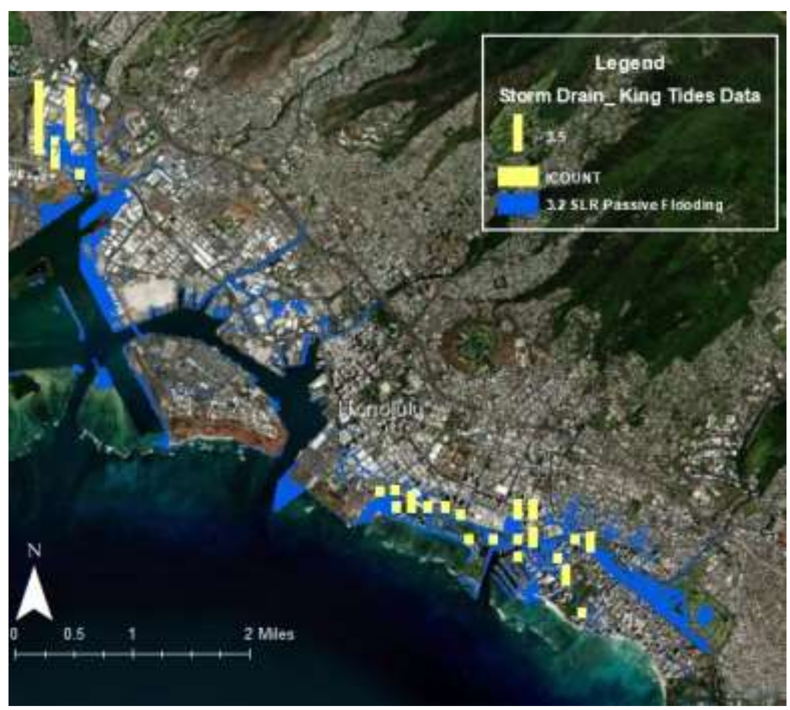


Figure 3.30 Oahu Storm Drain Locations Affected By 3.2 ft Of Passive Flooding: Storm drain locations that were documented within the King Tides data were overlaid with 3.2 ft of passive flooding. The left map displays storm drain documentations within Oahu as a whole, and the correct map shows the most documented region, Honolulu. Storm drain data collected from Hawaii King Tide Project. Passive flooding layer composed from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.31 Current Flooding Conditions Of Honolulu Storm Drains: Water is bubbling out of storm drain and on top of the roads in both images. Both images taken by Matthew Gonser, Hawaii King Tides Project, 2017.

Similarly to the road's in Honolulu being the most at risk to SLR (Figure 3.26), storm drains in Honolulu have the most photo documentation within the data (Figure 3.30). More specifically, the storm drains that seem to be most reported within the King Tide data are along the Ala Wai Canal and Waikiki beach (Figure 3.30). Out of the 165 photos documented, 14% of those locations will be impacted by .5 ft of SLR, 18% at 1.1 ft, 32 % at 2ft, and 45% at 3.2 ft (Table 6.4). The photos within the King Tides data revealed that drainage backflow and groundwater inundation are types of passive flooding affecting storm drains (Figure 1.2 & 3.31).

3.3.5 FLOODING IMPACTS ON PARKING

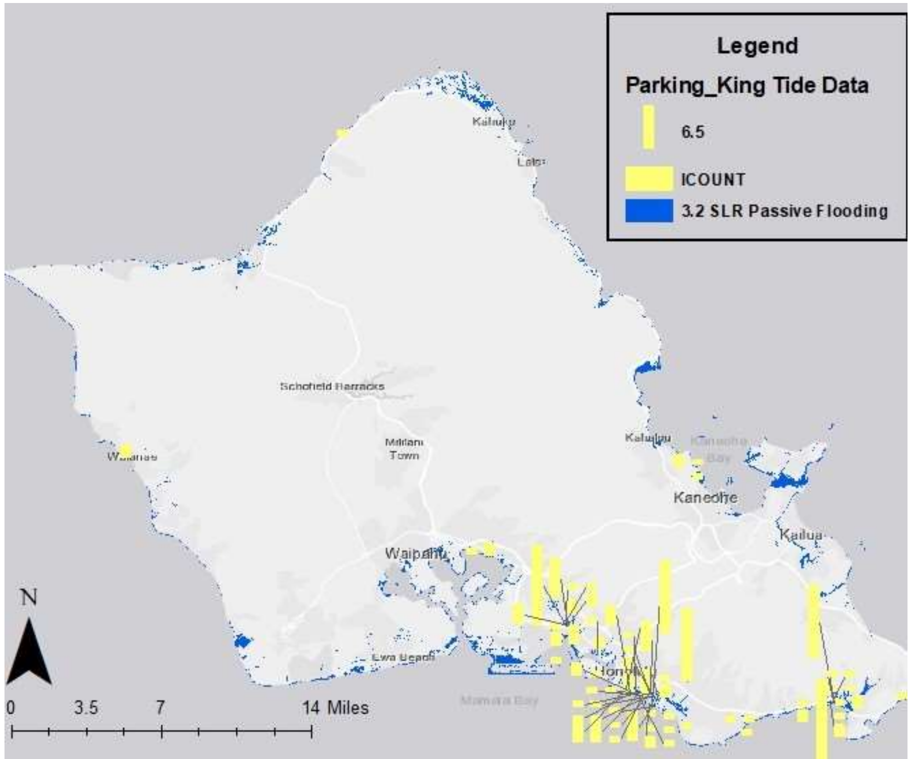


Figure 3.32 Oahu Parking Locations Affected By 3.2 ft Of Passive Flooding: Parking locations documented within the King Tides data were overlaid with a 3.2 passive flooding layer. The resulting map displays Honolulu and Maunalua Bay as the most reported. Parking data was collected from Hawaii King Tide Project. Passive flooding layer composed from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

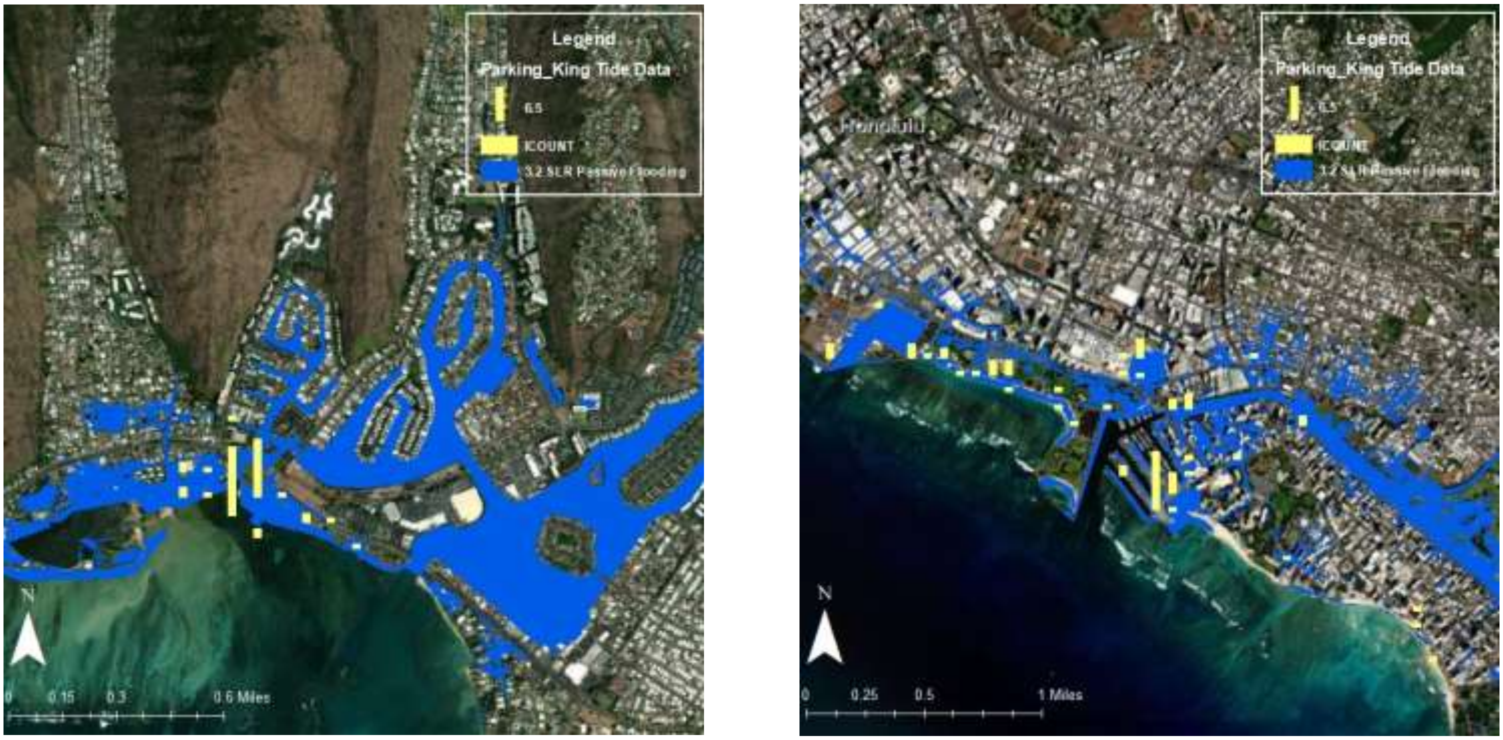


Figure 3.33 Honolulu & Maunalua Bay, Oahu Parking Locations Affected By 3.2 ft Of Passive Flooding: Parking in Maunalua Bay (Left) & Honolulu (Right) are likely to be fully and partially flooded by 3.2 ft of passive flooding. Parking data was collected from the Hawaii King Tide Project. Passive flooding layer composed from (https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/).

