Developing Strategic Approaches or Climate Change Adaptation and Resilience Planning in Hawai‘i

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Submitted by:

Jake Brady

Max Halloran

Emily Howard

Aidan Lynn

Submitted to:

Professor Lauren Mathews

Sponsor:

Danielle Bass, State Sustainability Coordinator,

State of Hawai‘i Office of Planning and Sustainable Development

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Professor Lauren Mathews, *WPI*

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Susan Asam, *ICF*

Justine Nihipali, *Coastal Zone Management Program, State of Hawai'i*

Dr. Michael Bruno, *University of Hawai'i at Mānoa*

Dr. Chip Fletcher, *University of Hawai'i at Mānoa*

Matthew Gonser and Alex Yee, *Office of Climate Change, Sustainability and Resiliency, City and County of Honolulu*

Dr. Victoria Keener, *East-West Center*

Maggie Messerschmidt, *ICF*

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Dr. Christopher Sabine, *University of Hawai'i at Mānoa*

Dr. Tiffany Wise-West, *City of Santa Cruz*

Abstract

The State of Hawai‘i has published many plans and reports in order to promote sustainability and climate resilience but is in need of a statewide climate adaptation and resilience plan as the impacts of climate change continue to intensify. The goal of this project was to provide a report containing relevant information about climate adaptation planning approaches, adaptation strategies, and recommendations as to which strategies and approaches could be beneficial to Hawai‘i. This was accomplished through literature reviews and semi-structured interviews with climate change experts, planning experts, and authors of various climate adaptation plans. We then provided recommendations for planning approaches and technological strategies for climate adaptation that could contribute toward the development of a statewide adaptation and resilience plan.

Executive Summary

The growing effects of climate change are strongly impacting coastal regions throughout the world. The state of Hawai‘i is particularly vulnerable because it is made up of small islands that contain a wide range of natural systems and communities. As these impacts continue to intensify, it is important for Hawai‘i to have an official statewide climate adaptation and resilience plan. The State of Hawai‘i’s Office of Planning and Sustainable Development (OPSD) has published multiple climate-related plans that address climate change and sustainability, but these plans do not provide a comprehensive and holistic statewide strategy identifying specific climate risks, climate vulnerabilities, and adaptations for multiple climate change impacts. The goal of this project was to assist the State of Hawai‘i’s Office of Planning and Sustainable Development by providing a report containing relevant information about climate adaptation planning approaches, technological strategies that have been implemented in other areas throughout the world, and recommendations as to which strategies and approaches could be applied to a future climate change adaptation and resilience plan for the State of Hawai‘i. To accomplish this goal, our team developed the following objectives:

Objective 1: Obtain and analyze information from experts on the current and ongoing impacts of climate change local to Hawai‘i.

This objective required the team to gain a strong understanding of the climate change impacts that are uniquely affecting Hawai‘i, planning that is currently underway, and the gaps that have been experienced in climate planning for the state. To do this, our team conducted semi-structured interviews with local government officials, professors, and researchers.

Objective 2: Analyze the processes and developmental approaches of adaptation plans from other areas.

This objective required the team to conduct semi-structured interviews with planning experts to understand the decisions behind how the overall plan was developed, and how the adaptation plan is enforced, monitored, and funded.

Objective 3: Identify adaptation strategies that have been suggested for implementation in regions outside of Hawai‘i.

Our team identified eight climate change impacts based on the information gathered in objectives 1 and 2. Additional literature reviews were performed to

determine five strategies that have been implemented in other places throughout the world to address each impact.

Results

Through the information gathered in the semi-structured interviews and additional research in objective 1, we identified eight climate change impacts that most severely affect the state of Hawai‘i. These eight impacts of focus were: sea level rise (SLR), extreme hurricanes, intense rainfall, ocean warming/acidification, drought, urban heat, wildfires, and landslides.

We determined that two common approaches to writing an adaptation plan are traditional adaptation planning and the application of adaptation pathways. Traditional adaptation planning looks far into the future and relies on implementing adaptation measures early to reduce the impacts of climate change when they arrive. Whereas, adaptation pathways act as a series of adaptation measures that can be implemented as environmental conditions change over time (Werners et al, 2021). Unlike traditional planning, finalizing decisions and implementation is delayed until certain environmental or community thresholds are reached so that necessary changes to the plan or adaptation measures can be made in order to adapt to changing conditions or political climate.

We collected information about various strategies that have been implemented or are planned to be implemented in other areas of the world. Some of these strategies have already been implemented in Hawai‘i but were reiterated in this objective to demonstrate their use in other places. These strategies were compiled for each of the eight impacts of climate change that were identified in objective 1. We then analyzed these strategies to make recommendations for which measures could most benefit the State of Hawai‘i if included in a statewide climate adaptation and resilience plan.

Recommendations

Based on our findings, we developed three main recommendations. Recommendations 1 and 2 include our suggestions for approaches and specific adaptation strategies for addressing each impact. We recommend that the State utilize adaptation pathways to address coastal flooding due to SLR, urban heat, and wildfires. Our second recommendation is that the State utilizes traditional adaptation planning approaches to address flash floods and landslides due to increased rainfall and storms, ocean warming, and drought. Finally, our third recommendation includes strategies to promote stakeholder involvement and community engagement. Each of

these recommendations is supported by a detailed rationale and an explanation for how it could be implemented in the state. It is our hope that the State of Hawai‘i’s Office of Planning and Sustainable Development (OPSD) will benefit from the recommendations and research our team has provided.

Authorship

Section Title/Number	Primary Author(s)	Primary Editor(s)
Abstract	Emily Howard	Max Halloran
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1.0 Introduction

Climate change effects are detrimental to the natural environment and functions of societies across the globe. Shifts in temperature and weather patterns have been occurring at a faster rate due to human-driven activities including the accumulation of greenhouse gases (GHGs) in the atmosphere. NASA estimates that a two degrees Celsius increase in average global temperature would result in 37% of the global population being exposed to extreme heat waves once every five years (Buis, 2019). Additionally, droughts are becoming increasingly common, rising sea levels are causing coastlines to change, and severe wildfires are destroying natural habitats and homes (United Nations, n.d.). As these issues become more prevalent, the importance of climate adaptation and resilience planning is crucial.

Adaptation plans have already been developed and implemented in other regions around the globe. For example, in Rotterdam, Netherlands there are plans to build underground water storage to contain flooding (Rotterdam Climate Initiative, 2013). Additionally, in Rincón, Puerto Rico there are plans to repair and replace infrastructure to prepare for devastating storms (Tetra Tech, 2015).

The State of Hawai‘i does not currently have an official statewide adaptation and resilience plan in place to prepare for the multiple impacts of climate change. There have been many plans and reports published such as the “Hawai‘i 2050 Sustainability Plan” in 2021, which serves as the State of Hawai‘i’s official climate and sustainability strategic action plan, the “Ocean Resource Management Plan,” which focuses on resolving coastal issues, the “Hawai‘i Highways Climate Adaptation Plan,” which focuses specifically on coastal highway climate adaptation, and the “Hawai‘i Sea Level Rise Vulnerability and Adaptation Report,” which examines the state’s coastal vulnerability as sea level rises (State of Hawai‘i Office of Planning et al, 2020; State of Hawai‘i Office of Planning et al, 2020; Hawai‘i Department of Transportation, 2021; Hawai‘i Climate Change Mitigation and Adaptation Commission, 2017). Adapting to sea level rise (SLR) and increasingly dangerous hurricanes is already a top priority for the State, as identified in the State of Hawai‘i SLR Report, State of Hawai‘i Hazard Mitigation Report, Ocean Resource Management Plan, and the Hawai‘i 2050 Sustainability Plan. The State must also continue preparing for future effects such as increasing wildfires and drastic temperature changes (Ionesco, 2019). Climate change cannot be ignored, and delays in planning for its effects will lead to an increased difficulty for the state in managing its impacts.

The goal of this project was to assist the State of Hawai‘i’s Office of Planning and Sustainable Development by providing a report containing relevant information about climate adaptation planning approaches, technological strategies that have been implemented in other areas throughout the world, and recommendations as to which strategies and approaches could be applied to a statewide adaptation and resilience plan. To accomplish this goal, our team developed the following objectives:

1. Obtain and analyze information from experts on the current and ongoing impacts of climate change local to Hawai‘i.
2. Analyze the processes and developmental ideas of previous adaptation plans.
3. Identify adaptation strategies that have been suggested for implementation in regions outside of Hawai‘i.

This report will assist the State of Hawai‘i’s Office of Planning and Sustainable Development in developing the preliminary plan for a statewide climate adaptation and resilience plan.

2.0 Background

In 2021, the State of Hawai‘i’s Office of Planning and Sustainable Development published the “Hawai‘i 2050 Sustainability Plan” and is currently working to develop a statewide climate adaptation and resilience plan. In order for our team to assist in preparing this plan, it is crucial to understand the threats presented by climate change and how these threats will impact the State of Hawai‘i. In this section, we will discuss the specific aspects of climate change that Hawai‘i will most prominently face and define adaptation planning and strategies. This will be followed by a discussion of the climate plans and reports that have been published in Hawai‘i to inform our approach in developing recommendations for a statewide climate adaptation and resilience plan.

2.1 Climate Change

Climate change is defined as “long-term shifts in temperatures and weather patterns” that are driven by human activities, specifically the excess amount of greenhouse gases (GHGs) that are released into the atmosphere (United Nations, 2020). The volume of GHGs in the atmosphere began increasing dramatically during the Industrial Revolution due to the widespread adoption of burning “fossil fuels” (CoP26, 2021). By 1950, the amount of carbon dioxide released into the atmosphere surpassed the capacity of natural absorbent processes on the planet (Eia, 2020). This

has led to a buildup of gases in the atmosphere and the oceans that prevents heat from escaping and decreases the pH of the ocean (NASA, n.d.; United Nations, 2020). These conditions also contribute to environmental hazards like sea level rise, ocean acidification, rising temperatures, changes in precipitation, and increased wildfires.

2.1.1 Sea Level Rise

Sea level rise (SLR) is a major effect of climate change caused by the warming of ocean waters and the melting of the Arctic sea ice. In Hawai‘i, the sea level surrounding Hilo Bay has risen by 10 inches since 1950 and is rising by about one inch every four years (NOAA, 2017). These changes have caused increased erosion throughout the State of Hawai‘i’s coastline, and thirteen miles of beaches have already been destroyed (State of Hawai‘i, 2021). Flooding also becomes more common due to SLR. In 2017, there were thirty-seven tidal flood days in Honolulu. This surpassed the yearly average of four days per year (State of Hawai‘i, 2021). The Sea Level Rise Vulnerability and Adaptation Report shows that the island of O‘ahu would have over 9,000 more acres of land exposed to flooding events compared to without the effects of SLR (State of Hawai‘i Climate Change Mitigation and Adaptation Commission, 2017). Currently, 66,000 people are regularly at risk of flooding, which could impact not only infrastructure and beaches, but cultural heritage, tourism, and natural ecosystems as well (State of Hawai‘i, 2021).

2.1.2 Ocean Acidification & Ocean Warming

Hawai‘i’s marine ecosystems will be heavily impacted as oceans become warmer and more acidic. The National Oceanic and Atmospheric Association (NOAA) estimates that global sea surface temperature has been increasing by 0.13° Celsius per decade (IUCN, 2021). Additionally, the ocean is becoming more acidic. Studies of the ocean water surrounding Hawai‘i show that between 1990 and 2015, average seawater pH values fell from an average range of 8.11-8.13 to a range of between 8.06-8.08 (Acar et al., 2019). These two factors negatively impact marine life that dwells on or near the surface of the ocean. This includes coral reefs, which are home to about 25% of all marine life (Environmental Protection Agency, 2021). Ocean warming and ocean acidification also lead to coral bleaching– when corals turn white after expelling protective algae on their surface due to extreme weather, making them more vulnerable to disease and death (NOAA, n.d.). During an extreme heat event in the summers of

2014 and 2015, average seawater temperatures around Hawai‘i rose by nearly 4° Celsius (Ritson & Gates, 2020). This was correlated to more than 67% of coral cover becoming bleached in the Kane‘ohe Bay alone, putting reefs and the diverse species that inhabit them at risk (Ritson & Gates, 2020).

2.1.3 Rising Temperatures

Shifts in global temperature severely impact atmospheric temperatures, the ocean, and weather patterns across the globe (United Nations, 2020). In 2018, the United Nations stated that in order to maintain a livable climate, the increase in the Earth's temperature must not exceed 1.5° Celsius. However, if no changes are made to current climate actions, it is predicted that the global temperature will increase by 2.7° Celsius by the end of the century. (United Nations, 2020).

The State of Hawai‘i's rising temperatures leads to an increased risk that a person will develop heat illness. This is especially true in cities that experience greater temperatures when compared to rural areas, a phenomenon known as an urban heat island (UHI). On average, Hawai‘i experiences 15 heatwaves annually. (States at Risk, 2016). Heatwaves are defined as "a period of abnormally and uncomfortably hot and unusually humid weather" over the course of two or more days (NOAA, 2022). Types of heat illness include heat rash, heat exhaustion, heat syncope, and heat shock, which can be deadly (Leffers, 2021). In Honolulu, the average temperature is 29.4° Celsius in the warmer months and 27.3° Celsius during the cooler months (WeatherSpark, 2021). In 2019, these hot temperatures caused the State to advise the public to reduce the use of air conditioners due to the fact that the electrical demand exceeded what the State could provide, putting the public at a higher risk for heat illness (State of Hawai‘i, 2021). These issues will continue as temperatures increase.

2.1.4 Changes in Precipitation

Periods of intense rainfall and increased frequency of storms will cause major flooding issues in Hawai‘i. In April 2018, the island of Kauai experienced severe rainfall. In 24 hours, 50 inches of rain fell and caused severe flash flooding on the north and east sides of the island (NOAA, 2018). Because of this, there were 20 million dollars in damages to public properties (NOAA, 2018). In many cities in Hawai‘i, urban infrastructure is based along the coastlines, leading to a higher likelihood of damages due to flooding and landslides. In the last three years,

the Mapunapuna industrial area, located on the southern side of O‘ahu, has been in a state of chronic flooding (State of Hawai‘i, 2021). This flooding has overwhelmed the drainage systems, damaging businesses, vehicles, and buildings. Landslides in Hawai‘i have resulted in the destruction of homes and obstruction of roadways (State of Hawai‘i, 2021). A landslide occurred in west Kauai in early January of 2022, covering one of the main roads and causing the residents to be isolated from the rest of the island (Nagaoka, 2022).

It is also expected that droughts will continue to become more severe and more frequent. In 2010, all counties were considered primary natural disaster areas due to drought (Fraizer et al, 2019). When precipitation decreases, the surface water also decreases and is unable to support agricultural systems. There is currently a push to expand the agricultural center to be self-reliant, but drought could lead to issues in food and water security (Agribusiness Development Corporation, 2020; Dasaklis, Pappis, 2013). Additionally, water demands can place stress on important aquifers that are used to provide drinking water. This is because the loss of upland forest and degraded soil makes it difficult for aquifers to recharge and retain moisture, which is necessary for the aquifer’s function (One World One Water, 2017).

2.1.5 Wildfire

Due to rising levels of drought, wildfires have become four times as likely in recent decades on the island of Hawai‘i (Trauernicht, 2018). According to the Hawai‘i Wildfire Management Organization, 0.5% of Hawai‘i’s total land burns each year (HWMO, n.d.). This is a greater percentage of total territory than any other US state (HWMO, n.d.). Wildfires can cause habitats to be destroyed, the death of animals, and the depletion of key food sources (HWMO, n.d.). As a result, animals may move to higher elevations, leading to smaller ranges for habitats that are more isolated. This increases the likelihood that species moving to habitats at higher elevations will face extinction along with the plants that already inhabit the ecosystem (Monzon, et al, 2011).

