UNIVERSITY of HAWAIʻI at MĀNOA
INSTITUTE for SUSTAINABILITY and RESILIENCE

Costs and Tradeoffs of Managed and Unmanaged Retreat in Response to Sea Level Rise

A Case Study of the North Shore of Oʻahu, Hawaiʻi

Photo Credit: Renee Setter. Rocky Point on the North Shore of Oʻahu, Hawaiʻi, October 2022.

April 29, 2023

ISR Research Team

University of Hawaiʻi at Mānoa (UHM)

Rachael Han
Climate Impacts Research Specialist
Institute for Sustainability and Resilience (ISR)
rxhan@hawaii.edu

Makena Coffman
Director, ISR
Professor, Urban and Regional Planning
Research Fellow, University of Hawaiʻi Economic Research Organization (UHERO)
makenaka@hawaii.edu, isr@hawaii.edu

Conrad Newfield
Research Assistant, ISR
Urban and Regional Planning MURP Student, UHM
conrad4@hawaii.edu

Kammie Tavares
Research Assistant, ISR
Urban and Regional Planning PhD Student, UHM
kdat@hawaii.edu

Renee Setter
Research Assistant, ISR
Geography and Environment PhD Candidate, UHM
rsetter@hawaii.edu

Alice Terry
Research Assistant, ISR
Urban and Regional Planning MURP Student, UHM
alicelt@hawaii.edu

Isabella Roberson
Research Assistant, ISR
Urban and Regional Planning MURP Student, UHM
irobe@hawaii.edu

Nori Tarui
Professor, Economics
Research Fellow, UHERO
nori@hawaii.edu

Executive Summary

The Intergovernmental Panel on Climate Change (IPCC) projects that global sea levels may rise up to 3.3 feet (1.01 meters) by 2100, with a range of scenarios based on greenhouse gas emissions reductions achieved. As a result, coastal communities will experience consequences with threats to people, infrastructure, and ecosystems. The Hawaiian Islands are already experiencing the impacts of sea level rise (SLR), including exacerbated effects of coastal erosion, storm surge, and coastal flooding. Beaches in Hawaiʻi are protected as a public trust resource; however, many beaches in Hawaiʻi are experiencing chronic erosion and overall beach loss. To contribute to an understanding of SLR response for Hawaiʻi, this report identifies SLR adaptation options and, in particular, characterizes costs and tradeoffs of approaches to retreat of coastal development in the context of residential areas adjacent to sandy beaches.

Using a case study of the North Shore of Oʻahu, from Rocky Point to Sunset Point, we assess the costs of three types of retreat (all-at-once, threshold-based, and reactive) through the year 2100. We quantify the following costs within the study area: property acquisition, property tax loss, private structure removal, public infrastructure removal, public infrastructure relocation, and private property loss. The all-at-once retreat approach is the most proactive, assessed for two scenarios. The first is that dwellings and infrastructure within the entire SLR exposure area (SLR-XA), based on the State's Sea Level Rise Viewer, are retreated in the immediate future. The second is that only dwellings and infrastructure within the area up to the estimated coastal erosion boundary (SLR-CE) are retreated. The threshold-based approach is also proactive, but less aggressively so. This approach is based on an identified distance of at-risk built environment assets to the projected future coastal erosion line; for our purposes, assumed to be within 20 feet (6 meters). Once this threshold is met, we assume that dwellings and infrastructure are retreated. There are two cost scenarios within the threshold-based approach, the first of which assumes that the state enforces its definition of the shoreline and that land is transferred from private to public based on the annual high wash of the waves. The second assumes that enforcement of the shoreline remains more aligned with the status quo, meaning that the shoreline is determined by the projected coastal erosion line. Lastly, the reactive approach captures the current approach to coastal management on Oʻahu, where the inland migration of the shoreline will cause failure of at-risk dwellings and infrastructure. Without proactive intervention, failed assets will end up on the public beach. Here we assume that clean-up costs are borne by asset owners, though this is again an issue of enforcement of existing laws. We consider a range of clean-up costs, which are considerably greater if the dwelling breaks up into the nearshore environment. As such, a reactive approach will result in substantial public safety costs as well as potential for environmental contamination (e.g. asbestos and lead) – that are outside our scope of quantification but are important when considering the public costs of retreat alternatives. An additional and important quantification we make is a comparison of beach area gained under each of the three approaches to retreat, using the same SLR-CE maps (i.e. overall beach width over time). Because we are only looking at retreat, at no point do we consider a case where the entire sandy coastline lacks access. The estimate of beach width gained serves as an indicator of potential public benefits from retreat alternatives.

Lastly, while we are not yet able to expand our methodology to the entire island or state, we contribute to the understanding of island-wide consequences of SLR by leveraging the same data on land and dwelling value for the case study area to the island of Oʻahu. We estimate the number of people, real estate value, and property tax revenues, located within SLR-XA for Oʻahu.

Our key findings are as follows:

All-at-once

The highest overall costs and the highest costs to the public occur under an all-at-once approach, though this approach also yields the largest beach area gained. If the area includes the entire SLR-XA, we estimate that the total cost to acquire property, remove local roads, and realign the affected highway is just over $330 million ($2021). If only the area expected to be impacted by erosion (i.e. up to SLR-CE) is addressed, this value drops to just over $200 million ($2021) because fewer parcels and buildings are retreated (a change from 138 buildings to 63).

Since an all-at-once approach occurs before there is any property damage (for most properties, not including the current beachfront homes experiencing extreme erosion currently), full market rate compensation is required to either voluntarily or involuntarily acquire properties. As such, all costs, both acquisition and infrastructure removal/relocation, are found to be accrued to the public.

Threshold-based

In comparison to all-at-once, the threshold-based approach scenarios are substantially lower in cost, ranging from $60-90 million ($2021). In addition, particularly in the scenario where the state enforces its definition of the shoreline as the highest wash of waves annually, there is a mixture of costs that accrue to public and private entities. The costs are lower because there is value accrued from allowing properties that are not yet at high risk to remain in place, assuming that the 20 ft (6 m) threshold is large enough to mitigate public safety concerns. We find that by 2030, 20 buildings fall within the SLR-CE, an additional 15 by 2050, and an additional 20 by 2100. Because the approach to retreat is more piecemeal than the all-at-once, there is less beach area gained, particularly in early years. The beach area gained is similar to the all-at-once scenario up to the SLR-CE by the year 2080.

There are multiple policy tools that could be employed to support a threshold-based approach, including rolling “easements” (defined in our study as a rolling shoreline) coupled with buyout programs and strategic use of eminent domain for public purposes.

Reactive

The rolling shoreline is already established within Hawaiʻi’s coastal zone management law and is what sets the framework for our reactive scenario. In contrast to all-at-once, we find the reactive scenario has the lowest estimated cost ($50-70 million, $2021) and, in particular, the lowest direct cost to the public. However, our estimates do not account for risks to public safety and the introduction of environmental pollutants, both of which could result in large public costs and should be factored into decision-making. In this context, the difference in measured cost between reactive and threshold-based scenarios is relatively small.

Though coastal property owners relatively gain value from owning their assets for a longer duration before reactive retreat, this duration is not considerably longer than in the threshold-based scenario and the reactive scenario accrues considerably more cost to private property owners – up to an estimated $53 million in private property value loss and $9 million in clean-up costs ($2021). For this reason, private property owners experience the highest costs in this scenario.

SLR-XA for O‘ahu

We find that 28,000 O‘ahu residents currently reside in SLR-XA, accounting for 2.7% of O‘ahu’s 2020 population. There is $9 billion ($2020) in total net taxable property value within SLR-XA, amounting to 5% of the island’s property tax revenues. The largest category of land value within SLR-XA is residential (over 60%), followed by hotel and resort (almost 30%).

In sum, we find that the cost of retreat for the area between Rocky Point to Sunset Point on the island of O‘ahu could range from $50 million to $330 million ($2021) depending on the approach implemented. This estimate has implications for decision-makers specific to this important area of the island and beach resource, but also gives a sense of the magnitude of adaptation costs for coastal and sandy beach areas throughout the Hawaiian Islands. With $9 billion in real estate assets within SLR-XA on O‘ahu, careful attention is needed to understand the tradeoffs inherent to SLR response actions.

Though the reactive approach has the lowest measured costs, it also maintains the least beach area as well as presents potentially high risks to public safety and environmental contamination. As such, given that the threshold-based approach has comparable costs, largely mitigates public safety concerns and is similar to all-at-once in terms of environmental contamination concerns, the threshold-based approach merits further inquiry as an enormous improvement towards a more proactive approach to retreat than today’s status quo. The all-at-once approach is appealing from the perspective of beach area gained, and more research is needed to understand dune restoration dynamics as well as human and ecological values for beach width. Given the magnitude of adaptation needs, public investments in adaptation should also be made in the context of broader public finance implications. More research on remediation and restoration processes is important to building a more complete understanding of the benefits of retreat interventions.

Table of Contents

List of Figures

List of Tables

Glossary of Terms & Abbreviations

Ahupuaʻa - A land division extending from the mountain to the sea

Ma ke kai - Along the sea

Makai - Seaward

Mauka - Landward

BLNR - Board of Land and Natural Resources

BRIC - Building Resilient Infrastructure and Communities

CCH - City and County of Honolulu

CMSS - Charlotte-Mecklenburg Storm Water Services

CZM - Coastal Zone Management

CZMA - Coastal Zone Management Act

DLNR - Department of Land and Natural Resources

FEMA - Federal Emergency Management Agency

FMA - Flood Mitigation Assistance

HAR - Hawaiʻi Administrative Rules

HMA - Hazard Mitigation Assistance

HMGP - Hazard Mitigation Grant Program

HRS - Hawaiʻi Revised Statutes

IPCC - Intergovernmental Panel on Climate Change

NFIP - National Flood Insurance Program

NOAA - National Oceanic and Atmospheric Association

NOV - Notice(s) of Violation

NPS - National Park Service

OSDS - Onsite Sewage Disposal Systems

ROH - Revised Ordinances of Honolulu

SLR - Sea Level Rise

SLR-AHWF - Sea Level Rise Annual High Wave Flooding

SLR-CE - Sea Level Rise Coastal Erosion

SLR-PF - Sea Level Rise Passive Flooding

SLR-XA - Sea Level Rise Exposure Area

SMA - Special Management Area

TDR - Transferable Development Rights

I. Introduction

Global mean sea level is expected by the Intergovernmental Panel on Climate Change (IPCC) to rise by up to 3.3 feet (1.01 meters) by 2100 relative to the year 1901 due to a combination of thermal expansion of water and melting of glaciers and ice sheets (IPCC, 2021; Sweet et al., 2017; Sweet et al., 2022). There is a range of sea level rise (SLR) projections dependent on a variety of factors including the continued burning of fossil fuels.[1] SLR will exacerbate the effects of other hazards, such as heavy rainfall and subsequent flooding, storm surge, high wave flooding, and coastal erosion. These consequences will force coastal communities to adapt at an unprecedented rate (Bindoff et al., 2007). Approximately one billion people residing in coastal communities across the world are projected to be impacted by SLR by 2100, with total assets valued at US$8-14 trillion ($2011; IPCC, 2022). A recent IPCC report finds that in addition to the direct impacts to people, infrastructure, and coastal ecosystems, there will be threats to food security as well as increasing disparities in social equity. Unless the adaptive capacity of vulnerable and affected populations is addressed, coastal communities and environments will be severely and negatively impacted (IPCC, 2022).

The viability, longevity, and socio-ecological impacts of SLR response measures vary widely (California Coastal Commission, 2015; IPCC, 2022). Despite the urgent need for action, careful SLR response is necessary to avoid maladaptive outcomes, particularly to already burdened communities (IPCC, 2022). Maladaptive actions tend to prioritize short-term benefits over long-term gains and neglect the interconnectedness of issues, which can exacerbate climate impacts, even if unintentional (IPCC, 2022). For example, the hardening of coastal areas with eroding sandy beach fronts is often viewed as maladaptation due to its exacerbation of coastal erosion, resulting in loss of the sandy beach, and perpetuating increasing risk to the public (California Coastal Commission, 2015; Hawaiʻi Climate Change Mitigation and Adaptation Commission, 2021; IPCC, 2022).

Applying these global SLR projections within the local context, the Hawaiian Islands are tremendously exposed SLR and the hazards it amplifies. Coastal erosion, for example, is exacerbated by SLR, which can be seen in the continual narrowing of many of Hawaiʻi's beaches (Anderson et al., 2015; Tavares et al., 2020). Beaches are legally protected as part of the state's public trust (Hawaiʻi Constitution, Article 11 Section 1). Though coastal managers in Hawaiʻi have stated the importance of maintaining the wide array of uses and values of Hawaiʻi's beaches in the face of SLR, there is little consensus on how these goals can be achieved (Bremer et al., 2022). In recognition of the importance of maintaining Hawaiʻi's sandy beaches, the State released an initial report in 2019 laying out potential options and considerations for managed retreat (Hawaiʻi State Office of Planning, 2019).

To build on past work and contribute to an understanding of SLR response for Hawaiʻi, this report identifies SLR adaptation options and, in particular, characterizes costs and tradeoffs of

---

[1] IPCC (2021) estimates mean sea level rise of 0.28-1.01m by 2100 relative to 1995-2014 global mean sea levels. This likely range is determined based on assumptions of Representative Concentration Pathways (RCPs) regarding levels of continued fossil fuel combustion and other anthropogenic greenhouse gasses that cause climate change.

approaches to retreat of coastal development in the context of residential areas adjacent to sandy beaches. To provide context for this work, a review of current and projected SLR impacts in Hawai‘i and a description of Hawai‘i's laws and policies related to coastlines and beaches is presented (Section II), as well as types of SLR responses and various policy mechanisms for implementation (Section III). Our primary contribution is a case study of the costs of retreat strategies within the Sunset Beach area on the North Shore of O‘ahu (Section IV). We selected this area because it is a world-famous beach experiencing chronic erosion; homes in the study area have been threatened by erosion events (Cocke, 2022a; Fletcher et al., 2012). A recent report, “Adaptive Coastal Management Recommendations, Actions and Strategies,” authored by a multi-sector working group for the North Shore of O‘ahu, identified the need for “additional technical study to evaluate costs, benefits and feasibility of various solutions” (North Shore Coastal Resilience Working Group, 2022). This case study helps to fill this need. We identify the types of costs related to three approaches to retreat and are able to quantify the removal of dwellings and related infrastructure like on-site disposal systems and local roads, and relocation of the highway. We quantify these costs through the year 2100. To provide a sense of scale of SLR impacts to O‘ahu, we also quantify the value of land and buildings and number of people likely to be impacted by SLR – though considerably more work is needed in this area of inquiry and is an area for future research (Section V). Last, we offer key takeaways and conclusions (Section VI).

II. Sea Level Rise Impacts and Coastal Governance in Hawai'i

Expected SLR Impacts

The coastal communities and ecosystems of Hawai'i are highly at risk from SLR and its compounding impacts. Sea levels are expected to rise approximately 0.8 ft (0.24 m) by 2050 from the 2000 baseline under the National Oceanic and Atmospheric Association's (NOAA) "likely median" projection, far exceeding the historical rates of SLR (NOAA, 2022a). SLR is initially experienced as an increasing incidence of high tide flooding, which can compromise coastal buildings and infrastructure, cause road closures and disrupt livelihoods (NOAA, 2022a). In 2017, the Honolulu tide gauge recorded 15 days that were 3 ft (0.9 m) above the flooding threshold (mean lower low water), which prior to 2017 had only occurred during 40 days total in the 112-year record (Yoon et al., 2018). Researchers project a rapid rise from one day to more than 60 days of high tide flooding events occurring each year throughout the Hawaiian Islands between the 2030s and 2050s (Thompson et al., 2021).

In 2017, the State of Hawai'i Climate Change Mitigation and Adaptation Commission (Commission) released the Hawai'i Sea Level Rise Vulnerability and Adaptation Report and a complementary online viewer of expected SLR impacts across the state. Modeled projections of Passive Flooding (SLR-PF), Annual High Wave Flooding (SLR-AHWF), and Coastal Erosion (SLR-CE) for 0.5, 1.1, 2.0, and 3.2 ft (0.2, 0.3, 0.6, and 1.0 m, respectively) of relative SLR were combined to create the SLR exposure area (SLR-XA) (Hawai'i Climate Change Mitigation and Adaptation Commission, 2017).

The Commission's report estimates that the 3.2 ft (1 m) SLR-XA covers an area of 25,800 acres, with a land and dwelling value of $19 billion ($2013) (Hawai'i Climate Change Mitigation and Adaptation Commission, 2017; City and County of Honolulu Climate Change Commission, 2020). Another study finds that the length of potable water pipes owned by the Board of Water Supply on O'ahu that will be affected by marine inundation quadruples between 1.1 to 3.2 ft (0.3 to 1 m) of SLR, from 14,000 to 60,000 ft (4,000 m to 18,000 m) (Nakano et al., 2019). Coastal highways on O'ahu and Maui have already been experiencing erosion and flooding from high tides and storm surge (Richardson, 2020; Tanji, 2022). The Hawai'i Department of Transportation finds that 76 road segments of the 302 mileposts along coastal highways evaluated are highly susceptible to infrastructure damage from increased coastal hazards associated with SLR (Francis et al., 2019). Recently, portions of Honoapi'ilani Highway on Maui and Kamehameha Highway on O'ahu have been in the process of realignment in part due to acute erosion (HDOT, 2021; Kubota, 2020).

Coastal erosion is another ongoing coastal management challenge in Hawai'i that is and will continue to be exacerbated by SLR. In terms of the consequences of SLR to Hawai'i's natural environment, approximately 70% of beaches on Maui, Kaua'i, and O'ahu are eroding, at an average rate of 0.4 ft/yr (0.12 m/yr). Between Maui, Kaua'i, and O'ahu, 9% of the total beach length studied was completely lost to erosion in the past century (Fletcher et al., 2012). SLR is expected to more than double the historical erosion rate by the end of the century (Anderson et al., 2015). With 2.4 ft (0.7 m) of SLR, half of Hawaiʻi's sandy shorelines will be at risk of beach loss (Tavares et al., 2020). Many property owners have controlled erosion impacts to their parcel through shoreline hardening, mainly seawalls. Such actions often and, in the case of chronically eroding shorelines with SLR, inevitably, lead to beach narrowing and eventual beach loss. The further loss of Hawaiʻi's beaches has compounding detrimental ecological, social, cultural and economic impacts to gathering spaces for social and cultural events, ecological services and habitats for threatened and endangered species, as well as the natural protection that beaches provide to inland coastal communities (Francis et al., 2019; USGCRP, 2018). SLR-induced groundwater inundation can also lead to an increase in saltwater concentration in wetlands and estuaries that threaten coastal ecosystems and agriculture (Kane et al., 2015; Nunn et al., 2017). Cultural sites will also continue to become exposed as a byproduct of the shoreline being allowed to migrate inland, which is already happening along some coasts (Cerizo, 2022).

The impacts of SLR to the built environment are numerous and vary based on urban typology in combination with SLR response intervention. SLR-induced groundwater inundation, for example, intensifies flooding and drainage issues (Habel et al., 2020). The Māpunapuna area of Honolulu floods frequently due to the combination of high tides and heavy rain, as the storm drain system is below sea level (Habel et al., 2020). Another consequence of groundwater inundation is increased public health risk, as SLR is projected to jeopardize wastewater systems (cesspools and septic tanks) near the coast (Habel et al., 2017; McKenzie et al., 2021). A study conducted in Honolulu confirmed the increase of frequency, duration, and severity of wastewater contamination of coastal waters as SLR (McKenzie et al., 2021). There are approximately 88,000 cesspool and septic systems in Hawaiʻi, 1,500 of which are within just 200 ft (60 m) of the shoreline (State of Hawaiʻi Department of Health, 2021; Whittier & El-Kadi, 2014).

If unmitigated, a combination of SLR with other hazards like coastal erosion will lead to the failure of critical infrastructure like roads and utilities. Especially for coastal properties built on sand dunes, the loss of physical land due to erosion can threaten and weaken foundations, causing dwellings to become a large safety risk for both the dwelling's residents and the public. For residential areas, our focus of study, structure deterioration and collapse could pose potentially large risks to homeowners and public safety, as well as introduce contaminants from building debris into coastal environments. Many Hawaiʻi houses still contain asbestos in their ceilings and lead in their paint, so an unmitigated collapse of a structure into the coastal area without proper remediation could introduce these contaminants into the beach and nearshore environment (Felton & van der Zander, 2021). If not properly remediated, housing debris would pollute the beach and nearshore environment. Other public safety concerns arise if materials like rebar or chunks of concrete are left on the beach and interact with people transiting or recreating in the area.

SLR can also impact home prices because of increased exposure risk. Hedonic studies of coastal real estate markets have found mixed results on whether exposure to SLR has affected housing prices. In a national study, Bernstein et al. (2019) found a 7% decline in average home values exposed to SLR. Murfin and Spiegel (2020) found no effect on housing price from SLR exposure, in a study of single-family homes and duplexes. Tyndall (2021), using real estate transactions from 2000 to 2017 for Long Island, found properties exposed to SLR appreciated at a rate 1% below unexposed homes, showing possible regional variation in how SLR affects real estate markets across the US. Other factors affecting coastal housing prices include information and individual beliefs on inundation risk, occurrence of recent floods, coastal proximity, and status of coastal armoring (Atreya et al., 2013; Bakkensen & Barrage, 2022; Baldauf et al., 2020; Bin & Landry, 2012; Bin et al., 2008; Dumm et al., 2016; Gibson & Mullins, 2020; Hino & Burke, 2021; Jin et al., 2015; Krause, 2014; Walsh et al., 2019).

Coastal Governance in Hawaiʻi

Hawaiʻi's beaches and coastlines are held under public trust as a natural and cultural resource to be protected and preserved by the State for public use.[2] Based on common law, Hawaiʻi's public trust doctrine requires the State and its political subdivisions to protect the beach for the benefit of the public and to prohibit any use that substantially impairs this trust (Callies, 2019). Hawaiʻi's public trust doctrine additionally incorporates Native Hawaiian traditional and customary law interpreting the seaward boundary as *ma ke kai* (along the sea) (*In re Ashford*, 1968; Sproat, 2009).

Hawaiʻi's Coastal Zone Management Act (CZMA), passed in 1975 and codified as Hawaiʻi Revised Statutes (HRS) Chapter 205A, protects the shoreline and State waters by managing coastal development and growth. The CZMA applies to the entire state as all land in Hawaiʻi is within 30 miles of the ocean (OP-HCZM Program, 2011). Hawaiʻi's Coastal Zone Management (CZM) program is a coordinated and comprehensive system that sets forth objectives to "promote the protection, use, and development of marine and coastal resources to assure their sustainability." The CZM objectives along the coastline are implemented through state administrative rules and county ordinances, including shoreline certification and shoreline setbacks (HRS Ch. 205A, Part III; Hawaiʻi Administrative Rules (HAR) Ch. 13-222; Revised Ordinances of Honolulu (ROH), Ch. 23 and 25). Additionally, under HRS Ch. 205A, the State owns all land up to the shoreline. The legally defined shoreline is, therefore, a critical, dynamic, physical location that delineates private property and development from public resources.

Defining the Shoreline

Hawaiʻi's shoreline is defined as the highest wash of the waves, "other than storm or seismic [sic] waves, at high tide during the season of the year in which the highest wash of the waves occur" (HRS § 205A-1). This shoreline definition has been established and updated through a series of Hawaiʻi Supreme Court decisions, notably *In re Ashford* (1968), *Sotomura* (1973), *In re*

[2] "For the benefit of present and future generations, the State and its political subdivisions shall conserve and protect Hawaii's natural beauty and all natural resources, including land, water, air, minerals and energy sources, and shall promote the development and utilization of these resources in a manner consistent with their conservation and in furtherance of the self-sufficiency of the State. All public natural resources are held in trust by the State for the benefit of the people" (Hawaiʻi Constitution, Article 11 Section 1).

Sanborn (1977), *Diamond I* (2006), and *Diamond II* (2014).[3] The Court has held that "[p]ublic policy . . . favors extending to public use and ownership as much of Hawai[']i's shoreline as is reasonably possible" under the public trust doctrine (*Sotomura,* 1973, p. 182).

Recent judicial court proceedings have highlighted ongoing gaps in the definition of the shoreline. Specifically, *State of Hawaiʻi v. OʻShea*, illustrated that the definition of a "storm" remains unsettled under HRS § 205A-1. The case centered around the construction of a seawall without permits at Kammie's surf break on the North Shore of Oʻahu (i.e. within our case study area). The State sued the homeowner, arguing that the illegal seawall (a fact agreed upon by both parties) could not be used to fix the shoreline makai (seaward) of the high wash of the waves and therefore the seawall constituted trespass on State land (State of Hawaiʻi, 2021). The Circuit Court ruled that an artificial structure, if not approved by government agencies, could not set the seaward boundary (as defined by *Ashford)*; however, the court left unresolved the question as to whether the waves in the State's key evidence on the location of the shoreline were from a "storm," which would then not alter the "high wash of the waves" line under HRS § 205A-1.

To date, no Hawaiʻi case has answered the question of the location of the ownership line on coastlines where the shoreline is artificially fixed by a seawall or other man-made structures (Deputy A.G. Wynhoff & A.G. Chin, 2017; State of Hawaiʻi, 2021). If the structure is illegal, the shoreline is legally mauka (landward) of the structure (other than if waves hitting the structure were caused by "storm or seismic waves"). Similarly, the precise location of the artificially obstructed shoreline remains undetermined for permitted seawalls (State of Hawaiʻi, 2021).[4] [5]

[3] *Ashford* centered on the seaward boundary of two properties on Molokai. Royal land patents declared the properties ran *ma ke kai*, which the Hawaiʻi Supreme Court interpreted to mean that the seaward boundary of both was "along the upper reaches of the wash of waves, usually evidenced by the edge of vegetation or by the line of debris left by the wash of the waves" (p. 77). In *Sotomura,* the Court expanded the shoreline definition, finding that the high water mark is subject to change and erosion, and held that "where the wash of the waves is marked by both a debris line and a vegetation line lying further mauka; the presumption is that the upper reaches of the wash of the waves over the course of a year lies along the line marking the edge of vegetation growth" (p. 182). In *Sanborn,* which involved another dispute over the seaward boundary of private property, the Court held that "beachfront title lines run along the upper annual reaches of the waves, excluding storm and tidal waves" (p. 588).

[4] If waves wash underneath or over a *legal* structure, that structure is nonetheless on land now owned by the State, and the BLNR must require the former landowner to pay fair market value for an easement or remove the structure as such action by the private property owner would otherwise constitute trespass (Deputy A.G. Wynhoff & A.G. Chin, 2017).

[5] When beachfront homeowners take illegal actions, such as installing shoreline hardening without permits, they may be fined and required to appear before the BLNR. However, homeowners can, and usually do, ask for a "contested case" hearing under HRS Ch. 91, triggering a lengthy administrative process. The contested case goes first to a hearing officer and then back to the BLNR, whose decision can be appealed to Circuit Court, and in turn, that decision can be appealed and eventually remanded to BLNR, sometimes taking several years, if not decades, to resolve. This prolonged process extends the duration of the homeowner's infringement on the shoreline at the expense of the public trust and public access. Unless strong action is taken to reform the contested case process for these cases, homeowners would have a strong incentive to contest violations or orders to remove armoring and may seek to protect their home at great cost to themselves and the public.

Identifying the Shoreline

Despite the continuing legal debate over the exceptions, the shoreline is commonly evidenced by a vegetation or debris line that indicates the high wash of the waves. Additional sources of evidence include other physical indicators (e.g., salt deposits, biological indicators), neighboring shorelines, wave modeling, and local knowledge (Vance & Wallsgrove, 2006). The State Department of Land and Natural Resources (DLNR) administers a process for evaluating the "certified shoreline" (HAR Ch. 13-222).[6] The "shoreline" and "certified shoreline" are related but legally distinct and serve different purposes. The certified shoreline, although using nearly the same definition as the shoreline, is evaluated through a survey process and is used for determining building setbacks (discussed below) rather than ownership.