Figure 3.34 Current Flooding Conditions Of Honolulu Parking Locations: Parking garage is inundated by water. Image taken by Oryn Nakamura, Hawaii King Tides Project, 2017.

Similar to the road and storm drain map of Oahu projecting Honolulu to be the most at risk of SLR in terms of transportation (Figure 3.27 & Figure 3.30), parking in Honolulu has the highest photo documentation within the King Tides data (Figure 3.32). Inundation of parking locations within the King Tides photos results from groundwater inundation (Figure 1.2 & 3.34). Parking recorded within Honolulu is significantly impacted along Waikiki beach, Fort Shafter, and Ala Moana (Figure 3.33). Parking locations along the coast of Maunalua Bay also seem to be heavily affected by 3.2 ft of SLR (Figure 3.33). Out of the 165 photos documenting tidal flooding affecting parking locations, 7% of these locations will be affected by .5 ft of SLR, 11% at 1.1 ft, 19 % at 2.0 ft, and 39% at 3.2 ft (Figure 3.19).

4.0 DISCUSSION

4.1 FLOODING PERCEPTION VALIDATION

To validate and complement the king tide project data, an online survey was distributed to neighborhood boards, environmental nonprofits, urban planners, and scientists on Oahu to further understand the community perception of flooding impacts on cultural and recreational activities. Survey participants were asked questions regarding the location of tidal flooding, frequency, depth, and effects of flooding. Oahu were grouped into 8 regions based on the Hawaii City Planning districts: The Primary Urban Center, Central 'Oahu, East Honolulu, 'Ewa, Ko'olau Loa, Ko'olauPoko, North Shore, and Wai'anae (Figure 4.1) (City & County of Honolulu 2019). Utilizing these regions and maps, allowed the survey participants to easily identify the location of tidal flooding impacts.

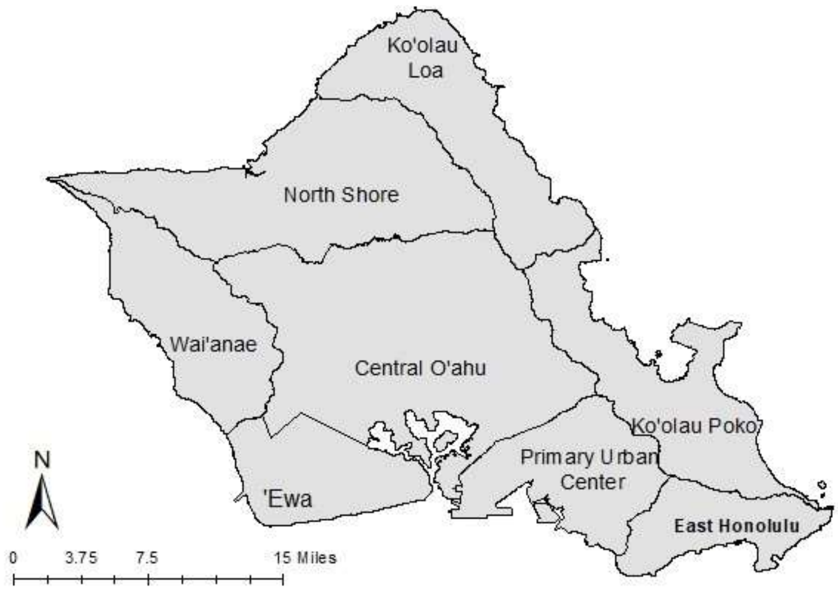


Figure 4.1 Oahu Survey Region City & County of Honolulu (2019)

Out of the 37 survey participants, only 22 revealed their permanent place of residence. The majority of the survey participants permanently reside in locations such as the Primary Urban Center (11), Ko'olauPoko (5), East Honolulu (4), and North Shore (2). No reported survey participants reside in Wai'anae, 'Ewa, Central Oahu, and Ko'olau Loa (Figure 4.2). Participants were asked to provide their location of residence to indicate the region they are most familiar with. However, participants were allowed to answer questions for multiple areas outside of their residence regarding tidal flooding as many participants may be familiar with numerous regions of Oahu. Given that the survey data does have a drastic uneven distribution of the location of survey participants, there may potentially be an underrepresentation of some regions within the data. Nevertheless, the survey results will complement the King Tides data by providing insight into community preferences regarding adaptation and community perception of flooding.

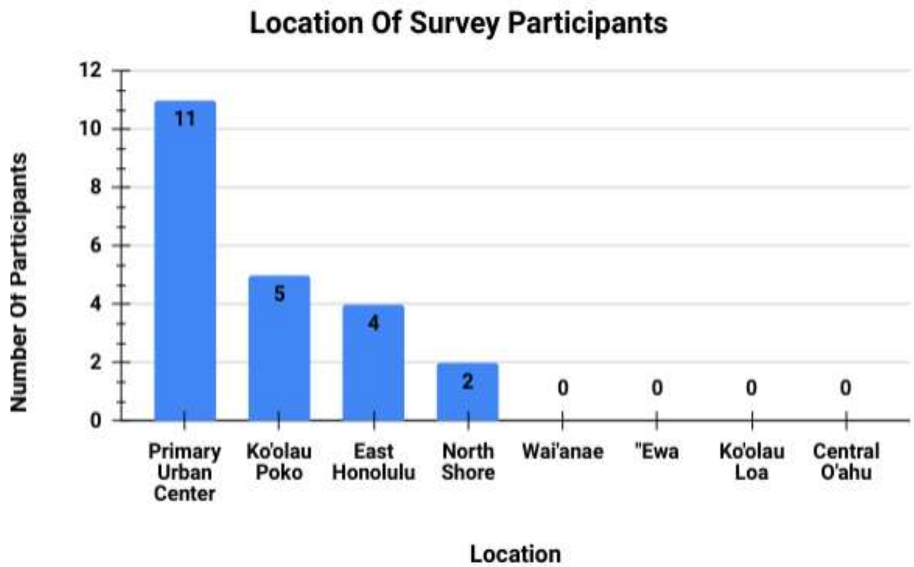


Figure 4.2 Location Of Survey Participants: 37 participated in the survey, and only 22 participants provided their information on their location of residence. The Primary Urban Center is the location where the majority of participants are located.

Within the King Tides data, the Primary Urban Center had the highest photo submissions than any other region of Oahu (Figure 1.5). The Primary Urban Center stretches from Kahala to Pearl City and includes the Waikiki coast. Due to the heavy urbanization and infrastructure along the beach, the Primary Urban Center is the most at risk to the impacts of SLR. The results within the survey data are consistent with the high photo submissions of the Primary Urban Center. When survey participants were asked to identify what region of Oahu they have experienced tidal flooding, 65% of the survey participants chose the Primary Urban Center (Figure 4.3).