2.2 Importance of Climate Adaptation

As the multiple impacts of climate change become more noticeable, many states and nations have begun developing climate adaptation and resilience plans to manage these threats. One note to make is the distinction between mitigation, resilience, and adaptation. Climate change mitigation refers to limiting global climate change by reducing emissions of GHGs

(Füssel, 2007). Climate resilience defines a region's capability or capacity to handle climate change effects (Congressional Research Service, 2021). Climate change adaptation refers to adjustments in ecological, social, or economic systems in response to expected impacts of climate change (UNFCCC, n.d.). It is important to clarify that climate change mitigation and adaptation are typically complementary, not entirely exclusive. For example, planting trees and green spaces can provide additional shade in warm regions (adaptation), while also absorbing GHGs (mitigation). Adaptation planning is important because it provides the necessary boundaries and conditions states must conform to and operate under in order to adapt to a future based on some of the effects of climate change (Füssel, 2007).

2.2.1 Climate Change Adaptation Planning Strategies and Approaches

Since climate change affects each region differently, many climate adaptation plans contain strategies personalized to that unique region. Yet, the process these places take to develop their own unique adaptation strategy are often universal (A. Molenaar, personal communication, January 20, 2022). Climate change adaptation planning has been carried out at all levels of government. At the federal level, the Environmental Protection Agency Climate adaptation plan covers a wide range of hazards in multiple regions (U.S. Environmental Protection Agency, 2014). The content within the plan is more generalized to provide recommendations to be carried out at a lower level of government. Many strategies include forming partnerships with states and tribes (U.S. Environmental Protection Agency, 2014). An adaptation plan can also be applied at the state level. Statewide plans are able to focus more specifically on the needs of their region rather than the whole country's needs. For example, the "California Climate Adaptation Strategy" focuses on problems that will be particularly severe in that state, such as temperature increases, precipitation changes, wildfires, ocean warming, and SLR (California Natural Resources Agency, 2021). This allows the State of California to create adaptation strategies specifically tailored to these hazards, identifying access and functional needs of communities exposed to greater risks of climate impacts (California Natural Resources Agency, 2021).

Following statewide and regional adaptation plans, there are also adaptation plans for towns, cities, and even for specific bodies of water. Some of these plans include the "Rotterdam Climate Change Adaptation Strategy," the "City of Santa Cruz Climate Adaptation Plan Update," and the "San Juan Bay Estuary Climate Change Adaptation Plan." These adaptation

plans are more specific in what strategies could be developed for those particular regions and in what resources they use. For example, Rotterdam was able to convert public parks into water storage areas to reduce flooding (Rotterdam Climate Initiative, 2013). Santa Cruz is a coastal city in California and utilizes the implementation of sea walls along some of the city's beaches to protect them from SLR and hurricanes (Wise-West, 2018). Lastly, the "San Juan Bay Estuary Climate Change Plan" lays out numerous strategies for the different bodies of water the plan covers. These include discharge points with valves allowing flow in one direction and deploying artificial coral reefs to redirect currents and deposit sand (Bauza-Ortega, 2015). These plans are also capable of interacting with localized communities to receive feedback and ideas for future adaptation strategies (Bauza-Ortega, 2015; Rotterdam Climate Initiative, 2013; Wise-West, 2018).

2.3 History of Climate Planning in Hawai‘i

It is helpful to examine actions that have already been taken by the State of Hawai‘i to address the threat of climate change in order to build on these efforts. In 2021, the State of Hawai‘i Office of Planning and Sustainable Development published the Hawai‘i 2050 Sustainability Plan to set goals for the State to follow. (State of Hawai‘i Office of Planning et al, 2021). This plan discusses community engagement and makes recommendations to implement (State of Hawai‘i Office of Planning et al, 2021). The plan was recently published in June 2021, officially serves as the State of Hawai‘i's climate and sustainability strategic action plan for the 2020- 2030 Decade of Action, and is required by State law to be updated every ten years, according to Hawai‘i Revised Statutes §226-65.

The Hawai‘i Sea Level Rise Vulnerability and Adaptation Report provides information on estimated projections, scenarios, and potential coastal impacts within Hawai‘i's sea level rise exposure area by mid-century. This plan is required by State law to be re-evaluated every five years. (Hawai‘i Climate Change Mitigation and Adaptation Commission 2017; Hawai‘i Revised Statutes §225P-3). The report was developed by a collaboration of different government departments, experts from the University of Hawai‘i, and independent organizations. The State of Hawai‘i also published the Ocean Resource Management Plan (ORMP), which is required by the State and seeks to address coastal issues. (Hawai‘i Office of Planning & Coastal Zone Management Program, 2020). This plan was updated in 2020 by the Coastal Zone Management Program and is required to be updated every 5 years. (State of Hawai‘i Office of Planning &

Sustainable Development Coastal Zone Management Program, 2020). Like the Hawai‘i Sea Level Rise Vulnerability and Adaptation Report, the ORMP recognizes that collaboration between different partnerships and counties is critical to implementing the goals outlined in the plan. The ORMP's strategic plan assigns specific management priorities to state agencies, but relies on collaboration between federal organizations, state/county partners, and independent organizations for the implementation phase. (State of Hawai‘i Office of Planning & Sustainable Development Coastal Zone Management Program, 2020).

The 2018 State of Hawai‘i Multi-Hazard Mitigation Plan identifies hazards and risks the state will face and provides recommendations to address them (Tetra Tech, 2018). Each county has also published its own Hazard Mitigation Plan, which is smaller-scale and more specific to the risks of each individual island. The State plan does not override these plans, but offers a large-scale mitigation plan to provide recommendations for all state counties to build on. Additionally, Maui and Hawai‘i counties have a combined county adaptation plan to address SLR (Benesovska et al, 2012). This plan works under the guidance of the State Coastal Zone Management Program and focuses on observing current rules for development along the shoreline and provides recommendations to update those rules (Benesovska et al, 2012). This plan was voluntary and Honolulu County, Kalawao County, and Kauai County have not published adaptation plans. Similar to the hazard mitigation plans, the State climate adaptation and resilience plan would not override the county plans, but add to it, offering guidance for action, recommendations, and steps to resilience.

3.0 Methodology

The goal of this project was to assist the Office of Planning and Sustainable Development by providing a report containing relevant information about climate adaptation planning approaches, technological strategies that have been implemented in other areas throughout the world, and recommendations as to which strategies and approaches could be applied to an adaptation and resilience plan in Hawai‘i. To accomplish this goal, our team developed the following objectives:

1. Obtain and analyze information from experts on the current and ongoing impacts of climate change local to Hawai‘i.
2. Analyze the processes and developmental ideas of adaptation plans from other areas.

3. Identify adaptation strategies that have been suggested for implementation in regions outside of Hawai‘i.

3.1 Objective 1: Obtain and Analyze Information from Experts on the Current and Ongoing Impacts of Climate Change in Hawai‘i

The first objective aimed to conduct research on the climate change impacts that are affecting Hawai‘i, gather information regarding ongoing adaptation planning, and gain insight on the challenges in developing and implementing those plans. Our team conducted semi-structured interviews with local government officials, professors, and researchers. These interviews provided insight into the issues that different departments have focused on, current planning efforts, and the gaps in adaptation planning and strategies. Additionally, these interviews led to our team developing 7 climate change focus areas. Different impacts that are being felt in Hawai‘i due to climate change.

3.1.1 Semi-Structured Interviews with Climate Change Experts

For this objective, we utilized semi-structured interviews with experts recruited from local organizations including a leader of the State Coastal Zone Management Program and researchers from the University of Hawai‘i. These interviews provided information on how climate change uniquely impacts Hawai‘i and on climate change planning in Hawai‘i. The information collected allowed the team to determine how the planning process is navigated in Hawai‘i and gather information about ongoing planning efforts. Experts provided their insight into why certain approaches have been used in the past and why they are/are not effective. By gaining an understanding of what has been and is being done, we were able to identify gaps and potential strategies that may not have been addressed yet. This information provided direction for research into objective 2, as we looked into other places that have addressed these gaps and alternative planning processes. Table 1 contains the full list of experts interviewed for objective one.

In Appendix A, we described our focus areas and provided several general guiding questions. The individual questions asked in each interview can be found in Appendix B. Gathering information from local experts provided our team with a wide variety of perspectives and ensured we were not working against what local experts have already accomplished.

Table 1: Interviewees for Objective 1

Name	Affiliation/Organization	Date	Format	How They Were Identified
Justine Nihipali	Planning Program Manager, Coastal Zone Management Office	01/14/2022	Zoom	Recommendation from Danielle Bass
Matthew Gonser Alex Yee	Chief Resilience Officer and Executive Director Coastal and Water Program Manager	01/20/2022	Zoom	Recommendation from Danielle Bass
Charles Fletcher	Chairperson of the Honolulu Climate Change Commission	01/24/2022	Zoom	Recommendation from Danielle Bass
Michael Bruno	Provost at the University of Hawai‘i	01/28/2022	Zoom	Research
Victoria Keener	Serves on the Climate Commission for the City and County of Honolulu, Research Fellow at the East-West Center	02/02/2022	Zoom	Recommendation from Danielle Bass

3.2 Objective 2: Analyze the Processes and Developmental Ideas of Adaptation Plans in Areas Outside of Hawai‘i.

This objective aimed to identify potentially useful approaches for climate adaptation planning. As discussed in our background, there are many other adaptation and resilience plans that have been developed in a variety of different places. These plans gave our team knowledge of technical strategies to confront climate change impacts. However, this objective was focused on understanding the decisions behind how the overall plan was developed and how the adaptation plan is enforced, monitored, and funded.

3.2.1 Semi-Structured Interviews with Adaptation and Resilience Plan Experts

The goal of these semi-structured interviews was to gain information on the planning process and the challenges that these experts have faced or expect to face in the planning process. These interviews also provided information as to where planners overlapped in their

approaches to certain issues such as community involvement. This allowed our team to notice patterns that may suggest the effectiveness of certain approaches. We reached out to 25 experts listed in Appendix H and organized Zoom meetings with 6 respondents. Appendix H contains the full list of experts our team reached out to throughout the duration of the project. Table 2 contains the full list of experts interviewed for objective two. For these participants, we conducted additional background research on their professional work, enabling us to develop targeted questions specific to the interview. This includes drawing from the climate adaptation plan the interviewee worked on as well as the organization or government branch they work with. For example, in an interview with Arnaud Molenaar, Chief Resilience Officer for the City of Rotterdam, we asked about which strategies were most effective in Rotterdam and how they facilitated community involvement. For the full list of questions asked to each of the experts below, please reference Appendix D.

Table 2: Interviewees from Objective 2

Name	Affiliation/Organization	Date	Format	How They Were Identified
Arnaud Molenaar	Rotterdam Climate Change Adaptation Strategy	01/20/2022	Zoom	Research
Tiffany Wise West	City of Santa Cruz Climate Adaptation Plan Update 2018-2023	01/27/2022	Zoom	Research
Susan Asam	Vice President of ICP Climate Planning	02/01/2022	Zoom	Recommendation from Danielle Bass
Christian Kamrath	Miami-Dade Climate Action Strategy	02/3/2022	Zoom	Research
Maggie Messerschmidt	ICF Environmental Scientist and Project Manager	2/18/2022	Zoom	Research
Nani Barretto and Elizabeth Pickett	Co-Executive Directors, Hawai‘i Wildfire Management Organization	2/18/2022	Zoom	Research

3.3 Objective 3: Identify adaptation strategies that have been suggested for implementation in regions outside of Hawai‘i.

For each of the impacts of climate change our team identified in objective 1, we determined places globally that addressed the impact well and performed an analysis of the sections of their plan which addressed the focus area. This was done to highlight the best possible strategies for each impact. We asked questions in the interviews with authors of climate adaptation plans in objective 2 about the effectiveness of strategies that have been implemented. Using the information from analyzing plans and interviews, we were then able to combine knowledge from different locations to compare strategies for dealing with the breadth of issues present in Hawai‘i.

4.0 Results

The following section details the findings for each of our research objectives.

4.1 Objective 1: Information on the Current and Ongoing Impacts of Climate Change in Hawai‘i

Information and insights on the impacts of climate change in Hawai‘i were gathered through semi-structured interviews and additional research. The most important and novel of this information is summarized in this section. Summaries of individual interviews are included in Appendix F.

In an interview with Dr. Charles Fletcher, an Interim Dean of the School of Ocean and Earth Science and Technology (SOEST) and chairperson of the Honolulu Climate Change Commission, he made us aware of technologies being used in Hawai‘i to combat flash flooding due to storms including duckbill valves for drains. In addition, information shared in an interview with Justine Nihipali, the Planning Program Manager for the Coastal Zone Management Office (CZM), provided insight into how the State is preparing for these changes. She informed us that the CZM office updated the Ocean Resource Management Plan (ORMP) in 2020. This update included funding for additional research to update the erosion maps in their plan. Ms. Nihipali explained that these maps are used by counties to “shift new development further away from the shoreline to reduce the risk, not only to the houses themselves but also to the impacts of development to nearshore waters” and coastlines.

Our team reached out to Christopher Sabine, interim vice provost for research and scholarship at the University of Hawai‘i at Mānoa, to gather more information on action taken to address the impact on coral reefs. He informed us of multiple ongoing projects at Hawai‘i Institute of Marine Biology (HIMB), including projects to selectively breed corals to be more tolerant to higher temperatures, inserting artificial reefs to promote coral growth, and putting more tolerant corals onto artificial corals to promote repopulation. This information highlighted ongoing efforts for us to research further.

In addition to learning about technical approaches and existing technologies, we also utilized interviews with in-state experts to gain insight into existing planning efforts that are ongoing in Hawai‘i. In an interview with Matthew Gonser, Chief Resilience Officer and Executive Director, and Alex Yee, Coastal and Water Program Manager, we gained information that Honolulu County is currently working on a local climate adaptation plan, which has not yet been published. The function of this plan is similar to that of the Maui and Hawai‘i county adaptation plans that were discussed in section 2.3, where a state plan would not conflict with the county plan, but rather build upon it.

4.2 Objective 2: Evaluation of Established Resilience and Adaptation Plans

In the following section, we have gathered information about different planning approaches, community involvement, and strategies for implementation and accountability. This section was informed by semi-structured interviews with planners and authors of adaptation plans in out-of-state locations as well as reviews of established resilience and adaptation plans to bring new insight to Hawai‘i.

4.2.1 Approaches

Traditional Adaptation Planning vs Adaptation Pathways

We determined that two common approaches to writing an adaptation plan are traditional adaptation planning and the application of adaptation pathways. Traditional adaptation planning looks far into the future and relies on implementing adaptation measures early to reduce the impacts of climate change when they arrive. This approach has been used in Rotterdam, Netherlands and in the San Juan Bay Estuary Climate Change Adaptation Plan (Bauzá-Ortega, 2015). Rotterdam has already begun implementing adaptation measures such as constructing water squares as a long-term solution for flash flooding (Rotterdam Climate Initiative, 2013).

Additionally, the San Juan Bay Estuary plan predetermined a timetable for the implementation of adaptation strategies (Bauzá-Ortega, 2015).