A Supreme Court decision involving a shoreline property owner on Kauaʻi, *Diamond I* (2006), focused on the nuances of the shoreline certification process. The Court found that the homeowner's artificially planted vegetation was not "naturally rooted and growing" (as defined under HAR § 13-222-2) and therefore did not fall under the vegetation growth part of the shoreline definition. The Court furthermore "reject[ed] attempts by landowners to evade" public shoreline policy, as established by *Sotomura* and defined by HRS Ch. 205A, "by artificial extensions of the vegetation lines on their properties" (*Diamond I*, p. 30).

When structures sit within the shoreline, or if waves wash underneath or over a legal structure, that structure is on land now owned by the State. Legally, the Board of Land and Natural Resources (BLNR) must require the former landowner to pay fair market value for an easement or remove the structure because such action by the private property owner's use of state land would otherwise constitute trespass (Deputy A.G. Wynhoff & A.G. Chin, 2017; HRS § 171-13; HRS § 171-53). However, this encroachment policy is not necessarily enforced. In past decades, BLNR granted perpetual or 55-year term shoreline encroachment easements (See, for example, BLNR Submittals: D-9 Aug. 9, 2013; D-10 June 13, 2014). In addition, the Hawaiʻi Legislature has attempted to amend the law to allow BLNR to charge less than fair market rent for shoreline encroachment easements. These measures, however, failed (see *S.B. 3093*, 2018*).* In response to SLR-XA projections, DLNR's Land Division recently decided to lower the duration of encroachment easements to reduce "1) the potential for accidents and liabilities that may result from the presence of dysfunctional shoreline structures by increasing the periodicity in which shoreline encroachments are reviewed and managed, and 2) facilitate a process of managed retreat from the shoreline" (BLNR Submittal D-5, Aug. 26, 2022, p. 2).[7] This enforcement issue is still in flux.

---

[6] Typically, coastal landowners initiate the certification process and hire private land surveyors to prepare shoreline documentation for the state land surveyor, who, after a 15-day window for public comments, conducts a site inspection before completing an application to the Chair of the BLNR. Upon a decision by the BLNR Chairperson, notice of the decision is released and an appeal period starts. If approved subsequent to the appeal period, the shoreline certification is valid for 12 months (HRS § 205A-42).

[7] The rent charged by BLNR in the past decade for such easements range from $4-80 per sq ft for mostly 55-year easements. This range was calculated using the following BLNR submittals: Item D-18 ($53/sq ft), 07/12/2013; Item D-9 ($4/sq ft), 08/09/2013; Item D-11 ($80/sq ft), 06/27/2014; Item D-5 ($61/sq ft), 04/08/2016. In most shoreline encroachment easement submittals, the amount due ("consideration") is left untabulated and simply described as "one-time payment to be determined by independent or staff

Coastal Development Setbacks

Hawaiʻi's CZMA determines a minimum "setback" for coastal development from the certified shoreline and enables counties to increase the setback from the state minimum. Setbacks allow construction only at a certain distance from shore to create what can be thought of as a buffer zone. In this shoreline setback area, structures are prohibited without a variance or exception (HRS § 205A-44). Although variances for shoreline hardening measures such as seawalls used to be granted by the City and County of Honolulu (CCH) Department of Permitting and Planning on the grounds of "hardship," in Act 16 (2020), the State Legislature removed this option from being available in county ordinances, leaving substantially fewer justifications for variances (C. Lee, 2021). The CZMA "prohibit[s] construction of private shoreline hardening structures, including seawalls and revetments, at sites having sand beaches and at sites where shoreline hardening structures interfere with existing recreational and waterline activities" (HRS § 205A-2(c)(9)). Thus, the construction of new seawalls across Hawaiʻi is now effectively prohibited and the intent of the statute is that few exceptions should be made.

Act 16 (2020) also amended the CZMA to increase the minimum state setback to no less than 40 ft (12 m) mauka of the shoreline, double the previous minimum of 20 ft (6 m). Kauaʻi and Maui Counties have previously enacted greater, variable, erosion rate-based setbacks (Kauaʻi County Code 1987, Ordinance No. 979, Bill No. 2461, Draft 5; Maui County Chapter 203). The City & County of Honolulu recently increased the minimum setback to 60 ft (18 m) with additions based on historic rates of erosion up to a total of 130 ft (39 m) (Honolulu City Council Bill 41, 2022).

A Rolling Shoreline and Setback

As the sea level rises, so does the high wash of the waves – and with it, the shoreline, the certified shoreline, and the setback. A seawall or other artificial structure that prevents landward migration of the shoreline quite literally erodes the public trust; put simply, "seawalls violate the public trust in a time of rising seas" (Caldwell & Segall, 2007, p. 554). Despite some concerns that the dynamic landward migration of the shoreline could constitute a "taking," the Hawaiʻi Supreme Court has already rejected such claims (Deputy A.G. Wynhoff & A.G. Chin, 2017). A landmark 2017 Attorney General opinion clarified that, because the State has an inchoate[8] right to land that may be transferred through SLR or erosion, real property interest lost through this process by the private property owner "was not part of private title to begin with and cannot be the basis of a taking claim" (Deputy A.G. Wynhoff & A.G. Chin, 2017, p. 3).

In addition to the inchoate ownership of land below the dynamic shoreline, the government can regulate land for the health, safety, and welfare of the public. The U.S. Supreme Court has

appraisal establishing fair market rent, subject to review and approval by the Chairperson." See Item D-6, 07/13/2018 for example.

[8] The legal definition of "inchoate" is: "A legal right or entitlement that is in progress and is neither ripe, vested nor perfected." (Duhaime's Law Dictionary, 2022).

decided numerous cases on the extent of a state's ability to regulate property up to the point of "taking." In the seminal decision *Pennsylvania Coal Company v. Mahon* (1922), the Supreme Court stated, "while property may be regulated to a certain extent, if regulation goes too far it will be recognized as a taking." If a taking has occurred, under the Fifth and Fourteenth Amendment, "just compensation" must be paid. Two forms of takings, per se (physical) and regulatory, are relevant to the situation facing shorelines in Hawaiʻi. In the former, the government condemns property and immediately acquires title, leaving the question of compensatory value up to a jury. The latter can occur if government regulation "goes too far," a phrase whose meaning has been interpreted by a series of subsequent U.S. Supreme Court cases.

Penn Central Transportation Company v. New York City (1978) established a three-part test for a regulatory taking: (1) the character of the government's action, (2) the economic impact of the regulation, and (3) the extent to which the regulation has interfered with reasonable investment-backed expectations. In *Lucas v. South Carolina Coastal Commission* (1992), the Supreme Court ruled that if a government regulation deprives an owner of *all* economic use of their land, such action constitutes a taking unless, as Justice Antonin Scalia wrote for the majority, "the proscribed use interests were not part of the [owner's] title to begin with" (*Lucas*, 1992, p. 1027). Notably, exceptions to the Lucas "total takings" test can arise from state property law (state custom, statutory law, and public trust doctrine) or public nuisance law (Codiga et al., 2011; C. Lee, 2021).[9]

In Hawaiʻi, the public trust doctrine and nuisance law have previously and would likely continue to protect the State from a regulatory takings claim in a situation where the landowner challenges the landward movement of the shoreline (Codiga et al., 2011). However, if the State (or counties) decide to condemn structures using eminent domain, then the owner must be compensated for "fair market value."[10] The question of "how much?" in the context of SLR is still unaddressed within research and legal frameworks, in Hawaiʻi and elsewhere. Based on our research, condemnation has not yet been used in Hawaiʻi to manage shoreline change, and the just compensation of a structure and its land would depend greatly on whether the structure was within or outside of the public shoreline. This issue of how to value, for purposes of just compensation, shoreline property and structures that are threatened or already being undermined by shoreline erosion presents important and complex economic, policy, moral, and legal issues that are unresolved in Hawaiʻi or elsewhere, but these issues must be addressed in the near future as SLR continues to move the shoreline mauka.

Shoreline Disclosure Laws

In May 2022, a Legislative amendment to Hawaiʻi's mandatory real estate disclosure law went into effect, requiring sellers to inform buyers if the residential property is located within the 3.2 ft

---

[9] Public nuisance is a common law offense. CCH ordinance defines it as "any unsafe or unsanitary use or condition on real property that harms or threatens to harm the health, safety, or welfare of the general public." (ROH § 27-2.1).

[10] Fair market value is what a willing buyer would pay to a willing seller, both under no compulsion and having reasonable knowledge of relevant facts (*United States v. Cartwright*, 1973).

(1 m) SLR-XA (Act 179, 2021). Previously, the Hawaiʻi Association of Realtors used a voluntary disclosure to indicate whether a property was oceanfront and subject to SLR. Data is not available on how widely the voluntary disclosure was used. The economic argument for mandatory disclosure is to lessen market failures around asymmetric information – sellers presumably know more about coastal processes than new buyers. Conceptually, a disclosure of future SLR impacts within the area should bring down market values and investment-backed expectations, all else equal.[11]

[11] An active civil case *Rudisill et al. vs. Oberlohr et al.* focuses on possible disclosure errors during the recent sale of a beachfront North Shore property.

III. Sea Level Rise Response

There are three generic categories of SLR adaptation responses, initially introduced by the IPCC (Dronkers et al., 1990): protect, accommodate, and retreat. To protect means to reinforce the shoreline and maintain existing land area (i.e. not to be confused with beach or environmental protection and, in fact, is often at odds with beach and environmental protection). The protect approach requires engineered solutions that can be divided into 'hard' and 'soft' approaches. Hard measures include building structures such as seawalls and revetments, and soft measures include beach nourishment and revegetation (California Coastal Commission, 2015; Codiga & Wager, 2011; Hawai'i Center for Sustainable Food & Agriculture, 2016; Revell et al., 2021).

To accommodate SLR means to embrace solutions that enable "living with water," which aims to adapt infrastructure and residents to the changing environment while staying in-place (Waggonner & Ball, LLC et al., 2019). Accommodation typically consists of engineered solutions as well but tends to prioritize flood management more than protection. Examples of coastal accommodation include elevated/floating structures and water storage, recharge, and stormwater management using pumps and floodplains/ditches (California Coastal Commission, 2015; Codiga & Wager, 2011; Hawai'i Center for Sustainable Food & Agriculture, 2016; Revell et al., 2021).

Both protection and accommodation are approaches to *in situ* adaptation, i.e. to adapt-in-place (Figure 1).

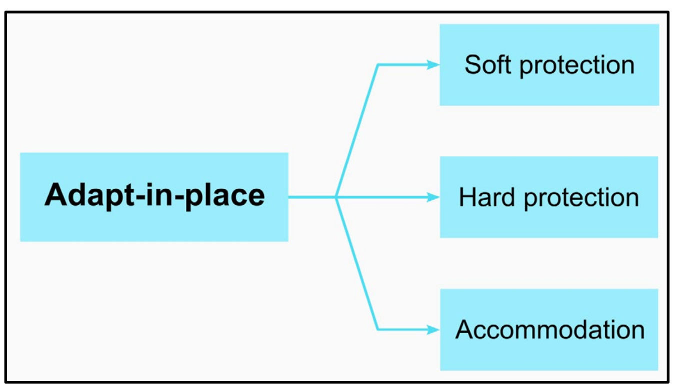

Figure 1. Adaptation in-place options

Retreat, the focus of this study, means moving people, assets, and infrastructure out of harm's way (California Coastal Commission, 2015; Hawai'i Climate Change Mitigation and Adaptation Commission, 2021; Hino et al., 2017; Mach & Siders, 2021). There is a growing consensus that retreat will become an increasingly important strategy to adapt to SLR in some locations (Siders, 2019; Hino et al., 2017; Dyckman et al., 2014). Retreat can happen all at once (e.g. planned relocation) or more gradually. Retreat that is done purposefully and systematically is often called "managed retreat."[12] The converse, retreat that is "unmanaged," can be thought of as retreat that happens haphazardly and/or without shared intention.

Retreat from the coastline can be classified into two general approaches, proactive and reactive, both of which can utilize direct or indirect tools to be achieved. Proactive retreat, which by definition must be "managed," involves the planned, coordinated movement of communities, buildings, and other assets inland (Griggs & Reguero, 2021). Two types of proactive retreat include what we are calling "all-at-once," an aggressive form of retreat, and "threshold-based," where a pre-determined trigger is selected that starts the retreat process for a parcel. This should be in advance of any major damage or risk to public safety. Reactive retreat, on the other hand, is typically enacted after a disaster event, where the only option remaining is for residents to evacuate (Griggs & Reguero, 2021). This would generally be considered an "unmanaged" approach to retreat from the coastline; however, there could still be shared intention between government and landowners in this approach, as well as means to mitigating public risk. For example, the type of government response could include condemnation of unsafe dwellings and debris management (Hernandez, 2015; Hibbs, 2022). Figure 2 displays a flow chart of tools that are available to enact these retreat scenarios.

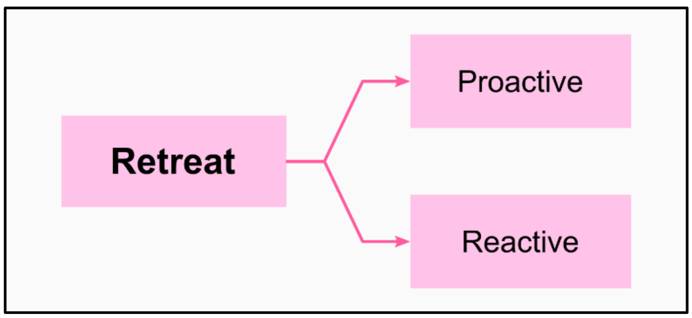

Figure 2. Approaches to implement retreat.

Although retreat has high potential to increase long-term resilience of coastal communities, it is understudied and less applied compared to protection and accommodation. Moreover, the protect, accommodate, and retreat options are not necessarily mutually exclusive. Some management approaches combine two or more of these for a hybrid solution, such as accommodating in the present with the intention of retreating in the future (California Coastal Commission, 2015). Dedekorkut-Howes et al. (2020) conducted an extensive literature review on existing coastal flooding and SLR adaptation practices and found there is more published research on hard protection and accommodation measures over ecosystem-based measures and retreat. Without policy intervention, studies find that most SLR responses would result in *in situ* adaptation because of the prioritization of short-term economic benefits, the maintaining of status quo, and a lack of public support for retreat (IPCC, 2022; Siders, 2019). In addition, research has noted that retreat could affect community cohesion positively or negatively

[12] The phrase "managed retreat" is the most popularized term to describe the relocation of people and assets, but it can be associated with negative or controversial connotations (Dundon and Abkowitz, 2021). Dundon and Abkowitz (2021) present a variety of terms used in literature that have evolved from managed retreat, such as "managed realignment" or "strategic retreat."

depending on the tools used to enact retreat, and if retreat is coordinated or piecemeal (Hino et al., 2017; Mach & Siders, 2021).

Existing and Potential Policy Tools for Retreat

In the context of Hawai‘i’s sandy shorelines, this study focuses on retreat because existing laws prohibit private shoreline armoring and protection in recognition of the harm they have caused to beach resources. Hawai‘i’s moving shoreline and ban on new seawalls implies that retreat from the coast is inevitable under SLR. Here we present types of policy tools for retreat, and their application to Hawai‘i given current coastal management laws and practices.

Rolling Easements

A rolling easement enables the inland boundary of the shoreline to “roll” (i.e. migrate inland with SLR) (Titus, 2011). An easement establishes the right for an entity to enter or use land that is owned by others, in this case for lateral beach access. Typically, rolling easements also prohibit hard protective measures–ones that would either prevent public lateral access or landward migration of the shore (Titus, 2011). Depending on enforcement, prior precedents, and local statutes, rolling easements can require the demolition of existing structures within the easement (Titus, 2011). Compensation for rolling easements is decided on a case-by-case basis in state courts that determine if rolling easements are ruled to be a “taking” (Titus, 2011).

Hawai‘i’s CZM program generally fits under the rolling easement policy umbrella; however, use of the term “rolling easement” in Hawai‘i may be misconstrued as to imply that the State uses easements as a coastal land management tool, when in reality, easements are typically only used for access to and from the beach. The beach itself is owned by the State and, by exception and agreement, the local county. For these reasons, our report conceptualizes the implementation of Hawai‘i’s CZM laws as a “rolling shoreline.” The rolling shoreline constitutes an indirect retreat mechanism. The main challenges with rolling shoreline approach are determining the responsibility for the removal of structures once they enter the easement/shoreline and enforcing actions to responsible parties. In Hawai‘i, there is little clarity from the State’s executive branch system regarding the treatment of existing structures that find themselves on the public beach. The removal of pre-existing structures and transfer of land from private to public within the shoreline has not been heavily enforced, falsely leading some coastal property owners to expect that structures can remain (Pennybacker & Cocke, 2020). In *DLNR v. McNamara*, for example, an unpermitted seawall on the North Shore of O‘ahu was ordered to be removed at the cost of the landowner and with an additional $35,000 fine (Office of Conservation and Coastal Lands, 2021). However, the seawall remains on the shoreline at the time of writing this report. Though the State would have precedent to remove the structure and then bill the property owner, this is not common practice.[13]

[13] A coastline that is part of the Cape Hatteras National Seashore in Rodanthe, North Carolina, meaning that is managed by the National Park Service (NPS), illustrates some of these challenges (Barber, 2022; Patrick, 2022). Though NPS has advised property owners to retreat from the beach and reminded

Voluntary Buyouts

A voluntary buyout program is where homeowners voluntarily enter into an agreement with another party, typically the government, to sell their property at a mutually agreed-upon price. This option could encourage coastal residents to proactively sell their properties and leave a place at risk of SLR. However, historically, buyouts are most often used in reaction to a disaster event (FEMA, 2018). While most voluntary buyouts are facilitated through federal government agencies, some states also offer programs (like New York, New Jersey, and Florida), which are increasingly under consideration to address long-term SLR impacts. Recently in Hawaiʻi, H.B. 1092 (2023) proposed the establishment of a sea level rise voluntary relocation fund, which would enable voluntary buyouts of vulnerable coastal properties.

From 1989 to 2017, the Federal Emergency Management Agency (FEMA) funded nearly 44,000 voluntary buyouts of properties in flood zones (Mach et al., 2019). An estimated 82% of the buyouts were single-family homes, of which 72% were the owner's primary residence and 12% were rental properties. The average amount of compensation per property from FEMA was $54,000, which was based on the pre-disaster market value of the home excluding inflation and flood insurance claims (Weber & Moore, 2019). Bought-out properties must be maintained as open spaces, meaning existing structures are relocated outside of flood zones, and are thereafter ineligible for federal disaster assistance (Horn, 2022; Lewis, 2012).

FEMA offers multiple types of residential flood assistance, which include buyouts. FEMA's Hazard Mitigation Assistance (HMA) program is the most commonly used program for buyouts, as it includes the Hazard Mitigation Grant Program (HMGP), the Flood Mitigation Assistance (FMA) grant program,[14] and the Building Resilient Infrastructure and Communities (BRIC) grant program.[15] Prior to receiving any grants through FEMA's HMA program, state and local governments where the applicants are located must have an approved Hazard Mitigation Plan (Lewis, 2012). Out of all these offerings, the HMGP is the main program that funds flood buyouts (Horn, 2022; Lewis, 2012). The HMGP was established by the 1988 Stafford Act and authorizes the President to disburse federal funding after a declared disaster for "hazard mitigation measures which substantially reduce the risk of future damage, hardship, loss or suffering" (42 U.S. Code § 5170c). Severe storms, floods, hurricanes, and other flood-related disasters have historically been eligible for HMGP funding (Mach et al., 2019). After

property owners of their responsibility for damages in national parks, which includes the contamination of the coast from housing collapse debris (Kozak, 2022), many property owners have not heeded the warning. If the property owner doesn't live nearby or cannot be contacted in time to hire a contractor for cleanup, NPS then takes responsibility for the cleanup and may get reimbursed later (Kozak, 2022).

[14] The FMA grant program funds states, local communities, federally recognized tribes, and territories to engage in projects that decrease or eliminate the risk of recurring flood damage to structures insured by the NFIP (FEMA, 2022a). Unlike HMGP, funding for the FMA program is appropriated annually by Congress and is not event-associated.

[15] Similar to the FMA program, BRIC program funding is also appropriated annually by Congress, and it accounts for 4% of buyouts historically (Weber & Moore, 2019). The BRIC program differs from the FMA program and HMGP in that it focuses on pre-disaster resilience instead of reactive post-disaster measures.

amendments made in 1993 to the Stafford Act, FEMA was authorized to provide buyout and relocation assistance through the HMGP while enacting participation limits and future property use restrictions within the buyout program (Lewis, 2012). The process to receive HMGP funding is lengthy and starts with FEMA inviting affected states to apply after a disaster declaration, where applications are accepted for up to one year (Weber & Moore, 2019).[16] Each state's application includes individual projects or sub-applications compiled from the impacted communities, which are typically local governments or flood control districts. Upon selection, the average time for HMGP funding to be disbursed to the sub-applicants is 20 months (Horn, 2022). A study by the Natural Resource Defense Council found that it takes more than 5 years on average to complete a FEMA buyout project after a flood (Weber & Moore, 2019). The study found that residents who are anxious about the wait time, which is particularly hard on low-income households, would rather participate in a quick cash sale of their property, which transfers flood risk exposure to the next resident (Weber & Moore, 2019).

FEMA has funded flood buyouts in 49 states and in Guam, Puerto Rico, and the U.S. Virgin Islands. States that face high flood risk are not necessarily the ones that participate most in the programs. For example, Florida, Louisiana, and Mississippi are a few of the most vulnerable states to inland flooding but none are within the top twenty most-funded states for property buyouts (Mach et al., 2019). There have been no federal flood buyout programs in Hawaiʻi, which may be due to the longer time scale at which SLR impacts occur compared to the sudden impacts (Weber & Moore, 2019; Dobbyn, 2022). The only example of federal buyout programs in Hawaiʻi come from the 2018 Kīlauea volcanic eruption, with $107 million provided by the Department of Housing and Urban Development through its Community Development Block Grant Disaster Recovery Voluntary Housing Buyout Program (Moore, 2022). The buyout program gave priority to low- and middle-income residents who lost their primary home (Moore, 2022), potentially setting a precedent for future buyouts in Hawaiʻi. The maximum payout was $230,000, the median pre-disaster (2017) total market value of properties used as primary homes (Moore, 2022).

In addition to long wait times, there are other challenges with FEMA's buyout programs as it relates to SLR response. The primary and most important for Hawaiʻi is that most federal programs tend to focus on post-disaster buyouts, but anticipating SLR is quite different from responding to a disaster event. Generally, SLR can be thought of as a "stressor" rather than a "shock" event (City and County of Honolulu Climate Change Commission, 2020). This difference is particularly meaningful in the context of proactively maintaining Hawaiʻi's sandy beaches. As such, several FEMA programs as currently constructed would be irrelevant to many of Hawaiʻi's communities likely to be affected by SLR until after they are inundated and/or affected by multiple flood hazards. The BRIC program is currently the only proactive program to which we

[16] The small application window can be problematic, as it generally takes months after a disaster for a buyout process to begin. For example, following Hurricane Irma, the Notice of Funding Availability for Florida was issued five months after the September 2017 storm, giving sub applicants only seven months to create a competitive application (Weber & Moore, 2019). However, states can request a 180-day extension to the HMGP application (Weber & Moore, 2019).

are aware; however, the scale at which communities in the US will face displacement due to SLR makes it unlikely that BRIC program buyouts would be able to form a sufficient response. Another problem with the structure of FEMA buyout programs in application to SLR response is that the HMGP uses pre-disaster value for buyouts, and the HMGP is the most commonly used program to fund buyouts currently (FEMA, 2022b). The presence of a full market-based buyout could introduce perverse incentives to existing homeowners to engage in risky development. In economics, this is called "moral hazard," where there is a lower incentive to guard against risk knowing that the risk will be borne elsewhere. This concept is similar to a common critique of the National Flood Insurance Program (NFIP),[17] as the program may promote maladaptive behavior by incentivizing risky (re)development (Young, 2018). A quarter of NFIP claims since 1978 are from repetitive-loss properties (Craig, 2019). Addressing the inundation of coastal properties from SLR would be a departure for FEMA from its historical and predominant practice of buyouts of properties that repeatedly flood from storms. Moreover, the funds available to buy out all of the impacted properties will be further restricted as the scale and frequency of natural disasters increases (Carson, 2021).

Eminent Domain

Eminent domain (also called condemnation) enables private property to be acquired for public use, so long as "just compensation" is paid. Through use of eminent domain, governments can either enact involuntary buyouts or easements. Involuntary buyouts in response to SLR would entail the condemnation of property to maintain public trust resources and public benefits. Eminent domain for involuntary easements has been used for coastal adaptation in some states, such as New Jersey post-Hurricane Sandy. Use of eminent domain for proactive coastal retreat in Hawaiʻi could be justified by the (re)establishment of the beach or coastline, a clear public purpose. Eminent domain is used in Hawaiʻi for infrastructure development purposes.

As decided in *Olson v. United States* (1934), just compensation is the fair market value of property at the time of its condemnation; though this interpretation has wide discretion (Rabak, 2021). Governments may wait until after there has been some depreciation in market value, likely due to SLR in this scenario, to comprehensively purchase coastal properties using eminent domain (Rabak, 2021). This approach would be categorized as threshold-based retreat as it involves waiting until a property is at risk. However, this then becomes an economic, public safety, and timing issue, as the value of the properties may not decrease quickly enough to fit to a government's budget before the properties are inundated (Rabak, 2021). Additionally, property acquisition through eminent domain can create incentives for purchasers or developers of risky coastal properties, if they are under the impression the government will buy them out.

[17] In 2021, FEMA updated its NFIP pricing methodology with the new rating system called "Risk Rating 2.0," which aims to be more equitable in its premium distribution across policyholders by adjusting insurance rates based on home value and individual flood risk (FEMA, 2021). Differing from the previous Risk Rating, the Risk Rating 2.0 includes storm surge and coastal erosion (FEMA, 2021). Although SLR and climate change are not explicitly mentioned in the new methodology, the inclusion of coastal hazard language of storm surge and coastal erosion is a significant departure. However, the update of the NFIP's risk rating process is nascent relative to the time of writing of this report, so there have been no published studies yet surrounding the impact of Risk Rating 2.0 on NFIP premiums for coastal properties.

Buyouts with Rentbacks

Buyouts with rentbacks, also called "leasebacks," are when a government entity buys a property but allows the former property owners to stay onsite as a renter while the government serves as the landlord (Keeler et al., 2022). Buyouts with rentbacks are often established such that there is either an agreed upon date or environmental threshold for when the property is no longer suitable for residential use and the former property owner must move out and complete the sale (Keeler et al., 2022).[18] Conceptually, Hawaiʻi has an effective buyouts with rentbacks program in that structures found within the public shoreline are required to make easement payments at fair market value, as governed by current BLNR rules. Though not a buyout program per se, it is conceptually similar in terms of land acquisition with a land rentback. As discussed above, this is not evenly enforced in Hawaiʻi.