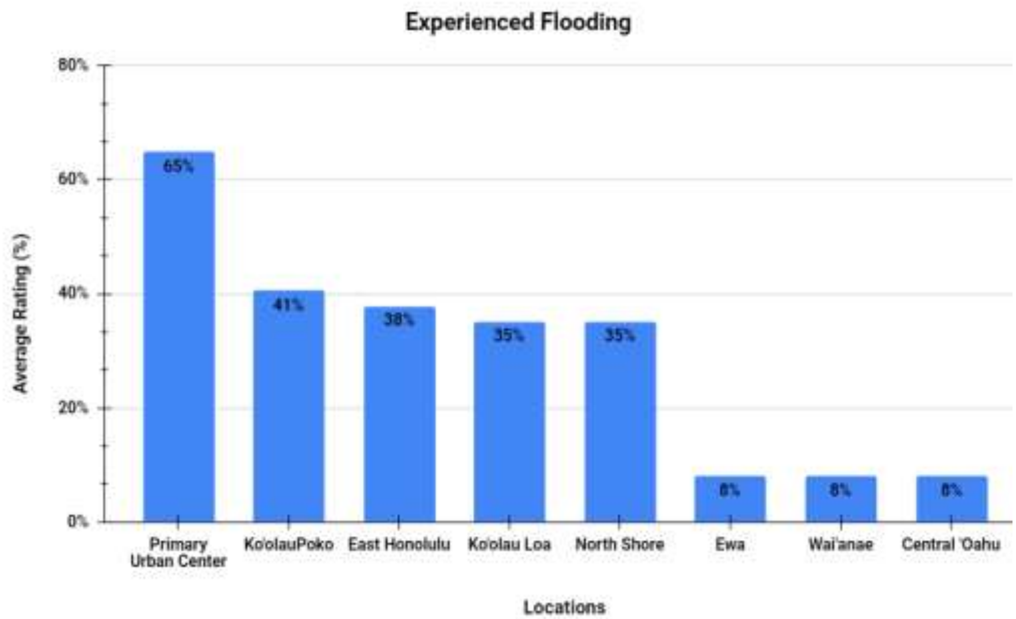


Figure 4.3 Locations Where Survey Respondents Have Experienced Flooding: 37 survey participants were asked to identify regions of Oahu where they have experienced flooding. This is a subjective question and respondents were allowed to make their own determinations as to what can be considered flooding. The average ratings reflect the percentage of the 37 respondents that selected each location. 65% of the respondents selected the Primary Urban Center, while Wai'anae (8%) and 'Ewa (8%) have the lowest rating. (Refer to Table 6.5).

However, the Primary Urban Center is where the majority of survey respondents reside and are potentially most familiar within this region. As a result, this can contribute to the underrepresentation of other areas of Oahu (Figure 4.2).

Based on the flooding observations of survey participants, 54 % of the 37 respondents voted for the Primary Urban Center for the region with the highest depth of flooding (Figure 4.4). 51% of the respondents also selected the Primary Urban Center for the highest flooding frequency and potential of increased damage caused by flooding (Figure 4.5, 4.6). Within the King Tides, data locations within the Primary Urban Center such as Honolulu, Waikiki coast, and the Ala Wai Canal had the highest photo frequency. Tidal flooding impacting transportation within Honolulu was the most common documentation among the infrastructure category (i.e.roads, storm drains, and parking) (Figure 3.27, 3.30, 3.32). Places such as the Ala Wai Canal, a canoeing location in Honolulu, and beach parks along the Waikiki coast are also places that have been heavily documented within the King Tides data and are projected to be affected by 3.2 ft of SLR (Figure 3.6, 3.13, 3.20).

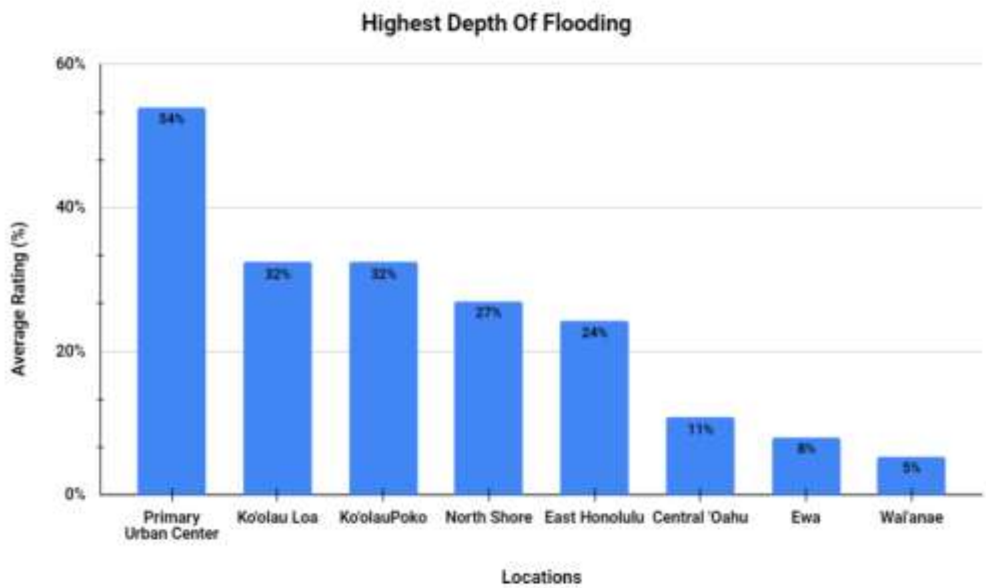


Figure 4.4 Locations Of Highest Depth Of Flooding Based On Survey Respondents: 37 survey participants were asked to identify regions of Oahu that had the highest depth of flooding. This is a subjective question and respondents were allowed to make their own determinations about the depth of each flooding location. The ratings reflect the percentage of the 37 respondents that selected each location. 54% of respondents selected the Primary Urban Center, following Ko'olau Loa and Ko'olauPoko at 20%, while Wai'anae (5 %) and ‘Ewa (8%) have the lowest rating. (Refer to Table 6.5).

On the Windward side of Oahu, the Ko'olaupoko region, including Waimanalo, Kailua, and Kaneohe Bay, is the second-highest rated by survey respondents. Ko'olaupoko is also the second-highest location where survey participants reside (Figure

4.2). Out of the 37 participants, 41% selected that they have experienced tidal flooding within Ko'olaupoko, 32% selected highest depth of flooding, 38% for highest frequency, and 35% for the potential of increased damage caused by tidal flooding (Figure 4.3,4.4, 4.5, 4.6). Within the Ko'olaupoko region, the He'eia fishpond and boat harbors have a high number of photo documentation within the King Tides data and were projected to be impacted by 3.2 ft of SLR as well (Figure 3.4 & Figure 3.10). The high reports of this region within both the King Tides data and survey data confirm that this location is at an increased risk of tidal flooding.

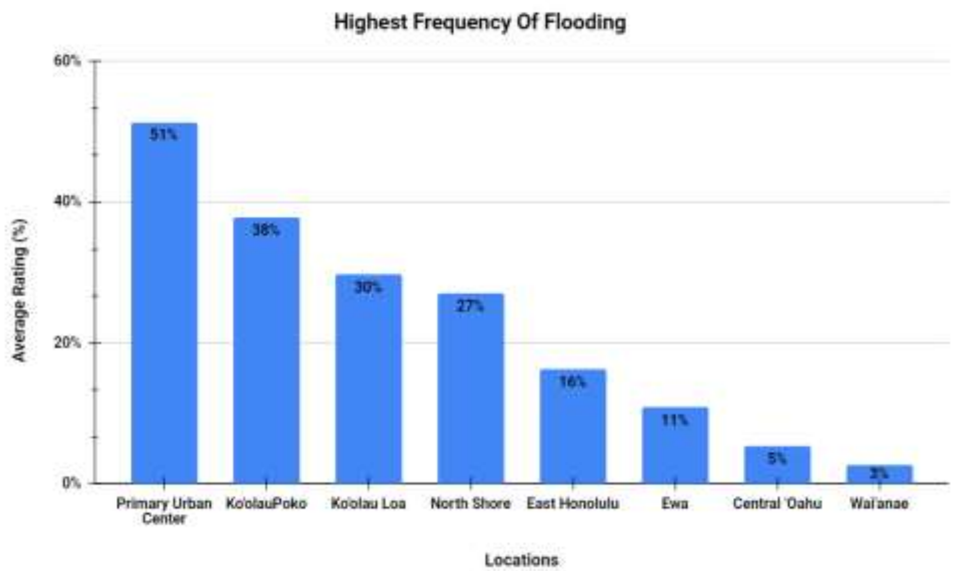


Figure 4.5 Highest Frequency Of Flooding Based On Survey Respondents: 37 survey participants were asked to identify regions of Oahu that had the highest frequency of flooding. This is a subjective question, and respondents were allowed to make their own determinations on the frequency of flooding for each region. The ratings reflect the percentage of the 37 respondents that selected each location. 51% of respondents selected the Primary Urban Center, followed by Ko'olauPoko at 38%, and Wai'anae (3%) at the lowest rating. (Refer to Table 6.5).

East Honolulu encompasses the center of Honolulu to Waimanalo Bay and has a high report of flooding in the survey as well. In East Honolulu, 38% of survey respondents selected that they have experienced flooding within this region, 24% selected that this area has the highest depth, and 16% for frequency of flooding; lastly, 27 % selected there may potentially be an increase in damage caused by tidal flooding (Figure 4.3, 4.4, 4.5, 4.6). In the King Tides data, Maunalua Bay has the highest photo documentation within this region and seems to be the most at-risk area to SLR in East Honolulu. Maunalua Bay has had high photo frequency regarding tidal flooding affecting canoeing, boat harbors, beach picnic activities, and housing (Figure 3.6, 3.10, 3.13, 3.23).