On the other hand, adaptation pathways act as a series of measures that can be implemented as environmental conditions change over time (Werners et al, 2021). Unlike traditional planning, the implementation of strategies is determined by environmental thresholds that are set in advance (Kay et al, 2021). By planning for impacts of climate change ahead of time, this approach is cost-effective, as it prevents the State from over-investing in adaptation strategies and allows time for efficient planning and funding. (Messerschmidt, personal communication, 2022). Additionally, pathways consider multiple strategies and leave room for change by decision-makers and experts as new policies are developed. (Messerschmidt, personal communication, 2022). Pathways have been used in the adaptation plan for Santa Cruz, California and are currently being discussed in the City and County of Honolulu, Hawai‘i.

Stakeholder and Community Involvement

Community feedback has been incorporated into planning through online surveys, community open houses, and adaptation cafes. The planning process for the Financial District and Seaport Climate Resilience Master Plan in New York City was divided into phases, with community feedback gathered after each phase. (MOCR, 2022). The city of Boston utilized community open houses about heat risks to collect feedback for a heat resilience study. At the end of the meeting, attendees were asked to fill out a survey for ideas to protect the city from urban heat (City of Boston, 2022). Similarly, Rotterdam used adaptation cafes to facilitate stakeholder involvement (Rotterdam Climate Initiative, 2013.) At these casual events, the public is invited to come to brainstorm adaptation approaches and strategies in small groups.

Approaches to Funding

Through our interviews, we identified the importance of funding in implementing a climate adaptation and resilience plan. Dr. Tiffany Wise-West, the Sustainability and Climate action manager for the Santa Cruz, California adaptation plan, explained in an interview that the city of Santa Cruz was able to pair their adaptation strategy with their Federal Emergency Management Agency (FEMA) certified Local Hazard Mitigation Plan (LHMP). This is a program under which states identify geographical hazards and provide a vulnerability assessment for each hazard with mitigation strategies. Once these plans are in place, state governments can

draw on federal funding and grants when a disaster has been declared by the president.

Accountability and Monitoring Progress

Through our interviews, it was clear that two ways to ensure accountability are to require regular updates and to involve different levels of government. Periodic updates have already been included in many plans in Hawai‘i such as the “Ocean Resource Management Plan”, which is updated every five years and the “Hawai‘i 2050 Sustainability Plan,” which is updated every ten years. Requiring updates holds government agencies accountable to their superiors, peers, and the public for both the planning process and implementation of strategies.

Collaboration between different levels of government also contributes to increased accountability. This was done well in Miami, Florida, where the Miami-Dade County office and city offices in Miami and Miami Beach collaborated on the Resilient305 strategy (Greater Miami and the Beaches, 2019). This is a general climate adaptation and resilience strategy for the entire county. For each strategy it includes, a lead collaborator is assigned to be in charge of implementing the strategy.

4.3 Objective 3: Identify Adaptation Strategies That Have Been Suggested for Use in Other Regions

This section contains a summary of some of the adaptation strategies we have found in other regions around the world and how they can be utilized. Some of these strategies have already been discussed or implemented in Hawai‘i, including but not limited to managed retreat, seafloor dredging for erosion, restoration of coral reefs, seawalls, and updates to drainage systems. A full list of strategies can be found in Appendix E.

Sea level rise (SLR)

Many places have implemented adaptation strategies that vary based on the type of impact SLR may cause such as increased flooding, coastal erosion, and retreating shorelines. One adaptation strategy that our team discovered is the implementation of anti-backflow valves at the end of drainage systems such as Duckbill valves and WaStop inline check valves. These valves prevent water from returning back up through pipes due to storms or rising sea levels and are further discussed in the recommendation section.

Coral reefs are valuable assets when attempting to reduce wave action or even alter ocean currents to reduce erosion (NOAA, 2021). To combat the loss of natural coral reefs, deploying

artificial reefs on large sturdy structures in the ocean could promote accelerated growth and combat the impacts of SLR (Bauzá-Ortega, 2015). Because SLR is rapidly shrinking coastlines, the concept of managed retreat is gaining traction in many parts of the world. Thus far, FEMA has funded managed retreats in 49 states and 1,100 communities (Siders, 2019). Although there are many barriers and difficulties in successfully conducting managed retreat such as individual property rights, and many people's lack of awareness of the risk, managed retreat "is the strategy that most effectively eliminates risk," according to A.R. Siders, author of Managed Retreat in the United States (Siders, 2019).

Intense Rainfall

Intense rainfall causes an increase in flooding in the streets and damage to infrastructure. Combatting the impact of flooding can be accomplished in a city-wide manner by replacing roads and parking lots with permeable pavement. Pavements that are porous allow water to diffuse through the material into the ground while still being strong enough to drive on (Japan for Sustainability, 2002). Constructing water squares in public areas could be utilized in targeted neighborhoods that are more prone to flooding. Water squares are large, multipurpose depressions in the ground that can serve as a public recreational space during dry periods. During heavy rainfall, water squares are capable of storing large quantities of water to avoid overwhelming drainage systems (Rotterdam Climate Initiative, 2013). Landslides are typically one result of excessive rainfall. Some places such as Switzerland, Norway, Hong Kong, and Seattle have implemented forecasting systems to alert residents if there is a high probability of a landslide (Guzzetti, et al, 2020).

Hurricanes

The combination of high winds and heavy rainfall causes an increase in the severity of hurricanes. Adaptation strategies for storms can be designed to either reduce the magnitude of the storm or reduce the impact of the storm. Introducing wind-wave pumps into the ocean can bring colder, deep water to the surface, decreasing the surface temperature of the water, and thus reducing the sea's surface temperature enough to decrease the intensity of the storm (Kilma et al., 2011). Building stilt houses is a strategy that can reduce the impact of the storm by elevating homes securely and safely. (Miami-Dade County, 2021). These types of houses can be found in Florida and Kiribati. Following an intense storm, it is important community members understand the risks of future storms and rebuild more resilient than before. States such as Florida require

property owners to follow new current building codes following a storm to ensure the future safety of local communities.

Ocean Warming

The issues of ocean warming will cause coral reefs to bleach and in some cases die. One strategy to address ocean warming and acidification is seeding corals with more heat-tolerant algae (Carballo-Bolaños et. al., 2019). This is largely a theoretical solution, but it could be done with the goal of producing reefs that can withstand a greater range of temperatures. Another solution involves breeding corals either through simulated naturally selective processes or cross-breeding between coral species (Howells, et al, 2021; Barott, et al, 2020). This process would create corals that can handle fluctuations in temperature. Research regarding these methods of adaptation to ocean warming are being done at the University of Hawai‘i.

Urban Heat

Rising temperatures pose many risks related to the health and safety of local communities. A potential strategy to keep people safe and limit heat illness could be to create more green spaces. One benefit of parks, trees, and more greenery is they can provide more shade and help protect against direct heat (Kurn et al., 1994). An example of a larger-scale adaptation strategy to reduce the urban heat island effect is to install cool pavement. Cool pavement is a relatively new technology that is designed to reflect more solar energy, keeping roads, sidewalks, and parking lots cooler (EPA, 2014). One example of this strategy being implemented can be found in Tokyo, Japan (Iwama et, al., 2011).

Drought

Most strategies our team has discovered to limit the effects of drought involve methods of maximizing the utility of water and ensuring water supply does not decrease below water demand. One strategy to accomplish this is creating more space for surface water by expanding or creating reservoirs, canals, and lakes to catch and store more water when it rains to store during droughts. (Rotterdam Climate Initiative, 2013). Recycling water through purification can allow for water to be used multiple times before it is discarded and does not decrease the overall water supply (Orange County Water District, Orange County Sanitation District, 2021). In order to increase supply, states such as Texas have begun diversifying their water sources (Wythe, n. d.). Utilizing groundwater, surface water, and desalination techniques can help increase the

overall water supply which will be especially useful in times of drought (United States Environmental Protection Agency, 2015).

Wildfires

Some measures for stopping wildfires are more preventative. Producing fire pamphlets and hosting information sessions through organizations like the HWMO are possible solutions for stopping fires before they happen. Additional solutions that can be implemented to mitigate the devastation of wildfires involve the clearing out of fuel sources for wildfires to interfere with their ability to spread. Removing invasive grass species such as "guinea grass" is a strategy that could create fuel breaks to keep the fire from spreading out of control (Ammondt et. al., 2011). To be able to effectively extinguish wildfires once they break out, new roads and water sources need to be built in rural areas to provide access to the fire (Pickett, personal communication, 2022).

5.0 Recommendations/ Discussion

The following section describes recommendations that include climate adaptation planning approaches and climate adaptation technologies that we believe could benefit the State of Hawai‘i. There have already been significant efforts to adapt to the effects of climate change by the State and different organizations. These recommendations are meant to build upon efforts that have already been made to increase the resilience of Hawai‘i. It is our hope that these recommendations can be used by the Hawai‘i Office of Planning and Sustainable Development to write a statewide climate adaptation and resilience plan.

5.1 Recommendation #1: Utilize Adaptation Pathways to Address Flooding Due to Sea Level Rise (SLR), Urban Heat, and Wildfires

We suggest that the Office of Planning and Sustainable Development utilize adaptation pathways when addressing flooding due to SLR, urban heat, and wildfires in the State climate adaptation and resilience plan. We are recommending pathways for these effects as opposed to traditional planning because their intensity increases gradually. The pathways approach would address the effects of these impacts over an extended period of time and implement lower-cost, lower-impact strategies first. For this approach to be successful, thresholds would need to be set in order to decide when the next measure should be implemented. The flexibility of pathways for these effects would allow for adjustments to be made to the schedule or to the adaptation

measures as conditions change and new technologies emerge. Due to the time constraints of this project, we were not able to determine specific thresholds for adaptation pathways. Experts in these particular disciplines of environmental science and government decision-makers are more knowledgeable and equipped to make these determinations for a statewide adaptation and resilience plan. The recommendations in the following section are organized with the most low-cost, low-impact strategies listed first. These strategies would be implemented earlier in the adaptation pathway. The strategies listed further down would be implemented later in the pathway after particular thresholds are met.

We recommend that the State of Hawai‘i utilize adaptation pathways to address coastal flooding due to SLR. We recommend the following adaptation measures to be included in the adaptation pathway for coastal flooding due to SLR in the State of Hawai‘i:

- Install additional anti-backflow measures in stormwater drain pipes, such as duckbills or WaStop inline check valves, to prevent water from reentering pipes. This technology is already being utilized in Hawai‘i and could be implemented in additional locations across the islands. Although there are challenges associated with duckbills, such as debris build-up around the outside of the valves due to outside water trying to get in, this issue can be solved in a number of ways. The most feasible ideas include removing the sand around the valves periodically, raising the height of the valve, or replacing duckbills with WaStop inline check valves. The design of the WaStop valve does not rely on opening outwards to release water, but rather water flows through a small opening underneath the cone-shaped inside. This cone is what prevents water from returning back into the drainage system.
- Expand on projects to restore and construct coral reefs. Repairing and constructing coral reefs have many benefits associated with SLR while simultaneously creating an opportunity for expanding marine life habits. Coral reefs are capable of buffering wave action and redirecting currents, shifting sand down beaches, and restoring the coastline. Projects involving constructing artificial reefs have previously been done in Hawai‘i and further research is currently taking place at the University of Hawai‘i. There is room to expand on these efforts, especially projects related to seeding coral with more temperature-tolerant algae, which is further discussed in recommendation two.

We recommend that the State of Hawai‘i utilizes adaptation pathways to address the increase in urban heat. We recommend the following adaptation measures to be included in the adaptation pathway for urban heat in the State of Hawai‘i:

- Create additional green space by planting trees and constructing parks to create more shade. Creating areas of shade can be a low-cost and efficient solution to reduce temperatures in urban areas. Although some neighborhoods have many green spaces, there are areas of the city and island that could benefit from trees along roadsides or additional park spaces. Local communities and schools could also organize green space events where communities come together to plant trees and plants around their neighborhoods.
- Replace current roads, walkways, and parking lots with cool pavement to reflect infrared rays off of a reflective surface. This will decrease the amount of heat absorbed by the pavement surface. Although replacing each road and walkway with new pavement could be very costly, cool pavement has the ability to be used in conjunction with permeable pavement, which is discussed in recommendation two. Cool pavement technology is relatively new, and the State of Hawai‘i does not currently utilize it. However, this technology has been implemented in Tokyo, Japan. Further research into the effectiveness of cool pavements is necessary to develop the most effective strategy for implementing them in Hawai‘i.

We also recommend that the State of Hawai‘i utilizes adaptation pathways to address increasing wildfires. We recommend the following adaptation measures to be included for wildfires in the State of Hawai‘i:

- Increase community outreach through the distribution of fire pamphlets in the mail, workshops on causes of wildfire, and the distribution of contact information for reporting invasive grasses. According to an interview with Elizabeth Pickett from the Hawai‘i Wildfire Management Organization, approximately 99% of all wildfires in Hawai‘i are caused by human activity, only 1% are caused by lava or lightning. One of the most feasible and cost-efficient strategies our team recommends is increasing community awareness of dangerous actions that may cause wildfires and how severe these wildfires can be if they begin to spread.

- Remove invasive grass species, specifically guinea grass, from barren lava flows similarly to how pampas grass was eradicated on the Big Island in 2020 (Big Island Invasive Species Committee, n.d.). Hawai'i contains many large flat grasslands prone to wildfires. As these grasslands burn and approach tree lines, the fire also begins to burn down trees. Because the grass grows quicker than the trees, the land is further overtaken by invasive grass species. Conducting land surveys to map locations where the grass has spread and informing the public of how to report sightings of guinea grass will help identify where guinea grass is located. Then, the State could send in teams to carefully remove it at all sights. This will create fuel breaks to keep the fire from spreading
- Construct new roads through grasslands and forests to provide additional access to wildfire sources when they occur. Due to the lack of roads through many grasslands, firefighters often face difficulty reaching fires when they occur. The HWMO explains that due to the lack of roads, the Big Island relies on two helicopters to fight these fires that trucks cannot reach. Although this may be a difficult strategy to implement due to some grasslands being owned by private property owners, constructing roads on property owned by the State will allow existing trucks to reach more land areas to extinguish fires before they spread significantly.

5.2 Recommendation #2: Utilize Traditional Adaptation Practices to Address Flash Flooding and Landslides Due to Increased Rainfall and Storms, Ocean Warming, and Drought

Our team recommends traditional approaches for implementing strategies to manage flash flooding and landslides due to increased rainfall and storms, ocean warming, and drought. The State of Hawai‘i has previously developed documents including but not limited to the 2018 State of Hawai‘i Hazard Mitigation Plan (HMP), which details the state's vulnerabilities to various hazards. However, the State is currently in need of a statewide plan to reduce the effects of these hazards. For example, the HMP details a full risk assessment of hurricanes in Hawai‘i. Despite this, current building codes in the state are not capable of withstanding the effects of low-intensity storms such as tropical storms or category one hurricanes (Keener, personal communication, 2022). This is an example of one of the gaps that can be filled with a traditional planning approach because these events are not gradual, but can happen at any time.