Buyouts with rentbacks have been implemented in Mecklenburg County, North Carolina by the Charlotte-Mecklenburg Storm Water Services (CMSS) utility through a locally-funded floodplain buyout program (Keeler et al., 2022). Within the over 400 homes and businesses purchased through the program, buyouts with rentbacks have been granted on a case-by-case basis (Spidalieri et al., 2020). As of 2019, a dozen buyouts with rentbacks have been granted since CMSS started offering them in 2008 (Spidalieri et al., 2020). Although an average of one buyout with rentback per year was granted, the buyouts with rentbacks offered by CMSS were targeted towards those who would be potential holdouts in the buyout program, like the elderly who want to remain in their homes for the remainder of their lives or households that need more time to find an affordable new home (Spidalieri et al., 2020). The Mecklenburg County program was funded using both federal and local funds with buyouts with rentbacks recapturing some of the costs (Spidalieri et al., 2020). Because buyouts with rentbacks are not allowed within federal programs unless specifically authorized by Congress for a specific project, the buyouts with rentbacks offered in Mecklenburg did not use federal funds (GAO, 2003).[19]

Buyouts with rentbacks address the redevelopment and repetitive-loss challenges associated with traditional buyouts by prohibiting redevelopment in coastal areas through government ownership, while sustaining managed retreat efforts (Keeler et al., 2022). Additionally, buyouts with rentbacks offer property owners flexibility in the relocation timeline which can reduce stress and consequently decrease the number of holdouts in a buyout program (Keeler et al., 2022). Another way buyouts with rentbacks can ease the transition to a full retreat is through the supplemental rental income that can assuage the loss in property tax revenue and program costs (Keeler et al., 2022). However, buyouts with rentbacks are not as common of an

[18] Another possible strategy that is akin to a reversed buyouts with rentbacks is known as government leasing, which is where the government rents the at-risk land from the private property owner for relocation assistance and the lease structure covers the cost of removal of structures for eventual rezoning to discourage redevelopment (Young, 2018).
[19] Revell et al. (2021) assesses a buyouts with rentbacks program for Imperial Beach, California, and find that it would take approximately 25 years for the City to be paid back in its initial buyout cost through rental fees at present interest rates if using municipal bonds at an average California rate of 2.5% per year and assuming maintenance costs are 5% per year.

adaptation strategy compared to buyouts or rolling easements, so there is less documentation on pricing methodology for rental payments for areas that have implemented buyouts with rentbacks. Considerations for evaluating a purchase price for a property partaking in a buyout with rentback program include the present discounted value of future rents, avoided expenses for disaster relief, and potential economies of scale (Keeler et al., 2022).

For a true buyout with rentbacks approach to be cost-effectively implemented in Hawaiʻi for proactive retreat (i.e. before a structure is found in the public shoreline), analysis of the fee-simple cost of properties compared to the revenue from rent would need to be considered along with the duration of the lease. A buyout with rentbacks program in Hawaiʻi would ideally set the lease period to align with SLR projections in order to recoup the majority of costs and be able to use the program for its intended purpose of financing and incentivizing retreat. Such a program may also have additional economic benefits of beach health and access.

Transferable Development Rights (TDR)

Transferable development rights (TDR) is a market-based mechanism designed to redistribute development from one area to another in a manner that would otherwise not be possible under current zoning and land use regulations (Nelson et al., 2011; Pruetz & Standridge, 2008; Robb et al., 2020).[20] TDR programs allow landowners in designated “sending areas” to unbundle the development rights from a given parcel and transfer those rights to a different parcel in a defined “receiving area” (Johnston & Madison, 1997; Nelson et al., 2011).[21] Once a parcel’s development rights have been severed, a restrictive deed, covenant, or conservation easement is placed on the sending area property, outlining the future permitted and prohibited uses (Machemer & Kaplowitz, 2002; Robb et al., 2020). Sending areas may be environmentally sensitive, rural, or otherwise undesirable for development (Nelson et al., 2011; Pruetz, 2013). Receiving areas should be sufficiently well-defined to create demand from developers, diverse enough to encompass various real estate development options, and have adequate infrastructure to support a growing population (Nelson et al., 2011; Pizor, 1986; Pruetz, 2013).

Developers use credits purchased in the TDR marketplace to build to an extent that would not have been permitted under current zoning in the receiving area (DePasquale, 2016; Nelson et al., 2011). For cities that already have permissible zoning, TDR programs can provide other incentives to developers such as increased floor-area ratio, increased lot coverage, or waivers

---

[20] New York City’s 1916 Zoning Ordinance established the idea of “air rights” and gave owners who held multiple parcels in the same block the ability to transfer development rights between parcels (Giordano, 1987; Nelson et al., 2011). In 1961, Gerald Lloyd introduced the concept of TDR as it is known today, and New York City was the first to implement a TDR program in 1968 (Nellermoe, 2016). Since then the concept has been refined and adopted by over 260 U.S. jurisdictions (Pruetz, 2013).

[21] TDR is conceptually rooted in the British common law tradition of property ownership as a “bundle of rights” which the owner can use, trade, lease, or give away (Jacobs, 1998; Johnson, 2007; Nelson et al., 2011). Fee simple land ownership encompasses the physical land itself as well as the space extending above and below the surface of the parcel (Platt, 2014). The bundle of property rights encompasses this entire space and includes the rights of resources such as timber, minerals, and water, as well as the right to sell the property and develop it to its fullest extent under local zoning ordinances (Nelson et al., 2011; Renard, 2007; McGilvray et al., 1986).

for requirements such as parking or open space (Nelson et al., 2011). In contrast to purchase of development rights programs which typically use private grants or taxpayer dollars to purchase and retire development rights (akin to buyouts), TDR is funded by developers and thus has relatively low direct public cost (Kaplowitz et al., 2008); however, potentially notable indirect public cost in the form of development that may have otherwise been thought to be undesirable by the community. Additionally, municipalities can create a TDR bank and purchase development credits as needed to balance the market and provide further incentives for sending area property owners to participate (Machemer & Kaplowitz, 2002).

Pruetz and Standridge (2008) identified ten factors that largely contributed to the success of a TDR program–two of which they deemed essential: demand for additional development and receiving areas customized to local community needs. Another evaluation found that the copresence of a purchase of development right program, the use of TDR banks, high demand for housing, and conducting background studies prior to program implementation were all significantly related to the success of a program (Kaplowitz et al., 2008). One common characteristic of successful TDR programs is strict sending area land use controls, which generally make development credits more affordable by lowering the potential development value of sending area properties (Robb et al., 2020). In contrast, many TDR programs fail because developers are able to achieve their desired density without purchasing development credits (Pruetz & Standridge, 2008). While TDR programs may be more successful in achieving land preservation if they are compulsory (Pizor, 1986), it may be safest from a legal standpoint to make them voluntary to avoid a potential takings issue (Nellermoe, 2016).

After selling development rights, landowners in the sending areas may continue permitted uses as outlined in the deed restrictions or conservation easement (Machemer & Kaplowitz, 2002). In coastal areas, this could include the ability to maintain the property for recreation, camping and beach access while prohibiting permanent structures (Williams, 2014). A conservation group such as a land trust could also purchase and retire development rights (McGilvray et al., 1986). A TDR program focused on land restoration can offer incentives to sending area property owners for early participation, demolishing existing structures, and restoring the property to native habitat at the time of transfer (Nellermoe, 2016).

Despite the potential of TDR programs to tackle SLR at minimal direct public cost, the method has not been widely adopted in coastal areas (Williams, 2014). This may be due in part to the incredibly high development value (borne to developers and therefore future buyers) needed to compensate sending area property owners and encourage them to abandon desirable coastal locations (Robb et al., 2020). Expensive coastal real estate, contrasted with the often lower value of inland property, can make it difficult for a voluntary TDR program to function because it attempts to work counter to the real estate market by forcing development to shift from a high activity, high development value area (the coastal region) to a low activity, low development area (the inland region) (McGilvray et al., 1986). Additionally, coastal and inland areas (including commercial and TOD areas) often operate as separate markets, making it difficult to connect the two through development credits (McGilvray et al., 1986).

One challenge to implementing a TDR program for SLR would be the high cost of coastal real estate, which continues to exact a premium despite climate risks. Enforcement of existing laws prohibiting shoreline hardening may help to keep development credits at a more affordable amount. In addition, along with sending areas, receiving areas would need to be carefully considered. A market analysis should be conducted to ensure that there is adequate demand for housing units in potential receiving areas, and that developers would not be able to achieve their desired density for free without purchasing credits. A market analysis should also examine the potential interactions between other programs that award additional density and incentives, such as Transit-Oriented Development neighborhoods.

In Hawaiʻi there have been recent attempts to implement a TDR program. The passage of H.B. 1436 in the 2022 Hawaiʻi legislative session signals the state's interest in the method to address SLR. The bill, which was signed into law as Act 223, amends the scope of the counties to implement TDR programs for the purpose of "protect[ing] from development lands that are vulnerable to impacts and hazards from sea level rise, coastal erosion, storm surge, and flooding associated with climate change" (H.B. 1436, 2022). However, this has yet to be implemented by counties. A form of TDR was included in Honolulu City Council Bill 10 (2022), which intended to update the CCH zoning code, but was not passed (Downey, 2022). The proposal in this bill was for the ratio of development credits for floor area ratio to remain 1:1, which is not likely to be successful due to the high cost of coastal real estate. It is important to conduct a market study for sending and receiving areas, and to determine the structure of the TDR credit.

Land Swaps

Land swaps exchange property in perpetuity between two or more property owners. They can be supplemented by money as well, and can occur between the government, private landowners, and/or land trusts/non-profit organizations (Georgetown Climate Center, 2023). Land swaps may decrease public financial cost of retreat compared to tools such as buyouts and may increase voluntary participation in retreat as property owners are aware of the new location prior to the exchange. If implemented comprehensively, land swaps may help maintain community cohesion while increasing community resilience by moving people out of an area vulnerable to SLR impacts. Additionally, land swaps would provide public benefit by maintaining or restoring open space along the coast, potentially restoring beach width and public access. However, this retreat tool may have high overall costs in the form of public land loss, and residents may not want to transfer public land into private ownership in fear of misuse or overdevelopment (Georgetown Climate Center, 2023).

An instance of public resistance was seen in the land swap project in Long Beach, California, where 5 acres of public wetlands within the Los Cerritos Wetland Complex were to be transferred for 154 acres of privately-owned wetlands in 2018 to facilitate the restoration of wetlands that had been degraded by oil production (Adaptation Clearinghouse, 2023). Lawsuits led by environmentalists and residents were filed against this exchange, but in 2021, a Los Angeles Superior Court judge ruled against the lawsuit, allowing the project to move forward (H. Lee, 2021). Although the lawsuit did not result in favor of the plaintiffs, the project was delayed by a few years due to public opposition.

IV. Identifying Costs and Tradeoffs within Shoreline Retreat: A Case Study of Paumalū, Oʻahu

Here we present a case study that quantifies the costs for retreat from the shoreline, within SLR-XA, between Rocky Point to Sunset Point within the Paumalū[22] *ahupuaʻa* on the island of Oʻahu, as shown in Figure 3 below. The North Shore Coastal Resilience Working Group's (2022) report found that retreat is the only viable long-term solution for Sunset Beach, given the history of chronic (Figure 5) and episodic erosion at Sunset Beach and the importance of the beach to residents and tourists. Within this area, there are 59 parcels adjacent to or makai of the 3.2 ft (1 m) SLR-CE line and 88 parcels adjacent to or makai of the 3.2 ft (1 m) SLR-XA border (shown in Figures 8 and 9). In our study area, there are approximately 200 people residing within 3.2 ft (1 m) SLR-CE, and about 400 people residing within 3.2 ft (1 m) SLR-XA.[23] The case study area was chosen because it has experienced extreme erosion in recent years, resulting in multiple private structure failures including the collapse of a home onto the beach for the first time in decades on Oʻahu (Cocke, 2022a). Additionally, this is a high-value beach area with prime beach, ocean and surfing conditions that are threatened by ongoing erosion and intersection to the adjacent private properties and dwellings. For the properties in the study area (Figure 3) between Rocky Point and Paumalū Stream, we refer to them as being at "Kammie's," the name of an adjacent surf break.

[22] The Native Hawaiian traditional name for the area, Paumalū ("taken by surprise" or "taken secretly"), comes from a legend about a renowned fisherwoman who caught more octopuses than the number that was permitted for this reef. As she made her way to shore, a large shark, the guardian of the reef, attacked and killed her. After the incident, the area was called Paumalū (Clark, 2004; Pukui et al., 1981).

[23] These population estimates were calculated by multiplying the number of dwellings within SLR-CE or SLR-XA in the study area (determined using spatial analysis) by the average household size in Hawaiʻi, which is roughly 3 persons per household according to the 2020 Census (American Community Survey, 2022).

Figure 3. Case study area. The area contains the stretch of Sunset Beach within Paumalū *ahupuaʻa*, and the surf breaks of Sunset Point, Kammie's, and Rocky Point.

Site Description

Strong trade winds and winter swells, combined with SLR, make the Paumalū area shoreline particularly dynamic. West to northwest swells tend to push sand easterly (from Rocky Point towards Sunset Point) while the opposite is true for more northwest to north swells (Eversole, 2009; Smith et al., 2018). Sand tends to accumulate at Sunset Beach during the winter season but large year-to-year variation is possible, especially in the Kammie's area, depending on the dominant swell direction of the surf. Throughout the summer months, east to northeast prevailing trade wind swell tends to move sand towards Rocky Point (Eversole, 2009; Smith et al., 2018).

A significant portion of the existing public and private structures in the area are built on sand dunes, as shown in Figure 4, including a portion of the highway. The dune underlying the Kammie's area may be more accurately described as a high wave berm because the coarse-grained nature of the sand implies deposition by waves rather than wind (BLNR Item K-1, 11/10/2022).

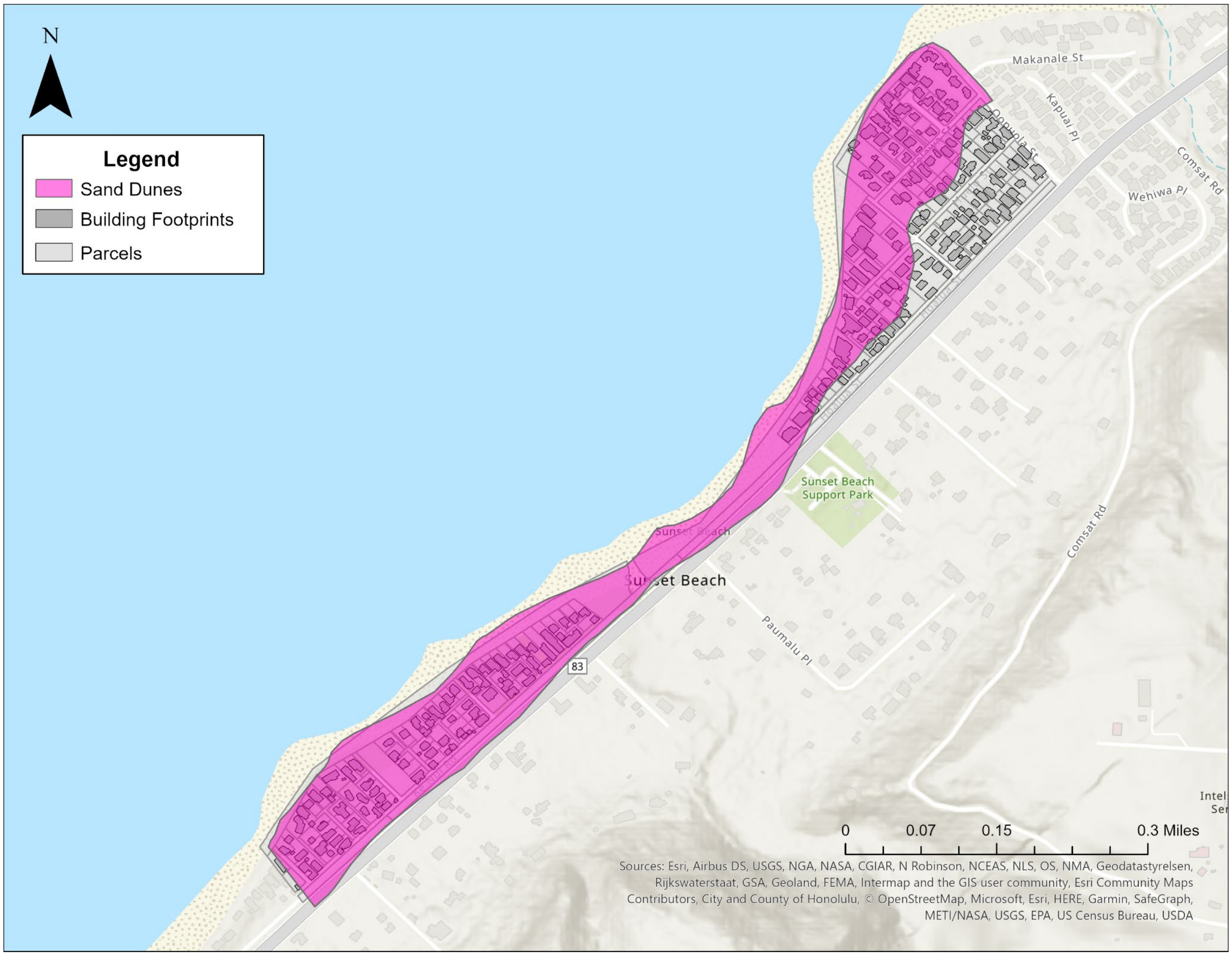

Figure 4. Sand dunes in case study area (from USDA NRCS Soil Survey). Due to construction of dwellings on top of sand dunes and accelerated erosion, sand dunes may have depleted or shifted.

A 1969 winter swell destroyed or severely damaged 60 North Shore homes over three days and killed two people (Shikina & Hurley, 2014). Bouts of extreme erosion at Sunset Beach have occurred in recent years, most notably during the winters of 2013-14, 2017-18, and 2021-22 (Cocke, 2021, 2022a; Essoyen, 2016; Hurley, 2013a, 2013b; Kakesako, 2014; Shikina, 2017; Shikina & Hurley, 2014; Star-Advertiser, 2017; Wu, 2017a, 2017b, 2018a, 2018b, 2018c, 2018d). Erosion along this coastline commonly leaves 20 ft (6 m) sand cliffs (Wu, 2017b), or, in locations with soft and hard protection measures, no beach at all (Cocke, 2021). As illustrated in Figure 5, there is an overall trend towards erosion in this area.[24]

[24] 73% of the North Shore shoreline is eroding in the long-term (Fletcher et al., 2012).

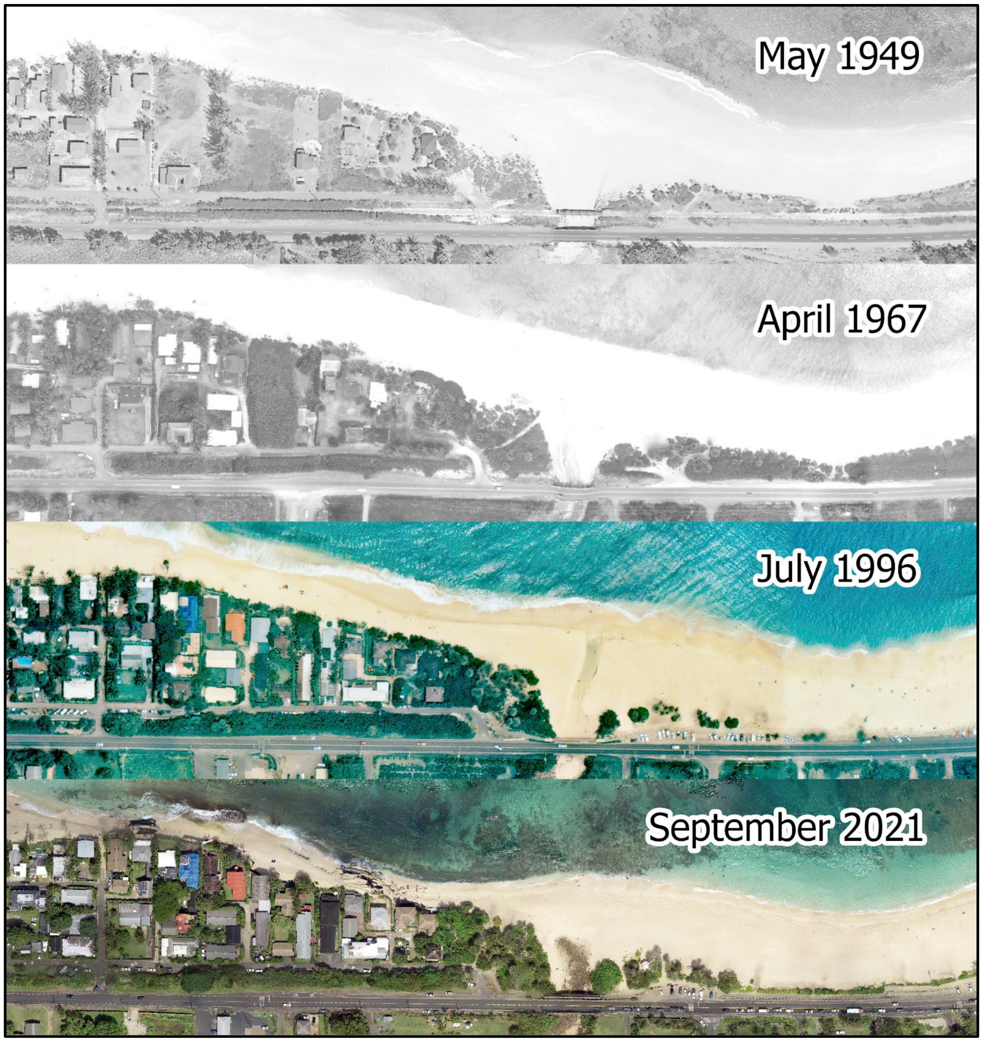

Figure 5. Erosion of Sunset Beach over time. (Source of Images: Climate Resilience Collaborative, 2022b. Figure compiled by Authors.) Though images depicted are taken at different times of the year, and beach widths on the North Shore of Oʻahu vary depending on seasonality, there is documentation of chronic erosion occurring in this area (Climate Resilience Collaborative, 2022a).

Structures constituting shoreline hardening interrupt sand transport processes in the study area and exacerbate erosion (BLNR Item K-1, 11/10/2022; Romine et al., 2021). Protection and accommodation of homes in the long term are not feasible in this area if the beach is to be preserved (Romine et al., 2021; North Shore Coastal Resilience Working Group, 2022).

In February 2022, a late season winter swell eroded sand from underneath a series of homes, causing one to collapse onto the beach (Cocke, 2022a). The home was eventually lifted and rolled back onto the remaining portion of the property within days, constituting a form of reactive retreat (Cocke, 2022b). Two months later, further erosion prompted a nearby homeowner to push sand in front of their home, in violation of DLNR Conservation District Rules HAR Ch. 13-5. Eighteen homes in the Kammie's area have received notices of violation (NOV) in recent years for unauthorized land uses, mostly unauthorized or expired erosion control measures (OCCL NOVs on file with Authors). Some homeowners in the area have resorted to illegal measures, such as pouring concrete onto the beach, which further damage the nearshore environment.

Erosion and high wave flooding in this area, as it interacts with shoreline hardening, not only limits and destroys public access but also threatens and damages private and public infrastructure. Kamehameha Highway, the only transportation corridor for the region, runs through the case study site, adjacent to the beach for nearly 1,000 ft (300 m). The highway also contains a bridge over the mouth of Paumalū stream. A portion of the bike path along Sunset Beach collapsed in December 2017, threatening Kamehameha Highway and CCH Ocean Safety infrastructure (Wu, 2017b). Sand pushing, a form of beach profile shaping, is performed by the CCH to remediate erosion caused by foot traffic at Sunset Beach but the solution should be considered a short-term one to be used sparingly in the face of chronic erosion accelerated by SLR (Eversole, 2009).

In addition to transportation infrastructure, the area contains stormwater management structures and pipes but lacks a regional sewer service. All properties in the study area have onsite sewage disposal systems (OSDS), consisting mainly of cesspools (Hawaiʻi State Office of Planning, 2022). The nearshore coastal environment within the case study area is highly vulnerable to the excess nutrients, potential chemicals, bacteria, and viral threats that can leach from cesspools (Hawaiʻi Sea Grant, 2020).[25]

Case Study Approach

For the case study, we operationalize two types of proactive retreat. The first is all-at-once retreat, meaning that all considered properties are acquired and retreated simultaneously and as soon as possible. Less proactive, but in advance of major public safety risks due to structure failure, is threshold-based retreat. This uses a predefined "trigger" for retreat – and for our purposes we adopt when erosion is within 20 ft (3 m) from a dwelling or infrastructure. Reactive retreat, on the other hand, occurs after major public safety risks and structure failure. We assume that reactive retreat occurs when the erosion line has passed the dwelling or infrastructure's makai boundary.

All-at-once and threshold-based retreat are considered forms of managed retreat, as they both substantially mitigate public safety and environmental damage risks. Reactive retreat is unmanaged in nature, as it incurs high risks and involves considerable clean-up. Figure 6 displays the differences in retreat approach as used in the case study.

[25] Act 125 (2017) requires all cesspools in Hawaiʻi to be converted to septic systems by 2050.

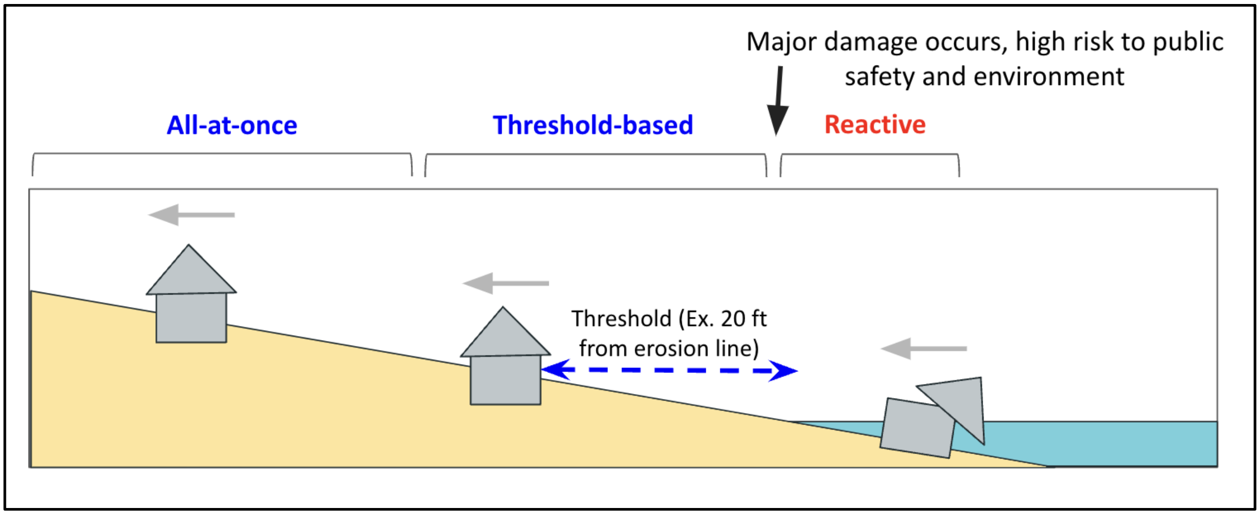

Figure 6. Depiction of retreat framework. Managed retreat approaches are shown in blue (all-at-once and threshold-based), and unmanaged retreat is shown in red (reactive).

Costs Considered

This study uses the SLR-XA projections developed for the Hawai'i Climate Change Mitigation and Adaptation Commission (2017) to estimate the costs associated with all-at-once, threshold-based, and reactive retreat within the study area. To develop these estimates, we identify the types of costs from these varying approaches to retreat, based on our review of prior studies, as well as to whom they first accrue (federal, state, and county government and private actors i.e. current homeowners). We assume property acquisition costs are borne to the public, although these costs could be decreased and/or the bearer of costs could change depending on the retreat mechanism used. The costs identified are relevant to communities with sandy beaches and natural coastlines (i.e. not intended for industrial areas like airports and harbors). Figure 7 below lists the types of costs accrued in retreat and identifies to whom costs are directly attributed.