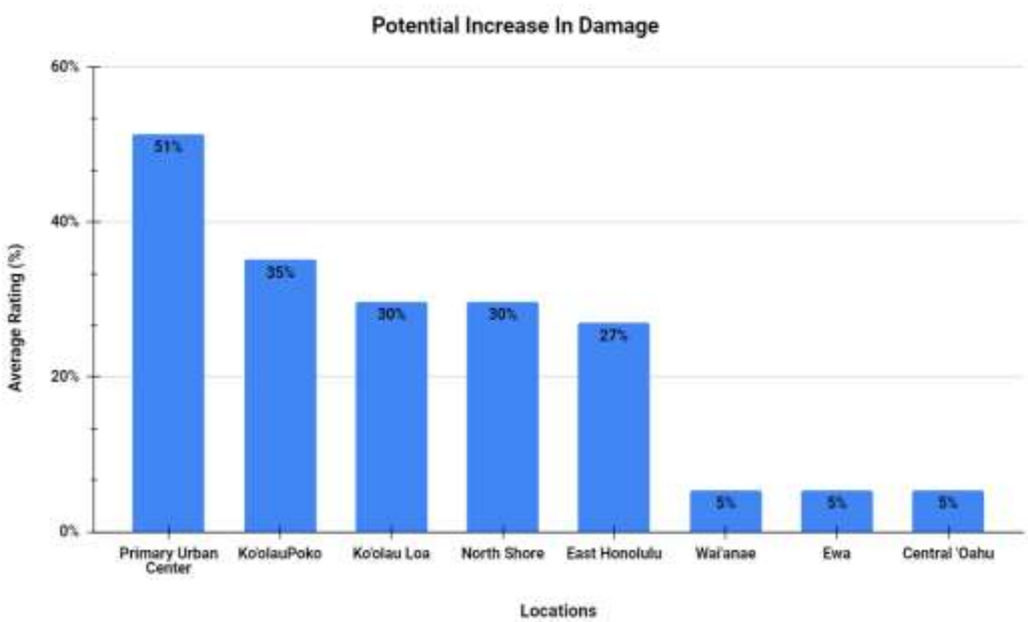


Figure 4.6 Locations Likely To Experience Increase Risk Of Damage Based On Survey Respondents: 37 survey participants were asked to identify regions of Oahu that had the highest potential for increases of damages caused by flooding. This is a subjective question, and respondents were allowed to make their own determinations on the potential flooding damage for each region. The ratings reflect the percentage of the 37 respondents that selected each location. 51% of respondents selected the Primary Urban Center, followed by Ko'olauPoko at 35%, and Wai'anae, Ewa, and Central Oahu had the lowest rating (5%). (Refer to Table 6.5).

The Northside of Oahu includes the Ko’olau Loa and North Shore regions. Within the King Tides data, these regions are severely underrepresented, resulting in the lack of information regarding the impacts of tidal flooding. However, within the survey data, the respondents selected both of these regions as locations where they have experienced tidal flooding. For Ko'olau Loa, 35% of respondents selected that they have experienced flooding in Ko'olau Loa, 32% selected the highest depth of flooding, and 30% for highest frequency and increased damage caused by flooding (Figure 4.3,4.4, 4.5, 4.6). Similarly to Ko'olau, for the North Shore, 35% selected that they experienced flooding in this region, 27% chose this region for the highest depth and frequency of flooding, and 30% for the potential increase in damage caused by flooding (Figure 4.3,4.4, 4.5, 4.6).

Regions within the west side of Oahu had the lowest response rate in terms of experiencing tidal flooding, with Central Oahu, Ewa, and Waianae all at 8% (Figure 4.3). The survey results for these locations also correlate with the King Tides data as these regions often had little to no photo documentation compared to the rest of Oahu. The findings from the King Tides data and survey results both suggest that Ewa, Waianae, and Central Oahu are the least at risk to SLR compared to other locations.

4.2 SPATIAL DISTRIBUTION OF FLOODING IMPACTS

With Oahu's population of 1,455,271 for the year 2020, the island of Oahu is the most vulnerable and most densely populated than any other island of Hawaii (State of Hawaii, 2020). Out of the 386,188 acres of Oahu, 9,400 acres accounted for land located within the 3.2ft passive flooding layer, and over half of the 9,400 acres are designated for urban use (Hawaii Climate Change Mitigation, 2017). More specifically, 15.58% of the land dedicated to agriculture, 25.4% to conservation, and 58.8% of land for urban use are all within the 3.2ft passive flooding layer for Oahu and are projected to be impacted by SLR (Hawaii Climate Change Mitigation, 2017). To better understand the spatial distribution of flooding within each region of Oahu, survey answers from survey participants and photo submissions within the King Tides project were compared.

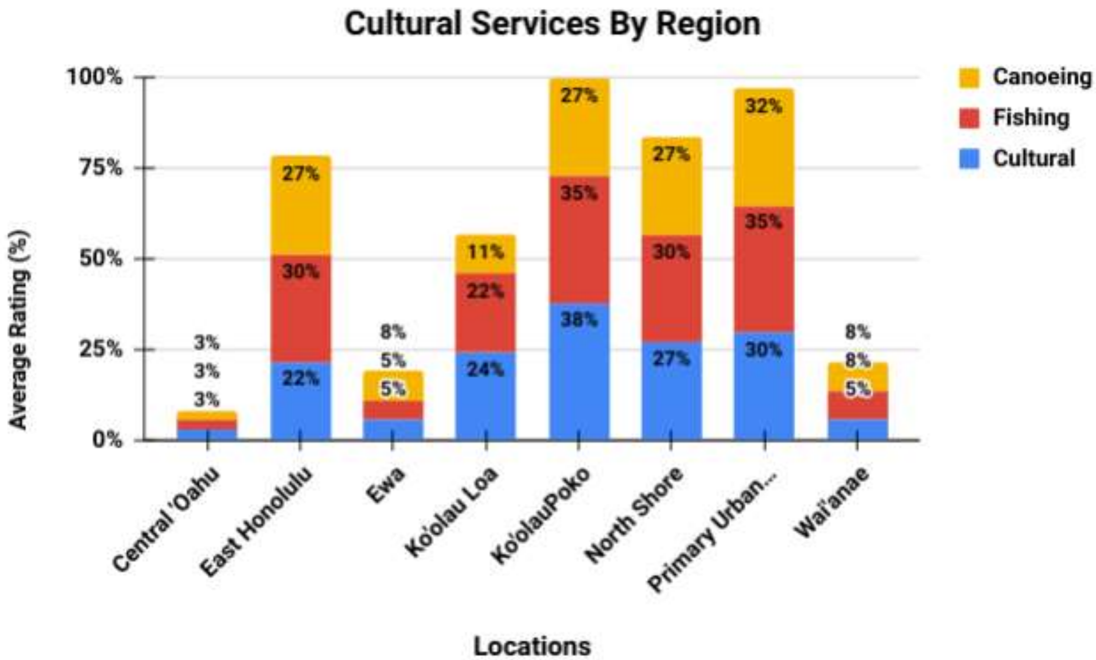


Figure 4.7: Cultural Services By Region Based On Survey Respondents: Cultural services were categorized as canoeing, fishing, and general cultural services that were not listed within the survey. The ratings reflect the percentage of the 37 respondents that selected each location. Out of the 37 survey participants, the Primary Urban Center was selected the highest for canoeing (32%) and fishing (35%). While Ko'olauPoko was selected the highest for overall cultural services (38%).

To determine the importance of different cultural functions within each community and what assets each region provided. Survey participants were asked to identify the locations of where various types of cultural activities identified by the King Tides data are practiced, such as canoeing and fishing. The ratings reflect the percentage of the 37 respondents that selected each location. Based on the selection of survey participants, most canoeing regions are within the Primary Urban Center, 32%, and 27% of participants selected East Honolulu, Ko’olaupoko, and North shore (Figure 4.7). In the

King Tides data, most of the photos showing where canoeing is practiced and influenced by tidal flooding were taken in the Primary Urban Center and East Honolulu (Figure 3.6). The results from the survey suggest that there may potentially be more canoeing locations at risk of SLR that were not reported within the King Tides Project. Another possible explanation is that due to the Primary Urban Center being heavily urbanized, there may be more activity within this region or more activities at risk of flooding compared to Ko'olaupoko and North Shore. When comparing the survey results to the King Tide data, the canoeing locations within the Primary Urban Center are suggested to be the most at risk to SLR (Figure 3.6).