We recommend the following adaptation measures to be included in the plan to address flash flooding caused by intense rainfall and storms in the State of Hawai‘i:

- Develop and implement new building codes designed to minimize future damages. Following hurricanes, Hawai‘i could require residents and homeowners to rebuild any damaged property according to the new building codes. After dangerous storms, it is important to learn and adapt to the changing climate. Rebuilding using old building codes will significantly increase the likelihood of similar damages being experienced during future intense storms or rain bombs. Examples could include raising the important infrastructure like heating and energy units above predicted flood levels.
- Replace current roads, walkways, and parking lots with permeable pavement to reduce flooding along streets. Pavement that is porous in design could be more beneficial to use than regular asphalt because it allows floodwaters to drain off the streets. The technology is also extremely useful for reducing flooding during other periods of rainfall. As mentioned in recommendation one, permeable pavement could potentially be used simultaneously with cool pavement technologies. This would allow the state to keep urban areas cool while lowering its risk of flooding. Although it would be expensive to replace every road at once, the state could develop a list of high-priority roads to be replaced first. During periods of intense rain, the State could monitor locations experiencing large floods and replace old pavement following the event.
- Construct water squares in dense urban areas to allow for large quantities of water to be stored. Large depressions could be made with stairs leading down into them to serve as both a water-storage method during storms and a recreational space during dry times. Although quite large in size, water squares are effective at removing and draining large quantities of water off the streets. Water squares would ideally be placed in dense urban areas to collect water that is funneled from rooftops and roads. The water would drain through holes below the bottom layer of the structure.
- Utilize online tools and forecasting services to create an early warning landslide system to preemptively alert citizens when the risk of landslides is highly probable. Our team believes the most critical adaptation strategy the State could benefit from without investing in hard infrastructure is the implementation of an early warning system, which notifies residents and community members during periods of rainfall when a landslide is

likely to impact the area. This will allow citizens enough time to seek shelter in another location away from the danger during that time. Additional research into the early warning systems in Switzerland and Norway could be helpful.

We recommend the following adaptation measures to be included for ocean warming in the State of Hawai‘i:

- Expand on research for seeding corals with more heat-tolerant algae to determine if reducing the likelihood of bleaching events is viable. Symbiotic algae called zooxanthellae are critical for sustaining coral colonies. Coral bleaching often occurs when the coral's environment changes sufficiently to cause them to expel these algae. By selectively breeding the algae to be more heat tolerant and seeding the new algae in pre-existing corals, reefs may have a higher chance of survival as oceans become warmer. Further research may need to be done on the effectiveness and feasibility of this strategy over extended periods of time.

We recommend the following adaptation measures to be included for drought in the State of Hawai‘i:

- Recycle water through purification methods, allowing it to be used multiple times before being placed in the ocean. This strategy will be useful as the water supply begins to decrease in times of drought. The ability to reuse water multiple times before depositing it back into the ocean maximizes the utility of existing water. Further research must be done, especially on Orange County, California's method of water recycling.
- Diversify water supply options to reduce the risk of water supply falling below water demand. Currently, the main water source for the state is the utilization of groundwater through aquifers. However, as droughts become more intense and last for longer periods of time, relying only on aquifers may be a great challenge. Utilizing as many water sources as possible will help the total supply of water stay above the levels of demand in times of drought. Additional sources of water could include surface water or desalination of seawater.

5.3 Recommendation #3: Stakeholder Involvement and Collaboration

Our team recommends adopting approaches that facilitate community stakeholder involvement and collaboration between government agencies and private organizations. It is necessary to implement involvement outside one level of government. The most effective plans

our team reviewed involve participation from the public and collaboration to implement strategies. Examples of where this has worked include Rotterdam, Netherlands, and Miami, Florida. Planning officers in these areas saw high levels of community involvement. Due to these successes in other plans, our team recommends the following strategies.

- Involve stakeholders in the development of the plan to create commitment among organizations and to increase the involvement that stakeholders have in the projects. This was very effective in Rotterdam due to their "adaptation cafes," which are open house discussions that allow any member of the community to give their input to the planning process. Another model of community discussion that has been used in Hawai‘i is the Kukakuka project from the Honolulu Office of Climate Change, Sustainability, and Resiliency. These were virtual one-on-one or small group meetings with organizational community leaders in services including affordable housing, human service, and food security, to discuss community resilience in a crisis.
- Institute a lead collaborator, at either the county or the state level, on every adaptation strategy that the plan will outline for implementation. To determine which level of government should take the lead on a particular adaptation measure, there should be meetings with both state and county planners. In addition, any strategies already outlined in county adaptation plans should also inform what strategies the county takes the lead on. For example, the State could be the lead on restoring the beaches from erosion, as shorelines are State-owned. The county governments could lead projects to develop additional green spaces in their cities and towns to adapt to extreme heat. This would distribute responsibility and encourage the county and state governments to hold each other accountable for making progress.
- Hold biannual meetings with representatives from community-based organizations and government organizations to track progress and maintain accountability. Biannual meetings were effective for the Financial District and Seaport Climate Resilience Plan in Manhattan, which held 4 public open houses over their roughly 2-year planning process (MOCR, 2021). This will keep the community informed on how implementation is progressing, which allows for transparency and trust between the planners and other stakeholders.

- Update the plan regularly. By continuously updating the climate adaptation and resilience plan, it will be better suited for adapting with Hawai‘i as the climate changes over time. If new issues arise or if certain issues develop differently than expected, a plan update would consider those factors to develop new solutions. This creates more opportunities for other stakeholders in Hawai‘i to contribute to new or developing projects.

6.0 Conclusion

The State of Hawai‘i and the Office of Planning and Sustainable Development (OPSD) have made tremendous progress in developing climate change reports and studies on various impacts of climate change. They have also developed a network of collaborators from other levels of government, academia, and the nonprofit sector. This work has provided our team with a crucial framework from which we were able to expand our research.

The topic of climate change is an ever-evolving discussion, and predictions for the future can be very uncertain. However, due to great strides in technologies, Hawai‘i has a tremendous opportunity to adapt to the many impacts felt by the effects of climate change. Our work aimed to explore different approaches to adaptation planning, as well as identify adaptation strategies in other regions around the world and how these strategies can be effective. Future research must be done into how some strategies could be implemented in certain communities. In addition, collaboration with many stakeholders must occur in order to develop a successful plan. Our hope is that the OPSD and the State of Hawai‘i will greatly benefit from the initial work our team has provided.

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Appendices

Appendix A: Example Climate Expert Interviews

Pre Interview Information

This interview will consist of several questions related to your work in order to gauge climate change effects in Hawai‘i. This will be used for our project developing a report for the Hawai‘i State Office of Planning and Sustainable Development.

Sample Interview Questions

- What is your educational background?
- What is your current job position?
- Can you describe your professional background in climate change?
- We are working on a project to develop suggestions for climate adaptation strategies for the state. Are you aware of any strategies that have already been implemented?
- Could you describe some of the current effects of climate change that you are witnessing in Hawai‘i?
- Can you locate any specific sites in the state that are currently in urgent need of an adaptation strategy?
- Have you taken part in adaptation planning and/or implementation?
    - If yes: Can you talk about your role in this experience?
    - Did you work with any other organizations?
- Can you direct us towards any resources or organizations that could also provide information about climate adaptation strategies?
- Would you be willing to give our team some feedback on a draft of the operational outline for our adaptation and resilience plan?

Appendix B: Individual Interview Questions With Climate Change Experts in Hawai‘i

Justine Nihipali

- What is your professional background and current job position?
- We are working on a project to develop suggestions for climate adaptation strategies for the state. Are you aware of any strategies that have already been implemented in coastal zones?
- I have a question about maps regarding zones that are vulnerable to tsunamis. You mentioned that building codes are different and evacuation procedures are very clear, how are these instructions related to the public?
- Can you locate any specific sites that are currently in urgent need of an adaptation strategy?
- When reading through the Hawai‘i Ocean Resources Management Plan, we learned that during the original adaptation phase (2013-2019), many priorities were not addressed. What challenges were faced and how is the “Focused Implementation Phase” (2020-2030) different?
    - Additionally, what does it mean by the approach “elevating select topic areas from a wide spectrum of issues” (10)?
- It is indicated that the Coastal Hazard Action Team is a collaboration to develop a statewide plan. What was the process for developing this team? How do all organizations interact/stay connected?
- We found the concept of managed retreat to be interesting. Has this been done in Hawai‘i? What is its effectiveness?
- It has been researched that seawalls actually have a negative effect on erosion. Do you know of any alternative solutions that have been implemented in place of seawalls?
- Can you direct us towards any resources or organizations that could also provide information about climate adaptation strategies?
- Would you be willing to give our team some feedback on a draft of the operational outline for our adaptation and resilience plan?

Matthew Gonser & Alex Yee

- Can you describe your professional background in climate change?

- We noticed on the Resilience office website that there is a section called “Climate ready Oʻahu. Within that there is a timeline to create an adaptation strategy, and phase 3 included writing a plan from June 2021- September 2021. What is the current status of this plan?
- The Oʻahu resilience plan was written specifically for Oʻahu. What would the challenges be in writing a plan for the whole state in comparison to just one island?
- How do you go about enforcing or holding the government accountable for following the resilience plan?
- Your organization focuses on equality for all members of the Hawaiian community alongside the methods for dealing with climate change, using an “Equity Lens.”. How does your organization implement equity into their plans and operations as opposed to equality?
- What sectors of Hawaiʻi, such as transportation or energy, do you believe have been the most successful in your organization’s quest to make the state more resilient to climate change?
- Can you direct us towards any resources or organizations that could also provide information about climate adaptation strategies?
- Throughout mid 2020, as well as the later half of 2021, your organization has worked on Community Kūkākūkā, listening to the people in order to determine various problems or hardships through discussion. Is Community Kūkākūkā effective? How does this tie into climate resilience work?

Charles Fletcher

- Introductions
- As reported in “Modeling multiple Sea Level Rise stresses reveals up to twice the land at risk compared to strictly passive flooding methods,” an estimated 70% of beaches on the islands of Kauai, Maui, and Oʻahu are retreating. The island of Oʻahu has many large coastal communities, what are some efforts being done to protect these communities?
- It has been proven that seawalls actually have a negative effect on erosion. Do you know of any alternative solutions that have been implemented in place of seawalls?
- We found the concept of managed retreat to be interesting. What is the effectiveness of this approach and what are the challenges that would be faced?

- As sea levels rise, storm drain backflow will become a great problem and cause more flooding even with no precipitation. Has the state looked into this issue? In your research, have you found any potential solutions?
- We have conducted many hours of research on strategies that are used in Rotterdam, Netherlands. One method of reducing flooding that they have implemented is water squares. Would this be a feasible strategy in Hawai‘i?
- Why does Hawai‘i have a higher than average sea level rise?
- Sea Level Rise and the increasing frequency of cyclonic events will make the islands more vulnerable to flooding. Besides the concept of managed retreat and updating building codes, what are some potential ways we can protect the communities from these impacts?
- Can you direct us towards any resources or organizations that could also provide information about climate adaptation strategies?
- Would you be willing to give our team some feedback on a draft of the operational outline for our adaptation and resilience plan?

Michael Bruno

- Can you describe your professional background in climate change?
- Which effects of climate change do you believe to be the most important to address at this time?

The Urban Ocean and Resilience Strategies

- What is the correlation between human-induced climate change (which would cause increased storms) and how that would increase long-term beach erosion? Are there different approaches to adapting to long-term erosion vs natural erosion?
- You wrote about how natural methods of restoring coastlines such as sediment replenishment aren’t possible due to urban development. Are there any ways we could replicate natural sediment replenishment or coastline restoration?
- How feasible would it be to implement an adaptation strategy to reduce coastal erosion utilizing the attractive force of small-sized sediments such as clay?
- Developed coastlines do not allow beaches to be pushed back and the consequences of this could be quite devastating to many coastlines communities. What are some solutions that have been proposed?

- What are the challenges to dredges? Is this accepted by the community?

Collaboration and community acceptance

- You also mentioned that efforts to support community resilience require public and private stakeholders to collaborate and establish community goals. How are these collaborations initiated and upheld?
- Are you aware of any strategies to include cultural and historical significance as part of the conversation in policy planning?
- Can you direct us towards any resources or organizations that could also provide information about climate adaptation strategies?
- How are these conversations initiated and make sure that indigenous voices are heard?

Susan Asam

- What is your educational background?
- What are some of the projects you have worked on addressing climate change?
- What are some of the resilience strategies that you have helped develop?
- In your experiences, what are the major differences between climate resilience planning at the state level and at the federal level?
- In "Stormwater Management in Response to Climate Change Impacts: Lessons from the Chesapeake Bay and Great Lakes Regions," different approaches to adaptation strategies were analyzed and discussed. How would you use this data to determine which approach would work best in Hawai‘i? What are the major factors to consider besides geographical characteristics?
- How do you ensure equity and inclusion in adaptation planning?
- How is the idea of managed retreat being discussed in Hawai‘i? Is there a plan to gather community support if a policy like this was enforced?
- How do you go about enforcing or holding the government accountable for following the resilience plan and implementing strategies? How do you measure progress?
- Are you aware of how an adaptation plan can be developed and become FEMA certified to become eligible for more funding?
- How do you approach working at the local level and the state level differently? What would the differences be in the way you approach writing a plan for the state in comparison to just one island?

- How are collaborations between organizations and departments initiated? How do they keep in contact?
- How do you decide on strategies?

Victoria Keener

- What is your educational background?
    - Can you describe your professional background or area of expertise?
- The increasing frequency of cyclonic events will make the islands more vulnerable to flooding. What other effects besides flooding do we need to prepare for?
- The state currently imports many agricultural resources, however as the state begins searching for more sustainable options, how might drought play a different role than it currently is?
- Since the US drought monitor has been implemented, we can see that there have been long periods of drought, specifically from 2008-2018. What were the most severe impacts that you saw during this time?
- One of the major effects of drought in Hawai‘i is a rise in risk of wildfires, what are some of the challenges Hawaiian firefighting efforts have faced due to this increase?
    - Do you know of any proposed solutions to these problems?
- Can you direct us towards any resources or organizations that could also provide information about climate adaptation strategies?

Christopher Sabine

- What is your educational background?
    - Can you describe your professional background or area of expertise?
- We know that a major concern due to ocean changes (warming and acidification) in Hawai‘i is the effect these have on coral reefs. Do you know of any efforts to combat the effects of ocean warming and acidification on reefs in Hawai‘i?
    - It seems like most organizations seeking to restore reefs in Hawai‘i are primarily focused on stopping human-based pollution such as trash, fishing disruptions, and chemicals. Do you know any groups that have made efforts to make reefs more resilient to bleaching?
    - Is there more that you believe that state could be doing to combat ocean warming? Acidification?

- In our research, we read up on the extreme bleaching events that occurred in Hawai‘i in 2014 and 2015 due to extreme ocean temperatures. What is the likelihood of an event on this scale happening again? Can the corals continue to be resilient if events such as this become more common?

Appendix C: Example Climate Adaptation Plan Interviews

Sample Interview Questions

- What is your educational background?
- Can you describe your professional background or area of expertise?
    - Follow-up: How did you transition to working on climate adaptation strategies?
- What inspired your research for developing this climate adaptation and resilience plan?
    - Follow-up: Did you research other climate resilience and adaptation plans when developing your plan? If so, what plans did you draw from?
- What was your personal involvement or contribution in developing this adaptation and resilience plan?
    - Follow-up: Did you focus on a particular subject area or the organization of the outline as a whole?
- How did you draw conclusions about what strategies would work best for your plan?
    - Follow-up: Can you point to evidence that the strategies you implemented have worked or have been working?
- What are some challenges you faced along the way in developing an adaptation plan?
- Has this plan changed since first written? If so, how?
- Can you give an estimate on the cost of implementing [insert strategy]?
- Did you have to factor in the perspectives of diverse groups of people in your plan? This includes people of varying cultures, ethnicities, or indigenous populations.
    - Follow-up: How did you include these perspectives in your plan? Were these inclusions based on input from these groups?
- What is the approximate time frame it took to complete the development of this adaptation plan?
- Would you be willing to give our team some feedback on a draft of the operational outline for our adaptation and resilience plan?