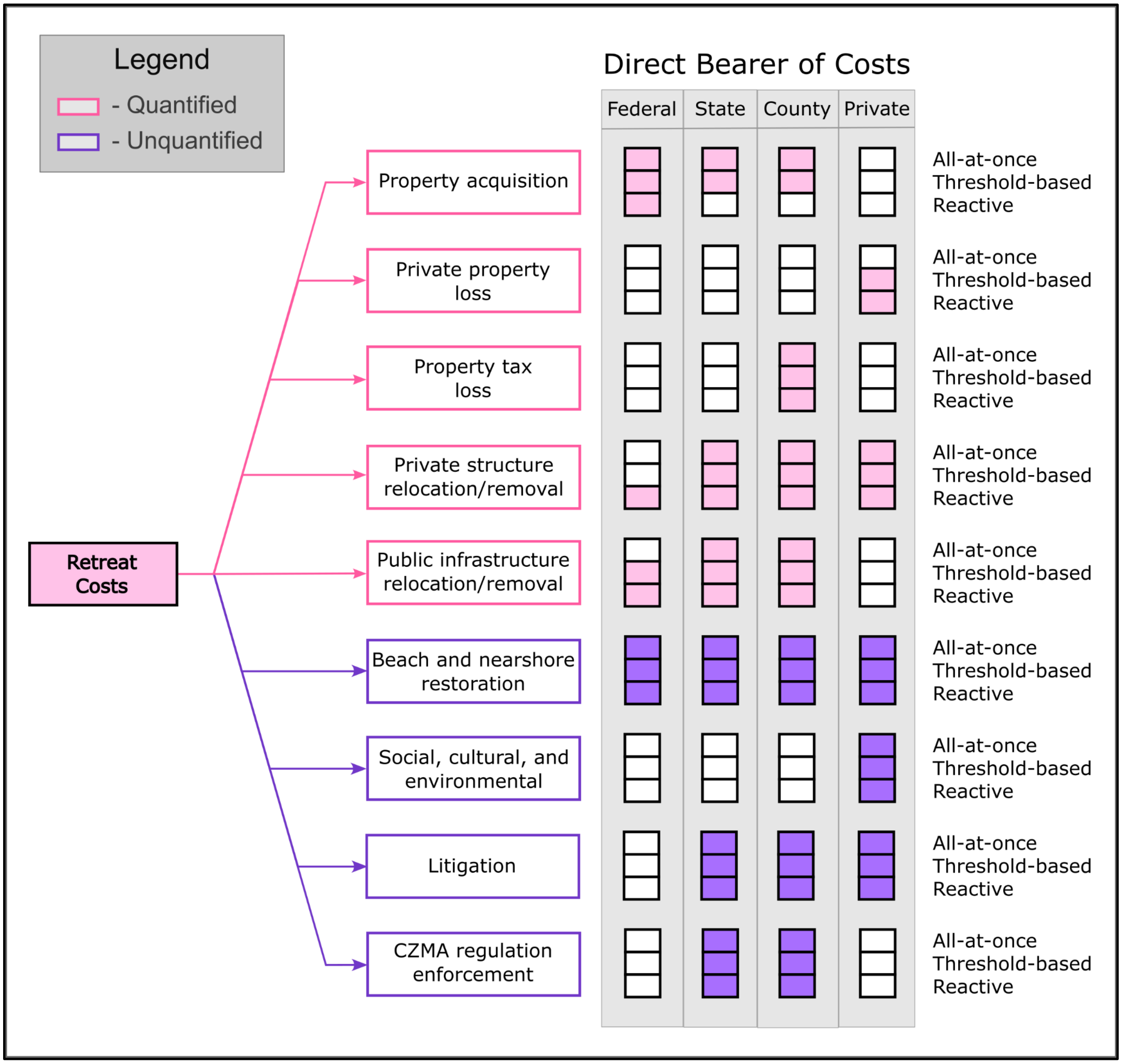

Figure 7. Types and bearers of costs related to retreat. A filled in box indicates if the burden of the cost is directly borne to an actor at each retreat approach (broader incidence is outside of the scope of this analysis). The cost categories that are operationalized and quantified within this case study are shown in pink. Costs that we identify but do not quantify within the scope of this analysis are shown in purple.

We quantify a broad range of costs: property acquisition (e.g. voluntary buyouts or eminent domain); structure removal (both private structures and public infrastructure); ecosystem restoration; loss of property tax revenues; private property loss. Unquantified costs include litigation and enforcement costs as well as other and social, cultural and environmental costs such as the potential loss of community cohesion due to dislocation (Mach & Siders, 2021). There are potentially high environmental (and public health) costs from the introduction of pollutants (e.g. asbestos and lead) into the nearshore environment, depending on the quality of removal and remediation. While our cost estimates address debris removal, they are not necessarily at the level that would entail full remediation. There are also other potential costs related to lost business days and access due to road closures, given there is one main thoroughfare along the coastline. Such road closures have occurred on the North Shore before, including from rockfall, severing residents from their jobs and social networks (Song & Morse, 2000; HDOT, 2023), giving insight into how the local community might be affected when coastal erosion reaches Kamehameha Highway.

Benefits Considered

While our study primarily focuses on quantifying costs, we also gathered several metrics to represent benefits of retreat. Specifically, we estimate the beach area restored from each retreat approach. To do so, we make the assumption that as a parcel is vacated, the land returns to the beach. The majority of the affected properties in the case study area sit on top of sand dunes. To estimate total beach area, we sum the area of retreated parcels over each time period, net of coastal erosion.

We also provide a basic estimate of the total use value of Sunset beach, based on a travel cost model that primarily relies on lifeguard visitor count data. Because we are focusing on retreat itself, rather than comparing retreat to adapt-in-place (which would have substantial differences in environmental outcomes), we posit that the variation in the costs of retreat relate to how long the community and its dwellings stay in place, rather than full degradation. If we were to study the variation in cost from retreat to adapt-in-place, there would be more permanent damage to the beach resource and our travel cost model should be taken in this context.

Estimating the Costs of Retreat for the Study Area

The costs that we focus on and quantify for this case study are acquisition costs, property loss, private structure removal, public structure removal and relocation, and property tax loss, using three types of data. The first dataset used is the exposure area (SLR-XA). Among the flooding hazards that define SLR-XA, we specifically use the measure of coastal erosion (SLR-CE) and annual high wave flooding (SLR-AHWF). The second type of data is the CCH property value (assessor's) data for 2021, which includes tax payments (City and County of Honolulu Department of Budget and Fiscal Services, 2021). This data is taken as a proxy for housing market value. As awareness of SLR impacts grows and the consequences of SLR become more visceral, local housing values may be affected (Tarui et al., forthcoming), which is not accounted for in this study. The last datasets used are geospatial data for parcels, dwellings, and infrastructure[26] (roads, bridges, and OSDS) (Hawaii State Office of Planning, 2022).

Within the study area, the measure of passive flooding (SLR-PF) is negligible in terms of its mauka edge due to the high elevations of existing homes on the sand dunes (Tetra Tech, Inc. and University of Hawaiʻi Coastal Geology Group, 2017). As such, the mauka edge of SLR-XA is determined by SLR-AHWF (and thus can be used interchangeably). For simplicity, we will

[26] Due to unavailability of geospatial data of potable water infrastructure for public safety concerns, we assume potable water mains are embedded within the roads, as per common practice.

refer to this as SLR-XA, as shown in Figure 8 below. SLR-XA is shown for 0.5, 1.1, 2.0 and 3.2 ft (0.2, 0.3, 0.6, and 1.0 m, respectively) of SLR, which are related to years 2030, 2050, 2075, and 2100, respectively.[27]

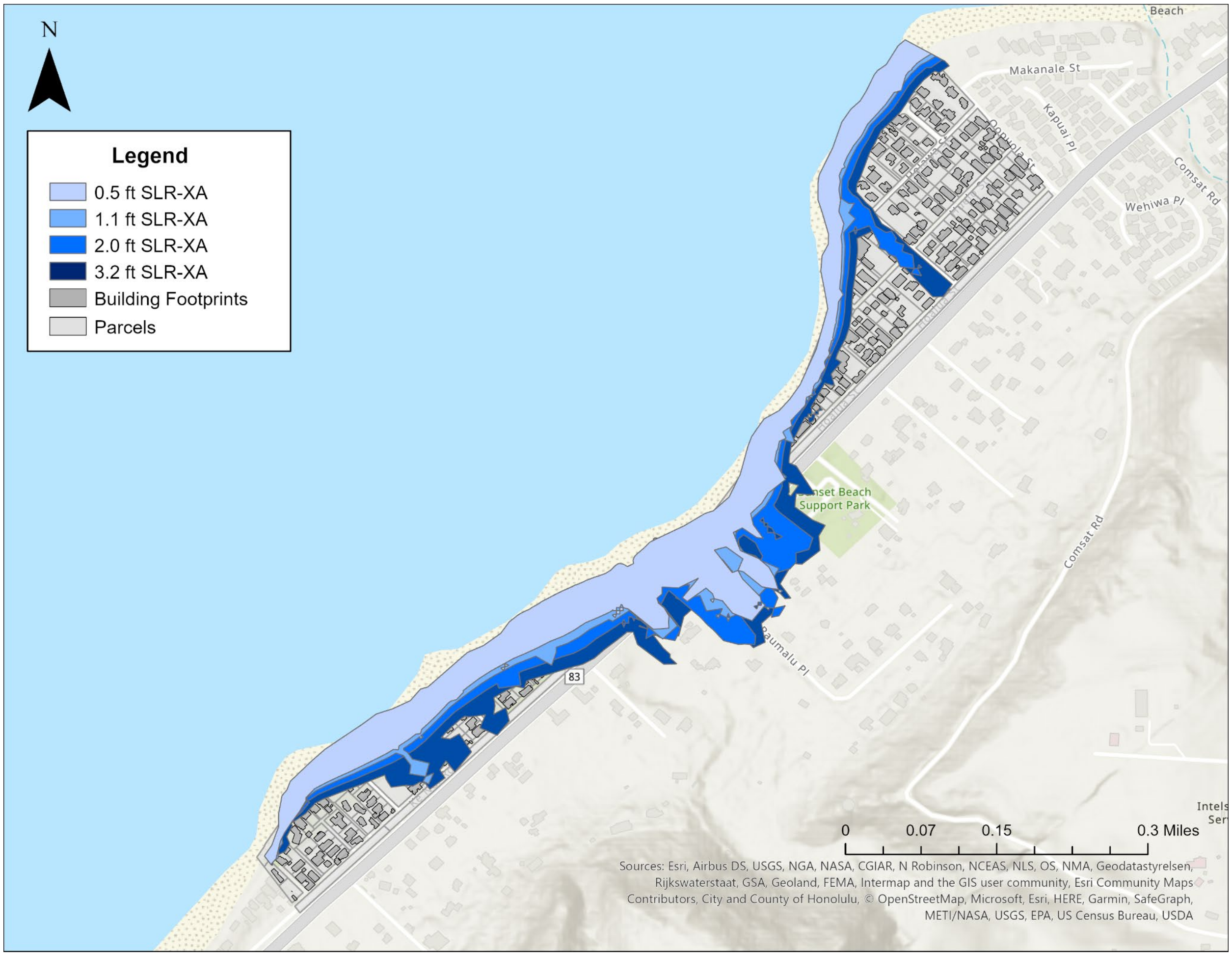

Figure 8. SLR-XA projections in the case study area.

As discussed in Section II, State law is that land automatically transfers to the State through the highest wash of the waves (akin to annual high wave flooding); however, enforcement of this line is infrequent and can be challenging. More often, the shoreline is determined by debris lines or other evidence of the upper reach of the waves, including erosion scarps,[28] sand deposits, salt deposits and photographic evidence. As such, we use both the SLR-XA and the SLR-CE to determine land ownership and value transfer (from private to public). The SLR-CE is shown in Figure 9, in addition to a recent 2021 vegetation line.

[27] Using RCP8.5 from IPCC AR5.

[28] An erosion scarp is a geologic feature typically left by erosion that is characterized by steep coastal cliffs.

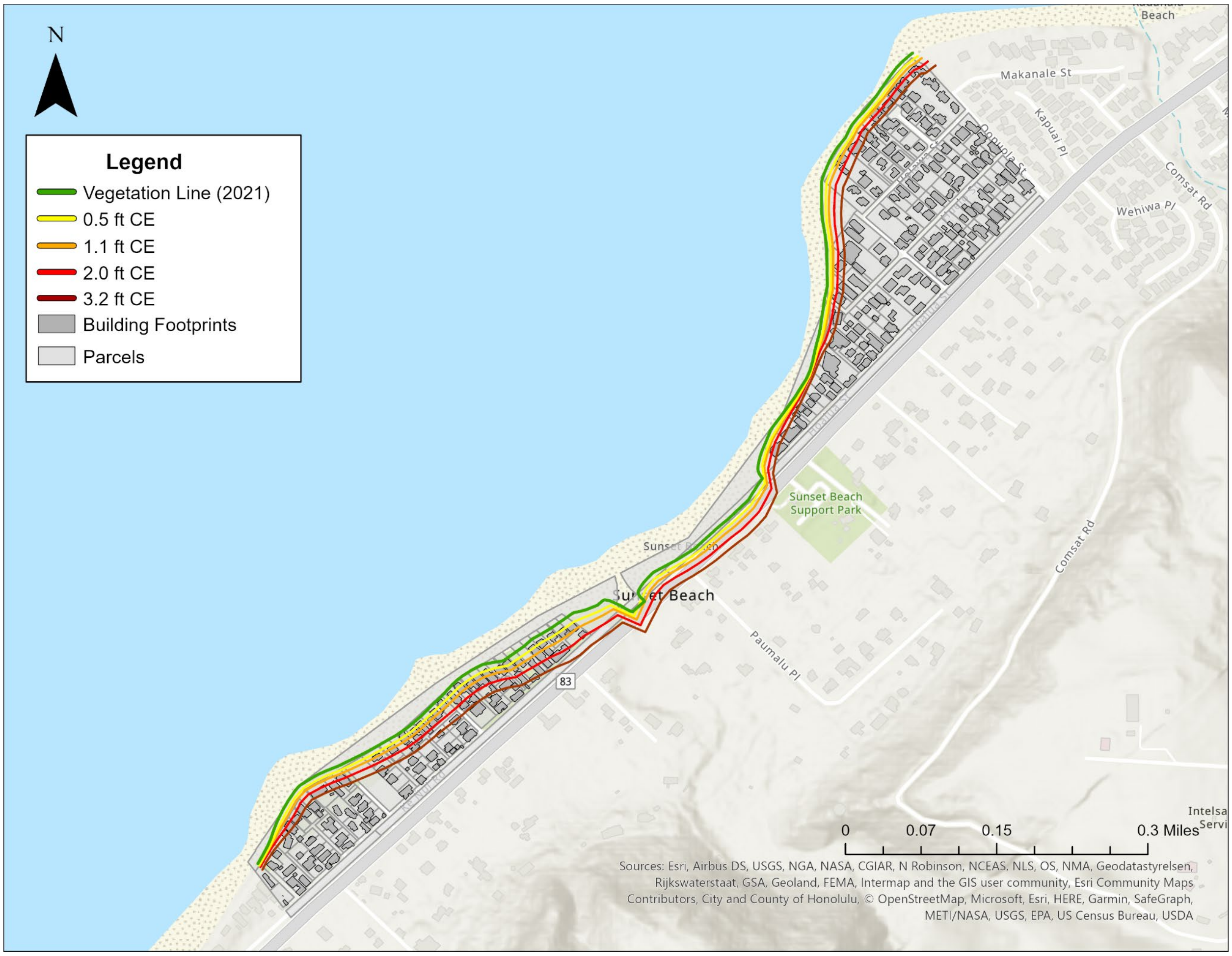

Figure 9. SLR-CE projections in the case study area. The most recently available vegetation line (2021) is included to illustrate the approximate shoreline.

The SLR-CE, both in terms of its geospatial position and the implied time frame through 2100, are used to categorize dwellings and infrastructure into all-at-once, threshold-based, and reactive retreat for every measured time period (2030, 2050, 2075, and 2100).

All-at-once Retreat

For our purposes, all-at-once retreat means that all existing coastal structures within the SLR-XA or SLR-CE boundaries are purchased now through a buyout program at market rates (which are the $2021 assessed values). Private structures (houses and OSDS) are demolished and debris is removed. Public structures (roads, bridges, and water infrastructure) are relocated inland. Since retreat can be enacted through a range of methods, we identify the highest and lowest cost scenarios for how all-at-once retreat could occur.

The most extreme scenario for all-at-once retreat (All-at-once-XA) is that all parcels inside the 3.2 ft (1 m) SLR-XA projection are bought out and removed (including OSDS) at one time, all at the expense of the “public” (i.e. some combination of state residents and federal taxpayers, depending on which tool is used). To be consistent with the assessor's data, costs are all given in $2021. See Figure 10 for an illustration of this scenario.

Figure 10. Properties within All-at-once-XA scenario.

Our more conservative scenario for all-at-once retreat (All-at-once-CE) is the same as above except it is only the parcels makai of the 3.2 ft (1 m) SLR-CE projection that are purchased and removed (Figure 11). There are fewer parcels and dwellings in the All-at-once-CE scenario, as SLR-XA extends more mauka than SLR-CE. We assume there is a full market value acquisition at cost to the public.

Figure 11. Properties within All-at-once-CE scenario.

For public infrastructure, we assume that roads, bridges, and potable water pipes are removed and retreated inland at the expense of the public, also given in $2021. Both scenarios use the SLR-CE line to determine lengths of infrastructure that need to be realigned. We assume that the water infrastructure lies under the main highway and must also be relocated with that thoroughfare. Highway and potable water pipe retreat costs include removal cost, eminent domain cost for those private properties where the new road would be realigned inland to (assumed to be outside of SLR-XA), and rebuilding costs. We assume that local neighborhood roads would only necessitate the cost of removal, as the properties relying on those local roads are assumed to also be retreated. See Figure 12 for a depiction of the infrastructure to be addressed by 2100. Our cost estimates for infrastructure, given in Table 1 below, are almost certainly an underestimate because we take only the length of infrastructure within the study area (multiplied by the per foot cost), and thus do not account for realigning the adjacent infrastructure.

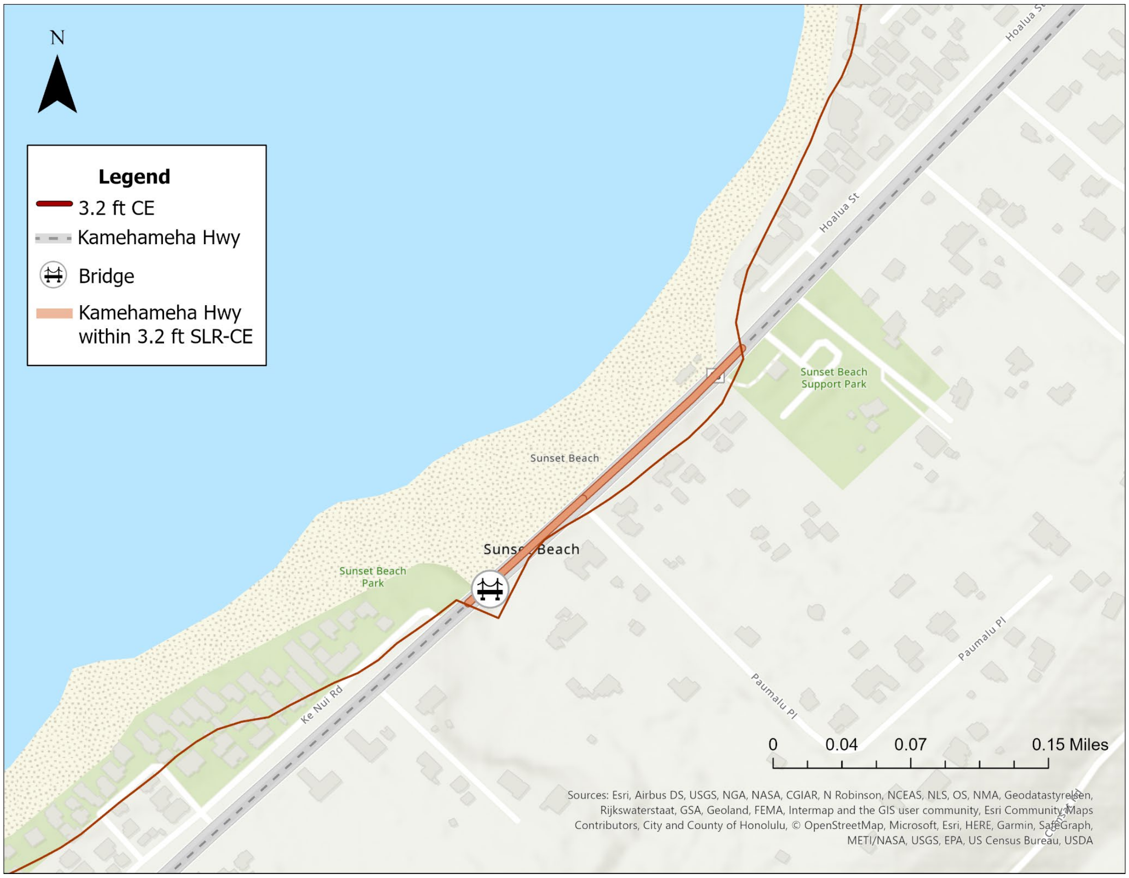

Figure 12. Infrastructure to be realigned by 2100.

Threshold-based Retreat

Threshold-based retreat occurs prior to any major loss or before a predetermined threshold (Griggs & Reguero, 2021). Threshold-based retreat implies either the use of eminent domain or a more piecemeal approach of voluntary buyouts–we treat these as having the same costs. We consider two scenarios, where land transfer is determined through either (1) SLR-XA or (2) SLR-CE; in both, homeowners are compensated for their dwelling. We assume that there is a linear relationship between land loss and land parcel value. In reality, the relationship is likely nonlinear with increasing value lost at higher levels of SLR. There may also be additional market effects as SLR interacts with other coastal hazards (Tarui et al., forthcoming). We assume that the property acquisition costs, as well as the costs of dwelling and OSDS removal, are at the expense of the public.

A parcel is characterized as triggering threshold-based retreat if the projected SLR-CE line is less than or equal to 20 ft (6 m) away from the makai edge of the building footprint and has not yet crossed the building footprint for each study period: 2030, 2050, 2075, and 2100. We choose 20 ft (6 m) as the threshold since a property is considered "imminently threatened" if an eroding shoreline is 20 ft (6 m) away from a dwelling (HAR § 13-5-2). If a parcel is labeled as all-at-once in one study period and reactive (described below) in the following period, we assume that threshold-based occurs in the years halfway between. To normalize dwelling cost estimates during the study time horizon, buyout costs are expressed in discounted present value of $2021 using a discount rate of 2.6%, a long-run discount rate for real estate (Giglio et al., 2021).

In one threshold-based scenario (Threshold-based-Veg), we assume the value of land transfers with the SLR-CE and dwelling value is fully compensated at the time of acquisition (Figure 13).

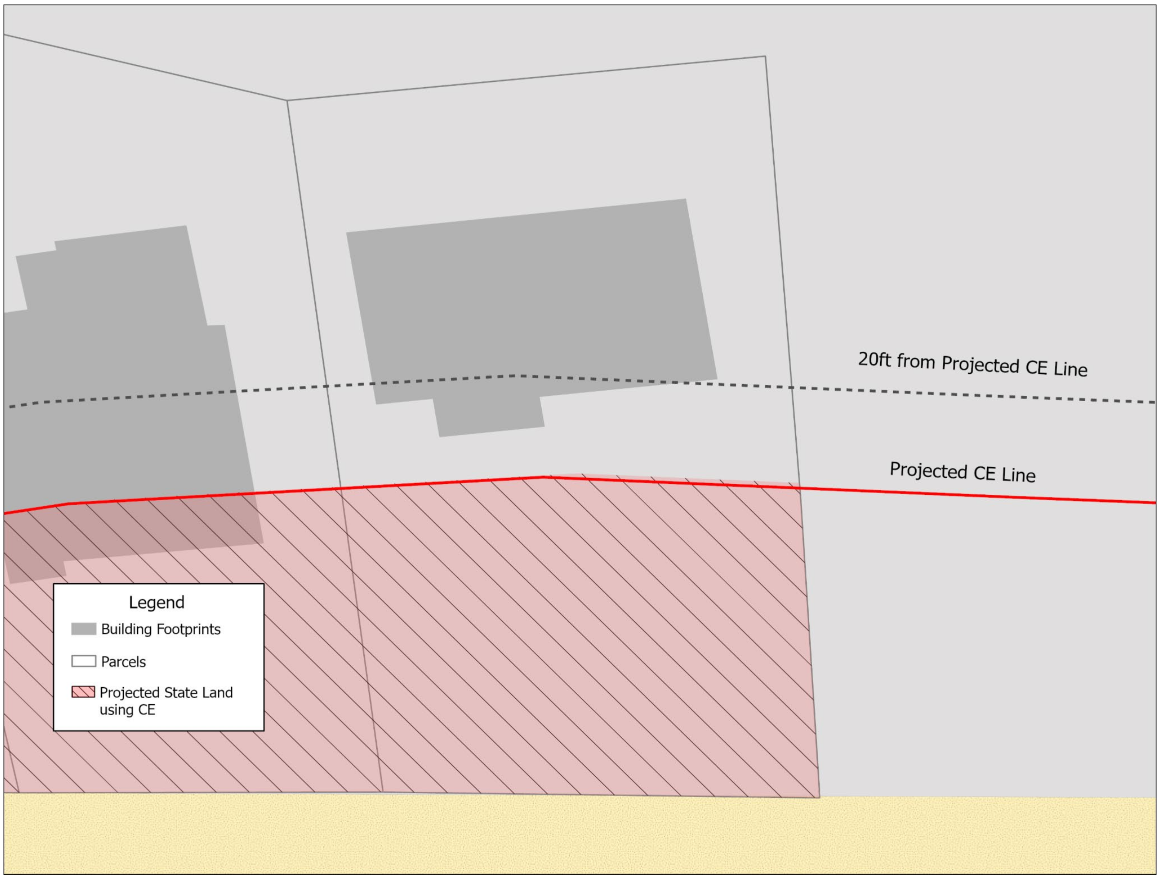

Figure 13. Threshold-based-Veg scenario for parcels and buildings (demonstration).

In another threshold-based scenario (Threshold-based-Wave), we assume that the value of land transfers with the high wash of the waves, SLR-XA, as this captures the legal definition of Hawai‘i’s shoreline. In addition, we assume that only the dwelling value is compensated (Figure 14). The same number of affected parcels and dwellings are affected in both threshold-based scenarios.