Along with canoeing, survey participants were also asked to identify cultural activities such as fishing or select the general cultural activity if an activity was not listed. In regards to fishing locations, 35 % of survey participants selected that fishing activities are most practiced within the Primary Urban Center and Ko'olaupoko, 31% selected East Honolulu and North Shore and Ko'olau Loa at 22% (Figure 4.7). In terms of regions that provided the most cultural activities that were not listed within the survey, 38% of the survey participants selected Ko'olauPoko and 30% the Primary Urban Center (Figure 4.7). When asked to identify what specific cultural activities were practiced within this region, four survey participants listed that Hawaiian education and volunteer opportunities were provided within the Ko'olauPoko region, and one mentioned a wildlife sanctuary named Paiko Lagoon within east Honolulu. These findings highlight that there were other cultural activities practiced within Oahu that were not reported in the King Tides Project that will need to be identified in future research.

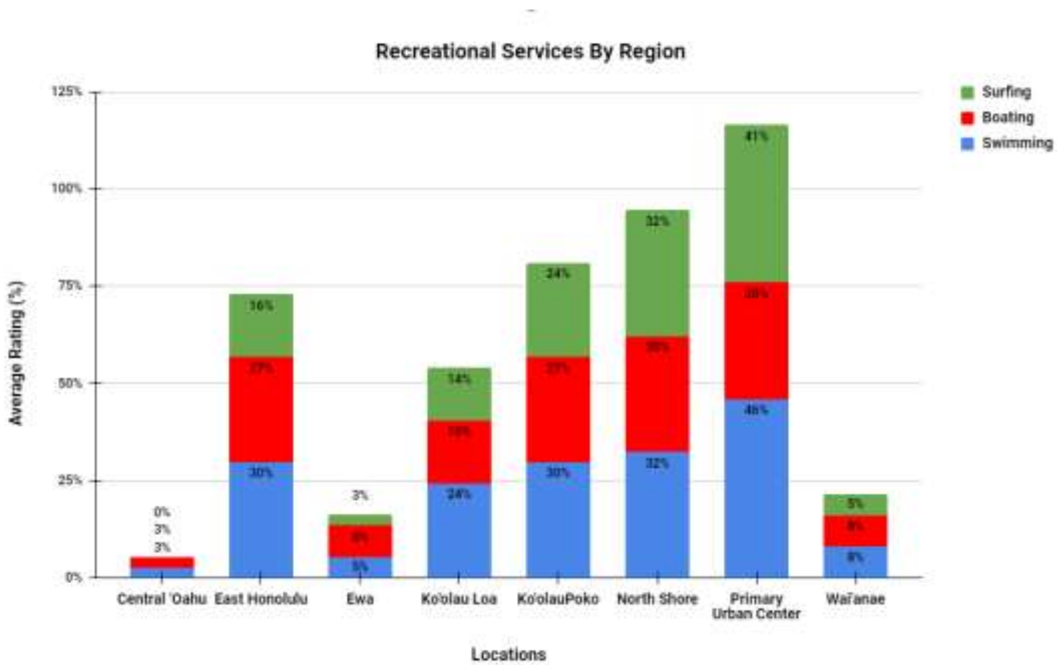


Figure 4.8 Recreational Services By Region Based On Survey Respondents: Recreational activities were categorized as surfing, boating and swimming.The ratings reflect the percentage of the 37 respondents that selected each location. Survey participants were allowed to make their own determination as to what type of boating fits within this category. Out of the 37 survey participants, the Primary Urban Center was the highest selected region for surfing (41%), boating (30%), and swimming activities (46%).

Similar to identifying the cultural activities practiced within each region, survey participants were asked to identify what recreational activities are practiced in various locations of Oahu. The ratings still reflect the percentage of the 37 respondents that selected each location. The Primary Urban Center had the highest ratings among survey respondents in each category in terms of recreational assets. 30% of survey participants selected the Primary Urban Center for boating (30%), swimming (46%), beach picnic activities (51%), surfing (41%) (Figure 4.8, 4.9). Survey participants were allowed to make their own determination as to what type of boating fits within this category. In the King Tide data, the Primary Urban Center also had the highest photo frequency of locations where boating, beach picnic activities, and surfing occurred and were impacted by tidal flooding (Figure 3.10, 3.13, 3.16). Both the survey and King Tides data show recreational activities are heavily practiced within the Primary Urban Center than in any other region of Oahu.

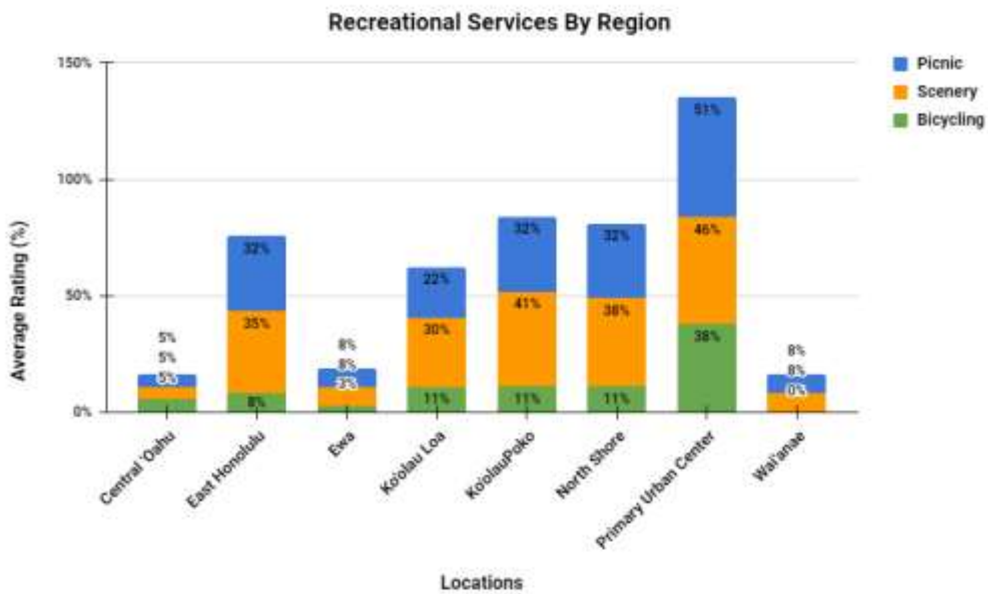


Figure 4.9 Recreational Services By Region Based On Survey Respondents: Recreational activities were categorized as picnic activities, scenery, and bicycling. The ratings reflect the percentage of the 37 respondents that selected each location. Out of the 37 survey participants, the Primary Urban Center was the highest selected region for pickining (51%), scenery (46%), and bicycling (38%).

Other regions such as East Honolulu, North Shore, Ko’olau Loa, and Ko’olaupoko all had a high percentage of survey participants select these regions for various recreational services (Figure 4.8, 4.9). The Ko’olau Loa and North Shore region of Oahu were significantly underrepresented within the King Tides data in terms of documenting recreational activities that were practiced within these locations. The survey results indicated that these regions of Oahu should be further assessed to identify how tidal flooding will impact the services that these locations provide.

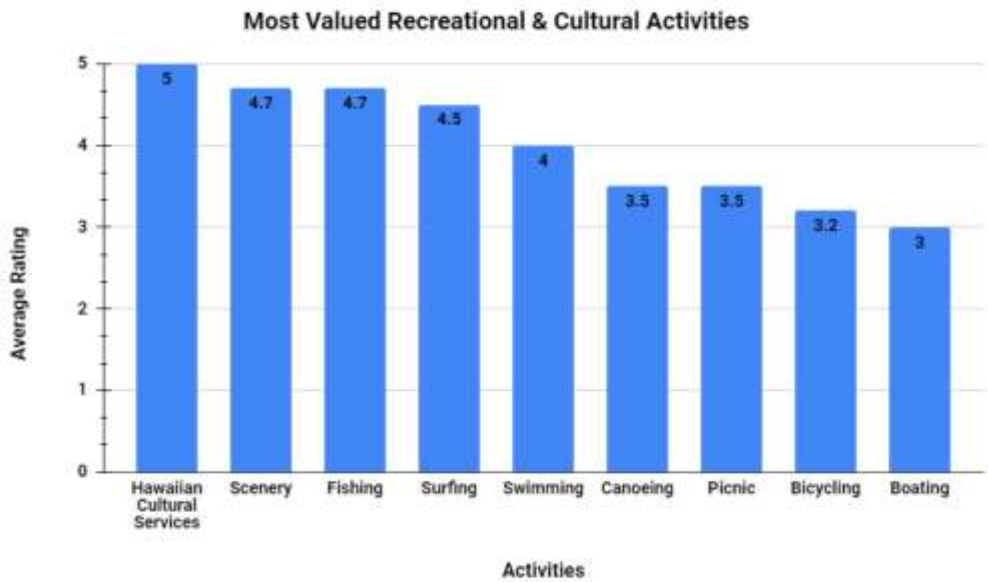


Figure 4.10 Most Valued Recreational & Cultural Activities: 37 survey participants rated recreational and cultural activities based on importance. They were asked to select each activity as 1 least important to 5 most important. General Hawaiian cultural activities (5) were rated of higher value than boating (3) and bicycling (3.2).