Appendix D: Individual Interview Questions for Climate Adaptation Experts

Arnaud Molenaar

- What is your educational background?
    - Can you describe your professional background or area of expertise?
- What was your personal involvement or contribution in developing this adaptation and resilience plan?
- What are a couple of the most effective adaptation strategies that have been implemented in Rotterdam to reduce the effects of flooding and sea level rise.
- What does the process of implementing an adaptation strategy look like?
- How did you draw conclusions about what strategies would work best for your plan?
    - Can you point to evidence that the strategies you implemented have worked or have been working?
- What are some challenges you faced along the way in developing an adaptation plan?
- How was implementing the adaptation strategies enforced?
- Has this plan changed since it was first written? If so, how?
- What is the approximate time frame it took to complete the development of this adaptation plan?
- Can you direct us towards any resources or organizations that could also provide information about climate adaptation strategies?
- Would you be willing to give our team some feedback on a draft of the operational outline for our adaptation and resilience plan?

Tiffany Wise-West

- What is your educational background?
    - Can you describe your professional background or area of expertise?
    - How did you transition to working on climate adaptation strategies?
- What was your personal involvement or contribution in developing this adaptation and resilience plan?
- What was the process of developing an adaptation strategy like?
- What are some challenges you faced along the way in developing an adaptation plan?
- How was implementing the adaptation strategies enforced?

- What is the approximate time frame it took to complete the development of this adaptation plan?
- Has this plan changed since it was first written? If so, how?
- Can you direct us towards any resources or organizations that could also provide information about climate adaptation strategies?
- Would you be willing to give our team some feedback on a draft of the operational outline for our adaptation and resilience plan?

Support Questions

- One of the largest problems in Hawai‘i is Sea level rise. While Santa Cruz is also a coastal city, are sea walls currently the only method of adaptation along the coast in the city?
    - Have there been any drawbacks of using sea walls?
    - In the adaptation plan, there is a reference to a report citing sea walls may not cause as much coastal erosion as previously thought, what report might this be?
    - Are you aware of any other adaptation strategies that may substitute sea walls?
- Hawai‘i is facing a similar problem of water being contaminated due to rising sea levels, how has the city of Santa Cruz planned for this possibility?
    - As drought caused by rising temperatures increases, does the city have a plan to maintain a sufficient water supply?
- We noticed throughout the Santa Cruz climate adaptation plan that drought and wildfires are mentioned quite a bit. Is Santa Cruz experiencing these effects similar to more inland cities and states?
    - How is the city planning to manage these changes as they worsen?

Christian Kamrath

- What is your educational background?
    - Can you describe your professional background or area of expertise?
    - How did you transition to working on climate adaptation strategies?
- What was your personal involvement or contribution in developing this adaptation and resilience plan?

- We know the state of Florida has its own resilient coasts climate adaptation strategy. With this in mind, what led to the county's push to create its own plan for climate adaptation as well?
    - Are there challenges with coordinating State and county-level adaptations?
- Miami relies heavily on tourism just like Hawai‘i, because of this measures like sea walls along the coast are likely to be very unpopular. Has Miami considered any options other than sea walls to combat Sea Level Rise?
- One strategy we’ve heard a lot about here in Hawai‘i is the possibility of managed retreat, moving a community back over time in response to sea-level rise, has Miami considered this option?
- Miami’s main source of freshwater is the Biscayne Aquifer, due to the high levels of limestone Miami sits on have there been concerns of salt-water intrusion into this water supply?
    - How has Miami begun to prepare for this type of contamination?
- How has community involvement been incorporated into your planning process?
- Miami is a very diverse community, did you aim to factor in the perspectives of diverse groups of people in your plan? This includes people of varying cultures, ethnicities, or indigenous populations.
    - How did you include these perspectives in your plan? Were these inclusions based on input from these groups?
- What is the approximate time frame it took to complete the development of this adaptation plan?

Appendix E: Tables of Adaptation Strategies

Table 3: Adaptation Strategies for Sea Level Rise

The following table details the results of our research and interviews into adaptation strategies for sea-level rise. The table lists strategies as well as places outside of Hawai‘i where they have been discussed or implemented. It is important to note that some of these strategies have already been discussed or implemented in Hawai‘i in some form. The purpose of this table is to provide models for further implementation of and information on various strategies. Implementing managed retreat is a strategy that is heavily considered within the state. The Office of Planning and Sustainable Development's Coastal Zone Management Program compiled a report in 2019 assessing the feasibility of managed retreat in Hawai‘i (Coastal Zone Management Program, 2019). The installation of artificial coral reefs has occurred for a long period of time in Hawai‘i, dating all the way back to the 1960s in Maunaloa Bay (State of Hawaii, Division of Aquatic Resources, 2022). Mangrove trees are already present in Hawai‘i but are an invasive species that many groups are attempting to remove. Seafloor dredging to replenish sand on beaches has been done in Hawai‘i, including at Waikiki Beach. Seawalls have been constructed in many areas of Hawai‘i, also including Waikiki beach, in order to protect the shorelines from erosion. Finally, duckbill drain valves have already seen some implementation in Mapunapuna on O‘ahu (Hohnholz, 2021).

Impact	Strategies	Description	Example Locations of Implementation	Source
Rising sea levels will erode coastlines and undermine the foundations of coastal structures	Managed retreat	This strategy involves shifting communities inland away from the threat of the sea moving further inland. This may include buying out homes and buildings using federal funding.	Implemented in Soldiers Grove, Wisconsin and Valmeyer, Illinois	Managed Retreat in the United States (Siders, 2019); The lost history of managed retreat and community relocation in the United States (Printer, 2021)
Rising sea levels will	Raise shoreline	Raising the immediate shoreline with	Implemented along Miami	Resilient 305

erode and lower coastlines, making it easier to flood surrounding areas		3-5 feet of fill can better protect infrastructure against flooding and provide opportunities for improved drainage of rain or floodwater.	Beach Discussed in Manhattan, New York	(Greater Miami and the Beaches, 2019) Financial District and Seaport Climate Resilience Master Plan (MOCR, NYCEDC, 2021)
Rising sea levels will affect underwater currents and tides	Coral reef restoration/ Install artificial coral reefs	The restoration of coral reefs and installation of artificial reefs can buffer wave action and redirect currents. Implementation can be done by building supports or using pre-existing structures to house new/restored corals.	Discussed in San Juan Bay, Puerto Rico	San Juan Bay Estuary Climate Change Adaptation Plan (Bauzá-Ortega, 2015)
Rising sea levels will erode coastlines and make the shore more vulnerable to strong waves	Install and create mangrove forests	Planting mangroves in coastal areas can prevent erosion and flooding by stopping wave action.	Discussed in Miami-Dade County, Florida	Miami-Dade County Sea Level Rise Strategy (Miami-Dade County, 2021); Mangroves for Coastal Defense (Spalding et. al., 2014)
Rising sea levels will	Seafloor	The ocean floor can be dredged for	Implemented in New Jersey	The Urban Ocean (Blumberg,

erode shorelines and affect underwater currents and tides	dredging	natural and local materials, which can then be used for beaches. This will raise the shoreline to lessen the effects of coastal erosion and change the topography of the undersea floor to change the underwater current which in turn will lessen the currents' effects on the coastlines.	and Hawai'i	2018)
Rising sea levels will increase the possibility of flooding in coastal areas	Construct Seawalls	A seawall can be built to protect areas from coastal flooding as well as coastal storms. The practice of building sea walls has been in use for centuries, though it often causes increased erosion of the shoreline. In New York, there is a plan for a 15 to 18 foot sea wall to be built that is pulled back from the shoreline, with closable openings to allow shoreline access when the weather is calm but to block it off when the weather gets to be more threatening.	Implemented in Manhattan, New York, Seattle, Washington, Bembridge, United Kingdom, Ventnor, United Kingdom, and Bonchurch, United Kingdom	Financial District and Seaport Climate Resilience Master Plan (MOCR, NYCEDC, 2021); Waterfront Seattle (Waterfront Seattle, n. d.); Coastal Defence Schemes (Isle of Wight Council, Coastal Management, 2013)

Rising sea levels could potentially cause backflow in stormwater systems and sewers that empty into oceans, which could cause flooding due to sewer overflow	Implement duckbill valves on the end of pipes	Special attachments can be placed on the ends of drainage pipes whose structure and shape allow water to flow outwards with enough pressure, but also to block water from reentering the pipe, thus allowing better drainage and lessening the risks of backflow in the storm drain system.	Implemented in Hawai‘i and Zalec, Slovenia	Back-Flow Prevention Strategies for Stormwater Lines (Evins, 2016); Slovenia City Uses Duckbill Check Valve for Backflow Prevention (Storm Water Solutions, 2016)
Rising sea levels could potentially cause backflow in stormwater systems and sewers that empty into oceans, which could cause flooding due to sewer overflow	Implement WaStop inline check valves inside drain pipes	This type of valve, similar to the duckbill valves mentioned above, can allow stormwater to flow out of pipes while preventing backflow through drain systems, lessening the risks of flooding. The structure of these valves is an oblique cone shape, such that water can flow under the cone with its own pressure, while it would not be able to come back from where it came from during periods of backflow, getting caught in the conical part of the valve instead.	Implemented in Longboat Key, Florida	Longboat to Install New Valves (Hauff, 2018); The Valve Agency, Inc. (The Valve Agency, Inc, 2012)

Figure 1: Artificial Coral Reef (NOAA, 2011)

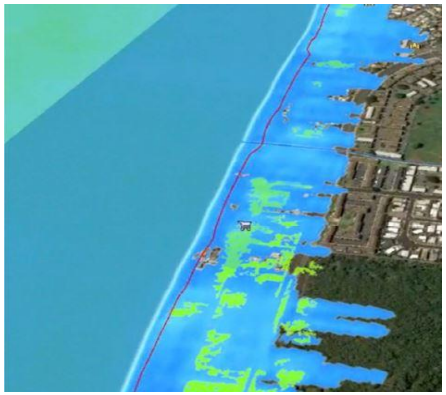

Figure 2: Managed Retreat Feasibility (Webster, n. d.)

Figure 3: Mangrove Trees (NOAA, 2021)

Figure 4: Raised Shoreline (U.S. Department of Transportation, 2020)

Figure 5: Ocean Seafloor Dredging (Smithsonian, n.d.)

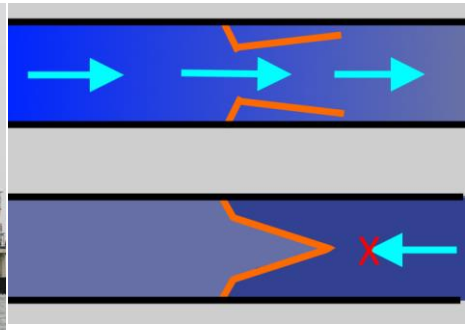

Figure 6: How a Duckbill Check Valve Works (Cowlinator, 2020)

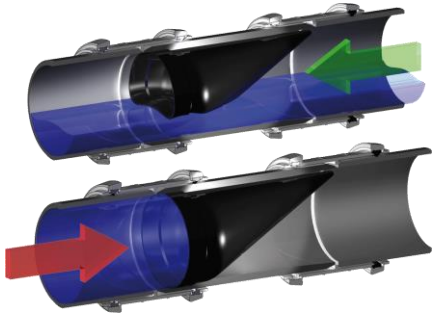

Figure 7: How a WaStop Inline Check Valve Works

Figure 8: Implementation of a Seawall (Tinari, 2017)

(Magnusson, 2010)

Table 4: Adaptation Strategies for Intense Rainfall

The following table details the results of our research and interviews into adaptation strategies for intense rainfall. The table lists strategies as well as places outside of Hawai‘i where they have been implemented. It is important to note that some of these strategies have already been discussed or implemented in Hawai‘i in some form. The purpose of this table is to provide models for further implementation of and information on various strategies. There have been bioswales installed in Wailupe Beach Park and Kuli‘ou‘ou Beach Park to reduce pollutants in stormwater runoff that drains into Maunalua Bay (Sustainable Resource Group Intn’l, Inc., 2021). In 2017, workshops were conducted by the Hawai‘i Asphalt Paving Industry that included at least one exhibit for porous pavement, showing that it is already being considered (Hawaii Asphalt Paving Industry, 2017).

Impact	Strategies	Description	Location	Source
Too much rainwater can flood streets and areas, and the runoff from roofs and other structures may bring pollutants into water sources and other such areas.	Install bioswales	Depressions in between or on the sides of roads can be made and filled with various biological substances such as vegetation, compost, or mulch. These depressions can channel rain water or runoff from roofs into themselves, allowing for a place where the water can drain more easily, while also cleaning out various pollutants.	Implemented in Manhattan, New York, and California	Financial District and Seaport Climate Resilience Master Plan Homepage (MOCR, NYCEDC, 2021); California Urban Area Bioswales (Dudek, 2012)
Inadequate sewer	Implement a plan	Keeping stormwater and sewage	Discussed in San Juan Bay	San Juan Bay Estuary

systems could lead to malfunctions, which could worsen the ability to handle stormwater as well as cause flooding in cities.	for frequent maintenance of stormwater and sewage systems	systems maintained and up to date will lower the chances for sewer-related infrastructure to fail. Creating a monitoring system for said infrastructure could protect the health and lives of many people.	Estuary, Puerto Rico Implemented in South Bend, Indiana	Climate Change Adaptation Plan (Bauzá-Ortega, 2015); South Bend, Indiana Uses Smart Sewer Technology to Monitor and Manage Increased Water Levels (Environmental Resilience Institute, n. d.)
Lots of water that comes from heavy rainfall could flood streets and make conditions that are harder if not impossible to drive in.	Implement permeable pavement into streets	Instead of using asphalt on roads, pavement that is porous in nature and design could be more beneficial to use. The pavement would be hard so that people could still drive on it while also allowing water to diffuse through it and into the ground, thus giving better drainage.	Discussed in Manhattan, New York Implemented in Tokyo, Japan	Financial District and Seaport Climate Resilience Master Plan (MOCR, NYCEDC, 2021); Water-Permeable Road Surface in Tokyo (Japan for Sustainability, 2002)
The amount of rain that comes from intense	Construction of water squares in	In areas with large amounts of room, large depressions could be made with	Implemented in Rotterdam, Netherlands	Rotterdam Climate Change Adaptation

rainfall, if there is no place to store or redirect it, could flood areas that would be at a detriment due to flooding.	urban areas	stairs leading down into them to serve as both a public square for recreational purposes and also as an extra place for stormwater to be stored during periods of intense rainfall. The depressions can be equipped with extra drainage that can take care of any stored water after the storms have passed.		Strategy (Rotterdam Climate Initiative, 2013)
Intense rainfall can result in more flooding, causing damage to homes and other buildings in the path of the flooding.	Address the need for improved insurance programs to protect against increased flooding	Coverage for flooding must be purchased in a separate insurance policy since catastrophic risk is defined differently than insured risks. Since catastrophic events are often thought to be infrequent, many individuals choose not to purchase insurance for these risks as they tend to underestimate their vulnerability. Many people buy flood insurance following an event, however, they often let their policies lapse if no claim has been made.	Implemented New York City, New York	A Stronger, More Resilient New York (City of New York, 2013)

With rainfall intensity increasing over time, landslides are occurring more often as a result of harder and faster rainfall, which can pose a threat to people who live in places they can occur, and due to their nature they can be difficult to avoid when they happen	Forecasting service and Landslide Early Warning System	An online tool can be used to collect data that can be used in a landslide forecaster, and the data that results can be used to determine the probability of a landslide occurring in an area, and send out a warning to areas that may be impacted.	Implemented in Norway and Switzerland	The Norwegian forecasting and warning service for rainfall- and snowmelt-induced landslides (Krøgli et. al., 2018)

Figure 9: Bioswales (Vance, 2010)

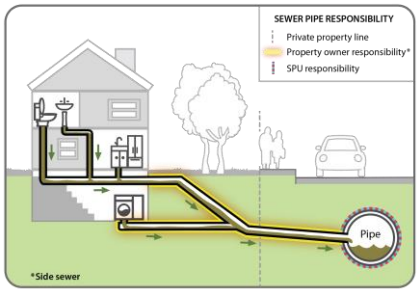

Figure 10: Frequent Stormwater and Sewer System Maintenance (Seattle Public Utilities, n. d.)