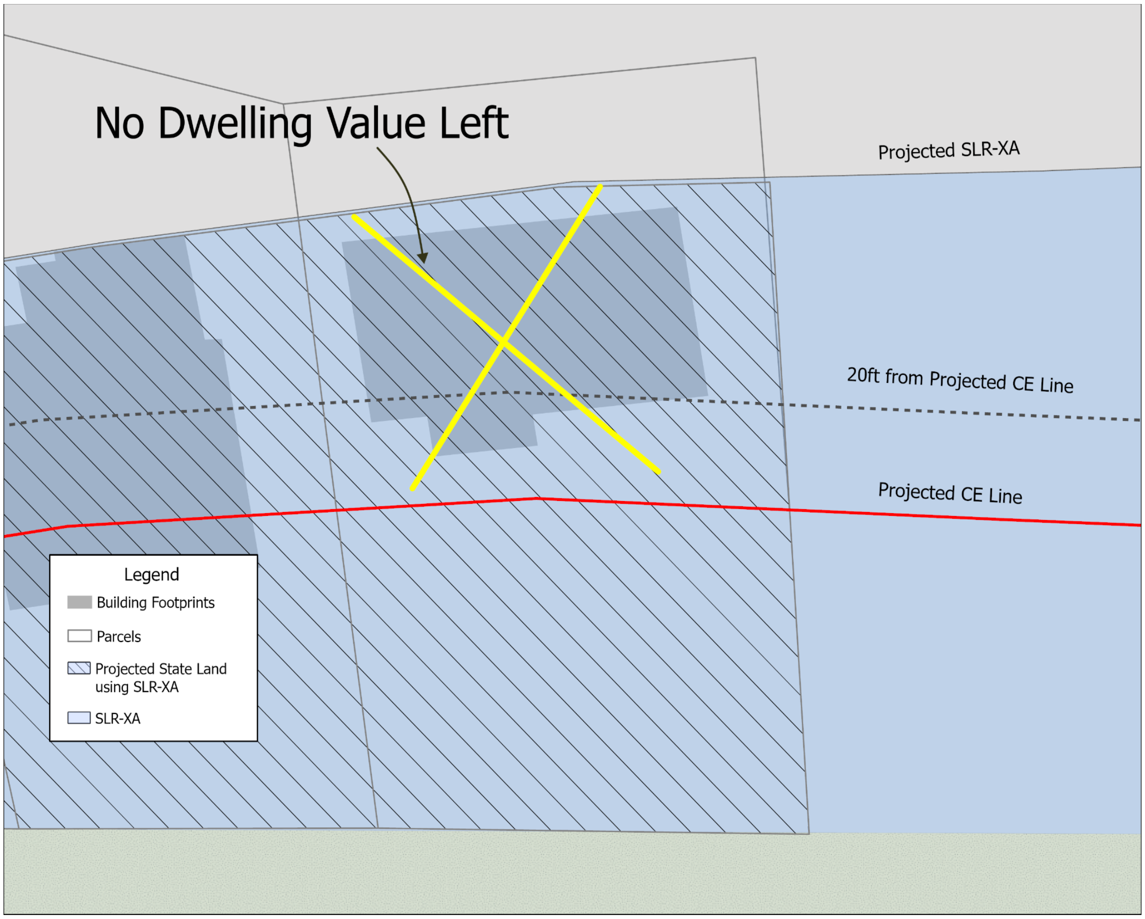

Figure 14. Threshold-based-Wave scenario for parcels and buildings (demonstration).

For public infrastructure (Figure 15), we assume the lowest cost solution is implemented, which entails that roads are hardened until the entire segment of infrastructure is within 20 ft (6 m) from the SLR-CE line, leading to a one-time retreat and realignment (as described in the All-at-once scenarios) at 3.2 ft (1 m) of SLR. The values are in $2021 using a 3% discount rate for public infrastructure, which would be akin to the long-term bond rate.

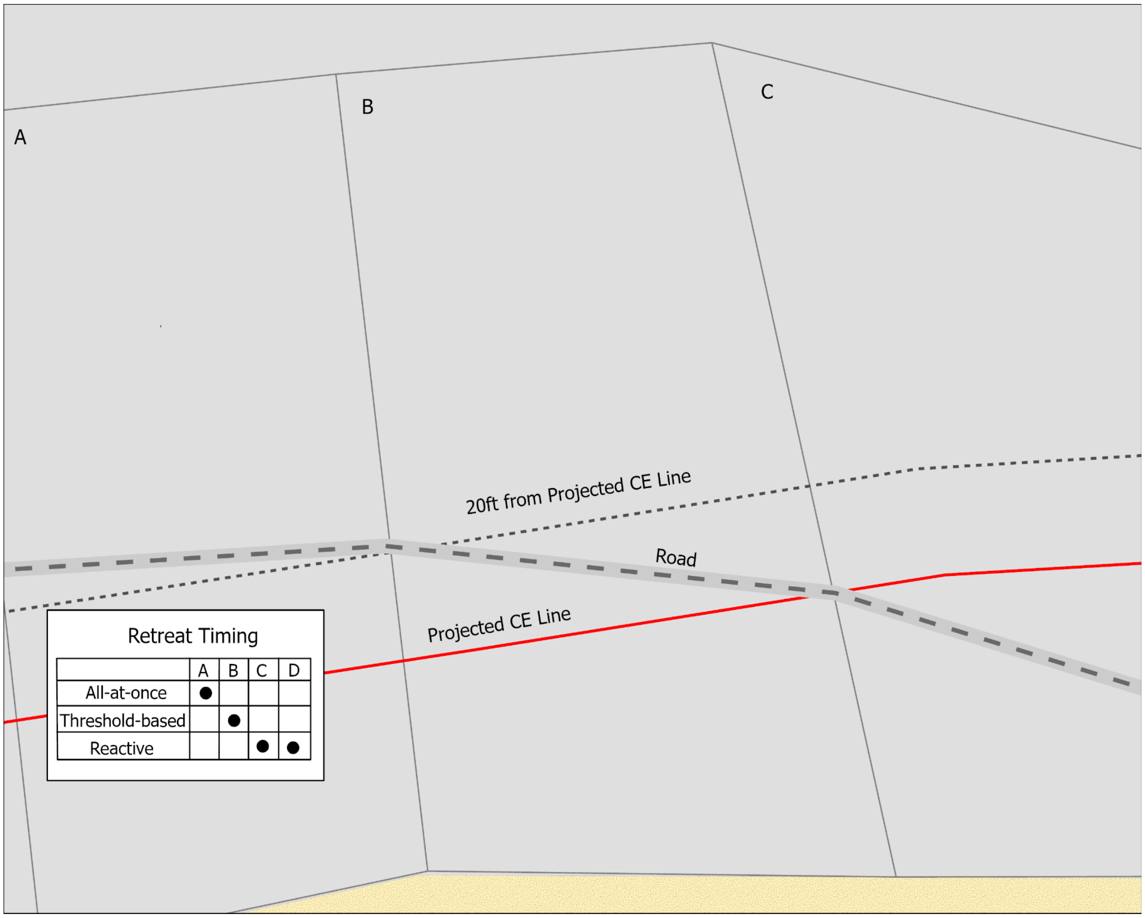

Figure 15. Threshold-based scenario for roads (demonstration).

Reactive Retreat

Retreat of a parcel is considered reactive when the projected SLR-CE line is within or mauka of the building footprint, implying the dwelling has likely collapsed or been considerably damaged, creating public safety and environmental risks, as well as potentially incurring large clean-up costs. Because the dwelling is now assumed to be on the public beach and likely inhabitable, no dwelling value remains. The clean-up costs are assumed to be borne by the dwelling owner (i.e. private costs).

From conversations with local demolition, construction and coastal engineering companies, a range of clean-up costs were identified. The lower cost clean-up outcome occurs when a dwelling has a post-and-pier foundation, and the dwelling remains intact on the beach. Clean-up becomes more expensive if a dwelling has a slab foundation and the dwelling breaks apart, with debris falling into the ocean, due to the need for crew to be working offshore on boats and on the beach, recovering heavy chunks of concrete.

In one reactive scenario (Reactive-Veg), we assume that there may still be land mauka of the dwelling and the remaining land value is calculated the same as in threshold-based approach, which uses the SLR-CE line to determine land transfer (Figure 16). The public is assumed to bear the cost of the remaining land. The clean-up scenario associated with Reactive-Veg, where dwellings have slab foundations and break apart, is the higher cost option.

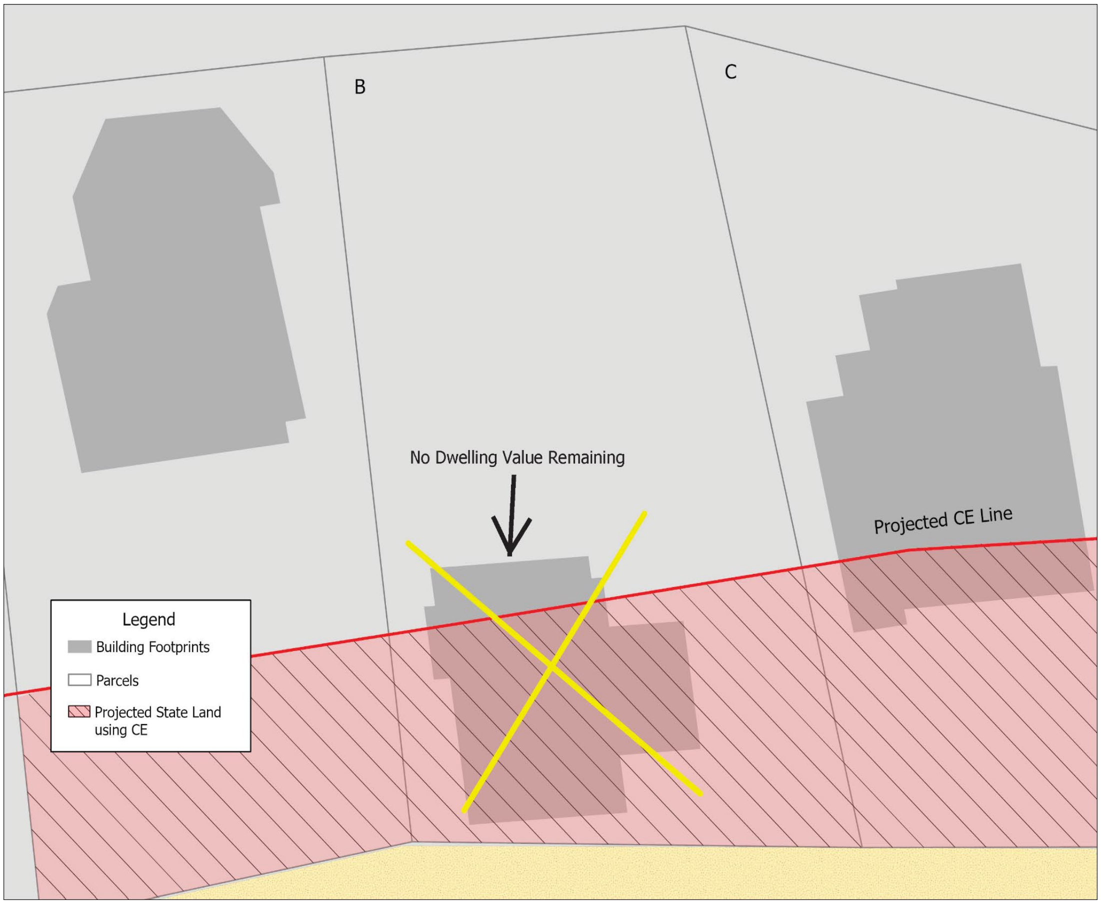

Figure 16. Reactive-Veg scenario for parcels and buildings (demonstration).

In the other reactive scenario (Reactive-Full Loss), we assume no land value remains (Figure 17). This represents an outcome where the land has no development potential because the remaining private land is essentially undevelopable under coastal county regulations. The Reactive-Full Loss scenario incurs the lower clean-up costs, which is that dwellings have post-and-pier foundations and stay intact. The lower clean-up cost option is added to the Reactive-Full Loss scenario to give the lowest potential bound in the range of total costs.

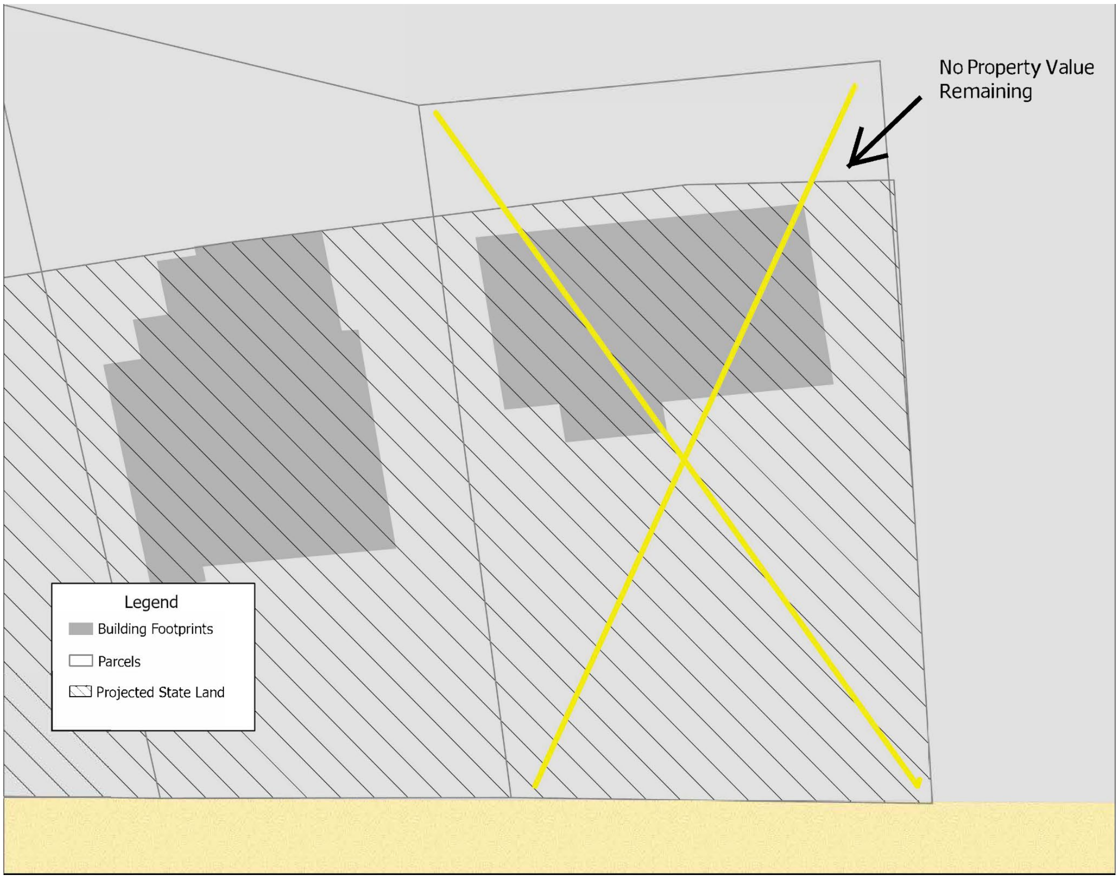

Figure 17. Threshold-based-Full Loss scenario for parcels and buildings (demonstration).

In both reactive scenarios, public infrastructure costs are such that the roads are hardened until the event of a one-time retreat, entailing removal and realignment (Figure 18). This scenario is the same as in threshold-based retreat; however, infrastructure retreat is only triggered once the infrastructure is critically affected (i.e. SLR-CE has reached or gone landward of the infrastructure).

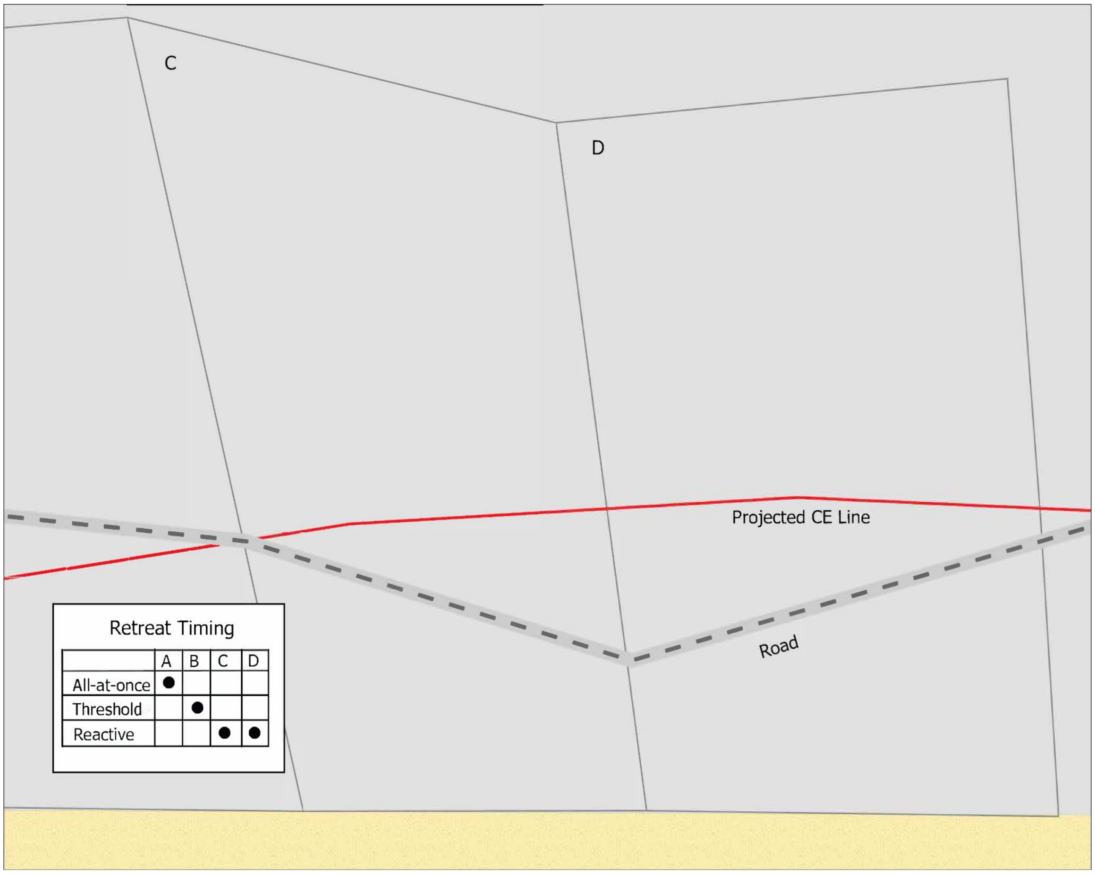

Figure 18. Reactive scenario for roads (demonstration).

We attribute a parcel once within each retreat approach. For example, if a parcel is threshold-based for both 2050 and 2075, the value of the parcel using a threshold-based approach is only counted for 2050, not for 2075. The same method applies for reactive retreat. As such, all parcels within our study area that are reactive by 2100 have been categorized once each as all-at-once, threshold-based, and reactive.[29] Due to building footprint and parcel being spatially analyzed separately, for the parcels that have multiple dwellings, the timing of when a parcel is categorized as threshold-based or reactive is determined by the most makai building footprint.[30] Figures 19 and 20 visually demonstrate our methodology to apply all-at-once, threshold-based, and reactive categorizations of retreat to individual dwellings/parcels and infrastructure (roads), respectively, using SLR-CE. A review of the retreat scenarios and criteria used in the case study is presented in Table 1. Table 2 breaks down costs per unit for the relocation, demolition, decomissioning, condemnation, and retrofitting of various infrastructure.

[29] When conducting the analysis, some properties reverted back from reactive to threshold-based, or threshold-based to all-at-once as SLR scenarios progressed, likely due to uncertainties within SLR-CE projections. For consistency, we decided these properties cannot revert back once they have progressed to threshold-based or reactive.

[30] Due to the degrees of specificity available in existing building footprint, parcel, and assessor's datasets, we were only able to go up to Tax Map Key (TMK) 8, which does not differentiate between Condominium Property Regime (CPR) parcels. CPR units have the same TMK8 but are differentiated for tax purposes at TMK12.

Figure 19. Methodology for retreat timing for dwellings/parcels (left) and roads (right) using SLR-CE (demonstration).

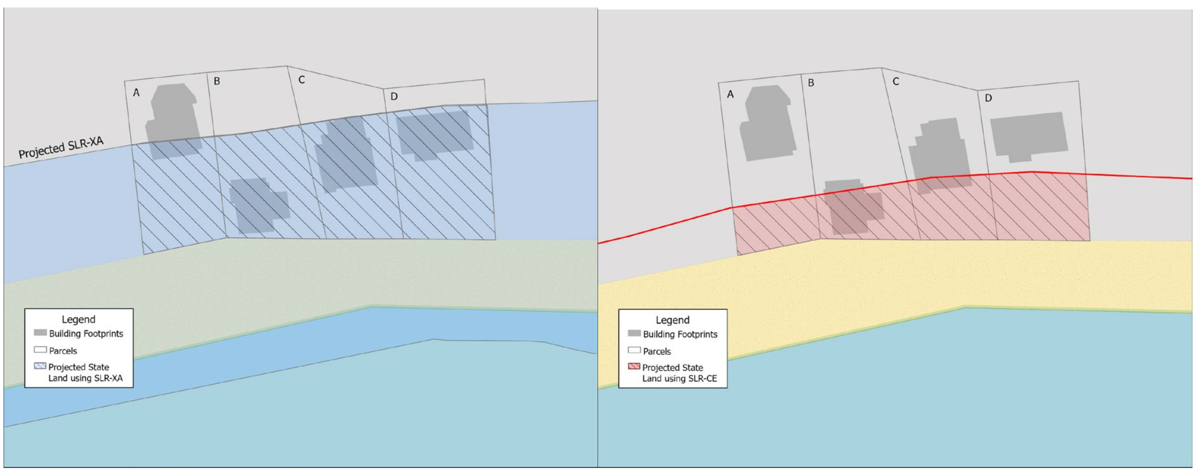

Figure 20. Methodology for public/private land transfer under two scenarios: land transfer by SLR-XA or SLR-CE.

Table 1. Summary of scenarios.

<table>
<tr><th>Approach</th><th>Scenario</th><th>Dwelling Retreat Criteria</th><th>Land Transfer Criteria</th><th>Infrastructure Retreat Criteria</th></tr>
<tr><td rowspan="2">All-at-once</td><td>All-at-once-XA</td><td>3.2 ft (1 m) SLR-XA</td><td rowspan="2">Full value</td><td rowspan="2">3.2 ft (1 m) SLR-CE</td></tr>
<tr><td>All-at-once-CE</td><td>3.2 ft (1 m) SLR-CE</td></tr>
<tr><td rowspan="2">Threshold-based</td><td>Threshold-based-Veg</td><td rowspan="2">≤20 ft (6 m) from SLR-CE</td><td>SLR-CE</td><td rowspan="2">Harden ≤ 20 ft (6 m) SLR-CE, retreat all at 2100 using 3.2 ft (1 m) SLR-CE</td></tr>
<tr><td>Threshold-based-Wave</td><td>SLR-XA</td></tr>
<tr><td rowspan="2">Reactive</td><td>Reactive-Veg</td><td rowspan="2">Intersecting or makai of SLR-CE</td><td>SLR-CE</td><td rowspan="2">Harden road intersecting or makai of SLR-CE, retreat all at 2100 using 3.2 ft (1 m) SLR-CE</td></tr>
<tr><td>Reactive-Full Loss</td><td>No value left</td></tr>
</table>

Table 2. Per unit costs of retreat.

Cost Types	Cost/Unit	Scenarios	Source
Bridge retreat	$40,000,000 per mile ($94,000 per ft)	All	Estimated based on existing Department of Transportation bridge replacement projects (Department of Transportation Highways, 2019, 2021). The total estimated cost is divided by the length of the bridge.
Bridge retrofitting	$20,000 per ft	All	Estimated based on existing bridge rehabilitation projects (such as Koukouai bridge) found in County of Maui (2020). The total estimated cost is divided by the length of the bridge.
Road realignment	$70,000 per ft	All	Francis et al. (2019)
Single-lane road removal	$10 per ft	All	Hometown Demolition (2022) estimates $1-$3 per sq ft for asphalt removal. National Association of City Transportation Officials (2013) estimates the average width of a lane is 10 ft (3 m). Thus, a conservative estimate for single-lane road removal is $10 per ft.
Eminent domain of mauka properties for highway retreat	$386 per ft	All	For properties just mauka of the SLR-CE projection, the total parcel cost was divided by the total area (sq ft) and multiplied by 20 ft, per the National Association of City Transportation Officials (2013) estimate for the average length of a two-laned highway. We assume only the width of the highway is subject to eminent domain.
New shoreline hardening	$10,000 per ft	All	Francis et al. (2019)

Decommissioning/ replacement of potable water mains	$1,443 per ft	All	Estimated based on Teague (2017), which reported the annual cost to replace 1% of the 2,100 miles of water pipes on O‘ahu is ~$160 million. Conversion to cost per foot resulted in the estimate. Personal correspondence with a Board of Water Supply official confirmed this estimate.
Demolition of dwellings	$8,000 per average-sized home (~1,500 sq ft)	All-at-once; Threshold-based	Estimated based on average values obtained from quote requests from local residential demolition companies.
Decommissioning of OSDS	$2,000 per cesspool[31]	All-at-once; Threshold-based	Babcock et al. (2019)
Structural debris clean-up[32]	Post and pier, dwelling stays intact: $10,000 to 25,000 per average-sized home (~1,500 sq ft) Slab foundation, dwelling breaks apart and falls into ocean: $100,000 to 200,000 per average-sized home (~1,500 sq ft)	Reactive	Estimated based on average values obtained from quote requests from local engineering and construction companies.

[31] Since a majority of properties in the area use cesspools, we apply the cesspool closure cost for all OSDS (State of Hawai‘i Department of Health, 2017).
[32] In the reactive approach, we presume that a dwelling is no longer supported due to erosion and incurs high public safety risks, as the dwelling may collapse, slide, or fall. The foundation type of a dwelling and the condition of the foundation have the greatest impact on clean-up costs, according to conversations with local construction and demolition companies. In order to address uncertainties concerning levels of damage from reactive retreat, we applied a wide range of clean-up costs for two scenarios. These costs are assumed to include all structures on a parcel, including OSDS closures.

Remaining Retreat Costs

Other costs of retreat for the cast study area include tax revenue loss and private property value loss. Tax revenue loss is calculated under the assumption that taxes would decrease proportionally to the value of a parcel after applying our land transfer and retreat timing methodologies. Using 2022 tax rates for O‘ahu,[33] we calculate future potential taxes based on Residential and Residential A tax rates. Private property value loss is calculated by summing the differences between the 2021 assessed values and values remaining (land and dwelling, calculated separately) for each retreat approach. The total value under each scenario represents the discounted present value in $2021. Table 3 summarizes how costs are borne, either public or private.

Table 3. Types of costs incurred in each retreat approach, categorized by bearers of cost. No shading means there is no cost in that specific retreat approach.

Types of Costs	All-at-once	Threshold-based	Reactive
Property Acquisition	Public	Public	Private / Public
Demolition* & Clean-up	Public	Public	Private
Infrastructure Retreat	Public	Public	Public
Tax Revenue Lost	Public	Public	Public
Private Property Value Lost		Private	Private

(blue)	Public
(red)	Private

*includes OSDS removal

Findings

The total number of parcels retreated if using the SLR-XA boundary (All-at-once-XA) is 83. Using the SLR-CE line, there are 52 parcels that are retreated and categorized as all-at-once, threshold-based, or reactive by 2100. To disaggregate these numbers over time, the highest number of parcels are considered newly threshold-based (17) by 2030, with the number of parcels considered newly reactive (18) peaking by 2075. As time progresses, the number of parcels that become newly threshold-based decreases. The number of parcels retreated under a reactive scenario varies more; the number of newly reactive parcels decreases significantly between 2030 and 2050 and then peaks at 2075, with about a quarter (12) of the 52 parcels becoming reactive by 2100. By 2100, all remaining parcels become reactive, with the 3 threshold-based parcels being addressed by, and not at, 2100. This is summarized in Table 4, along with the number of impacted buildings per retreat category and year.

[33] The assessor's data included homeowner exemptions, which were included in future tax revenue calculations. We used tax rates set forth by the CCH, which are 0.35% for Residential, and 0.45% up to $1 million followed by 1.05% for remaining value beyond $1 million for Residential A.

Table 4. Number of parcels and building footprints within each retreat approach by year (timing of projected SLR intervals).

Retreat Approach		Now	By 2030	By 2050	By 2075	By 2100	Total
# of Parcels	All-at-once-XA	83	-	-	-	-	83
	All-at-once-CE	52	-	-	-	-	52
	Threshold-based	8	17	12	12	3	52
	Reactive	-	16	6	18	12	52
# of Buildings	All-at-once-XA	138	-	-	-	-	138
	All-at-once-CE	63	-	-	-	-	63
	Threshold-based	8	20	15	15	5	63
	Reactive	-	17	8	23	15	63

To connect these retreat projections to the costs summarized in Table 2 and Figure 21, in Table 5 we display the range of total costs for each retreat approach (and each scenario therein). Figure 22 disaggregates our findings by types of cost and cost bearers. Table 5 shows the underlying data that populates these figures. Although we show these figures and tables as singular values, each number represents the sum of the discounted present value of cost flows between 2021 and 2100 (all in $2021).