To discover which recreational and cultural activities are most valued by the community, survey participants were asked to rate each activity as 1 least important to 5 most important. (Figure 4.10). General Hawaiian cultural activities were ranked highest among each of the categories at 5, while bicycling (3.2) and boating (3) were the least valued activities (Figure 4.10). These values align with the potential findings within the King Tides data, with the exception of scenery and fishing; there are high photo documentations of swimming, canoeing, picnicking, and surfing. These survey findings reveal that there needs to be further research and prioritization on how Hawaiian cultural activities will be affected by tidal flooding.

4.3 ADAPTATION PREFERENCE

When considering which SLR adaptation would be most effective, the concerns and preferences of the community need to be heard as well. Selecting an effective adaptation strategy should preserve the vulnerable locations from tidal flooding while also preserving the recreational and cultural uses of that location as well.

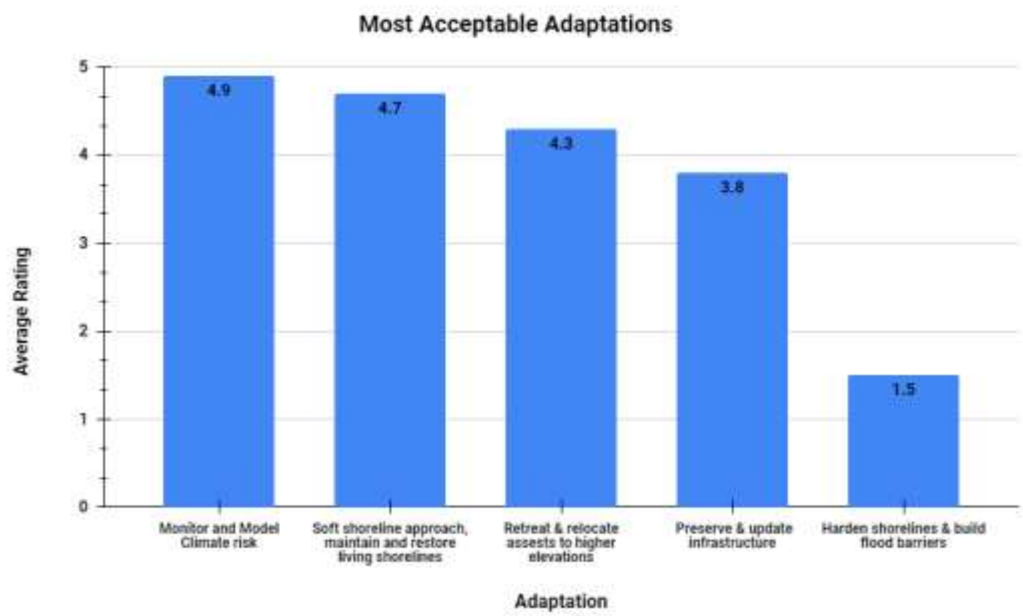


Figure 4.11 Most Acceptable Adaptations Based On Survey Respondents: 37 survey participants were asked to rate which adaptation strategies are 1 least acceptable to 5 most acceptable. Monitor and model climate risk (4.9) was most acceptable while hardening shorelines (1.5) was the least acceptable.

To understand the perception and values of the community in terms of SLR adaptations, survey participants identified and ranked acceptable adaptations. Acceptability was defined within the survey as what SLR adaptations are deemed most ethical and align most with community values. They were asked to select each adaptation as 1 least acceptable to 5 most acceptable. A significant portion of the survey participants resides in the Primary Urban Center (Figure 4.2). As a result, most of the rankings reflect flooding perception and community values of the Primary Urban Center. For each adaptation, participants were given the pros and cons of each adaptation based on the findings of the environmental protection agency (EPA). Monitoring and modeling climate risk is an essential foundational step that should be implemented within all regions of Oahu to identify what regions are the most vulnerable and gain a greater understanding of how SLR would affect its existing communities and structures. Monitoring and modeling climate risk had the highest acceptability rating by survey participants, with an average rating of 4.9 out of 5 (Figure 4.11). Demonstrating how important it is to the community members that scientists and land-use planners continue with more research on how SLR will affect vulnerable communities and infrastructure.

Hardening adaptation methods are a proactive approach to SLR that prioritizes the longevity of existing and future infrastructure while trading off the health of its ecosystem. Hardened structures such as sea walls, dikes, and bulkheads are a quick fix to SLR, require low maintenance, and effectively protect the coast from high wave heights (SAGE, 2015). Hardened adaptation methods can also cause adjacent shorelines to lose sediment supply leading to more rapid shoreline erosion and can also cause the loss of intertidal habitats (U.S. EPA, 2009). Hardened shorelines may affect recreational and cultural access to activities such as canoeing, surfing, and fishing and affect the scenery of the beach. Within the survey, participants voted that hardening shorelines was the least acceptable adaptation and had an average rating of 1.5 out of 5 (Figure 4.11). Indicating that community members value protecting natural ecosystems and recreational and cultural access while protecting infrastructure with less harmful SLR adaptations.

Soft shoreline approaches would be most appropriate to use in locations with high recreational and cultural usage in vulnerable sites affected by SLR as they prioritize preserving the health of ecosystems by creating living shorelines such as beach nourishment and aquatic vegetation (U.S. EPA, 2009). In terms of acceptability by the community, soft shoreline approaches had the second-highest average rating of 4.7 out of 5 (Figure 4.11). Implying that the community prioritizes protecting existing shorelines from being hardened and favors adaptations that protect ecosystems.

Soft shorelines have many benefits as they reduce the down drift erosion of adjacent beaches (U.S. EPA, 2009) while maintaining intertidal habitats along with maintaining recreational and cultural access. Beach nourishment is an SLR adaptation that focuses on expanding an eroded shoreline by adding sand (SAGE, 2015). Beach nourishment has some constraints as well; it requires regular maintenance and can become costly to re-import sand to eroding shorelines (SAGE, 2015). However, creating a beach dune and adding vegetation after beach nourishment can help anchor the new sand, slow erosion, and strengthen its resilience during storms (SAGE, 2015). In terms of aquatic vegetation methods, they can do well under the right conditions and regular maintenance but become less reliable to withstand the severe waves and storms during the winter months (U.S. EPA, 2009). Vegetation methods are more suitable in areas with the least risk and do not experience high wave height and storms (SAGE, 2015).

Retreating and relocating facilities can be done through zoning undeveloped areas along the coast or as a proactive measure to prevent future development and relocate high-risk facilities to a higher elevation (U.S. EPA, 2009). This method of relocating vulnerable areas can preserve cultural and recreational assets but can also be costly. Survey participants chose this method as the third most acceptable adaptation and had an average rating of 4.3 out of 5 (Figure 4.11). Preserving infrastructure through updating existing facilities focuses on repairing infrastructure to withstand the impacts of SLR. Improving storm drain pumps to reduce storm water backflow and raising the level of roads are some examples of how infrastructure can be updated. This adaptation method is often more expensive and is more suitable for areas that are highly vulnerable to SLR. Survey participants deemed this adaptation method the fourth most acceptable and had an average rating of 3.8 out of 5 (Figure 4.11).

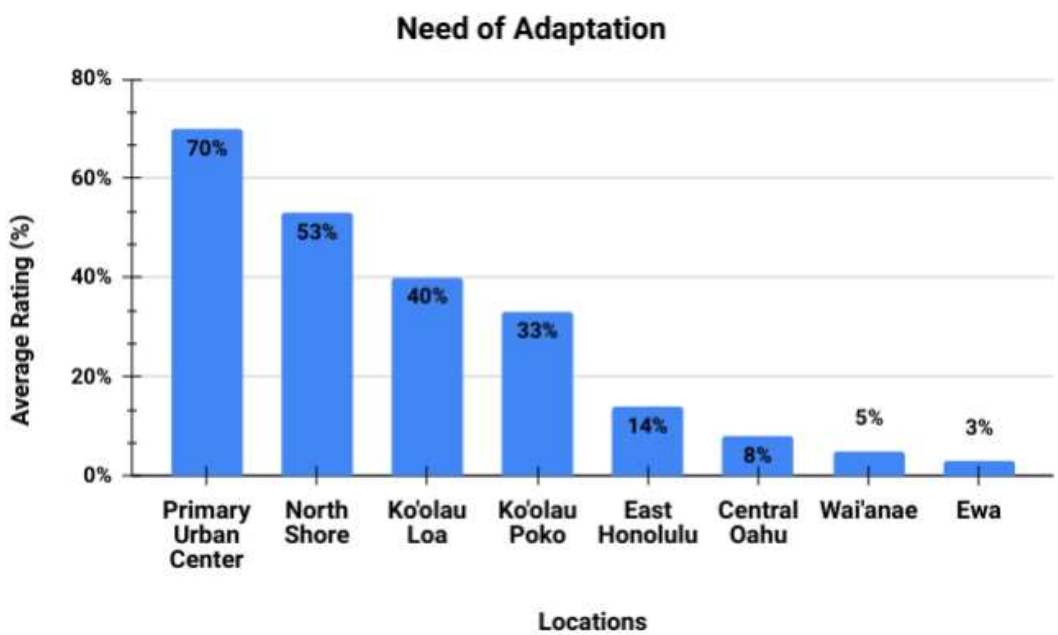


Figure 4.12 Location Most In Need Of Adaptation Based On Survey Respondents: Regions were selected by 37 survey participants based on the need for adaptation. The ratings reflect the percentage of the 37 respondents that selected each location. This is a subjective question, and respondents were allowed to make their own determinations on the need for adaptation for each region.70% of participants selected the Primary Urban Center, 53% selected the North Shore, while Wai'anae (5%) and Ewa (3%) had the lowest selection.