Figure 11: Permeable Pavement (Pixnio, n.d.)

Figure 12: Water Squares (Wikimedia Commons, 2017)

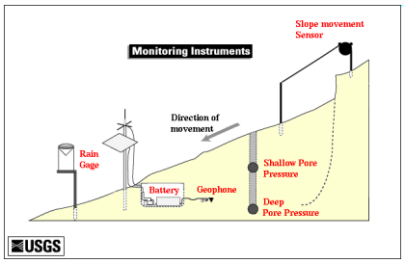

Figure 13: Forecasting Service (United States Geological Survey, n. d.)

Table 5: Adaptation Strategies for Hurricanes

The following table details the results of our research and interviews into adaptation strategies for hurricanes. The table lists strategies as well as places outside of Hawai‘i where they have been implemented. It is important to note that some of these strategies have already been discussed or implemented in Hawai‘i in some form. The purpose of this table is to provide models for further implementation of and information on various strategies. Hawai‘i has already begun raising infrastructure. Many homes have been traditionally built on stilts for a number of reasons including cooling, prevention of flooding, and protection from bugs (Jennings, n.d.).

Impact	Strategies	Description	Location	Source
Hurricanes are being influenced by the surface of the sea and ocean being warmer with increased storm	Introduction of wind-wave pumps to raise colder deep water to the surface to decrease	Water that is closer to the seafloor is typically colder than water at the surface, so cycling the colder water below with the warmer water at the	Implemented in Miami-Dade County, Florida	Hurricane Modification and Adaptation in Miami-Dade County, Florida (Kilma et. al.,

intensity, and with global temperatures rising, the intensity of these storms will keep worsening	sea surface temperature	surface could reduce the sea's surface temperature enough to decrease the intensity of storms in the area.		2011)
Stronger hurricanes can generate intense rains and winds that can disable power grids and render buildings powerless	Establish alternative or on-site power supply.	In the event that a power outage occurs, having backup energy supplies onsite can keep buildings operational, which would be especially good for buildings of high importance, as well as for any building in general.	Discussed by United States Environmental Protection Agency	EPA Climate Impacts on Water Utilities (Environmental Protection Agency, 2016)
Stronger hurricane winds and rains can cause more intense flooding and damage homes and other buildings in the path of said flooding	Raise infrastructure	Raising the elevation of buildings or infrastructure that are close to water as a whole, such as putting them on stilts, could be good for preventing them from being affected by flooding or other effects of intense rainfall. Florida regulations require when buildings below base flood elevation are damaged by flooding, they must	Implemented in Miami-Dade County, Florida and Kiribati	Miami-Dade County Sea Level Rise Strategy (Miami-Dade County, 2021); Republic of Kiribati National Adaptation Program of Action (Government of Kiribati, 2007)

		be elevated or protected from future water damage.		
Climate change is causing storms to be more severe and the forces felt by these storms on buildings are greater than now.	Promote building codes designed to minimize future damage.	Storm damage can be very costly, and spending time during the construction phase can save millions of dollars. One study in 2012 found the Safe Building Code Act of 2011 would have saved the federal government $500 million if it were to have been enacted in 1988. Another study conducted by researchers at Louisiana State University found that if stronger building codes were in place, wind damages from Hurricane Katrina would have been reduced by 80%.	Implemented across Florida	Florida's Energy Action Plan (Governor's Action Team on Energy and Climate Change, 2008); Support for climate adaptation and resilience | EESI (Environmental and Energy Study Institute, n.d.)
Stronger hurricane winds and rains can cause more intense flooding and damage homes and other buildings in the path of said flooding.	Address the need for improved insurance programs to protect against increased flooding.	Coverage for flooding must be purchased in a separate insurance policy since catastrophic risk is considered different from insured risks. Since catastrophic events are	Discussed in New York City, New York	A Stronger, More Resilient New York (City of New York, 2013); Hurricane Sandy and

		often thought to be infrequent, many individuals choose not to purchase insurance for these risks as they tend to underestimate their vulnerability. Many people buy flood insurance following an event and often let their policies lapse if no claim has been made.		adaptation pathways in New York: Lessons from a first-responder city (Rosenzweig, 2014)

Figure 14: Wind-wave Pumps (Pxfuel, n.d.)

Figure 15: Alternative Power Supply (Wonderlane, 2014)

Figure 16: Raising Infrastructure (The U.S. National Archives, 2007)

Table 6: Adaptation Strategies for Ocean Warming

The following table details the results of our research and interviews into adaptation strategies for ocean warming. The table lists strategies as well as places outside of Hawai‘i where they have been implemented. It is important to note that some of these strategies have already been discussed or implemented in Hawai‘i in some form. The purpose of this table is to provide models for further implementation of and information on various strategies. Research into the breeding of heat-tolerant corals is an action already being undertaken in labs in Hawai‘i (Sabine, personal communication, 2022). This is still largely theoretical and in the research stages at this time. According to our interviews, there has also been research into creating designer coral reefs with specific corals (Sabine, personal communication, 2022). Again, there has not been much widespread implementation of this beyond typical artificial reefs. Finally, there are many organizations in Hawai‘i that are involved in ocean and coral reef cleanup, in order to reduce land-based pollution (Coral Reef Alliance, 2022).

Impact	Strategies	Description	Location	Source
The warming of the ocean is causing corals that are not acclimated to such high temperatures to bleach and die off more easily	Seeding corals with more heat tolerant algae	Adding cultures of more heat tolerant algae species could help corals by making them less likely to become bleached by oceanic temperature shifts. This can be seen in the example image. The Claddocopium species is more dominant in stable water temperatures. However, the Durusdinium species is more effective where heat fluctuations are common.	Discussed theoretically in a study in Taiwan	Temporal variation and photochemical efficiency of species in Symbiodinaceae associated with coral Leptoria phrygia exposed to contrasting temperature regimes (Carballo-Bolaños et. al., 2019); ‘Move, adapt or die’: could scientists help corals survive climate change? (Toropov, 2021)
Increasing ocean temperatures may cause fish to migrate	Store more water on the landscape, maintain and	With fish and other aquatic species migrating to other locations, taking action such as increasing resilience to disturbance	Implemented in Oregon rivers	Climate Change Vulnerability and Adaptation in South-Central Oregon

to other locations, reducing the amount of local fish to catch	restore vegetation and thermal conditions	or restoring natural vegetation could potentially slow the rate of fish emigration from their normal habitats.		(United States Department of Agriculture Forest Service, 2019)
Rising ocean temperatures can cause corals to bleach and die	Breeding heat-tolerant corals to be placed in reefs	It has been observed during bleaching events that some corals seem to have a higher rate of survivability than most. These corals can be bred and then seeded in existing coral reefs over time to allow a greater percentage of the reef to be heat tolerant. This can also be achieved by breeding corals from extreme heat regions with those from midler climates	N/A	Cross Breeding Corals (Howells et. al., 2021); Heat Resistant corals Hawai‘i (Barott, 2021)
When coral reefs die they need to be replaced in order to preserve ecosystems	Implement designer reefs	Designer reefs are artificial coral reefs with live corals seeded on them. Once being implemented these live corals grow and eventually encompass the entire reef. This theoretically could be paired with thermally resistant corals, as a means of producing a new thermally resistant reef	Implemented in Florida	Project | NOAA Gulf Spill Restoration; Florida artificial reefs (NOAA, 2022)

Coral Reefs have decreased protection from disease and while bleached which can be exacerbated by the presence of land-based human pollutants	Implementation of statewide ocean cleanup efforts	Increase coral cleanup efforts by reducing sources of land-based pollution and removal of trash and debris from corals. This can be done by increasing coordination with nonprofits like the Coral Reef Alliance which already engage in ocean cleanup	Implemented in both Hawai‘i and Australia in some form	Coral Reef Alliance(Coral Reef Alliance, 2022); Plastic and Coral Reefs (Lamb et al, 2019); Reef Trust (Australian Government, 2022)

Figure 17: Artificial Coral Reef (NOAA, 2011)

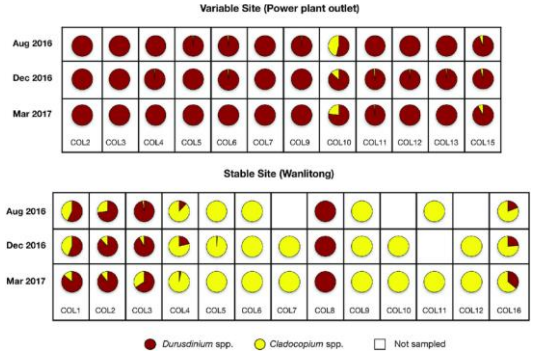

Figure 18: Dinoflagellates Algae (Carballo-Bolaños,et. al, 2019)

Figure 19: The Donner und Blitzen River (Bureau of Land Management Oregon and Washington, 2016)

Table 7: Adaptation Strategies for Urban Heat

The following table details the results of our research and interviews into adaptation strategies for urban heat. The table lists strategies as well as places outside of Hawai‘i where they have been implemented. It is important to note that some of these strategies have already been discussed or implemented in Hawai‘i in some form. The purpose of this table is to provide models for further implementation of and information on various strategies. Since the early 1990s, Hawai‘i has been increasing the amount of green space in the state with state parks (Aloha Plus Challenge, n. d.). Research on the implementation of green roofs has been ongoing at the University of Hawai‘i since 2007, and could potentially transition into more widespread use around the state (Greenroofs.com, n. d.).

Impact	Strategies	Description	Location	Source
Warmer global temperatures are pushing for a greater need for more energy-efficient ways to cool down homes and infrastructure	Addition of green space	Integrating more green spaces into an area can cause more shade to be made by plants and trees to decrease temperatures in the area, which can be beneficial for the local population. Singapore is going to be adding 130 hectares of new parks, implementing further maintenance of existing parks, and planting 1 million trees to add more green spaces. Organizations such as Green Space Alliance in Texas are educating the public about green spaces, as well as	Implemented in Singapore and San Antonio, Texas	Singapore Government Green Plan (Singapore Ministry of Sustainability and the Environment, 2022); About Green Space Alliance (Green Space Alliance, n. d.)

		working to preserve more land and implement more green spaces in cities like San Antonio.		
Warmer global temperatures are pushing for a greater need for more energy-efficient ways to cool down homes and infrastructure	Install Green-Blue Roofs	Putting greenery and environmental technology on rooftops can provide various benefits, such as cooling of the air in the area via evapotranspiration.	Implemented in Rotterdam, Netherlands and Chicago, Illinois	Rotterdam Climate Change Adaptation Strategy (Rotterdam Climate Initiative, 2013); Chicago Green Roofs (Jacobson, 2012)
Increases in global temperatures are making things much hotter, the asphalt in modern roads absorbs heat and does not reflect light well, causing roadways and nearby areas to heat up even more as a result	Implement cool pavement into streets[1]	Pavements that can reflect more infrared rays off a reflective surface applied to the top layer of the pavement can decrease the amount of heat absorbed by the pavement's surface and the area as a whole.	Implemented in Tokyo, Japan Testing in Phoenix, Arizona	Using Cool Pavements to Reduce Heat Islands (EPA, 2014); Perfect Cool (Iwama et, al., 2011); Cool Pavement Program (City of Phoenix, 2021)
Increases in global	Require the installation of	Installing roofs that reflect sunlight	Implemented in Atlanta,	Cool Roofs |

temperatures are making things much hotter, solar energy is absorbed by roofs and increases the temperature of the buildings even more as a result, requiring more energy to cool down	cool roofs for all new or replacement low-slope roofs.	and absorb less solar energy can decrease the temperature of the roof. These roofs also give off infrared radiation to release heat.	Georgia, California, Chicago, Illinois, Dallas, Texas, Denver, Colorado, Houston, Texas, Miami Beach, Florida, and Washington D.C.	Department of Energy Science of Cool Roofs (CoolCalifornia, n. d.); Guide to Cool Roofing Requirements in California (Maintco Corp, 2021)
Increasing temperatures in urban settings put people at risk for heat illness	Create alternative cooling methods	Installing spray parks or cooling stations in densely populated areas can provide people with a space to cool off.	Implemented in Rome, Italy and Anconda, Italy	Thermal comfort improvement in urban spaces with water spray systems: Field measurements and survey - ScienceDirect (Ulpiani et. al., 2019); Heatwave Guide for

				Cities (International Red Cross Red Crescent Movement, 2019)

Figure 20: More Green Space (Seeman, 2016)

Figure 21: Green-Blue Roofs (NPS, 2021) Engineers, 2018)

Figure 22: Permeable Pavement (Pixnio, n.d.)

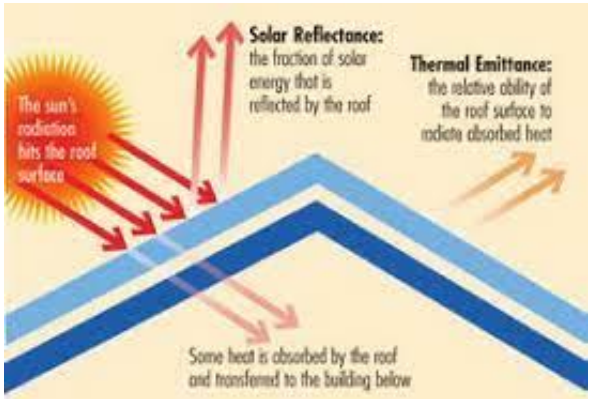

Figure 23: Cool Roof Technology (Cool Roof Rating Council, 2022)

Figure 24: Splash Pad (CDC, 2022).

[1] Permeable pavement and cool pavement are able to be combined together to create a cooler, more permeable street.

Table 8: Adaptation Strategies for Drought

The following table details the results of our research and interviews into adaptation strategies for drought. The table lists strategies as well as places outside of Hawai‘i where they have been implemented. It is important to note that some of these strategies have already been discussed or implemented in Hawai‘i in some form. The purpose of this table is to provide models for further implementation of and information on various strategies. Research on the implementation of green roofs has been ongoing at the University of Hawai‘i since 2007, and could potentially transition into more widespread use around the state. Water recycling has been an important part of Hawai‘i’s ability to sustain itself for years, with several million gallons of water being reused throughout the state every day (State of Hawaii, Department of Health, 2022).