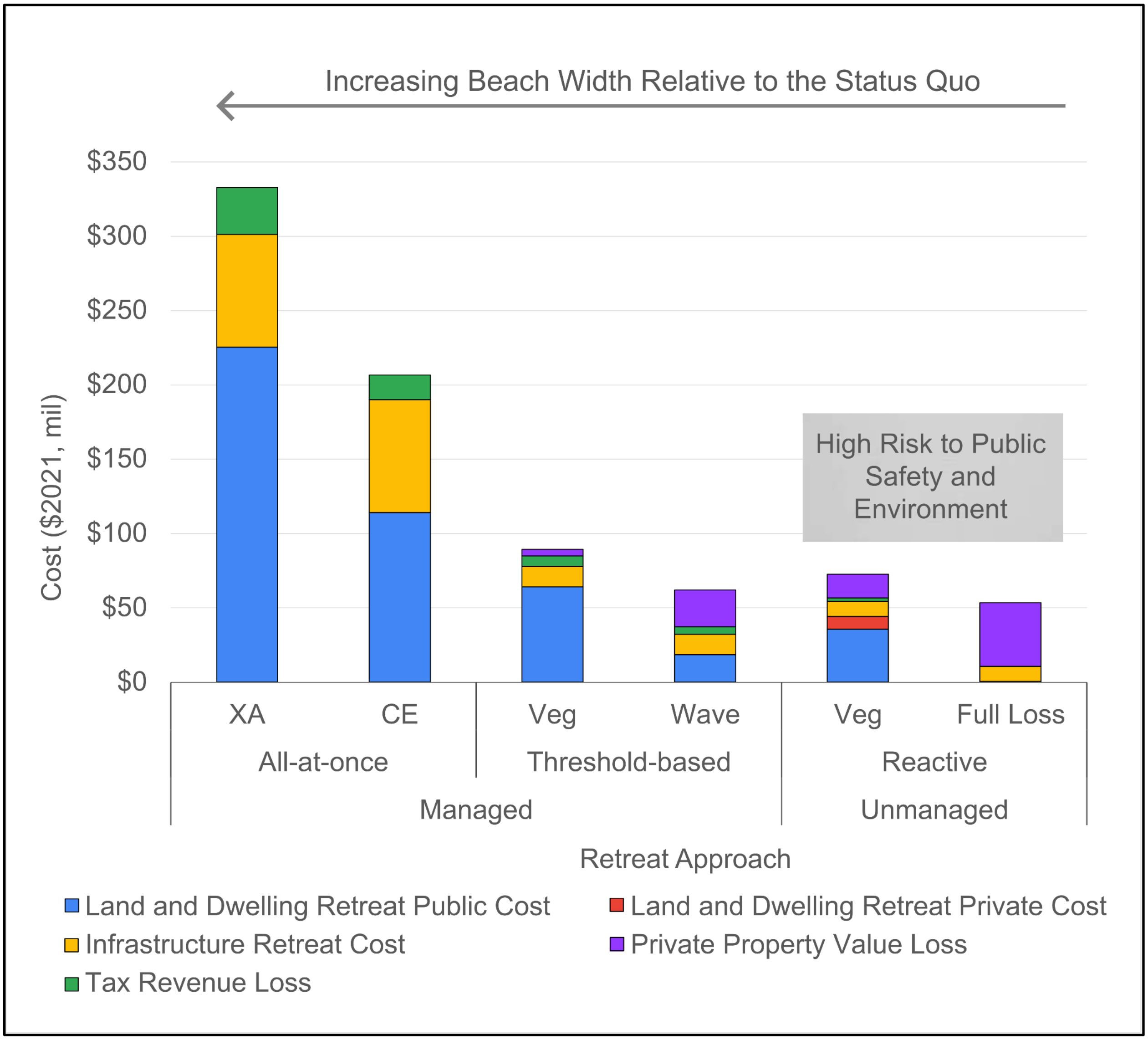

Figure 21. Costs of retreat approaches by type of cost and cost bearers.

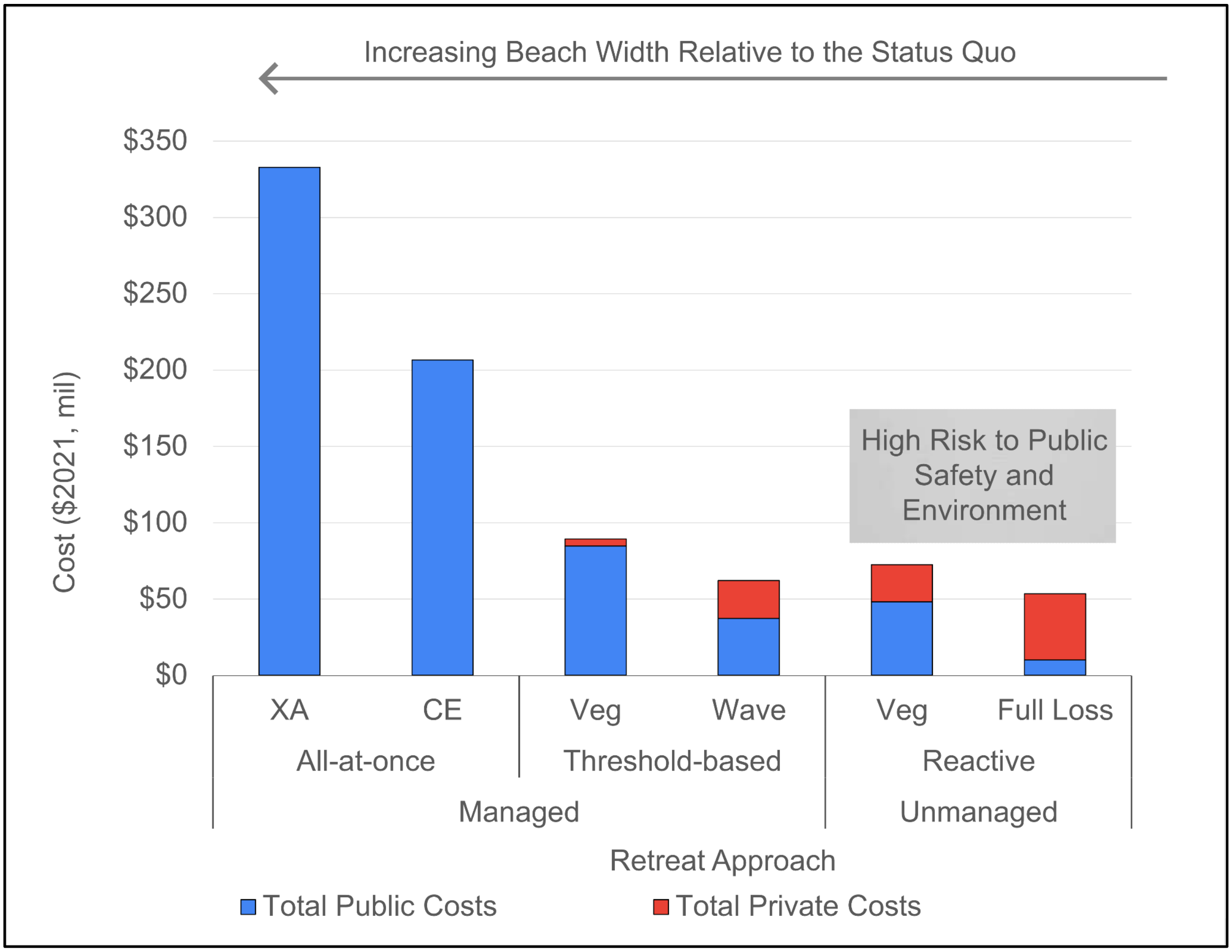

Figure 22. Public and private costs for three retreat approaches. Shades of blue are costs borne to the “public,” and shades of red are “private.”

Table 5. Underlying estimates to Figure 21.[34]

Cost Types ($2021, mil)	Managed				Unmanaged	
	All-at-once		Threshold-based		Reactive	
	XA	CE	Veg	Wave	Veg	Full Loss
Land and Dwelling Retreat Public Cost	$225.3	$114.1	$64.2	$18.5	$35.7	$ -
Land and Dwelling Retreat Private Cost	$ -	$ -	$ -	$ -	$8.5	$0.4
Infrastructure Retreat Cost	$75.9		$13.6		$10.1	
Tax Revenue Loss	$31.6	$16.7	$7.0	$5.2	$2.5	$ -
Private Property Value Loss	$ -	$ -	$4.6	$24.8	$15.8	$42.9
Total Costs and Losses	$332.9	$206.7	$89.4	$62.1	$72.5	$53.4

In addition to presenting total costs, we disaggregate costs for each time period (2021, 2030, 2050, 2075 and 2100) as real dollars expressed using 2021 assessed values (Figure 23).[35] These costs are non-cumulative and represent the range of costs to address the parcels that are newly threshold-based or reactive at each study period.

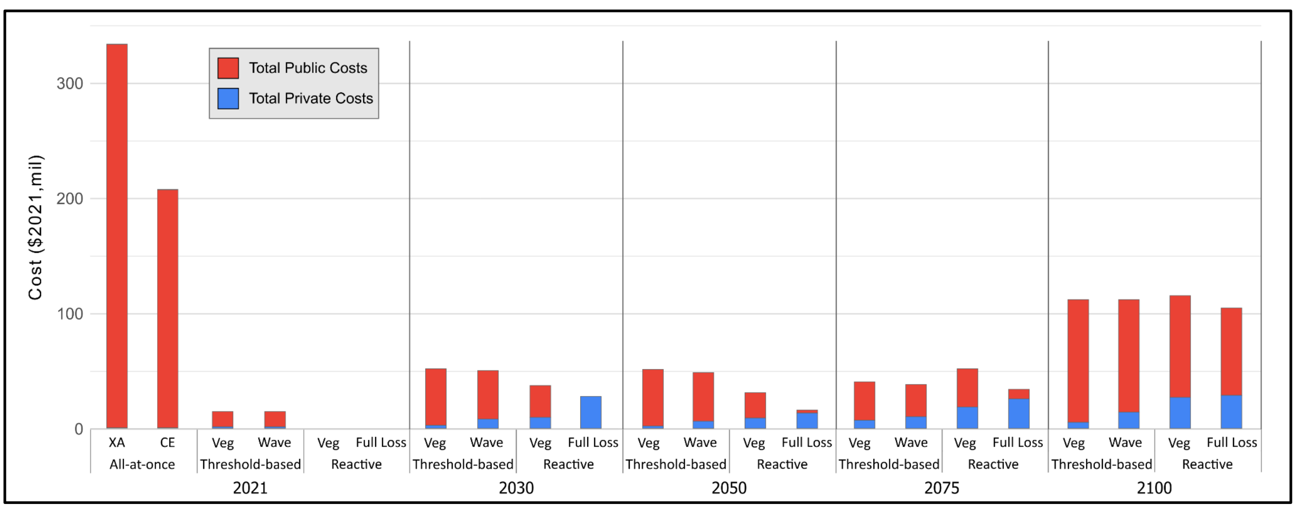

Figure 23. Retreat approach costs disaggregated by timing.

All-at-once

[34] Inflation is not addressed in the cost estimate calculations as housing has increased similarly to other goods in the past three decades in Hawai'i (UHERO, 2022).
[35] Lost property tax revenues is the only on-going cost within the all-at-once scenario and is quite small and thus excluded from the figure.

The highest overall costs and the highest costs to the public occur under the all-at-once scenarios. If the area includes the entire SLR-XA, we estimate that the total cost to acquire property, remove local roads, and realign the affected highway is $332 million ($2021). If only the area expected to be impacted by erosion (i.e. up to SLR-CE) is addressed, it is $207 million ($2021) because fewer parcels and buildings are retreated (a change from 138 buildings to 63). An all-at-once approach also results in the largest relative loss in property tax revenues, up to $32 million in All-at-once-XA.

Since an all-at-once approach occurs before there is any property damage (for most properties, not including the current beachfront homes experiencing extreme erosion currently), full market rate compensation is required to either voluntarily or involuntarily acquire properties. As such, all costs, both acquisition and infrastructure removal/relocation, are found to be accrued to the public.

Threshold-based

In comparison to all-at-once, the threshold-based approach scenarios are substantially lower in cost, ranging from $62-89 million ($2021). In addition, particularly in the scenario where the state enforces its definition of the shoreline as the highest wash of waves annually, there is a mixture of costs that accrue to public and private entities. The costs are lower because there is value accrued from allowing properties that are not yet at high risk to remain in place, assuming that the 20 ft (6 m) threshold is large enough to mitigate public safety concerns. We find that by 2030, 20 buildings fall within the SLR-CE, an additional 15 by 2050, and an additional 20 by 2100.

There are multiple policy tools that could be employed to support a threshold-based approach, including rolling “easements” (defined in our study as a rolling shoreline) coupled with buyout programs and strategic use of eminent domain for public purposes.

Reactive

The rolling shoreline is already established within Hawai‘i’s coastal zone management law and is what sets the framework for our reactive scenario. We find the reactive scenario has the lowest estimated cost ($50-70 million, $2021) and, in particular, the lowest direct cost to the public. However, our estimates do not account for risks to public safety and the introduction of environmental pollutants, both of which could be large public costs and should be factored into decision-making.

Though coastal property owners relatively gain value from owning their assets for a longer duration before reactive retreat, this duration is not considerably longer than in the threshold-based scenario and the reactive scenario accrues considerably more cost to private property owners – up to an estimated $53 million in private property value loss and $9 million in clean-up costs ($2021). This finding is predominantly driven by the assumption that the private owner would take responsibility for clean-up costs, and requires enforcement.[36] For this reason, private property owners experience the highest costs in this scenario.

Benefits of Retreat

While we do not claim that this study represents a comprehensive cost-benefit analysis, we do provide important insights into the benefits of retreat captured in: (1) the amount of beach area preserved under retreat scenarios; and (2) how residents and visitors value Sunset Beach under a travel-cost model.

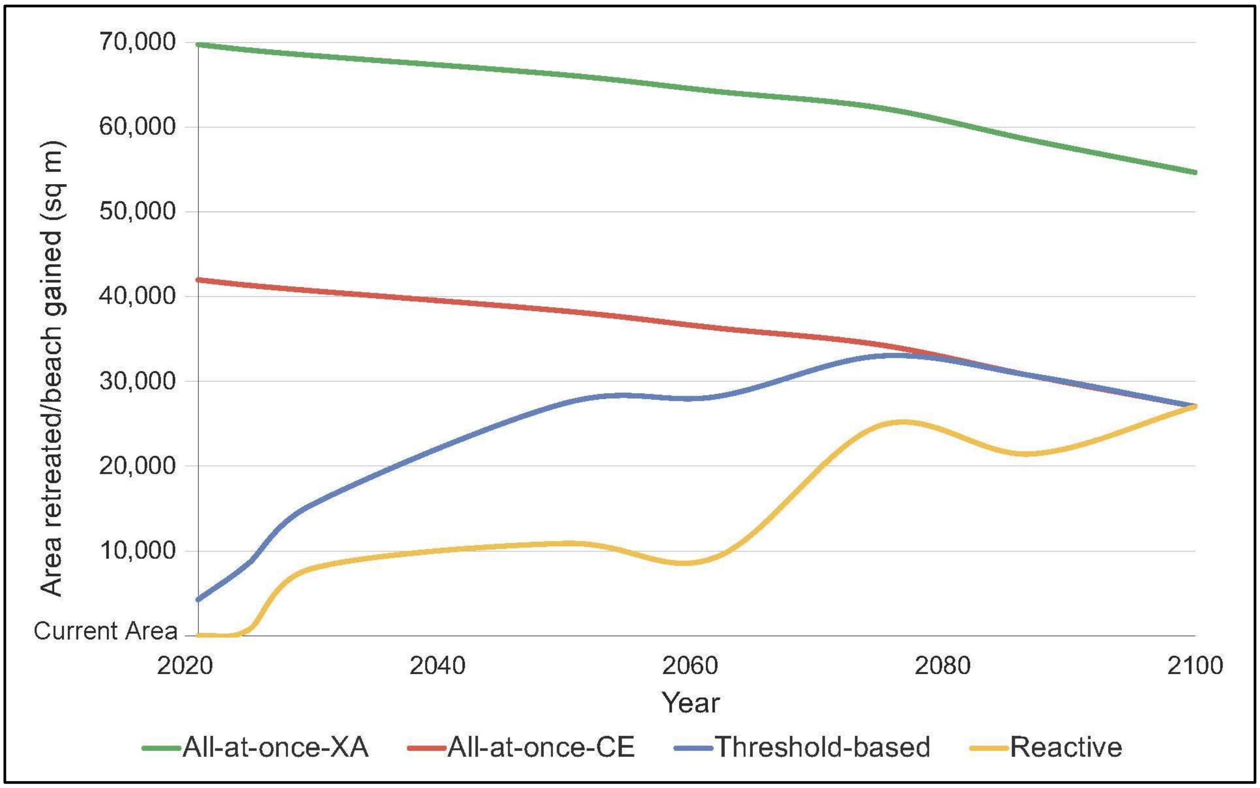

Figure 24. Case study beach area gained by retreat approach. Due to the complex and unknown nature of how retreat affects sand transport mechanics, these projections are calculated under the simplistic assumption that as dwellings retreat, the land area of the parcel is returned to the beach, as a majority of the retreated properties are constructed on a sand dune.

We tabulate how each retreat approach may affect beach area in the study area using the assumption that as parcels retreat, the land returns to the beach. To generate each curve in

[36] In early 2023, a private yacht ran aground in Honolua Bay, a Marine Life Conservation District, on Maui (Department of Land and Natural Resources, 2023). The State has said they will "aggressively pursue" repayment of the yacht removal, $460,000, and reef restoration costs from the yacht owner (Riker, 2023). The outcome of this case may give insight into the DLNR's willingness and ability to enforce private property owners to be responsible for ocean debris clean-up.

Figure 24, we summed the area of retreated parcels at each time period for each scenario with different physical footprints, net of SLR-CE. These results do not imply beach area will be evenly distributed along the coastline nor will the beach actually “converge” in 2100 under the All-at-once-CE, Threshold-based and Reactive scenarios, because SLR will continue past 2100.

We find that the All-at-once-XA provides the most beach area gained, followed by All-at-once-CE, because the area is retreated at one time. Though the threshold and reactive scenarios are more piecemeal, they do result in additional beach area gained in comparison to today. The Reactive scenario would result in limited beach access at points in time and along the case study area. The Threshold-based scenario does not have any point in time when there is no lateral beach access and results in the lowest cost per beach area gained.

While none of our scenarios consider the full loss of the beach, we nonetheless felt it was important to give a broad sense of the value of the beach in sum. To do so, we apply a travel cost model using lifeguard count data and applying visitor information from a similar beach survey. This is a methodology that estimates the economic value of environmental goods by calculating the costs incurred by each individual in traveling to the site, grouped by locality (NOAA, 2022b). Specifically, we find that the net present value of the beach from 2021 to 2100, the same time period as our other estimates, is approximately $2 billion, amounting to $60 million annually ($2021). [37] In the literature, there is a wide range for annual beach value due to the place-specific nature of these valuations, which span from US$144,000 in Crikvenica, Croatia to US$0.8 billion in Qingdao, China (Ariza et al., 2012; Blackwell, 2007; Liu et al., 2010; Liu et al., 2019; Logar & van den Bergh, 2014; Pendleton & Kildow, 2006; Rodella et al., 2020). We would expect Sunset Beach to be valued on the higher end of this spectrum due to its location in a popular tourist destination. On one hand, this rather simplified and single-site modeling approach may overestimate the value by not considering visitors possibly switching to alternative beaches. On the other hand, the travel cost approach may underestimate a beach’s benefits by not capturing the visitors’ whole willingness to pay to visit the beach, which could include non-recreational benefits (e.g., the value of ecosystem services) and other intrinsic values such as option value and bequest value (National Research Council, 2005). More research is needed across Hawaiʻi on the value of beach resources to better inform tradeoffs as it relates to management decisions, particularly adapt-in-place.

[37] We used lifeguard count data (corrected in line with Harada et al., 2011) to estimate annual visitor count to Sunset Beach, a proxy locality dataset from a nearby beach study (Szuster et al., 2020), current market values for travel cost prices, census-reported median hourly income for salary values, and Hawaiʻi Tourism Authority’s Symphony Data Dashboard to estimate mean visitor length of stay. We adjust the annual lifeguard count data for Sunset beach based on the difference in lifeguard count data and actual entries for Hanauma Bay. We use the proportion of visitors and their destinations from Szuster et al. (2020) for Kailua Beach, and assume that Sunset receives the same distribution of visitor types. We estimate travel cost for Oʻahu visitors based on gasoline and time costs, and for others that fly in, we take standard airline and hotel costs, but only attribute one day of the average trip duration to visit Sunset beach. For consistency with our analysis, we use a 3% discount rate of future values. Variation of +/- 2% in the chosen discount rate could lead to a difference of $1 to $1.5 billion in net present value. There are strong arguments as to why discount rates for ecological goods should be substantially lower than other assets, which would push the overall number higher.

Additional Considerations for Retreat in the Case Study Area

Our findings are sensitive to a number of factors – notably the variation in demolition and clean-up costs, the enforcement of the definition of the shoreline, and the future value of dwellings in our study area. Here we provide a few additional considerations relating to these issues.

In terms of demolition and clean-up costs, an important factor that is unexplored in our cost estimates is the level to which there would need to be (or should be) environmental remediation for pollutants such as asbestos and lead. As a proxy indicator, we note that 26 buildings (9%) in our study area were built prior to 1970 and thus likely contain asbestos (U.S. Consumer Product Safety Commission, 2022), and 44 buildings (15%) were built prior to 1978 and thus likely contain lead in the paint (US EPA, 2013). In addition, the demolition costs assumed in Table 2 may either be an underestimate or overestimate depending on the size of the house and number of additional structures on a parcel, such as a detached garage or shed. In addition, when demolition of properties occurs, if environmental remediation is found to be required, costs can increase drastically.

In terms of the definition of the shoreline, this legal definition has been in effect since the establishment of Hawai‘i's CZMA Act in 1975 (though case law has updated the interpretation of the shoreline, particularly as it relates to the interaction with hardened structures). Thus, homes that were last transacted pre-1975 may have claim (though, of course, this is a legal question) to be grandfathered into prior shoreline regulations in terms of how the shoreline moves makai. However, the public trust doctrine and public and private nuisance law have been in place for centuries. Note that, under the *Penn Central* takings test, courts are less likely to find that government regulation of coastal development interferes with the landowner's investment-backed expectations if the relevant rules and regulations were in place prior to or early on in the development process (Codiga et al., 2011).

The assessor's dataset does not, however, go as far back as 1975. Nonetheless, displaying transactions pre-1989 (when the dataset starts) is still illustrative. Of the 61 beachfront parcels, there was data for 59 of them, and the earliest purchase recorded was 1989 (Figure 25). Thus, the vast majority of beachfront properties were purchased since the establishment of the CZMA and the rolling shoreline law. Moreover, 80% of beachfront parcels have transacted since 2006, with the most occurring recently between 2018 and 2022.

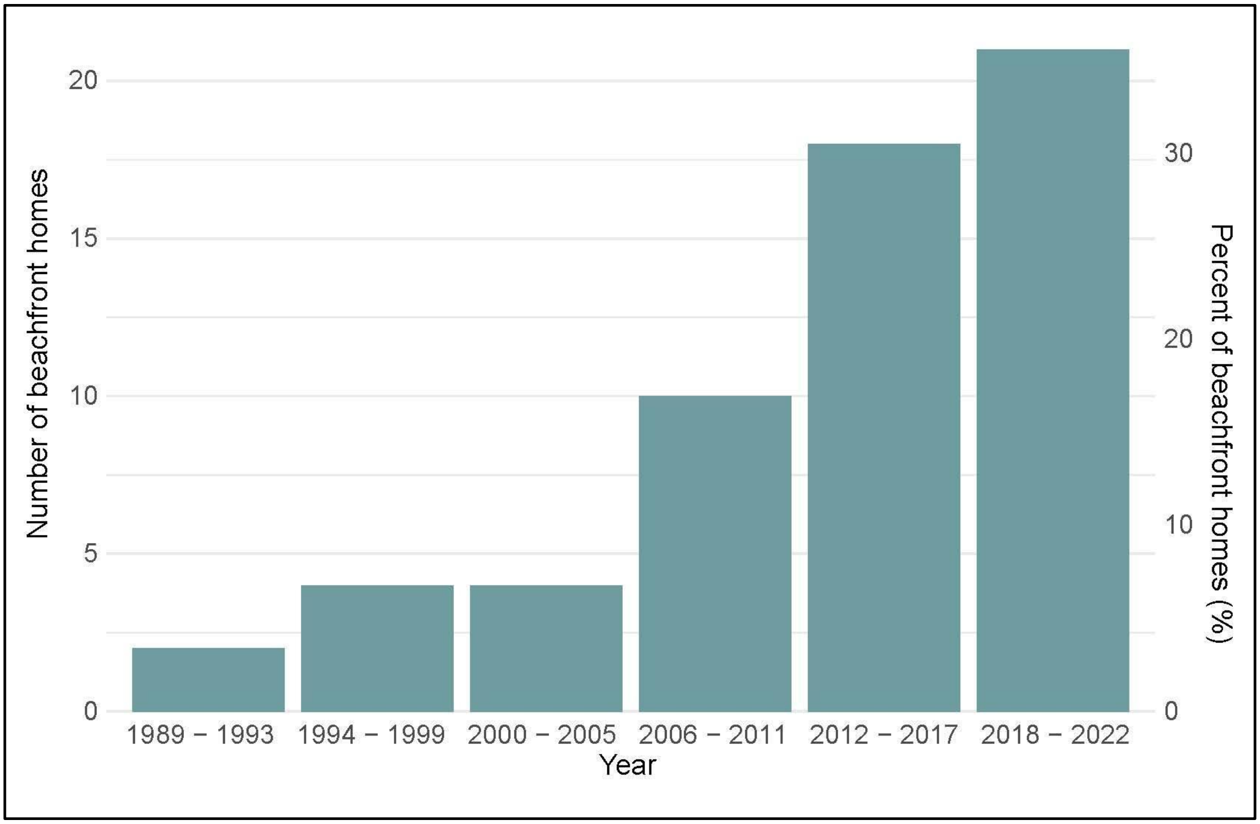

Figure 25. Most recent transaction year for each beachfront home in case study area.

While it is outside the scope of this analysis to assess how home values are changing as a result of SLR (see Tarui et al., forthcoming), we acknowledge the limitation of relying on the assessor's data. First, the assessor's data reflect a one-year lag in market conditions and may not fully capture attributes of a specific property. In addition, value can be accrued not just from the stock value of the house, but also in rental flows. In particular, we find that a high proportion of properties in our study area have been listed as short-term rentals. Using data from the Hawaii Tourism Authority (2022), which tracks listings across Airbnb, Booking.com, HomeAway, and TripAdvisor, we find 158 unique listing locations from 2018 to 2022 in our study area, which is 81% of the parcels and 61% of the building footprints. When looking at these listings spatially, they appear to be evenly spread over the study area (i.e. there are no obvious clusters). Of these listings, 90% are listed as entire homes. This income could serve as a substantial private motivation to delay retreat, even if property loss occurs from land transfer or private adaptation efforts. Recent changes to the CCH's short-term rental policies, however, have likely affected rental income expectations (Yerton, 2022).

V. O‘ahu Property Value, Property Tax, and Population Estimates in SLR-XA

Though it is outside the scope of our analysis to estimate costs for SLR response options for all of O‘ahu (this is an area for future inquiry), here we provide summary estimates for property values and property tax values within SLR-XA using our assessor's dataset. At a high level, this can be taken as a proxy for the cost of voluntary buyouts within the entire SLR-XA (though differing from our case study, these estimates are missing key costs of demolition and clean-up costs). In addition, we provide an overall estimate of the population within SLR-XA using census data.