When rating what region of Oahu needed the most adaptation, 70% of survey participants selected the Primary Urban Center for the highest region in need of adaptation (Figure 4.12). In all of the recreational and infrastructure categories within the survey and King Tides data, the Primary Urban Center is often identified as the most at-risk region to tidal flooding. With heavy urbanization along the coast, the Primary Urban Center, existing structures, and stakeholders will need to take into account when considering what SLR adaptations should be put in place. Within the King Tides project, infrastructure flooding as a result of storm drain backflow and direct marine flooding was the most common (Figure 1.2, 3.26, 3.27, 3.30). To prevent infrastructure flooding, adaptation measures such as dry or wet proofing should be implemented in order to avoid further infrastructure damage. For cultural and recreation, the Primary Urban Center should focus on implementing adaptation measures that maintain public access. This can often include soft adaptations such as beach nourishment or creating a beach dune with vegetation that would be beneficial to combat erosion and flooding.

53% of survey participants selected the North Shore region as the second-highest location in need of adaptation (Figure 4.12). The North Shore region of Oahu may have been severely underreported within the King Tides Project. Many survey results have selected the North Shore regions as one of the most at-risk regions, second to the Primary Urban Center. In contrast, the King Tide data had much less photo documentation of the North Shore than other Oahu regions. The survey responses also reveal that various recreational activities are occurring within this region, such as surfing, swimming, picnicking, and boating (Figure 4.8, 4.9). With the North Shore Region receiving winter swells of over 5m, this region will need to implement multiple soft adaptation strategies to combat SLR while also maintaining access to recreational activities (Figure 1.4). This region may also need to implement adaptation measures such as retreat to relocate and protect infrastructure and homes at risk of flooding. Overall this region will need to be further assessed to determine how tidal flooding has impacted cultural and recreational activities and infrastructures such as roads and homes.

The Ko’olau Loa region was selected as the third most needed for SLR adaptation by 40% and the fourth Ko’olaupoko at 33% (Figure 4.12). These regions selected by the survey participants also align with the annual wave height of each region. The Ko’olaupoko region is home to many Hawaiian cultural activities and fishponds (Figure 3.3 & 4.7). Similar to the North Shore region, Ko’olau Loa and Ko’olaupoko have been underrepresented in many infrastructures and recreational categories within the King Tides data. However, the survey data suggest that many other activities have been practiced here that have not been documented, such as swimming, boating, fishing, and canoeing (Figure 4.8, 4.9). With both of these regions being heavily cultural and recreational, natural soft adaptations such as aquatic vegetation would protect the natural ecosystem and provide educational opportunities for the community.

While many canoeing, boating, and swimming activities occur within East Honolulu, homes within this region have been documented within the King Tides Project (Figure 3.23). To preserve access to cultural and recreational activities, soft adaptations such as beach nourishment or aquatic vegetation would benefit East Honolulu. As for the homes that have been affected, relocation or updating infrastructure with wet or dry proofing to withstand SLR would be most effective.

5.0 CONCLUSION

This study aimed to determine how tidal flooding affects the recreational and cultural functions on the island of Oahu by utilizing King Tide and survey data. The survey results and King Tides data concluded that infrastructure such as roads, canals, homes, and recreational and cultural assets within the Primary Urban Center are the most vulnerable to the effects of tidal flooding.

Crowdsourcing photo data has the advantage of helping to extract details about the types of impacts, develop survey questions, and pinpoint the locations of where recreational and cultural activities have occurred. Crowdsourcing tidal flooding data allows community members to document virtually anything they view affected by tidal flooding and erosion. This allows land-use planners and scientists to gain insight into what the community values and the community's perspective on how tidal flooding affects Oahu. In terms of cultural activities, the He'eia fishpond and canoe paddling locations such as the Ala Wai Canal and Maunalua Bay had the highest photo documentation. While recreational activities such as beach parks, boat harbors, and surfing activities were most documented within the Primary Urban Center.

Crowdsourcing allowed community members to submit photos and a short comment but couldn't quantify people's risk perception and value preference. A conventional survey developed based on the crowdsourcing findings, on the other hand, was performed to obtain such complemental information. The survey allowed community members to explain further why they value different recreational and cultural functions, what adaptations they prefer, and present data for regions under-reported within the King Tides Project. When comparing the general survey findings to the findings in the crowdsourcing data, the survey results were also able to fill in the missing information regarding the frequency and depth of tidal flooding for each region and cultural and recreation activities for unreported regions.

Along with identifying the most vulnerable region of Oahu, the survey data, in general, has consistent findings with the crowdsourcing king tide photo data. Comparing the survey data, passive flooding maps, and crowdsourced data also helps validate the findings and reveal many limitations of using crowdsourcing data for impact assessment. Many regions of Oahu, such as North Shore, Ko'olau Loa, and Ko'olaupoko, had little to no photos in infrastructure or recreational categories. The low rate in documentation may be due to the smaller population density and less infrastructure than the Primary Urban Center.

Due to potential underrepresentation within the King Tides Project, the limited number of survey participants, and the majority of survey respondents residing within the Primary Urban Center. There will need to be further assessments on the flooding frequency and the impacts of tidal flooding for each region of Oahu to produce a more detailed impact assessment. With more data, land-use planners and scientists could effectively determine how to best prepare Oahu for future SLR projections.

6.0 APPENDIX

6.1 DATA TABLES

Theme	**Code**	**Photo Frequency**	**Percentage Out Of Total Photos (1,980)**
Cultural	Fishponds	165	5%
	Canoeing	150	4.5%
Recreational	Boat Harbors	140	4.2%
	Parks	629	19%
	Surfing	514	15.5%
Infrastructure	Canal	207	6.3%
	Homes	289	8.7%
	Roads	335	10.1%
	Storm Drain	44	1.3%
	Parking	165	5%

Table 6.1 Summary Table Of Photo Categories Within King Tides Project

Cultural Activities	Photo Frequency (Total)	SLR .5 ft	SLR 1.1 ft	SLR 2 ft	SLR 3.2ft
Fish Pond (Photo Frequency #)	165	22	64	81	83
Fish Pond (Photo Frequency %)		13%	39%	49%	50%
Canoeing (Photo Frequency #)	150	51	51	54	91
Canoeing (Photo Frequency %)		34%	34%	36%	61%

Table 6.2 Summary Table Of Cultural Photos Within King Tides Project

Recreational Activities	Total	SLR .5 ft	SLR 1.1 ft	SLR 2 ft	SLR 3.2ft
Boat Harbor (Photo Frequency #)	140	11	11	20	37
Boat Harbor (Photo Frequency %)		8%	8%	14%	26%
Picnic (Photo Frequency #)	629	106	106	109	151
Picnic (Photo Frequency %)		17%	17%	17%	24%
Surfing (Photo Frequency #)	514	57	57	58	85
Surfing (Photo Frequency %)		11 %	11%	11%	17%

Table 6.3: Summary Table Of Recreational Photos Within King Tides Project

Infrastructures	Total	SLR .5 ft	SLR 1.1 ft	SLR 2 ft	SLR 3.2ft
Canal (Photo Frequency #)	207	56	59	61	97
Canal (Photo Frequency %)	207	27%	28%	29%	46%
Homes (Photo Frequency #)	289	72	72	76	91
Homes (Photo Frequency %)	289	25%	25%	26%	31%
Roads (Photo Frequency #)	335	79	80	114	162
Roads (Photo Frequency %)	335	23%	23%	34%	48%
Storm Drain (Photo Frequency #)	44	6	8	14	20
Storm Drain (Photo Frequency %)	44	14%	18%	32%	45%
Parking (Photo Frequency #)	165	12	18	32	65
Parking (Photo Frequency %)	165	7%	11%	19%	39%