Impact	Strategies	Description	Example Location	Sources
Droughts limit the amount of water that people are able to access, making them rely more on whatever they already have stored	Create extra surface water via techniques such as dredging	The expansion of existing or creation of new lakes, canals, waterways, and/or ditches via dredging can make extra room to store water, being able to store more water when it does rain to prepare for the times when it does not.	Implemented Rotterdam, Netherlands	Rotterdam Climate Change Adaptation Strategy (Rotterdam Climate Initiative, 2013)
Droughts limit the amount of water that people are able to access, making them rely more on whatever they already have stored	Install Green-Blue roofs	These types of roofs can act as reservoirs or tanks to collect excess water from rain and plants, allowing for convenient accessibility and storage for water.	Implemented in Rotterdam, Netherlands Chicago, Illinois	Rotterdam Climate Change Adaptation Strategy (Rotterdam Climate Initiative, 2013); Chicago Green Roofs (Jacobson, 2012)
Droughts limit the amount of water that can be used by people, making water that is “one-time use” less	Water recycling	This process takes water that is highly treated, and purifies it so that it is fit for consumption. By allowing water to be used multiple	Implemented in Orange County Water District, California	Groundwater Replenishment System Technical Brochure (Orange County Water

viable		times before it is released back into the ocean, it expands the water's usability and allows better access to water as well.		District, Orange County Sanitation District, 2021)
During periods of drought water demand increases, putting increased stress on a regions safe drinking water supply	Diversify options for water supply and expand current sources.	Diversifying sources of water will help to reduce the risk of water supply falling below water demand. Examples of diversifying sources can include using a mix of surface water, ground water, and employing desalination when necessary.	Implemented in San Antonio, Texas El Paso, Texas	Adaptation Strategies Guide for Water Utilities (United States Environmental Protection Agency, 2015); Texas Water Resource Institute | Diversifying Water Portfolios (Wythe, n. d.)

Figure 25 : Create Extra Surface Water (Gobertz, 2012)

Figure 26 : Green-Blue Roofs (NPS, 2021)

Figure 27 : Water Recycling (Walton, 2014)

Table 9: Adaptation Strategies for Wildfires

The following table details the results of our research and interviews into adaptation strategies for wildfires. The table lists strategies as well as places outside of Hawai‘i where they have been implemented. It is important to note that some of these strategies have already been discussed or implemented in Hawai‘i in some form. The purpose of this table is to provide models for further implementation of and information on various strategies. Organizations such as the Hawai‘i Wildfire Management Organization work with other organizations they are partnered with for community outreach and education to help reduce wildfires at a state level.

Impact	Strategies	Description	Location	Source
An increase in global temperatures makes it easier for wildfires to occur, and they can be started by just a simple spark if there is enough fuel around it	Clearing out Fuel Sources	Removing small trees, trimming branches, and clearing forest floor debris lowers the chance for random sparks to cause wildfires in places where they are not wanted.	Implemented in Oregon	Oregon Adaptation Framework (United States Department of Agriculture Forest Service, 2019)
An increase in global temperatures makes it easier for wildfires to occur, and they can be very difficult to deal with if the public is uninformed about their	Community Outreach	The creation of pamphlets to educate the public on causes and evacuation strategies can help save lives when wildfires become an issue for communities.	Initially implemented in Oregon, Montana	Oregon Adaptation Framework (United States Department of Agriculture Forest Service, 2019); Montana Wildfire Resources

effects and what to do when one occurs				(Montana Wildfire Smoke, n. d.)
An increase in global temperatures makes it easier for wildfires to occur, and they can be very difficult to deal with if there is a limited number of people trained to deal with them	Greater Number of Personnel	Hiring more staff to combat wildfires when backup is not as readily available would assist in taking care of wildfires more efficiently, having to rely less on external help and maintain self-sustainability.	Recommended by adaptation plan in Santa Rosa, California	New York Times (Romero, 2021); Santa Rosa Fire Department Staffing Study (Emergency Services Consulting International, 2019)
An increase in global temperatures makes it easier for wildfires to occur, and they can be spread further and more easily when invasive fuel sources are present in once barren areas	The removal of invasive grass species	Invasive grass species have colonized many previously barren lava flows, especially on the Big Island. Removing these grasses will keep fires more contained to certain areas rather than allowing them to spread due to the easily burned grass.	Implemented in Hawai‘i, Big Island Sonoran Desert, Arizona	Guinea Grass (Ammondt et. al., 2011); Pampas Grass Eradication (Big Island Invasive Species Committee, n.d.); Sonora Desert Grass eradication (Espinoza et. al., 2020); Sonora Buffelgrass control (Arizona-Sonora

				Desert Museum, n.d)

Figure 28 : Clearing Out Fuel Sources (U.S. Department of the Interior, 2021)

Figure 29 : Community Outreach (United States Department of Agriculture, n. d.)

Figure 30 : More Personnel (Honolulu Fire Department, n. d.)

Appendix F: Interview Summaries

Matthew Gonser and Alex Yee Interview Summary

The interview with Mathew Gonser and Alex Yee from the Office of Climate Change, Sustainability, and Resiliency in Honolulu, Hawai‘i provided great insight into potential areas of climate adaptation improvement. This interview was conducted with the intent to gather information about climate adaptation strategies that are in effect or are being thought about for the state of Hawai‘i, as well as specific information about some of the key aspects that they use when determining their course of action. These key aspects include equity, accountability, and measuring success, all of which are important things for making sure an adaptation plan is successful.

Mr. Gonser and Mr. Yee discussed the current status of Hawai‘i’s adaptation strategies and plans. They have an early draft of the strategy, where they are working with city agencies to work on ways to develop better infrastructure for the island of O‘ahu. They are approaching this plan with a holistic perspective, thinking like an island or a city, with goals set to manage and organize responsibilities to fill in the various portions of the plan. These goals, responsibilities, and plans are quite expensive, which is something they must consider given that this will also impact the economy of the island. The community aspect is important as well, as without community support these plans will be slowed down or halted. One of their next actions is to take a draft of the city actions they have, and begin revealing it more to the community.

They said that equity is something that nobody has perfected in their plan, because it has not been around for long enough for proper data to be analyzed. They have an equity program that they are using to establish contact and develop tools that will help them, developing a climate equity index as one result of the endeavors. They have done multiple things to establish more and better contacts with the community, such as their outreach project known as Kukakuka, which has experts get into discussions with the local community to talk about various things that they may find are issues, or their opinions, etcetera. At this point, they are thinking through things practically, and walking through different stages of considering results of projects, actions, consequences, benefits, and burdens, setting goals and accountability for the project.

They plan to ask for annual reports on the progress that has been made in each sector for how far they are developing their plans and their progress with the implementation of said plans.

Some other strategies they are aware of for accountability are things such as breaking tasks down into smaller steps, writing things into laws, finding motivated individuals, or collecting strong data that can be utilized. These strategies can also be used to keep track of progress, which is important for determining the pace of how the plan is being executed and making sure the plan is being executed properly. With all of that, the Office of Climate Change, Sustainability, and Resiliency is going to continue working to implement their strategies and try to get them in a state where they are accepted by the community, and they will be implemented in an effective manner.

Arnoud Molenaar Interview Summary

During our interview with Arnoud Molenaar, the "architect" of the Rotterdam adaptation plan, he explained how big of a threat SLR is today and how many climate change effects are all interconnected. Climate change is no longer just about SLR, but also drought, extreme rainfall, and heatwaves. In the development of the Rotterdam adaptation plan, Mr. Molenaar did not treat water as a threat, but rather an opportunity to utilize the surrounding water in smart ways and developed a long-term vision for it with relevant stakeholders. Doing this, he said, allowed them to feel a sense of ownership in the vision, and when they have ownership in the vision it becomes easier to translate a long-term plan into a shorter action plan. Although a long-term plan is necessary it can be difficult for people to buy into something such as an adaptation plan. He recommended implementing feasible measures first to show politicians and citizens what climate adaptation is all about. He explained how it is not just about the big infrastructure, such as water squares, sea walls, and levees, but also small projects such as little pocket gardens to catch rainfall. Community involvement was another large topic that Mr. Molenaar went into great detail about. He mentioned during the initial development of the first water square, people were allowed to join the design process and submit their ideas for how it could look. The people of Rotterdam have also begun to create adaptation cafes, which are light gatherings where people can come and talk about different ways to green the streets and make the community more climate adapt. Involving the community is important because although the government can implement adaptation strategies in public areas if the private sector does not buy into the idea, then it is not capable of becoming a climate-adapted city. Finally, Molenaar discussed briefly

how these strategies received funding. He claimed that once there is a common sense of urgency, it becomes easier to talk about money later.

Coastal Zone Management Interview Summary

In our interview with the Coastal Zone Management Program (CZM), we spoke with Justine Nihipali, the Coastal Zone Program Manager within the Office of Planning and Sustainable Development. CZM is responsible for upholding environmental and natural resource policies and is the lead agency for the Ocean Resource Management Plan (ORMP). The goal of the ORMP is to address coastal issues and originally outlines eleven priorities. Nihipali explained that the plan was updated in 2020 to focus on three main areas because it is more feasible to make significant investments. Nihipali also discussed the process of upholding collaborations within the ORMP. CZM holds quarterly meetings with the working group, which is made up of higher-level managers and administrators. The cabinet-level staff meets biannually and within that, action team meetings are held. These teams are made up of primary knowledge holders and those who are implementing the projects. These discussion-based meetings serve as a way to track progress and facilitate changes, which is a new approach for the state. Nihipali explained that CZM also coordinates state facilities to integrate adaptation to civil structures due to SLR. A gap that CZM is experiencing is the ability to manage county and road infrastructure and developments that are not considered "facilities" such as campuses and airports. Next steps include assessing how other states provide guidance and integrate adaptation into infrastructure.

Nihipali also discussed the concept of managed retreat, which the state has been discussing. The most popular method to shift communities out of vulnerable areas is through buyouts. This is currently happening due to lava on Big Island. However, this is challenging in areas affected by SLR and erosion because these processes are slow and property values are high, which requires a significant amount of funding. Managed retreat is challenging and new approaches need to be explored.

Tiffany Wise-West Interview Summary

Tiffany Wise-West, an author and developer of the Santa Cruz California Adaptation Plan, began by noting that their plan is updated every five years, and at the end of this year she will begin writing the next update of their adaptation plan. In the most recent update, they

considered the risks associated with public health for the first time, as well as integrating equity into their work. She explained how they spent a lot of time in neighborhoods talking to people of various backgrounds and communities. In the next update, Ms. Wise-West said that she would like to center the focus around equity and these communities, ensuring as many voices will be heard as possible. Moving forward she would also like to include a mechanism for accountability in the plan. When asked how Santa Cruz enforces the adaptation strategies set forth in the adaptation plan, she explained how there is no real enforcement mechanism. They instead rely on annual reviews of projects and actions to understand priorities.

When developing adaptation strategies Santa Cruz chose to look at individual hazards, rather than look at the hazards of climate change as integrated with each other. They also follow an adaptation pathways approach which is a decision making framework based under uncertainty. She explained that since it is difficult to know exactly how much sea level rise will be present in the year 2050, it does not necessarily make sense to build certain adaptation strategies. Rather, they utilize triggers and thresholds to decide when to implement the next series of adaptation plans. A few example triggers which were given could be if the width of the beach gets to 100 feet or less three times a season, or if the water reaches the top of the sea wall three times in a season, then it could be time to move on to the next strategy. Currently they have put in place a coastal monitoring program to monitor SLR related triggers. Lastly, when implementing adaptation strategies, funding can often become a concern. Santa Cruz has integrated their adaptation plan with their FEMA certified LHMP which has enabled them to become eligible for more funding, allowing for more adaptation strategies to be created.

Dr. Michael Bruno Interview Summary

The Interview with Dr. Michael Bruno provided information primarily on coastal erosion, as well as strategies to guard against it. His main strategy to combat this involved different methods of dredging the seafloor. This included placing dredges through the walls of manmade inlets at port facilities. These inlets stop sand that otherwise would have been able to flow naturally to replenish the coast. He explained that putting a dredge through the inlet allows this sand to keep from being blocked and can simulate natural flow. Additionally, offshore dredging is another method he discussed for replenishing sand lost in coastal erosion. This has already been done in Waikiki beach in Honolulu. However, both of these strategies do face considerable

opposition in the state. As Dr. Bruno said, dredging inlets can kill and destroy habitats for crustaceans living there. This disrupts the ecosystem and the fishing industry which relies on these sources of food. Additionally, offshore dredging has its problems too. It has already been opposed by locals in Waikiki, and in areas other than Hawai‘i where dredging of this nature has occurred there have been issues beyond opposition. Notably, Dr. Bruno spoke of examples in New Jersey where dredging led to decaying organic substance and even civil war era munitions to be deposited on the beach. Despite all this Dr. Bruno still did suggest dredging as a potential solution to erosion, though it will certainly need to be put in place with many safeguards.

Victoria Keener Interview Summary

Our interview with Victoria Keener gave us insight on climate stressors and their effects on Hawai‘i. We discussed how storms are going to be getting more intense as time goes on, as well as their consequences on the Hawaiian population. The state, according to Keener, is unprepared to accommodate for human safety in the event of a large tropical storm or hurricane. Very few shelters are up to code to properly handle these storms, and the houses themselves are not projected to withstand intense winds either. During a previous storm, the main road going around the island of O‘ahu was destroyed and made it very difficult to transport materials to places they were needed, showing that the infrastructure is not up to code either. We also discussed drought and how that is affecting Hawai‘i’s food supply. One of the largest droughts in Hawai‘i’s history was in 2008, which some climate trends show is still continuing at the time this is being written. The drought is affecting the amount of water there is for Hawaiians to use, as the groundwater aquifers are drying up as well as a result. This drought is also affecting local produce, as coffee beans are not able to be grown as well as they were, and cattle do not have enough water to live until they can be shipped to the mainland to be grain-fed. It also has influenced invasive species to some extent, due to the weakening of plants via dehydration, it allows invasive pests to affect the plants more. With all of this information, we were able to further our research on these various climate stressors.

Dr. Charles Fletcher Interview Summary

The Interview with Dr. Charles Fletcher provided very useful information on the effects of both SLR and urban heat in Hawai‘i. In addition he discussed some possible solutions to these issues that he has advocated for as member of the Honolulu Climate Change Commision. The

beginning of our discussion centered around SLR and why it is such a big issue for Hawai‘i in particular. Dr. Fletcher explained that due to a phenomenon known as sea level fingerprinting, caused by the gravity of large glaciers at the poles melting, areas further from the poles like Hawai‘i experience larger levels of SLR. This is then compounded by the lack of consideration for SLR in the planning for most of Hawai‘i’s communities which have houses very close to the coast. As he explained this has led to issues where houses are actively having their foundations eroded by SLR, with still very little action taken to stop it. One proposed solution for this is managed retreat, which Hawai‘i has already started in some areas with new building standards that require new buildings to be placed and pulled back from the shore. However, as he explained the state still has not adopted this throughout and there is no plan for moving communities already built within an SLR flood zone. We also discussed issues of water management in the state, particularly storm drain backflow and saltwater intrusion. One strategy Dr. Fletcher said was already in place for storm drain backflow was duckbills, slits placed on the end of storm drain exits that prevent water from flowing in. In terms of saltwater intrusion and drought, Fletcher heavily suggested the adoption of green roofs to both collect water for drinking and cool down large buildings to contain urban heat. Another possible solution was the adoption of artificial wetlands to capture rainwater and put it into the ground, to both replenish aquifers and contain flooding. He even gave an example of an already implemented wetland, Tanner Springs Park in Oregon. This gave us some good points to facilitate further research.

Susan Asam Interview Summary

In our interview with Susan Asam, Vice President of ICF Climate Planning, she shared information regarding approaches to adaptation planning, maintaining accountability, and community involvement. She discussed the concept adaptation pathways, which map out triggers and set thresholds that decide when to implement certain adaptation strategies. These pathways are more complicated than a traditional list of adaptation strategies, but are more feasible and appealing to decision makers. It is also more cost-efficient because it does not require strategies to be implemented right away, but rather over time as the climate changes. Another approach is to create a combined Hazard Mitigation Plan and Climate Adaptation Plan. This has been done successfully in Massachusetts and is included in FEMA. This is a creative solution and requires efficient collaboration between actors. Asam explained that the two lanes of hazard mitigation

and climate adaptation do not always come together, and doing so requires a proactive and progressive set of actors.