To assess the property value within SLR-XA, we use the 2020 assessor's data, as the dataset for 2021 was incomplete island-wide at the time of request.[38] Similar to our case study, the data set contains property values, totaled and separated by land and dwellings, and the value of property tax for each parcel. We use the simplistic approximation that the value of a parcel is linearly affected by its exposure to SLR-XA. For example, if a parcel is 30% exposed to SLR-XA, we assume that the parcel's total assessed and net taxable values (building and land value together) within SLR-XA are also decreased by 30%. In reality these relationships are likely non-linear, meaning our assumption is likely to under-represent affected property values at higher levels of SLR. Table 6 summarizes our findings for the net taxable value of land in SLR-XA, as well as property tax revenues. Table 7 shows the same data given in Table 6 but broken down by property type (as classified by property tax type). Figure 26 displays the distribution of value within 3.2 ft (1 m) SLR-XA at 2100 by property type.

Table 6. Total net taxable property value and property tax revenue within SLR-XA for O‘ahu.

	SLR-XA 0.5 ft	SLR-XA 1.1 ft	SLR-XA 2.0 ft	SLR-XA 3.2 ft
Total Net Taxable Property Value Within SLR-XA ($2020, mil)	$2,110.3	$2,655.8	$4,191.9	$9,149.0
% of Total Net Taxable Property Value Within SLR-XA	0.8%	1.0%	1.6%	3.4%
Total Tax Revenue within SLR-XA ($2020, mil)	$18.3	$22.7	$37.1	$83.7
% of Tax Revenue within SLR-XA	1.1%	1.4%	2.2%	5.1%

[38] Some TMKs available on the assessor's online directory were not found in the assessor's data set. We found, and confirmed with the assessor's office, that this could mostly be explained by the exclusion of non-taxable properties from the data set. Yet, some TMKs were taxable, private properties, likely missing from the data set a result of data compilation or processing errors.

Table 7. Total taxable value within SLR-XA by property types for O‘ahu, Hawai‘i. Does not include value of non-taxable properties, such as government-owned lands or fully exempt properties.

Property Type	Total Net Taxable Value ($2020, mil)	SLR-XA 0.5 ft		SLR-XA 1.1 ft		SLR-XA 2.0 ft		SLR-XA 3.2 ft	
		$2020 Taxable Value within SLR-XA ($2020, mil)	%	$2020 Taxable Value within SLR-XA ($2020, mil)	%	$2020 Taxable Value within SLR-XA ($2020, mil)	%	$2020 Taxable Value within SLR-XA ($2020, mil)	%
Agricultural	$1,405.2	$5.1	0.4%	$6.2	0.4%	$10.0	0.7%	$24.2	1.7%
Commercial	$29,479.3	$56.9	0.2%	$101.6	0.3%	$319.8	1.1%	$828.9	2.8%
Hotel and Resort	$22,616.7	$571.9	2.5%	$652.6	2.9%	$1,053.4	4.7%	$2,831.3	12.5%
Industrial	$15,881.1	$31.0	0.2%	$53.5	0.3%	$177.1	1.1%	$503.1	3.2%
Preservation	$660.5	$12.9	1.9%	$15.7	2.4%	$19.3	2.9%	$28.5	4.3%
Public Service	$0.3	-	-	-	-	-	-	-	-
Residential	$172,143.5	$749.2	0.4%	$945.0	0.5%	$1,385.8	0.8%	$2,999.5	1.7%
Residential A	$23,883.6	$683.3	2.9%	$881.2	3.7%	$1,226.4	5.1%	$1,933.5	8.1%
Total	$266,070.2	$2,110.3	0.8%	$2,655.8	1.0%	$4,191.9	1.6%	$9,149.0	3.4%

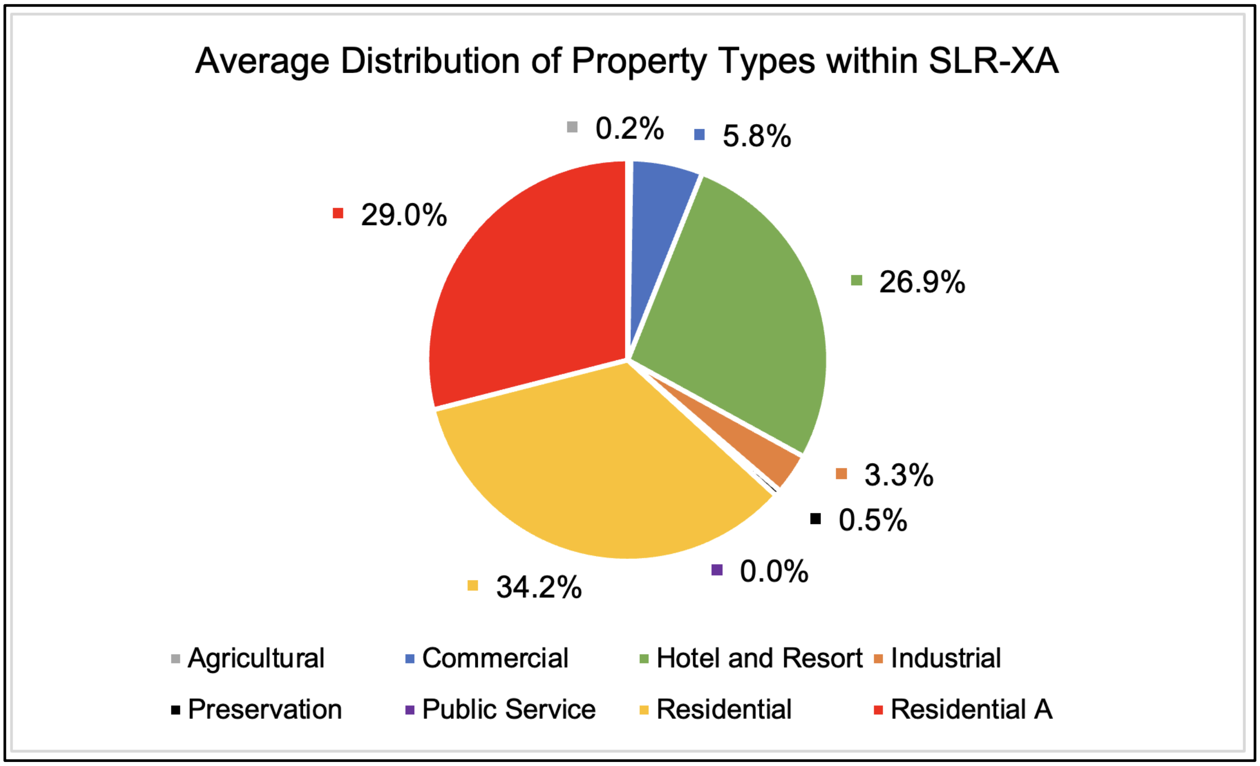

Figure 26. Property type of total exposed assessed (2020) value within 3.2 ft (1 m) SLR-XA.

We find a total of $31 billion in land and parcel value are within or intersect with SLR-XA. Taking the linear percentage of SLR-XA area to property value, a total of $9 billion (3.4%) of O‘ahu's net taxable property value lies within the 3.2 ft (1 m) SLR-XA. This accounts for 5% of CCH property tax revenues. We also find that exposure to SLR-XA increases greatly from 2.0 ft (0.6 m) to 3.2 ft (1 m) of projected SLR.

The property types with the highest total assessed value in the SLR-XA are hotels and resorts. For example, 12.5% of Hotel and Resort value is within the 3.2 ft (1 m) SLR-XA. The next property type most affected is "Residential A," which are residential units that are taxed as investor-owned and therefore at a higher rate.[39]

[39] CCH property tax rates were also used to calculate tax revenues (Department of Business, Economic Development & Tourism, 2019). Percent changes of tax revenue are directly proportional to total assessed and net taxable property values within SLR-XA for all property classifications, except for Residential A, which has a tiered property tax structure for properties greater than $1 million. To confirm our calculations, we compared the values presented in Tables 6-9 to the CCH Real Property Tax Valuation for Fiscal Year (FY) 2021-2022 (Department of Budget and Fiscal Services, 2021). For O‘ahu, the total assessed property value is $279 billion, the total net taxable value is $240 billion, and total tax revenue is $1.4 billion (Department of Budget and Fiscal Services, 2021). Using the 2020 assessor's dataset, our estimate for total assessed value is $303.5 billion, $266 billion for total net taxable value, and $1.7 billion for total tax revenue (Tables 7-9). Our numbers are slightly larger than reported, with the discrepancies possibly arising anywhere from data entry to quality to processing.

We are careful in this analysis not to say that the estimated values are necessarily a "loss" because it is yet unclear whether properties will adapt-in-place or retreat island-wide. Moreover, in terms of net property tax values and revenues, it is likely that there is a shifting landscape of value inland (Keenan et al., 2018). As such, being within SLR-XA does not inherently mean that island-wide property values or property values will decline in net, although there is literature that suggests some areas vulnerable to SLR are decreasing in value (Bernstein et al., 2019; Tyndall, 2021).

In addition, the tabulated values only represent direct land values and not the full range of economic impacts. For example, although industrial property is projected to have $554 million of total assessed property value exposed within 3.2 ft (1 m) SLR-XA, the specific industrial infrastructure at risk may be of critical nature and thus have larger economic implications.

We estimate there is a residential population of 28,000 residents within SLR-XA on O'ahu, equating to 2.7% of O'ahu's 2020 population (Decennial Census, 2020).[40] This number was calculated by multiplying the population at the census block level by percent coverage of SLR-XA under the assumption of uniform population distribution.[41]

[40] This is substantially different from what was found in the 2017 Climate Change Mitigation and Adaptation Commission report, likely due to different methodologies.
[41] The population within SLR-XA was calculated for other counties as well, with approximately 2,100, 3,900, and 500 residents affected in the Counties of Kaua'i, Maui, and Hawai'i, respectively. This numbers are likely an underestimation for rural areas because their census blocks are typically much larger than the built area.

VI. Conclusion

Sea level in Hawaiʻi is expected to rise 0.8 ft (0.24 m) by 2050, endangering coastal communities and ecosystems across the islands (NOAA, 2022a). General responses to SLR include protect, accommodate, and retreat. Beaches in Hawaiʻi are protected for public use and statutes require that the State maintains beach access and beaches themselves, meaning that retreat is the only long-term option for many coastlines with sandy beaches.

In this report, we make several contributions to existing SLR adaptation literature. First and predominantly is through our case study of the shoreline community of the Paumalū ahupuaʻa, extending from Rocky Point to Sunset Point on the North Shore of Oʻahu. We compare key costs of approaches to retreat from the shoreline, categorized as all-at-once, threshold-based, and reactive retreat, informed by Oʻahu's existing shoreline regulations. Second, as a preliminary result for future work and inquiry, we provide island-wide estimates for population, property values, and property tax revenues that are within SLR-XA.

Key findings include:

- Retreat is the current regulatory status quo for sandy beach areas in Hawaiʻi given the rolling shoreline and banning of erosion control structures. Since there are no implemented efforts to coordinate retreat or the movement away from the shoreline, the current regulations can be considered a form of reactive (unmanaged) retreat.
- All-at-once retreat poses the largest public cost by far, ranging from $207 to $332 million in public costs ($2021) in the case study area. It also likely introduces incentive to other Hawaiʻi coastal investors to not fully incorporate future risk in their decision-making, which would pose additional costs for adaptation across the island and state.
- Private landowners are financially best off under an all-at-once retreat, assumed to be through a buyout program. However, this does not account for any delays in program development or payouts, nor does it account for place attachment that might prompt a homeowner to delay retreat despite financial reasoning.
- Threshold-based retreat is substantially lower in cost than all-at-once, ranging from $62-89 million in total costs ($2021). Threshold-based retreat is the second-best option for private actors (ranging from $5- $25 million in private property loss, $2021), which could be prompted through either voluntary buyouts or eminent domain.
- Reactive retreat has the lowest estimated total cost, ranging from $50-70 million ($2021). It has the lowest measured public costs (ranging from $10-$46 million, $2021), and the highest private costs (ranging from $24-$43 million, $2021), based on private land loss and the cost of structure clean-up. Other public costs that are incurred in the reactive scenario include risks to public safety and environmental contamination and this should be factored into decision-making.
- All-at-once retreat preserves the most amount of beach area over time, and threshold-based retreat preserves the most amount of beach at lowest cost. Reactive retreat also

preserves beach area over time, but will result in limited beach access along the case study area at points in time.

- Our estimates for the cost of retreat are dependent on the enforcement of the state's shoreline regulations. This includes enforcement of the definition of the shoreline to the highest wash of the waves as well as clean-up costs.
- The conservation of beaches should be a priority, not only because they are constitutionally protected, but also because they are immensely valuable to beach goers. Using the same timeline (2021-2100) and a discount rate of 3%, Sunset Beach has an estimated net present value of $2 billion based on a basic travel cost model, which is many times greater than the cost of retreat approaches.
- In terms of island-wide considerations, we find approximately 28,000 O'ahu residents currently reside in the SLR-XA. In total value, the largest types of property that are within SLR-XA are Hotel & Resort, Residential, and Residential A (i.e. investor-owned). Residential A has the highest relative share of taxes within SLR-XA, given its tiered tax rate as well as the tendency for coastal properties to be investor-owned.

Though the reactive approach has the lowest measured costs, it also maintains the least beach area as well as presents potentially high risks to public safety and environmental contamination. As such, given that the threshold-based approach has comparable costs, largely mitigates public safety concerns and is similar to all-at-once in terms of environmental contamination concerns, the threshold-based approach merits further inquiry as an enormous improvement towards a more proactive approach to retreat than today's status quo. The all-at-once approach is appealing from the perspective of beach area gained, and more research is needed to understand dune restoration dynamics as well as human and ecological values for beach width. Given the magnitude of adaptation needs, public investments in adaptation should also be made in the context of broader public finance implications. More research on remediation and restoration processes is important to building a more complete understanding of the benefits of retreat interventions.

This report is intended to aid stakeholders and decision-makers in better understanding the costs and tradeoffs of SLR response, specifically in our case study area and for other Hawai'i communities adjacent to sandy beaches. We recognize there are important limitations of our analysis, including the use of assessor's data (which may not be fully representative of future land and structure values as SLR impacts worsen), underestimated infrastructure costs (given we consider only the study area), and not accounting for potential safety risks or fully incorporating environmental damages related to pollution remediation. Future iterations of our methodology aim to include different development typologies (e.g. urban areas with sandy beaches, urban areas with waterfront, areas with sewer infrastructure), other SLR-induced coastal hazards (e.g. groundwater intrusion), and additional SLR responses.

References

Adaptation Clearinghouse. (2023). *Managing the Retreat from Rising Seas—Long Beach, California: Los Cerritos Wetlands Restoration and Land Swap*. Georgetown Climate Center. https://www.adaptationclearinghouse.org/resources/managing-the-retreat-from-rising-seas-eo-long-beach-california-los-cerritos-wetlands-restoration-and-land-swap.html

American Community Survey. (2022). *B25010: Average Household Size Of Occupied Housing Units By Tenure.* https://data.census.gov/table?q=B25010:+AVERAGE+HOUSEHOLD+SIZE+OF+OCCUPIED+HOUSING+UNITS+BY+TENURE+hawaii&tid=ACSDT5Y2020.B25010

Anderson, T. R., Fletcher, C. H., Barbee, M. M., Frazer, L. N., & Romine, B. M. (2015). Doubling of coastal erosion under rising sea level by mid-century in Hawaii. *Natural Hazards*, *78*(1), 75–103. https://doi.org/10.1007/s11069-015-1698-6

Ariza, E., Jiménez, J. A., & Sardá, R. (2012). An Interdisciplinary Analysis of Beach Management in the Catalan Coast (North-Western Mediterranean). *Coastal Management*, *40*(4), 442–459. https://doi.org/10.1080/08920753.2012.692308

Atreya, A., Ferreira, S., & Kriesel, W. (2013). Forgetting the Flood? An Analysis of the Flood Risk Discount over Time. *Land Economics*, *89*(4), 577–596. https://doi.org/10.3368/le.89.4.577

Babcock, R., Barnes, M. D., Fung, A., Goodell, W., & Oleson, K. L. L. (2019). *Investigation of Cesspool Upgrade Alternatives in Upcountry Maui Final Report*. Hawaii Department of Health. https://health.hawaii.gov/sdwb/files/2020/04/CesspoolUpgradeAlternativesUpcountryMaui.20191018_FinalReport.pdf

Bakkensen, L. A., & Barrage, L. (2022). Going Underwater? Flood Risk Belief Heterogeneity and Coastal Home Price Dynamics. *The Review of Financial Studies*, *35*(8), 3666–3709. https://doi.org/10.1093/rfs/hhab122

Baldauf, M., Garlappi, L., & Yannelis, C. (2020). Does Climate Change Affect Real Estate Prices? Only If You Believe In It. *The Review of Financial Studies*, *33*(3), 1256–1295. https://doi.org/10.1093/rfs/hhz073

Barber, M. (2022, May 10). *Another house in Rodanthe, N.C. collapses at Cape Hatteras National Seashore.* National Park Service. https://www.nps.gov/caha/learn/news/another-house-in-rodanthe-nc-collapses-at-cape-hatteras-national-seashore.htm

Bernstein, A., Gustafson, M., & Lewis, R. (2019). Disaster on the Horizon: The Price Effect of Sea Level Rise. *Journal of Financial Economics*. https://doi.org/10.1016/j.jfineco.2019.03.013

Bin, O., Crawford, T. W., Kruse, J. B., & Landry, C. E. (2008). Viewscapes and Flood Hazard: Coastal Housing Market Response to Amenities and Risk. *Land Economics*, *84*(3), 434–448. https://doi.org/10.3368/le.84.3.434

Bin, O., & Landry, C. E. (2013). Changes in implicit flood risk premiums: Empirical evidence from the housing market. *Journal of Environmental Economics and Management*, *65*(3), 361–376. https://doi.org/10.1016/j.jeem.2012.12.002

Bindoff, N. L., Willebrand, J., Artale, V., Cazenave, A., Gregory, J., Gulev, S., Hanawa, K., Le Quéré, C., Levitus, S., Nojiri, Y., Shum, C. K., Talley, L. D., & Unnikrishnan, A. (2007). Observations: Oceanic Climate Change and Sea Level. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Blackwell, B. (2007). The value of a recreational beach visit: An application to Mooloolaba Beach and comparisons with other outdoor recreation sites. *Economic Analysis and Policy*, *37*(1), Article 1.

Bremer, L. L., Coffman, M., Summers, A., Kelley, L. C., & Kinney, W. (2022). Managing for diverse coastal uses and values under sea level rise: Perspectives from O‘ahu, Hawai‘i. *Ocean & Coastal Management*, *225*, 106151. https://doi.org/10.1016/j.ocecoaman.2022.106151

Caldwell, M., & Segall, C. H. (2007). No Day at the Beach: Sea Level Rise, Ecosystem Loss, and Public Access Along the California Coast. *Ecology Law Quarterly*, 34:533.

California Coastal Commission. (2015). *California Coastal Commission Sea Level Rise Policy Guidance Chapter 7*. California Coastal Commission. https://documents.coastal.ca.gov/assets/slr/guidance/August2015/7_Ch7_Adopted_Sea_Level_Rise_Policy_Guidance.pdf

Callies, D. L. (2019). The Public Trust Doctrine. *8 Brigham-Kanner Prop. Rts. Conf. J. 71.*

Carson, K. (2021). The Water Is Coming: How Policies for Internally Displaced Persons Can Shape the U.S. Response to Sea Level Rise and the Redistribution of the American Population Notes. *Hastings Law Journal*, *72*(4), 1279–1312.

Cerizo, K. (2022, June 18). Iwi kūpuna found at West Maui surf spot Puamana may find rest soon. *Maui Now*. https://mauinow.com/2022/06/18/iwi-kupuna-found-at-west-maui-surf-spot-puamana-beach-park-may-find-rest-soon/

City and County of Honolulu Climate Change Commission. (2020). *Climate Change and Financial Risk—Guidance Document*. Office of Climate Change, Sustainability and Resiliency. https://static1.squarespace.com/static/5e3885654a153a6ef84e6c9c/t/5f3436a7779f0079da854e00/1597257386586/CLIMATE+CHANGE+AND+FINANCIAL+RISK_7-20_FINAL.PDF

Clark, J. R. K. (2004). *Beaches of O‘ahu* (Rev. ed). University of Hawai‘i Press.

Climate Resilience Collaborative. (2022a). Hawai‘i Shoreline Study web map. *Climate Resilience Collaborative*. https://www.soest.hawaii.edu/crc/index.php/resources/hawaii-shoreline-study-web-map/

Climate Resilience Collaborative. (2022b). Paumalū to Kaunala, Oʻahu. *Climate Resilience Collaborative*. https://www.soest.hawaii.edu/crc/index.php/resources-2/historical-mosaics/paumalu-kaunala/

Cocke, S. (2020, December 31). Officials Let Hawaii's Waterfront Homeowners Damage Public Beaches Again and Again. *ProPublica*. https://www.propublica.org/article/officials-let-hawaiis-waterfront-homeowners-damage-public-beaches-again-and-again?token=dQhE1DjH5S-s5oiZGbyX7NoNfXm5VycL

Cocke, S. (2021, January 23). Hawaii's Land Board cracks down on illegal seawalls. *Honolulu Star - Advertiser*.

Cocke, S. (2022a, March 1). Home collapses on Oahu's North Shore. *Honolulu Star - Advertiser.*

Cocke, S. (2022b, July 31). Wealthy beachfront homeowners turn to the courts to avoid Hawaii environmental laws. *Honolulu Star - Advertiser*.

Codiga, D., & Wager, K. (2011). *Sea-Level Rise and Coastal Land Use in Hawaiʻi: A Policy Tool Kit for State and Local Governments*. Center for Island Climate Adaptation and Policy. http://www.islandclimate.net/wp-content/uploads/2012/05/icap-sealevelrisetoolkit_web.pdf

Codiga, D., Hwang, D., & Delaunay, C. (2011). *Climate Change and Regulatory Takings in Coastal Hawaiʻi*. Center for Island Climate Adaptation and Policy, University of Hawaiʻi Sea Grant College Program.

County of Hawaii v. Sotomura, 55 Haw. 176 (Supreme Court of Hawaiʻi 1973).

County of Maui. (2020). *Public Works Capital Improvement Program, Fiscal Year 2020*. Mayor's Proposed Budget.

Craig, R. K. (2019). Coastal adaptation, government-subsidized insurance, and perverse incentives to stay. *Climatic Change*, *152*(2), 215–226. https://doi.org/10.1007/s10584-018-2203-5

Decennial Census. (2020). *Table P1*. https://data.census.gov/table?q=honolulu+county+population+2020

Dedekorkut-Howes, A., Torabi, E., & Howes, M. (2020). When the tide gets high: A review of adaptive responses to sea level rise and coastal flooding. *Journal of Environmental Planning and Management*, *63*(12), 2102–2143. https://doi.org/10.1080/09640568.2019.1708709

Department Of Budget And Fiscal Services. (2021, January 8). City And County Of Honolulu Real Property Tax Valuation For Fiscal Year 2021—2022. *City and County of Honolulu*. https://www.realpropertyhonolulu.com/media/1788/honolulufy22.pdf

Department of Business, Economic Development & Tourism. (2019). *The State of Hawaii Data Book 2019*. State of Hawaii.

Department of Land and Natural Resources. (2023, February 24). *02/24/23 – FRIDAY UPDATE ON GROUNDED YACHT AT HONOLUA BAY*. https://dlnr.hawaii.gov/blog/2023/02/28/nr23-38/

Department of Transportation Highways. (2019). *Traffic Shift on Farrington Highway for Maipalaoa Bridge Replacement*. https://hidot.hawaii.gov/highways/traffic-shift-on-farrington-highway-for-maipalaoa-bridge-replacement/

Department of Transportation Highways. (2021). *Preparation for Makaha 3 and 3A Bridge Replacements to Begin March 8*. https://hidot.hawaii.gov/highways/preparation-for-makaha-3-and-3a-bridge-replacements-to-begin-march-8/

DePasquale, D. J. (2016). A Pragmatic Proposition: Regionally Planned Coastal TDRs in Light of Rising Seas. *Urban Lawyer*, *48*(1), 179–208.

Deputy A.G. Wynhoff, W. J., & A.G Chin, D. (2017). *Opinion No. 17-01: State of Haw. Att'y Gen., Opinion Letter on Shoreline Encroachment Easements.*

Diamond v. Craig Dobbin & Wagner Eng'g Servs., 132 Hawai`i 9 (Supreme Court of Hawai'i 2014).

Diamond vs. State, Bd. Of Land and Nat. Res, 112 Hawai`i 161 (Supreme Court of Hawai'i 2006).

Dobbyn, P. (2022, August 3). Hawaii Is The Only State Not Seeking Federal Buyouts To Move Residents Away From Floods. *Honolulu Civil Beat*. https://www.civilbeat.org/2022/08/hawaii-is-the-only-state-not-seeking-federal-money-to-move-residents-away-from-floods/

Downey, K. (2022, September 27). Honolulu City Council Puts Controversial Land-Use Bill On Hold Amid Criticism. *Honolulu Civil Beat*. https://www.civilbeat.org/2022/09/honolulu-city-council-puts-controversial-land-use-bill-on-hold-amid-criticism/

Dronkers, J., Gilbert, J. T. E., Butler, L. W., Carey, J. J., Campbell, J., James, E., McKenzie, C., Misdorp, R., Quin, N., Ries, K. L., Schroder, P. C., Spradley, J. R., Titus, J. G., Vallianos, L., & von Dadelszen, J. (1990). *Strategies for Adaptation to Sea Level Rise*. IPCC Coastal Zone Management Subgroup: Intergovernmental Panel on Climate Change.

Duhaime's Law Dictionary. (2022). Inchoate. http://www.duhaime.org/LegalDictionary/I/Inchoate.aspx

Dumm, R. E., Sirmans, G. S., & Smersh, G. T. (2016). Price Variation in Waterfront Properties Over the Economic Cycle. *Journal of Real Estate Research*, *38*(1), 1–26. https://doi.org/10.1080/10835547.2016.12091435

Dundon, L. A., & Abkowitz, M. (2021). Climate-induced managed retreat in the U.S.: A review of current research. *Climate Risk Management*, *33*, 100337. https://doi.org/10.1016/j.crm.2021.100337

Dyckman, C. S., St. John, C., & London, J. B. (2014). Realizing managed retreat and innovation in state-level coastal management planning. *Ocean & Coastal Management*, *102*, 212–223. https://doi.org/10.1016/j.ocecoaman.2014.09.010

Essoyen, S. (2016, October 30). North Shore residents want help restoring dunes of Sunset Beach. *Honolulu Star - Advertiser*.

Eversole, D. (2009). *Pupukea-Paumalu (Sunset Beach Park) Beach Maintenance Guidelines*. State of Hawaiʻi DLNR OCCL, prepared by UH Sea Grant College Program.

Felton, D., van der Zander, I. (2021). *Risks of Sea Level Rise and Increased Flooding on Known Chemical Contamination in Hawaii*. State of Hawaiʻi Department of Health.