Table 6.4 Summary Table Of Infrastructure Photos Within King Tides Project

Location	Experienced Flooding (#)	Experienced Flooding (%)	High Depth Of Flooding (#)	High Depth Of Flooding (%)	High Frequency of Flooding (#)	High Frequency of Flooding (%)	Increased Damage Of Flooding (#)	Increased Damage Of Flooding (%)
Central 'Oahu	**3**	8%	4	11%	2	5%	2	5%
East Honolulu	**14**	38%	9	24%	6	16%	10	27%
Ewa	**3**	8%	3	8%	4	11%	2	5%
Ko'olau Loa	**13**	35%	12	32%	11	30%	11	30%
Ko'olauPoko	**15**	41%	12	32%	14	38%	13	35%
North Shore	**13**	35%	10	27%	10	27%	11	30%
Primary Urban Center	**24**	65%	20	54%	19	51%	19	51%
Wai'anae	**3**	8%	2	5%	1	3%	2	5%

Table 6.5: Summary Of Flooding Perception Within Survey

Location	General Cultural Activities#	Cultural %	Fishing #	Fishing %	Canoeing #	Canoeing %
Central 'Oahu	1	3%	1	3%	1	3%
East Honolulu	8	22%	11	30%	10	27%
Ewa	2	5%	2	5%	3	8%
Ko'olau Loa	9	24%	8	22%	4	11%
Ko'olauPoko	14	38%	13	35%	10	27%

North Shore	10	27%	11	30%	10	27%
Primary Urban Center	11	30%	13	35%	12	32%
Wai'anae	2%	5%	3%	8%	3	8%

Table 6.6: Summary Of Cultural Activities Within Survey

Location	**Swimming#**	**Swimming %**	**Boating #**	**Boating %**	**Surfing #**	**Surfing %**	**Picnic #**	**Picnic %**	**Bicycling #**	**Bicycling %**	**Scenery #**	**Scenery %**
Central 'Oahu	1	3%	1	3%	0	0%	2	5%	2	5%	2	5%
East Honolulu	11	30%	10	27%	6	16%	12	32%	3	8%	13	35%
Ewa	2	5%	3	8%	1	3%	3	8%	1	3%	3	8%
Ko'olau Loa	9	24%	6	16%	5	14%	8	22%	4	11%	11	30%
Ko'olauPoko	11	30%	10	27%	9	24%	12	32%	4	11%	15	41%
North Shore	12	32%	11	30%	12	32%	12	32%	4	11%	14	38%
Primary Urban Center	17	46%	11	30%	15	41%	19	51%	14	38%	17	46%
Wai'anae	3	8%	3	8%	2	5%	3	8%	0	0%	3	8%

Table 6.7: Summary Of Recreational Activities Within Survey

6.2 CONSENT FORM

Aloha!

My name is Kayla Palmer and you are invited to take part in a research study. I am a senior undergraduate student studying environmental science at the University of Hawai'i at Mānoa in the Department of SOEST. The goal of this project is to better understand how to preserve or adapt cultural and recreational areas that have been impacted by tidal flooding and provide corresponding suggestions to community members and land-use planners.

1) What am I being asked to do?

If you participate in this project, you will be asked to fill out a survey.

2) Taking part in this study is your choice.

**Your participation in this project is completely voluntary. You may stop participating at any time. If you stop being in the study, there will be no penalty or loss to you. **

3) Why is this study being done?

We are asking you to participate in this survey because as a resident of Oahu, you will have the best knowledge of what is happening within your community in terms of tidal flooding as well as the recreational and cultural activities practiced within your area.

4) What will happen if I decide to take part in this study?

The survey will consist of 8 multiple choice and open-ended questions. It will take less than 10 minutes. During this survey, you will be asked to identify area(s) within Oahu where you have seen flooding occur and identify area(s) that are recreationally or culturally important to you.

Here are some of the questions that will be asked in the survey:

a) Please use the map above to select the area(s) where you have experienced tidal flooding.

b) If any of the area(s) you have identified is a recreational or cultural site please describe what services this area(s) provides?

c) When taking into account the cultural and recreational services that the site(s) provides what adaptations would you deem more acceptable or least acceptable for your community and will not inhibit the services provided by the site(s)?

6) Risks and Benefits

There is little risk to you for participating in this research project. You may become stressed or uncomfortable answering any of the survey questions. If you do become stressed or uncomfortable, you can skip the question or take a break. You can also stop taking the survey or you can withdraw from the project altogether.

There will be no direct benefit to you for participating in this survey. The results of this project may help improve the dialogue between land-use planners and community members in regards to tidal flooding and its impacts on recreational and cultural services.

7) Confidentiality and Privacy

Only your email will be requested. **You have the right to withhold your contact information from the survey.** Your contact information will only be used to contact you if there are any questions regarding your survey answers and no other purposes.

I will keep all study data secure in a locked filing cabinet in a locked office/encrypted on a password-protected computer. Only my University of Hawai'i advisor and I will have access to the information. **Other agencies that have legal permission have the right to review research records. The University of Hawai'i Human Studies Program has the right to review research records for this study.**

Even after removing identifiers, the data from this study will not be used or distributed for future research studies.

8) If you have any questions about the research, complaints, or problems, please contact me:

[Kayla Palmer, Email: kayla38@hawaii.edu - directly].

You may also contact my faculty advisor, Dr. Suwan Shen at [suwans@hawaii.edu]. You may contact the UH Human Studies Program at [808.956.5007 or uhirb@hawaii.edu] to discuss problems, concerns and questions, obtain information or offer input with an informed individual who is unaffiliated with the specific research protocol. Please visit http://go.hawaii.edu/jRd for more information on your rights as a research participant.

9) Agreement to Participate:

Your participation is completely voluntary, and you can withdraw at any time.

To take this survey, you must be:

a) At least 18 years old
b) Resident of Oahu

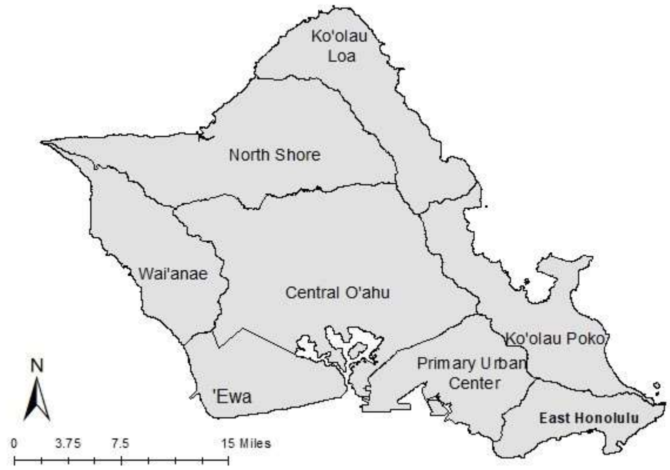
If you meet these criteria and would like to take the survey, click the button below to start. Starting the survey implies your consent to participate in this study.

Please print or save a copy of this page for your reference.

Mahalo!

Table 6.8: Survey Consent Form

6.3 SURVEY LINK AND SURVEY QUESTIONS



Question 1: Please use the map above to select the area(s) where you have experienced tidal flooding in Oahu. To become more familiar with tidal flooding in your neighborhood, please visit this interactive flooding map of Oahu: http://go.hawaii.edu/gU3.

Question 2: Within the area(s) you have identified please classify the depth of flooding for each location. ** You do not need to select an answer for the area(s) you did not identify.**

Question 3: What is the frequency of flooding for each location that you have identified? High (more than 5 times a year), medium (between 1-5 times a year), low (once a year or less), unsure.

Question 4: Overtime has the damage of flooding of the affected area(s) you've identified: increased, decreased, stayed the same?

Question 5: If any of the area(s) you have identified is a recreational or cultural site please describe what services this area provides? (Part 1)

Question 6: If any of the area(s) you have identified is a recreational or cultural site please describe what services this area provides? (Part 2)
Question 7: If any of your locations have cultural and recreational services that were not listed please list them below. EX: Central' Oahu- provides.....

Section 5: Adaptations & Preservation

Question 1: Please rate the following cultural and recreational activities based on its importance. Please rate each activity as 1-5 (1-least important, 3-neutral, 5- most important). Question 2: Given the importance of the sites and their exposure to tidal flooding, where do you think need urgent adaptation most? Please choose the top-ranking site(s). Question 3: What adaptations would you deem more acceptable for the ABOVE IDENTIFIED MOST URGENT community (in terms of not inhibiting the cultural and recreational services provided by the site)? Please rate each adaptation from 1-5 (1 being least acceptable, 3 neutral, and 5 most acceptable). Question 4: Do you have any adaptation or preservation suggestions to combat tidal flooding that were not listed?

Table 6.9: Survey Questions. Survey Link: https://forms.gle/EBWVKPnosNYRZVpt7

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