Asam also shared that one strategy to ensure accountability is to involve stakeholders in the development of the plan so they have ownership and are more likely to be invested. Challenges include collaboration since it creates more points for breakdown. However, assigning actors specific roles and pre-discussing topics such as funding and breaking down the project into steps can help manage these challenges. To measure progress in the plan, metrics must be discussed in ways that focus on the most impacted population. Strategies that have been used in Hawai‘i to gain community engagement include listening sessions and reaching out to community partners that are already working with vulnerable populations, as they can be helpful in bringing people together for discussion. Lastly, Honolulu has an equity index to help identify places where adaptation strategies would be most beneficial and could be used in a climate adaptation plan.

Christian Kamrath Interview Summary

Christian Kamrath, a resilience coordinator with the government of Miami-Dade county, gave our team a number of insights into strategies, methods of funding, and how his team facilitates community involvement. In terms of strategies, we discussed mainly methods for SLR as Christian explained his office is divided between certain areas and he is specifically on the SLR resilience team. Many of the strategies Mr. Kamrath outlined were related to more green and blue infrastructure. For example, he discussed the creation and expansion of green and blue ways. This involves adding more green space to areas in cities to improve water retention and reduce flooding. Blue ways are any sort of water source like rivers or canals, and he explained that Miami-Dade’s plan would involve expanding these areas to handle increased water levels. Additionally, we discussed some of the related effects of SLR like saltwater intrusion into groundwater supplies. Mr. Kamrath talked about how their plan includes provisions for Everglades restoration projects to improve water replenishment in the aquifers of the county and slow the incursion of saltwater into this supply.

Moving on from specific technical strategies we also asked about funding sources for the County plan, apart from taxes and state funding. Mr. Kamrath talked about how their funding is a mix of a number of sources, including the use of many different grants from federal institutions. These include the Department of Housing and Urban Development (HUD) which has grants that

can be used for community restoration projects to adapt buildings in cities to flooding and more powerful storms. In addition, HUD as well as FEMA both have disaster recovery-related grants which he explained can be a source of funding for resilience projects. To rebuild after powerful storms or flooding events occur. Another source of funding he talked about are environmental organizations like the National Fish and Wildlife Service, which could be used to finance projects like the restoration of the Everglades.

Finally, we discussed community involvement within the Miami-Dade planning process. In Particular, Mr. Kamrath talked about how they collaborated with multiple community activist groups throughout the creation of their plan to ensure community voices were heard. This collaboration extends beyond the planning process as well, with the dissemination of information and accomplishment of some small goals being carried out by these local groups.

Christopher Sabine Interview Summary

Christopher Sabine, interim vice provost for research and scholarship at the University of Hawai‘i at Manoa, provided our team with great insight into some of the difficulties coral reefs are facing due to ocean warming and acidification. He explained that although ocean acidification is really a global problem, reducing local stresses on the reefs could provide coral reefs more time to adapt to warmer temperatures. Coral bleaching occurs when their environment changes, causing them to release an algae called zooxanthellae. When a coral initially bleaches it does not die, and often if their environment is returned to normal quickly the rate at which they can recover is often high. Climate change is currently making these bleaching events last longer and this is what prevents the corals from recovering. In addition, macro algae can cover reef areas following a bleaching event and prevent the corals from recovering.

Mr. Sabine also noted a handful of projects associated with coral reefs that we should note. The first project by the gates lab, out of the Hawai‘i Institute of Marine Biology (HIMB), deals with selectively breeding corals to make them more tolerant to higher temperatures. A second project mentioned also came from the HIMB where they are creating designer reefs, where they put a large infrastructure in the ocean to promote the growth of corals. Lastly, one idea Mr. Sabine mentioned, could be to put these more tolerant corals, on to a designer reef which would then allow them to repopulate.

Maggie Messerschmidt Interview Summary

Maggie Messerschmidt, who works at the Intermediate Care Facilities in California, provided valuable information and greater insight on adaptation pathways, accountability, and equity. Messerschmidt discussed the implementation of adaptation pathways and the process by which thresholds are determined. Thresholds should be decided by both the scientists leading the research for climate change and decision-makers.

Messerschmidt also discussed community outreach and indigenous involvement. Ms. Messerschmidt commented that community engagement should be incorporated in a working group for projects regarding climate adaptation. She also mentioned that community-based organizations often know what is working and what is not working in a plan or project, so feedback from these organizations can prove useful for determining what should be reworked or adjusted in a project.

Hawai‘i Wildfire Management Organization Interview Summary

Our team interviewed Elizabeth Pickett and Nani Barretto, the co-executive directors of the Hawai‘i Wildfire Management Organization (HWMO) for information about wildfires and their impacts on the state of Hawai‘i. One major point that was made was the fact that while other states may have naturally occurring fires that are good for the area, recharging the soil with nutrients from the ashes, in Hawai‘i all wildfires are bad fires. They primarily start in the large swathes of grasslands, and from there they move their way toward the forests, which do not hold against fires very well due to not being adapted to such conditions. The cause of these fires primarily occurs from human activities, and even parking on the grassy side of a road for a small period of time can generate enough heat under the car and cause a fire.

A primary issue that is faced when dealing with wildfires is that they do not have enough resources or infrastructure in place in order to effectively deal with wildfires that occur. Most of the time, the wildfires that occur are rather distant from civilization or infrastructure, which makes it significantly more difficult to bring usable water to put them out with. In this case, the main concern regarding the resource allocation is not having enough funding to purchase more or better resources to manage wildfire issues. One topic of high importance to the interviewees was getting the community involved with community outreach, especially through educational value such as management of fields, proper home preparation for wildfires, etcetera. This topic was discussed through the last third of the interview, and was heavily emphasized as an important point to address when determining strategies for coping with wildfires in adaptation planning.

Appendix G: Informed consent for interviews

This interview will consist of several questions related to your work in order to gauge climate change effects in Hawai‘i. This will be used for our project developing an operational outline for a climate resilience and adaptation plan for the state of Hawai‘i in conjunction with Hawai‘i’s Office of Planning and Sustainable Development.

Do you, having been fully informed of the purpose, use, and risks of this study, give permission to be interviewed and for your comments to be republished, with credit, in the project report for developing strategic approaches for climate change adaptation and resilience planning?

Appendix H: Interview Contact Master list

Table 10: Climate Change - Objective 1

Person/ Organization	Purpose	Contact info	Did we reach out?	Who reached out?	Did they respond?	Did they say yes?	Day/time/place
D. Kapua'ala Sproat	Spent nine years as an attorney in the Hawai'i office of Earthjustice, expert in Native Hawaiian law, Indigenous rights, and natural resource protection and management.	kapuas@hawaii.edu	yes	Emily	no		
Hawai'i Coastal Zone Management Program	Mission is to "provide for the effective management, beneficial use, protection, and development of the coastal zone."	dbedt.op.czm@hawaii.gov	yes	Emily	yes	yes	Friday, January 14, 11:00
Office of Climate Change, Sustainability, and Resiliency	"Our mission is to support the City and County of Honolulu in its vision of a more economically self-sufficient and safer O'ahu"	resilientoahu@honolulu.gov	yes	Jake	yes	Yes	Thursday January 20th, 9 AM to 10 AM
B. Szuster	Prof at UH-Manoa Expert in resource management and planning issues with coastal tourism, agriculture	szuster@hawaii.edu	yes	Emily	yes	no	
Makena Coffman	Director for the Institute for Sustainability and Resilience, professor in the Department of Urban and Regional Planning, expert in climate change policy, climate adaptation.	makena.coffman@hawaii.edu.	yes	Emily	no		
Sustainable Coastlines Hawai'i	Nonprofit focused on keeping beaches clean and preserving the coastlines	@sustainablecoastlineshawaii on Instagram	yes	Emily	yes	no	
Hawai'i Shore and Beach Preservation Association	"Organization of private sector, academic, government professionals, students, and local community members dedicated to the preservation and restoration of Hawai'i's beaches and coastal environments"	hisbpa@gmail.com	yes	Jake	no		

Hawai‘i Department of Land and Natural Resources	Organization that is responsible for managing, administering, and exercising control over public lands, water resources, ocean waters, navigable streams, coastal areas (except commercial harbors), minerals, and all interests therein	dlnr@hawaii.gov	yes	Jake	no		
Albizia Project	“The Albizia Project was founded in 2017 to develop innovative uses of the prolific invasive albizia tree and to support native ecosystem restoration across the Hawaiian Islands. Building with albizia wood helps us to replace problematic species with native trees to forge pathways to a circular economy for Hawai‘i.”	https://thealbiziaproject.com/lika1	yes	Emily	no		
Sierra club	“We are working hard to advocate for strong environmental policies, hold decision-makers and corporations accountable and build sustainable communities”	hawaii.chapter@sierraclub.org	yes	Emily	no		
Dr. Michael Bruno	His research and teaching interests include ocean observation systems, climate change, and community resilience. He is the author of more than 100 technical publications in various aspects of these fields, including the book, *The Urban Ocean*, published by Cambridge University Press in 2018.	provost@hawaii.edu	yes	Emily	yes	yes	January 28, 2022, 10:00 am
KAHEA - The Hawaiian-Environmental Alliance	KAHEA is about Hawai`i. About a healthy environment and thriving cultural traditions for Ka Pae `Āina. In the face of increasing assaults to Hawai`i's land, ocean, water, native species, culture, and way of life, we are charting a different course.	KAHEA-alliance@hawaii.rr.com	yes	Jake	no		
Dr. Victoria Keener	Research Fellow at the East-West Center, the Lead Principal Investigator of the Pacific Regional Integrated Sciences & Assessments (Pacific RISA) program, serves on the Climate Commission for the City and County of Honolulu, and is the Lead Author of the Hawai‘i and US-Affiliated Pacific Islands chapter of the 4th US National Climate Assessment.	keenerv@eastwestcenter.org	yes	Emily	yes	yes	Feb 2, 2022 9:00 AM

Dr. Chip Fletcher	Interim Dean of the School of Ocean and Earth Science and Technology (SOEST), UH. He is Chairperson of the Honolulu Climate Change Commission.	fletcher@soest.hawaii.edu	yes	Emily	yes	yes	January 25, 2022 12:00 PM
Robert Miyasaki	DOT	robert.miyasaki@hawaii.gov	yes	Max	no		
Genevieve Sullivan	DOT Planner	genevievehsullivan@hawaii.gov	yes	Max	no		
Christopher Sabine	University of Hawai‘i	csabine@hawaii.edu	yes	Max	yes	yes	February 8, 2022 1:00 PM
Diana Felton	State Toxicologist	diana.felton@doh.hawaii.gov	yes	Max	no		

Table 11: Climate Adaptation Planning - Objective 2

Person/ Organization	Purpose	Contact info	Did we reach out?	Who reached out?	Did they respond?	Did they say yes?	Day/time/place
Joel Scheraga	Chair and senior advisor of EPA “I lead EPA's efforts to adapt to climate change to ensure the Agency continues to protect public health and the environment even as the climate changes. I build and strengthen the adaptive capacity of states, tribes, and local communities.”	To meet Joel Scheraga, please send an email with the **subject line "ECN"** to John Reeder (reeder@american.edu) and Candra Reeves (cr0910a@student.american.edu).	yes	Emily	no		
Fernando Pagés Rangel	Author of Rincon, Puerto Rico climate plan	fernando.pages@tetratech.com	yes	Emily	yes	no	
The Bahamas	Author of New Plan for Bahamas	bestnbs@bahamas.gov.bs	yes	Emily	no		

Environment, Science and Technology Commission, Director Phillip Weech	https://www.preventionweb.net/files/60986_5b2b9776d.pdf	philipweech@bahamas.gov.bs					
Corjan Gebraad	Worked on rotterdam plan, General strategy advisor at Urban Management division. Focus on climate adaptation and governance, city resilience and long term climate and watermanagement related policies.	Linkedin linkedin.com/in/corjangebraad	Yes	Emily	no		
Arnoud Molenaar Chief resilience officer (CRO)	"Arnoud Molenaar works as a program manager for the municipality of Rotterdam and is the CRO for our city. The CRO brings stakeholders, the municipality and residents together in a smart way. He is the pivot between knowledge exchange between Rotterdam, other cities in the world and the Resilient Cities Network. Arnoud regularly gives presentations, lectures and workshops to show what we are already doing in Rotterdam on resilience and how others can also contribute."	a.molenaar@rotterdam.nl	yes	Emily	yes	yes	January 20, 2022 6:00AM.
COP26		Meeting website conact: cop26media@cabinetoffice.gov.uk	yes	Emily	no		
COP26	ARA: RA is a global, collaborative effort to increase investment and opportunities for action research to develop/inform effective adaptation solutions. Web:	ARA: ara@southsouthnorth.org	yes	Emily	no		

	https://southsouthnorth.org/portfolio_page/adaptation-research-alliance/						
Andrea Ambriz	California adaptation plan	Andrea.Ambriz@resources.ca.gov	yes	Max	yes	Nno	
Shirley E. Brown/ USDA	USDA Adaptation Plan USDA Plan	shirley.brown@usda.gov	yes	Aidan	no		
Mr. Gosner CRO	Oʻahu Resilience office	resilientoahu@honolulu.gov	yes	Max	yes	yes	January 20, 9:00AM
Dr. Tiffany Wise-West	Sustainability and Climate action manager Santa Cruz	twise-west@cityofsantacruz.com	yes	Aidan	yes	yes	January 27, 2022 2:30PM
Jennifer Granholm	US Department Secretary of Energy	Facebook	yes	Aidan	no		
James Murley CRO	Miami Climate Strategy	resilience@miamidade.gov	yes	Max	yes	yes	January 21, 2022 10:00AM
Dan Lert	Paris Climate Plan	dan.lert@paris.fr	yes	Max	no		
Susan Asam	Climate Resilience in Hawaiʻi	susan.asam@icf.com sasam@icfi.com	yes	Emily	yes	yes	February 1, 2022 1:00 PM
John D'Antonio	State engineer for New Mexico, oversees that office and the interstate stream commission	ose.webmaster@state.nm.us	yes	Max	no		
Sussan Ley	Australian Minister for the environment	Contact form on website	yes	Max	no		
Theresa Woznick	State Hazard Mitigation Plan	theresa.m.waznick@hawaii.gov	yes	Max	no		
Maggie Messerschmidt	ICF Environmental Planner, Project Manager, expert in adaptation pathways	ICF website contact form	yes	Emily	yes	yes	February 18, 10:00 AM
SW Climate Change (Australia)	http://www.swclimatechange.com.au/climatechange	Website contact form	yes	Emily	no		

	Adaptation pathways						
Jorge Bauza-Ortega	Scientific Director, San Juan Bay Estuary Program	jbauza@estuario.org	yes	Aidan	no		
Shaun O'Rourke	Chief Resilience Officer, Resilient Rhody	sorourke@riib.org	yes	Aidan	no		
Eugene Benson	Expert in environmental law, land use and planning law. Professor at BU. Member of the Climate Change Adaptation Advisory Committee.	EBBenson@bu.edu	yes	Aidan	no		
Peter I wanowicz	Acting Commissioner of Environmental Conservation, Member of the New York Climate Action Council	piwanowicz@eany.org	yes	Aidan	no		
Robert Kay	ICF principal, climate change innovation, climate center senior fellow	ICF website contact form	yes	Emily	no		
Saskia Elisabeth Werners	Wageningen University and Research, the Netherlands Institute for Environment and Human Security (UNU-EHS), United Nations University, Germany	werners@mungo.nl	yes	Emily	no		
Radhika Fox	Assistant administrator at the Office of Water	radhikafox@gmail.com	yes	Aidan	no		