FEMA. (2018, November 13). *FACT SHEET: Acquisition of Property After a Flood Event*. https://www.fema.gov/news-release/20200220/fey-enfomasyon-akizisyon-pwopriyete-apre-yon-inondasyon

FEMA. (2021, April). *FEMA Updates Its Flood Insurance Rating Methodology to Deliver More Equitable Pricing*. https://www.fema.gov/press-release/20210401/fema-updates-its-flood-insurance-rating-methodology-deliver-more-equitable

FEMA. (2022a, March 22). *Flood Mitigation Assistance (FMA) Grant*. FEMA. https://www.fema.gov/grants/mitigation/floods

FEMA. (2022b, July 21). *Hazard Mitigation Grant Program—Property Acquisitions*. https://www.fema.gov/openfema-data-page/hazard-mitigation-grant-program-property-acquisitions-v1

Fletcher, C. H., Romine, B. M., Genz, A. S., Barbee, M. M., Dyer, M., Anderson, T. R., Lim, S. C., Vitousek, S., Bochicchio, C., & Richmond, B. M. (2012). National assessment of shoreline change: Historical shoreline change in the Hawaiian Islands (Report No. 2011–1051; Open-File Report, pp. i–55). *USGS Publications Warehouse*. https://doi.org/10.3133/ofr20111051

Francis, O., Brandes, H., Zhang, G., & Ma, D. (2019). *Statewide Coastal Highway Program Report. State of Hawaii Department of Transportation Highways Division*. https://hidot.hawaii.gov/highways/files/2019/09/State-of-Hawaii-Statewide-Coastal-Highway-Program-Report_Final_2019.pdf

GAO. (2003, August 21). *Budget Issues: Alternative Approaches to Finance Federal Capital*. https://www.govinfo.gov/content/pkg/GAOREPORTS-GAO-03-1011/html/GAOREPORTS-GAO-03-1011.htm

Georgetown Climate Center. (2023). Managed Retreat Toolkit » Land Swaps. *Georgetownclimatecenter.org*. https://www.georgetownclimate.org/adaptation/toolkits/managed-retreat-toolkit/land-swaps.html

Gibson, M., & Mullins, J. T. (2020). Climate Risk and Beliefs in New York Floodplains. *Journal of the Association of Environmental and Resource Economists*, *7*(6), 1069–1111. https://doi.org/10.1086/710240

Giglio, S., Maggiori, M., Rao, K., Stroebel, J., & Weber, A. (2021). Climate Change and Long-Run Discount Rates: Evidence from Real Estate. *The Review of Financial Studies*, *34*(8), 3527–3571. https://doi.org/10.1093/rfs/hhab032

Giordano, M. (1987). Over-Stuffing the Envelope: The Problems with Creative Transfer of Development Rights Note. *Fordham Urban Law Journal*, *16*(1), 43–68.

Griggs, G., & Reguero, B. G. (2021). Coastal Adaptation to Climate Change and Sea-Level Rise. *Water*, *13*(16), 2151. https://doi.org/10.3390/w13162151

Habel, S., Fletcher, C. H., Anderson, T. R., & Thompson, P. R. (2020). Sea-Level Rise Induced Multi-Mechanism Flooding and Contribution to Urban Infrastructure Failure. *Scientific Reports*, *10*(1), 3796. https://doi.org/10.1038/s41598-020-60762-4

Habel, S., Fletcher, C. H., Rotzoll, K., & El-Kadi, A. I. (2017). Development of a model to simulate groundwater inundation induced by sea-level rise and high tides in Honolulu, Hawaii. *Water Research*, *114*, 122–134. https://doi.org/10.1016/j.watres.2017.02.035

Harada, S. Y., Goto, R. S., & Nathanson, A. T. (2011). Analysis of lifeguard-recorded data at Hanauma Bay, Hawaii. *Wilderness & Environmental Medicine*, *22*(1), 72–76. https://doi.org/10.1016/j.wem.2010.10.012

Hawaiʻi Center for Sustainable Food & Agriculture. (2016). *HINAʻI Final Report*.

Hawaiʻi Climate Change Mitigation and Adaptation Commission. (2017). *Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report.*

Hawaiʻi Climate Change Mitigation and Adaptation Commission. (2021). *State of Hawaiʻi Sea Level Rise Viewer*. Pacific Islands Ocean Observing System (PacIOOS) for the University of Hawaiʻi Sea Grant College Program and the State of Hawaiʻi Department of Land and Natural Resources, Office of Conservation and Coastal Lands. http://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

Hawaiʻi Sea Grant. (2020). *Cesspool Issues Rising – Hawaii Sea Grant*. https://seagrant.soest.hawaii.edu/cesspool-issues-rising/

Hawaiʻi State Office of Planning. (2019). *Assessing the Feasibility and Implications of Managed Retreat Strategies For Vulnerable Coastal Areas in Hawaiʻi Final Report*.

Hawaii State Office of Planning. (2022). *Hawaii Statewide GIS Program*. https://geoportal.hawaii.gov/

Hawaii Tourism Authority. (2022). *Infrastructure Research. Data compiled and provided by UHERO*. Hawaii Tourism Authority. http://www.hawaiitourismauthority.org/research/infrastructure-research/

HDOT. (2021, September 27). *HDOT plan for Honoapiilani Highway in Olowalu*. https://hidot.hawaii.gov/blog/2021/09/27/hdot-plan-for-honoapiilani-highway-in-olowalu/

HDOT. (2023, February 5). *Kamehameha Highway Near Waimea Bay Will Remain Closed Sunday Due to Rockfall*. https://hidot.hawaii.gov/blog/2023/02/05/kamehameha-highway-near-waimea-bay-will-remain-closed-sunday-due-to-rockfall/

Hernandez, J. (2015, July 17). NJ uses eminent domain to continue post-Sandy beach protection projects. *WHYY*. https://whyy.org/articles/nj-uses-eminent-domain-for-post-sandy-beach-protection-projects/

Hibbs, M. (2022, February 14). Cleanup of fallen house begins; beach near site closed. *Coastal Review*. https://coastalreview.org/2022/02/cleanup-of-fallen-house-begins-beach-near-site-closed/

Hino, M., & Burke, M. (2021). The effect of information about climate risk on property values. *Proceedings of the National Academy of Sciences*, *118*(17), e2003374118. https://doi.org/10.1073/pnas.2003374118

Hino, M., Field, C. B., & Mach, K. J. (2017). Managed retreat as a response to natural hazard risk. *Nature Climate Change*, *7*(5), 364–370. https://doi.org/10.1038/nclimate3252

Hometown Demolition. (2022). *Asphalt Driveway Removal Cost Guide: Factors that Affect Your Final Bill*. https://www.hometowndemolitioncontractors.com/blog/asphalt-driveway-removal-cost-guide

Horn, D. P. (2022, April 8). Flood Buyouts: Federal Funding for Property Acquisition. *Congressional Research Service*. https://crsreports.congress.gov/product/pdf/IN/IN11911

Hurley, T. (2013a, October 15). Officials investigate severe erosion. *Honolulu Star - Advertiser*.

Hurley, T. (2013b, October 22). Owners of North Shore homes on edge. *Honolulu Star - Advertiser*.

In re Application of Ashford, 440 P. 2d 76 (Supreme Court of Hawaiʻi 1968).

In re Sanborn, 57 Haw. 585 (Supreme Court of Hawaiʻi 1977).

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. In Press.

IPCC, 2022: Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.

Jacobs, H. M. (1998). *Who Owns America?: Social Conflict over Property Rights*. University of Wisconsin Press.

Jin, D., Hoagland, P., Au, D. K., & Qiu, J. (2015). Shoreline change, seawalls, and coastal property values. *Ocean & Coastal Management*, *114*, 185–193. https://doi.org/10.1016/j.ocecoaman.2015.06.025

Johnson, D. R. (2007). Reflections on the Bundle of Rights, Lecture. *Vermont Law Review*, *32*(2), 247–272.

Johnston, R. A., & Madison, M. E. (1997). From Land marks to Landscapes: A Review of Current Practices in the Transfer of Development Rights. *Journal of the American Planning Association*, *63*(3), 365–378. https://doi.org/10.1080/01944369708975929

Kakesako, G. K. (2014, January 22). 'Giant' surf rolls into the North Shore. *Honolulu Star - Advertiser.*

Kane, H. H., Fletcher, C. H., Frazer, L. N., Anderson, T. R., & Barbee, M. M. (2015). Modeling sea-level rise vulnerability of coastal environments using ranked management concerns. *Climatic Change*, *131*(2), 349–361. https://doi.org/10.1007/s10584-015-1377-3

Kaplowitz, M. D., Machemer, P., & Pruetz, R. (2008). Planners' experiences in managing growth using transferable development rights (TDR) in the United States. *Land Use Policy*, *25*(3), 378–387. https://doi.org/10.1016/j.landusepol.2007.07.004

Keeler, A. G., Mullin, M., McNamara, D. E., & Smith, M. D. (2022). Buyouts with rentbacks: A policy proposal for managing coastal retreat. *Journal of Environmental Studies and Sciences*, *12*(3), 646–651. https://doi.org/10.1007/s13412-022-00762-0

Keenan, J. M., Hill, T., & Gumber, A. (2018). Climate gentrification: From theory to empiricism in Miami-Dade County, Florida. *Environmental Research Letters*, *13*(5), 054001. https://doi.org/10.1088/1748-9326/aabb32

Kozak, C. (2022, March 9). Frustrations mount over imperiled Outer Banks houses. *Coastal Review*. https://coastalreview.org/2022/03/frustrations-mount-over-imperiled-outer-banks-houses/

Krause, A. (2014, September 12). What is Waterfront Worth? *Zillow Research*. https://www.zillow.com/research/what-is-waterfront-worth-7540/

Kubota, L. (2020, January 29). State proposes $35M highway realignment plan to ease Laniakea gridlock. *Hawaii News Now*. https://www.hawaiinewsnow.com/2020/01/30/state-proposes-m-highway-realignment-plan-ease-laniakea-gridlock/

Lee, C. A. (2021). Eliminating the Hardship Variance in Honolulu's Shoreline Setback Ordinance: The City and County of Honolulu's Public Trust Duties as an Exception to Regulatory Takings Challenges. *University of Hawai'i Law Review*, *43*(2), 464–518.

Lee, H. (2021). Judge rules in favor of California Coastal Commission in Los Cerritos Wetlands land swap. *Press Telegram*. https://www.presstelegram.com/2021/03/11/judge-rules-in-favor-of-california-coastal-commission-in-los-cerritos-wetlands-land-swap

Lewis, D. A. (2012). The Relocation of Development from Coastal Hazards through Publicly Funded Acquisition Programs: Examples and Lessons from the Gulf Coast Legal Solutions to Coastal Climate Change Adaptation in Connecticut Symposium. *Sea Grant Law and Policy Journal*, *5*(1), 98–139.

Liu, S., Costanza, R., Troy, A., D'Aagostino, J., & Mates, W. (2010). Valuing New Jersey's Ecosystem Services and Natural Capital: A Spatially Explicit Benefit Transfer Approach. *Environmental Management*, *45*(6), 1271–1285. https://doi.org/10.1007/s00267-010-9483-5

Liu, J., Liu, N., Zhang, Y., Qu, Z., & Yu, J. (2019). Evaluation of the non-use value of beach tourism resources: A case study of Qingdao coastal scenic area, China. *Ocean & Coastal Management*, *168*, 63–71. https://doi.org/10.1016/j.ocecoaman.2018.10.030

Logar, I., & van den Bergh, J. C. J. M. (2014). Economic valuation of preventing beach erosion: Comparing existing and non-existing beach markets with stated and revealed preferences. *Journal of Environmental Economics and Policy*, *3*(1), 46–66. https://doi.org/10.1080/21606544.2013.863742

Lucas v. South Carolina Coastal Council, 505 U.S. 1003 (1992).

Mach, K. J., Kraan, C. M., Hino, M., Siders, A. R., Johnston, E. M., & Field, C. B. (2019). Managed retreat through voluntary buyouts of flood-prone properties. *Science Advances*, *5*(10), eaax8995. https://doi.org/10.1126/sciadv.aax8995

Mach, K. J., & Siders, A. R. (2021). Reframing strategic, managed retreat for transformative climate adaptation. *Science*, *372*(6548), 1294–1299. https://doi.org/10.1126/science.abh1894

Machemer, P. L., & Kaplowitz, M. D. (2002). A Framework for Evaluating Transferable Development Rights Programmes. *Journal of Environmental Planning and Management*, *45*(6), 773–795. https://doi.org/10.1080/0964056022000024334

McGilvray, L. J., Anderson, G. D., & West, N. (1986). Managing coastal development: An evaluation of the transfer of development rights approach. *Coastal Zone Management Journal*, *13*(1), 25–47. https://doi.org/10.1080/08920758609361975

McKenzie, T., Habel, S., & Dulai, H. (2021). Sea-level rise drives wastewater leakage to coastal waters and storm drains. *Limnology and Oceanography Letters*, *6*(3), 154–163. https://doi.org/10.1002/lol2.10186

Moore, L. (2022). *Tiered Environmental Assessment 24 CFR Part 58: Kīlauea Voluntary Housing Buyout Program*. CDBG-DR & County of Hawai'i.

Murfin, J., & Spiegel, M. (2020). Is the Risk of Sea Level Rise Capitalized in Residential Real Estate? *The Review of Financial Studies*, *33*(3), 1217–1255. https://doi.org/10.1093/rfs/hhz134

Nakano, D., Stephens, L. W., Turk, J., Mukai, S., & Stultz, J. (2019). *Impacts of Climate Change on Honolulu Water Supplies and Planning Strategies for Mitigation*. Board of Water Supply.

National Association of City Transportation Officials (Ed.). (2013). *Urban Street Design Guide*. Island Press.

National Research Council. (2005). *Valuing Ecosystem Services: Toward Better Environmental Decision-Making*. National Academies Press. https://doi.org/10.17226/11139

Nellermoe, E. M. (2016). Coastal TDRs: A Solution for Shifting Sands on Folly Beach? *Coastal Management*, *44*(3), 223–240. https://doi.org/10.1080/08920753.2016.1160204

Nelson, A. C., Pruetz, R., & Woodruff, D. (2011). *The TDR Handbook: Designing and Implementing Transfer of Development Rights Programs*. Island Press.

NOAA. (2022a). *2022 Sea Level Rise Technical Report*. https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html

NOAA. (2022b). *Primer for Using Economic Valuation Methodology Guides*. https://seagrant.noaa.gov/Portals/1/Network%20Resoruces/Economic%20valuation%20guides/All_guides_new.pdf

North Shore Coastal Resilience Working Group. (2022). *Adaptive Coastal Management Recommendations, Actions and Strategies. Surfrider Foundation*. https://hawaii.surfrider.org/wp-content/uploads/2022/10/web-North-Shore-Coastal-Erosion-Report_102122_Web-1.pdf

Nunn, P. D., Runman, J., Falanruw, M., & Kumar, R. (2017). Culturally grounded responses to coastal change on islands in the Federated States of Micronesia, northwest Pacific Ocean. *Regional Environmental Change*, *17*(4), 959–971. https://doi.org/10.1007/s10113-016-0950-2

Office of Conservation and Coastal Lands. (2021). *Conservation District Enforcement Case OA 21-03*. Hawaiʻi DLNR. https://dlnr.hawaii.gov/wp-content/uploads/2021/01/K-3.pdf

Olson v. United States, 292 U.S. 246 (1934)

OP-HCZM Program. (2011). *State of Hawaiʻi Office of Planning Hawaiʻi Coastal Zone Management Program: Sustainable Management of the Islands*.

Patrick, J. (2022, February 9). Beachgoers alerted to collapsed house in surf in Rodanthe: *WRAL*. https://www.wral.com/beachgoers-alerted-to-collapsed-house-in-surf-in-rodanthe/20127236/

Pendleton, L., & Kildow, J. (2006). The Non-Market Value of Beach Recreation in California. *Shore and Beach*, *74*(2), 34–37.

Penn Central Transportation Co. v. New York City, 438 U.S. 104 (1978)

Pennsylvania Coal Co. v. Mahon, 260 U.S. 393 (1922)

Pennybacker, M., & Cocke, S. (2020, December 31). Hawaii Officials Promise Changes to Seawall Policies That Have Quickened Beach Destruction. *ProPublica*. https://www.propublica.org/article/hawaii-officials-promise-changes-to-seawall-policies-that-have-quickened-beach-destruction?token=dQhE1DjH5S-s5oiZGbyX7NoNfXm5VycL

Pizor, P. J. (1986). Making TDR Work: A Study of Program Implementation. *Journal of the American Planning Association*, *52*(2), 203–211. https://doi.org/10.1080/01944368608976620

Platt, R. H. (2014). Land Use and Society: Fundamentals and Issues. *In Land Use and Society: Geography, Law, and Public Policy* (pp. 13–39). Island Press/Center for Resource Economics. https://doi.org/10.5822/978-1-61091-455-0_2

Pruetz, R., & Standridge, N. (2008). What Makes Transfer of Development Rights Work?: Success Factors From Research and Practice. *Journal of the American Planning Association*, *75*(1), 78–87. https://doi.org/10.1080/01944360802565627

Pruetz, R. (2013). Transfer of Development Credits Helps Cities Grow Up. *Built Environment*, *39*(4), 502–518. https://doi.org/10.2148/benv.39.4.502

Pukui, M. K., Elbert, S. H., & Mookini, E. T. (1981). *Place names of Hawaii* (2nd ed.). University Press of Hawaii.

Rabak, D. (2021). What to Do When People Don't Move: Ending the "Condemnation Blight" Value Rule for Forced Retreat Resulting from Sea Level Rise. *Cardozo Journal of Equal Rights and Social Justice*, *28*(1), 133–162.

Renard, V. (2007). Property rights and the "transfer of development rights": Questions of efficiency and equity. *Town Planning Review*, *78*(1), 41–60. https://doi.org/10.3828/tpr.78.1.4

Revell, D., King, P., Giliam, J., Calil, J., Jenkins, S., Helmer, C., Nakagawa, J., Snyder, A., Ellis, J., Jamieson, M., Zou, Q., & Reeve, D. E. (2021). A Holistic Framework for Evaluating Adaptation Approaches to Coastal Hazards and Sea Level Rise: A Case Study from Imperial Beach, California. *Water (20734441)*, *13*(9), 1324–1324. https://doi.org/10.3390/w13091324

Riker, M. S. (2023, March 6). The Yacht Was Finally Freed From Honolua Bay—Then It Sank Off Maui. *Honolulu Civil Beat*. https://www.civilbeat.org/2023/03/the-yacht-was-finally-freed-from-honolua-bay-then-it-sank-off-maui/

Robb, A., Stocker, L., Payne, M., & Middle, G. J. (2020). Enabling Managed Retreat from Coastal Hazard Areas through Property Acquisition and Transferable Development Rights: Insights from Western Australia. *Urban Policy and Research*, *38*(3), 230–248. https://doi.org/10.1080/08111146.2020.1768842

Rodella, I., Madau, F. A., & Carboni, D. (2020). The Willingness to Pay for Beach Scenery and Its Preservation in Italy. *Sustainability*, *12*(4), Article 4. https://doi.org/10.3390/su12041604

Romine, B. M., Eversole, D., & Hintzen, K. D. (2021). *Climate Change and Sea Level Rise, A Technical Resource Paper for the North Shore, Oʻahu Sustainable Communities Plan*. Prepared by the University of Hawaiʻi Sea Grant College Program for SSFM International Inc. and the City and County of Honolulu. (TT-21-02).

Shikina, R. (2017, December 18). City installs 'sand mattress' to combat erosion at Kuhio Beach. *Honolulu Star - Advertiser*.

Shikina, R., & Hurley, T. (2014, January 23). Biggest swell in a decade hits North Shore, threatens homes. *Honolulu Star - Advertiser*.

Siders, A. R. (2019). Managed Retreat in the United States. *One Earth*, *1*(2), 216–225. https://doi.org/10.1016/j.oneear.2019.09.008

Smith, T., Podoski, J., Demirbilek, Z., & Lin, L. (2018). *Understanding regional shoreline change and coastal processes at the Sunset Beach Region, Oahu, Hawaii*. Coastal and Hydraulics Laboratory (U.S.). https://doi.org/10.21079/11681/26285

Song, J., & Morse, H. (2000, April 1). Wipeout! The temporary road at Waimea is washed away but the state vows to quickly rebuild. *Star-Bulletin*.

Spidalieri, K., Smith, I., & Grannis, J. (2020). *Managing the Retreat from Rising Seas*. Georgetown Climate Center. https://www.georgetownclimate.org/files/MRT/GCC_20_FULL-3web.pdf

Sproat, K. (2009). *Ola I Ka Wai: A legal primer for water use and management in Hawai'i*. Ka Huli Ao Center for Excellence in Native Hawaiian Law.

Star-Advertiser. (2017, December 17). Public warned away from Sunset Beach after extreme erosion. *Honolulu Star - Advertiser*.

State of Hawaiʻi. (2021). *State of Hawaiʻi's Motion for Partial Summary Judgment to First Circuit Court* (*State of Hawaiʻi v. O'Shea*). https://www.environment-hawaii.org/wp-content/uploads/2021/11/State-MPSJ-OShea.pdf

State of Hawaiʻi Department of Health. (2017). *On-site Sewage Disposal Systems—Oahu*. Hawaii Statewide GIS Program. https://geoportal.hawaii.gov/

State of Hawaiʻi Department of Health. (2021). *Cesspool Conversions Finance Research Summary Report*.

Sweet, W.V., Hamlington, B.D., Kopp, R.E., Weaver, C.P., Barnard, P.L., Bekaert, D., Brooks, W., Craghan, M., Dusek, G., Frederikse, T., Garner, G., Genz, A.S., Krasting, J.P., Larour, E., Marcy, D., Marra, J., Obeysekera, J., Osler, M., Pendleton, M., Roman, D., Schmied, L., Veatch, W., White, K.D., and Zuzak, C. (2022). Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities along U.S. Coastlines. Silver Spring, Maryland: National Oceanic and Atmospheric Administration.

Sweet, W.V., Kopp, R.E., Weaver, C.P., Obeysekera, J., Horton, R.M., Thieler, R.E., Zervas, C., NOAA technical report (2017). NOS CO-OPS 083. Global and Regional Sea-level Rise Scenarios for the United States, Silver Spring, Maryland.

Szuster, B., Eversole, D., Spencer, D., & Lesar, L. (2020). *Recreational Use and Management at Kailua Beach Park*. University of Hawaii.

Tanji, M. (2022, October 1). Winter swells could bring back beach, but long-term fix elusive. *The Maui News*. https://www.mauinews.com/news/local-news/2022/10/winter-swells-could-bring-back-beach-but-long-term-fix-elusive/

Tavares, K.-D., Fletcher, C. H., & Anderson, T. R. (2020). Risk of shoreline hardening and associated beach loss peaks before mid-century: O‘ahu, Hawai‘i. *Scientific Reports*, *10*(1), 13633. https://doi.org/10.1038/s41598-020-70577-y

Teague, C. (2017, April 27). Why Honolulu’s Water Pipes Keep Rupturing. *Honolulu Civil Beat*. https://www.civilbeat.org/2017/04/why-honolulus-water-pipes-keep-rupturing/

Tetra Tech, Inc. and University of Hawai‘i Coastal Geology Group. (2017). *Sea Level Rise – Exposure Area*. http://planning.hawaii.gov/gis/download-gis-data/

Thompson, P. R., Widlansky, M. J., Hamlington, B. D., Merrifield, M. A., Marra, J. J., Mitchum, G. T., & Sweet, W. (2021). Rapid increases and extreme months in projections of United States high-tide flooding. *Nature Climate Change*, *11*(7), Article 7. https://doi.org/10.1038/s41558-021-01077-8

Titus, J. G. (2011). *Rolling Easements*. EPA. https://www.epa.gov/sites/default/files/documents/rollingeasementsprimer.pdf

Tyndall, J. (2021). Sea Level Rise and Home Prices: Evidence from Long Island. *The Journal of Real Estate Finance and Economics*. https://doi.org/10.1007/s11146-021-09868-8

UHERO. (2022). *UHERO Data Portal*. CPI: Other Goods and Services. https://data.uhero.hawaii.edu/#/series?sa=false&id=151711&data_list_id=27&start=2012-01-01

U.S. Consumer Product Safety Commission. (2022). *Asbestos In The Home*. U.S. Consumer Product Safety Commission. https://www.cpsc.gov/safety-education/safety-guides/home/asbestos-home

US EPA (2013, February 12). *Protect Your Family from Sources of Lead* [Overviews and Factsheets]. https://www.epa.gov/lead/protect-your-family-sources-lead

United States v. Cartwright, 411 U.S. 546 (1973)

USGCRP. (2018). *Fourth National Climate Assessment* (pp. 1–470). U.S. Global Change Research Program, Washington, DC. https://nca2018.globalchange.govhttps://nca2018.globalchange.gov/chapter/27

Vance, S. L., & Wallsgrove, R. J. (2006). More than a Line in the Sand: Defining the Shoreline in Hawai’i After Diamond v. State. *University of Hawai’i Law Review*, *Vol. 29:521*, 521–552.

Waggonner & Ball, LLC, The Water Institute of the Gulf, & Royal Netherlands Embassy. (2019). *Dutch Dialogues Charleston*. https://www.charleston-sc.gov/DocumentCenter/View/24059/2019_0426-Dutch-Dialogues-Charleston-Handout-overview-of-4-Project-Areas

Walsh, P., Griffiths, C., Guignet, D., & Klemick, H. (2019). Adaptation, Sea Level Rise, and Property Prices in the Chesapeake Bay Watershed. *Land Economics*, *95*(1), 19–34. https://doi.org/10.3368/le.95.1.19

Weber, A., & Moore, R. (2019). *Long Wait Times For Post-flood Buyouts Leave Homeowners Underwater*. National Resources Defense Council.

Whittier, R. B., & El-Kadi, A. I. (2014). *Human and environmental risk ranking of onsite sewage disposal systems for the Hawaiian islands of Kauai, Molokai, Maui, and Hawaii*. State of Hawaiʻi Department of Health.

Williams, N. R. (2014). Coastal TDRs and Takings in a Changing Climate. *Urban Lawyer*, *46*(1), 139–172.

Wu, N. (2017a, December 21). Severe Sunset Beach erosion could cause cliff's catastrophic collapse. *Honolulu Star - Advertiser*.

Wu, N. (2017b, December 22). Erosion at Sunset Beach could cause 'catastrophic' collapse, state says. *Honolulu Star - Advertiser*.

Wu, N. (2018a, April 16). Erosion is eating away at Hawaii's shorelines. *Honolulu Star - Advertiser*.

Wu, N. (2018b, August 16). Sunset Beach dune restoration could be a model for preserving Oahu's coast. *Honolulu Star - Advertiser*.

Wu, N. (2018c, September 24). North Shore homes are in danger from erosion and homeowners say the state isn't doing enough to help. *Honolulu Star - Advertiser*.

Wu, N. (2018d, November 26). City officials say Sunset Beach dune restoration is promising. *Honolulu Star - Advertiser*.

Yerton, S. (2022, October 21). Mayor Vows To Enforce New Law Against Short-Term Rentals. *Honolulu Civil Beat*. https://www.civilbeat.org/2022/10/mayor-vows-to-enforce-new-law-against-short-term-rentals/

Yoon, H., Widlansky, M. J., & Thompson, P. R. (2018). Nuʻa Kai: Flooding in Hawaii caused by a 'stack' of oceanographic processes [in 'State of the Climate in 2017']. *Bulletin of the American Meteorological Society*, *99(*8). https://journals.ametsoc.org/downloadpdf/journals/bams/99/8/2018bamsstateoftheclimate.1.pdf

Young, A. W. (2018). How to Retreat: The Necessary Transition from Buyouts to Leasing. *Coastal Management*, *46*(5), 527–535. https://doi.org/10.1080/08920753.2018.1498716

Acknowledgements

We thank Maja Schjervheim and Seth Urbanski for their research assistance in the development of this report. This study was funded as part of the Climate Resilience Collaborative at the University of Hawaiʻi at Mānoa. We thank Denise Antolini, Leah Bremer, Juliette Budge, Dolan Eversole, Chip Fletcher, Shellie Habel, Colin Lee, Ruby Pap, Kirsten Oleson, Regina Ostergaard-Klem, Brad Romine, and Chris Wada for their valuable feedback and guidance.